10 Asia

Coordinating Lead Authors: Rajib Shaw (Japan), Yong Luo (China), Tae Sung Cheong (Republic of Korea)

Lead Authors: Sharina Abdul Halim (Malaysia), Sanjay Chaturvedi (India), Masahiro Hashizume (Japan), Gregory E. Insarov (Russian Federation), Yoichi Ishikawa (Japan), Mostafa Jafari (Iran), Akio Kitoh (Japan), Juan Pulhin (Philippines), Chandni Singh (India), Kripa Vasant (India), Zhibin Zhang (China)

Contributing Authors: Rawshan Ara Begum (Bangladesh), Xi Chen (China), Rajarshi Dasgupta (India), Ronald C. Estoque (Philippines), Wanqin Guo (China), Garima Jain (India), Brian Johnson (USA), Tarek Katramiz (Syria), Pankaj Kumar (India), Xianbing Liu (China), Mythili Madhavan (India), Bijon Kumer Mitra (Bangladesh), Farah Mulyasari (Indonesia), Santosh Nepal (Nepal), Rekha Nianthi (Sri Lanka), Fereidoon Owfi (Iran), Gulsan Ara Parvin (Bangladesh), Shobha Poudel (Nepal), Atta-ur Rahman (Pakistan), Mihoko Sakurai (Japan), Amin Shaban (Lebanon), Dmitry Streletskiy (Russian Federation), Vibhas Sukhwani (India), Prabhakar S.V.R.K (India), Ai Tashiro (Japan), Tống Thị Mỹ Thi (Vietnam), Noralene Uy (Philippines), Xinru Wan (China), Cunde Xiao (China)

Review Editors: Soojeong Myeong (Republic of Korea), Joy Jacqueline Pereira (Malaysia)

Chapter Scientist: Rajarshi Dasgupta (India), Yan Yang (China)

This chapter should be cited as:

Shaw, R., Y. Luo, T.S. Cheong, S. Abdul Halim, S. Chaturvedi, M. Hashizume, G.E. Insarov, Y. Ishikawa, M. Jafari, A. Kitoh, J. Pulhin, C. Singh, K. Vasant, and Z. Zhang, 2022: Asia. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1457–1579, doi:10.1017/9781009325844.012.

Table of Contents

Executive Summary ... 1459

10.1 Introduction ... 1462

Box 10.1 | What Is New on Asia in AR6? ... 1462

10.2 Major Conclusions from Previous Assessments ... 1462

10.3 Regional and Sub-regional Characteristics ... 1463

10.3.1 Climatic Characteristics ... 1463

10.3.2 Ecological Characteristics ... 1466

10.3.3 Demographics and Socioeconomic Characteristics ... 1466

10.4 Key Systems and Associated Impacts, Adaptation and Vulnerabilities ... 1468

10.4.1 Energy Systems ... 1468

Box 10.2 | Migration and Displacement in Asia ... 1469

10.4.2 Terrestrial and Freshwater Ecosystems ... 1472

Box 10.3 | Case Study on Sand and Dust Storm, Climate Change in West Asia's Iranian Region ... 1478

10.4.3 Ocean and Coastal Ecosystems ... 1478

10.4.4 Freshwater Resources ... 1483

Box 10.4 | Case Study on Climate Vulnerability and Cross-Boundary Adaptation in Central Asia ... 1489

10.4.5 Agriculture and Food ... 1490

10.4.6 Cities, Settlements and Key Infrastructures ... 1497

10.4.7 Health and Well-Being ... 1506

10.5 Adaptation Implementation ... 1510

10.5.1 Governance ... 1510

Box 10.5 | Bangladesh Delta Plan 2100 ... 1513

10.5.2 Technology and Innovation ... 1514

10.5.3 Lifestyle Changes and Behavioural Factors ... 1516

10.5.4 Costs and Finance ... 1519

Box 10.6 | Loss and Damage Across Asia: Mapping the Evidence and Knowledge Gaps ... 1520

10.5.5 Risk Insurance ... 1522

10.5.6 Social Protection ... 1523

10.5.7 Education and Capacity Development ... 1525

10.6 Climate Resilient Development Pathways ... 1526

10.6.1 Climate Resilient Development Pathways in Asia ... 1526

10.6.2 Disaster Risk Reduction and Climate-Change Adaptation Linkages ... 1529

10.6.3 Food–Water–Energy Nexus ... 1530

10.6.4 Social Justice and Equity ... 1531

Frequently Asked Questions

FAQ 10.1 | What are the current and projected key risks related to climate change in each sub-region of Asia? ... 1532

FAQ 10.2 | What are the current and emerging adaptation options across Asia? ... 1534

FAQ 10.3 | How are Indigenous knowledge and local knowledge being incorporated in the design and implementation of adaptation projects and policies in Asia? ... 1535

FAQ 10.4 | How can Asia meet multiple goals of climate-change adaptation and sustainable development within the coming decades? ... 1536

References ... 1538

Executive Summary

Observed surface air temperature has been increasing since the 20th century all over Asia (*high confidence*[1]). Significant warming has intensified the threat to social and economic sustainability (*medium confidence*). Rising temperatures increase the likelihood of the threat of heatwaves across Asia, droughts in arid and semiarid areas of West, Central and South Asia, delays and weakening of the monsoon circulation in South Asia, floods in monsoon regions in South, Southeast and East Asia, and glacier melting in the Hindu Kush Himalaya region (*medium confidence*). {10.3.1, 10.3.3}

Asian countries are experiencing a hotter summer climate, resulting in an increase in energy demand for cooling at a rapid rate, together with the population growth (*high confidence*). Decrease in precipitation influences energy demand as well as desalination, underground water pumping and other energy-intensive methods are increasingly used for water supply (*high confidence*). More energy demands in summer seasons will exceed any energy savings from relatively lower heating demand due to warmer winter. Among 13 developing countries with large energy consumption in Asia, 11 are exposed to high-energy insecurity and industrial-systems risk (*high confidence*). {10.4.1}

Asian terrestrial-ecosystems change is driven by global warming, precipitation and Asian monsoon alteration, permafrost thawing and extreme events like dust storms, along with natural and human-related factors which are in interplay (*high confidence*). Treeline position in North Asian mountains moves upwards after the 1990s, while in Himalaya treeline demonstrates a multi-directional shift, either moves upwards or does not show upslope advance, or moves downwards. This can be explained by site-specific complex interaction of positive effect of warming on tree growth, drought stress, change in snow precipitation, land-use change (especially grazing) and other factors (*high confidence*). The increased considerable changes in biomes in Asia are a response to warming (*medium confidence*). Terrestrial and freshwater species, populations and communities are altered in line with climate change across Asia (*medium to high confidence*). Climate change, human activity and lightning have caused the increase in wildfire severity and area burned in North Asia after the 1990s (*medium confidence*). Length of plant growth season has increased in some parts of East and North Asia, while the opposite trend, or no change at all, has been observed in other parts (*high confidence*). Observed biodiversity or habitat losses of animals plants have been linked to climate change in some parts of Asia (*high confidence*). There is evidence that climate change can alter species interaction or spatial distribution of invasive species in Asia (*high confidence*). Changes in ecosystems in Asia during the 21st century are expected to be driven by projected climatic, natural and socioeconomic changes. Across Asia, under a range of representative concentration pathways and other scenarios, rising temperatures are expected to contribute to a northward shift of biome boundaries and an upwards shift of mountain treeline (*medium confidence*). {10.4.2}

Coastal habitats of Asia are diverse, and the impacts of climate change including rising temperatures, ocean acidification and sea level rise (SLR) has brought negative effects to the services and the livelihoods of people depending on it (*high confidence*). The degree of bleaching of coral reefs is diverse among different presences of stress-tolerant symbionts and higher thermal thresholds. The risk of irreversible loss of coral reefs, tidal marshes, seagrass meadows, plankton community and other marine and coastal ecosystems increases with global warming, especially at 2°C temperature rise or more (*high confidence*). Mangroves in the region continue to face threats due to pollution, conversion for aquaculture, agriculture and climate-based threats like SLR and coastal erosion. {10.4.3}

Both climatic and non-climatic drivers such as socio-economic changes have created water stress conditions in both water supply and demand in all sub-regions of Asia, except for North Asia (*medium confidence*). These changes in space and time directly or indirectly have affected water-use sectors and services. By mid-21st Century, the international transboundary river basins of Amu Darya, Indus, Ganges could face severe water scarcity challenges due to climatic variability and changes acting as stress multipliers (*high confidence*). Due to global warming, Asian countries could experience an increase in drought conditions (5–20%) by the end of this century (*high confidence*). {10.4.4}

The Asian glaciers were in minor-area shrinkage and mass loss during 2006–2016, resulting in the instability of water resource supply (*high confidence*). Glaciers in Asia are the water resources of about 220 million people in the downstream areas. The glacier melt water in the southern Tibetan Plateau increased during 1998–2007, and will further increase till 2050. The total amount and area of glacier lakes have increased during the past decade (*high confidence*). More glacier collapses and surges were found in western Tibetan Plateau. Glacier lake outburst flood (GLOF) will threaten the securities of the local and downstream communities (*high confidence*). Snowmelt water contributed 19% of the increase change in runoff of arid regions' rivers in Xinjiang, China, and 10.6% of the upper Brahmaputra River during 2003–2014 (*medium confidence*). {10.4.4, Box 10.4}

Since IPCC AR5, more studies have reinforced the earlier findings on the spatio-temporal diversity of climate-change impacts on food production in Asia depending on the geographic location, agroecology and crops grown, recognising that there are winners and losers associated with the changing climate across scales (*high confidence*). Most of these impacts have been associated with drought, monsoon rain and oceanic oscillations, the frequency and severity of which have been linked with the changing climate. Climate-related risks to agriculture and food systems in Asia will progressively escalate with the changing climate, with differentiated impacts across the region (*medium confidence*). Major projected impacts of climate change in the agriculture and food sectors include decline in fisheries, aquaculture, crop production (particularly in South and Southeast Asia), reduction in livestock production in

1 In this Report, the following summary terms are used to describe the available evidence: limited, medium or robust; and for the degree of agreement: low, medium or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and is typeset in italics (e.g., *medium confidence*). For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence.

Mongolia and changes in crop, farming systems and crop areas in almost all regions, with negative implications to food security (*medium confidence*). In India, rice production can decrease from 10 to 30%, whereas maize production can decrease from 25 to 70% assuming a range of temperature increase from 1°C to 4°C. Similarly, rice production in Cambodia can decrease by 45% by 2080 under the high-emissions scenario. Occurrence of pests, such as the golden apple snail (*Pomacea canaliculate*), associated with the predicted increase in climatically suitable habitats in 2080, threatens the top Asian rice-producing countries including China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, the Philippines and Japan. Increasing temperatures, changing precipitation levels and extreme climate events, such as heatwaves, droughts and typhoons, will persist in being important vulnerability drivers that will shape agricultural productivity particularly in South, Southeast and Central Asia. {10.4.5, Figure 10.6}

Asian urban areas are considered high-risk locations from projected climate change, extreme events, unplanned urbanisation and rapid land-use change (*high confidence*) but also sites of ongoing adaptation (*medium confidence*). Asia is home to the largest share of people living in informal settlements, with 332 million in Eastern and Southeast Asia, and 197 million in Central and Southern Asia. By 2050, 64% of Asia's population will be urban. Coastal cities, especially in South and Southeast Asia, are expected to see significant increases in average annual economic losses between 2005 and 2050 due to flooding, with very high losses in East Asian cities under the high-emissions scenario (*high confidence*). Climate change will amplify the urban heat-island effect across Asian cities (especially South and East Asia) at 1.5°C and 2°C temperature rise, both substantially larger than under the present climate (*medium evidence, high agreement*). Under the high-emissions scenario, higher risks from extreme temperature and precipitation are projected for almost all cities (*medium confidence*), with impacts on freshwater availability, regional food security, human health and industrial outputs. By 2080, 940 million to 1.1 billion urban dwellers in South and Southeast Asia could be affected by extreme heat lasting more than 30 d yr^{-1} (*high confidence*), with poorer populations affected the most. {10.4.6, Cross-Chapter Box URBAN in Chapter 6}

Climate change has caused direct losses due to the damage in infrastructure, disruption in services and affected supply chains in Asia (*medium confidence*) and will increase risk to infrastructure as well as provide opportunities to invest in climate-resilient infrastructure and green jobs (*medium confidence*). At higher warming, key infrastructures, such as power lines, transport by roads and railways, and built infrastructures, such as airports and harbours, are more exposed to climate-induced extreme events, especially in coastal cities (*medium confidence*). Evidence on urban adaptation across Asia is growing with examples of infrastructural adaptation (e.g., flood protection measures, and climate-resilient highways and power infrastructure), institutional adaptation (e.g., sustainable land-use planning, zoning plans), nature ecosystem-based solutions (e.g., mangrove restoration, restoring and managing urban green spaces, urban farming), technological solutions (e.g., smart cities, early warning systems) and behavioural adaptation (e.g., improved awareness and preparedness measures). However, adaptation actions tend to be in the initial stages and more reactive (57% of urban adaptations focus on preparatory interventions, such as capacity building, and 43% of cities report implemented adaptation interventions) (*medium confidence*). The degree of implementation of urban adaptation is uneven with large cities receiving more funding and priority, and smaller cities and towns, and peri-urban spaces, seeing relatively lower adaptation action (*medium confidence*). {10.4.6}

Climate change is increasing vector-borne and water-borne diseases, undernutrition, mental disorders and allergy-related illnesses in Asia by increasing hazards such as heatwaves, flooding and drought, and air pollutants, in combination with more exposure and vulnerability (*high confidence*). Sub-regional diversity in socioeconomic and demographic contexts (e.g., ageing, urban compared with agrarian society, increasing population compared with reduced birth rate, high income compared with low to middle income) and geographic characteristics largely define the differential vulnerabilities and impacts within countries in Asia. Under the medium-to-high emissions scenario, rising temperatures and extreme climate events will have an increasing impact on human health and well-being with varying types and magnitudes of impact across Asia (*high confidence*). More frequent hot days and intense heatwaves will increase heat-related deaths. Increased floods and droughts will have adverse impacts on food availability and the prices of food, resulting in increased undernourishment in South and Southeast Asia. Increases in heavy rain and temperature will increase the risk of diarrhoeal diseases, dengue fever and malaria in tropical and subtropical Asia. {10.4.7}

Increased climate variability and extreme events are already driving migration (*robust evidence, medium agreement*) and projecting that longer-term climate change will increase migration flows across Asia (*medium confidence*). One in three migrants comes from Asia, and the highest ratio of outward migrants is seen from hazard-exposed Pacific countries. In 2019, Bangladesh, China, India and the Philippines each recorded more than 4 million disaster displacements. In Southeast Asia and East Asia, cyclones, floods and typhoons triggered internal displacement of 9.6 million people, almost 30% of total global displacements in 2019. {Box 10.2}

There is a small but growing literature highlighting the importance of behavioural aspects of adaptation in Asia (*high confidence*), but this is restricted primarily to agriculture and disaster risk reduction (DRR). Factors motivating adaptation actions include risk perception, perceived self-efficacy, sociocultural norms and beliefs, previous experiences of impacts, levels of education and awareness (*high confidence*). There is growing evidence on behavioural aspects of individual adaptation but lesser evidence on the socio-cognitive factors motivating governments and private-sector actors to adapt. {10.5.3}

Climate change is already causing economic loss and damage across Asian regions, and this will increase under higher warming (*medium confidence*). Non-material losses and damages are reported to a lesser degree, but this is due to under-reporting and methodological issues with detection and attribution to climate change (*high confidence*). Loss and damage represents a key knowledge gap, especially in West, Central and North Asia. Insufficient literature differentiating loss and damage under future adaptation scenarios renders a comprehensive assessment of residual damages, along with future loss and damage, difficult. {Box 10.6}

Options such as climate-smart agriculture, ecosystem-based DRR and investing in urban blue–green infrastructure meet adaptation, mitigation and Sustainable Development Goals simultaneously, presenting opportunities for climate resilient development (CRD) pathways in Asia (*high confidence*). Climate risks, vulnerability and adaptation measures need to be factored into decision making across all levels of governance (high confidence). To help achieve this, there is a need to advance the current understanding of climate impacts across sectors and spatio-temporal scales, and improve on the current strategies in planning and budget allocation. More accurate forecasting of extreme events, risk awareness and prioritising individual and collective decision making also need to be addressed (high confidence). Options for Asian countries are transforming the risks of climate change into opportunities for the advancement of projects in the energy sector, including promoting investment in non-fossil energies, securing local natural gas resources, enhancing water harvesting, adopting green building technologies and encouraging multi-stakeholder partnerships. However, there are significant barriers to CRD such as fragmented, reactive governance; inadequate evidence on which actions to prioritise and how to sequence them; and finance deficits. Some Asian countries and regions offer solutions to overcome these barriers: through use of advanced technologies (in situ observation and remote sensing, a variety of new sensor technologies, citizen science, artificial intelligence and machine learning tools); regional partnerships and learning; improved forecasting capabilities; and better risk awareness (high confidence). {10.5, 10.6}

10.1 Introduction

Asia is defined here as the land and territories of 51 countries/regions (Figure 10.1). It can be broadly divided into six sub-regions based on geographic position and coastal peripheries (IPCC, 2014b). These are, in alphabetical order, Central Asia (5 countries), East Asia (7 countries/regions), North Asia (2 countries), South Asia (8 countries), Southeast Asia (12 countries) and West Asia (17 countries). The population of Asia was reported to be over 4.46 billion in 2016, which is about 60% of the world's population with an estimated density of 100 people per square kilometre (UNDESA, 2017). The highest life expectancy at birth is 84 years (Japan) and the lowest is 52 years (Afghanistan) (CIA, 2017). The gross domestic product (GDP) per capita ranged from US$587 (Afghanistan) to US$81,585 (Macao, SAR, PRC) (IMF, 2018).

Box 10.1 | What Is New on Asia in AR6?

- Adaptation in energy sector is becoming increasingly crucial in the Asian region, which has been assessed in a new subsection.
- Adaptation technology and innovations are also of high importance for the region. Classification of adaptation technology and its use in different systems are assessed.
- On the governance side, the nexus approach among several systems like food, energy and water is highlighted, and its importance is assessed.
- New concepts on decentralised and self-reliant society, such as the Circulating and Ecological Sphere (CES), are emerging for integrated adaptive governance.
- As a part of a sustainable development pathway, inter-linkages of climate-change adaptation (CCA) and disaster risk reduction (DRR) are highlighted.

10.2 Major Conclusions from Previous Assessments

As the most populous continent, Asia is faced with a unique set of challenges that vary across its climatic zones:

- The most perceptible change in climatic trends is observable in the increasing surface air temperature and rise in nighttime temperature, particularly during winter. This is accompanied by monsoon rainfall variability, which is observable interseasonally, interannually and spatially.
- There is increasing evidence of an upwards trend in the intensity and frequency of extreme weather events in Asia.
- The predictions for future climatic trends suggest an increase in warming along the higher latitudes of North Asia.
- Projections show that agricultural and food security will be impacted substantially, particularly in the area of cereal production, by the end of the 21st century.
- Malnutrition among the poor and marginalised sections of the population in Asia remains a major concern that is further rendered complex by climate change.
- Projections of an increase in the incidence of pests and diseases impact directly on the food security and health of vulnerable populations.
- Erosion will occur simultaneously with SLR. The projected rise could lead to large-scale flooding in low-lying areas, particularly South, Southeast and East Asia.
- The erosion of the major deltas of Asia may take place through a rise in sea levels, an increased frequency of extreme weather events and the excessive withdrawal of groundwater.
- The priority areas for Asia include an enhancement of capabilities to collect social and biophysical data, information sharing, sectoral interactions, a mainstreaming of science and the identification of critical climate thresholds across regions and sectors.

Drawing upon a greater number of studies made possible by greater use of advanced research tools, such as remote sensing as well as meticulous modelling of impacts, the Fifth Assessment Report could significantly expand its coverage of pertinent issues (IPCC, 2014c). For example, the discussion on the Himalayas was expanded to cover observed and projected impacts of climate change on tourism (WGII AR5 Section 10.6.2); livelihood assets such as water and food (WGII AR5 Sections 9.3.3.1, 13.3.1.1, 18.5.3, 19.6.3); poverty (WGII AR5 Section 13.3.2.3); culture (WGII AR5 Section 12.3.2); flood risks (WGII AR5 Sections 18.3.1.1, 24.2.1); health risks (WGII AR5 Section 24.4.6.2); and ecosystems (WGII AR5 Section 24.4.2.2; IPCC, 2014b, 2014c).

- Over the past century, and across most of Asia, warming trends and increasing temperature extremes have been observed.
- Adequate supplies of freshwater resources are under considerable threat due to both the existing pattern of socioeconomic growth and climate change.
- With a number of regions already close to the heat stress limits, most models, using a range of general circulation models (GCMs) and Special Report on Emission Scenarios (SRES) scenarios, suggest that higher temperatures will lead to shorter growing periods of rice cultivation, resulting in lower rice yields.
- Climate-change impacts have led to visible shifts on the terrestrial systems in many parts of Asia in the phenologies, growth rates and distributions of plant species.
- Coastal and marine systems in Asia are under increasing stress from both climate-impact drivers (CIDs) and non-climate drivers, and mean SLR will contribute to upwards trends in extreme coastal high water levels (WGI AR5 Section 3.7.6) (Rhein, et al., 2013). Mangroves, salt marshes and seagrass beds may decline unless they can move inland, while coastal freshwater swamps and marshes will be vulnerable to saltwater intrusion with rising sea levels. Damage to coral reefs will increase during the 21st century because of both warming and ocean acidification.
- Climate change will further compound multiple stresses caused due to rapid urbanisation, industrialisation and economic growth. Development of sustainable cities in Asia with fewer fossil-fuel-driven vehicles and with more trees and greenery would have a number of co-benefits, including improved public health.
- Extreme climate events will have an increasing impact on human health, security, livelihoods and poverty, with the type and magnitude of impact varying across Asia.

Countries and regions in Asia

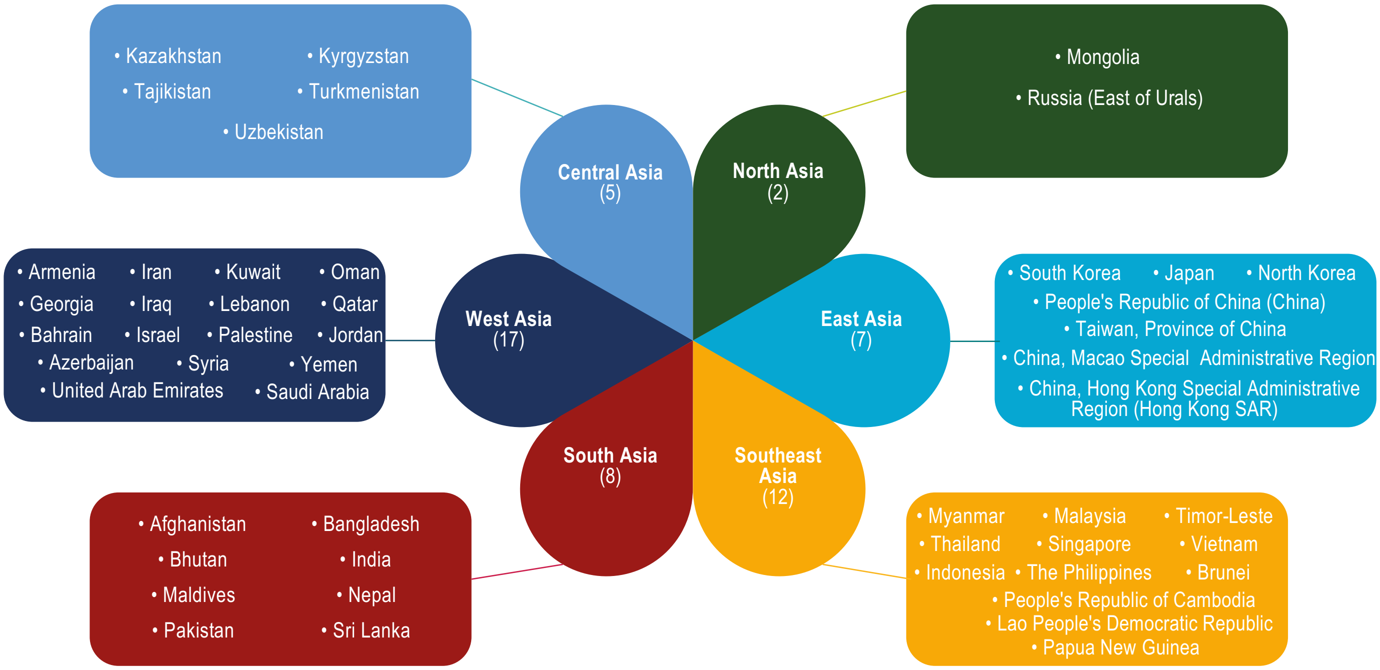

Figure 10.1 | Countries and regions in Asia

- Indigenous knowledge and local knowledge (IKLK) play an important role in the formulation of adaptation governance and related strategies (IPCC, 2007), and best quality, locality-specific knowledge can help address serious lack of education on climate change and uncertainties surrounding quality, salience, credibility and legitimacy of the available knowledge base.

Knowledge and research gaps identified in AR5 include, but are not limited to, an insufficient understanding of the impacts, vulnerability and adaptation in urban settlements, under-researched linkages between local livelihoods, ecosystem functions and land resources, and a poor understanding of the impacts of projected climate changes on the vegetation of the lowland tropics.

10.3 Regional and Sub-regional Characteristics

10.3.1 Climatic Characteristics

Climate characteristics in Asia are diverse covering all climate zones from tropical to polar, including mountain climate. Monsoonal winds and associated precipitation are dominant in South, Southeast and East Asia. Annual mean surface air temperature averaged over the sub-region ranges from coldest in North Asia (–3°C) to warmest in Southeast Asia (25°C) based on JRA-55 (Kobayashi et al., 2015) climatology for 1981–2010. Most of North Asia and higher altitude is underlain by permafrost. West Asia is the driest and Southeast Asia is the wettest, with the annual precipitation averaged over the sub-region ranging about ten times from 220 mm in West Asia to 2570 mm in Southeast Asia based on GPCC (Schamm et al., 2014) climatology for 1981–2010. Indonesia in Southeast Asia has the longest coastline in the world, causing this area (maritime continent) to be the wettest region (Yamanaka et al., 2018). The Hindu Kush Himalaya (HKH) region is a biodiversity hotspot (Wester et al., 2019) and also has significant impacts on the Asian climate because of its orographic and thermodynamic effects (Wu et al., 2012).

Extreme precipitation events and related flooding occur frequently in monsoon Asia (i.e., Southeast, South and East Asia) (Mori et al., 2021b). Tropical cyclones also affect East and South Asia with torrential rain, strong winds and storm surge. Floods and other weather-related hazards are causing thousands of casualties and millions of people are affected each year (CRED/UNISDR, 2019). On the other hand, droughts have long-lasting effects on agriculture and livestock threatening water security in West Asia, Central Asia and northern China (Ranasinghe et al., 2021; Seneviratne et al., 2021). Adaptation to such extreme events has been limited in Asia.

10.3.1.1 Observed Climate Change

Observations of past and current climate in Asia are assessed in IPCC WGI AR6 (IPCC, 2021). Examples of observed impacts in Asia with attributed CIDs are shown in Figure 10.2. Surface temperature has increased in the past century all over Asia (*very high confidence*). Elevation-dependent warming (i.e., the warming rate is different across elevation bands is observed in HMA) (*medium confidence*) (Hock et al., 2019; Krishnan et al., 2019). While there is an overall trend of decreasing glacier mass in HMA, there are some regional differences and even areas with a positive mass balance due to increased precipitation (Wester et al., 2019). Rising temperatures have resulted in an increasing trend of growing-season length. The number of hot days and warm nights continues to increase in all of Asia (*high confidence*), while cold days and nights are decreasing except in the southern part of

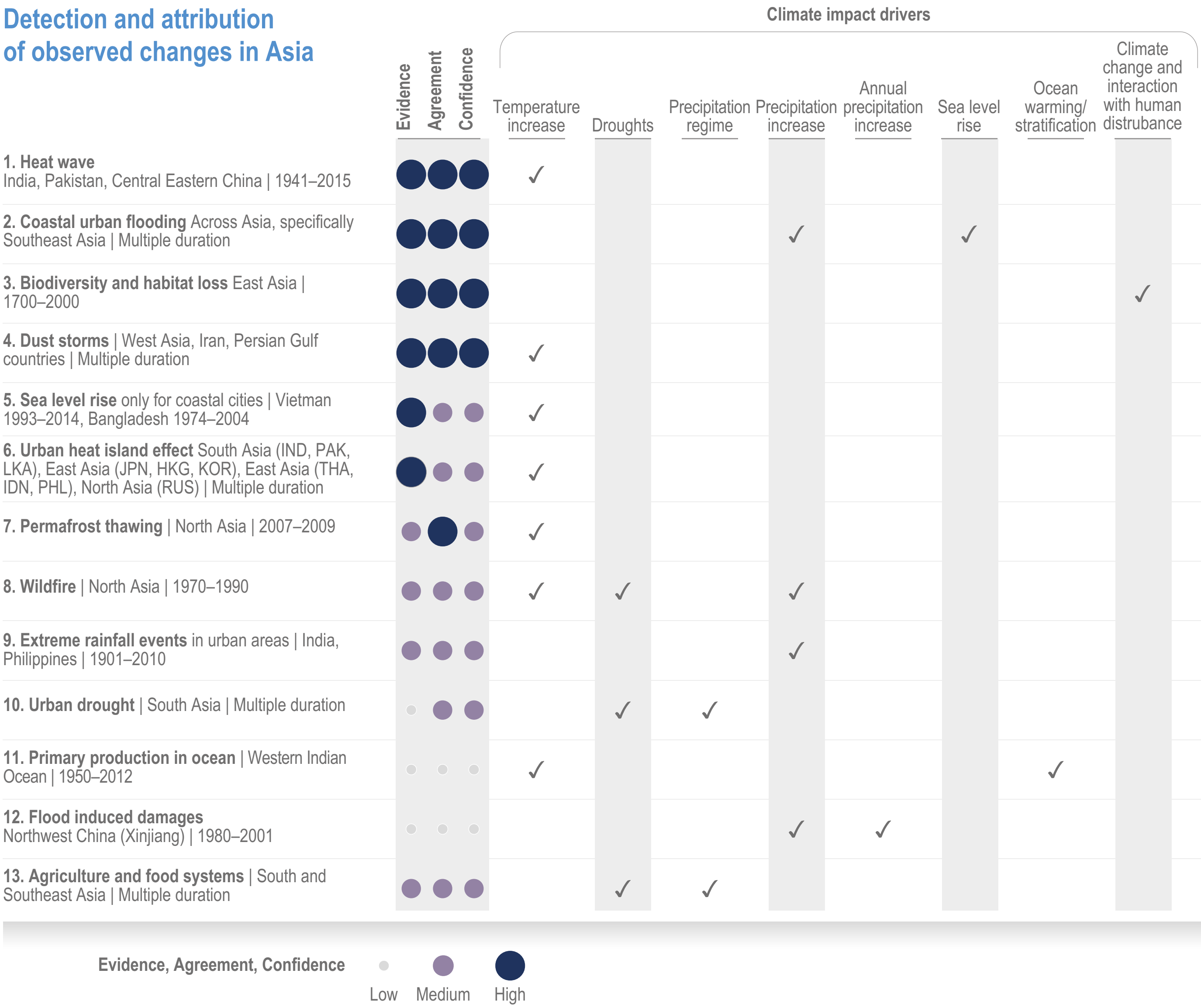

Figure 10.2 | Detection and attribution of observed changes in Asia. Levels of Evidence (E), Agreement (A) and Confidence (C) are ranked by High (H), Medium (M) or Low (L). CID: climate-impact driver. References: (1) Heatwaves (Mishra et al., 2015; Rohini et al., 2016; Chen and Li, 2017; Panda et al., 2017; Ross et al., 2018); (2) Coastal urban flooding (Dulal, 2019); (3) Biodiversity and habitat loss (Wan et al., 2019); (4) Dust storms (Kelley et al., 2015; Yu et al., 2015; Alizadeh-Choobari et al., 2016; Nabavi et al., 2016); (5) Sea level rise (only for coastal cities) (Brammer, 2014; Shahid et al., 2016; Hens et al., 2018); (6) Urban heat island (UHI) effect (Choi et al., 2014; Santamouris, 2015; Estoque et al., 2017; Ranagalage et al., 2017; Kotharkar et al., 2018; Li et al., 2018a; Hong et al., 2019c); (7) Permafrost thawing (Shiklomanov et al., 2017a; Biskaborn et al., 2019); (8) Wildfire (Schaphoff et al., 2016; Brazhnik et al., 2017); (9) Extreme rainfall events (in urban areas) (Ali et al., 2014); (10) Urban drought (Gu et al., 2015; Pervin et al., 2020); (11) Primary production in ocean (Roxy et al., 2016); (12) Flood-induced damages (Fengqing et al., 2005); (13) Agriculture and food systems (Heino et al., 2018; Prabnakorn et al., 2018).

Siberia (Gutiérrez et al., 2021). Large increases in temperature extremes are observed in West and Central Asia (*high confidence*). Temperature increase is causing strong, more frequent and longer heatwaves in South and East Asia. The 2013 East China heatwaves case is such an example (Xia et al., 2016). In 2016 and 2018, extreme warmth was observed in Asia for which an event-attribution study revealed that this would not have been possible without anthropogenic global warming (*medium confidence*) (Imada et al., 2018; Imada et al., 2019).

There are considerable regional differences in observed annual precipitation trend (*medium confidence*). Observations show a decreasing trend of the South Asian summer monsoon precipitation during the second half of the 20th century (*high confidence*) (Douville et al., 2021). No clear trend in precipitation is observed in high-mountain Asia (Nepal and Shrestha, 2015), while a continuous shift towards a drier condition has been observed since the early 1980s in spring over the central Himalaya (Panthi et al., 2017). Increase in heavy precipitation occurred recently in South Asia (*high confidence*), and in Southeast and East Asia (*medium confidence*) (Seneviratne et al., 2021). In Japan, there is no significant long-term trend in the annual precipitation, while significant increasing trend is observed in the annual number of events of heavy precipitation (daily precipitation ≥400 mm) and intense precipitation (hourly precipitation ≥50 mm) (JMA, 2018). Decreased precipitation and increased evapotranspiration are observed in West and Central Asia, contributing to drought conditions and decreased surface runoff.

Annual surface wind speeds have been decreasing in Asia since the 1950s (*high confidence*) (Ranasinghe et al., 2021). The observed changes in the frequency of sand and dust storms vary from region to region in Asia (*medium confidence*). The frequency and intensity of dust storms are increasing in some regions, such as West and Central Asia, due to land use and climate change (Mirzabaev et al., 2019). Significant decreasing trends of dust storms are observed in some parts of Inner Mongolia and over the Tibetan Plateau (Ranasinghe et al., 2021). In contrast, West Asia has witnessed more frequent and intensified dust storms affecting Iran and Persian Gulf countries in recent decades (*medium confidence*) (Nabavi et al., 2016).

There is no significant long-term trend during 1951–2017 in the numbers of tropical cyclones (TCs) with maximum winds of 66.37 km h^{-1} or higher forming in the western North Pacific and the South China Sea (*medium confidence*). There are substantial inter-decadal variations in basin-wide TC frequency and intensity in the western North Pacific (Lee et al., 2020a). Numbers of strong TCs (maximum winds of 124.93 km h^{-1} or higher) also show no discernible trend since 1977 when complete wind-speed data near TC centre become available (JMA, 2018). According to Cinco et al. (2016), for TCs in the Philippines there are no significant trends in the annual number of TCs during 1951–2013. Their analysis showed that the Philippines have been affected by fewer TCs above 124.93 km h^{-1}, but affected more by extreme TCs (above 158.11 km h^{-1}). There has been a significant northwestward shift in TC tracks since the 1980s, and a detectable poleward shift since the 1940s in the average latitude where TCs reach their peak intensity in the western North Pacific (*medium confidence*) (Lee et al., 2020a).

According to Bindoff et al. (2019), the oceans have warmed unabatedly since 2004, continuing the multi-decadal ocean-warming trends. Their report also summarised that there is increased agreement between coupled model simulations of anthropogenic climate change and observations of changes in ocean heat content (*high confidence*). Observed SLR around Asia over 1900–2018 is similar to the global mean sea level change of 1.7 mm yr^{-1}, but for the period 1993–2018, the SLR rate increased to 3.65 mm yr^{-1} in the Indo-Pacific region and 3.53 m yr^{-1} in the Northwest Pacific, compared with the global value of 3.25 mm yr^{-1} (Ranasinghe et al., 2021). The extreme SLR has occurred since the 1980s along the coast of China (Feng et al., 2018b).

Ocean acidification continues with surface seawater pH values having shown a clear decrease by 0.01–0.09 from 1981–2011 along the Pacific coasts of Asia (*high confidence*) (Lauvset et al., 2015). For the western North Pacific along the 137°E line, the trend varies from –0.013 at 3°N to –0.021 at 30°N per decade during 1985–2017 (JMA, 2018). Ocean interior (about 150–800 m) pH also shows a decreasing trend with higher rates in the northern than the southern subtropics, which may be due to greater loading of atmospheric CO_2 in the former (JMA, 2018).

10.3.1.2 Projected Climate Change

Rising temperatures increase the likelihood of the threat of heatwaves across Asia, droughts in arid and semiarid areas of West, Central and South Asia, floods in monsoon regions in South, Southeast and East Asia, and glacier melting in the HKH region (*high confidence*) (Doblas-Reyes et al., 2021; Ranasinghe et al., 2021; Seneviratne et al., 2021). Confidence in the direction of the projected change in CIDs in Asia are summarised in Table 12.4 of WGI AR6 Chapter 12 (Ranasinghe et al., 2021).

Projections of future changes in annual mean surface air temperature in Asia are qualitatively similar to those in the previous assessments with greater warming at higher latitudes (i.e., North Asia) (*high confidence*) (Gutiérrez et al., 2021). Projected surface air temperature changes in the Tibetan Plateau, Central Asia and West Asia are also significant (*high confidence*) (Gutiérrez et al., 2021). The highest levels of warming for extremely hot days are expected to occur in West and Central Asia with increased dryness of land (*high confidence*) (SR1.5). Over mountainous regions, elevation-dependent warming will continue (*medium confidence*) (Hock et al., 2019). Glaciers will generally shrink, but rates will vary among regions (*high confidence*) (Wester et al., 2019). Thawing permafrost presents a problem in northern areas of Asia, particularly Siberia (Parazoo et al., 2018). Temperature rise will be strongest in winter in most regions, while it will be the strongest on summer in the northern part of West Asia and some parts of South Asia where a desert climate prevails (*high confidence*) (Gutiérrez et al., 2021). The wet-bulb globe temperature, which is a measure of heat stress, is *likely*[2] to approach critical health thresholds in West and South Asia under the RCP4.5 scenario, and in some other regions, such as East Asia, under the RCP8.5 scenario (*high confidence*) (Lee et al., 2021a; Seneviratne et al., 2021). The occurrence of extreme heatwaves will *very likely* increase in Asia. Projections show that a sizeable part of South Asia will experience heat stress conditions in the future (*high confidence*). It is *virtually certain* that cold days and nights will become fewer (Ranasinghe et al., 2021).

Projections of future annual precipitation change are qualitatively similar to those in the previous SREX and AR5 assessments (IPCC, 2021). A *very likely* large percentage increase in annual precipitation is projected in South and North Asia (*high confidence*) (Douville et al., 2021; Lee et al., 2021a). Precipitation is projected to decrease over the northwest part of the Arabian Peninsula and increase over its southern part (*medium confidence*) (Gutiérrez et al., 2021). Both heavy and intense precipitation are projected to intensify and become more frequent in South, Southeast and East Asia (*high confidence*) (Seneviratne et al., 2021). There will be a large increase in flood frequency in these monsoon regions (Oppenheimer et al., 2019). Without further mitigation efforts, this will lead to continued loss of lives and infrastructure. SR1.5 assessed higher risk from heavy precipitation events at 2°C compared with 1.5°C of global warming in East Asia. A large ensemble-modelling study shows that future warming is expected to further increase winter precipitation, and extreme weather events,

2 In this Report, the following terms are used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10% and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100% and extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics (e.g., *very likely*). This Report also uses the term '*likely* range' to indicate that the assessed likelihood of an outcome lies within the 17–83% probability range.

such as rain-on-snow, will result in an increase in extreme runoff in Japan (*low confidence*) (Ohba and Kawase, 2020). Furthermore, the earlier snowmelt will affect energy supply by hydropower.

Monsoon land precipitation *likely* will increase in East, Southeast and South Asia mainly due to increasing moisture convergence by elevated temperature (*high confidence*); however, there is *low confidence* in the magnitude and detailed spatial patterns of precipitation changes at the sub-regional scale in East Asia (Doblas-Reyes et al., 2021). Increasing land–sea thermal contrast and resultant lower tropospheric circulation changes, together with increasing moisture, are projected to intensify the South Asian summer monsoon precipitation (*medium confidence*). Anthropogenic aerosols greatly modify sub-regional precipitation changes, and their spatio-temporal changes are uncertain (Douville et al., 2021). Monsoonal winds will generally become weaker in a future warming world with different magnitudes across regions (*medium confidence*). Future changes in sand and dust storms are uncertain.

The global proportion of very intense TCs (category 4–5) will increase under higher levels of global warming (*medium to high confidence*). Mean global TC precipitation rate will increase (*medium to high confidence*). Models suggest a reduction in TC frequency but an increase in the proportion of very intense TCs over the western North Pacific in the future; however, some individual studies project an increase in western North Pacific TC frequency (*medium confidence*) (Cha et al., 2020). In the western North Pacific, some models project a poleward expansion of the latitude of maximum TC intensity, leading to a future increase in intense TC frequency south of Japan (*medium confidence*) (Yoshida et al., 2017).

Relative SLR associated with climate change in Asia will range from 0.3–0.5 m in SSP1-2.6 to 0.7–0.8 m in SSP5-8.5 for 2081–2100 relative to 1995–2014 (Ranasinghe et al., 2021). In coastal regions, evaluation of SLR is necessary at the regional scale to assess the impacts on coastal sectors. Liu et al. (2016c) investigated the regional-scale SLR using dynamic downscaling from the three global-climate models in the western North Pacific. In their projection in the case following the RCP8.5 scenario, the regional sea level rises along Honshu Island in Japan during 2081–2100 relative to 1981–2000 are 6–25 cm higher than the global mean SLR due to the dynamic response of the ocean circulation. For the impact assessment of coastal hazards, the total SLR included extreme events due to storm surge and high ocean waves, which are influenced by the changes in TCs (Seneviratne et al., 2021). Mori and Takemi (2016) summarised the characteristics of TCs in the western Pacific in the past and in the future, and the extreme value of significant wave height increased in several regions. There is considerable increase in the return levels along the China coast under 2.0°C warming compared with that under the 1.5°C warming scenario (Feng et al., 2018b).

Ocean acidification will continue over the 21st century (*virtually certain*) (SROCC). Projected decrease in global surface ocean pH from 1986–2005 to 2081–2100 is about 0.145 under RCP4.5 (Lee et al., 2021a).

Diverse and complex climate characteristics in Asia limit climate models' ability to reasonably simulate the current climate and project its future change (Gutiérrez et al., 2021).

10.3.2 Ecological Characteristics

Ecosystems in Asia are characterised by a variety of climate and topographic effects, and can be divided into several distinct areas (Figure 10.3). In addition, valuable ecosystem services provide vital support for human well-being and sustainable development (IPBES, 2018).

Boreal forests and tundra dominate in North Asia: deserts and xeric shrublands in Central and West Asia; and alpine ecosystems in the HKH, Tian Shan, Altai-Sayan, Ural and Caucasus mountain regions. Human-transformed landscapes occupy most parts of other sub-regions. The remaining natural ecosystems in East Asia are temperate broadleaf and mixed forests, and there are subtropical evergreen forests, deserts and grasslands in the West Asia. South Asia has tropical forests and semi-deserts in the northwest, and Southeast Asia is covered mainly by tropical forests (Figure 10.3).

Ocean and coastal regions in Asia have various ecological characteristics, such as high productivity in arctic and subpolar regions, large biodiversity in tropical regions and unique systems in marginal seas. In the atlas of WGI AR6, the ocean biomes in Asia are divided into six sub-regions (WGI AR6 Figure Atlas.4) (Gutiérrez et al., 2021). For the coastal region, the concept of the large marine ecosystem (e.g., see Sherman, 1994) provides the biological characteristics of each marginal/semi-enclosed region and the regions characterised by boundary current system.

Biodiversity and ecosystem services play a critical role in socioeconomic development as well as the cultural and spiritual fulfilment of the Asian population (IPBES, 2018). For example, species richness reaches its maximum in the 'coral triangle' of Southeast Asia (central Philippines and central Indonesia) (IPCA, 2017), and the extent of mangrove forests in Asia is about 38.7% of the global total (Bunting et al., 2018). These coastal ecosystems provide multiple ecosystem services related to food production by fisheries/aquaculture, carbon sequestration, coastal protection and tourism/recreation (Ruckelshaus et al., 2013).

10.3.3 Demographics and Socioeconomic Characteristics

In the six sub-regions of Asia, nature and biophysical impacts of climate change are observed in three climate-change hotspots where strong climate signals and high concentrations of vulnerable people are present, namely in semiarid, glacial-fed river basins and mega deltas (De Souza et al., 2015; Kilroy, 2015; Szabo et al., 2016b). The impacts of global climate events also have profound social implications, threatening human health and well-being, destabilising assets, weakening coping capacities and response infrastructures and substantially increasing the number of socially, economically and psychologically vulnerable individuals and communities (Ford et al., 2015).

Vulnerability to climate change varies by geography and by the economic circumstances of the exposed population (Sovacool et al., 2017). The concentration of population growth in less developed regions means that an increasing number of people live in countries with the least ability to adapt to climate change (Auffhammer and

Terrestrial ecoregions, large marine ecosystems and major fishing areas of Asia

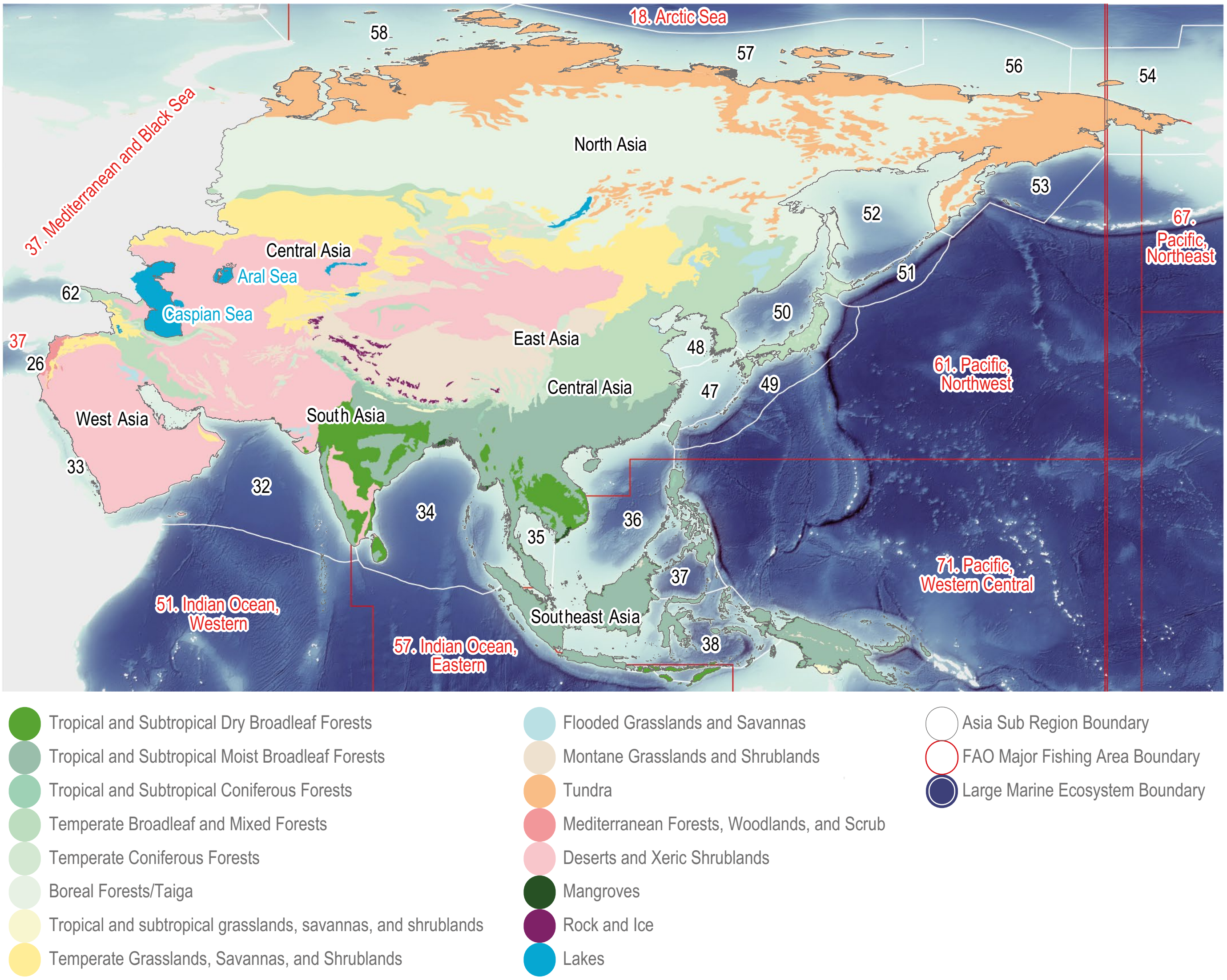

Figure 10.3 | Terrestrial ecoregions, large marine ecosystems and major fishing areas of Asia. Large marine ecosystems: *26* Mediterranean Sea; *32* Arabian Sea; *33* Red Sea; *34* Bay of Bengal; *35* Gulf of Thailand; *36* South China Sea; *37* Sulu-Celebes Sea; *38* Indonesian Sea; *47* East China Sea; *48* Yellow Sea; *49* Kuroshio Current; *50* Sea of Japan; *51* Oyashio Current; *52* Sea of Okhotsk; *53* West Bering Sea; *54* Northern Bering and Chukchi seas; *56* East Siberian Sea; *57* Laptev Sea; *58* Kara Sea; *62* Black Sea. Developed after Olson et al. (2001), NOAA (2010) and FAO (2019), and made with Natural Earth. Natural Earth is a public domain map dataset archive available at https://www.naturalearthdata.com/. The software used for generating the map was ArcGIS 10.0. Note that the map is for illustrative purposes only.

Kahn, 2018). Bangladesh with 163 million people, an example, is one of the most vulnerable countries in the world to climate risks and natural hazards, and faces severe floods, cyclones, droughts, heatwaves and storm surges on a regular basis (Dastagir, 2015; Hossain et al., 2018; Roy and Haider, 2019).

Differential human vulnerability to environmental hazards results from a range of social, economic, historical and political factors, all of which operate at multiple scales (De Souza et al., 2015; Thomas, 2019). Climate change is expected to have serious impacts on people living within these hotspot areas, as observed from loss of food crop yields to disasters such as floods, fluctuations in seasonal water availability or other systemic effects (De Souza et al., 2015). For instance, in South Asia, extreme climatic conditions are threatening food security; thus, agro-based economies, such as those of India and Pakistan, are the most vulnerable to climate change in this regard (Mendelsohn, 2014; Ahmad, 2015; Kirby et al., 2016; Ali et al., 2017).

A broad-based understanding of gender vulnerability in the context of poverty and social discrimination, as well as diverse social and cultural practices in different political, geographic and historical settings, apart from climate variability along with environmental and natural risks, is central to understanding people's capacities to cope with, and adapt to change (Morchain et al., 2015; Yadav and Lal, 2018; Rao et al., 2019). Studies highlight the fact that disasters do not affect people equally; mostly findings show that insufficient disaster education, inadequate protection measures and powerful cultural issues, both pre- and post-disaster, increase women's vulnerability during and after disasters (Isik et al., 2015; Reyes and Lu, 2016; Hamidazada et al., 2019). In particular, cultural issues play a role after disasters by affecting women's security, access to disaster aid and health care (Raju, 2019). There must be more nuanced understanding and examination of gender, as well as poor, disadvantaged and vulnerable groups, in vulnerability and risk assessments (Reyes and Lu, 2016; Reyer, 2017; Xenarios et al., 2019).

Based on the 'World Economic Situation and Prospects as of mid-2019 Report', the region has an estimated 400 million people living in extreme poverty below the threshold of 1.90 USD d^{-1}. At the higher international poverty line of 3.20 USD d^{-1}, the number of poor rises to 1.2 billion people, accounting for more than a quarter of the region's total population (Holland, 2019). Beyond monetary measures, indicators of multi-dimensional aspects of poverty, most notably in Southern Asia, indicate that a large share of the population still lacks access to basic infrastructure and services (Bank, 2017b).

For instance, South Asia illustrates that on average it could lose nearly 2% of its GDP by 2050, rising to a loss of nearly 9% by 2100 under a business-as-usual scenario (Ahmed and Suphachalasai, 2014). The relationship between economic outcomes and cross-sectional climate variation is confounded by regional heterogeneity, including historical effects of settlement and colonisation (Dell et al., 2014; Newell et al., 2018). Climate change vulnerability may also depend on sufficient employment opportunities in the risk-prone areas, land-holding size, gender, education level, and family and community size, as observed in Nepal, Thailand and Vietnam (Baul and McDonald, 2015; Lebel L., 2015; Phuong et al., 2018a).

As poor households are constrained in their ability to receive nutrition, schooling and health care for their children, this is greatly dampening progress in human capital development and productivity growth, both of which are critical imperatives for sustainable development (Carleton and Hsiang, 2016; Schlenker and Auffhammer, 2018). Studies also have shown negative impacts of climate change on several essential components of people's livelihoods and well-being, such as water supply, food production, human health, availability of land and ecosystems (Alauddin and Rahman, 2013; Arnell et al., 2016; Roy and Haider, 2019).

Major population trends of urbanisation and urban area expansion are forecast to take place in Asia. It has been mentioned that demographic change will make humanity more vulnerable to climate change, particularly in places with high poverty rates and potentially prone to systemic disruptions in the food system (Puma et al., 2015; d'Amour et al., 2016; d'Amour et al., 2017).

The urban population of the world has grown rapidly from 751 million in 1950 to 4.2 billion in 2018. Asia, despite its relatively lower level of urbanisation, is home to 54% of the world's urban population (United Nations, 2019). Some cities have experienced population decline in recent years. Most of these cities are located in the low-fertility countries of Asia, where overall population sizes are stagnant or declining, as observed in a few cities in Japan and the Republic of Korea (e.g., Nagasaki and Busan), which experienced a population decline between 2000 and 2018 (United Nations, 2019). By 2030, the world is projected to have 43 megacities with more than 10 million inhabitants, most of them in developing regions. However, some of the fastest-growing urban agglomerations are cities with fewer than 1 million inhabitants, many of them located in Asia and Africa (United Nations, 2019). Challenges with water supply, in many cases, have existed for decades (Dasgupta, 2015). Climate change increases these challenges (Hoque et al., 2016). As more people inhabit urban areas, the number of people vulnerable to heat stress is thus *likely* to rise, a problem that will be compounded by rising temperatures due to climate change (Acharya et al., 2018). Compared with rural areas, hot temperature risk is even higher in urban regions (Luo, 2018a; Ye, 2018; Setiawati Martiwi Diah, 2021).

The impact of heat in rural areas has been a blind spot so far, particularly for farmers and outdoor labourers who are increasingly exposed to high outdoor temperatures due to increased intensity in agriculture combined with changes in working hours (Tasgaonkar, 2018).

Farmers as a group have shown an increasing number of females over the years due to migration of male members into urban areas for employment, which is putting women at more severe risk in the context of climate variability (Singh, 2019). Women are required to acquire new capacities to manage new challenges, including risks from climate change, through capacity-building interventions to strengthen autonomous-adaptation measures (Banerjee et al., 2019; James, 2019; Mishra, 2019). However, the overlapping crises of climate change and the global public health crisis of COVID-19 represent a major challenge to gender equality and sustainable development (Katherine Brickell, 2020; Sultana, 2021).

For vulnerable populations, such as Indigenous Peoples, older and low-income groups, women, children, people with disabilities and minorities, the health effects of climate-change-related extreme weather events can be especially devastating (McGill, 2016). Such populations may be more susceptible to disease, have pre-existing health conditions or live in areas that do not promote good health or well-being; for instance, loss of income and food supply shortages could lead children in rural households to nutritional deprivations that can have both immediate and lifelong impacts (Gleick, 2014; UNICEF, 2015). Children, already susceptible to age-related insecurities, face additional destabilising insecurities from questions about how they will cope with future climate change (Hansen et al., 2013).

10.4 Key Systems and Associated Impacts, Adaptation and Vulnerabilities

10.4.1 Energy Systems

10.4.1.1 Regional Diversity

Energy consumption of Asia accounts for 36% of the global total at present. China, India and the ASEAN countries have largely contributed to the ever-growing global energy consumption. Asia is predicted to account for 80% of coal, 26% of natural gas and 52% of electricity consumption of the world by 2040 (IEA, 2018). The share of Asia in the global primary energy consumption will increase to 48% by 2050. China continues to be the world's largest energy consumer, and the combined consumption of India and ASEAN will be similar to that of China by that time (IEEJ, 2018).

Box 10.2 | Migration and Displacement in Asia

Migration is a key livelihood strategy across Asia and is driven by multiple factors such as socioeconomic changes, increasing climate variability and disaster incidence, and changing aspirations. Displacement denotes a more involuntary movement in reaction to climatic or non-climatic factors. There is *robust evidence, medium agreement* that increased climate variability and extreme events are already driving migration (Gemenne et al., 2015; Rigaud et al., 2018; IDMC, 2019; Jacobson et al., 2019; Siddiqui et al., 2019; IDMC, 2020; Maharjan et al., 2020) and *medium evidence, medium agreement* projecting that longer-term climate change will increase migration flows across Asia (Abubakar et al., 2018; Rigaud et al., 2018; Hauer et al., 2020; Bell et al., 2021).

Detection and attribution: Does climate change drive migration? Ascertaining the role of climate change in migration is difficult and contested (see Cross-Chapter Box MIGRATE in Chapter 7 and RKR-H in Chapter 16), with observation-based studies either linking extreme event incidence, weather anomalies and environmental change with migration numbers or drivers (McLeman, 2014; Singh et al., 2019a; Kaczan and Orgill-Meyer, 2020), and projection studies looking at particular risks such as SLR or drought by linking increasing warming (often through representative concentration pathways, RCPs) and population growth. Despite methodological disagreement on detection and attribution of migration due to climate change, there is medium confidence that higher warming and associated changes in frequency and intensity of slow-onset events (such as drought and sea level rise) and rapid-onset events (such as cyclones and flooding) will increase involuntary displacement in the future, especially under SSP3 and SSP4 pathways (Dasgupta et al., 2014a; Davis et al., 2018; Rigaud et al., 2018; Hauer et al., 2020). But its role is smaller than non-climatic socio-economic drivers of migration (Wodon et al., 2014; Adger et al., 2021).

Current migration and displacement. One in three migrants comes from Asia and the highest ratio of outward migrants is seen from hazard-exposed Pacific countries (Ober, 2019). In 2019, approximately 1900 disasters triggered 24.9 million new displacements across 140 countries; in particular, Bangladesh, China, India and the Philippines each recorded more than 4 million disaster displacements (IDMC, 2019). Tajikistan, Kyrgyzstan and Russia see significant disaster-associated displacements: for example, heavy rain-induced flooding in Khatlon (Tajikistan) triggered 5400 new displacements; landslides in the Jalal-Abad (Kyrgyzstan) saw 4700 new displacements; and floods in Altai, Tuva and Khakassia (Russia) displaced 1500 people. Iran reported the highest sub-regional figures with >520,000 new disaster-related displacements in 2019 (IDMC, 2019). In Southeast and East Asia, cyclones, floods and typhoons triggered internal displacement of 9.6 million people in 2019, almost 30% of total global displacements (IDMC, 2019). With most migrants in the region being temporary migrant workers, loss of jobs and wages among them have been particularly severe due to adverse economic climate triggered by COVID-19 (ESCWA, 2020). It has also resulted in large-scale returns of migrant workers, and remittances have declined drastically (Khanna, 2020; Li et al., 2021). Remittances to Eastern Europe and Central Asia are expected to decline 16.1% from 57 billion USD in 2019 to 48 billion USD in 2020. Remittances in East Asia and the Pacific are estimated to fall 10.5% over the same period, from 147 billion to 131 billion USD (United Nations, 2020). The COVID-19 pandemic has had significant impacts on migrants (Rajan, 2020) in the region, and some countries have targeted migrants in economic stimulus packages or income-support programmes; however, access to such support has been heterogeneous.

Projected migration. Regional variation is significant across Asia. By one estimate, in South Asia, internal climate migrants (i.e., those migrating due to climate change and associated impacts such as water scarcity, crop failure, SLR and storm surges) are projected to be 40 million by 2050 (1.8% of regional population) under high warming (Rigaud et al., 2018). While methodological critiques remain on projected migration estimates, what is certain is that some countries will be more affected that others; it is estimated that in southern Bangladesh, SLR could displace 0.9–2.1 million people by direct inundation by 2050 (Jevrejeva et al., 2016; Davis et al., 2018). In South Asia, migration hotspots include the Gangetic Plain and the Delhi–Lahore corridor, and coastal cities such as Chennai, Chittagong, Dhaka and Mumbai, which will be simultaneously exposed to climate-change impacts, major migration destinations and amplified rural–urban migration (Ober, 2019). Importantly, there is *low agreement* on projected numbers (see Boas et al., 2019) with uncertainties around how local policies and individual behaviours will shape migration choices. Even in high-risk places, people might choose to stay or be unable to move, resulting in 'trapped' populations (Zickgraf, 2019; Ayeb-Karlsson et al., 2020). There is currently inadequate evidence to ascertain the nature and numbers of trapped populations currently or in the future.

Implications of migration for adaptation. The evidence on migration and its impacts on adaptive capacity and risk reduction are mixed (Upadhyay, 2014; Banerjee et al., 2018; Szabo et al., 2018; Maharjan et al., 2020; Singh and Basu, 2020). Financial remittances help vulnerable households spread risk through better incomes, expanded networks and improved assets such as housing, education and communication technology (Jha et al., 2018; Szabo et al., 2018; Ober, 2019; Maharjan et al., 2020). Benefits from international remittances across the Asia Pacific region were approximately 276 billion USD in 2017 (UN, 2018), and in countries such as Kyrgyzstan, Tajikistan and Nepal remittances were ~25% of the national GDP in 2015. However, migration requires a minimum level of resources, and liquidity constraints impede internal migration by the poorest households often rendering them immobile (Ayeb-Karlsson et al., 2020; Maharjan

Box 10.2 (continued)

et al., 2020). Furthermore, migration does not necessarily mean that people move out of risk; in fact, often they might be subjected to new risks. Notably, migrants in South and Southeast Asia have been severely affected by the compounding crises of disasters and the COVID-19 pandemic, and there is emerging evidence that inclusion of universal safety-net provisions that embed adaptation planning can reduce vulnerabilities of migrants (Sengupta and Jha, 2020; Cundill et al., 2021; Sultana, 2021).

While there is *robust evidence* (*medium agreement*) that migration exacerbates gendered vulnerability and work burdens (Banerjee et al., 2019; Singh, 2019; Rao et al., 2020), it is well established that differential vulnerability of migrants intersects with ethnicity, age and gender; political networks and social capital; and livelihoods in destination areas (Maharjan et al., 2020; Cundill et al., 2021). Across Asia, international and internal migration are changing social norms and household structures, with significant implications for local adaptive capacity (Singh, 2019; Evertsen and van der Geest, 2020; Porst and Sakdapolrak, 2020; Rao et al., 2020).

The current energy structure of Asia is dominated by fossil fuels. As the trend indicates, the share of coal in China's primary energy consumption is forecasted to sharply decline from 60% in 2017 to around 35% in 2040 (BP, 2019). In contrast, India and ASEAN rely more on coal since coal may meet their soaring energy demand. Accordingly, more than 80% of the global coal will be consumed in Asia by 2050. China will surpass the USA in about 10 years to become the world's largest oil consumer. India will then replace the USA to be the second largest by the late 2040s (IEEJ, 2018).

Around 60% of the incremental electricity demand globally, predicted to double by 2050, will occur in Asia. By that time, the electrification rate will increase to 30%, but 40% of electricity demand will be still covered by coal (IEEJ, 2018). Asia accounts for almost half of the growth in global renewable power generation. It is hardly possible for Japan and Republic of Korea to develop additional nuclear power plants as planned, whereas nuclear generation continues to increase quickly in China and the scale will be similar to the entire generation of OECD by 2040 (BP, 2019). India and Russia's nuclear power sectors are also growing fast (e.g., the recent launch of the Akademik Lomonosov offshore nuclear power plant in Russia).

The rapid growth of energy demand in Asia reinforces the region's position as the largest energy importer (BP, 2019). Around 80% of energy traded globally will be consumed in Asia, and the rate of self-sufficiency will decrease from 72 to 63% by 2050. This tendency is especially remarkable for ASEAN, which will become a net importer in the early 2020s. The self-sufficiency rate of coal will be maintained at a level of 80%, while that of oil and natural gas will decline significantly. The additional oil imports of the emerging Asian economies will be from North America, the Middle East and North Africa. The main players in Asia for the liquefied natural gas imports will extend from Japan and Republic of Korea to China and India. ASEAN has been a net exporter of natural gas but starts to expand its importation due to the increased consumption and resource depletion (IEEJ, 2018).

The increase in energy demand at a rapid rate in these countries thus cannot be attributed only to population growth and rising living standards, but also to increasingly extreme temperature variations. The decrease in precipitation influences energy demand as well, as countries are becoming more dependent on energy-intensive methods (e.g., desalination, underground water pumping) to supply water. Similarly, energy systems are influenced by the way the agriculture sector, mainly in Al Mashrek, relies increasingly on energy-intensive methods (e.g., more fertilisers, different irrigation and harvesting patterns) (Farajalla, 2013).

Climate change has direct and indirect impacts on energy and industrial systems. It has a particularly wide and profound impact on energy systems (energy development, transportation, supply, etc.). With global warming, the energy consumption for heating in winter decreases, while the energy consumption for cooling in summer significantly increases, but the overall energy demand shows an upwards trend (*high confidence*) (Sailor, 2001; Szabo et al., 2018). Such demands in summer seasons will by far exceed any energy savings from the decrease in heating demand due to warmer winters. Higher demand for cooling due to hotter temperatures has become a major challenge in the energy sector in all countries. Furthermore, decreased water levels due to lower precipitation reduces hydroelectric output. This is particularly the case for countries such as Syria and Iraq with large hydroelectric capacity (Hamid and Raouf, 2009). Additionally, the decrease in water levels negatively affects low-carbon energy systems such as concentrated solar power and thermal-generation plants that require regular cooling and cleaning.

Climate change adds extra pressure to current energy infrastructures in most countries where systems failures and blackouts are already common (Assaf, 2009). In the wake of extreme weather events (e.g., heatwaves), energy infrastructures remain inadequate to cope. This is particularly the case for countries such as Lebanon, Syria, Jordan and Palestine, with poor electricity infrastructures (Jordan, 2015). Extreme weather events could generate grave damage to power plants, most being located only a few metres above sea level, as well as power-transmission towers and lines. In Lebanon, a small country where there are no Indigenous energy resources, the disruption of shipping of fuel supplies due to extreme weather events is a major risk. Other extreme weather events, such as floods and sandstorms, expose energy and industrial systems in the coastal areas due to a rise in sea level. Countries of the Arabian Peninsula are projected to experience significant inland flooding as sea levels rise (Hamid and Raouf, 2009). In East Asia wet snow accretion enhanced by global warming often causes damage to electric power lines (Sakamoto, 2000; Ohba and Sugimoto, 2020).

10.4.1.2 Key Drivers to Vulnerability, with Observed and Projected Impacts

Universal energy access is a big challenge for Asia (IEA, 2018). About 230 million Indian people lack access to electricity, and around 800 million still use solid fuels for cooking (Sharma, 2019). The average electricity access rate in South Asia was 74%, the equivalent of 417 million people without electricity and accounting for more than a third of the global 1.2 billion lacking the access (Shukla et al., 2017). With a total population of nearly 640 million in ASEAN, an estimated 65 million people remain without electricity and 250 million rely on solid biomass for cooking fuel (IEA, 2017). Universal access to electricity is expected to be achieved by 2030, while 1.6 billion people in Asia will still lack clean energy for cooking (UNESCAP, 2018b).

Asia faces an energy security problem even with the rapid growth in production and trade (IEEJ, 2018). Among 13 developing countries with large energy consumption in Asia, 11 are exposed to high energy security risk (WEC, 2018). This will be a major challenge for the sustainable development of Asia due to the vulnerability to global energy supplies and price volatility (Nangia, 2019). Asia lacks natural energy resources and has the smallest oil reserve but largely relies on fossil fuels. The dependency on fossil fuels was as high as 88.3% in China, 72.3% in India, 89.6% in Japan and 82.8% in Republic of Korea in 2013 (BP, 2014). Many countries in South Asia rely on a single source to supply more than half of the electricity (i.e., 67.9% from coal for India, 99.9% from hydropower for Nepal, 91.5% from natural gas for Bangladesh and 50.2% from oil for Sri Lanka) (Shukla et al., 2017). Additionally, cooperation in Asia to create the integrated energy systems needed for enhancing overall security is still at a very preliminary stage due to countries having different strategic plans and lack of cooperation among them on the common concerns (Kimura and Phoumin, 2013).

Even though energy efficiency is improving, the deployment of low-carbon energy, such as renewables, is not sufficient in Asia. To be consistent with the temperature goal of the Paris Agreement, the share of renewables in total energy consumption needs to reach 35% in Asia by 2030. Moreover, the financing to deploy renewables presents another considerable challenge (UNESCAP, 2018b).

In order to cope with climate change, renewable energy has become the core of energy development and transformation. Since the 1960s, the total solar radiation on the ground in Asia has shown a downwards trend as a whole, which is consistent with the change in global total solar radiation on the ground, and has experienced a phased change process of 'first darkening and then brightening' (*high confidence*). This conclusion has been further confirmed by ground station observations, satellite remote sensing inversion data and model simulation research (Wang and Wild, 2016; Qin et al., 2018; Yang et al., 2018a).

However, wind speed over most Asian regions is obviously decreasing (*high confidence*). Based on meteorological observation records or reanalysis data, many studies have analysed the variation of near-surface average wind speed in Asia. It is generally found that wind speed has declined since the 1970s, although the declining trend is different in different subregions. (Yang et al., 2012c; Lin et al., 2013; Liu et al., 2014b; Zha et al., 2016; Guo et al., 2017a; Torralba et al., 2017; Wu et al., 2017a; Ohba, 2019). The decline of near-surface wind speed in Asia is consistent with the general decline of global land-surface wind speeds, among which the frequency of strong winds and the decline of wind speed are more prominent (McVicar et al., 2012; Jiang et al., 2013; Blunden and Arndt, 2017; Wu et al., 2018c). Since the early 2010s, the average wind speed in the world and some parts of Asia has shown signs of increasing (Li et al., 2018d; Wu et al., 2018c; Zeng et al., 2019), which seems to be an inter-decadal variability. Whether this means a change in its trend needs the support of longer observation data.

At the same time, with the increase in the proportion of renewable energy in the power system, the power system will be more vulnerable to climate change and extreme weather and climate events, and the vulnerability and risk of the power system will greatly increase (*medium confidence*).

10.4.1.3 Adaptation Options

The overall solution would be to develop a resilient energy system and avoid the risk of unsustainable energy growth in developing Asia. This requires that strategic planning be consistent with the long-term climate projection, impact and adaptation (EUEI-PDF, 2017). Although no single policy package would be applicable for all the countries across the region, several measures could be addressed as the common options, including fortification of energy infrastructure and diversification of the sources by sufficient investment, improvement of energy efficiency for sector flexibility, and promotion of regional cooperation and integration for increasing energy security (UNESCAP, 2018b). Adaptation also includes promoting renewable energy resources, securing local natural gas resources, enhancing water production and adopting green-building technologies. These adaptation measures may help increase readiness for the anticipated impact of climate change.

The improvement of energy efficiency and demand-side management can alleviate supply constraints and thus lower overall required-energy capacity. Energy storage, smart grids for the electricity network as well as other flexible management measures enable this energy demand shifting. Regional integration of energy markets drives productivity increase, cost reduction, new investment, human capability and diversity of energy sources (WEC, 2018). For example, better interconnection of natural gas supply networks among the ASEAN countries enhances gas security in the region. The development of the long-planned regional power grid would make large-scale renewable projects more viable and aid the integration of rising shares of wind and solar power (IEA, 2017).

Providing enough investment in energy supply is a top priority to extend the connections to those without access to electricity and satisfy the soaring demand (IEA, 2017). The investment in non-fossil energies like renewables has been expanding to leverage the economic growth in China, India and Republic of Korea. According to the updated estimate of ADB, 14.7 trillion USD will be needed for the infrastructure development in the power sector of developing Asia over the 15 years from 2016 to 2030 (ADB, 2017a). The cumulative investment needs of ASEAN for energy supply and efficiency up to 2040 is estimated at 2.7 to 2.9 trillion USD (IEA, 2017). Mobilising investment to such a scale will require significant participation from the private sector and international financial institutions.

Diversifying energy sources increases energy security and thus the resilience of the whole system. The deployment of renewable energy is widely recognised as a crucial measure for enhancing energy access and diversity. There remains huge potential for renewable sources in Asia (i.e., India has massive solar power potential) (Shukla et al., 2017). Many renewable technologies (i.e., hydro- and wind power as well as solar photovoltaics) are becoming competitive, and their life-cycle costs may fall below those of coal and natural gas in the near term. Great progress has been made in enhanced geothermal systems (EGS), and in the conventional and unconventional fusion power that China is promoting. Conventional and underground pumped hydropower will level out supplies for intermittent renewable energy generation.

Substantial progress may be fulfilled by increasing the share of renewable energy in the overall energy consumption of Asia (ADB, 2017a). Access to energy, particularly in rural areas, can reduce climate vulnerability of developing Asia. Due to the high cost of extending the electricity network to rural regions, an alternative way is to develop the off-grid renewable energy systems in these areas. The distributed, instead of centralised, energy systems can increase energy access and resilience (EUEI-PDF, 2017).

Some countries in the Arabian Peninsula, such as the United Arab Emirates (UAE), are adopting an array of approaches to enhance the adaptive capacity of the energy infrastructure and diffuse the risk of climate change over a larger area (e.g., energy efficiency, demand management, storm planning for power plants). In Al Mashrek, building institutional capacity in the energy sector is a necessary first step to mainstream climate-change adaptation (CCA). Countries such as Lebanon and Jordan have already made progress in mainstreaming CCA into electricity infrastructure. In the UAE, buildings account for more than 80% of the total electricity consumption. There are currently a set of measures and regulations on building conditions and specifications that are being applied to increase energy efficiency in buildings, but the rehabilitation and upgrading of old buildings still require further efforts (Environment, 2015). In Kuwait, one adaptation measure to dust storms is through the reduction of the proportion of open-desert land from 75 to 51%, the increase in protected areas from 8 to 18% and greenbelt projects in desert areas (Kuwait, 2015). Addressing climate-change impact on energy systems in Lebanon, Jordan, Syria, Iraq and Palestine needs to simultaneously consider other interlinked challenges of population growth, rapid urbanisation, refugee influx, conflict and geopolitical location. To address these challenges and provide solutions for CCA, the promotion of multi-stakeholder partnerships is key to breaking the silo approach.

These CCA measures need to be broadened to fit the scope and depth of mitigation efforts by each country. Risk assessments and vulnerability assessments are in their early stages in the energy and industrial sectors, and are not currently based on a comprehensive plan of action. The first step is to undertake comprehensive national assessments of the risks associated with climate change based on existing studies on climate impacts and risks, and by making evidence-based decisions on adaptation actions.

10.4.2 Terrestrial and Freshwater Ecosystems

Sub-regional diversity of ecosystems is high in Asia (Section 10.2.2). Climate-impact drivers of Asian terrestrial ecosystems (ATS) change are global warming, precipitation and Asian monsoon alteration, permafrost thawing and extreme events like dust storms. Observed and projected changes in ATS are affected by several interacting factors. Non-climatic human-related drivers are change of land use, change of human use of natural resources, including species and ecosystems overexploitation as well as other non-sustainable use, socioeconomic changes and direct impacts of rising greenhouse gases (GHGs). Ecosystem vulnerability has resulted from complex interactions of CIDs and non-climate drivers. Species interaction and natural variability of organisms, species and ecosystems is currently poorly understood, and much more work still needs to be done to unravel these multiple stressors (i.e., Berner et al., 2013; Brazhnik and Shugart, 2015).

10.4.2.1 Observed Impacts

10.4.2.1.1 Biomes and mountain treeline

Changes in biomes in Asia are compatible with a response to regional surface air temperature increase (Arias et al., 2021) (*medium agreement, medium evidence*). Expansion of the boreal forest and reduction of the tundra area is observed for about 60% of latitudinal and altitudinal sites in Siberia (Rees et al., 2020). In Central Siberia, the changes in climate and disturbance regimes are shifting the southern taiga ecotone northward (Brazhnik et al., 2017). In Taimyr, no significant changes in the forest boundary have been observed during the past three decades (Pospelova et al., 2017). For the Japanese archipelago, it is suggested that the change in tree community composition along the temperature gradient is a response to past and/or current climate changes (Suzuki et al., 2015).

Alpine treeline position in Asian mountains in recent decades either moves upwards in North Asia or demonstrates multi-directional shifts in Himalaya (*high confidence*). Since AR5, in North Asia new evidence has appeared of tree expansion into mountain tundra and steppe, of intensive reproduction and increase in tree stands productivity in the past 30–100 years at the upper treeline in the Ural Mountains (Shiyatov and Mazepa, 2015; Zolotareva and Zolotarev, 2017; Moiseev et al., 2018; Sannikov et al., 2018; Fomin et al., 2020; Gaisin et al., 2020), in the Russian Altai Mountains (Kharuk et al., 2017a; Cazzolla Gatti et al., 2019) and in the Putorana Mountains (Kirdyanov et al., 2012; Pospelova et al., 2017; Grigor'ev et al., 2019). Lower treelines in the southernmost *Larix sibirica* forests in the Saur Mountains, eastern Kazakhstan, have suffered from increased drought stress in recent decades causing forest regeneration and tree growth decrease, and tree mortality increase (Dulamsuren et al., 2013). In Jeju Island, Republic of Korea, recent warming has enhanced *Quercus mongolica* growth at its higher distribution and has led to *Abies koreana* (ABKO) growth reduction at all elevations, except the highest locality. Thus, the combination of warming, increasing competition and frequent tropical cyclone disturbances could lead to population decline or even extinction of ABKO at Jeju Island (Altman et al., 2020). In the Himalaya, the treeline over recent decades either moves upwards (Schickhoff et al., 2015; Suwal et al., 2016; Sigdel et al., 2018; Tiwari and Jha, 2018) or does not show upslope advance (Schickhoff et al., 2015; Gaire et al., 2017; Singh et al., 2018c), or moves downwards (Bhatta et al., 2018). In the Tibetan Plateau, the treeline either shifted upwards or showed no significant upwards shift (Wang et al., 2019c). This can be explained by site-specific complex interaction of positive effect of warming on tree growth, and negative effects of drought stress, change in snow precipitation, inter- and intraspecific interactions of trees and shrubs, land-use change (especially grazing) and other factors (Liang et al., 2014; Lenoir and Svenning, 2015; Tiwari et al., 2017; Sigdel et al., 2018; Tiwari and Jha, 2018; Sigdel et al., 2020). It is largely unknown how broader-scale climate inputs, such as pre-monsoon droughts, interact with local-scale factors to govern treeline response patterns (Schickhoff et al., 2015; Müller et al., 2016; Bhatta et al., 2018; Singh et al., 2019b).

10.4.2.1.2 Species ranges and biodiversity

Since AR5, new evidence has appeared of alterations in terrestrial and freshwater species, populations and communities in line with climate change across Asia (*medium to high confidence*) (Arias et al., 2021). In North Asia, temperature increase and droughts have promoted spread northward of the current silk moth outbreak (has affected nearly 2.5×10^6 ha) in Central Siberia dark taiga since 2014 (Kharuk et al., 2017b; Kharuk et al., 2020). The climatic range of the Colorado potato beetle (*Leptinotarsa decemlineata*) in 1991–2010 expanded east- and northward in Siberia and the Russian Far East compared with the 1951–1970 range (Popova, 2014). The climatic range of *Ixodes ricinus*, a vector of dangerous human diseases, expanded into Central Asia and south of the Russian Far East (Semenov et al., 2020). A butterfly (*Melanargia russiae*) in the Middle Urals moved northward (Zakharova et al., 2017). Thrush birds in West Siberia penetrated northward up to the limits of the sparse woodlands (Ryzhanovskiy, 2019a). The increase in the length of frost-free period observed in the Ilmen Nature Reserve, Middle Urals, during recent decades is supposed to be interlinked with changes in the amplitude and frequency of population waves of bank vole (Kiseleva, 2020). In Katunskiy Biosphere Reserve, Russian Altai, in the period 2005–2015, alpine plant species have shifted towards higher altitudes by 5.3 m on average (Artemov, 2018). Wild reindeer herds in Taimyr, north of Central Siberia, migrated northward to the Arctic Sea coast in hot summers between 1999–2003 and 2009–2016 because of an earlier massive emergence of bloodsucking insects (Pospelova et al., 2017). In Yakutia, the ranges of red deer, elk and the northern pika are expanding, and the winter survival of the mouse-like rodents has increased (Safronov, 2016). In the Chukchi Sea, in recent decades the average duration polar bears spent onshore increased by 30 d (Rode et al., 2015b) in line with global warming and the rapid decline of their sea ice habitat (Derocher et al., 2013; Jenssen et al., 2015; Rode et al., 2015a).

In Central Kazakh Steppe, in line with warming, in 2018 there were more 'southern' sub-arid species in the communities and fewer relatively 'northern' boreal and polyzonal species of ground beetles (Carabidae) and black beetles (Tenebrionidae) than in 1976–1978 (Mordkovich et al., 2020). The present distribution of Asian black birch (*Betula davurica* Pall.) in East and North Asia was formed as a result of northward expansion during post-Last Glacial Maximum global warming (Shitara et al., 2018). Both upper and lower limits of avifauna of two New Guinean mountains, Mt. Karimui and Karkar Island, have been shifting upslope since 1965 (Freeman and Freeman, 2014). In Republic of Korea, for the past 60 years, the northern boundary line of 63 southern butterfly species has moved further north (Bae et al., 2020). The change in the butterflies' occurrence in this period has been influenced mostly by large-scale reforestation, not by climate change (Kwon et al., 2021). Warming-driven geographic range shift was recorded in 87% of 124 endemic plant species studied in the Sikkim Himalaya in the periods 1849–1850 and 2007–2010 (Telwala et al., 2013). In Darjeeling, India, significant change in lichen community structure was shown in response to climate change and anthropogenic pollution (Bajpai et al., 2016).

The observed loss of biodiversity and habitat of animals and plants has been linked to climate change in some parts of Asia (*high confidence*). Climate change, together with human disturbances, have caused local extinction of some large and medium-sized mammals during the past three centuries in China (Wan et al., 2019). Climate change has shown significant impacts on subalpine plant species at low altitudes and latitudes in Republic of Korea and may impose a big threat to these plant species (Adhikari et al., 2018; Kim et al., 2019c). Climate change has caused habitat loss of amphibians (Surasinghe, 2011) and extinction of some endemic species in Sri Lanka (Kottawa-Arachchi and Wijeratne, 2017).

There is evidence that climate change can alter species interaction or spatial distribution of invasive species in Asia (*high confidence*). Climate warming has enhanced the competitive ability of the native species (*Sparganium angustifolium*) against the invasive species (*Egeria densa*) in China under a mesocosm experiment in a greenhouse (Yu et al., 2018e). It has also increased the non-target effect on a native plant (*Alternanthera sessilis*) by a biological control beetle (*Agasicles hygrophila*) in China due to range expansion of the beetle and change of phenology of the plant (Lu et al., 2015). Climate warming has expanded the distribution of invasive bamboos (*Phyllostachys edulis* and *P. bambusoides*) northward and upslope in Japan (Takano et al., 2017), while soil dry-down rates have been a key driver of invasion of dwarf bamboo (*Sasa kurilensis*) in central Hokkaido above and below the treeline (Winkler et al., 2016).

Climate change along with land-use and land-cover change influences soil organic carbon content, microbial biomass C, microbial respiration and the soil carbon cycle in the Hyrcanian forests of Iran (Soleimani et al., 2019; Francaviglia et al., 2020). In the fir forest ecosystems of the Tibetan Plateau, winter warming affects the ammonia-oxidising bacteria and archaea, thus altering the nitrogen cycle (Huang et al., 2016). Ecosystem carbon pool in the spruce forests of the northeast Tibetan Plateau was reduced by about 25% by deforestation due to recent decades of climate warming as well as wood pasture and logging (Wagner et al., 2015). In Mongolia's forest steppe, recent decades of drought- and land-use-induced deforestation has reduced the ecosystem carbon stock density by about 40% (Dulamsuren et al., 2016). In Inner Mongolia, the predicted decreases in precipitation and warming for most of the temperate grassland region could lead to a pH change, which would contribute to a soil C-N-P decoupling that could reduce plant growth and production in arid ecosystems (Jiao et al., 2016).

In Central Asia, in the Vakhsh, Kafirnigan and Kyzylsu river basins, Tajikistan, it has been shown that temperature stimulates algal species diversity, while precipitation and altitude suppress it (Barinova et al., 2015). In line with the warming of Lake Baikal, Russia, since the 1990s in the lake's south basin, there have been shifts in diatom community composition towards higher abundances of the cosmopolitan *Synedra acus* and a decline in endemic species, mainly *Cyclotella minuta* and *Stephanodiscus meyerii*, and to a lesser extent *Aulacoseira baicalensis* and *A. skvortzowii* (Roberts et al., 2018). In Gonghai Lake, North China, diatom biodiversity has increased remarkably from 1966, but began to decline after 1990 presumably in response to rapid climate warming (Yan et al., 2018).

10.4.2.1.3 Wildfires

Climate change, human activity and lightning determine increases in wildfire severity and area burned in North Asia (high detection with medium-to-low attribution to climate change). In North Asia, the extent of fire-affected areas in boreal forest can be millions of hectares in a single extreme fire year (Duane et al., 2021) and nearly doubled between 1970 and 1990 (Brazhnik et al., 2017). During recent decades, the number, area and frequency of forest fires increased in Putorana Plateau (north of Central Siberia), in larch-dominated forests of Central Siberia and in Siberian forests as a whole. This increase is in line with an increase in the average annual air temperature, air temperature anomalies, droughts and the length of fire season (Ponomarev et al., 2016; Kharuk and Ponomarev, 2017; Pospelova et al., 2017). The number of forest fires and damaged areas in Gangwon Province and the Yeongdong area in the 2000s increased by factors of 1.7 and 5.6, respectively, compared with the 1990s (Bae et al., 2020). Climate change is not the sole cause of the increase in forest fire severity (Wu et al., 2014; Wu et al., 2018d). Ignition is often facilitated by lightning (Canadell et al., 2021), and over 80% of fires in Siberia are *likely* anthropogenic in origin (e.g., (Brazhnik et al., 2017). Gas field development and Indigenous tundra burning practices that may get out of control contribute to fire frequency in the forest–tundra of West Siberia (Adaev, 2018; Moskovchenko et al., 2020). Climate change in combination with socioeconomic changes has resulted in an increase in fire severity and area burned in South Siberia, and illegal logging increases fire danger in forest–steppe Scots pine stands (Ivanova et al., 2010; Schaphoff et al., 2016).

10.4.2.1.4 Phenology, growth rate and productivity

In East and North Asia, satellite measurements and ground-based observations in recent decades demonstrate either an increase in the length of plant growth season over sub-regions or in some territories in line with climate warming, or do not show any significant trend in other territories (*high confidence*). In recent decades in China, there has been an increasing trend in annual mean grassland net primary production (NPP), average leaf area index and lengthening of the local growing season (Piao et al., 2015; Zhang et al., 2017b; Xia et al., 2019). Nevertheless, phenology patterns vary across different studies, species and parts of China. In most regions of Northeast China, start date and length of land surface phenology from 2000 to 2015 had advanced by approximately 1 d yr^{-1}, except in the needle-leaf and cropland areas (Zhang et al., 2017d). For Inner Mongolia, it has been shown that neither the start of growing season (SOS) nor the end of growing season (EOS) presented detectable progressive patterns at the regional level in 1998–2012, except for the steppe–desert (6% of the total area) (Sha et al., 2016). In the Tianshan Mountains in China, the NPP of only 2 out of 12 types of vegetation increased in spring, and the NPP of only one type increased in autumn from 2000–2003 to 2012–2016 (Hao et al., 2019). In Republic of Korea, from 1970 to 2013, the SOS has advanced by 2.7 d per decade, and the EOS has been delayed by 1.4 d per decade (Jung et al., 2015). During the past decade, leaf unfolding has accelerated at a rate of 1.37 d yr^{-1}, and the timing of leaf fall has been delayed at a rate of 0.34 d yr^{-1} (Kim et al., 2019d). Cherry blossoms are predicted to flower 6.3 and 11.2 d earlier after 2090 according to scenarios RCP4.5 and RCP8.5, respectively (Bae et al., 2020). On the Tibetan Plateau, it was found that the SOS has advanced and the EOS has been delayed over the past 30–40 years (Yang et al., 2017). Using normalised difference vegetation index (NDVI) datasets and ground-based Budburst data (Wang et al., 2017c) found no consistent evidence that the SOS has been advancing or delaying over the Tibetan Plateau during the past two to three decades. The discrepancies among different studies in the trends of spring phenology over the Tibetan Plateau could be largely attributed to the use of different phenology retrieval methods. An uncertainty exists with the relationship between land-surface phenology and climate change estimated by satellite-derived NDVI because these indices are usually composite products of a number of days (e.g., 16 d) that could fail to capture more details. Besides, due to lack of *in situ* observations, the SOS and EOS at large areas cannot be easy defined (Zhang et al., 2017d).

In North Asia, in Central Siberia and south of West Siberia, the growth index of Siberian larch based on tree-ring width increased with the onset of warming and changed in antiphase with aridity in the 1980s (Kharuk et al., 2018). In Mongolia and Kazakhstan, the temperature increase over the previous decade promoted radial stem increment of the Siberian larch. However, the simultaneous influence of increased temperature, decreased precipitation and increased anthropogenic pressure resulted in widespread declines in forest productivity and reduced forest regeneration, and increased tree mortality (Dulamsuren et al., 2013; Lkhagvadorj et al., 2013a; Lkhagvadorj et al., 2013b; Dulamsuren et al., 2014; Khansaritoreh et al., 2017). In Eastern Taimyr, growing season, the number of flowering shoots, annual increment, success of seed ripening and vegetation biomass have increased considerably in recent decades (Pospelova et al., 2017). In Vishera Nature Reserve, northern Ural Mountains, annual temperature has increased in recent decades in parallel with a summer temperature drop and an increase in summer frost numbers. As a result, trends in vegetation change are mostly unreliable (Prokosheva, 2017).

In Asia, the date of arrival of migrant birds to nesting areas and the date of departure from winter areas are changing consistently with climate change (*medium confidence*). Time of arrival of the grey crow to the Lower Ob river region, northwest Siberia, shifted to earlier dates in the period 1970–2017, which is consistent with an increase in the daily average temperatures on the day of arrival (Ryzhanovskiy, 2019b). In Ilmen Nature Reserve, Urals, an earlier arrival of the majority of nesting bird species has not been observed in recent decades. This is explained by the fact that other factors, such as the weather of each spring month of particular years, population density in the previous nesting period, the seed yield of the main feeding plants and migration of wintering species from adjacent areas, determinate the long-term dynamics of bird arrival (Zakharov, 2016; Zakharov, 2018). In Yokohama, Japan, observations since 1986 have revealed that the arrival of six winter bird species came later and the departure earlier than in the past, due to warmer temperatures (Kobori et al., 2012; Cohen et al., 2018). Some papers corroborate that earlier start and later end of phenological events in Asia are associated with global warming; however, other papers do not confirm such a connection. Comparison and synthesis of results is impeded by usage of different metrics, measurement methods and models (e.g., Hao et al., 2019). Relative contribution of climatic stress and other factors to phenology and plant growth trends are poorly understood (e.g., Andreeva et al., 2019).

10.4.2.2 Projected Impacts

10.4.2.2.1 Biomes and mountain treeline

Across Asia, under a range of representative concentration pathways (RCPs) and other scenarios, rising temperatures are expected to contribute to a northward shift of biome boundaries and an upwards shift of mountain treeline (*medium confidence*). Northward shift and area change of bioclimatic zones in Siberia (Anisimov et al., 2017; Torzhkov et al., 2019) and northeast Asia (Choi et al., 2019) are projected. Projected changes in vegetation in China at the end of the 21st century reveal that the area covered by cold–dry potential vegetation decreases as the area covered by warm–humid potential vegetation increases (Zhao et al., 2017a). Forest expansion into mountain tundra of the northern Urals is expected (Sannikov et al., 2018). In Republic of Korea, projected under RCP4.5 and RCP8.5 in the 2070s, suitable area loss of six subalpine tree species, namely, Korean fir, Khingan fir, Sargent juniper, Yeddo spruce, Korean yew and Korean arborvitae, range from 17.7 ± 20.1% to 65.2 ± 34.7%, respectively (Lee et al., 2021b). Korean fir forests would be replaced by temperate forests at lower elevations, while they would continuously persist at the highest elevations on Mt. Halla, Jeju Island and Republic of Korea (Lim et al., 2018). Himalayan birch at its upper distribution boundary either is projected to move upwards (Schickhoff et al., 2015; Bobrowski et al., 2018) or considered to downslope as a response to global-change-type droughts (Liang et al., 2014). Upwards shift in elevation of bioclimatic zones, decreases in area of the highest elevation zones and large expansion of the lower tropical and sub-tropical zones can be expected by the year 2050 throughout the transboundary Kailash Sacred Landscape of China, India and Nepal, and *likely* within the Himalayan region more generally (Zomer et al., 2014).

In North Asia, a shift is projected in the dominant biomes from conifers to deciduous species across Russia after 20 years of altered climate conditions (Shuman et al., 2015). In South Siberia, Brazhnik and Shugart (2015) projected a shift from the boreal forest to the steppe biome. Rumiantsev et al. (2013) also project a positive northward shift of vegetation boundaries for the greater part of West Siberia in line with warming; however, no shift for the north of West Siberia and negative shift for the southern Urals and northwest Kazakhstan are projected for 2046–2065. The replacement of forest–steppe with steppe at the lower treeline in South Siberia is projected (Brazhnik and Shugart, 2015), and retreat of larch forests from the southernmost strongholds of boreal forest in eastern Kazakhstan is expected as part of a global process of forest dieback in semiarid regions (Dulamsuren et al., 2013). In North Asia, tree growth is intertwined with permafrost, snowpack, insect outbreaks, wildfires, seed dispersal and climate (e.g., Klinge et al., 2018). It is challenging to isolate the affects of individual factors, particularly since they can interact on one another in unanticipated ways because the underlying mechanisms are not well understood (Berner et al., 2013; Brazhnik and Shugart, 2015). The accuracy of treeline-shift projections is limited because projections are based on vegetation models which do not consider all the factors (Tishkov et al., 2020). The regional vegetation model structure and parameterisation can affect model performance, and the corresponding projections can differ significantly (Shuman et al., 2015).

10.4.2.2.2 Species ranges and biodiversity

Considerable changes in plant and animal species distribution under warming stress are expected in Asia until 2100 (*high confidence*). In East Asia, *Cunninghamia lanceolate*, a fast-growing and widely distributed coniferous timber species in China, is projected to increase distribution, to decrease the establishment probability and to reduce total NPP by the 2050s (Liu et al., 2014c). In the monsoon regions of Asia, by the end of the 21st century, NPP is projected to increase by 9–45% (Ito et al., 2016). Under climate change on the Korean Peninsula (KP), the potential habitat for *Abies nephrolepis* is the northern part of KP, and *A. koreana* will disappear from Jeju Island and shrink significantly in the KP (Yun et al., 2018), while evergreen forests will expand to the northern part of KP (Koo et al., 2018; Lim et al., 2018). It is expected that under projected warming, fig species in China will expand to higher latitudes and altitudes (Chen et al., 2018c). In Japan, under the A1B scenario, 89% of the area currently covered by the *Fagus crenata*-dominant forest type will be replaced by *Quercus* spp.-dominant forest types (Matsui et al., 2018). Current trends of climate change will reduce distribution of tall (2–2.5 m high) herb communities in Japan, and will increase suitably for them in the Russian Far East (Korznikov et al., 2019). A range expansion of *Lobaria pindarensis*, an endemic epiphytic lichen in the HKH region, is projected to move to the northeast and to higher altitudes in response to climate change, although the species' low dispersal abilities and the local availability of trees as a substratum will considerably limit latitudinal and altitudinal shifts (Devkota et al., 2019).

The climatic range of Italian locust (*Calliptamus italicus* L.) under RCP4.5 will expand north- and east-ward to Siberia, the Russian Far East and Central Asia (Popova et al., 2016). In Krasnoyarsk Krai, Siberia, it is projected that the needle cast disease caused by fungi from the genus *Lophodermium* Chevall. in the Scots pine nurseries would shift northward up to 2080 under A2 and B1 scenarios (Tchebakova et al., 2016). All four RCP scenarios showed north-ward expansion of vulnerable regions to pine wilt disease in China, Republic of Korea, the Russian Far East and Japan under climate conditions in 2070 (Hirata et al., 2017), and during 2026–2050 in Japan (Matsuhashi et al., 2020). It is noteworthy that disease expansion depends not only on climatic factors but also on the dispersal capacity of insect vectors, the transportation of infected logs to non-infected regions and the susceptibility of host trees (e.g., Gruffudd et al., 2016). The suitable habitat area of the snow leopard *Panthera uncia* is projected to increase by 20% under the IPCC Scenario

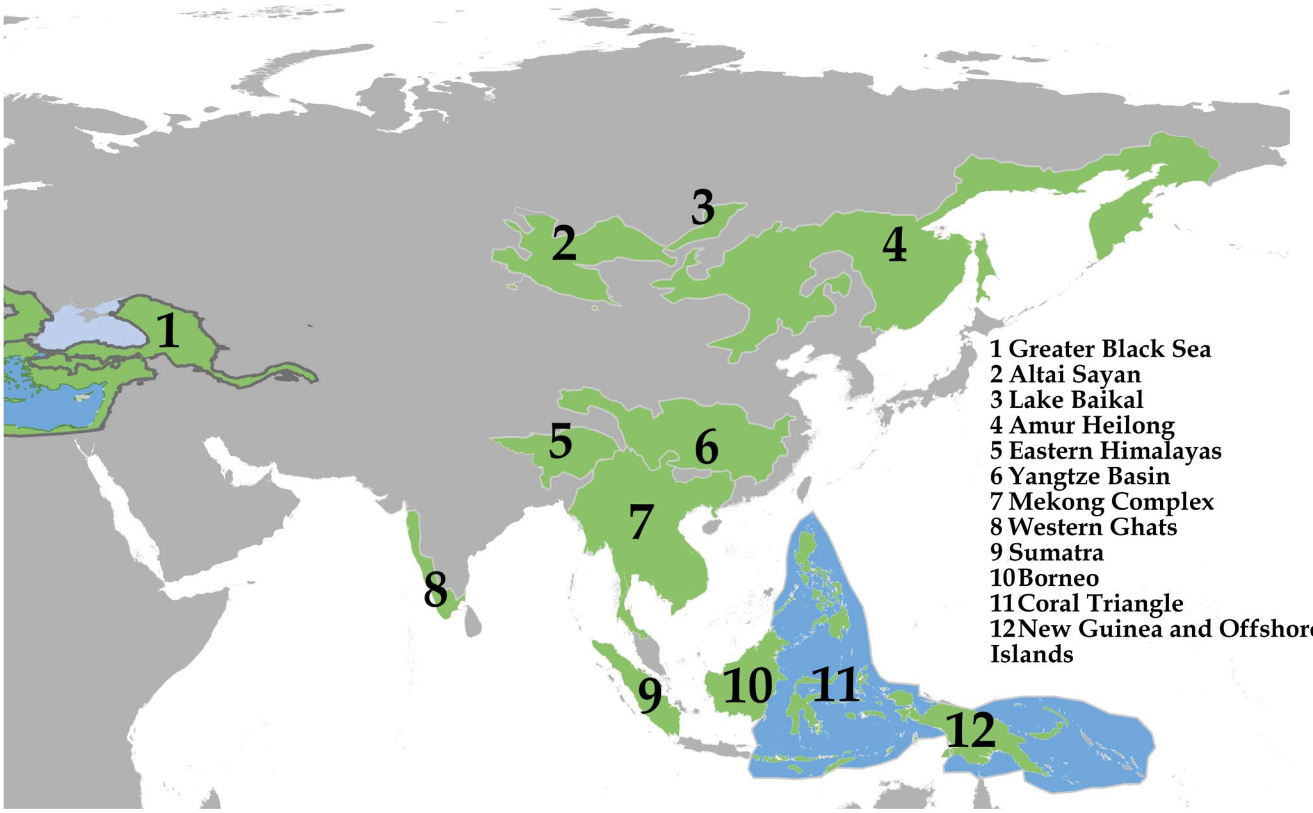

Figure 10.4 | Location of 'priority places' in Asia. (Modified from Warren et al., 2018).

A1B by 2080: for the seven northernmost snow leopard range states (Afghanistan, Tajikistan, Uzbekistan, Kyrgyzstan, Kazakhstan, Russia and Mongolia) the suitable habitat area will increase, while habitat loss is expected on the southern slope of the Himalaya and the southeast Tibetan Plateau (Farrington and Li, 2016). Climate change projected under four RCP scenarios will not affect the distribution patterns of Turkestan Rock Agama *Paralaudakia lehmanni* (Nikolsky 1896; Sancholi, 2018). In Iran, among 37 studied species of plants and animals, the ranges of 30 species are expected to shrink and ranges of 7 species are expected to increase between 2030 and 2099 under climate-change stress (Yousefi et al., 2019).

Future climate change would cause biodiversity and habitat loss in many parts of Asia using modelling approaches (*high confidence*). Warren et al. (2018) projected that extirpation risks to terrestrial taxa (plants, amphibians, reptiles, birds and mammals) from 2°C to 4.5°C global warming in 12 'priority places' in Asia, under the assumption of no adaptation (i.e., dispersal) by the 2080s, is from 12.2–26.4% to 29–56% (Table 10.1; Figure 10.4). Under different scenarios, future climate change could reduce the extent of a suitable habitat for giant pandas (Fan et al., 2014), moose (*Alces alces*) (Huang et al., 2016), black muntjac (*Muntiacus crinifrons*) (Lei et al., 2016) and the Sichuan snub-nosed monkey (*Rhinopithecus roxellana*) (Zhang et al., 2019d) in China; the Persian leopard (*Panthera pardus saxicolor*) in Iran (Ashrafzadeh et al., 2019a); the Bengal tiger (Mukul et al., 2019) in India; and four tree-snail species (*Amphidromus*) in Thailand (Klorvuttimontara et al., 2017). However, climate change would have little impact on the habitats of the Asian elephant, but would cause extinction of the Hoolock gibbon in Bangladesh by 2070 (Alamgir et al., 2015). Climate change would increase the distribution of the Mesopotamian spiny-tailed lizard (*Saara loricate*) in Iran (Kafash et al., 2016). Future climate change would reduce the suitable habitat of certain protected plants (Zhang et al., 2014) including *Polygala tenuifolia* Wild (Lei et al., 2016); relict species in East Asia (Tang et al., 2018); tree *Abies* (Ran et al., 2018) in China; two threatened medicinal plants (*Fritillaria cirrhosa* and *Lilium nepalense*) in Nepal (Rana et al., 2017); a medicinal and vulnerable plant species *Daphne mucronata* (Abolmaali et al., 2018) and *Bromus tomentellus* in Iran (Sangoony et al., 2016); a valuable threatened tree species, *Dysoxylum binectariferum*, in Bangladesh (Sohel et al., 2016); and plant diversity in Republic of Korea (Lim et al., 2018).

The impact of future climate change on invasive species may be species- or region specific (*medium confidence*). Climate change would promote invasion of a highly invasive aquatic plant *Eichhornia crassipes* (You et al., 2014), *Ambrosia artemisiifolia* (Qin et al., 2014), alligator weed (*Alternanthera philoxeroides*) (Wu et al., 2016), invasive alien plant *Solidago canadensis* (Xu et al., 2014), three invasive woody oil-plant species (*Jatropha curcas, Ricinus communis* and *Aleurites moluccana*) (Dai et al., 2018), and 90 of ~150 poisonous plant species (Zhang et al., 2017a) in China; six mostly highly invasive species (*Ageratum houstonianum* Mill., *Chromolaena odorata* (L.) R.M. King & H. Rob., *Hyptis suaveolens* (L.) Poit., *Lantana camara* L., *Mikania micrantha* Kunth and *Parthenium hysterophorus* L.) in Nepal (Shrestha et al. 2018); 11 invasive plant species in the western Himalaya (Thapa et al., 2018); alien plants in Georgia (Slodowicz et al., 2018); the invasive green anole (*Anolis carolinensis*) in Japan (Suzuki-Ohno et al., 2017); the Giant African Snail

Table 10.1 | Projected extirpation risks: percentage of taxa (plants, amphibians, reptiles, birds and mammals) for 2°C and 4.5°C global warming in 'priority places' in Asia, without adaptation by the 2080s. (From Warren et al., 2018).

Priority places	At 2°C (%)	At 4.5°C (%)
Mekong	26.4	55.2
Baikal	22.8	49.5
Yangtze	20	42.6
Coral Triangle	19.2	41.8
Western Ghats	18.8	41.67
New Guinea	19.8	41.2
Atlai-Syan	18.6	37
Sumatra	16.8	37
Borneo	17.6	36.8
Amur	14.2	35.6
Eastern Himalayas	12.2	29
Black sea	26.2	56

in India (Sarma et al., 2015); and a major insect vector (*Monochamus alternatus*) of the pine wilt disease (Kim et al., 2016b) and melon thrips (*Thrips palmi* Karny) (Park et al., 2014) in Republic of Korea. In contrast, a few studies have projected that climate change would inhibit the invasion of one exotic species (*Spartina alterniflora*) (Ge et al., 2015), alien invasive weeds (Wan et al., 2017), an invasive plant (*Galinsoga parviflora*) (Bi et al., 2019) and an invasive species (*Galinsoga quadriradiata*) (Yang et al., 2018b) in China; and two invasive plants (*Chromolaena odorata* and *Tridax procumbens*) in India (Panda and Behera, 2019).

Five of 15 endemic freshwater fish species in Iran will lose some parts of their current suitable range under climate change by 2070 (Yousefi et al., 2020). In line with projected large increases in mean water temperature, the strongest increase is projected in exceeded frequency and magnitude of maximum temperature tolerance values for freshwater minnow (*Zacco platypus*) in East Asia for 2031–2100 (Van Vliet et al., 2013). Climate change under the A1B scenario is projected to decrease diversity (–0.1%) along with increased local richness (+15%) and range size (+19%) of stream macroinvertebrates in the Changjiang River catchment, southeast China, for the period 2021–2050, while land-use change is predicted to have the strongest negative impact (Kuemmerlen et al., 2015). The Asian clam *Corbicula fluminea* Müller, an invasive species native to southeast China, the Republic of Korea and southeast Russia, is projected to invade Southeast Asia under all four RCP scenarios for the 2041–2060 and 2061–2080 periods (Gama et al., 2017). Projected SLR, related aquatic salinisation and alteration in fish species composition may have a negative impact on poor households in southwest coastal Bangladesh (Dasgupta et al., 2017a).

10.4.2.2.3 Wildfires

Under regional projections for North Asia, warmer climate will increase forest fire severity by the late 21st century (*medium confidence*). For the southern taiga in Tuva Republic, Central Siberia, in a warmer climate, both the annual area burned and fire intensity will increase by 2100. For the central taiga in the Irkutsk region, the annual area burned as well as crown fire-to-ground fire ratiowill increase by the late 21st century compared with the historical (1960–1990) estimate. This moves forest composition towards greater contribution of hardwoods (e.g., *Betula* spp., *Populus* spp.) (Brazhnik et al., 2017). This shifting was also proved by observations in northern Mongolia, where boreal forest fires *likely* promote the relative dominance of *B. platyphylla* and threaten the existence of the evergreen conifers, *Picea obovata* and *Pinus sibirica* (Otoda et al., 2013). For Tuva Republic, warming ambient temperatures increase the potential evapotranspiration demands on vegetation, but if no concurrent increase in precipitation occurs, vegetation becomes stressed and either dies from temperature-based drought stress or more easily succumbs to insects, fire, pathogens or wind throw (Brazhnik et al., 2017). Although Torzhkov et al. (2019) also projected fire risk (FR) increase in Tuva Republic, they expect FR decrease in the Irkutsk region and Yakutia under RCP8.5, and FR decrease in major parts of Central and East Siberia under RCP4.5 for 2090–2099. This discrepancy is due to differences in models, climate projections, fire severity metrics and other assumptions. According to global projections, FR will increase in Central Asia, Russia, China and India under a range of scenarios (Sun et al., 2019).

10.4.2.3 Vulnerabilities to Key Drivers

Both natural and managed ecosystems, ecosystem services and livelihoods in Asia will potentially be substantially impacted by changing climate (Wu et al., 2018d). There will be increased risk for biodiversity, particularly many endemic and threatened species of fauna and flora already under environmental pressure from land-use change and other regional and global processes (Zomer et al., 2014; Rashid et al., 2015; Choi et al., 2019). Biomes shift not only serves as a signal of climate change but also provides important information for resources management and ecotone ecosystem conservation. A widespread upwards encroachment of subalpine forests would displace regionally unique alpine tundra habitats and possibly cause the loss of alpine species (Schickhoff et al., 2015). In North Asia, emissions from fires reduce forests' ability to regulate climate. A warmer and longer growing season will increase vulnerability to fires, although fires can be attributed both to climate warming and to other human and natural influences. Recent field-based observations revealed that the forests in South Siberia are losing their ability to regenerate after fire and other landscape disturbances under a warming climate (Brazhnik et al., 2017). Data support the hypothesis of a climate-driven increase in fire frequency in boreal forests with the possible turning of boreal forests from a carbon sink to a carbon source (Ponomarev et al., 2016; Schaphoff et al., 2016; Brazhnik et al., 2017; Ponomarev et al., 2018); however, warming resulting from forest fire is partly offset by cooling in response to increased surface albedo of burned areas in a snow-on period (Chen and Loboda, 2018; Chen et al., 2018a; Jia et al., 2019; Lasslop et al., 2019).

10.4.2.4 Adaptation Options

Modelling of the interactions between climate-induced vegetation shifts, wildfire and human activities can provide keys to how people in Asia may be able to adapt to climate change (Kicklighter et al., 2014; Tian et al., 2020). Conservation and sustainable development would benefit from being tailored and modified considering the changing climatic conditions and shifting biomes, mountain belts and species ranges (Pörtner et al., 2021). Expanding the nature reserves would help species

Box 10.3 | Case Study on Sand and Dust Storm, Climate Change in West Asia's Iranian Region

The West Asia region, especially the Tigris–Euphrates alluvial plain, has been recognised as one of the most important dust-source areas in the world (Cao et al., 2015). The inhabitants of each of these settlements have experienced a decline in dust storms in recent decades, since the late 1980s at Nouakchott, since 2004 at Zabol and since the late 1970s at Minqin. Iran is mostly arid or semiarid, with deserts making up at least 25 million hectares of the country (NASA, 2018). Iran is experiencing unprecedented climate-related problems such as drying of lakes and rivers, dust storms, record-breaking temperatures, droughts and floods (Vaghefi et al., 2019). There are three key factors responsible for the generation of sand and dust storms: strong wind, lack of vegetation and absence of rainfall (EcoMENA, 2020). It seems that all of this is closely related to the heating surface and the occurrence of local dry instabilities (Ghasem et al., 2012). According to EcoMENA (2020), sand and dust storms cause significant negative impacts on society, the economy and the environment at the local, regional and global levels. The seasonality of the numbers of dusty days (NDD) in Iran shows the highest frequency in summer followed by spring and autumn (Modarres and Sadeghi, 2018). In the past decade, West Asia has witnessed more frequent and intensified dust storms affecting Iran and other Persian Gulf countries (Nabavi et al., 2016). In terms of long-term frequency of dust events, observational analyses show an overall rising trend of the frequency of Iran's dust events in recent years (Alizadeh-Choobari et al., 2016). Results show that there has been a direct relationship between dust event, drought and years of intensive drought (Dastorani and Jafari, 2019). Compared with the period 1980–2004, in the period 2025–2049, Iran is *likely* to experience more extended periods of extreme maximum temperatures in the southern part of the country, more extended periods of dry (for ≥120 d: precipitation <2 mm, T_{max} ≥30°C) as well as wet (for ≤3 d: total precipitation ≥110 mm) conditions and a higher frequency of floods (Vaghefi et al., 2019). The slope of precipitation in West Asia shows that during the period 2016–2045 in January, February, July and August, precipitation would increase and decrease in other months of the year (Ahmadi et al., 2018). Temperatures in Central Asia have risen significantly within recent decades, whereas mean precipitation remains almost unchanged (Haag et al., 2019); however, climatic trends can vary greatly between different sub-regions, across altitudinal levels and within seasons (Haag et al., 2019).

conservation; to facilitate species movements across climatic gradients, an increase in landscape connectivity can be elaborated by setting up habitat corridors between nature reserves and along elevational and other climatic gradients (Brito-Morales et al., 2018; D'Aloia et al., 2019; United Nations Climate Change Secretariat, 2019). Assisted migration of species should be considered for isolated habitats as mountain summits or where movements are constrained by poor dispersal ability. Introducing seeds of the species to new regions will help to protect them from the extinction risk caused by climate change (Mazangi et al., 2016). In Asian boreal forests, a strategy and integrated programmes should be developed for adaptation of the forests to global climate change, including sustainable forest management, firefighting infrastructure and forest fuel management, afforestation, as well as institutional, social and other measures in line with Sustainable Development Goal (SDG) 15 'Life on Land' (Isaev and Korovin, 2013; Kattsov and Semenov, 2014; Bae et al., 2020). Improvements in forest habitat quality can reduce the negative impacts of climate change on biodiversity and ecosystem services (Choi et al., 2021). Adaptation options for freshwater ecosystems in Asia include increasing connectivity in river networks, expanding protected areas, restoring hydrological processes of wetlands and rivers, creating shade to lower temperatures for vulnerable species, assisted translocation and migration of species (Hassan et al., 2020; Chapter 2). Reduction of non-climate anthropogenic impacts can enhance the adaptive capacity of ecosystems (Tchebakova et al., 2016).

10.4.3 Ocean and Coastal Ecosystems

Coastal habitats of Asia are diverse, and the impacts of climate change, including rising temperatures, ocean acidification and SLR, are known to affect the services and livelihoods of the people depending on them. The risk of irreversible loss of many marine and coastal ecosystems increases with global warming, especially at 2°C or more (*high confidence*) (IPCC, 2018b). In the South China Sea, coral growth and sea surface temperature (SST) have shown regional long-term trends and inter-decadal variations, while coral growth is predicted to decline by the end of this century (Yan et al., 2019). Increasing human impacts have also been found to reduce coral growth (Yan et al., 2019). In the South China Sea, nearly 571 coral species have been severely impacted by global climate changes and anthropogenic activities (Huang et al., 2015a).

The 2014–2017 global-scale coral bleaching event (GCBE) resulted in very high coral mortality on many reefs, rapid deterioration of reef structures and far-reaching environmental impacts (Eakin et al., 2019). The thermally tolerant Persian Gulf corals (Coles and Riegl, 2013) are facing an increasing frequency of mass bleaching (Riegl et al., 2018) and each event leaves a substantial long-term impact on coral communities (Burt, 2014) with low capacity for recovery indicating a bleak future for Persian Gulf reefs (Burt et al., 2019).

One of the probable results of global warming is high SLR. Scientists believe that increasing GHGs (the Earth's temperature controllers) is the cause of this global warming, and by using satellite measurements, these scientists have forecasted on average 1–2 mm for SLR (Jafari et al., 2016). The level of thermal stress (based on a degree heating month index, DHMI) at these locations during the 2015–2016 El Niño was unprecedented and stronger than previous ones (Lough et al., 2018). In the Persian Gulf, the reef-bottom temperatures in 2017 were among the hottest on record, with mean daily maxima averaging 35.9 ± 0.10°C across sites, with hourly temperatures reaching as high as 37.7°C (Riegl et al., 2018). About 94.3% of corals were bleached, and about 66% perished, in 2017 (Burt et al., 2019). In 2018 coral cover averaged just 7.5% across the southern basin of the Persian Gulf. This mass mortality did not cause dramatic shifts in community composition as earlier bleaching events had removed the most sensitive taxa. An exception was the already rare *Acropora* spp. which were locally extirpated in summer 2017 (Burt et al., 2019). During 2008–2011 also the coral communities of Musandam and Oman showed changes depending on the stress-tolerance levels of the species and the local environmental disturbance level (Bento et al., 2016).

The health and resilience of corals have been found to be associated with beneficial microorganisms of coral (BMC) which alter during environmental stress. Increasing seawater temperatures have been found to affect the functioning of the symbiotic algae of corals (Lough et al., 2018; Gong et al., 2019) and its bacterial consortia leading to coral bleaching and mortality (Bourne et al., 2016; Peixoto et al., 2017; Bernasconi et al., 2019; (Motone et al., 2020).

Coral reefs were found to be affected differentially during bleaching episodes, and those species which survived had more stress-tolerant symbionts and higher tolerance to thermal changes (Majumdar et al., 2018; Thinesh et al., 2019; van der Zande et al., 2020). Rare thermally tolerant algae and host species-specific algae may play important roles in coral bleaching (van der Zande et al., 2020). Along the Indian coast, in the coral reefs of Palk Bay (Bay of Bengal), varied bleaching and recovery patterns among coral genera was observed during the 2016 bleaching episode (Thinesh et al., 2019). Bleaching was high in *Acropora* spp. (86.36%), followed by *Porites* (65.45%), while moderate to no bleaching was observed in *Favites Symphyllia, Favia, Platygyra* and *Goniastrea*.

The presence of stress-tolerant symbiont Durusdinium (Clade D) during the post-bleach period indicated the high adaptive capacity of *Acropora* spp. in tropical waters (Thinesh et al., 2019). Also *Porites* spp. were found to have higher thermal thresholds and showed better resilience to bleaching than species like *Fungiid* spp. (Majumdar et al., 2018). In the Philippines, during the 2010 bleaching event, the size structure of the mushroom coral was found to be affected (Feliciano et al., 2018). In Indonesia, it was found that branching coral diversity may decrease relative to massive, more resilient corals (Hennige et al., 2010). This would have large-scale impacts upon reef biodiversity and ecosystem services, and reef metabolism and net reef accretion rates, since massive species are typically slow growers (Hennige et al., 2010).

Macro-tidal coral reefs are particularly sensitive to medium- to long-term changes in sea-level Andaman trenches (Simons et al., 2019). Data compiled from 11 cities throughout East and Southeast Asia, with particular focus on Singapore, Jakarta, Hong Kong and Naha (Okinawa), highlights several key characteristics of urban coral reefs, including 'reef compression' (a decline in bathymetric range with increasing turbidity and decreasing water clarity over time and relative to shore), dominance by domed coral growth forms and low reef complexity, variable city-specific inshore–offshore gradients, early declines in coral cover with recent fluctuating periods of acute impacts and rapid recovery, and colonisation of urban infrastructure by hard corals (Heery et al., 2018).

In Taiwan, Province of China, the calcification rate of the model reef coral *Pocillopora damicornis* was higher in coral reef mesocosms featuring seagrasses under ocean acidification conditions at 25°C and 28°C. The presence of seagrass in the mesocosms helped to stabilise the metabolism of the system in response to simulated climate change (Liu et al., 2020a).

An increase in host susceptibility, pathogen abundance or virulence has led to higher prevalence and severity of coral diseases and to decline and changes in coral reef community composition (Maynard et al., 2015). Relative risk has been found to be high in the province of Papua in Indonesia, the Philippines, Japan, India, northern Maldives, the Persian Gulf and the Red Sea. For the combined disease-risk metric, relative risk was considered lower for locations where anthropogenic stress was low or medium, a condition found for some locations in Thailand (Maynard et al., 2015).

Degradation and loss of coral reefs can affect about 4.5 million people in Southeast Asia and the Indian Ocean (Lam et al., 2019). In the coral reef fisheries sector, there are about 3.35 million fishers in Southeast Asia and 1.5 million fishers in the Indian Ocean (Teh et al., 2013). The economic loss under different climate-change scenarios and fishing efforts were estimated to range from 27.78 to 31.72 million USD annually in Nha rang Bay, Vietnam. A survey conducted in Taiwan, Province of China, showed that the average annual amount that people were personally willing to pay was 35.75 USD and the total amount was 0.43 billion USD. These high values indicate the need to preserve these coral reef ecosystems (Tseng et al., 2015). In Bangladesh, the coral reef of St. Martin's Island contributes 33.6 million USD yr^{-1} to the local economy, but climate change, along with other anthropogenic activities, has been identified as a threat these habitats (Rani et al., 2020a).

Mitigation of global warming has been identified to be essential to maintain healthy coral reef ecosystems in Asia (Comte and Pendleton, 2018; Heery et al., 2018; Lam et al., 2019; Yan et al., 2019). Restoration of reefs (Nanajkar et al., 2019) and building resilience through multiple mechanisms, such as innovative policy combinations, complemented by environmental technology innovations and sustained investment (Hilmi et al., 2019; McLeod et al., 2019), are suggested.

An ecosystem-based approach to managing coral reefs in the Gulf of Thailand is needed to identify appropriate marine protected area (MPA) networks and to strengthen marine and coastal resource policies in order to build coral reef resilience (Sutthacheep et al., 2013). Broadening the scope to develop novel mitigation approaches towards coral protection through the use of symbiotic bacteria and their metabolites (Motone et al., 2018; Motone et al., 2020) has been suggested. Coral culture and transplantation within the Gulf are feasible for helping maintain coral species populations and preserving genomes and adaptive capacities of Gulf corals that are endangered by future thermal-stress events (Coles and Riegl, 2013). Greater focus on understanding the flexibility and adaptability of people associated with coral reefs, especially in a time of rapid global change (Hoegh-Guldberg et al., 2019), and a well-designed research programme for developing a more targeted policy agenda (Lam et al., 2019), is also recommended. Cutting carbon emissions (Bruno and Valdivia, 2016) and limiting warming to below 1.5°C is essential to preserving coral reefs worldwide and protecting millions of people (Frieler et al., 2013; Hoegh-Guldberg et al., 2017). Many visitors to coral reefs have high environmental awareness, and reef visitation can both help to fund and encourage coral reef conservation (Spalding et al., 2017).

The largest mangrove forests are in Asia contributing to about 42% of the world's mangroves. This includes Sundarbans, the world's largest remaining contiguous mangrove forest (Dasgupta et al., 2020). Mangrove ecosystems are rich in biodiversity. The ecosystems are supported and maintained by both flora and a large array of living things, which include mammals, birds, fish, crustaceans, shrimps, insects and microbes[3]. Contemporary rates of mangrove deforestation are lower than in the late 20th century (Gandhi and Jones, 2019; Friess et al., 2019); however, some areas in Asia continue the trend. Myanmar is the primary mangrove-loss hotspot in Asia, exhibiting 35% loss from 1975 to 2005 and 28% from 2000 to 2014. Rates of loss in Myanmar were four times the global average from 2000 to 2012. The Philippines is additionally identified as a loss hotspot, with secondary hotspots including Malaysia, Cambodia and Indonesia (Gandhi and Jones, 2019).

Mangrove deforestation is expected to increase as many tropical nations utilise mangrove areas for economic security. Increased river damming would reduce fluvial sediment sources to the coast making mangroves more vulnerable to SLR, and uncertain climate with extreme oscillations can create unstable conditions for survival and propagation of mangrove (Friess et al., 2019).

Valuation of ecosystem services of mangroves have indicated that they prevent more than 1.7 billion USD in damages for extreme events (i.e., one event in 50 years) in the Philippines (Menéndez et al., 2018). They reduce flooding to 613,500 people yr^{-1}, 23% of whom live below the poverty line and avert damages up to 1 billion USD yr^{-1} in residential and industrial property. Mangroves have also become a very popular source of livelihood in Asia through tourism (Dehghani et al., 2010; Kuenzer and Tuan, 2013; Spalding and Parret, 2019; Dasgupta et al., 2020) and they also support fisheries (Hutchison et al., 2014).

Mangroves, tidal marshes and seagrass meadows (collectively called coastal blue carbon ecosystems) have sequestered carbon dioxide from the atmosphere continuously over thousands of years, building stocks of carbon in biomass and organic rich soils. Carbon dynamics in mangrove-converted aquaculture in Indonesia indicate that the mean ecosystem carbon stocks in shrimp ponds are less than half of the relatively intact mangroves (Arifanti et al., 2019). Conversion of mangroves into shrimp ponds in the Mahakam Delta have resulted in a carbon loss equivalent to 226 years of soil carbon accumulation in natural mangroves. In the Philippines, abandoned fishpond reversion to former mangrove has been found to be favourable for enhancing climate change mitigation and adaptation (Duncan et al., 2016). Integrated mangrove-shrimp farming, with deforested areas not exceeding 50% of the total farm area, has been suggested to support both carbon sequestration as well as livelihood (Ahmed et al., 2018).

Globally, the extent of the blue carbon ecosystem has been estimated at 120,380 km^2, with the highest spread by mangroves at 114,669 km^2 (95.3%), followed by seagrass meadows at 2,201 km^2 (1.8%) and salt marshes at 3510 km^2 (2.9%) (Himes-Cornell et al., 2018). In Asia, the total extent of these three ecosystems is 33,224 km^2, forming 27.6% of the global total with the highest spread of mangrove at 32,767 km^2, which forms 28.6% of the global mangrove coverage. The area of seagrass meadows spread in Asia has been estimated as 236 km^2 and salt marsh 220 km^2,which forms 10.8 and 6.03% of the respective ecosystems globally (Himes-Cornell et al., 2018). Found at the land–sea interface, seagrasses provide varied services apart from acting as ecosystem engineers providing shelter and habitat for several marine fauna which are fished in several Asian countries (Jeyabaskaran et al., 2018; Nordlund et al., 2018; Unsworth et al., 2019b) thereby providing livelihood to millions across the continent (UNEP, 2020).

The seagrass meadows are also good sinks of carbon (Fourqurean et al., 2012) capable of storing 19.9 petagrams (pg) of organic carbon, but with very high regional and site- and species variability (Ganguly et al., 2017; Stankovic et al., 2018; Gallagher et al., 2019; Ricart et al., 2020). As highly efficient carbon sinks, they store up to 18% of the world's oceanic carbon, and they also reduce the impacts of ocean acidification (UNEP, 2020).

The deterioration of this ecosystem is fast, 7% yr^{-1} since 1990 (Waycott et al., 2009), which has led to development of restoration protocols across Asia (Paling, 2009; van Katwijk et al., 2016). In Vietnam, the loss of seagrass has been estimated as above 50% and in some regions complete loss has been observed (Van Luong et al., 2012). The seagrass meadows of Indonesia are fast deteriorating, and the need for increased local autonomy for the management of marine resources and restoration has been highlighted (Unsworth et al., 2018). Development of science-based policies for conservation, including participatory methods (Fortes, 2018; Ramesh et al., 2019; Unsworth et al., 2019a) and large-scale planting (van Katwijk et al., 2016), has been recommended to preserve the ecosystem services of these habitats.

Globally, the diversity of the plankton community has been predicted to be affected by warming and related changes (Ibarbalz et al., 2019), and these changes are expected in Asia also. Combined effects of high temperature, ocean acidification and high light exposure would affect important phytoplankton species in the SCS, *Thalassiosira pseudonana* (Yuan et al., 2018) and *Thalassiosira weissflogii* (Gao et al., 2018b). Also in the SCS the phytoplankton-assemblage responses to rising temperatures and CO_2 levels were found to differ between coastal and offshore waters and the predicted increases in temperature and pCO_2 may not boost surface-phytoplankton primary productivity (Zhang et al., 2018).

Ocean warming and acidification can affect the functioning and ecological services of sedentary molluscs like the bivalves (Guo et al., 2016; Zhao et al., 2017b; Cao et al., 2018; Zhang et al., 2019c; Liu et al., 2020b) and gastropods (Leung et al., 2020), and also sea urchins (Zhan et al., 2020). The oyster *Crassostrea gigas* becomes more vulnerable

3 Tropical Coastal Ecosystems Portal. Available at www.nies.go.jp/TroCEP/index.html, accessed 8 October 2020.

to disease when exposed to acidification conditions and pathogen challenge indicating incapability for supporting long-term viability of the population (Cao et al., 2018). More tolerance and benefits to rising pCO_2 was observed in clam species like *Paphia undulate* which has been attributed to adaptation to its acidified sediment habitat (Guo et al., 2016). Warming boosted the energy budget of marine calcifiers like the gastropod *Austrocochlea concamerata*, by faster shell growth and greater shell strength, making them more mechanically resilient while acidification negatively affected shell building thereby impacting the physiological adaptability (Leung et al., 2020). It is expected that there will be transgenerational acclimation to changes in ocean acidification in marine invertebrates (Lee et al., 2020b).

Assessment of the potential impacts and the vulnerability in marine biodiversity in the Persian Gulf under climate change has suggested a reduction of up to 35% of initial species richness and habitat loss for hawksbill turtles in the southern and southwest parts of the Persian Gulf (Wabnitz et al., 2018).

Seaweeds are an important biotic resource capable of capturing carbon and used widely as food, medicine and as raw material for industrial purposes. Warming and altered pH can affect seaweeds in different ways (Gao et al., 2016; Gao et al., 2017; Gao et al., 2018a; Wu et al., 2019b). Outbreak of intense blooms of species like *Ulva rigida* (Gao et al., 2017) and *Ulva prolifera* (Zhang et al., 2019 f) have increased due to varied factors including climate change. These blooms have created huge economic losses in the Yellow Sea affecting local mariculture, tourism and the functioning of the coastal and marine ecosystems (Zhang et al., 2019 f). Increased temperature was found to enhance the dark respiration and light compensation point of *Ulva conglobate*, which thrives in the mid-intertidal to upper subtidal zones, while the altered pH showed a limited effect (Li et al., 2020). Elevated temperature significantly enhanced growth, photosynthetic performances and carbon-use efficiency of *Sargassum horneri* in both elevated and ambient CO_2 levels suggesting that the present greenhouse effect would benefit the golden tide blooming macroalgae *Sargassum horneri*, which might enhance both the frequency and scale of golden tide (Wu et al., 2019b).

10.4.3.1 Key Drivers to Vulnerability

The vulnerabilities to disaster in coastal regions with high population densities are reported in several studies (Sajjad et al., 2018) that have assessed the vulnerabilities of coastal communities along the Chinese coast and shown that roughly 25% of the coastline, and more than 5 million residents, are in highly vulnerable coastal areas of mainland China, and these numbers are expected to double by 2100. Husnayaen et al. (2018) assessed the Semarang coast in Indonesia and showed that 20% of the total coastline (48.7 km) is very highly vulnerable. Mangroves continue to face threats due to pollution, conversion for aquaculture, agriculture, apart from climate-based threats like SLR and sea erosion (Richards and Friess, 2016; Romañach et al., 2018; Wang et al., 2018b; Friess et al., 2019). Hypersalinity, storm effects on sediment deposition, fishery development and land erosion are responsible for most of the Sunderban mangrove degradations leading to loss of livelihood (Uddin, 2014; Paul, 2017). In the Sunderbans of Asia, climate change is expected to increase river salinisation, which in turn could significantly negatively impact the valued timber species, *Heritiera fomes* (Dasgupta et al., 2017b). Augmented potential for honey production is also predicted, which could increase the conflict between humans and wildlife (Dasgupta et al., 2017b).

Destruction by natural hazards was found to remove the above-ground C pool, but the sediment C pool was found to be maintained (Chen et al., 2018b). In the Andaman and Nicobar Islands, the 2004 Indian Ocean tsunami severely impacted mangrove habitats at the Nicobar Islands (Nehru and Balasubramanian, 2018), although new inter-tidal habitats suitable for mangrove colonisation did develop. Mangrove species with a wide distribution and larger propagules showed high colonisation potential in the new habitats compared with other species (Nehru and Balasubramanian, 2018). Mangrove sites in Asia are predominantly minerogenic, so continued sediment supply is essential for the long-term resilience of Asia's mangroves to SLR (Lovelock et al., 2015; Balke and Friess, 2016; Ward et al., 2016a; Ward et al., 2016b).

10.4.3.2 Observed Impacts

Primary production in the western Indian Ocean showed a reduction by 20% during the past six decades, attributed to rapid warming and ocean stratification which restricted nutrient mixing (Roxy et al., 2016). Variation in secondary-production zooplankton densities and biomass in the East Asian Marginal Seas affected the recruitment of fishes due to mismatch in spawning period and larval-feed availability during the last three climate regime shifts (CRS) in the mid-1970s, late 1980s and late 1990s, which were characterised by the North Pacific index and the Pacific Decadal Oscillation index (Kun Jung et al., 2017). In the western North Pacific, climate change has affected recruitment and the population dynamics of pelagic fishes, such as sardine and anchovy (Nakayama et al., 2018), and also shifts in the spawning ground and extension of the spawning period of the chub mackerel *Scomber japonicas* (Kanamori et al., 2019).

Varied responses to CRS in the China seas have been observed for small pelagic fishes (Ma et al., 2019) and cephalopods (Ichii et al., 2017). The winter and summer SSTs have shown evidence of decadal variability with abrupt changes from cold to warm in substantial association with climate indices to which coastal cephalopods in the China seas respond differentially, with some benefiting from warmer environments while others respond negatively (Pang et al., 2018). In the western and eastern North Pacific marine ecosystem, it is indicated that groundfish may suffer more than pelagic fish (Yati et al., 2020). Habitat Suitability index models using SST, chlorophyll-*a*, sea surface height anomaly (SSHA) and sea surface salinity (SSS), as well as fishing effort, strongly indicate that Neon flying squid is affected by interannual environmental variations and undertakes short-term migrations to suitable habitat, affecting the fisheries (Yu et al., 2015). The 2015–2016 El Niño was found to impact coral reefs of shallower regions (depth of 5–15 m) in South Andaman, India, more than those beyond 20 m (Majumdar et al., 2018). On the southeast coast of India, with bleaching largely mediated by the SST anomaly and during the recovery period, macroalgae outgrowth has been observed (2.75%) indicating impacts on the benthic community (Ranith and Kripa, 2019). In the South China Sea, the increase in SST was found to be higher than predicted in recent decades, while the pH decreased at a rate of

0.012–0.014 yr^{-1}, more than the predicted level, due to high microbial respiratory processes releasing CO_2 (Yuan et al., 2019). Simulation experiments have shown differential adaptation capacity of common species (Zheng, 2019; Yuan et al., 2019).

The UN's (2019) report on climate action and support trends highlights that the impacts of climate change on coastal ecosystems are mainly increased risks due to flooding, inundation due to extreme events, coastal erosions, ecosystem processes and, in the case of fisheries, variations in population or stock structures due to ocean circulation pattern, habitat loss degradation and ocean acidification. Analysis of data on the occurrence of varied natural hazards from 1900 to 2019 has shown that tropical cyclones, riverine floods and droughts have increased significantly, and the impacts of these events on coastal communities are also severe and destructive. The UN's average score for SDG Goal 14 (Life Under Water) for Asia was estimated as 46 among the scores of 40 nations, and the Ocean Health Biodiversity index was comparatively high (average 87.9); however, the indices show that more region-specific action plans are required to achieve the UN 2030 goal for Life Under Water.

Apart from the human impacts, the ecology and resource abundance of coastal waters have been found to be impacted by extreme events. During tropical cyclones ecological variations, like lowering of SST, an increase in chlorophyll-*a* and a decrease in oxygen (Chacko, 2019; Girishkumar et al., 2019) have been observed. Global analyses of such events have indicated that they may have an impact on the fishery directly by creating unfavourable ecological conditions and destruction of critical habitats indirectly by affecting the eggs and larvae as well as subsequent fishery recruitment (McKinnon et al., 2003; Bailey and Secor, 2016). In the South China Sea in July 2000, during a 3-day cyclone period, an estimated thirtyfold increase in surface chlorophyll-*a* concentration was observed (Lin et al., 2003). The estimated carbon fixation resulting from this event alone is 0.8 Mt, or 2–4% of the SCS's annual new production (Lin et al., 2003). Since an average of 14 cyclones pass over this region annually, the contribution of cyclones to the annual new production has been estimated to be as high as 20–30% (Lin et al., 2003).

10.4.3.3 Projected Impacts

Water pollution and climate stressors have been considered major challenges to ecosystem sustainability, and now it has been shown that the combined effect these two stressors would be more damaging (Buchanan et al., 2019). For seagrass beds the pollution stress was found to increase by 2.6% (from 39.7 to 42.3%) when climate factors were added. Assuming the pollution levels remain at the 2014 levels, different scenarios including RCP2.6 and RCP8.5 were worked out for the Bohai Sea, and the results indicated amplification of the impacts on the ecosystem. Pollutants like petroleum hydrocarbons, dissolved inorganic nitrogen and soluble reactive phosphorus were the major pollution stressors (Lu et al., 2018). In the future, policies that focus strictly on pollution control should be changed and take into account the interactive effects of climate change for better forecast and management of potential ecological risks (Lu et al., 2018).

Projected changes in catch potential (in percent) by 2050 and 2100 relative to 2000 under RCP2.6 and RCP8.5, based on outputs from the dynamic bioclimate envelop model and the dynamic size-based food-web models, indicate that the marine and coastal resources of most Asian countries will be impacted with varying intensity (FAO, 2018b).

Better management of resources through projections of resource distribution, abundance and catch is required; however, lack of data (e.g., oceanographic surveys) and scientific knowledge is a constraint to this aim (Maung Saw Htoo et al., 2017). Effective forecasts of areas of resource abundance based on habitat preference have to be worked out for Asian regions.

Modelling and assessment of the vulnerability and habitat suitability of the Persian Gulf for 55 species to climate change indicated that there is a high rate of risk of local extinction in the southwest part of the Persian Gulf, off the coast of Saudi Arabia, Qatar and the United Arab Emirates (UAE). Likelihood of reduced catch was observed, and Bahrain and Iran were found to be more vulnerable to climate change (Wabnitz et al., 2018). Projected changes in fish catches can impact the supply of fish available for local consumption (i.e., food security) and exports (i.e., income generation) (Wabnitz et al., 2018). As per (UNESCAP, 2018a), over 40% of coral reefs and 60% of coastal mangroves in the Asia-Pacific region have already been lost, and approximately 80% of the region's coral reefs are currently at risk.

Regionally, the escalation in thermal stress estimated for the different global warming scenarios is greatest for Southeast Asia and least for the Pacific Ocean (Lough et al., 2018). For the 100 reef locations examined here and given current rates of warming, the 1.5°C global warming target represents twice the thermal stress they experienced in 2016 (Lough et al., 2018).

In the Southeast Asia region threats from both warming and acidification has indicated that by 2030, 99% of reefs will be affected, and by 2050, 95% are expected to be in the highest levels of the 'threatened' category (Burke et al., 2011), similar to global corals (Frieler et al., 2013; Bruno and Valdivia, 2016). Modelling results indicate that even under RCP scenarios, the functional traits of coral reefs can be affected (van der Zande et al., 2020) and coral communities will mainly consist of small numbers of temperature-tolerant and fast-growing species (Kubicek et al., 2019). Increases in temperature (+3°C) and pCO2 (+400 matm) projected for this century can reduce the sperm availability for fertilisation, which along with adult population decline either due to climate change or anthropogenic impacts (Hughes et al., 2017) can affect coral reproductive success thereby reducing the recovery of populations and their adaptation potential (Albright and Mason, 2013; Hughes et al., 2018; Jamodiong et al., 2018). In the southern Persian Gulf, increased disturbance frequency and severity has caused progressive reduction in coral size, cover and population fecundity (Riegl et al., 2018), and this can lead to functional extinction. Connectivity required to avoid extinctions has increased exponentially with disturbance frequency and correlation of disturbances across the metapopulation. In the Philippines experiments have also proved that scleractinian corals, such as *A. tenuis, A. millepora* and *F. colemani*, which spawn their gametes directly into the water column, may experience limitations from sperm dilution and delays in initial sperm–egg encounters that can impact successful fertilisation (de la Cruz and Harrison, 2020).

Table 10.2 | Status of ocean health and mean of marine protected areas (MPA)[a]

	Ocean Health index: Clean waters (0–100)	Fish stocks over-exploited or collapsed (%)	Ocean Health index: Fisheries (0–100)	Fish caught by trawling (%)	Ocean Health index: Biodiversity (0–100)	Mean MPA (%)
Eastern Asia	54.0	29.1	49.5	39.8	89.6	32.5
Southeast Asia	54.1	28.5	54.9	34.7	84.6	25.0
Western Asia	54.3	28.3	46.2	20.4	89.4	18.3
Southern Asia	50.3	17.4	51.0	15.1	88.3	41.2
Northern Asia	91.6	55.4	57.6	60.0	93.4	30.0
Asia (whole)	54.6	26.9	50.3	27.3	87.9	27.0

(a) Data are from Sachs et al. (2018).

Apart from these threats, natural hazards have also been found to affect coral reefs of Asia. The extensive and diverse coral reefs of Muscat, Oman, in the northeast Arabian Peninsula were found to have long-term effects from Cyclone Gonu, which struck the Oman coast in June 2007, more than coastal development (Coles et al., 2015).

Sandy beaches are subject to highly dynamic hydrological and geomorphological processes, giving them more natural adaptive capacity to climate hazards (Bindoff et al., 2019). Progress is being made towards models that can reliably project beach erosion under future scenarios despite the presence of multiple confounding drivers in the coastal zone (Chapter 3). Assuming minimal human intervention and projected impacts of SLR by 2100 under RCP8.5-like scenarios, 57–72% of Thai beaches (Ritphring, 2018), at least 50% loss of area on around a third of Japanese beaches (Mori, 2018) will disappear.

Marine heatwaves (MHWs) in Asia have been making changes to the structure and functioning of coastal and marine ecosystems (Kim and Han, 2017; Oliver et al., 2017; Frölicher and Laufkötter, 2018; Oliver et al., 2019; Smale et al., 2019), affecting resources like copepods (Doan et al., 2019) and coral reefs (Zhang et al., 2017c). Coral reefs of the southeast Indian Ocean have been affected by MHWs (Zhang et al., 2017c).

Simulation of RCP scenarios have shown that continued warming can drive a poleward shift in distribution of the seaweed *Ecklonia cava* of Japan, and under the lowest-emissions scenario (RCP2.6) most populations may not be impacted, but under the highest-emissions scenario (RCP8.5) the existing habitat may become unsuitable and it can also increase predation by herbivorous fishes (Takao et al., 2015).

10.4.3.4 Adaptation Options

The UN (2019) has identified establishment of protected areas, restoring ecosystems like mangroves and coral reefs, integrating coastal-zone management practices, sand banks and structural technologies, and implementing local monitoring networks for increasing adaptive capacity and protecting the biodiversity of the coastal ecosystem. In Asia, management of marine sites by earmarking protected areas (SDG 14) has been found to be low with only 27% of areas being protected. In India, detailed CCA guidelines for coastal protection and management has been prepared considering various environmental and social aspects (Black et al., 2017). The Ocean Health index for clean waters was also low (54.6), and the threat to the ecosystem due to the combined effects of pollution and climate change was high. Table 10.2 shows the ocean and MPAs.

Conservation and restoration of mangroves were found to be effective tools for enhancing ecosystem carbon storage and an important part of Reducing Emissions from Deforestation and forest Degradation plus (REDD+) schemes and climate-change mitigation (Ahmed and Glaser, 2016). In East Asia, restoration success has been attributed to choosing the right geomorphological locations (Van Cuong et al., 2015; Balke and Friess, 2016) and co-management models (Johnson and Iizuka, 2016; Veettil et al., 2019).

In South Asia, restoration programmes have been largely successful (Jayanthi et al., 2018) but in some regions partly a failure due to inappropriate site selection, poor post-planting care and other issues (Kodikara et al., 2017). Using remote sensing it has been observed that there are high recovery rates of mangroves in a relatively short period (1.5 years) after a powerful typhoon, indicating that natural recovery and regeneration would be a more economically and ecologically viable strategy. Better mangrove management through mapping is suggested (Castillo et al., 2018; Gandhi and Jones, 2019). Statistical tools developed for modelling biomass and timber volume (Phan et al., 2019), and allometric models to estimate above-ground biomass and carbon stocks (Vinh et al., 2019), will be useful in estimating stocks in mangroves. Future mangrove loss may be offset by increasing national and international conservation initiatives that incorporate mangroves, such as the SDGs, Blue Carbon, and Payments for Ecosystem Services (Friess et al., 2019). Since seagrass meadows and marine macroalgae are important habitats capable of combating impacts of climate change, the need for a global networking system with participation of stakeholders has been suggested (Duffy et al., 2019).

10.4.4 Freshwater Resources

In Asia, freshwater resources, an important component of ecosystem services, are widely used for agriculture, domestic, irrigation, navigation, energy and industry. Freshwater availability is changing at the global scale because of unsustainable use of surface water and groundwater, pollution and other environmental changes. These changes in space and time, directly or indirectly, affect water-use sectors and services (Wheater and Gober, 2015; Rodell et al., 2018). About 82% of the global population served by freshwater provisions from upstream areas are exposed to high threat (Green et al., 2015). Given that some of the fastest-growing economies in the world are in Asia, and the geographies of development are highly uneven, both CIDs and non-climate drivers, such as socioeconomic changes, have contributed to water stress conditions in both water supply and demand in diverse sub-regions of Asia. In the case of Asia, therefore, the entanglement between the non-climate drivers and CIDs makes it difficult to attribute environmental changes—both present and projected—neatly and exclusively to CIDs.

Immerzeel et al. (2020) have ranked all mountain-dependent water towers according to their water-supplying role and the downstream dependence of ecosystems, societies and economies. The resulting Global Water Tower index indicates that the upper Indus basin is both the most important and the most vulnerable water tower unit (WTU) in the world. A WTU is defined as 'the intersection between major river basins and a topographic mountain classification based on elevation and surface roughness'. Whereas all important transboundary WTUs in Asia remain highly vulnerable, it is the Indus WTU (inhabited by approximately 235 million people in the basin in 2016 (which is projected to increase by 50% by the middle of 21st century) where the average annual temperature is projected to increase by 1.9°C between 2000 and 2050, with wide-ranging consequences and trans-sectoral spillovers. The Indus WTU faces a deep risk produced by a combination of factors including water stress, ineffective governance, hydropolitical tensions, population growth and density, urbanisation and social transformations, with a significant bearing on SDG 6 on water, SDG 2 on food and SDG 7 on energy.

10.4.4.1 Key Drivers

Across Asia and its various sub-regions, the key drivers behind an increasingly inadequate supply of freshwater resources, affecting the livelihood security of millions, are varied, complex and intersect with multiple social, cultural, economic and environmental stressors (Luo et al., 2017; Tucker et al., 2015; Kongsager et al., 2016). Water stress has been defined as the situation 'when the demand for water exceeds its supply, during a certain period of time, or when poor quality restricts its use'(Felberg et al., 1999; see also Figure 4.32 in Lee et al., 2021a).

Freshwater resources in Asia, which include both surface water and groundwater, are considerably strained, and changing climate is *likely* to act as a major stress multiplier (Dasgupta et al., 2015; Fant et al., 2016; Gao et al., 2018c; Mack, 2018). In Southern and Eastern Asia (SEA) nearly 200 million people are at risk of serious water-stressed conditions. Effective mitigation might reduce the additional population under threat by 30% (60 million people), but still there is a 50% chance that 100 million people across SEA might face a 50% increase in water stress and a 10% chance that water stress will almost double in the absence of wide-ranging, multi-scalar adaptive measures (Gao et al., 2018c). With Millennium Development Goal 7c, which aimed to halve the population that had no sustainable access to water and basic sanitation before 2015, not having been fully realised, and Sustainable Development Goal 6 on water and sanitation not having been effectively operationalised, the water stress is *likely* to increase by the end of 2030 (Weststrate et al., 2019).

In Asia and elsewhere the interplay between the challenge of sustainability and climate change poses major policy challenges (von Stechow et al., 2016). The pursuit of SDG 6—protection and restoration of water-related ecosystems, universal and equitable access to safe and affordable drinking water for all, improvement in water quality by reducing pollution, elimination of dumping and significant reduction in release of hazardous chemicals and materials, and treatment of waste water through recycling and safe reuse globally—could be directly or indirectly challenged and undermined by climate change (Parkinson et al., 2019). Dissolved organic materials from sewage can enhance CO_2 emissions, especially in rapidly urbanising river systems which receive untreated waste water and/or sewage across developing countries (Kim et al., 2019b). Conversely, policy interventions aimed at significant augmentation in water-use efficiency across all sectors, ensuring sustainable withdrawals and supply of freshwater to address water scarcity and a significant reduction in the number of victims of water scarcity, especially the poor and marginalised, could mitigate vulnerabilities caused by climate change. More interdisciplinary research is needed on highly precarious future pathways and the intersection between CIDs and non-climate drivers in order to anticipate and mitigate diverging and uncertain outcomes.

10.4.4.2 Sub-regional Diversity

According to a quantitative scenario assessment for future water supply and demand in Asia to 2050, based on global climate change and socioeconomic scenarios (Satoh et al., 2017), water demand in sectors such as irrigation, industry and households will increase by 30–40% around 2050 in comparison with 2010. Water stress is *likely* to be more pronounced in Pakistan, and northern parts of India and China. By mid-21st Century, the international transboundary river basins of Amu Darya, Indus, Ganges could face severe water scarcity challenges due to climatic variability and changes acting as stress multipliers (*high confidence*). Within a country as well, the water scarcity could be exacerbated, such as in India and China, due to various drivers like population increase and climate change. Research on the differentiated impacts of climate change on freshwater sources across the Asian sub-regions remains inconclusive and requires assessment at the sub-regional scale (IPCC, 2014b; Wester et al., 2019).

10.4.4.3 Observed Impact

The climate-change impact on different parts of freshwater ecosystems (Section 10.4.2) has affected water supply in various sub-regions of Asia. While headwater zones are susceptible to change in snow cover, permafrost and glaciers, the downstream plain areas of these river systems are vulnerable to the increasing high demand of freshwater which will affect water availability in space and time. The observed impact of climate change has also been seen in direct physical losses such as precipitation (Mekong Delta), floods (Vietnam) and saltwater intrusion leading to low agricultural productivity (Mora et al., 2018; Almaden et al., 2019a; Pervin et al., 2020).

The HKH region extends 3,500 km from Afghanistan in the west to Myanmar in the east. It is a source of major river systems originating in Asia, supporting livelihoods, energy, agriculture and the ecosystem for 240 million people in the mountains and hills and 1.65 billion people

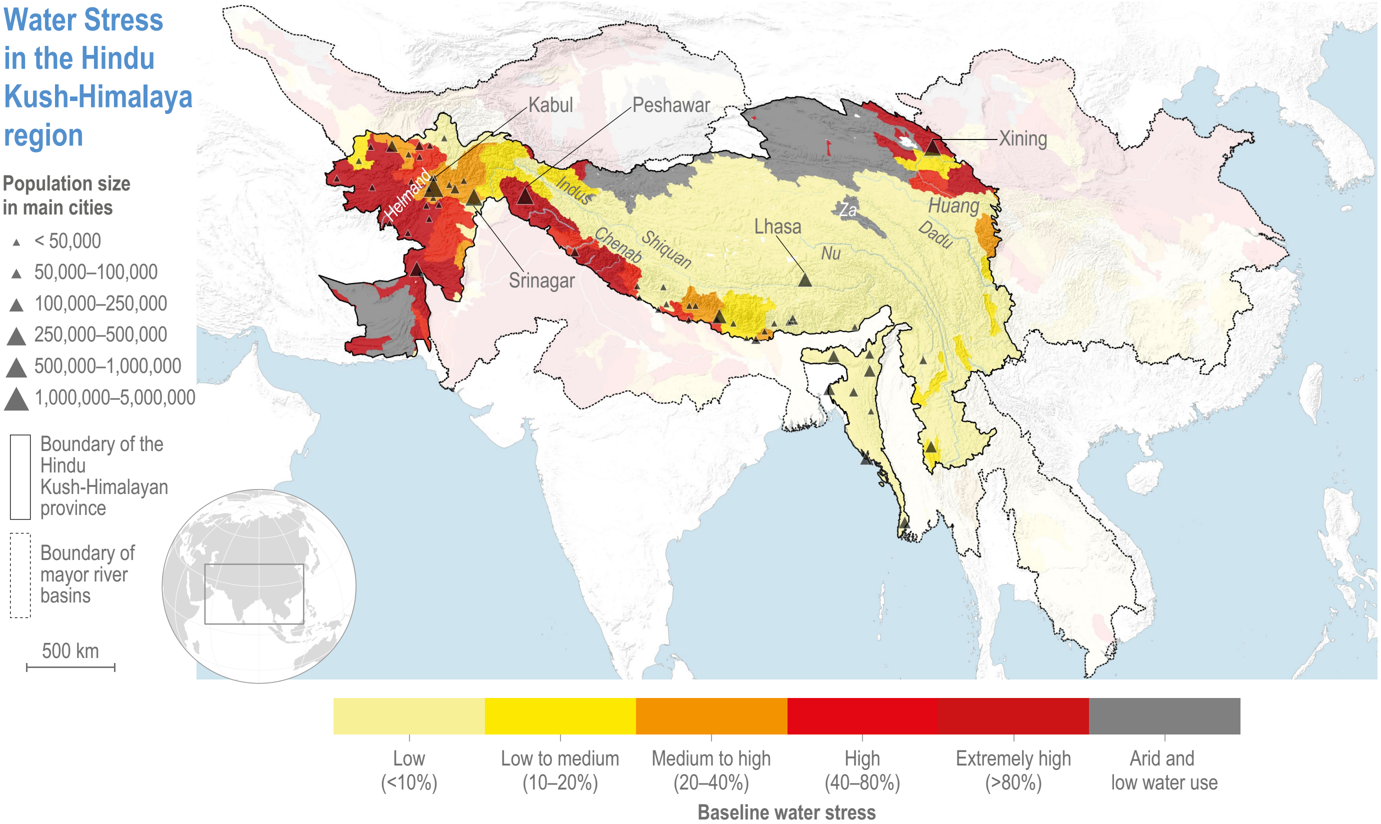

Figure 10.5 | Water stress in the Hindu Kush Himalaya (HKH) region according to Wester et al. (2019) and Hu and Tan (2018).

in the plains (Sharma et al., 2019). The HKH region stores about half of the ice mass in HMA, provisioning freshwater to almost 869 million people in the Indus, Tarim, Ganges and Brahmaputra river basins. While the warming climate increases the melt-water runoff enhancing water supply, it is indeed at the cost of glacier-mass reduction that would eventually reduce melt water and impact the people's livelihood downstream in the future (Nie et al., 2021). The melt runoff from the region plays an important role in downstream agriculture such as in the case of Indus where two-thirds of total irrigation withdrawal is from melt runoff in the pre-monsoon season (Biemans et al., 2019). Changes in cryosphere and other environmental changes have already impacted people living in high-mountain areas and are *likely* to introduce new challenges for water, energy and food security in the future (Borodavko et al., 2018; Adler et al., 2019; Bolch, 2019; Hoelzle et al., 2019; Rasul and Molden, 2019; Shen et al., 2020).

With climate-change impacts resulting in the shrinking and melting of snow, ice, glacier and permafrost, and correspondingly causing an increase in melt water, the incidences of flash floods, debris flow, landslides, snow avalanches, livestock diseases and other disasters in the HKH region have become more frequent and intense. Some of the key factors that get in the way of assigning confidence levels to climate-change impacts include lack of sufficient observed data on factors such as river discharges, precipitation and glacier melt (You et al., 2017). Climate-change impacts cryospheric water sources in the Hindu Kush, Karakoram and Himalayan ranges which, in turn, carry consequences for the Indus, Ganges and Brahmaputra basins.

The combined impacts of climate change and non-climate drivers on hydrological processes and water resources in transboundary rivers in diverse regions of Asia were well noted in AR5. In Central Asia, withdrawal is approximately equal to water availability, with Turkmenistan and Uzbekistan as the most water-stressed countries in the region (Karthe et al., 2017; Russell, 2018). A study on water availability in mainland South Asia has pointed in the direction of decreasing precipitation trends in recent years, which have also contributed to the increasing incidence and severity of droughts (Liu et al., 2018b). There are reports of increase in occurrence and severity of different forms of droughts in the Koshi River basin (Central Himalaya) (Wu et al., 2019a; Hamal et al., 2020; Dahal et al., 2021; Nepal et al., 2021). Figure 10.5 shows the water stress in the HKH region. The water stress is relatively higher in the western region compared with the central and eastern regions.

Climate change is also having an impact on stream flows. The changes in snowmelt water can explain 19% of the variations in rivers of arid regions like Xinjiang, China (Bai et al., 2018) (*medium confidence*), and the 10.6% of the runoff of the upper Brahmaputra River was contributed by snow during 2003–2014 (Chen et al., 2017c) (*medium confidence*). A recent study (Chen et al., 2018 f) has shown that with the average temperature after 1998 being 1.0°C higher than that during 1960–1998 in the Tienshan Mountains, the process of glacier shrinkage and decreases in snow cover are causing earlier peak runoff and aggravated extreme hydrological events, affecting regional water availability and adding to the future water crisis in Central Asia. The magnitude and frequency of flooding have increased across the Himalayan region, such as in the Tarim basin in China (Zhang et al., 2016c) and the higher Indus, Ganges and Brahmaputra, in the past six decades (Elalem and Pal, 2015). The latter also reported the highest number of flood disasters and greater spatial coverage in recent decades as compared with previous decades. In the Middle Yellow River basin, which has become much warmer and drier, climate variability accounts for 75.8% of streamflow decrease during 1980–2000, whereas during 2001–2016, change in land use and cover was the main factor in streamflow decrease, accounting for 75.5% of the decline (Bao et al., 2019). The changes in hydrological regime and extreme floods cause changes in river morphology and the river channel system which impact water availability.

In China, a quantitative assessment based on a multi-model dataset (six global hydrological models driven by three observation-based global forcings) during 1971–2010 suggested that climate variability dominated the changes in streamflow in more the 80% of river segments, while direct human impact dominated changes mostly in northern China (Liu et al., 2019b). In the Lancang-Mekong River basin, climate variability would have contributed 45% more flood occurrences in the middle of the basin, while reservoir operation reduced it by 36% during 2008–2016 as compared with 1985–2007 (Yun et al., 2020).

In western China, the total annual snow mass declines at a rate of 3.3×10^9 pg per decade ($p < 0.05$), which accounts for approximately 0.46% of the mean of annual snow mass (7.2×10^{11} pg). The loss could be valued in terms of replacement cost at 0.1 billion CN¥ (at the present value) every year (1 USD = 7 CN¥) compounded over the past 40 years (Wu et al., 2021). In the Mekong River Delta in Vietnam, climate-change impacts include a 30% annual increase in rainfall, shifting rainfall patterns, an average temperature increase of 0.5°C over the past 30 years and an average SLR of 3 mm yr^{-1} over the past three decades, resulting in a greater flooding threat (Wang et al., 2021a).

A recent study (Wang et al., 2021b) has shown that during 1936–2019, due largely to intensified precipitation induced by a warming climate, the streamflow of the Ob, Yenisei and Lena rivers has increased by ~7.7, 7.4 and 22.0%, respectively. While rising temperatures can reduce streamflow via evapotranspiration, it can enhance groundwater discharge to rivers due to permafrost thawing. In permafrost-developed basins, the thawing permafrost will continue to result in increased streamflow. However, with further permafrost degradation in the future, the positive effect of permafrost thaw on streamflow would probably be offset by the negative effect of the increase in basin evapotranspiration. This could result in a situation where runoff reaches threshold level and then declines. This is clearly marked in the Ob River basin, which is characterised by the highest precipitation, whereas in the case of the Yenisei and Lena rivers, further research is needed.

The HKH region is susceptible to floods and related hazards caused by a cloud burst and other landscape-based processes such as glacial lake outburst floods, which can seriously damage property, lives and infrastructure (Shrestha et al., 2010). The likely increased frequency of hazards caused by abnormal glacier changes, such as the glacier collapses happened on two glaciers in western Tibetan Plateau in 2016 (Kääb et al., 2018), and also surges which were frequently found in this vast region (e.g. Bhambri et al., 2017; Mukherjee et al., 2017; Ding et al., 2018), threatening the security of the local and down streaming societies (high confidence).The total amount and area of glacier lakes increased during last decade (Zhang et al., 2015; Chen et al., 2017c) (*high confidence*). Himalayan rivers are frequently hit by catastrophic floods caused by the failure of glacial lakes (Cook et al., 2018; Ahluwalia et al., 2016). In Kedarnath, India (western Himalaya), a flash flood was triggered by glacier lake outburst flood (GLOF) released from the Chorabari glacial lake in June 2013 which caused extensive flooding, erosion of riverbanks and damage to downstream villages and towns, as well as the loss of several thousand lives (Rafiq et al., 2019; Das et al., 2015). Nepal has experienced 24 GLOF events which have caused considerable loss of life and damage to property and infrastructure (Icimod, 2011). There is *high confidence* that current glacier shrinkages have caused more glacial lakes to form in most mountainous regions, including HMA, but there is limited evidence that the frequency of GLOF has changed (Hock et al., 2019). Veh et al. (2018) reported no clear trend of increasing GLOF events in the Himalayan region, although the southern Himalaya was identified as a hotspot region compared with the western Himalaya. Research has shown a decrease in glacier area of 24% in Nepal between 1980 and 2010 (Bajracharya et al., 2014).

Climate-change impacts on both the quantity and quality of freshwater resources will hinder the attainment of SDG-6 (Water, 2020). Contamination of drinking water is caused by wildfires and drought that contribute to elevated levels of nutrients (nitrogen, phosphorus and sulphates), heavy metals (lead, mercury, cadmium and chromium), salts (chloride and fluorides), hydrocarbons, pesticides and even pharmaceuticals. Heavy rains and flooding also increase nutrients, heavy metals and pesticides, as well as turbidity and faecal pathogens in water supplies–especially when sewage treatment plants are overwhelmed by runoff (Mora et al., 2018). Pharmaceuticals and personal-care products (from source to disposal) are contributing to the vulnerability of urban waters. A study of vulnerability assessment of urban waters in highly populated cities in India and Sri Lanka, through analysing the concurrence of Pharmaceuticals and Personal Care Products (PPCPs), enteric viruses, antibiotic-resistant bacteria, metals, faecal contamination and antibiotic resistance genes (ARGs), also underlines the need for a resilience strategy and action plan (Rafiq et al., 2019).

Adequate water supply for various uses is crucial for millions of people living in the mountains of Asia. Particularly in the HKH region, mountain springs play an important role in generating stream flow for non-glaciated catchments and in maintaining dry-season flows across many watersheds (Scott et al., 2019; Stott and Huq, 2014). There is a good deal of evidence that the springs are drying up or yielding less discharge (Tambe et al., 2012; Tiwari and Joshi, 2014; Sharma et al., 2016), threatening local communities who depend on spring water for their lives and livelihoods. Some of the main reasons for drying springs include anthropogenic impacts (deforestation, exploitative land use), infrastructure (road construction), socioeconomic changes (increasing demand and modernisation of facilities) and climatic changes (changes in rainfall regime and higher temperature) (Stott and Huq, 2014; Tiwari and Joshi, 2014; Sharma et al., 2016).

The Ganges–Brahmaputra region also faces the threat increased frequency of flood events (Lutz et al., 2019). Floods and extreme events can impact river channel systems (Grainger and Conway, 2014). One of the challenges in South Asia is the shifting boundaries of river channels. For instance, the major floods on the Indus in July 2010 altered the river's course in Pakistan, moving it closer to the Indian district of Kutch (Grainger and Conway, 2014). In the eastern tributary of the Ganges system, the alluvial fan of the Koshi River basin has shifted by more than 113 km to the west in the past two centuries (Chakraborty et al., 2010), which may be due to heavy sediment load from the Himalayan rivers in which about 50 million tons of sediment is deposited annually in the alluvial plains (Sinha et al., 2019; Chakraborty et al., 2010).

Asia is no exception to the global trend of lake ecosystems, which provide drinking water to millions of people, being degraded (Jenny et al., 2020) and severely threatened at the same time by climate change (Mischke, 2020). Lake surface conditions, such as ice cover, surface temperature, evaporation and water level react dramatically to this threat, and there are negative implications for water quantity and quality, food provisioning, recreational opportunities and transportation (Woolway et al., 2020). Due to substantial regional variability, the quantum of future changes in lake water storage remains uncertain. A recent study (Liu et al., 2019a) using Moderate Resolution Imaging Spectroradiometer 500-m spatial resolution global water product data, and applying the least squares method to analyse changes in the area of 14 lakes in Central Asia from 2001 to 2016, has shown that the area-shrinkage changes for all plains lakes in the study region could be attributed to climate change and human activities.

10.4.4.4 Projections

Asian and global water demands for irrigation, despite geographic variation in terms of water availability, are *very likely* to surpass supply by 2050 (Chartres, 2014). A regional quantitative assessment (Lutz et al., 2019) of the impacts of 1.5°C versus 2°C global warming for a major global climate-change hotspot–the Indus, Ganges and Brahmaputra river basins (IGB) in South Asia–shows adverse impacts of climate change on agricultural production, hydropower production and human health. A global temperature increase of 1.5°C with respect to pre-industrial levels would imply a ≈2.1°C temperature increase for IGB, whereas under a 2.0°C global temperature increase scenario, these river basins would warm by ≈2.7°C. Future warming is expected to further increase rain-on-snow events that can cause snowmelt flood during winter (Ohba and Kawase, 2020), affecting hydropower and resulting in river flooding, avalanches and landslides.

In the Mekong River Delta (in Vietnam), with an area of 40,500 km^2 and home to 17.8 million people in 2018, climate change is projected to increase the average temperature by 1.1–3.6°C, and the maximum and minimum monthly flow are projected to increase and decrease, respectively, and are *likely* to result in a high risk of food during the wet season and water shortages during the dry season (Wang et al., 2021a).

Researchers have found that the southern Tibetan Plateau has been consistently melting from 1998–2007 and is projected to continue melting until 2050 (Lutz et al., 2014b) (*high confidence*). In HMA, glacier ice is projected to decrease by 49 ± 7% and 64 ± 5% by the end of the century under RCP4.5 and RCP8.5 scenarios, respectively (Kraaijenbrink et al., 2017). Local- and regional-scale projections suggest that peak water will generally be reached around the middle of the century, followed by steadily declining glacier runoff thereafter (Hock et al., 2019). A global-scale projection suggests that a decline in glacier runoff by 2100 (RCP8.5) may reduce basin runoff by about 10% for at least 1 month of the melt season (Huss and Hock, 2018). Significantly, research on climate change and its impact across Asia remains inconclusive and requires an assessment at the sub-regional scale (IPCC, 2014a; Wester et al., 2019).

There is a projection of an increase in runoff until the 2050s mainly due to an increase in precipitation in the upper Ganges, Brahmaputra, Salween and Mekong basins, where it could be due to accelerated melting in the upper Indus basin. The runoff could increase in the range of 3–27% (7–12% in Indus, 10–27% in Ganges and 3–8% in Brahmaputra) by mid-century compared with the reference period (1998–2008) for Himalayan river basins depending on the different RCP scenarios (Lutz et al., 2014a). Likewise, Khanal et al. (2021) suggest contrasting responses to climate change for HMA rivers in which, on the seasonal scale, the earlier onset of melting causes a shift in magnitude and peak of water availability, whereas on the annual scale, total water availability increases for the headwaters. The future flow would increase in Nepal's Central Himalaya region (Nepal, 2016; Ragettli et al., 2016; Bajracharya et al., 2018). These changes in water availability in space and time will have serious consequences in downstream water availability for various sectoral uses and ecosystem functioning in Asia (Nepal et al., 2014; Green et al., 2015; Arfanuzzaman, 2018; Wijngaard et al., 2018; Rasul and Molden, 2019); however, future water availability is largely uncertain due to significant variation in climate-change projections among different global climate models (Nepal and Shrestha, 2015; Lutz et al., 2016; Li et al., 2019a).

A recent study (Didovets et al., 2021) covering eight river catchments having diverse natural conditions within Central Asia, where water availability or scarcity is also a major developmental concern, and using the eco-hydrological model SWIM (including scenarios from five bias-corrected GCMs under RCP4.5 and RCP8.5) has show an increase in mean annual temperature in all catchments for both RCPs to the end of the 21st century. The projected changes in annual precipitation indicate a clear trend to increase in the Zhabay and decrease in the Murghab catchments, and for other catchments, they were smaller. Both the projected trends for river discharge and precipitation show an increase in the northern and decrease in the southern parts of the study region, whereas seasonal changes include a shift in the peak of river discharge up to one month, a shortening of the snow accumulation period and a reduction in discharge during the summer months.

The intensity and frequency of extreme discharges are *very likely* to increase towards the end of the century. The future of the upper Indus basin water availability is highly uncertain in the long term due to uncertainty surrounding precipitation projections (Lutz et al., 2016). The future hydrological extremes of the upper Indus, Ganges and Brahmaputra river basins suggest an increase in the magnitude of extremes towards the end of the 21st century by applying RCP4.5 and RCP8.5 scenarios, mainly due to an increase in precipitation extremes

(Wijngaard et al., 2017). In the Brahmaputra, Ganges and Meghna, including the downstream component, the runoff is projected to increase by 16, 33 and 40%, respectively, under the climate-change scenarios by the end of the century during which the changes in runoff are larger in the wet seasons than the dry seasons (Masood et al., 2015). In the Mekong River basin also, extremely high-flow events are *likely* to increase in both magnitude and frequency, which can exacerbate flood risk in the basin (Hoang et al., 2016); however, uncertainty is high regarding future hydrological response due to large variation in precipitation projections, modelling approaches and bias-correction methods (Nepal and Shrestha, 2015; Lutz et al., 2016; Li et al., 2019a).

Current research on the adverse relationship between climate change and river flows suggests that there is a high possibility that some of the river basins affected by floods could be Brahmaputra, Congo, Ganges, Lena and Mekong, with a return period of 10 years (Best, 2018).

In most parts of the upper Ganges and Brahmaputra rivers, the 50-year return level flood is *likely* to increase and to a lesser degree in Indus River. Similarly, the extreme precipitation events are also expected to increase to a higher degree in the Indus than the Ganges and Brahmaputra basins (Wijngaard et al., 2017). Increase in extreme precipitation events is *likely* to cause more flash-flood events in the future (*medium confidence*). In the case of the Indus, increasing temperature trend in the future may lead to accelerated snow and ice melting which may increase the frequency and intensity of floods in the downstream areas (Hayat et al., 2019). The Ganges–Brahmaputra region also faces the threat of increased frequency of flood events (Lutz et al., 2019). Additionally, the Ganges basin also shows a higher sensitivity to changes in temperature and precipitation (Mishra and Lilhare, 2016).

Assessing the impact of climate change on water resources in nine alpine catchments in arid and semiarid Xinjiang of China (Li et al., 2019a), it has been noted that even though the total discharge revealed an overall increasing trend in the near future, the impact of climate change on different hydrological components indicated significant spatio-temporal heterogeneity in terms of the area, elevation and slope of catchments, which could be usefully factored into climate-adaptation strategies.

It was noted early on (Singh et al., 2011) that the main drivers that influence the provisioning of ecosystem services and human well-being in the HKH region are a mix of environmental change in general and climate change in particular, but much more data and knowledge on the HKH region are needed in order to develop either a regional or global understanding of climate-change processes.

Climate change impacts cryospheric water sources in the Hindu Kush, Karakoram and Himalayan ranges which in turn carry consequences for the Indus, Ganges and Brahmaputra basins. The impact of climate change on spring-fed rivers in the HKH is under-researched and therefore makes projections difficult. Further research is needed for understanding the impact of deforestation, urbanisation, development and introduction of water infrastructures, such as tube wells, in the hill region (Aayog, 2017). This in turn calls for greater investment in research and development for the HKH by both the national and regional organisations. There is *high confidence* that due to global warming, Asian countries could experience an increase in drought conditions (5–20%) by the end of this century (Prudhomme et al., 2014; Satoh et al., 2017).

Soil erosion in high-mountain areas is particularly sensitive to climate change. A recent study (Wang et al., 2020) that focused on the mid-Yarlung Tsangpo River, located in the southern part of the Tibetan Plateau, has revealed dramatic land surface environment changes due to climate change during recent decades. It has further shown that increasing precipitation and temperature would lead to increasing soil-erosion risk in ~2050 based on the Coupled Model Intercomparison Project (CMIP5) and RUSLE models.

High-resolution climate-change simulations suggest that due to deadly heatwaves projected in some of the densely populated agricultural regions of South Asia (i.e., the Ganges and Indus river basins), those regions are *likely* to exceed the critical threshold of wet-bulb temperature of 35°C under the business-as-usual scenario of future GHG emissions (Im et al., 2017).

10.4.4.5 Climate Vulnerability and Adaptation: Interfaces and Interventions

In Asia and its diverse sub-regions, the challenge of adaptation to climate change at diverse sectors, sites and scales of vulnerability in the domain of freshwater resources is compounded by the nexus between long-standing non-climatic vulnerabilities and climatic impacts, both observed and projected. Water insecurities in Asia are increasing due to excessive freshwater withdrawals (Satoh et al., 2017), economic and population growth (Gleick and Iceland, 2018), urbanisation and peri-urbanisation (Roth et al., 2019), food insecurity (Demin, 2014) and lack of access to clean and safe drinking water (Cullet, 2016), which mostly affects the health of the most vulnerable members of society.

Significantly, climate change will add to already existing vulnerabilities. In the case of the Yellow River basin in China, underlining the interface between future water scarcity and hydroclimatic and anthropogenic drivers, a recent study expects moderate-to-severe water scarcity over six Yellow River sub-catchments under the RCP4.5 scenario, and anticipates that human influences on water scarcity will be worse than that of climate change, with water availability in the downstream being impacted by concurrent changes in land use and high temperature (Omer et al., 2020). Nearly 8% of internationally shared or transboundary aquifers (TBAs), ensuring livelihood security for millions of people through sustaining drinking water supply and food production, are currently overstressed due to human overexploitation (Wada and Heinrich, 2013). The Asia Pacific region has the highest annual water withdrawal due to its geographic size, growing population and irrigation practices, and water for agriculture continues to consume 80% of the region's resources (Taniguchi et al., 2017b; Visvanathan, 2018).

In South Asia, surface water and groundwater resources are already under stress (both in terms of quality and quantity) due to population growth, economic development, poor governance and management, and poor efficiency of use in economic production. In the past 40 years,

Box 10.4 | Case Study on Climate Vulnerability and Cross-Boundary Adaptation in Central Asia

In Central Asia, water scarcity has been ranked in the top five global risks (Gleick, 1993; Zhupankhan et al., 2018). Cross-boundary adaptation remains critically important in this region with abundant glaciers in the Pamir Plateau of Tajikistan (Hu et al., 2017) and areas with severe glacier retreat in the Tianshan Mountains (Liu and Liu, 2015). The spatial variations of glacier and other climate variables have added to uncertainty related to the dynamic of the water cycle. The headwater regions, such as Pamir area, would be significantly affected by the climate parameters, such as the stronger rainfall intensity, more frequent rainfall and higher temperature (Luo et al., 2019). The water resources in the Pamir Plateau will range from –0.48 to 5.6% (Gulakhmadov et al., 2020), and the crop phenological period in Tajikistan and Kyrgyzstan will be about 1–2 weeks earlier. The threat of agricultural water stress is increasing as well. The oasis in downstream areas will face more complex water resource fluctuations, water crisis and desertification. In particular, rain-fed agriculture in northern Kazakhstan, Uzbekistan and western Turkmenistan is particularly dependent on water resources. Under the RCP2.6 and RCP4.5 scenarios, considering CO_2 fertilisation effects and land-use projections, the increase in CO_2 atmospheric concentration and accumulated temperature can contribute to a 23% increase in cotton yield in Central Asia (Tian and Zhang, 2019), but extreme climate, such as drought, heatwaves and rainstorms, will have a 10% negative impact on agricultural production and the ecological environment (Zhang and Ren, 2017). High-efficiency water-saving technology will help the upstream and downstream water resource management in Central Asian countries to adapt to the variation in water resources quantity, frequency and spatial pattern.

there has been an increasing reliance on groundwater in South Asia for irrigation (Rodell et al., 2009; Tiwari et al., 2009; Surie and Prasai, 2015; Bhanja et al., 2016; Shrestha et al., 2016; Mukherjee, 2018; Shah et al., 2018). It is noteworthy that India, Bangladesh, Pakistan and China together account for more than 50% of the world's groundwater withdrawals (Scott et al., 2019). A study conducted in the Shahpur and Maner districts of Bihar, India, in which drinking water sourced from the groundwater of 388 households was tested, showed that 70–90% of the sampled household's drinking water contained either arsenic or iron, or both (Thakur and Gupta, 2019). Given the nexus between CIDs and non-climate drivers, an effective adaptation to the impacts of climate change would also demand sustainable development and management of shared aquifer resources, which in turn require reliable TBA inventories and improved knowledge production and knowledge sharing on the shared groundwater systems (Lee et al., 2018a).

A study of peri-urban spaces involving four South Asian cities, Khulna (Bangladesh) (Pervin et al., 2020), Gurugram and Hyderabad (India), and Kathmandu (Nepal), has shown the nexus between intensifying use and deteriorating quality of water and the impact of climate change, resulting in peri-urban water insecurity and conflict (Roth et al., 2019). The challenge of ensuring access to water resources and their (re) allocation and prioritisation for marginalised communities remains on the agenda of policy-oriented interdisciplinary research and demands effective implementation of its findings at the grassroots level by the administrative agencies. Taking water security as a key CCA goal at the urban-city scale of Bangkok, a study (Babel et al., 2020) has shown the usefulness of a generic framework with 5 dimensions, 12 indicators and a set of potential variables to support national-level initiatives and plans in diverse climatic and socioeconomic conditions across various sub-regions of Asia.

In the Kathmandu valley in Nepal, where groundwater resources are under immense pressure from multiple stresses, including overextraction and climate change, mapping groundwater resilience to climate change has been demonstrated as a useful tool to understand the dynamics of groundwater systems, and thereby facilitate the development of strategies for sustainable groundwater management (Shrestha et al., 2020).

In the Mekong Delta, the groundwater storage is projected to decline by more than 120 and 160 million m^3 under RCP4.5 and RCP8.5 scenarios, respectively, by the end of the 21st century, in conjunction with land subsidence and SLR. This in turn calls for proactive planning and implementation of adaptation strategies that address multiple stresses in order to ensure sustainable utilisation of groundwater resources in the Mekong Delta in the context of future climatic conditions and associated uncertainties (Wang et al., 2021a). Proposed CCA strategies for the Mekong River basin include a better understanding of the complex linkages between climate change, technological interventions, land-use change, water-use change and socioeconomic developments both in the upstream and downstream riparian countries (Evers and Pathirana, 2018).

While South Asian countries have done well in attaining Goal 6 of Sustaining Development Goals, access to safe and clean drinking water remains a challenge. Taking Indian rivers as an example, it is suggested that participatory river protection and rehabilitation, based on comprehensive knowledge of the river-system dynamics, and local awareness at the community level, may act as a multiplier for river conservation measures (Nandi et al., 2016).

Hydroclimatic extremes in the HKH region could adversely impact the Ganga, Brahmaputra and Meghna basins (Wijngaard et al., 2017; Acharya and Prakash, 2019). Studies have recommended watershed or basin analysis to address the challenge of adaptation in urban spaces (Lele et al., 2018). A study of northern Bangladesh that focused on encouraging traditional ways of cultivation suggests that rural women have Indigenous knowledge and their participation can play a useful role (Kanak Pervez et al., 2015). The knowledge pertains to agriculture, soil conservation, fish and animal production, irrigation and water conservation. There has also been a focus on gendered construction of local flood-forecasting knowledge in rural communities in India living in the Gandak River basin (Acharya and Prakash, 2019).

While designing the adaptation options, understanding the water–energy–food (WEF) nexus among different water-use sectors is crucial (Section 10.5.3). Understanding of the WEF nexus could be beneficial for achieving water security in developing countries in Asia (Nepal et al., 2019).

AR5 identified a number of adaptation challenges and options facing the stakeholders in the wake of climate-change-induced vulnerabilities, uncertainties and risks in the freshwater sector, and underlined the importance of an integrated management approach as well as acknowledging diverse socioeconomic contexts, differentiated capacities and the uneven pace of impacts. Further validated by recent research in terms of their usefulness, these adaptation options include building and improving capital-intensive physical water infrastructure such as irrigation channels, flood-control dams and water storage (Nüsser and Schmidt, 2017). Drawing upon customary institutions and combining Indigenous knowledge systems with scientific knowledge, innovative structures, including artificial glaciers, ice stupas and snow barrier bands, have been built by local communities in Ladakh, Zanskar and Himachal Pradesh in India (Hock et al., 2019; Nüsser et al., 2019). Communities in Solukhumbu, Nepal, in response to depleting water flow in snow-fed rivers, have chosen adaptation through changing practices by collecting water from distant sources for domestic consumption (McDowell et al., 2013). Taking the IPCC concept of climate risk as a basis for adaptation planning, a pilot study of flood risk in Himachal Pradesh, India (Allen et al., 2018), integrating assessment of hazard, vulnerability and exposure in the complementary domains of CCA and DRR, has identified stakeholder consultation, knowledge exchange and institutional capacity building as key steps in adaptation planning. Aquifer storage and recovery has been proposed as an 'alternative climate-proof freshwater source' for deltaic regions in Asia, particularly those with a history of saline groundwater aquifers (Hoque et al., 2016). It is further argued (Hadwen et al., 2015) that water, sanitation and hygiene objectives would need to be addressed as a component of a wider integrated water resource management (IWRM) framework.

Ensuring sustainability of the rivers and ecosystems requires coordinated and collaborative action on the part of all countries, with the long-term goal of synergising political, social, cultural and ecological facets associated with the riverine system. Daunting as this challenge is, evidence suggests that a long-term view of transboundary basins is not very optimistic as big rivers of Asia contribute heavily towards urban and agricultural activities, and are experiencing challenges of increasing sedimentation, large-scale damming and pollution, among others (Best, 2018). In the case of China, Sun et al. (2016) have shown that the localised vulnerabilities within the Yangtze River basin prompt an 'integrated basin-wide approach' that is able to account for the specific needs of each of its sub-basins.

In HMA, factors that undermine effective adaptation to climate change include both sudden-onset and slow-paced disasters along with the knowledge deficit regarding cryospheric change and its adverse impacts on water resources and also the agriculture and hydropower sectors. Other key barriers include a sectoral approach, overemphasis on structural approaches and the lack of context-sensitive, community-centric understanding of how these changes influence perceptions, options and decisions about migration, relocation and resettlement (Rasul et al., 2020; Hock et al., 2019). More interdisciplinary research is needed on highly precarious future pathways and the intersection between CIDs and non-climate drivers in order to anticipate and mitigate diverging and uncertain outcomes.

10.4.5 Agriculture and Food

Asia accounts for 67% of global agricultural production (Mendelsohn, 2014) and employs a large portion of the population in many developing countries and regions (Briones and Felipe, 2013; ADB, 2017b; ILO, 2017a). Since the release of IPCC AR5, more studies have reinforced the earlier findings on the spatio-temporal diversity of climate-change impacts on food production in Asia depending on the geographic location, agroecology and crops grown (Hoegh-Guldberg et al., 2018; Ahmad et al., 2019), recognising that there are winners and losers associated with the changing climate across scales (Dasgupta et al., 2013a; Yong-Jian et al., 2013; Bobojonov and Aw-Hassan, 2014; Hijioka et al., 2014; Li et al., 2014a; Prabnakorn et al., 2018; Trisurat et al., 2018; Matsumoto, 2019). Despite the observed increase in total food production in terms of crops and food yields from 1990 to 2014 in Asia (FAO, 2015), there is *high confidence* that overall, at the regional level, the projected total negative impacts will far outweigh the expected benefits, with India emerging as the most vulnerable nation in terms of crop production (Figure 10.6). Recent evidence also indicates that climate-related risks to agriculture and food security in Asia will progressively escalate as global warming reaches 1.5°C and higher above pre-industrial levels (IPCC, 2018b) with differentiated impacts across the Asian continent.

10.4.5.1 Observed Impacts

There remains a paucity of data for observed climate-change impacts on Asian agriculture and food systems since the release of IPCC AR5. Most of these impacts have been associated with drought, monsoon rain and oceanic oscillations, the frequency and severity of which have been linked with the changing climate (Heino et al., 2018; Heino et al., 2020). In general, major impacts to agricultural production, such as those observed by the farmers in the Philippines and Indonesia, include among others delays in crop harvesting, declining crop yields and quality of produce, increasing incidence of pests and diseases, stunted growth, livestock mortality and low farm income (Stevenson et al., 2013). In South Asia, the series of monsoon floods from 2005 to 2015 contributed to a high level of loss in agricultural production with peaks in 2008 and 2015 (FAO, 2018a). Similarly, in Pakistan, farmers are experiencing a decline in crop yields and increasing incidence of crop diseases as a result of climate extremes, particularly floods, droughts and heatwaves (Fahad and Wang, 2018; Ahmad et al., 2019).

Limited studies have quantified the actual impacts of climate change on agricultural productivity and the economy. In a study in the Mun River basin, northeast Thailand, yield losses of rice due to past climate trends covering the period 1984–2013 was determined to be in the range of < 50 kg ha^{-1} per decade or 3% of actual average yields with a high possibility of more serious yield losses in the future (Prabnakorn et al., 2018). Likewise, in China, an economic loss of 595–858 million

USD for the corn and soybean sectors was computed from 2000 to 2009 (Chen et al., 2016b). On the other hand, the intensive wheat–maize system in China seems to have benefited from climate change with the northward expansion of the northern limits of maize and multi-cropping systems brought about by the rising temperatures (Li and Li, 2014).

There is *high agreement* in more recent studies that linked the frequency and extent of the El Niño phenomenon with global warming (Thirumalai et al., 2017; Wang et al., 2017a; Hoegh-Guldberg et al., 2018) that can trigger substantial loss in crop and fishery production. The 2004 El Niño caused the Philippines an 18% production loss during the dry season and a 32% production loss during the wet season (Cruz et al., 2017). In the 2015 El Niño event, the Indian oil sardine fishery declined by more than 50% of previous years (Kripa et al., 2018) severely impacting coastal livelihoods and economies (Shyam et al., 2017). The 2015–2016 El Niño also inflicted adverse impacts on agricultural productivity and food security, especially affecting the rural poor in middle- and lower-income countries in Southeast and South Asia (UNDP ESCAP OCHA RIMES APCC, 2017).

10.4.5.2 Projected Impacts

10.4.5.2.1 Fisheries and aquaculture

The fisheries and aquaculture production from Asia in 2019 was estimated at 159.67 mmt contributing to 74.7% of the global production (FAO, 2020). This sector provides employment to an estimated 50.46 million people where fishing and aquaculture are important socioeconomic activities and fish products are a substantial source of animal protein (Bogard et al., 2015; Azad, 2017; FAO, 2018c). The economic contribution could be as high as 44% of the coastal communities' GDP as in the case of Sri Lanka (Sarathchandra et al., 2018). Five Asian countries (i.e., China, Indonesia, India, Vietnam and Japan) are in the top ten of global fish producers, representing a cumulative share of 36% in 2018 (FAO, 2020). As a top producer with 15% global share, China also remains a top exporter of fish and fish products with 14% global market share.

There is *high agreement* in the literature that Asian fisheries and aquaculture, including the local communities depending on them for livelihoods, are highly vulnerable to the impacts of climate change. Asia has been impacted by SLR (Panpeng and Ahmad, 2017), a decrease in precipitation in some parts (Salik et al., 2015) and an increase in temperature (Vivekanandan et al., 2016), all of which have drastic effects on fisheries and aquaculture (FAO, 2018c). Its coastal fishing communities is exposed to disasters, which are predicted to increase (Esham et al., 2018). Fisheries in most of South Asia and Southeast Asia involve small-scale fishers who are more vulnerable to climate-change impacts compared with commercial fishers (Sönke Kreft et al., 2016; Blasiak et al., 2017), although there is a general decreasing trend in the number of small units (Fernandez-Llamazares et al., 2015; ILO, 2015). A regional study of South Asia forecast large decreases in potential catch of two key commercial fish species (hilsa shad and Bombay duck) in the Bay of Bengal (Fernandes et al., 2016), which forms a major fishery and food source for coastal communities. About 69% of the commercially important species of the Indian marine fisheries were found to be impacted by climate change and other anthropogenic factors (Dineshbabu et al., 2020). Likewise, water salinisation brought about by SLR is expected to impact the availability of freshwater fish in southwest coastal Bangladesh with adverse implications to poor communities (Dasgupta et al., 2017a). Analysis of fishery has indicated that there will be a continued decrease in catch impacting the seafood sector in the Philippines, Thailand, Malaysia and Indonesia (Nong, 2019). Climate change is predicted to decrease total productive fisheries potential in South and Southeast Asia, driven by a temperature increase of approximately 2°C by 2050 (Barange et al., 2014).

Like fisheries, Asian aquaculture is highly vulnerable to climate change. Shrimp farmers and fry catchers of Bangladesh are frequently affected by extreme climatic disruptions like cyclones and storm surges that severely damage the entire coastal aquaculture (Islam et al., 2016a; Kais and Islam, 2018). The majority of shrimp farmers also observed that weather has changed abruptly during the past 5 years and that high temperature is most detrimental because it lowers growth rate, increases susceptibility to diseases, including deformation, and affects production (Islam et al., 2016a). Low production in shrimp farming is also attributed to variation and intensity of rainfall perceived by the majority of farmers as part of climate-change impacts (Ahmed and Diana, 2015; Islam et al., 2016a; Henriksson et al., 2019). In Vietnam, small-scale shrimp farmers are likewise vulnerable to climate change, although those who practise an extensive type of farming with low inputs are more vulnerable compared with those who practise a more intensive type with more capital investment (Quach et al., 2015; Quach et al., 2017). Seaweed farming in Asia is very popular, and the significance of seaweed aquaculture beds in capturing carbon is recognised, but most of the farmed seaweeds are susceptible to climate change (Chung et al., 2017a; Duarte et al., 2017).

Marine heatwaves are a new threat to fisheries and aquaculture (Froehlich et al., 2018; Frölicher and Laufkötter, 2018) including disease spread (Oliver et al., 2017), live feed culture (copepods) (Doan et al., 2018) and farming of finfishes like Cobia (Le et al., 2020). Predicting MHWs is considered a prerequisite for increasing the preparedness of farmers (Frölicher and Laufkötter, 2018). In Southeast Asian countries more than 30% of aquaculture areas are predicted to become unsuitable for production by 2050–2070 and aquaculture production is predicted to decrease 10–20% by 2050–2070 due to climate change (Froehlich et al., 2018).

10.4.5.2.2 Crop production

Since IPCC AR5, more studies have been done on different scales from local to global that focus on the differentiated projected impacts of climate change on the production and economics of various crops with rice, maize and wheat among the major crops receiving more attention. New research findings affirm that climate-change impacts, and will continue to significantly affect, crop production in diverse ways in particular areas all over Asia (Figure 10.6). An increasing number of sub-regional and regional studies using various modelling tools provide significant evidence on the overall projected impacts of climate change on crop production at the sub-regional and regional

Projected impacts of climate change to agriculture and food systems in sub-regions of Asia IPCC-AR5 studies

South East Asia

Country/ Region	Commodity	Temp.	Prec.	Impact on production yield	Projected year
Cambodia	Rice			▼ 45%	2080
		+1°C		▽ 4%	
NW Vietnam	Agriculture			▼	2050 & 2100
Vietnam	Rice	+1°C		▽ 5.5–8.5%	
	Aquaculture			▽	
NE Thailand	Rice	+	+	▽	
				▼ 14%	2080
				▼ 10%	2080
				▲ 2.6%	2080–2099
				▲ 22.7%	2080 & 2100
Philippines	Crops	+1°C		▽	
SE Asia (5 countries)	Livestock			▽	2080

South Asia

Country/ Region	Commodity	Temp.	Prec.	Impact on production yield	Projected year
India	Rice/Wheat/ Pluses/			▽ 2.3%	2030
	Coarse cereals			▽ 8.62%	2050
Rajasthan (India)	Wheat/ Barley/ Maize			▲ ▲	2050
India	Rice			▽ 10–30%	
Hyderabao (India)	Maize	+1°C, +2°C, +4°C		△ 25–70%	
North India	Rice			△	2030
South India	Rice			▽ 5–17%	
Bangladesh	Rice			▽ 12.1–17%	
	Wheat			▽ 12.4–61%	
Bhutan Med latitude	Rice			▽ 6.7%	2050
Bhutan Med latitude	Rice			▽ 12.6%	2050
Sri Lanka	Rice			▽ 3.6–19.8%	
	Tea			▽ 8–17%	2050–2070
South Asia	Rice			▽ Up to 5%	2040
Bangladesh/ India/Pakistan	Wheat			▽ 5 to 10%	2040
South India (other than Bangladesh/ India/Pakistan	Wheat			△ 5–7% ▽	2040
Trishuli River, Nepal	Fisheries			▲ ▲	

East Asia

Country/ Region	Commodity	Temp.	Prec.	Impact on production yield	Projected year
China	Corn			▽ 3–12%	2100
	Soya			▽ 7–19%	2100
	Grain		+100 mm	△ 1.31%	2100
	Crops			▼ 0.1–0.52%	End of 21st century
North China	Grain			▽ 1.74%	
	Grain		+100 mm	△ 3%	
NE China	Maize	+1.32°C	+30 mm	▽ 17%	2030
South China	Grain		+100 mm	▽ 0.59–1.19%	
North China	Grain		+100 mm	▽ 3%	
SW China	Maize	+1.32°C	+30 mm	△ 22%	2030
Mongolia	Wheat	+		▲ △	
Japan	Rice	+1°C		▽	
	Aquaculture				
Rep. of Korea	Rice			▽ >25%	End of 21st century
	Maize			▽ 10–20%	End of 21st century
	Potato			▽ 30%	End of 21st century
Rep. of Korea (Yellow Sea)	Fisheries	+1°C		▽	
Rep. of Korea (Strait)	Fisheries			△	2030
D.P.R. of Korea Rep. of Korea	Seaweed/ Fish/ Shrimp/ Abalone			▼	

Central Asia

Country/ Region	Commodity	Temp.	Prec.	Impact on production yield	Projected year
West Kazakhstan	Wheat			▽ 1.9%	
Kazakhstan	Barley			▽ 4.8%	
	Wheat		+1 mm	Increase export by 0.7% Decrease import by 1.7%	
		+1°C		Increase export by 21.9% Decrease import by 49.4%	
Kazakhstan semi-arid & sub-humid region	Crops			△	
Tajikistan	General			Negative impact (80–157%)	
	Potato			△ Increase	
	Cotton			▽ Decrease	
	Wheat			No change	
Kyrgyztan	Crops			△ Increase	

Direction of change: △ Incresse ▽ Decrease

RCP4.5 RCP6.0 RCP8.5 No RCP analysis

Figure 10.6 | Projected impacts of climate change to agriculture and food systems in sub-regions of Asia based on post-IPCC-AR5 studies. The figure illustrates the spatio-temporal diversity of projected future impacts on food production highlighting that there are winners and losers associated with the changing climate at different scales. AGRI: agriculture; E: east; N: north; NRCP: no RCP analysis; Pre: precipitation; PY: production yield; RCP: representative concentration pathway; S: south; Temp: temperature; W: west. (Refer to Table SM10.2 for details and supporting references.)

scales with clear indications of winners and losers among and within nations (see, for instance, Mendelsohn, 2014; Cai et al., 2016; Chen et al., 2016b; Schleussner et al., 2016).

Beyond the usual research interest in crop yields which has dominated the current literature, recent studies, such as those in Japan, focus on the impacts of climate change on the *quality* of crops (see, for instance, Sugiura et al., 2013, for apple; as well as Morita et al., 2016, and Masutomi et al., 2019, for rice). A large-scale evaluation by Ishigooka et al. (2017) shows that the increased risk in rice production brought about by temperature increase may be avoided by selecting an optimum transplanting date considering both yield and quality. More studies of this nature have to be conducted for other crops in different locations to better understand and adapt to the negative impacts of the changing climate on the quality of crops (Ahmed and Stepp, 2016).

New studies have projected the *likely* negative impact of pests in Asian agriculture. The golden apple snail (*Pomacea canaliculate*), which is among the world's 100 most notorious invasive alien species, threatens the top Asian rice-producing countries, including China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, the Philippines and Japan, with the predicted increase in climatically suitable habitats in 2080 (Lei et al., 2017). Similarly, a study by (Shabani et al., 2018) in Oman projected that the pest of date palm trees, Dubas bug (*Ommatissus lybicus* Bergevin), could reduce the crop yield by 50% under future climate scenarios.

While there is general agreement that CO_2 promotes growth and productivity of plants through enhanced photosynthesis, there remains uncertainty on the extent to which carbon fertilisation will influence agricultural production in Asia as it interacts with increasing temperatures, changing water availability and the different adaptation measures employed (Ju et al., 2013; Jat et al., 2016; ADB, 2017b). As global warming compounds beyond 1.5°C, however, the likelihood of adverse impacts on agricultural and food security in many parts of developing Asia increases (Mendelsohn, 2014; IPCC, 2018b). There is a growing trend towards more integrated studies and modelling that combines biophysical and socioeconomic variables (including management practices) in the context of changing climate to reduce uncertainty associated with future impacts of climate change on the agriculture sector (see, for instance, Mason-D'Croz et al., 2016; Smeets Kristkova et al., 2016; Gaydon et al., 2017).

10.4.5.2.3 Livestock production

There is hardly any mention about the impacts of climate change on livestock production in the Asia chapter of AR5 due to limited studies on this area. This scarcity of information persists to the current assessment with very scant information on the projected impacts and adaptation aspects of livestock production (Escarcha et al., 2018a). The use of scenarios and models to determine alternative futures with participatory engagement processes has been recommended for informed policy and decision making with potential application in the livestock sector (Mason-D'Croz et al., 2016). Of the limited assessment available, a study on the smallholders' risk perceptions of climate change impacts on water-buffalo production systems in Nueva Ecija, the Philippines, identified feed availability and animal health as the production aspects most severely affected by multiple weather extremes (Escarcha et al., 2018b). In the Mongolian Altai Mountains, early snowmelt and an extended growing season have resulted in reduced herder mobility and prolonged pasture use, which has in turn initiated grassland degradation (Lkhagvadorj et al., 2013a). Furthermore, reduced herder mobility has increased the pressure on forests resulting in increased logging for fuel and construction wood and reduced regeneration due to browsing damage by increasing goat populations (Khishigjargal et al., 2013; Dulamsuren et al., 2014).

In terms of direct impacts, climate-change-induced heat stress and reduced water availability are *likely* to generally have negative effects on livestock (ADB, 2017b). In the HKH region, climate change has induced severe impacts on livestock through degradation of rangelands, pastures and forests (Hussain et al., 2019). However, indirect effects may be positive such as in Uzbekistan and South Asia where alfalfa and grassland productivity is expected to improve under warming conditions, which have beneficial effects on livestock production (Sutton et al., 2013; Weindl et al., 2015).

At the global level, analysis involving 148 countries in terms of the potential vulnerability of their livestock sector to climate and population change shows that some Asian nations, particularly Mongolia, are *likely* to be the most vulnerable while South Asia is the most vulnerable region (Godber and Wall, 2014).

10.4.5.2.4 Farming systems and crop areas

There is new evidence since AR5 that farming systems and crop areas will change in many parts of Asia in response to climate change. In South Asia, a study in Nepal showed that farmers are inclined to change practices in cropland use to reduce climate-change risk (Chalise and Naranpanawa, 2016). In India, climate change is also predicted to lead to boundary changes in areas suitable for growing certain crops (Srinivasa Rao et al., 2016). A study in Bangladesh revealed a shift in crop choices among farmers, implying changes in the future rice-cropping pattern. Specifically, a temperature increase will compel farmers to choose irrigation-based Boro, Aus and other crops in favour of the rain-fed Aman rice crop (Moniruzzaman, 2015).

In the coastal area of Odisha in India, adverse impact on the agriculture sector is anticipated considering the increasing temperature trends over the past 30 years for all the seasons (Mishra and Sahu, 2014). In a national study that groups Bangladesh into 16 sub-regions with similar farming areas, simulations of a 62 cm rise in mean sea level project damages to production because of area loss in excess of 31% in sub-region 15 and nearly 40% in sub-region 16 (Ruane et al., 2013). Also in Bangladesh, a study on predicting the design of water requirements for winter paddy rice under climate change conditions shows that agricultural water resource management will help minimise drought risk and implement future agricultural water resource policies (Islam et al., 2018) that may have important implications for crop areas and production.

In East Asia, the observed changes in agricultural flooding in different parts of China could influence farming systems and crop areas (Zhang et al., 2016b) as extreme events intensify in the context of changing climate. Agricultural management practice in China may also change to optimise soil organic carbon sequestration (Zhang et al., 2016a). A study on projected irrigation requirements under climate change using a soil-moisture model for 29 upland crops in the Republic of Korea showed that water scarcity is a major limiting factor for sustainable agricultural production (Hong et al., 2016). In terms of drought, despite increasing future precipitation in most scenarios, crop-specific agricultural drought is expected to be a significant risk due to rainfall variability (Lim et al., 2019a). On the other hand, a projected rise in water availability in the Korean Peninsula using multiple regional climate models and evapotranspiration methods indicates that it will *likely* increase agricultural productivity for both rice and corn, but would decrease significantly in rain-fed conditions (Lim et al., 2017b). Thus, irrigation and soil-water management will be a major factor in determining future farming systems and crop areas in the country.

Global studies on climate-change-induced hotspots of heat stress on agricultural crops show that large suitable cropping areas in Central and Eastern Asia, and the northern part of the Indian subcontinent, are under heat stress risk under the A1B emissions scenario (Teixeira et al., 2013) and hence may reduce cropping areas in these regions. In Japan, the projected decline in rice yield in some areas suggests that the current rice-producing regions would be divided into suitable and unsuitable areas as temperatures increases (Ishigooka et al., 2017), with important implications regarding the possible shift in cropping area. Similarly, it has been shown that there will be change in the geographic distribution of the occurrence of poor skin colour of table-grape berries (Sugiura et al., 2019) and suitable areas for cultivation of subtropical citrus (Sugiura et al., 2014) in Japan by the middle of the 21st century.

There is emerging evidence from modelling and field experimentation that designing future farming systems and crop areas that will promote sustainable development in Asia in the context of climate change would have to incorporate not only productivity and price considerations but also how to moderate temperature increase, enhance water conservation and optimise GHG mitigation potential (Sapkota et al., 2015; Zhang et al., 2016a; Ko et al., 2017; Lim et al., 2017b). The effects of agricultural landscape change on ecosystem services also need to be understood and taken into account in designing farming systems and allocating farm areas (Lee et al., 2015b; Zanzanaini et al., 2017).

10.4.5.3 Food Security

FAO (2001) defines food security as 'a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life'. There is significant evidence that climate change significantly undermines both agricultural production and food security in Asia (ADB, 2017b). Increasing evidence from sub-regions and individual countries suggests that climate-related hazards, such as increasing temperature, changing rainfall, SLR, drought, flooding and the more frequent and intense occurrences of El Niño–Southern Oscillation events, all impact agricultural production with significant effects on food security. All these hazards interact with non-climatic factors, such as competing demand for scarce water resources, rural–urban migration, food prices and increasing food demand in the long term, and poor governance, among other things, that may worsen food insecurity in the region (Montesclaros and Teng, 2021).

In West Asia, particularly in Saudi Arabia and Yemen, increasing water scarcity brought about by temperature rise is anticipated to have a severe impact on agriculture and food production that undermines food security (Al-Zahrani et al., 2019; Baig et al., 2019). Saudi Arabia, for instance, was forced to phase out its wheat production starting in 2016 and fully rely on importation to conserve its drying fossil water resources (Al-Zahrani et al., 2019), a situation which is also linked to a water governance issue.

In Central Asia, a study using a bioeconomic farm model shows very large differences in climate change impacts across farming systems at the subnational level. Large-scale commercial farms in the northern regions of Kazakhstan will have positive income gains, while small-scale farms in arid zones of Tajikistan will experience a negative impact with *likely* effects on farm income security (Bobojonov and Aw-Hassan, 2014). Impacts on farmers' income in western Uzbekistan will also significantly vary and could fall by as much as 25% depending on the extent of temperature increase and water-use efficiency (Bobojonov et al., 2016).

In a regional study among South Asian countries using an integrated assessment modelling framework, changes in rice and wheat productions brought about by climate change are anticipated to engender wild price volatilities in the markets (Cai et al., 2016). Price spikes are projected for 2015–2040 in all South Asian regions with India, Pakistan and Sri Lanka predicted to experience increasingly much higher rice and wheat prices than under the baseline scenario, creating major concerns about food affordability and food security. This will *likely* severely affect the overall economic growth of these countries since they are mainly agriculture-driven economies.

A study on mapping global patterns of drought risk projected an increase in drought frequency and intensity in the populated areas of South to Central Asia extensively used for crop and livestock production with serious repercussion to food security and potential civil conflict in the medium to long term (Carrão et al., 2016). In Southeast Asia, a Philippine study on the relationship between seasonal rainfall, agricultural production and civil conflict suggests that the projected change towards wetter rainy seasons and drier dry seasons in many parts of the country will lead to more civil conflict (Crost et al., 2018) with negative implications for food and human security. Similarly, floods and higher food prices are also associated with higher risks of social unrest in Asia that may undermine food security (Hendrix and Haggard, 2015; Ide et al., 2021).

Food insecurity will be localised across Asia where one part of the country or sub-region will be more food secured while the others, more insecure. This will require in-country or sub-regional trade and development cooperation to minimise the adverse impacts of food insecurity associated with the changing climate (Li et al., 2014a; Abid et al., 2016).

10.4.5.4 Key Drivers to Vulnerability

There is *high confidence* that agriculture will continue to be among the most vulnerable sectors in Asia in light of the changing climate (Mendelsohn, 2014; ADB, 2017b). Among the more vulnerable areas include mountain agriculture where fluctuation in crop production (Poudel and Shaw, 2016; Hussain et al., 2019), and food insufficiency, is more widespread than in lowland areas (Poudel and Shaw, 2015; Kohler and Maselli, 2009). Also vulnerable are flood-prone areas like the Vietnam Mekong River Delta where 39% of the total rice area is exposed to sustained flood risks (Wassmann et al., 2019a). Increasing temperatures and changing precipitation levels will persist to be important vulnerability drivers that will shape agricultural productivity particularly in South Asia, Southeast Asia and Central Asia as well as in selected areas of the region. With the increasing likelihood of extreme weather events, such as strong typhoons in the Philippines, the agriculture sector in the typhoon-prone areas of Southeast and East Asia, as well as the Indus Delta, will be more vulnerable to crop destruction (Mallari and Ezra, 2016). Projections on increasing SLR and flooding, such as those in Bangladesh and the Mekong Delta, will submerge and decrease crop production areas and severely affect agriculture and fishery sectors, but will also trigger outmigration from these areas (ADB, 2017b).

Vulnerability of aquaculture-related livelihoods to climate change was assessed at the global scale using the MAGICC/SCENGEN climate modelling tools, and Vietnam and Thailand were identified as most vulnerable in brackish-water aquaculture production (Handisyde et al., 2017). China, Vietnam and the Philippines are also ranked highly vulnerable in marine production. Moreover, a recent vulnerability assessment of Korean aquaculture based on predicted changes in seawater temperature and salinity according to RCP8.5 indicated that vulnerability was highest for seaweed, such as laver and sea mustard, while fish, shrimp and abalone are relatively less vulnerable as they are less sensitive to high water temperature and their farming environments are controllable to a large extent (Kim et al., 2019a). In Indonesia, farming of whiteleg shrimp (*Litopenaeus vannamei*) has been found to be vulnerable to increased rainfall and temperature decrease (Puspa et al., 2018).

Climate-change-induced vulnerability, however, is complicated by non-climate drivers. In Thailand, for instance, a 38% reduction (from 21,486 to 13,328 million at the present value (1 USD = 33.54 THB) in the export values of rice and products in the last quarter of 2011 has been attributed not only to the impact of tropical cyclone Nock-Ten on Thai rice export but also the economic slowdown in Thailand during 2011–2012 (Nara et al., 2014).

Considering the high vulnerability of Asia to climate change as a whole, there is a need to look at the drivers of vulnerability in an integrated and comprehensive manner. The increasing interest on nexus studies that links climate-change impacts on agriculture with the other sectors like water, energy, land-use change, urbanisation, poverty, economic liberalisation and others (see, for example, Takama et al., 2016; Aich et al., 2017; Eslamian et al., 2017; Duan et al., 2019b) could contribute to a systemwide vulnerability reduction and an important initial step towards a more climate-resilient future.

10.4.5.5 Adaptation Options

Since AR5, there has been a surge in the volume of literature that documents and assesses the different adaptation practices already employed in Asian agriculture as well as those that provide future adaptation options. There is *robust evidence* that a variety of adaptation practices already employed in agriculture and fisheries are valuable in reducing the negative effects of current climate anomalies but may not be sufficient to fully offset the adverse impacts of future climate scenarios. Recent literature, therefore, focuses on how to build on current adaptation initiatives and processes to improve current and future outcomes (Iizumi, 2019).

Asian farmers and fishers already employ a variety of adaptation practices to minimise the adverse impacts of climate change. In a recent systematic and comprehensive review of farmers' adaptation practices in Asia, Shaffril et al. (2018) categorised these practices into different forms such as crop management, irrigation and water management, farm management, financial management, physical infrastructure management and social activities. 'Climate-smart agriculture'—an integrated approach for developing agricultural strategies that address the intertwined challenges of food security and climate change—is increasingly being promoted in many parts of the region, especially in Southeast and South Asia, with potentially promising outcomes (Chandra et al., 2017; Khatri-Chhetri et al., 2017; Shirsath et al., 2017; Westermann et al., 2018; Wassmann et al., 2019b). Site-specific adaptations, such as those in Pakistan, include farmers' utilisation of several adaptation techniques which include changing crop type and variety, and improving seed quality; fertiliser application and use of pesticides, and planting of shade trees; and water storage and farm diversification (Fahad and Wang, 2018), as well as the implementation of comprehensive climate information services for farming communities (World Meteorological Organization, 2017).

Adaptation measures are also beneficial to small-scale fishers and fish farmers (Miller et al., 2018), and through fisheries management plans (FMP) and Early warning systems, the Asian region is reducing climate impact (FAO, 2018c). The most common FMPs adopted in different Asian countries are limits to fishing gear, licensing schemes and seasonal closures (ILO, 2015), protection of nursery grounds, providing alternative livelihoods (Azad, 2017), limiting fish aggregating devices (FADs) and introduction of monitoring and control tools (Department of Fisheries (Thailand), 2015). Fishers' strong sense of belonging to their place of residence and the sense of responsibility to protect the vulnerable fish stock has been advantageously used for developing cooperatives and starting community-based fisheries management (FAO, 2012; ILO, 2015; Shaffril et al., 2017), and these initiatives have yielded positive results.

In aquaculture, most households in shrimp communities rely on process-oriented multiple coping mechanisms such as consumption smoothing, income smoothing and migration that enhance farmers' resilience to climate anomalies (Kais and Islam, 2018). Diversification and integration of varied resources and interventions in feed and husbandry are seen to help the aqua farmers increase their profits and overcome the impacts of climate change (Henriksson et al., 2019). Strategies like polyculture, integrated multitrophic aquaculture (IMTA) and recirculating aquaculture

10

Adaptation-related strategies in Asian agriculture to enhance current and future adaptations

CREATE ENABLING POLICIES

Create enabling policies (e.g. security of land tenure and agricultural insurance policy) and enhance institutional capacity (e.g. effective extensions services and early warning system) to support farmers' adaptation

IMPROVE ADAPTATION PLANNING AND DECISION-MAKING

Improve adaptation planning and decision-making by:

- Conducting integrated and multi-sectoral adaptationassessment that explores synergies and trade-offs among energy, GHG emission, water, land use, urbanization, and food production
- Recognizing and integrating indigenous and local knowledge and practices ; and
- Mainstreaming adaptation into ongoing development planning and decision-making

PROMOTE SCIENCEBASED ADAPTATION MEASURES

Promote science-based adaptation measures. (e.g. development of drought-tolerant and short-maturing varieties, promotion of conservation-agriculture practices and technologies, use of weather and climate information to enhance farmers' adaptation

ADOPT AN INTEGRATED APPROACH TO IMPROVE ADAPTATION

Adopt an integrated approach to improve adaptation interventions from field-level practices and technological interventions, to management strategies shifting crops and sowing dates, to enacting adaptation policies and reforming agricultural institutions

INVEST ON CRITICAL INFRASTRUCTURE

Invest on critical infrastructure such as irrigation and transportation systems

ADDRESS FARMERS' ADAPTATION BARRIERS

Address farmers' adaptation barriers (e.g. labor shortage, insecure land tenure, limited market access, poor governmental and institutional support, poverty, lack of access to assets and technology, limited water sources, absence of credit facility; inadequate access to near-term and medium-term climate knowledge, etc.) to advance transformational adaption

Figure 10.7 | Adaptation-related strategies in Asian agriculture to enhance current and future adaptations.

systems (RAS) have been suggested to increase aquaculture productivity, environmental sustainability and climate change adaptability (Ahmed et al., 2019c; Tran et al., 2020). In Bangladesh, several adaptation measures, such as integrated community-based adaptation strategies (Akber et al., 2017) and integrated coastal zone management (Ahmed and Diana, 2015), have been recommended to increase climate resilience among shrimp farmers.

More recently, nature-based solutions (NbS) have gained attention globally to enhance climate adaptation. In the context of agriculture, NbS are seen as cost-effective interventions that can increase resilience in food production while advancing climate mitigation and improving the environment (Iseman and Miralles-Wilhelm, 2021). Experiences in implementing NbS in agricultural landscapes have been documented both in agriculture and fisheries sectors that promote production while providing co-benefits such as environmental protection and sustainability (Miralles-Wilhelm, 2021).

Despite the numerous adaptation measures already employed, there is sufficient evidence that farmers' current adaptation practices are inadequate to offset the worsening climate change impacts. A more comprehensive approach that integrates economic and social strategies with other measures is seen to reduce climate vulnerability. For instance, agriculture insurance is viewed as a promising adaptation approach to reduce risks and increase the financial resilience of farmers and herders in many Asian countries (Prabhakar et al., 2018; Matheswaran et al., 2019; Nguyen et al., 2019; Stringer et al., 2020). Similarly, participation of multiple stakeholders from all relevant sectors at different levels in adaptation planning and decision making is seen as an important factor in improving outcomes (Arunrat et al., 2017; Hochman et al., 2017; Chandra and McNamara, 2018). Moreover, while adaptation is local and context specific, the following general adaptation-related strategies are distilled from the current literature, based on the Asian experience, to enhance current and future adaptations (see Figure 10.7 for details or examples of each strategy):

- Create enabling policies (Chen et al., 2018d) and enhance institutional capacity (Wang et al., 2014; Hirota and Kobayashi, 2019)
- Improve adaptation planning and decision making (Xu and Grumbine, 2014; Asmiwyati et al., 2015; Dissanayake et al., 2017; Hochman et al., 2017; Qiu et al., 2018; Shuaib et al., 2018; Aryal et al., 2020b; Ruzol and Pulhin, 2021; Ruzol et al., 2021)
- Promote science-based adaptation measures (Alauddin and Sarker, 2014; Sapkota et al., 2015; Lim et al., 2017b)
- Adopt an integrated approach to improve adaptation (Teixeira et al., 2013; Yamane, 2014; Abid et al., 2016; Sakamoto et al., 2017; Sawamura et al., 2017; Trinh et al., 2018)
- Invest in critical infrastructure (Cai et al., 2016; Rezaei and Lashkari, 2018)
- Address farmers' adaptation barriers (Alauddin and Sarker, 2014; Pulhin et al., 2016; Fahad and Wang, 2018; Gunathilaka et al., 2018; Almaden et al., 2019b)

10.4.6 Cities, Settlements and Key Infrastructures

Cities across Asia have large populations exposed to climate risks but also present an opportunity for concerted climate action (Revi et al., 2014; Chu et al., 2017; Revi, 2017; Khosla and Bhardwaj, 2019) and report numerous examples of adaptation actions at various stages of planning and implementation (Dulal, 2019; Singh et al., 2021b). However, challenges specific (though not exclusive) to Asian cities such as uneven economic development, rapid land-use changes, increasing inequality, growing exposure to extreme events and environmental change, such as land subsidence (with antecedent impacts on people and infrastructure), and large, socially differentiated vulnerable populations, remain key concerns as Asian cities simultaneously tackle challenges of sustainable development and equitable climate action.

10.4.6.1 Sub-regional Diversity

By 2050, urban areas are expected to add 2.5 billion people, 90% of whom will be in Asia and Africa (UNDESA, 2018). Critically, this urban population increase will be concentrated in India, China and Nigeria, with India and China adding 416 million and 255 million urban dwellers, respectively, between 2018 and 2050 (UNDESA, 2018).

Asia is home to 54% of the world's urban population, and by 2050, 64% of Asia's 3.3 billion people will be living in cities. Asia is also home to the world's largest urban agglomerations: Tokyo (37 million inhabitants), New Delhi (29 million) and Shanghai (26 million) are the top three with Cairo, Mumbai, Beijing and Dhaka home to nearly 20 million people each (UNDESA, 2018). By 2028, New Delhi is projected to become the most populous city in the world. In certain parts of Asia (e.g., some cities in Japan and the Republic of Korea), a steep decline in urban population is projected, mainly due to declining birth rates (Hori et al., 2020). Within Asia, rates of urbanisation differ sub-regionally. Eastern Asia has seen the most rapid urban growth with the percentage of urban population having more than tripled from 18 to 60% between 1950 and 2015, while rates of urbanisation have decreased in West Asia and remained steady in Central Asia (UNDESA, 2018).

Asian cities are seeing growing income inequality, with rural poverty being replaced by urban poverty (ADB, 2013). Regional studies show high and growing inequality within Indian and Chinese urban areas and decreasing rural–urban income gaps in Thailand and Vietnam (Baker and Gadgil, 2017; Imai and Malaeb, 2018). Critically, East Asia and the Asia–Pacific in general continue to house the world's largest population of slum dwellers at 250 million, with most of them in China, Indonesia and the Philippines, and the highest rates of urban poverty in Papua New Guinea, Vanuatu, Indonesia and the Lao PDR (McIlreavy, 2015; Baker and Gadgil, 2017). A lot of urbanisation, especially in South Asia, is also 'hidden' due to poor, competing definitions of what is 'urban' and limited data (Ellis and Roberts, 2016).

10.4.6.2 Key Drivers of Vulnerabilities

In Asian cities, climatic hazards such as changes in precipitation and, during the Asian monsoon, SLR, cyclones, flooding, dust storms, heatwaves and permafrost thawing (Byers et al., 2018; Hoegh-Guldberg et al., 2018; Rogelj et al., 2018; Shiklomanov, 2019), as well as non-climatic vulnerabilities such as non-climatic hazards (e.g., seismic hazards), inadequate infrastructure and services, unplanned urbanisation, socioeconomic inequalities and existing adaptation deficits (Johnson et al., 2013; Araos et al., 2016; de Leon and Pittock, 2017; Meerow, 2017; Dulal, 2019) interact to shape overall urban risk (Shaw et al., 2016a; Rumbach and Shirgaokar, 2017; Dodman et al., 2019). Caught at the intersection of high exposure, socioeconomic vulnerability and low adaptive capacities, informal settlements in urban and peri-urban areas are particularly at risk (*robust evidence, high agreement*) (Meerow, 2017; Rumbach and Shirgaokar, 2017; Byers et al., 2018).

10.4.6.3 Observed and Projected Impacts

10.4.6.3.1 Multi-hazard risk

Of the multi-hazard global average annual loss (AAL)[4] of 293 billion USD, 170 billion USD (58%) is in the Asia Pacific region (UNISDR, 2017). Of the top ten highest AALs associated with multi-hazards, six are in

4 Average annual loss is the average amount that a country could expect to lose each year over the long term due to hazard incidence. It corresponds to the expected average loss per year considering all the events that could occur over a long time frame, including very intensive events. It is a probabilistic indication of the direct economic losses expected due to total or partial damage of physical assets existing in the affected area (UNISDR, 2017).

Asia (Japan, China, Republic of Korea, India, the Philippines and Taiwan, Province of China) (UNISDR, 2017). As per Gu et al. (2015), 56% of cities with populations greater than 300,000 in 2014 are exposed to at least one of the six physical hazards (cyclones, floods, droughts, earthquakes, landslides and volcanic eruptions). Cities in areas highly exposed and vulnerable to multiple hazards were also the ones that grew rapidly in population between 1950 and 2014, implying greater infrastructural investments in climate-sensitive areas. Among 27 cities highly exposed to multiple disasters, 13 cities had a population of 1 million or more in 2014. Among them were three megacities, Tokyo (Japan), Osaka (Japan) and Manila (the Philippines), with more than 10 million inhabitants exposed to three or more hazards. Seven other cities with 1 million inhabitants or more in Asia were at high risk of three or more types of disaster. Manila is highly vulnerable to economic losses and disaster-related mortality from all six types of disasters. Moscow (Russia) is the only megacity not exposed to the risk of any of the six types of physical hazards analysed (cyclones, floods, droughts, earthquakes, landslides and volcano eruptions). Of the eight megacities most vulnerable to disaster-related mortality, seven–Tokyo, Osaka, Karachi, Kolkata, Manila, Tianjin and Jakarta, totalling 143 million people–are in Asia (Gu et al., 2015).

10.4.6.3.2 Extreme temperatures and heatwaves

Urbanisation and climate change interact to drive an urban heat island (UHI) effect across Asian cities (Hauck et al., 2016; Chapman et al., 2017; also see Figure 6.4 in Chapter 6). Three regions which are expected to see higher maximum wet-bulb temperature than global averages are southwest Asia around the Persian Gulf and Red Sea, South Asia in the Indus and Ganges river valleys, and eastern China (Im et al., 2017; Perkins-Kirkpatrick et al., 2020).

Impacts of heatwaves at 1.5°C and 2°C in cities are substantially larger than under the present climate (Hoegh-Guldberg et al., 2018). In South Asia particularly, more intense heatwaves of longer durations and occurring at a higher frequency are projected with *medium confidence* over India (Murari et al., 2015) and Pakistan (IPCC AR6, WGI, Table 11.5; Ali et al., 2018; Nasim et al., 2018; Ali et al., 2020; IPCC, 2021). At the city level, these projections could translate into significant impacts: at 1.5°C, on average, every year Kolkata will experience heat equivalent to the 2015 record heatwaves; Karachi about once every 3.6 years; and under 2°C warming, both regions could expect such heat annually (Matthews et al., 2017). In Pakistan, Hyderabad is *likely* to be the hottest city by 2100 with the highest average temperature reaching 29.9°C (RCP4.5) to 32°C (RCP8.5) followed by Jacobabad, Bahawalnagar and Bahawalpur cities (Ali et al., 2020). The frequency of heatwave days (HWF) will increase by 22.8, 22.3 and 26.5 d yr^{-1} in northern, eastern and western Japan, respectively, with megacities such as Tokyo, Osaka and Nagoya seeing large increases in HWF and related deaths (Nakano et al., 2013).

In China's urban agglomerations, an increase in the global warming from 1.5°C to 2°C is *likely* to exacerbate the intensity of extreme maximum temperature 4.1 times (Yu et al., 2018d). From 1995 to 2014 China's urban agglomerations (Beijing–Tianjin–Hebei, Yangtze River Delta, Middle Yangtze River, Chongqing–Chengdu and Pearl River Delta) experienced no more than three heat danger d yr^{-1}, which is projected to increase to 3–13 d by 2041–2060 and 8–67 d by 2081–2100 under high-emissions shared socioeconomic pathways SSP3-7.0 and SSP5-8.5, resulting in approximately 260 million people (19% of the total population of China) and 310 million people (39% of the total population), respectively, facing more than three heat-danger days annually (Zhang et al., 2021). This projected risk exposure is reduced under low-emissions pathways (SSP1-2.6 and SSP2-4.5), where annual heat-danger days will remain similar to current levels or increase slightly (Zhang et al., 2021).

Critically, these projections of higher temperatures will have a significant impact on heat-related morbidity and mortality, labour productivity, mental health, and health and well-being outcomes across all sub-regions of Asia (*medium evidence, high confidence*) (Pal and Eltahir, 2016; Im et al., 2017; Arifwidodo et al., 2019; Arshad et al., 2020). In West Asia and the North China Plain especially, extreme wet-bulb temperatures are expected to approach, and possibly exceed, the physiological threshold for human adaptability (35°C) (Pal and Eltahir, 2016; Kang and Eltahir, 2018). By the end of the century, under higher projections (RCP8.5), the daily maximum wet-bulb temperature is expected to exceed the survivability threshold across most of South Asia (Im et al., 2017). City-specific studies articulate what these regional projections will mean for urban populations. For example, at 1.5°C warming, without adaptation, annual heat-related mortality in 27 major cities across China is projected to increase from 32.1 per million inhabitants annually in 1986–2005 to 48.8–67.1 per million. This number increases to 59.2–81.3 per million for 2°C warming (Wang et al., 2019a). In the Republic of Korea, deaths from heat disorders are expected to increase approximately fivefold under the RCP4.5 and 7.2-fold under RCP8.5 by 2060 compared with the current baseline value of ~23 people per summer (Kim et al., 2016a). Importantly, heat exposure is differentiated within cities: it disproportionally affects the poorest populations (Lohrey et al., 2021) and those with lesser access to green spaces (Arifwidodo and Chandrasiri, 2020).

10.4.6.3.3 Precipitation extremes: excess rainfall, drought and water scarcity

Warming from 1.5°C to 2°C will increase extreme precipitation events across Asia especially over East and South Asia (*medium evidence, high agreement*) (Zhang et al. 2018; Supari et al., 2020; Zhang et al., 2020b). In East and Central Asia, under 1.5°C warming, extreme 1- and 5-d precipitation will increase by 28 and 15% relative to 1971–2000 (Zhang et al., 2020b). In China's urban agglomerations, an increase in global warming from 1.5°C to 2°C is *likely* to increase the intensity of total precipitation of very wet days 1.8 times and double maximum 5-d precipitation (Yu et al., 2018d). Extreme rainfall has direct and increasing consequences on urban flooding risk (Dasgupta et al., 2013b), which is further exacerbated by urbanisation trends that reduce permeability, divert water flow and disrupt watersheds (Chen et al., 2015b; Duan et al., 2016).

Urban extent in drylands in expected to increase from 2000 to 2030 with large expansions in West Asia, Central Asia, South Asia and China and antecedent impacts on exposure to drought and water scarcity (Güneralp et al., 2015). Urban dryland extent in West Asia will increase from 19,400 to 67,400 km^2 (Güneralp et al., 2015). In the Haihe River basin in China, the proportion of people exposed to droughts at 1.5°C (without accounting for population growth) is projected to decrease by 30.4% but increase by 74.8% at 2°C relative to people exposed in 1986–2005 (339.65 million) (Sun et al., 2017). About 411 million people living in 330 cities above 300,000 population are exposed to drought risk, which include three Asian megacities Delhi (India), Karachi (Pakistan) and Kolkata (India). Drought-related economic losses are also high in Dhaka (Bangladesh) (Pervin et al., 2020), Istanbul (Turkey), Manila (the Philippines) and Shenzhen (China), and Manila is also highly vulnerable to drought-related mortality (Gu et al., 2015).

Increasing urban drought risk will also have cascading impacts on regions from where water is imported, exacerbating drought exposure beyond urban settlements and limiting water availability in certain regions (Chuah et al., 2018; Garrick et al., 2019; Zhang et al., 2020c; Zhao et al., 2020). There is *medium evidence* (*high agreement*) that urban water insecurity is experienced differentially based on income, risk exposure, and assets, and that urban drought and water scarcity is causing material and non-material losses and damage (Singh et al., 2021a). Importantly, in several Asian cities, flood and drought risk is expected to occur concurrently, especially in South Asia which is projected to see the largest increase in urban land exposed to both floods and droughts (25–32% increase in flood and drought risk between 2000 and 2030).

10.4.6.3.4 Sea level rise and coastal flooding

Global assessments identify Asia as the most exposed region to SLR (see Section CCP2.2.1) in terms of the number of people living in low-elevation coastal zones and the number of people exposed to flooding from 1-in-100-years storm surge events (Neumann et al., 2015; Jevrejeva et al., 2016; Kulp and Strauss, 2019; Abadie et al., 2020; Haasnoot, 2021). Twelve of the top 20 countries exposed to SLR and associated flood events are in Asia, and of these, China, India, Bangladesh, Indonesia and Vietnam are estimated to have the highest total coastal population exposure (Neumann et al., 2015; Edmonds et al., 2020). Critically, regardless of the emissions scenario, 70% of the global population exposed to SLR and land subsidence are in eight Asian countries: China, Bangladesh, India, Vietnam, Indonesia, Thailand, the Philippines and Japan (Kulp and Strauss, 2019). This is particularly worrisome since in highly populated low-lying coastal cities across Asia, it is estimated that land subsidence could be as influential as climate-induced SLR over the 21st century (Cao et al., 2021; Nicholls et al., 2021). In East Asia and the Asia–Pacific in general (expected to see 0.2–0.5 m SLR), without adaptation, 1 million people (range of 0.3–2.2 million) are projected to be affected by submergence under RCP8.5 by 2095. Limiting warming will reduce this risk, and under RCP4.5, these numbers of people at risk will be reached by 2140. However, continuing on RCP8.5 increases risk exposure to 7 million (estimated range of 2–24 million people) (Haasnoot, 2021). Notably, assuming present-day population and adaptation (in the form of existing protection standards), East and South Asia already have a large number of people at risk of a 1-in-100-years flooding event (63 million) because of relatively lower flood protection (except in China and Malaysia).

These global scenarios will have significant impacts on national and subnational populations. For example, in Bangladesh, under 0.44 and 2 m mean SLR, direct inundation is estimated to drive migration of 0.73–2.1 million people by 2100 (Davis et al., 2018). Such migration will have direct development implications: for example, destination locations could see additional demands on jobs (594,000), housing (197,000) and food (783×10^9 calories) by mid-century as a result of those displaced by SLR (Davis et al., 2018).

Among the 20 largest coastal cities with the highest flood losses by 2050, 13 are in Asia[5], with a regional concentration in South, Southeast and East Asia (Hallegatte et al., 2013). Furthermore, 9 of these cities (Guangzhou, Kolkata, Tianjin, Ho Chi Minh City, Jakarta, Zhanjiang, Bangkok, Xiamen, Nagoya) also have an additional risk of subsidence due to SLR and flooding (Hallegatte et al., 2013). Guangzhou, China, is estimated to be the most economically vulnerable city in the world to SLR by 2050, with estimated losses of 254 million USD yr^{-1} under 0.2 m SLR (Jevrejeva et al., 2016). With a 2°C warming, Guangzhou is expected to see SLR of 0.34 m; under 5°C warming, this number would rise to 1.93 m. A more recent estimate calculates expected damage in Guangzhou due to SLR under RCP8.5 to reach 331 billion USD by 2050 and 420 billion USD under the high-end scenario with figures doubling by 2070. By 2100, expected damage could reach 1.4 trillion USD under RCP8.5 and 1.8 trillion USD under the high-end scenario. Similarly, in Mumbai (India) SLR damages amount to US$ 112–162 billion by 2050 and could increase by a factor of 2.8–2.9 by 2070 (Abadie et al., 2020). In coastal cities such as Bangkok and Ho Chi Minh City, projected land subsidence rates, mainly due to excessive groundwater extraction, are comparable to, or exceed, expected rates of SLR, resulting in an additional 0.2 m SLR by 2025 (Jevrejeva et al., 2016). In Shanghai, current annual damage by coastal inundation is estimated at 0.03% of local GDP; under RCP4.5, this increases to 0.8% by 2100 (uncertainty range of 0.4–1.4%) and is further exacerbated by land subsidence and socioeconomic development (Du et al., 2020). It is important to note that these projections assume (a) no adaptation and (b) that damage repairs are undertaken and completed annually. Given these assumptions, while these estimates communicate the scale of projected impacts, they are indicators of possible damages in the absence of adaptation and *not* actual projections.

The SLR affects economic growth, its drivers and welfare outcomes (Hallegatte, 2012; Pycroft et al., 2016; Lee and Asuncion, 2020) through (a) permanent loss of land and natural capital, (b) loss of infrastructure and physical capital, (c) loss of social capital and migration, (d) temporary floods, food insecurity and loss of livelihoods and (e) added expenditure for coastal protection. Without adaptation, direct damage to the GDP by 2080 due to SLR would be highest in Asia (*robust evidence, medium agreement*), with China losing between 64.2 billion USD (under A1B of 2.4°C by the 2050s and 3.8°C by the 2090s at 0.47 m), 95.8 billion USD (under the RAHM scenario of 1.4 m SLR by 2100 at 1.12 m) and 118.4 billion USD (at a high SLR of 2 m by 2100 at 1.75 m) in direct damages, and an additional 5.7, 4.5 and 4.5 billion USD, respectively, due to migration (Pycroft et al., 2016). Closely after China will be India, the Republic of Korea, Japan, Indonesia and Russia. Overall, Asia can experience direct losses of about 167.6 billion USD (at 0.47 m), 272.3 billion USD (at 1.12 m) or 338.1 billion USD (at

5 Guangzhou, Mumbai, Kolkata, Shenzhen, Tianjin, Ho Chi Minh, Jakarta, Chennai, Surat, Zhanjiang, Bangkok, Xiamen and Nagoya

10

1.75 m), and an additional 8.5, 24 or 15 billion USD at the respective SLR projections, due to migration[6].

10.4.6.3.5 Tropical cyclones

Globally, there is *high confidence* that the proportion of intense tropical cyclones is expected to increase despite the total number of tropical cyclones being expected to decrease or remain unchanged (Arias et al., 2021), especially in Southeast and East Asia (Knutson et al., 2015; Yamamoto et al., 2021). Historical trends from South Asia indicate that more lives are lost due to storm surge levels than the intensity of the cyclone (Niggol and Bakkensen, 2017). The number of people exposed to 1-in-100-years storm surge events is highest in Asia. China, India, Bangladesh, Indonesia and Vietnam have the highest numbers of coastal populations exposed (Neumann et al., 2015) with Guangzhou, Mumbai, Shenzen, Tianjin, Ho Chi Minh City, Kolkata and Jakarta incurring losses of 1520 million USD due to coastal flooding in 2005 alone (Dulal, 2019), although Jakarta is exposed to monsoonal storm surge. It is projected that by 2050, without adaptation, the annual losses incurred in these cities will increase to approximately 32 billion USD (Dulal, 2019).

Globally, six of the top ten countries/places with the highest AAL associated with tropical cyclones are in Asia (Japan, Republic of Korea, the Philippines, China, Taiwan, Province of China, and India) (Mori et al., 2021a). The AAL associated with storm surge is primarily concentrated in Japan, China, Hong Kong SAR of China, and India. The AAL associated with wind and storm surge relative to the existing capital stock in the country is highest in New Caledonia, Tonga, Vanuatu, Palau, the Philippines, Fiji and the Solomon Islands, indicating less resilience. For example, in Ise Bay, Japan, the current storm surges are estimated to lead to property and business damage of approximately 100.04 billion JPY with current adaptation (protective sea wall), but this can more than double to 236.49 billion JPY under climate-change-induced increases in storm surge intensity (Jiang et al., 2016).

10.4.6.3.6 Riverine floods

Over one-third of Asian cities and about 932 million urban dwellers live in areas with high risk of flooding (Gu et al., 2015). Of 437 cities at low risk of flood exposure but highly vulnerable to flood-related economic losses, approximately half are in Asia (Gu et al., 2015).

Globally, China and India have the highest AALs associated with riverine floods, with a magnitude of 13 and 6 billion USD, respectively. Other countries from Asia among the top ten of absolute AALs are Japan, Bangladesh and Thailand. There is an increased flood risk for habitations on the deltas influenced by both riverine and coastal drivers of flooding (Szabo et al., 2016a), globally exposing 9.3% more people annually to riverine flooding than otherwise estimated without the compounded influence (Eilander et al., 2020). Simultaneously, SLR and subsidence are also expected to increase the risk due to frequent flood events for these delta regions than the longer-return periods otherwise associated with SLR (Yin et al., 2020).

10.4.6.3.7 Permafrost thawing and associated risks

In Northern Eurasia, observed and projected climate-change impacts are especially pronounced. On land, the presence of permafrost, which occupies substantial areas of eastern Russia, Mongolia and mountain regions of China, creates specific challenges for economic development and human activities. By 2050, it is likely that 69% of fundamental human infrastructure in the Pan Arctic will be at risk (RCP 4.5 scenario)(*medium confidence*), including more than 1200 settlements (Hjort et al., 2018). The majority of the population and the absolute majority (85%) of large settlements on permafrost are located in Russia, and 44% of those are expected to be profoundly affected by permafrost thaw by 2050 (Streletskiy et al., 2019; Ramage et al., 2021). Under RCP8.5, the climate-induced decrease of bearing capacity and, in regions with ice-rich permafrost, thaw subsidence, is projected to affect 54% of all residential buildings on permafrost with a combined worth of 20.7 billion USD; 20% of commercial and industrial structures and 19% in critical infrastructure with a total worth of 84.4 billion USD (Streletskiy, 2019). Transport infrastructure in Russia and China are impacted by thaw subsidence and, to a lesser degree, from frost heave, which add significant operational costs and limit accessibility to remote settlements (Porfiriev et al., 2019; Ni et al., 2021).

Especially in Russia, significant populations and fixed infrastructure assets are located in urban centres on permafrost that is degrading significantly. Two major risks associated with permafrost degradation are loss of permafrost bearing capacity and ground subsidence (Streletskiy et al., 2015). The former determines the ability to support foundations of buildings and structures and is a vital characteristic of sustainability of the economic centres, while the latter impacts the ability of critical infrastructure (roads, railroads) to provide transportation and support accessibility of remote populations and economic centres on permafrost. The proximity of some settlements to the coasts or areas with uneven topography may further increase risks associated with permafrost degradation as ice-rich coasts characterised by high rates of coastal erosion, while settlements located on slopes may experience higher rates of mass wasting processes.

Changes in climate have resulted in permafrost warming and increased thaw depth in undisturbed locations (Biskaborn et al., 2019), but in built up areas these transformations have been exacerbated by human activities (Grebenets et al., 2012). Norilsk, the largest city built on permafrost above the Arctic Circle (Shiklomanov et al., 2017b), was found to have one of the highest trends of near-surface permafrost warming (Streletskiy et al., 2012). Anomalous high temperatures and earlier snowmelt in 2020 may have contributed to oil storage collapse and the resulting spill of 20,000 tons of diesel fuel in Norilsk area (Rajendan et al., 2021). The ability of foundations to support structures has decreased by 10–40% relative to the 1960s in the majority of settlements on permafrost in Russia (Streletskiy et al., 2012) and is expected to further decrease by 20–33% by 2050–2059 relative to 2006–2015 (Streletskiy et al., 2019).

6 Cumulative migration in high SLR scenarios is always higher, but since much of the migration has already occurred in earlier decades, the additional migration is lower in the high-SLR scenarios than the A1B scenario.

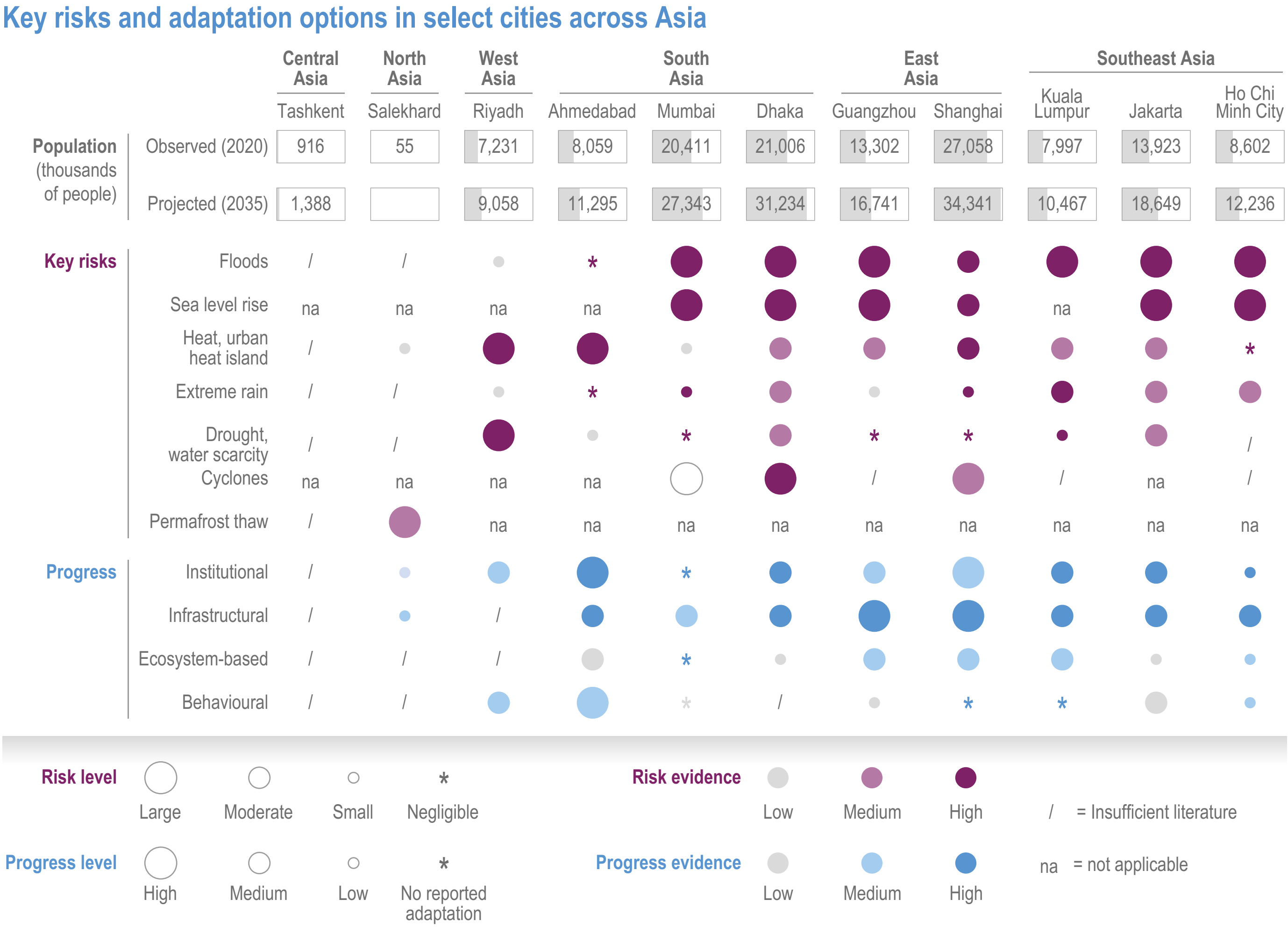

Figure 10.8 | Risks and key adaptation options in select cities across Asia. Cities were chosen to ensure coverage of different sub-regions of Asia, represent different risk profiles, different city sizes (based on current population and projected growth) and reported progress on different adaptation strategies (infrastructural, institutional, ecosystem based and behavioural). There is a full line of sight in SM10.4.

10.4.6.3.8 Risks and impacts on infrastructure

South Asia and Africa bear the highest losses from unreliable infrastructure, and climate change will increase these losses due to hazards and necessitate additional infrastructure investments to address new risks (Hallegatte et al., 2019; Lu, 2019)[7]. Specifically, power generation and transport infrastructure incur losses of 30 billion USD a year on average from hazards (about 15 billion USD each), with low- and middle-income countries shouldering about 18 billion USD of the total amount (Koks et al., 2019; Nicholls et al., 2019).

Among the top 20 countries that are rapidly expanding their infrastructure stock while facing high disaster risk and low infrastructure quality, the Asian countries are Lao PDR, the Philippines, Bangladesh, Cambodia, Kyrgyzstan, Bhutan and Vietnam. (UNISDR, 2017; WEF, 2018). The losses are due to direct damage to infrastructure, disruption in services and affected supply chains (Hallegatte et al., 2019). East Asia and the Pacific and South Asia have the highest adaptation deficits in coastal protection with 75 billion USD in the former and 49 billion USD in the latter (Nicholls et al., 2019). If overall damages are minimised, low- and middle-income countries may need to invest 0.1–0.5% of their GDP annually up to 2030 for protection against both coastal and river floods, varying based on level of acceptable risks, construction costs, urbanisation and climate uncertainties[8].

- **Power disruption:** Contrasting with high-income, countries such as the USA, where hazards, particularly storms, are responsible for 50% of power outages, this share is much lower in countries like Bangladesh or India, because system failures due to unnatural causes are very frequent. However, outages caused by hazards tend to be longer and geographically more widespread than other outages (Rentschler et al., 2019). Climate-change-induced SLR is

7 While Hallegatte et al. (2019) estimate that in low- and middle-income countries, the cost of infrastructure disruptions ranges from 391 to 647 billion USD, they emphasise that 'while these estimates are incomplete, they highlight the substantial costs that unreliable infrastructure impose on people in low- and middle-income countries'.

8 Estimates are based on the DIVA model, which uses SSP2, 3 and 5, and RCP2.6, 4.5 and 8.5 in Nicholls et al. (2019), and investments from Ward et al. (2017). According to this study, uncertainty regarding socioeconomic changes and climate change is small compared with the uncertainty around construction costs and tolerance to risk.

expected to impact power infrastructure, even necessitating power plant relocation (Hallegatte et al., 2019). In Bangladesh, to avoid inundations caused by SLR (SSP2, RCP8.5), approximately one-third of power plants may need to be relocated by 2030. An additional 30% of power plants are *likely* to be affected by increased salinity of cooling water and increased frequency of flooding, while power plants in the northern region will probably see a decrease in output because of droughts (Hallegatte et al., 2019). In 2013 in Chittagong (Pervin et al., 2020), users experienced about 16 power outages due to storms alone (Hallegatte et al., 2019). Furthermore, low-carbon technology diffusion might make certain infrastructures redundant, leading to stranded assets.

Across Asia, infrastructure impacts are mixed: net importers, such as China and India, will see GDP gains, while extreme examples include Russia, a net exporter, which could see steep declines in fossil fuel production (Mercure et al., 2018). In low- and middle-income countries globally, disruption in power supply can impact firms directly (up to 120 billion USD yr^{-1}), with coping costs (up to 65 billion USD yr^{-1}) and other indirect impacts. Similarly, for households, the direct impact and cost of coping could be between 2.3 and 190 billion USD yr^{-1}. Although all power outage is not due to natural hazards, there is a significant number that is attributed to disasters. Besides, outages caused by natural hazards tend to be longer and geographically larger than other causes (Hallegatte et al., 2019).

- **Transportation disruption:** Of the 20 countries in which the road and railway infrastructure is expected to be most affected in absolute terms due to multi-hazards, half are Asian (Koks et al., 2019). In low- and middle-income countries globally, the direct losses to firms on account of transportation disruption are about 107 billion USD yr^{-1}, excluding the costs due to sales losses or delayed supplies and deliveries alone (Hallegatte et al., 2019). In the transport sector, floods and other hazards disrupt traffic and cause congestion, taking a toll on people and firms in rich and poor countries alike.
- **Water supply and disposal infrastructure disruption:** In low- and middle-income countries, disruption of water supply could lead to direct losses of about 6 billion USD yr^{-1} for firms, and between 88 and 153 billion USD yr^{-1} for households (due to willingness to pay to avoid disruption). Additionally, there are second-order costs associated with finding alternate sources of water and also health issues (on the order of 6–9 billion USD yr^{-1} accounting for medical bills and missed income) (Hallegatte et al., 2019). In China, climate models project that an increasing number of wastewater-treatment-plant assets face climate-induced flood hazards in both the near and distant future, potentially affecting as many as 208 million users by 2050 (Hu et al., 2019).

10.4.6.4 Adaptation in Cities Across Asia

A review of urban adaptation in South, East and Central Asia found examples of 180 adaptation activities across 74 cities (Dulal, 2019). Most adaptation actions in Asia are in the initial stages (Araos et al., 2016) with 57% focused on preparatory actions, such as capacity building and vulnerability assessment, and 43% focused on implemented adaptation (see also SM10.4). Most adaptation actions were focused on disaster risk management (Dulal, 2019), although the proportion of climate finance spent on disaster preparedness is not very high (as Georgeson et al., 2016, show in the megacities of Beijing, Mumbai and Jakarta). Although key port cities across Asia are at high risk of climate impacts, it is estimated that adaptation interventions constitute only a small proportion of cities' climate efforts (Blok and Tschötschel, 2015). Figure 10.8 shows risks and key adaptation options in select cities across Asia.

Critically, most urban adaptation in South, East and Central Asia is reactive in nature (Dulal, 2019; Singh et al., 2021b), raising questions on preparedness, proactive building of adaptive capacities and whether present actions can lock certain cities or sectors into maladaptive pathways (Friend et al., 2014; Gajjar et al., 2018; Salim et al., 2019; Chi et al., 2020). China, India, Thailand and the Republic of Korea record the most number of urban adaptation initiatives, driven mainly by supportive government policies (Lee and Painter, 2015; Dulal, 2019). The number of actors working on urban adaptation is growing: in addition to national governments and local municipalities, civil society, private-sector actors (Shaw, 2019) and transnational municipal networks (Fünfgeld, 2015) are emerging as important for knowledge brokering, capacity building and financing urban adaptation (Karanth and Archer, 2014; Chu et al., 2017; Bazaz et al., 2018).

Adaptation options include: (a) infrastructural measures such as building flood protection measures and sea walls, and climate-resilient highways and power infrastructure (Shaw et al., 2016b; Ho et al., 2017); (b) sustainable land-use planning through zoning, developing building codes (Knowlton et al., 2014; Nahiduzzaman et al., 2015; Rahman et al., 2016; Ahmed et al., 2019b); (c) ecosystem-based adaptation measures such as protecting urban green spaces, improving permeability, mangrove restoration in coastal cities, etc. (Brink et al., 2016; Fink, 2016; Yu et al., 2018d); (d) relocation and migration out of risk-prone areas (McLeman, 2019; Hauer et al., 2020; Maharjan et al., 2020); and (e) disaster management and contingency planning such as through Early warning systems (EWS), improved awareness and preparedness measures (Shaw et al., 2016a). Asian cities are also focusing on institutional adaptation measures which cut across the five categories mentioned above such as through building capacity and local networks (Anguelovski et al., 2014; Friend et al., 2014; Knowlton et al., 2014), improving awareness (Knowlton et al., 2014), and putting local research and monitoring mechanisms in place (Lee and Painter, 2015) to enable adaptation. Figure 10.9 shows the effectiveness of select adaptation options in cities across Asia.

10.4.6.4.1 Infrastructural adaptation options

The challenge of adapting infrastructure to climate change across Asia is twofold: there are significant infrastructure deficiencies, especially in low-income countries, and key infrastructures are at high risk due to climate change (Hallegatte et al., 2019; Lu, 2019). Infrastructural adaptation options in cities attempt to enable networked energy, water, waste and transportation systems to prepare for, and deal with, climate risks better (Meerow, 2017) through interventions such as improved highways and power plants, climate-resilient housing, improved water infrastructure and so forth (ADB, 2014).

Effectiveness of select adaptation options in cities across Asia

Illustrative examples of adaptation plans and actions

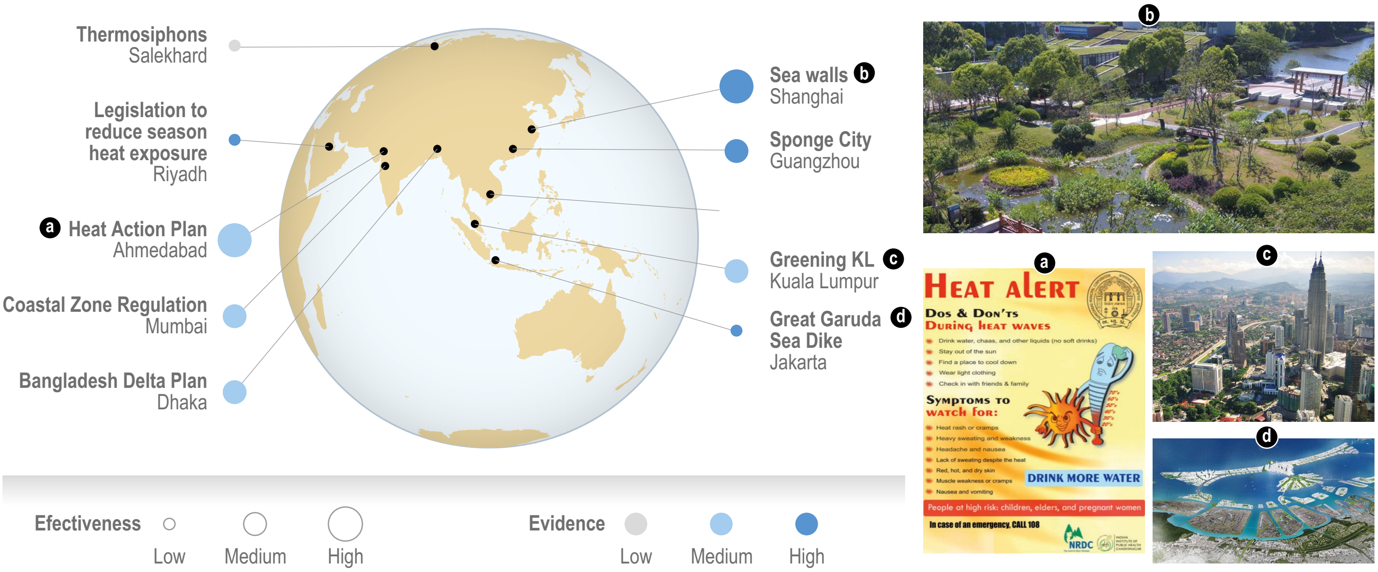

Figure 10.9 | Effectiveness of select adaptation options in cities across Asia. Effectiveness is assessed based on the option's ability to reduce risk as reported in the literature.

- **Power infrastructure:** Adaptations in electricity systems include climate-resilient power infrastructure, particularly essential for coastal megacities such as Manila, Mumbai, Bangkok and Ho Chi Minh City (Meerow, 2017; Duy et al., 2019), which double as regional economic hubs and are home to tens of millions of people. In the Philippines, solar panels at water pumping stations are installed to operate and maintain a minimal capacity to pump water if the electricity grid were to break down (Stip et al., 2019).
- **Water infrastructure:** Sustainable water supply and resource management are key to urban adaptation through improved water service delivery, wastewater recycling and storm-water diversion (Deng and Zhao, 2015; Xie et al., 2017; Yu et al., 2018d). Infrastructure-based adaptation options in urban water management include building water storage facilities, storm-water management and enhancing water quality improving permeability, managing runoff and enabling groundwater recharge. One example is of Shanghai (China), where infrastructural and policy incentives come together to enable adaptation: the city has been divided into 14 water conservancy zones, including 348 polder areas with 2517 km of dykes, 1499 pump stations and 2203 sluices (Yu et al., 2018d). It also depends on a regional inundation control system, flood Early warning system and an emergency plan to deal with flood risk and mitigate waterlogging (Chen et al., 2018e; Yu et al., 2018d). Another example is Ho Chi Minh City (Vietnam), where, given significant increases in area at risk of flooding under climate change, the city has invested in storm sewer upgradation, dike works, improving drainage and increasing the height of road embankments and minor bridges (Storch and Downes, 2011; ADB, 2014; Ho et al., 2017). These infrastructural interventions were complemented by designing an Early warning system to initiate flood mitigation procedures, such as isolating critical electrical and mechanical operating systems from water.
- **Built infrastructure:** Current built-infrastructure adaptation interventions are mostly reactive (e.g., strengthening housing units, using sandbags during flooding, storing of food, evacuation) rather than preventive (e.g., relocation, building multi-storey and stronger housing units), mainly due to limited resources within most vulnerable households for investing in proactive measures (Francisco and Zakaria, 2019). For cities in North Asia seeing permafrost thawing, adequate land-use practices, permafrost monitoring, maintenance of infrastructure and engineering solutions (e.g., using thermosiphons) may temporarily offset the negative effects of permafrost degradation in small, economically vital areas, but are unlikely to have an effect beyond the immediate areas (Shiklomanov et al., 2017b; Streletskiy, 2019). Importantly, thawing permafrost and GHG emissions create feedbacks where emissions amplify warming and drive additional thaw. Reducing these impacts through mitigation will reduce the need for adaptation significantly (Schaefer et al., 2014).
- **Infrastructure and technology:** Several infrastructural options employ technology, such as smart meters, to monitor water usage and service delivery, but these are differentially adopted across Asian sub-regions with higher adoption across East Asia. Examples include: the Yokohama smart city project in Japan, which has been smart eco-urbanism interventions since 2011 (e.g., energy saving and storage infrastructure, wastewater management, behavioural change towards renewable energy and low-carbon transportation) (IUC, 2019); the Tianjin Eco-city mega-project in China, which is testing a range of measures to meet urban sustainability goals in partnership with Singapore (ICLEI, 2014b; Blok and Tschötschel, 2015); development in New Songdo (Republic of Korea), which is experimenting with interventions, such as embedded smart waste management (Anthopoulos, 2017), and national policy initiatives such as the Smart Cities Mission covering 100 cities in India (e.g. technology-enabled water, energy and land management for urban

agriculture in Nashik city) (ICLEI, 2014a). However, the efficacy of such measures, especially for larger sustainability and climate-change goals, remains to be seen (ICLEI, 2014a; ICLEI, 2014b; Caprotti et al., 2015; Anthopoulos, 2017).

Infrastructural measures alone are seldom effective in building urban resilience as seen in the examples of the 2011 floods in Bangkok and the 2005 typhoon in Manila (Duy et al., 2019), or projected estimates by Pervin et al. (2020) who found that structural interventions in existing drainage systems reduce flooding risk by 7–19% in Sylhet (Bangladesh) and Bharatpur (Nepal); however, without proper solid waste management, areas under flood risk could increase to 18.5% in Sylhet and 7.6% in Bharatpur in five years, rendering the infrastructural interventions ineffective over time. While in some cities it is estimated that infrastructural adaptation through 'hard' flood protection strategies (e.g., storm surge barriers and floodwalls) is more effective than institutional or ecosystem-based adaptation by 2100, for example, Shanghai. A hybrid approach where hard strategies protect from flood risk, and soft strategies reduce residual risk from hard strategies, is suggested (Du et al., 2020). In Japan, without adaptation, estimated damage costs of floods (caused by tropical cyclones and altered precipitation) by 2081–2100 under RCP2.6 will be 28% higher (compared with 1981–2000), rising to 57% higher under RCP8.5 (Yamamoto et al., 2021). With a combination of adaptation measures (such as land-use control, piloti building and flood control measures), estimated damage costs can be reduced even below the 1981–2000 levels, and with a combination of mitigation and these adaptation measures, an estimated 69% reduction in flood damage costs are expected–demonstrating the importance of concerted and immediate climate action in reducing damage.

Infrastructural interventions can sometimes be maladaptive when assessed over longer time periods: for example, the Mumbai Coastal Road (MCR) project aimed at reducing flood risk and protecting against SLR will potentially cause damages to intertidal fauna and flora and local fishing livelihoods (Senapati and Gupta, 2017); and Jakarta's Great Garuda project aimed at reducing flood risk is expected to *increase* flood risk for the poorest urban dwellers (Salim et al., 2019).

10.4.6.4.2 Sustainable land-use planning and regulation

Land use in cities impacts resource use (e.g., water, energy), risk (a function of population density, service provision and hazard exposure) and adaptive capacity, all of which influence the efficacy of urban adaptation (de Coninck et al., 2018). Locally suited land-use planning and regulation (such as appropriate zoning or building codes and safeguarding land rights) can have adaptation co-benefits (Mitchell et al., 2015; Dhar and Khirfan, 2016): for example, strict building regulations can protect urban wetlands and associated ecosystem services (Jiang et al., 2015); appropriate land zoning can safeguard green spaces, ensure improvements in permeability and obviate new development in risk-prone locations (Duy et al., 2019); and ensuring tenurial security or regularising informal settlements can incentivise improvements to housing quality, thereby alleviating vulnerability of the most marginal people (Mitchell et al., 2015).

Land tenure arrangements strongly shape urban dwellers' vulnerability and their adaptive capacities (Roy et al., 2013; Michael et al., 2018). For example, in Khulna (Bangladesh), Roy et al. (2013) found significant differences between the adaptive strategies of homeowners and renters in low-income settlements, a finding echoed in Bangalore (India) (Deshpande et al., 2018) and Phnom Penh (Cambodia) (Mitchell et al., 2015). In Riyadh (Saudi Arabia), land-based adaptation strategies include land zoning to control population and building density, demarcating environmental protection zones, and sub-urbanisation (Nahiduzzaman et al., 2015; Rahman et al., 2016). In many Asian cities, land subsidence control can serve as an adaptation strategy since it is estimated to significantly reduce relative SLR (*high confidence*). This has an important implication in that subsidence control would be a good and complementary measure to climate mitigation and climate adaptation in many coastal urban settings in Asia (Cao et al., 2021; Nicholls et al., 2021). Urban land-use planning, if used proactively, can incentivise adaptation–mitigation synergies and obviate unintended negative consequences of urbanisation as Xu et al. (2019) have shown in Xiamen.

10.4.6.4.3 Ecosystem-based adaptation

The literature on urban ecosystem-based adaptation (EbA)[9], especially across Asia, has grown significantly since AR5 (Demuzere and al., 2014; Yao et al., 2015; Brink et al., 2016; Bazaz et al., 2018; de Coninck et al., 2018; Ren, 2018). This growing literature reflects the wide recognition that infrastructural adaptation can often have ecological and social trade-offs (Palmer et al., 2015) and need to be complemented by ecosystem-based actions to manage risk more effectively (Du et al., 2020), build adaptive capacity, and in some cases, meet mitigation and SDGs (Huang et al., 2020).

Illustrative examples of EbA in Asian cities include sponge cities in China for sustainable water management, flood mitigation and minimising heatwave impact (Jiang et al., 2018; Yu et al., 2018d; Wang et al., 2019a; Zhanqiang et al., 2019), Singapore's Active, Beautiful, Clean Waters (ABC Waters) Programme, which uses bio-engineering approaches to protect river channels and prevent localised flooding, improve water quality and create community spaces, and Dhaka's green roofs and urban agriculture (Zinia and McShane, 2018).

The EbA approaches to manage floods, capture and store rainwater, restore urban lakes and rivers, and reduce surface runoff often blend infrastructural and ecosystem-based approaches. For example, in Tokyo, stormwater management is done by sophisticated underground infrastructure and an artificial infiltration stormwater system (Saraswat, 2016; Mishra et al., 2019). China's Sponge City Programme aims to reduce the impacts of flooding through low-impact development measures, urban greenery and drainage infrastructure, such that 80% of

9 Ecosystem-based adaptation (EbA) is defined by IPBES as the conservation, sustainable management and restoration of natural ecosystems to help people adapt to climate change (Glossary, 2019). In urban areas, EbA includes improving ecological structures (e.g., maintaining watersheds, forests, green roofs), ecological functions and processes (e.g., wetland functioning for flood protection), valuation measures (including monetary or non-monetary values to ecosystem service benefits) and investing in ecosystem management practices (i.e., enabling adaption co-benefits through the maintenance, preservation and restoration or creation of ecological structures) (Liu et al., 2014a; Brink et al., 2016). Thus, EbA adaptation actions include protecting urban green spaces, improving permeability, fostering urban agriculture, mangrove restoration in coastal cities, improved wetland management and so forth (Doswald et al., 2014; Brink et al., 2016; de Coninck et al., 2018).

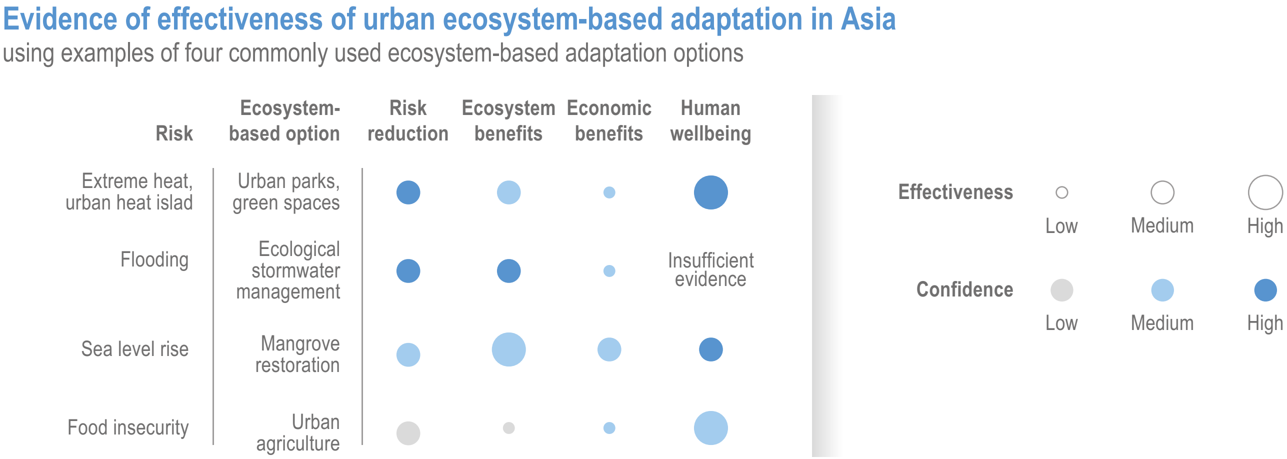

Figure 10.10 | Evidence of the effectiveness of ecosystem-based adaptation (EbA) using examples of four commonly used EbA options[10]. Effectiveness is assessed qualitatively based on the evidence (for a full line of sight see SM10.5) and is examined through four framings: potential to reduce risk (e.g., reduced exposure to hazard means to reduce risk); benefits to ecosystems (through improved ecosystem health and high biodiversity); economic benefits (e.g., improved incomes, fewer man-days lost, better livelihoods); and human well-being outcomes (e.g., health, quality of life, etc.). The darker shading signifies high effectiveness and the lightest shade signifies low effectiveness of an EbA option (i.e., the option scores low on the indicator).

urban areas reuse 70% of rainwater by 2020, which would help ensure the resilience of these cities to floods (Li et al., 2016b; Stip et al., 2019).

Case studies on urban EbA also raise equity concerns (*medium evidence, medium agreement*) such as interventions biased towards suburban areas in Haizhu District, Guangzhou (China) (Zhu et al., 2019); inadequate consideration of low-income, vulnerable populations (Blok and Tschötschel, 2015; Meerow, 2017; Mabon and Shih, 2021); and low familiarity with interventions such as artificial wetlands, water retention ponds as well as green façades and walls can restrict inclusiveness (Zinia and McShane, 2018). Furthermore, urban EbA is constrained by a range of factors such as inadequate institutional structures and processes for connecting different remits and knowledge systems along with trade-offs in land use for different purposes (Mabon and Shih, 2021; Singh et al., 2021b).

The EbA interventions are not uniform across Asian cities: in a global study on urban EbA, Brink et al. (2016) found that Eastern Asia, India and Israel report most EbA interventions and that there is variable and *limited evidence* on effectiveness and scalability (SM10.5). Using a risk framing (i.e., the extent to which an option reduces risk), urban EbA options in Asian cities score as being 'low to medium' effective (see SM10.5); however, when the assessment is expanded to include the ecosystem benefits, economic impacts and human well-being co-benefits of EbA, effectiveness increases. Figure 10.10 shows evidence of the effectiveness of EbA.

For example, urban agriculture is identified as offering multiple benefits such as mitigating emissions associated with food transportation from rural to urban areas, improving food and nutritional security, strengthening local livelihoods and economic development, improved microclimate, soil conservation, improved water and nutrient recycling, and efficient water management (Padgham and Dietrich, 2015; Patil et al., 2019). However, it can potentially undermine ecosystem services through land-use changes, water overextraction or applying chemical fertilisers (Ackerman et al., 2014), exposure of smallholders to volatile markets and crops that are not consumed by farming households themselves (thus undermining food security) or increasing the work burdens on women, as well as health externalities (e.g. through use of untreated wastewater, or rearing poultry and livestock in unsanitary conditions). There remain gaps in understanding the differential impacts of urban agriculture at different scales as well as its effectiveness in improving adaptive capacity at scale.

10.4.6.4.4 Migration and planned relocation

There is *medium evidence* with *high agreement* that climatic risks are exacerbating internal and international migration across Asia (see Box 10.2; IDMC, 2019; Maharjan et al., 2020). In coastal cities, formal 'retreat' measures, such as forced displacement and planned relocation (Oppenheimer et al., 2019), are commonly considered 'last resort' adaptation strategies once other infrastructural and ecosystem-based protect-and-accommodate strategies are exhausted (CCP2.3) (Haasnoot et al., 2019). In contrast, migration (which can take various forms from seasonal, temporary mobility to circular or permanent movement) is a regular feature across Asian urban settlements (Box 10.2, CCB MIGRATE, Maharjan et al., 2020).

There is *robust evidence* (*medium agreement*) that across Asia, migration (and increasingly planned relocation) will continue to be a key risk management strategy, especially in low-lying flood-prone cities (e.g., in Southeast and South Asia) and across drylands (e.g., in South and Central Asia) (Davis et al., 2018; Ajibade, 2019; Lincke and Hinkel, 2021). While there is insufficient evidence to project migration numbers under different warming levels, it is well established that migration as an adaptation strategy is not equally available to all (Ayeb-Karlsson,

10 Assessing the effectiveness of adaptation actions is challenging because of the lack of a clear goal that signifies effective adaptation, varied conceptual framings and metrics used to assess effectiveness, and low empirical evidence on the effectiveness of implemented adaptation actions (Owen, 2020; Singh et al., 2021a).

2020), and climatic risks might reduce vulnerable populations' ability to move due to loss of assets, thus reinforcing existing inequalities and differential adaptive capacities (Blondin, 2019; Zickgraf, 2019; Singh and Basu, 2020; Cundill et al., 2021; Gavonel et al., 2021).

There is *medium evidence* (*low agreement*) about the effectiveness of migration and planned relocation in reducing risk exposure. Evidence on climate-driven internal migration shows that moving has mixed outcomes on risk reduction and adaptive capacity. On one hand, migration can improve adaptive capacity by increasing incomes and remittances as well as diversifying livelihoods (Maharjan et al., 2020); on the other, migration can expose migrants to new risks. For example, in Bangalore (India), migrants often face high exposure to localised flooding, insecure and unsafe livelihoods, and social exclusion, which collectively shape their vulnerability (Michael et al., 2018; Singh and Basu, 2020). In greater Manila (the Philippines) and Chennai (India), planned relocations to reduce disaster risk have often exacerbated vulnerability, due to relocation sites being in environmentally sensitive areas, inadequate livelihood opportunities and exposure to new risks (Meerow, 2017; Ajibade, 2019; Jain et al., 2021).

10.4.6.4.5 Disaster management and contingency planning

There is rich case-based evidence across Asia on urban adaptation to extreme events with relatively more evidence on rapid-onset events such as cyclones and flooding than slow-onset disasters such as drought (see Box 10.6; Ray and Shaw, 2019; UNESCAP, 2019; Singh et al., 2021a). Overall, there has been a growing emphasis on 'build back better' interventions (Mannakkara and Wilkinson, 2013; Hallegatte et al., 2018) that approach disaster management holistically through infrastructural solutions such as climate-resilient housing or sea walls and soft approaches such as strengthening livelihoods, developing EWS[11], increasing awareness about disaster risks and impacts, and building local capacities to deal with them (Bhowmik et al., 2021). Notably, urban disaster management is effective when land-use planning processes, including greenfield development, zoning and building codes, and urban redevelopment, are leveraged to reduce and/or obviate risk, thereby averting potential maladaptation (Kuhl et al., 2021).

There is relatively lower empirical evidence on how microenterprises and businesses are adapting to increased risk, but recent examples in Mumbai, India (Schaer and Pantakar, 2018), and Kratie, Cambodia (Ngin et al., 2020), suggest that businesses primarily adopt temporary and reactive responses rather than long-term, anticipatory adaptation measures.

A review of innovative DRR approaches notes the use of geographic information system (GIS) and drone-based technologies for mapping risk exposure and impacts, mobile-based payments for post-disaster compensation, and transnational initiatives and learning networks to promote urban resilience (Izumi et al., 2019). Furthermore, technology-based innovations, such as using big data (Yu et al., 2018b), improved warnings through mobile phones or mobilising relief through social media (Carley et al., 2016), are proving effective for disaster preparedness, relief and recovery. Community-based DRR is consistently ranked as most effective for its role in transforming DRR towards being more context relevant and inclusive. Ecosystem-based DRR (EbDRR) is also gaining prominence and includes strategies such as mangrove plantation and rejuvenation in vulnerable coastal areas. Nature-based solutions for flood protection and reducing drought incidence have emerged as an alternative to costlier 'hard' infrastructure (UN-Water, 2018; Zevenbergen et al., 2018; Rozenberg and Fay, 2019). Some cities are also reporting adaptation to heat risk. For example, Ahmedabad (India) has pioneered preparedness for extreme temperatures and heatwaves by developing annual Heat Action Plans, building regulations to minimise trapping heat, advisories about managing heat stress and instituting a cool-roofs policy (Ahmedabad Municipal, 2018).

Financing, regulations and institutional processes play a significant role in incentivising DRR and resilience in large-scale, city-level built infrastructure by the private sector and other actors. Currently there are gaps in these mechanisms, leading to infrastructure development in disaster-prone areas, increasing exposure to people, property, economy and systems (Jain, 2013). Both firms and governments need to take disaster risks into consideration in supply-chain management to avoid disruptions and subsequent negative effects (Abe and Ye, 2013). There are several institutional challenges faced during DRR and CCA implementation including overlapping efforts and inefficient use of scarce resources due to inappropriate funding mechanisms, a lack of coordination and collaboration, a lack of implementation and mainstreaming, scale mismatches, poor governance, the social–political–cultural structure, competing actors and institutions, and lack of information, communication, knowledge sharing, and community involvement, as well as policy gaps (Seidler et al., 2018; Islam et al., 2020).

10.4.6.5 Enabling Urban Adaptation Across Asia

There is growing empirical evidence of conditions enabling and constraining urban adaptation (Table 10.3) with relatively more literature from South, Southeast and East Asia. Governance and capacity-related deficits are repeatedly identified as significant barriers to urban adaptation (*robust evidence, high agreement*) and interact with financial and informational constraints to mediate adaptation action.

10.4.7 Health and Well-Being

Climate change is increasing risks to human health in Asia by increasing exposure and vulnerability to extreme weather events such as heatwaves, flooding and drought, and air pollutants, increasing vector- and water-borne diseases, undernutrition, mental disorders and allergic diseases (*high confidence*). Sub-regional diversity in socioeconomic and demographic contexts (e.g., ageing, urban compared with agrarian society, increasing population compared with reduced birth rate,

11 The set of technical, financial and institutional capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organisations threatened by a hazard to prepare to act promptly and appropriately to reduce the possibility of harm or loss. Depending on context, EWS may draw upon scientific and/or Indigenous knowledge. These EWS are also considered for ecological applications (e.g., conservation, where the organisation itself is not threatened by hazard but the ecosystem under conservation is; an example is coral bleaching alerts), in agriculture (e.g., warnings of ground frost and hailstorms) and in fisheries (e.g., storm and tsunami warnings) (IPCC, 2018a).

Table 10.3 | Barriers and enablers to climate adaptation across Asian cities

Indicator	As an enabler	As a barrier
Governance and planning	National policy directives to adapt: for example, strong national climate commitments in China, India and Thailand (Dulal, 2019); and dedicated public–private councils on climate change in Seoul, Republic of Korea (Lee and Painter, 2015) Participatory planning, co-producing solutions and engaging multiple stakeholders: for example, Surat (Anguelovski et al., 2014; Karanth and Archer, 2014; Chu et al., 2017) and Guwahati (Archer et al., 2014) in India; Bandar Lampung and Semarang in Indonesia (Archer et al., 2014); and Seoul, Republic of Korea (Lee and Painter, 2015) Devolving decision making to city governments (ADB, 2013) and strong political leadership helps to institutionalise adaptation programmes (Anguelovski et al., 2014; Friend et al., 2014; Lee and Painter, 2015): for example, in Moscow where the city mayor has spearheaded climate action (van der Heijden et al., 2019). Mainstreaming climate adaptation in city plans (UN-HABITAT and UNESCAP, 2018)	Low accountability and transparency in planning processes with inadequate spaces for public dialogue (Friend et al., 2014) and limited accountability to the most economically and politically marginalised people within cities (Garschagen and Marks, 2019) Of 180 urban adaptation interventions across Asia, 65% are reactive in nature (Dulal, 2019), thus missing opportunities for risk prevention and preparedness (Francisco and Zakaria, 2019). Lack of forward-looking, learning-oriented processes constrain adaptation with short-term development priorities often overshadowing long-term climate-action needs (Friend et al., 2014; de Leon and Pittock, 2017; Gajjar et al., 2018; Khaling et al., 2018; Garschagen and Marks, 2019; Jain et al., 2021). Fragmented governance, lack of mainstreaming between CCA and DRR (Fuhr et al., 2018; Khaling et al., 2018): for example, in Vietnam, Thailand, Indonesia (Friend et al., 2014) and greater Manila (Meerow, 2017)
Information	Knowledge sharing through transnational municipal networks such as C40, ACCRN and A-PLAT (Fünfgeld, 2015) City-level knowledge creation and knowledge-transfer institutions (Lee and Painter, 2015)	Data gaps on projected climate risks and impacts in certain sub-regions and small settlements (Revi et al., 2014) Numerous tools for assessing vulnerability and adaptation planning (Nordgren et al., 2016)
Technology and infrastructure	Early warning systems, climate information and modelling studies inform adaptation decision making (Reed et al., 2015; Singh et al., 2018a)	Inadequate regional downscaled data at the city scale (ADB, 2013; Khaling et al., 2018); inadequate cost–benefit analyses of different adaptation strategies (Khaling et al. 2018)
Capacity and awareness	A focus on learning, experimentation, awareness and capacity building leads to more sustained, legitimate and inclusive adaptation (ADB, 2013; Anguelovski et al., 2014; Reed et al. (2015).	Limited access to, and capacity to use, risk assessment tools (ADB, 2013; Shaw et al., 2016b)
Finance	Dedicated adaptation financing (e.g., in Beijing, adaptation spending is 0.33% of the city's GDP) (Georgeson et al., 2016); steering international and local funding to leverage adaptation benefits in urban development programmes such as in Surat (India) (Cook and Chu, 2019); mainstreaming climate adaptation into development programming to leverage developmental finance for adaptation action (Cuevas et al., 2016; Narender and Sethi, 2018)	Inadequate adaptation funding and lack of financial devolution to city governments (Fuhr et al., 2018; Garschagen and Marks, 2019)

high income compared with low to middle income), and geographic characteristics, largely define the differential vulnerabilities and impacts in Asia (*high confidence*).

10.4.7.1 Observed Impacts

High temperatures affect mortality and morbidity in Asia (*high confidence*). In addition to all-cause mortality (Dang et al., 2016; Chen et al., 2018e), deaths related to circulatory, respiratory, diabetic (Li et al., 2014b) and infectious diseases (Ingole et al., 2015), as well as infant mortality (Son et al., 2017), are increased with high temperature (*high confidence*). Increased hospital admissions (Giang et al., 2014; Lin et al., 2019) and ambulance transport (Onozuka and Hagihara, 2015) coincide with increased ambient temperature (*high confidence*). Heatwaves are particularly detrimental to all-cause and cause-specific mortality (Chen et al., 2015a; Lee et al., 2016; Guo et al., 2017b; Yin et al., 2018). Both rural and urban populations are vulnerable to heat-related mortality (Ma et al., 2015; Chen et al., 2016a; Wang et al., 2018a). Individuals with lower degrees of education and socioeconomic status, older individuals and individuals living in communities with less green space are more susceptible to heat-related mortality (*high confidence*) (Yang et al., 2012a; Huang et al., 2015b; Seposo et al., 2015; Son et al., 2016; Kim and Kim, 2017). These heat effects have been attenuating over recent decades in East Asian countries, although the driving force behind this remains unknown (*high confidence*) (Chung et al., 2017c; Chung et al., 2018).

Rising ambient temperature accelerates pollutant formation reactions and may modify air-pollution-related health effects (*medium confidence*). Higher temperatures are associated with the increased effects of ozone on mortality (Shi et al., 2020). Climate change causes intensified droughts and greater wind erosion resulting in increased intensity and frequency of sand and dust storms (Akhtar et al., 2018). Mortality and hospital admissions for circulatory and respiratory diseases are increased after exposures to Asian dust events (*high confidence*) (Hashizume et al., 2020). El Niño has a major influence on weather patterns in various regions. For example, it causes dry conditions that sometimes result in forest fires and transboundary haze that increased all-cause mortality in children by 41% in Malaysia (Sahani et al., 2014).

Ambient temperature is associated with the risk of an outbreak of mosquito-borne disease in South and Southeast Asia (*high confidence*) (Servadio et al., 2018). Warmer climates are associated with a higher incidence of malaria (Xiang et al., 2018). Moderate rainfall also promotes malaria infection, while excessive rainfall decreases the risk of malaria (Wu et al., 2017b). El Niño intensity is positively associated with malaria incidence in a single year in India (Dhiman and Sarkar,

10

2017). The duration and survival rate of dengue mosquito development, mosquito density, mosquito biting activity, mosquito spatio-temporal range and distribution, and mosquito flying distance are all affected by temperature (*high confidence*) (Li et al., 2018b). Temperature, precipitation, humidity and air pressure are major weather factors associated with dengue fever transmission (*high confidence*) (Sang et al., 2014; Choi et al., 2016; Xu et al., 2017).

Climate change alters the hydrological cycle by increasing the frequency of extreme weather events such as excess precipitation, storm surges, floods and droughts (*high confidence*). Water-borne diseases, such as diarrhoea, leptospirosis and typhoid fever, can increase in incidence following heavy rainfall, tropical cyclones and flooding events (*high confidence*) (Deng et al., 2015; Levy et al., 2016; Li et al., 2018b; Matsushita et al., 2018; Zhang et al., 2019b). Droughts can cause increased concentrations of pathogens, which overwhelm water-treatment plants and contaminate surface water. A positive association between ambient temperature and bacterial diarrhoea has been reported, compared with a negative association with viral diarrhoea (Carlton et al., 2016; Wang et al., 2018c).

Asia has the highest prevalence of undernourishment in the world, which was 11.4% in 2017, representing more than 515 million people. Southeast Asia has been affected by adverse climate conditions such as floods and cyclones, with impacts on food availability and prices (FAO, 2018d). Crop destruction due to tropical cyclones can include salt damage from tides blowing inland (*medium confidence*) (Iizumi and Ramankutty, 2015). Sea level rises result in intrusion of saline water into the coastal area of Bangladesh and people living in this area face an increased risk of hypertension resulting from high salt consumption (Scheelbeek et al., 2016).

Weather conditions have been linked to mental health. High temperatures increase the risk of mental problems including mental disorders, depression, distress and anxiety in Vietnam (Trang et al., 2016), Hong Kong SAR of China (Chan et al., 2018) and the Republic of Korea (Lee et al., 2018d). In addition, high temperatures are reported to increase the risk of mortality from suicide in Japan, the Republic of Korea, Taiwan, Province of China (Kim et al., 2016c), India (Carleton, 2017) and China (Luan et al., 2019). Extreme weather events, such as storms, floods, hurricanes and cyclones, increase injuries and mental disorders (post-traumatic stress disorder and depressive disorders) (Rataj et al., 2016), thereby negatively affecting well-being (*high confidence*).

Higher temperatures and increased CO_2 elevate the level of allergens such as pollen, which can result in increased allergic diseases, such as asthma and allergic rhinosinusitis. The association between variations in ambient temperature and the occurrence of asthma has been reported in several Asian countries/regions such as Japan (Yamazaki et al., 2015), the Republic of Korea (Kwon et al., 2016), China (Li et al., 2016a) and Hong Kong SAR of China (*medium confidence*) (Lam et al., 2016).

10.4.7.2 Projected Impacts

Climate change is associated with significantly increased mortality (*high confidence*). Figure 10.11 shows projected health impacts due to climate change in Asia. The global estimates of excess deaths due to malnutrition, malaria, diarrhoea and heat stress will be approximately 250,000 deaths per year in 2030–2050 under the medium-to-high emissions scenario, assuming no adaptation (World Health Organization, 2014). The impacts are expected to be greatest in South, East and Southeast Asia. Another projection showed that the change in heat-related deaths is largest in Southeast Asia, which was a 12.7% increase at the end of the century under a high-emissions scenario (Gasparrini et al., 2017). As the proportion of older individuals in the population rises, the number of years lost due to disability increases more steeply (Chung et al., 2017b). In the 2080s, the number of annual temperature-related deaths is estimated to reach twice that in the 1980s in China (Li et al., 2018c). Over a 20-year period in the mid-21st century (2041–2060), the incidence of excess heat-related mortality in 51 cities in China is estimated to reach 37,800 (95% CI: 31,300–43,500) deaths per year under RCP8.5 (Bazaz et al., 2018).

Increased concentrations of fine particulate matter and ozone influenced by extreme events such as atmospheric stagnations and heatwaves are projected to result in an additional 12,100 and 8,900 deaths per year due to fine particulate matter and ozone exposure, respectively, in China in the mid-century under RCP4.5 (Hong et al., 2019a). Excess ozone-related future premature deaths is noticeable in 2030 in East Asia and India for RCP8.5 (over 95% of global excess mortality) (Silva et al., 2016).

The global estimates for increases in malaria and dengue deaths (annual estimates) are approximately 32,700 and 280 additional deaths, respectively, in 2050 under the medium-to-high emissions scenario (World Health Organization, 2014). Among these additional deaths, 9,300 and 200 deaths, respectively, are projected to occur in South Asia. The population at risk of malaria infection is estimated to increase by 134 million by 2030 in South Asia under the medium-to-high emissions scenario, considering socioeconomic development. If no actions are taken, malaria incidence in northern China is projected to increase by 69–182% by 2050 (Song et al., 2016). Another study suggested a decrease in climate suitability for malaria in northern and eastern India, southern Myanmar, southern Thailand, the Malaysia border region, Cambodia, eastern Borneo and Indonesia by 2050 (Khormi and Kumar, 2016). By contrast, climate suitability for malaria is projected to increase in the southern and southeast mainland of China and Taiwan, Province of China (Khormi and Kumar, 2016).

Dengue incidence is projected to increase to 16,000 cases per year by 2100 in Dhaka, Bangladesh, if ambient temperatures increase by 3.3°C without any adaptation measures or changes in socioeconomic conditions (Banu et al., 2014). This would represent an increase in incidence of over fortyfold compared with 2010. Higher numbers of dengue fever cases are projected to occur under RCP8.5 than RCP2.6 in China (Song et al., 2017). Compared with the average numbers in 1997–2012, the annual number of days suitable for dengue fever transmission in the 2020s, 2050s and 2080s will increase by 15, 25 and 40 d, respectively, in southern China under RCP8.5. In addition, areas in which year-round dengue fever epidemics occur will *likely* increase by 4500, 8800 and 20,700 km^2 in the 2020s, 2050s and 2080s, respectively, under RCP8.5 (Nahiduzzaman et al., 2015).

The global estimates for increases in deaths due to diarrhoeal disease (annual estimates) in children under 15 years in 2030 and

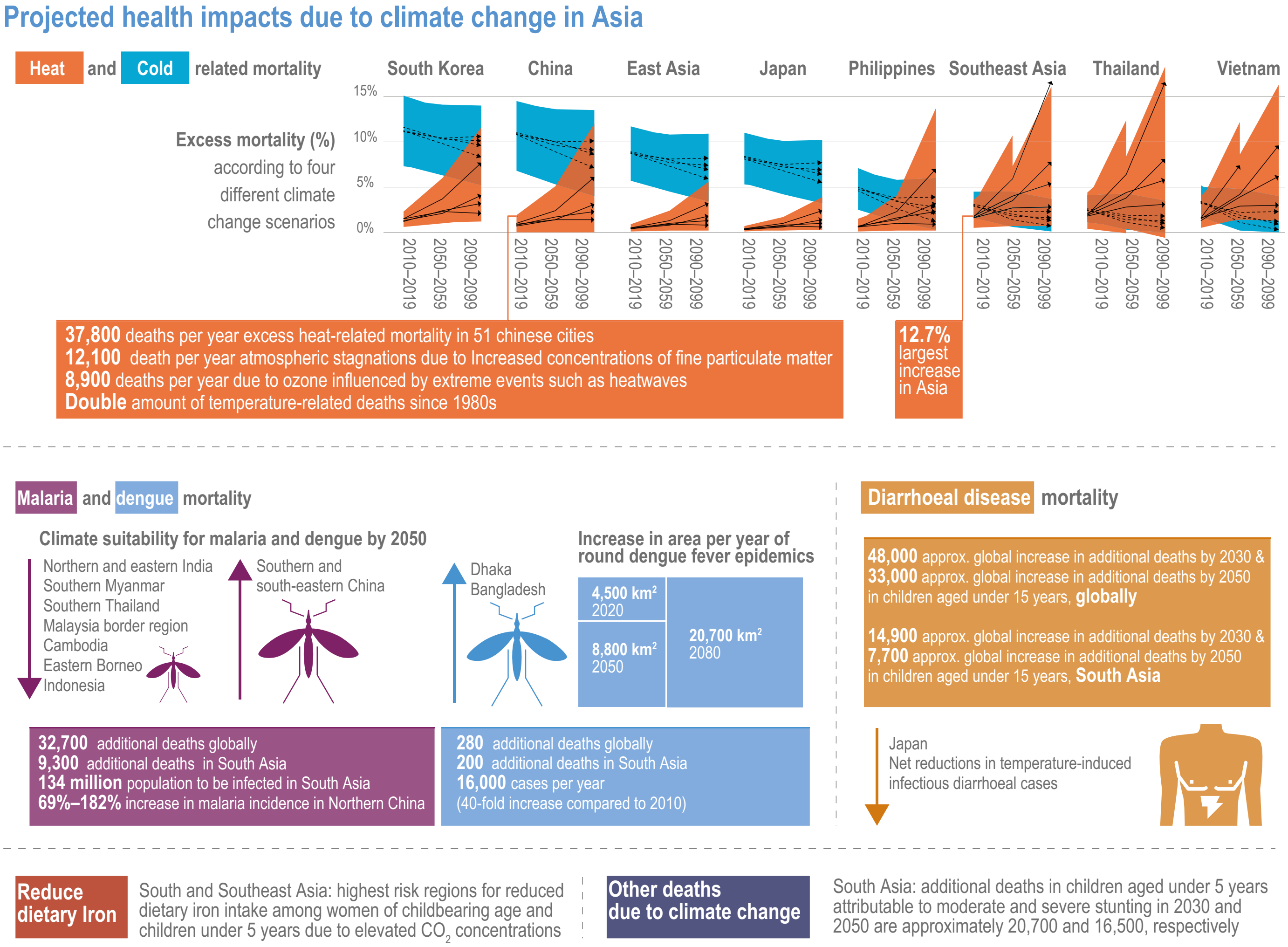

Figure 10.11 | Projected health impacts due to climate change in Asia.

2050 are approximately 48,000 and 33,000 additional deaths, respectively, under the medium-to-high emissions scenario (World Health Organization, 2014). Among these additional deaths, 14,900 and 7,700 deaths, respectively, are projected to occur in South Asia. An updated projection with a pathogen-specific approach estimated 25,000 additional annual diarrhoeal deaths in Asia in 2080–2095 under the high-emissions scenario (Chua et al., 2021), while in some countries, such as Japan, net reductions in temperature-induced infectious diarrhoeal cases were estimated, because viral infections are dominant in these countries during the cold season (Onozuka et al., 2019).

South and Southeast Asia are projected to be among the highest-risk regions for reduced dietary iron intake among women of childbearing age and children under five years due to elevated CO_2 concentrations (*medium confidence*) (Smith and Myers, 2018). The estimated number of additional deaths due to climate change in children aged under five years attributable to moderate and severe stunting in 2030 and 2050 are approximately 20,700 and 16,500, respectively, in South Asia, under the medium-to-high emissions scenario (World Health Organization, 2014). In Bangladesh, due to climate change, river salinity is projected to be increased in coastal and freshwater fishery communities leading to significant shortages of drinking water in the coastal urban areas (Dasgupta et al., 2014c).

10.4.7.3 Adaptation Options/Co-benefits

The health co-benefits of GHG mitigation measures in energy generation have been reported to reduce disease burden. In China, the implementation of GHG policies would reduce the air-pollution-associated disease burden by 44% in 2020 under the Integrate Carbon Reduction scenario compared with the business-as-usual scenario (Liu et al., 2017b). Transition to a half-decarbonised power supply for the residential and transport sectors would prevent 55,000–69,000 deaths in 2030 compared with the business-as-usual scenario (Peng et al., 2018). A shift in travel modes from private motor vehicles to the use of mass rapid-transit lines is estimated to reduce CO_2-equivalent emissions by 6% in greater Kuala Lumpur and bring important health co-benefits to the population (Kwan et al., 2017). The 25 measures developed for reducing air pollution levels in Asia and the Asia–Pacific in general would reduce CO_2 emissions in 2030 by almost 20% relative to baseline projections and decrease warming by 0.3°C by 2050, which could eventually reduce heat-related excess deaths in the region (UNEP, 2019). The 25 measures include conventional emissions controls focusing on emissions that lead to the formation of fine particulate matter (PM2.5), next-stage air-quality measures for reducing emissions that lead to the formation of PM2.5 and are not yet major components of clean-air policies in many parts of the region, and measures contributing to development-priority goals with benefits for air quality. Health co-benefits outweigh mitigation costs in the Republic of Korea up to 2050 (Kim et al., 2020). Low-carbon pathways consistent with the 2°C and 1.5°C long-term climate targets defined in the Paris Agreement are associated with the largest health co-benefits when coordinated with stringent air pollution controls in Asia followed by Africa and Middle East (Rafaj et al., 2021).

Strategies to increase energy efficiency in urban environments by compact urban design and circular-economy policies can reduce GHG emissions and reap ancillary health benefits; for example, compared with conventional single-sector strategies, national CO_2 emissions can be reduced by 15–36%, and the annual deaths from 25,500 to 57,500 are avoidable from air pollution reduction in 637 Chinese cities (Ramaswami et al., 2017). In a city in China, the existing mitigation policies (e.g., promotion of tertiary and high-tech industry) and the one-adaptation policy (increasing resilience) increased the co-benefits for well-being (Liu et al., 2016a).

Changing dietary patterns, particularly reducing red meat consumption and increasing fruit and vegetable consumption, contributes to reduced GHG emissions as well as reduced premature deaths. The adoption of global dietary guidelines was estimated to prevent 5.1 million deaths per year relative to the reference scenario in which the largest number of avoidable deaths occurred in East Asia and South Asia, and GHG emissions would be reduced most in East Asia (Springmann et al., 2016). In China, dietary shifts to meet national dietary reference intakes reduced the daily carbon footprint by 5–28% depending on the scenario (Song et al., 2017). In India, the optimised healthy diets (e.g., lower amounts of wheat and increased amounts of legumes) could help reduce up to 30% water use per person for irrigation and reduce diet-related GHG emissions. This would result in 6800 life-years gained per 100,000 population in 2050 (Milner et al., 2017).

10.5 Adaptation Implementation

10.5.1 Governance

10.5.1.1 Points of Departure

Climate-change governance is characterised by a scalar/stakeholder turn which includes: (a) acknowledgement of the importance of both subnational and transnational–regional scales along with the global scale; (b) involvement of diverse stakeholders in decision-making systems; (c) reliance on bottom-up architectures of governance that are supported by the framework given by the SDGs; (d) emphasis on developmental and environmental co-benefits; (e) recognition of diverse experiences of marginalisation and social stratification, and their impacts on participation in governance-related activities; and (f) greater decentralisation and strengthening of local institutions.

10.5.1.2 Findings

In order to facilitate local adaptation, especially in a context characterised by regional diversity and spatio-temporal variation, climate-adaptive governance invites greater policy attention to institution building (formal and informal) at multiple scales and across sectors (Mubaya and Mafongoya, 2017). An incremental EbA approach underlines the advantage of drawing upon ecosystem services for reducing vulnerabilities, increasing resilience of communities to adapt to climate change, and minimising threats to social systems and human security, provided climate change remains below 2°C or, better yet, below the 1.5°C of global warming (Barkdull and Harris, 2018).

Focus on multi-level governance, both below and beyond the state level, is steadily growing (Jogesh and Dubash, 2015; Jörgensen et al., 2015; Beermann et al., 2016). Discernible diversity across political systems and sectors in Asia notwithstanding, issues relevant to multi-level climate governance includes interplay between top-down national initiatives, which stem from supranational, regional and sub-regional levels. In the case of India, national climate governance has proliferated beyond the National Action Plan on Climate Change to include State Action Plans on Climate Change of over 28 states and union territories, demonstrating graphically the shared ‘co-benefit’ in terms of creating greater space for innovation and experimentation (Jörgensen et al., 2015).

In Japan’s Climate Change Adaptation Act, enacted by the Japanese Diet in June 2018, the national government shall formulate a national action plan to promote adaptation in all sectors. This Act recommends that prefectures and municipalities designate a ‘local climate change adaptation centre’ as a local climate-change data collection and provision centre to provide more locally specific information and support for adaptation planning at the level of local municipalities. The Japanese government, in partnership with the private sector, has formulated a new comprehensive strategy, named Society 5.0, which aims at devising a number of technologically innovative solutions (Mavrodieva and Shaw, 2020).

Significantly, the co-benefit concept for international city partnerships along with comparative analysis of the challenges, capabilities and limitations of urban areas in Asia with regard to CCA governance remains under-researched (Beermann et al., 2016).

In the case of Vietnam, especially at district and community levels, where the policy capacities in hierarchical governance systems to deal with climate-change impacts are generally constrained, the value of clear legal institutions, provision of financing for implementing policies and the training opportunities for governmental staff has been well demonstrated (Phuong et al., 2018b). A key finding is that any effort to support local actors (i.e., smallholder farmers) should ensure augmentation of policy capacity through necessary investments.

In the case of China, a combination of market-based policies, emissions trading systems, a growing number of environmental non-governmental organisations (NGOs) and international networks appear to be serving as an important tool for climate governance (Ramaswami et al., 2017; Wang et al., 2017b). Public private partnership (PPP) too is receiving increasing focus, especially with regard to climate-related cost-effective and innovative infrastructure projects. In the absence of major investments in resilience, climate change may force up to 77 million people into a poverty trap by 2030 (World Bank, 2016). As seen in the case of Japan, most of the countries in Asia face the challenge of contractual allocation of risks associated with natural hazards and climate change between the public and private sectors and its long-term management in the face of uncertainty. Risk sharing, therefore, could be addressed by clear definition and allocation (World Bank, 2017). Given that in Asia, especially Singapore, China, Japan and Republic of Korea, where the water sector is a target of industrial and technology policy, PPPs could prove to be mutually beneficial. As a middle ground, key findings of a study on Indonesia (Yoseph-Paulus and Hindmarsh, 2016) underline the importance of building, sustaining and augmenting local capacity by addressing inadequacies with regard to resource endowment and capacity building, public awareness about climate change, government–community partnerships, vulnerability assessment and providing inclusive decision-making spaces to Indigenous knowledge systems and communities.

In the agriculture sector, farmers in Asia are adapting to climate change at the grassroots level (Tripathi and Mishra, 2017). A recent, comprehensive and systematic review (Shaffril et al., 2018) shows how farmers in diverse sub-regions of Asia have adopted diverse adaptation strategies through management of crops, irrigation and water, farms, finances, physical infrastructure and social activities. Much more qualitative research on farmers' perceptions and decision-making processes about adaptation practices is needed in order to capture their location-specific priorities and get a diverse understanding of the risks and threats. A study of Vietnamese smallholder farmers' perceptions of their current and future capacity to adapt to climate change (Phuong et al., 2018a) found considerable differences between farmers in crop production and livestock production in terms of their motives behind adopting particular planned adaptation options.

A study on farmers' awareness of, and adaptation to, climate change in the dry zones of Myanmar, critically dependent on agriculture, indicates how those at the front line of the adverse effects of climate change are steadily abandoning the common sesame/groundnut cropping pattern, and trying to adapt to risks and uncertainties with the aid of conventional agricultural practices such as rainwater collection, water-harvesting techniques and even traditional weather forecasting techniques for weather prediction. Similarly, a case study of the Gandak basin in Nepal showed that incorporation of local knowledge into agricultural practices and weather warning systems works best when coupled with multiple sources of information based on a method of triangulation. This also intersects with gender outcomes, where women frequently receive information from the men of their households rather than directly from state institutional sources (Acharya and Prakash, 2019). Climate-change adaptive governance is facilitated by improved cross-scalar and cross-sectoral cooperation, exchange of information and experiences, and best practices (Smith et al., 2014; Watts et al., 2015; Gamble et al., 2016; Gilfillan et al., 2017).

An integrated approach informed by science, which examines multiple stressors along with Indigenous knowledge, appears to be of immense value (Elum et al., 2017). A study on Pakistan concluded that poor agricultural communities are among the worst victims of climate change (Ali and Erenstein, 2017) and that farmers who are younger, better educated, belong to joint families and possess more landholdings are *likely* to adapt sooner and better. Correspondingly, this category achieved higher levels of income and food security. The climate-development nexus suggests that CCA practices at the farm level can have significant development outcomes, besides reducing risk posed by changing weather patterns. Central to the CCA process is the growing recognition of the role that institutions play in both the hierarchical setting and across different scales to influence implementation of CCA in diverse areas of governance across social and political domains. Cuevas (2018) highlights the usefulness of mainstreaming CCA into local land-use planning in Albay, the Philippines, by involving networks of interacting institutions and institutional arrangements for overcoming obstacles that are potentially counterproductive and conflictual.

As noted by AR5 (IPCC, 2014a), research on issues related to both climate-change impacts on livestock production–demand for which is expected to double by 2050 in a world of 10 billion people–and policy choices with regard to adaptation, especially at the local scale, is still limited but progressing (Rojas-Downing et al., 2017). The promise of diversification of livestock animals (within species), crop diversification and transition to mixed crop–livestock systems needs to be further explored. A study of livestock farmers in Pakistan showed that risk-coping mechanisms, such as purchasing livestock insurance and increasing land areas for fodder, are far more rewarding policy options in comparison with selling livestock and migrating to another place. Relatedly, the association of migration with adaptation measures is context specific and involves a number of factors pertaining to the socioeconomic circumstances of vulnerable agricultural groups in countries like India and Bangladesh (Ojha et al., 2014). In the 2010 United Nations Framework Convention on Climate Change's Cancun Adaptation Framework, migration was recognised as a form of adaptation that should be included in a country's long-term adaptation planning where appropriate (Paragraph 14 f).

Furthermore, agricultural climate-adaptation policy targeting livestock farmers in rural areas is *very likely* to benefit from better education and awareness as well as increased access to extension services among livestock farmers on climate risk-coping choices and strategies (Rahut and Ali, 2018). In Myanmar, the lack of adequate agricultural extension strategies has had a negative impact on adaptation outcomes in what is labelled the 'central dry zone'. Farmers' perceptions of climate change contribute to a comprehensive understanding of the context where they identify deforestation and related activities as the main culprits. Their adaptive methods include agricultural land preparation and crop rotation practices in addition to rainwater-harvesting techniques (Swe et al., 2015). A study of vulnerable areas in Bangladesh (Alam et al., 2017) has shown that with policy support, livestock rearing can prove to be a viable substitute for crop production in areas prone to riverbank erosion. Carefully developed partnerships between government organisations and NGOs can come to the rescue of poor farmers and their precarious households by providing information about best practices for local adaptation strategies, including credit options with various institutions and creating an enabling environment for the promotion of agro-based industries. A study in community forestry in the Indian Himalayan region (Gupta and Koontz, 2019) has shown how the synergies and successful partnerships could evolve between government and NGOs in local forest governance, with the former providing technical and financial support, and the latter directing the communities to those resources, and in the making up for each other's limitations thereby enabling and augmenting community efforts in forest governance.

A study of Pakistan (Ali and Erenstein, 2017) shows that factors such as enhanced awareness about various climate risk-coping strategies, better education and agricultural extension services, augmenting farm-household assets, lowering the cost of adaptation, improving access to services and alternative livelihoods, and providing support to poorer households appear to have paid rich dividends. Countries such as Bhutan and Sri Lanka have included provisions for 'climate-smart agriculture' in their nationally determined contributions (NDCs) (Amjath-Babu et al., 2019).

In the domain of forest adaptive governance, ever since the introduction of Reducing Emissions from Deforestation and forest Degradation plus (REDD+) at COP 13 in 2007 in Bali, the Indonesian experience suggests that some of the major challenges include curbing emissions, changes in cross-sectoral land-use as well as practice within forestry and lack of effective, efficient and equitable implementation of diverse forest governance practices. The issue of how forest governance institutions are conceived and managed, both at national and subnational levels, involving state, private sector and civil society, also needs serious attention (Agung et al., 2014).

In an example from Nepal, Clement (2018) showed that deliberative governance mechanisms can create the space for alternative framings of climate change to take a hold in ways that are cognisant of both the local and global contexts; this moves beyond a dependence on techno-managerialism in the construction of solutions, where local governance solutions can support institutional changes. The possibilities more incorporating deliberative methods into wider governance architecture are also expanded through an acknowledgment of the role of social learning; this is observable in the multi-stakeholder involvement that this approach fosters in regions of South Asia such as the Brahmaputra River basin (Varma and Hazarika, 2018). Additionally, recent studies have reconfirmed the importance of linking Indigenous knowledge with the scientific knowledge of climate change in diverse regions of the globe, including Asia and Africa (Hiwasaki et al., 2014; Etchart, 2017; Taremwa et al., 2017; Vadigi, 2017; Apraku et al., 2018; Inaotombi and Mahanta, 2018; Makondo and Thomas, 2018) for building farmers' resilience, enhancing CCA, ensuring cross-cultural communication, promoting local skills, drawing upon Indigenous Peoples' intuitive thinking processes and geographic knowledge of remote areas.

A study of the Sylhet Division in Bangladesh, deploying a knowledge quality assessment tool, found significant correlation between a narrow technocratic problem framing, divorced from traditional knowledge strongly rooted in local sociocultural histories and relatively low project success due to skewed risk-based calculations disconnected from the ground realities (Haque et al., 2017; Wani and Ariana, 2018). Highlighting the vulnerability of the Bajo tribal communities, who inhabit the coastal areas of Indonesia, to climate change, the study showed how they share several examples of their Indigenous knowledge and traditions of marine resource conservation, and how this wisdom, a valuable asset for climate adaptation governance, has been passed from generation to generation through oral tradition.

10.5.1.3 Knowledge Gaps and Future directions

One of the major knowledge gaps in the domain of climate adaptation governance relates to implementation by various stakeholders at multiple scales, and sharing of information and experiences in this regard. There is a need to assuage the perceptions of distrust in global information, through governance methods that engage multiple stakeholders in open and lucid channels of communication (Stott and Huq, 2014). This is observable in the structure of the New Urban Agenda which formed part of the SDGs pertaining to cities and has been shaped by a bottom-up process marked by diverse participation including communities, experts and activists, rather than the top-down variant that is observable in the Millenium Development Goals (Barnett and Parnell, 2016). This approach could also be evidenced in the Paris Agreement, which placed the onus of a successful global governance regime on the development of efficient systems of regional governance. However, these emerging systems of regional governance could equally pose a challenge to the global governance in a way that can be witnessed through the development of financial groups such as the BRICS (associated economies of Brazil, Russia, India, China and South Africa) and Asian Infrastructure Investment Bank, which resulted from a perception of inadequate institutional transformation at the global level. From another perspective, a comprehensive approach would require simultaneous implementation of both bottom-up and top-down models of governance, retaining flexibility of scale.

Given the concerns surrounding food security, especially in light of the principles of common but differentiated responsibilities, under the NDCs submitted by South Asian nations under the Paris Agreement, emission reduction commitments are *less likely* to include the agriculture sector. Prospects for enhancing both adaptive capacity and food security could be improved by strengthening resilience and profitability through the introduction of a basket of policy choices and actions including structural reforms, agriculture value-chain interventions and landscape-level efforts for climate resilience. Correspondingly, the substantial adaptation finance gap could be closed with the help of both private finance (autonomous adaptation) and international financial transfers (Amjath-Babu et al., 2019).

For nearly five decades, integrated coastal management (ICM), advocated by several international organisations (e.g., IMO, UNEP, WHO, FAO) and adopted by over 100 countries, has been acknowledged as a holistic coastal governance approach aimed at achieving coastal sustainability and reducing the vulnerability of coastal communities in the face of multiple environmental impacts (*high confidence*). In view of threats posed to coastal ecological integrity by climate-change-induced tropical storm activity, accelerated SLR and littoral erosion and social–ecological impacts on the livelihood security of vulnerable coastal communities, the pressing need for approaches that innovatively combine coastal zone management and CCA measures is widely acknowledged (Rosendo et al., 2018) yet under researched. A study focusing on the three coastal cities of Xiamen, Quanzhou and Dongying, in China, a country with nearly 12% of its national coastline already covered under the ICM governance framework, suggests that

Box 10.5 | Bangladesh Delta Plan 2100

The Bangladesh Delta Plan (BDP) 2100 is the plan moving Bangladesh forward for the next 100 years. We have formulated BDP 2100 in the way we want to build Bangladesh. (Commission, 2018).

The vision of BDP is revealed by the foregoing statement from Sheikh Hasina, the prime minister of Bangladesh. The government approved BDP 2100 in 2018. Achievement of a safe, climate-resilient and prosperous delta is the aspiration of the delta plan. Ensuring water and food security with economic growth, environmental sustainability, climate resilience, vulnerability reduction to natural hazards and minimising different challenges of the delta through robust, adaptive and integrated strategies, and equitable water governance, are the mission of this mega plan. Under this mission, three higher-level goals and six specific goals have been determined. Three higher-level goals include elimination of extreme poverty by 2030, achievement of upper middle-income status by 2030 and becoming a prosperous country beyond 2041. Six specific goals of BDP 2100 are fully linked with SDG Goals 2, 6, 13 and 14 and partially linked with Goals 1, 5, 8, 9, 11 and 15. These specific goals comprise a wide range of issues, including land and water resources, climate change, disaster, wetlands and ecosystems, river systems and estuaries. The vision, mission and goals of BDP 2100 reveal that this mega plan is a holistic and integrated approach considering diversified themes and sectors for the whole country. The implementation of the BDP 2100 requires total spending of an amount of about 2.5% of the GDP per annum. A series of strategies have been formulated for better implementation of the mega plan.

Water is the key and complicated resource of Bangladesh, and therefore BDP 2100 has kept water at the centre of the plan. It aims to promote wise and integrated use of water and other resources through development of effective institutions and equitable governance for in-country and transboundary water resource management.

Along with water, for the first time in any development planning, BDP 2100 has taken the climate-change issue as an exogenous variable in developing the macroeconomic framework of the plan. In a brief, it is stated that the principle of BDP 2100 is 'Living with Nature'.

whereas the ICM approach has been found to be effective in promoting the overall sustainability of China's coastal cities (Ye et al., 2015) using accurate and reliable data, in addition, the developing unified standards could usefully reveal changing conditions and parameters related to ICM performance.

Steadily the regional scale of climate adaptive governance is acquiring salience in diverse sub-regions of Asia, and more policy-oriented empirical research is needed on how various regional forums, agencies and multilateral organisations could further contribute by way of in-house expertise and other resources, including financial. A study of climate adaptation in the health sector in Southeast Asia (Gilfillan, 2018) highlights the growing role of the Asian Development Bank (ADB) and the Asia-Pacific Regional Forum on Health and Environment, and shows that their mandates and goals could mutually benefit from the institutionalisation of coordination mechanism. An example from the Maldives shows that the 2014 Tsunami, climate change and the risk of extreme weather events have led to the legitimisation of state-led population resettlement programmes. In China, this has occurred through the renaming of previously existing resettlement initiatives as climate adaptation initiatives; however, the efficacy of resettlement as a CCA measure requires further scrutiny (Arnall, 2019). In India, the National Adaptation Fund on Climate Change has been instituted in order to enable states to implement adaptation programmes; however, this does not address the question of mainstreaming CCA into designs for development (Prasad and Sud, 2019). This is closely related to the development of National Adaptation Programmes of Action (NAPAs) where the mainstreaming of adaptation within countries has been an important concern. Insights from developing countries indicate that there is still much ground to cover. The NAPA of the Maldives prioritises food security, coastal resources and public health, while Nepal has prioritised ecosystem management and public health, and food security, among other concerns (Saito, 2013). Importantly, Bangladesh's NAPA has shown that there is potential for 'reflexivity' in the integration of adaptation objectives with sectoral objectives (Vij et al., 2018). Conspicuous by their absence are the transboundary-scale adaptation policies in South Asia (Vij et al., 2017).

A distinguishing feature of the case of Japanese apple growers is the co-existence of both top-down and bottom-up adaptation practices. The former pertains to farmers who rely on the support of the cooperative for agricultural support and follow institutional mechanisms. The latter pertains to non-co-op farmers who have been responsible for innovative practices of cultivation such as the shift to peaches and the sale in the market of apples without leaf-picking. Importantly, the non-co-op group also have access to sales channels that may not be accessible to the former owing to their direct interactions with customers, among other factors (Fujisawa and Kobayashi, 2011; Fujisawa et al., 2015). The significance of this combination of top-down and bottom-up approaches to agricultural adaptation practices may be further sharpened by formulating approaches for Asia and the Pacific region in ways that contribute to the fortification of food security objectives and the idea of co-benefits. This may be carried out by enhancing the ability of farmers to better manage cultivation practices in the context of climatic variability (FAO, 2018d).

There exist numerous barriers to the mainstreaming of CCA measures across Asia. The integration of CCA into the dissemination of localised climatic information and its uptake and implementation through institutional policy arrangements remain areas of concern (Cuevas, 2018). Institutional incentives to agricultural production, for instance, are frequently compounded by the negative impacts they have on existing bases of natural resources. The disconnected operations of local governmental agencies coupled with inadequacies of cross-sectoral coordination further highlights the prevalent food–water–energy nexus (Rasul, 2016). One possible way of addressing these intersecting sources' complexity is by locating emerging CCA measures in educational development. The introduction of CCA thinking into land-use planning in the Philippines is an example of the successful role of enhancing public education and awareness through the dissemination of information by institutional channels. The linkages between the strength of local leadership and the inclusion of CCA in localised planning activities are also well illustrated by the case study of Cuevas (2018).

As shown in the case of Pakistan, level of education shares a positive relationship with the implementation of adaptation measures (Ali and Erenstein, 2017). However, a closer examination of the educational imperatives that drive CCA in ways that improve the representational architecture of adaptation actions through a focus on gender is needed. Mainstreaming of gender into CCA would involve addressing a host of barriers to education and involvement that are often rooted in the differential structures of households, social norms and roles, and the domestic division of labour (Rao et al., 2019). A study from the Indian state of Bihar shows that gender plays a major role in determining intra-household decision making and also inhibits the ability of female-headed households to establish access to agricultural extension services (Mehar et al., 2016). Even within wider female farmer-operated federations, such as the Bangladesh Kishani Sabha (BKS), the barriers to participation stem from social factors that include the limitation of female mobility through the gendered division of labour and a lack of recognition of female agency (Routledge, 2015). Gendered inequalities in educational attainment and outcomes viewed through the lens of social vulnerability thus intersect with environmental vulnerabilities in ways that affect the ability of women to participate in CCA, owing also to a lack of access to health and sanitation facilities. These factors have a direct impact on the ability of adaptation to be effective in the global South, and are especially important in the context of the commitments of the UN Convention on the Elimination of All Forms of Discrimination Against Women countries to the objective of gender equality (Roy, 2018).

10.5.2 Technology and Innovation

10.5.2.1 Point of Departure

Much like any other field, CCA is greatly facilitated by science, technology and continuous innovation. These range from the application of existing science, to the development of new scientific tools and methods, to the utilisation of Indigenous knowledge and citizen science. Many of the pressing problems in Asia, including water scarcity, rapid urbanisation, loss of natural habitats, biodiversity, rising coastal and river basin hazards, and agricultural loss can be effectively minimised through the adoption of suitable scientific and technological methods. Despite the current challenges in the region, many significant advances in science and technology have been made, and the future prospects look bright. The following sections outline the present status and future prospects of science and technology in scaling up adaptation actions in four key sectors, namely (a) DRR, (b) urbanisation, (c) water and agriculture, and (d) forests and biodiversity.

10.5.2.2 Findings

10.5.2.2.1 Disaster risk reduction

Technological advances have enhanced the capabilities of Asian countries to monitor and prepare for climate-related hazards. Remote sensing technologies and GIS are widely used for DRR (Kato et al., 2017), for example, to assess and mitigate risks of an area to potential climate-related disasters (Wu et al., 2018b). The potential impacts of different types of hazards can be visualised using interactive maps (Lee, 2017), which help local communities to understand risks and find appropriate evacuation areas (Cadiz, 2018). These maps provide a situational overview and instant risk assessment (Yang et al., 2012b). As an emerging technology, artificial intelligence (AI) can identify conditioning factors of a landslide disaster (Hong et al., 2019b). Mobile virtual reality is used for disaster mitigation training through a three-dimensional visualisation of a past disaster (Ghosh et al., 2018).

A community-based DRR system provides risk investigation, training and information analysis (Liu et al., 2016b). Sharing information enhances establishment of such a system and contributes to disaster prevention (Nakamura et al., 2017). One example is an online mapping tool, which has been developed by volunteers (Sakurai and Thapa, 2017). Social media enables the population to access real-time information on a disaster (Ghosh et al., 2018), raises situation awareness (Yin et al., 2012) and empowers communities towards appropriate emergency actions (Leong et al., 2015). Among the various forms of social media, Twitter is widely used as a social sensor to detect what is happening in a disaster event (Sakaki et al., 2013). Accuracy of information on Twitter has been proved in collecting local details about floods (Shi et al., 2019b); however, it has been noticed that Twitter generates rumours as well (Ogasahara et al., 2019). Artificial intelligence is expected to reduce human error when they operate a decision-making system (Lin et al., 2018). Since technologies supporting DRR completely depend on electricity, the loss of power supply and communication constrains the recovery work in disaster-affected areas (Sakurai et al., 2014).

10.5.2.2.2 Urban sector

In the urban sector, a wide variety of sensor technologies are being used to monitor urban land-use and climate changes over time, and to better understand the potential impacts of future changes. These sensors range from large optical–thermal–radar satellite instruments with (near) global coverage—for example, Landsat (US Geological Service), Sentinel (European Space Agency), ALOS (Japan Aerospace Exploration Agency) and MethaneSAT—to portable sensors embedded in mobile phones (e.g., phone cameras or temperature sensors) whose data are collected into centralised databases through crowdsourcing (Fenner et al., 2017; Meier et al., 2017). To combine and extract useful information from these heterogeneous sensor data—for example, for conducting climate risk assessments (Perera and Emmanuel, 2018; Bechtel et al., 2019) and/or simulations of future land-use or climate changes in urban areas (Bateman et al., 2016; Iizuka et al., 2017; Liu et al., 2017c)–AI technologies (e.g., machine-learning algorithms) are now being widely adopted (Johnson and Iizuka, 2016; Joshi et al., 2016; Mao et al., 2017). Thanks to advances in cloud-computing technology, which allows for online processing of massive volumes of remote sensing data, high-resolution (~30 m) global urban-area maps from the late 1990s to 2018 are now available from several different sources (Gong et al., 2020). Using these historical maps, researchers have been able to generate maps of future urban land-use changes at the global level to 2100 (Chen et al., 2020a), which can help to elucidate the potential impacts of this future urban expansion and identify adaptation needs. Technology also plays a major role in urban planning and design in the context of adaptation. To mitigate rising urban temperatures and reduce the impacts of climate-related hazards, many new 'grey' infrastructure and 'green' infrastructure technologies are being adopted in urban areas in Asia, for example, cool (i.e., high solar reflectance) rooftops and pavements as well as green (i.e., vegetated) rooftops to mitigate high temperatures; and porous pavements to mitigate flooding (Akbari and Kolokotsa, 2016).

10.5.2.2.3 Water and agriculture

The majority of the Asian region is experiencing water stress in terms of both quantity and quality, due to poor management systems and governance. This has dire consequences for the national GDP as the majority of the population belongs to agrarian communities and their water-dependent agriculture system. Despite a substantial investment and progress in research and development, and capacity building in the recent past, the majority of developing countries in Asia are struggling to manage both water resources and agriculture sectors heavily *dependent* on water resources, in response to rapid global changes. Considering the frequent extreme weather conditions, progress in management tasks is even more consequential; hence, critically important for these countries, to achieve better CCA, are advanced science and technology viz. smart agriculture, robust EWS using downscaled meteorological information, a participatory approach, IWRM and so forth.

Having scientific knowledge relevant at the local scale through placed knowledge is important to identify climate-change risk and vulnerability. Moreover, once integrated with socioeconomic attributes, it can be useful for natural resource management, agriculture and so forth (Leith and Vanclay, 2017). Role of big data and data mining is undeniably very huge to get reliable climatic information and hence for designing appropriate adaptation measures for natural resource measurement. For example, use of big data in terms of EWS and real-time observation data provides more accurate information on hydro-meteorological extreme weather conditions or hazards like drought and flood, and will help farmers and local governments to improve their perception and hence preparedness for better adaptation (Hou et al., 2017; Ong and G.L.B.L., 2017). Using big data, different adaptation measures, such as new cultivar breeding, cropping-region adjustment, irrigation-pattern change, crop rotation and cropping-practice optimisation, are being designed in the agriculture sector, and these practices have greatly increased crop yield, leading to higher resource-use efficiency as well as greatly increased soil organic carbon content with reduced GHG emissions. It results in a win–win situation in terms of enhancing food security and mitigating climate warming (Deng et al., 2017). However, usability and application of this technology are still not common, especially in data-scarce regions. Integrated numerical simulations are efficient tools for estimating the current status and predicting the risk and efficiency of the adaptive capabilities of different countermeasures for sustainable natural resource management such as with water (Kumar, 2019). Similarly, the agent-based model is commonly used to estimate risk of food-borne diseases due to climate change, using tunable parameters such as hygiene level, the microorganism's growth rate and the number of consumers, and hence it has the potential to be a useful tool for optimising decision making and urban planning strategies related to health and climate change (Gay Garcia et al., 2017). The integrated assessment model under the shared-socioeconomic pathway (SSP) framework is effectively used to estimate future energy development and possible mitigation strategies to reduce GHG emissions related to the energy sector (Bauer et al., 2017). Sound understanding of different drivers, pressures and stress factors, such as abnormal temperature, rainfall, insect pests or pathogens and their interaction pattern with the genetic makeup of crops, is the key to produce high-yielding varieties of wheat with better nutritional quality and resistance to major diseases (Goel et al., 2017). Another critical point to address this water security is inclusive, polycentric and adaptive governance. Polycentric governance is a means by which water management plans and policies should be framed and agreed by all relevant stakeholders. For adaptive governance, more emphasis will be on finding the best pathways to make robust water management plans amid rapid global changes. The benefit of such plans should reach the end users in terms of providing clean water, protection from hydrological hazards and maintaining the health of the ecosystem. In addition, there is urgent need for co-management, which includes the cycle of co-design, co-implementation and co-delivery throughout the whole water cycle. The best suitable example is using the circulating and ecological sphere (CES) approach. The CES is a concept that complements and supports regional resources by building broader networks, which are composed of natural connections (connections among forests; city and countryside; groundwater, rivers and the sea) and economic connections (human resources, funds and others), thus complementing each other and generating synergy (Mavrodieva and Shaw, 2020). Another suitable example for managing water resources is the participatory watershed land-use management (PWLM) approach. The PWLM is another very innovative and successful approach for more robust water resource management as explained by Kumar et al. (2020). It helps to make land-use and CCA policies more effective at the local scale. This is an integrative method using both participating tactics and computer-simulation modelling for water resource management at the regional scale.

10.5.2.2.4 Forests and biodiversity

Technologies and their applications to identify habitat degradation, ecosystem functions and biodiversity conservation are increasing in Asia, with many countries looking to new and improved means for forest and biodiversity monitoring and conservation. In particular, there has been an impressive use of temporal satellite data, particularly from the Landsat and the Moderate Resolution Imaging Spectroradiometer

(MODIS) series for widespread monitoring of forests and ecological resources. These series have provided reliable information on forests and ecosystem services at the country level, in difficult terrains, such as the mountains, cross-boundaries and otherwise inaccessible areas. For instance, Yin et al. (2017) estimated cross-boundary forest resources in Central Asia, a region which traditionally suffered from lack of reliable forest data, using remote sensing techniques. In a separate study, Reddy et al. (2020) used long-term MODIS forest fire data from 2003 to 2017 to characterise fire frequency, density and hotspots in South Asia. Archives of scientific data, backed by state-of-the art modelling techniques, advanced-computing methods and innovations in big-data analysis, particularly helped the provisioning of scientific research. A number of studies simulated forest futures from the local to the continent scale under different socioeconomic and climate scenarios. For instance, at the local scale, Dasgupta et al. (2018) projected the future extent of mangroves in the Sundarban Delta under four local scenarios, while Estoque et al. (2019) modelled and developed spatial maps of regional forest futures in Southeast Asia using the five SSP scenarios. Science and technology also helped the monitoring of species diversity and abundance, pivotal for sustaining an ecosystem and ecosystem-based adaptation. Digital camera traps and radio-collaring methods have largely replaced old film cameras and labour-intensive methods of photo screening to count target species (Pimm et al., 2015). This enhanced scientific capacities to monitor biodiversity and facilitate better conservation in difficult terrains, control poachers and maintain steady ecological balance. Umapathy et al. (2016), for example, used VHF radio collars and satellite-based tracking tools to monitor the movement of Bengal tigers over hostile island terrain. Photo recognition and other non-invasive techniques for individual identification have been rising in Asia. For example, a study by Gray et al. (2014) used faecal-DNA samples to estimate the population density of the Asian elephant in Cambodia. Furthermore, the advancement of citizen science programmes has greatly facilitated better monitoring of forest resources, including invasive floral and faunal species (Chandler et al., 2017; Johnson et al., 2020). In Asia, citizen science has been used effectively in India (Chandler et al., 2017), and also in Malaysia for the monitoring urban bird abundance (Puan et al., 2019).

10.5.2.3 Knowledge Gaps and Future Directions

With rapid advances of technologies, the use of appropriate technologies generates some degree of management problems. To resolve such problems, the enhancement of information science is essential to understand design, implementation and adoption of digital tools under crisis (Xie et al., 2020). For example, social media research reveals a way of controlling malicious information (Tanaka et al., 2014), and its characteristics under COVID-19—showing a plain text message—can be more powerful in the context of citizen engagement than media-rich communications (Chen et al., 2020b). Information behaviour needs more investigation to understand how people survive and connect in the era of information overload (Pan et al., 2020). Moreover, a new set of data (e.g., travel history record, personal health data, etc.) becomes an important base of DRR (Xie et al., 2020). Analysis of these personal data requires careful consideration, as it generates ethical issues (Sakurai and Chughtai, 2020). Indicators or measurements of technology-enabled crisis response needs to be developed for further risk reduction (Akbari and Kolokotsa, 2016; Wong et al., 2020). On the other hand, adopting infrastructure technologies requires investment, and due to the inherent uncertainties of climate projections, the future payoffs of these investments are also somewhat uncertain (Ginbo et al., 2020). In the water and infrastructure sectors, for example, various options exist for conducting cost–benefit analysis considering future uncertainty (i.e., so-called robust approaches, which are able to identify adaptation projects and infrastructure that can achieve their intended purpose(s) across a wide range of climate scenarios) (Dittrich et al., 2016). Despite substantial investment and progress in research, development and capacity building in the recent past, the majority of the developing countries in Asia are struggling to manage both water resources and the agriculture sector. Considering the frequent extreme weather conditions, progress in management tasks has become even more mammoth and, hence, we need a holistic solution, which is currently missing in field implementation. This solution should be based on advanced science and technology in association with other attributes like social, economic and political dynamics, which play a pivotal role in sustainable management of water resources and agriculture, as a way forward.

10.5.3 Lifestyle Changes and Behavioural Factors

10.5.3.1 Point of Departure

Understanding the motivations and processes underpinning decisions to adapt or not is key to enabling adaptation (see Section 17.2.2.1; Clayton et al., 2015; de Coninck et al., 2018; Taylor, 2019; van Valkengoed and Steg, 2019a; van Valkengoed and Steg, 2019b), because how and why certain people adapt is shaped by sociocultural factors, ways of making sense of risks and uncertainty, and personal motivations to undertake action (Nguyen et al., 2016; Mortreux and Barnett, 2017; Singh et al., 2018b; van Valkengoed and Steg, 2019b). The IPCC's Assessment Report 5 was critiqued for silences on how perceptions shape climate action and the behavioural drivers of adaptation responses (Lorenzoni and Whitmarsh, 2014). Addressing this gap and assessing the growing literature from social sciences, notably psychology, behavioural economics and risk perception studies, the IPCC Special Report on 1.5°C (de Coninck et al., 2018) comprehensively assessed behavioural dimensions of CCA for the first time; however, compared with studies on mitigation behaviour, the literature on what motivates adaptation remains incomplete (Lorenzoni and Whitmarsh, 2014; Clayton et al., 2015).

10.5.3.2 Findings

There are three key aspects of adaptation to which psychology and behavioural science contribute: understanding perceptions of climate risk, identifying the behavioural drivers of adaptation actions and analysing the impacts of climate change on human well-being (Clayton et al., 2015). Overall, there is growing acknowledgement that individual adaptation is significantly shaped by perceptions of risk, perceived self-efficacy (i.e., beliefs about which options are effective and one's ability to implement specific adaptation interventions), sociocultural norms and beliefs within which adaptation decisions are taken, past experiences of risk management and the nature of the intervention itself (Grothmann and Patt, 2005; Werg et al., 2013; Clayton et al., 2015; Truelove et al., 2015; Pyhälä et al., 2016; Deng

Table 10.4 | Sectors and sub-regions where behavioural aspects of adaptation have been assessed

Sub-region	Sector	Adaptation interventions	Behavioural aspects affecting adaptation	Supporting references
West Asia	Agriculture	Soil and water conservation activities to mitigate drought impacts	Response efficacy and perceived severity shape water conservation.	Iran (Keshavarz and Karami, 2016)
Central Asia	NE[a]	NE[a]	NE[a]	NE[a]
South Asia	Agriculture	Conservation agriculture, adjusting agricultural practices	Risk perceptions shape adoption of adaptation strategy (e.g., perceptions of decreasing rainfall motivate building water storage tanks).	Nepal (Piya et al., 2013; Halbrendt et al., 2014)
		Sustainable water management practices, adjusting agricultural practices	Risk perception is shaped by sociocultural context, memories, experiences and expectations (of future change).	India (Singh et al., 2016)
		Alternate wetting and drying irrigation, alternative crop selection, using drought-resistant seeds	A combination of attitudes, self-efficacy, outcome efficacy, and community efficacy predict intent to adapt strongly.	Sri Lanka (Truelove et al., 2015)
		Adjustment in farm management including growing short duration or drought-tolerant varieties, pest-resistant varieties, changing planting distance, increasing weeding, soil conservation techniques, cultivation of direct-seeded rice, switching to non-rice crops	Farmers' education, access to credit and extension services, experience with climate-change impacts such as drought and flood, information on climate-change issues, belief in climate change and the need to adapt all variously determine their decision making.	Nepal (Khanal et al., 2018)
	Disaster management	Flood and cyclone preparedness measures such as using durable building materials, raising plinth levels, storing food and water	Disaster management behaviour is intuitive: low evidence to suggest outcome expectancy, self-efficacy, and preparedness intention follow linear patterns.	India (Samaddar et al., 2014); Bangladesh (Dasgupta et al., 2014b)
		Use of emergency toolkits and evacuation plans	Risk perception and knowledge of adaptation options shape uptake and perceived benefits.	Pakistan, Bangladesh (Alvi and Khayyam, 2020)
		Insurance to deal mitigate financial losses from floods and droughts	Frequency, the severity of previous extreme events, socioeconomic settings and ability to pay shape decisions to take crop insurance. Acceptability of flood insurance depends on the perceived efficacy of the insurance (among other factors such as age of household head, land ownership and off-farm income sources).	Pakistan (Arshad et al., 2016; Abbas et al., 2015)
		Embankments and dikes for flood risk mitigation	Willingness to contribute manual labour to flood protection measures is positively influenced by the number of adult family members, livestock damage, compensation received and expected effectiveness of the intervention, but is negatively influenced by age and education of the household head, farm income and the distance of the farm from the river.	Pakistan (Abbas et al., 2019)
Southeast Asia	Agriculture	Changing agricultural practices, diversifying livelihoods	Values along with personal and social beliefs of risk shape adaptation.	Vietnam (Le Dang et al., 2014; Cullen and Anderson, 2016; Nguyen et al., 2016; Arunrat et al., 2017)
	Disaster management	Raising floor height to avoid flooding, retrofitting houses	Perceived probabilities and perceived consequences of flood shape preparedness.	Vietnam (Reynaud et al., 2013; Ling et al., 2015)
		Flood insurance	Likelihood of purchasing flood insurance increased with higher physical exposure and subjective perceptions of vulnerability.	Malaysia (Aliagha, 2013; Aliagha et al., 2014)
		Evacuation	Individual risk perceptions lead to learning, but only where previous disaster experiences are traumatic.	Philippines, India (Walch, 2018)
		Disaster preparedness measures such as having kits, undertaking precautionary measures	Perceived self-efficacy was the most significant measure affecting reactive adaptation; education had the highest effect size on anticipatory adaptation.	Cambodia (Ung et al., 2015)
East Asia	Agriculture	Changing agricultural practices, diversifying incomes, adopting water-saving technology, purchasing weather insurance	Perceived self-efficacy strongly predicts adaptive intent.	China (Jianjun et al., 2015; Zhang et al., 2016a; Burnham and Ma, 2017; Feng et al., 2017)
	Disaster management	General	Higher education and being in environments where climate is discussed leads to stronger risk perceptions.	Taiwan, Province of China (Sun and Han, 2018)
		Drought management through early warnings, prevention information	Policies can positively shape adaptation decision making depending on how information is given and what support is provided.	China (Wang et al., 2015)

(a) No evidence

10

et al., 2017; Sullivan-Wiley and Short Gianotti, 2017; Taylor, 2019; van Valkengoed and Steg, 2019a). This is in addition to more commonly understood factors shaping adaptation behaviour such as technical know-how and the cost and benefits associated with an option.

Across Asia, behavioural aspects of adaptation have been studied to a lesser extent: a global meta-analysis of 106 studies found that most research focused on North America and Europe with only 12% of papers from Asia (van Valkengoed and Steg, 2019a). Within Asia, behavioural drivers of adaptation decision making have been studied primarily in agriculture (in South, East and Southeast Asia) and disaster risk management (from Southeast and East Asia) (Table 10.4) and tend to focus on technical adaptation interventions rather than how and why people adapt (Sun and Han, 2018).

In agriculture, studies demonstrate how perceptions of risk (e.g., climate variability) (Singh et al., 2016; Zheng and Dallimer, 2016; Burnham and Ma, 2017; Feng et al., 2017), sociocultural norms and personal experiences (Masud, 2016; Nguyen et al., 2016; Singh et al., 2016), and perceived efficacy of adaptation interventions in having a positive and desirable impact (Halbrendt et al., 2014; Truelove et al., 2015; Feng et al., 2017), affect adaptation decisions. Policies on providing early warnings of drought or information on prevention techniques shape farmer decisions to undertake adaptation interventions (Wang et al., 2015).

In disaster risk management, risk appraisal (Samaddar et al., 2014; Rauf et al., 2017; Hung et al., 2018), previous experience and losses (Said et al., 2015; Hung et al., 2018; Walch, 2018)[12], perceived probabilities and consequences (Reynaud et al., 2013), perceived self-efficacy (Ung et al., 2015; Hung et al., 2018) and awareness (Hung et al., 2018; Wu et al., 2018a; Alvi and Khayyam, 2020) shape preparedness. Individual risk management is nested within public policies, such as those on flood management, which shape individual flood risk perception and protective behaviours (Reynaud et al., 2013) as well as personal factors such as religious beliefs (Alshehri et al., 2013). For example, communities often perceive disasters as 'acts of God' (Birkmann et al., 2019) or punishment for wrongdoings (Alshehri et al., 2013; Iqbal et al., 2018), which might constrain adaptive action. However, religious faith can also motivate people to prepare for extreme events, as Alshehri et al. (2013) showed in Saudi Arabia demonstrating how 'Islam urges that it is most important to prepare the people to escape from disaster' (p.1825).

Trust in public action as a mediator of risk management has had conflicting evidence: some studies have discussed trust as being critical to effective preparedness (Kittipongvises and Mino, 2015; Walch, 2018), while others have found that trust in public actions, such as structural interventions to mitigate flood impacts, can lower individual motivations to act since they feel protected (Hung et al., 2018).

Belief in climate variability and change significantly shapes adaptation decision making (Le Dang et al., 2014; Singh et al., 2016; Khanal et al., 2018; Liu et al., 2018a) with those believing in climate change and associated impacts tending to engage in adaptation. Crucially, those who do not believe in climate change can be influenced by social norms (Arunrat et al., 2017) thereby incentivising adaptation behaviour. While risk perception is a critical step in adaptation decision making, higher risk perception does not necessarily signal better capacity to cope: in Taiwan, Province of China, Sun and Han (2018) highlight how perceptions of climate risk as a global problem tends reduce its urgency as an individual issue. Providing information on climate risks, impacts and possible adaptation options enables adaptation behaviour (Piya et al., 2013; Zheng and Dallimer, 2016; Rauf et al., 2017), but information alone is not sufficient to motivate adaptive behaviour. Specifically, awareness building on concrete measures and outcomes, such as the amount of water saved or number of deaths averted, rather than abstract notions of climate change, motivate adaptation (Deng et al., 2017; Rauf et al., 2017).

10.5.3.3 Lifestyle changes

Changes in current lifestyles and consumption patterns are acknowledged as critical to climate action (de Coninck et al., 2018; IGES, 2019). With rapidly changing diets and increasing purchasing power, lifestyle changes in countries across Asia, especially those with large populations such as China and India, will be critical to contributing to global climate solutions (IGES, 2019). Lifestyle shifts that can contribute towards adaptation include:

- Engaging in urban agriculture through rooftop gardening, community gardens in urban and peri-urban areas and so forth (with implications for food-associated footprints but also nutritional, livelihood and well-being benefits) (Mohanty et al., 2012; Ackerman et al., 2014; Padgham and Dietrich, 2015)
- Shifts towards organic farming and creating demand for organically sourced food and other materials
- Shifts towards water-saving behaviour such as rainwater harvesting, water conservation, reducing water usage and so forth

10.5.3.4 Knowledge gaps

Overall, understanding behavioural factors shaping adaptation implementation and uptake is important (*medium evidence*, *high agreement*). While there is a growing literature on behavioural drivers of adaptation at the individual and household levels, gaps remain in understanding how socio-cognitive factors affect adaptation behaviour at higher scales (e.g., at local or subnational government, in the private sector, etc.)[13]. More empirical evidence is needed in sectors beyond agriculture and disaster risk management (e.g., factors motivating urban adaptation) and better coverage across Asia's sub-

12 Two exceptions to this were found. One is a survey in Saudi Arabia which tested public perceptions of disaster risk and found that direct experience with such disasters does not directly influence risk perception (Alshehri et al., 2013). Second, a study on flood experience and ensuing adaptation behaviour in Pakistan found that those with prior flood experience do not make significantly different choices than those who have no experience of flooding. What is more significant is *repeated* exposure to flooding events (Said et al., 2015).

13 Some studies compare nationally representative surveys on climate perceptions and their impacts on climate action to demonstrate that higher risk perception leads to higher motivations to undertake climate action (Corner et al., 2014; Smith and Mayer 2018). Others, however, highlight that higher risk perception can lead to a normalisation of risks, leading to lower climate action (Luís et al., 2018). In all of these papers, there is a recognition that the literature on perceptual drivers of climate action is USA-centric and is negligible in Asia (Capstick et al. 2015).

regions. Importantly, there are no studies on the behavioural aspects of adaptation from Central Asia.

10.5.4 Costs and Finance

10.5.4.1 Point of Departure

Estimates of adaptation costs and financial needs have evolved significantly since the previous IPCC assessments. These developments are based on improvements in the understanding of how the hazard interacts with the physical and socioeconomic elements, and how to capture these interactions in systematic modelling frameworks. The developments are also clearly reported especially in the area of addressing the underestimates in adaptation costs that the previous studies suffered from as the previous studies tended to rely on data from wealthy economies (Hochrainer-Stigler et al., 2014; Carleton et al., 2020). The adaptation cost estimates have also improved since the previous IPCC reports due to constant improvements in capturing the loss and damages of disaster events (Hochrainer-Stigler et al., 2014). The reliance of earlier studies on correlations to derive adaptation costs was addressed to some extent by addressing the endogeneity of disaster measures (Kousky, 2014), especially by relying upon the physical measures of disasters such as wind speed, although more work is needed in this area.

10.5.4.2 Findings

Climate change can cause significant impacts and as a result can impose considerable adaptation costs on countries and people. Despite the importance, the research on adaptation costs is limited in Asia, especially on the economy-wide costs, while fragmented literature is available on sector-level adaptation costs. Most of the available literature on adaptation costs at the regional level originate from the work carried out by development finance institutions such as ADB.

Estimates suggest that climate-change impacts could result in a loss of 2% of the GDP of South Asian countries by 2050 and 9% by 2100 (Ahmed and Suphachalasai, 2014). These impacts will be felt in major vulnerable sectors, including agriculture, water, coastal, marine, health and energy, and will have significant impact on the economic growth and poverty reduction in the region. Countries could differ widely in terms of the economic costs they face. In South Asia, the economic costs were projected to be 12.6% of the GDP for the Maldives, which is the highest among the South Asian countries, and 6.6% for Sri Lanka, the least among the South Asian countries. The resultant adaptation costs for countries were projected to range from 0.36% (Copenhagen Cancun Scenario for 2050) to 1.32% (business-as-usual scenario) of the GDP in various scenarios during 2010–2050 (*Medium agreement*, *limited evidence*) (Ahmed and Suphachalasai, 2014).

Arto et al. (2019) have reported the adaptation costs of the Mahanadi Delta in India for agriculture, fisheries and infrastructure sectors (Arto et al., 2019). The cumulative adaptation costs for 2015–2016 were reported to be 276 million USD for agriculture and 0.163 million USD for fisheries. In comparison, the modelled cumulative agricultural GDP loss due to climate-change impacts was reported to be 5% up to 2050, and 8% for infrastructure. Adaptation interventions, such as embankments, were found to provide an avoided losses (adaptation benefits) to the tune of 2.2% of the delta's GDP by 2050. Similarly, input subsidies in seeds, fertilisers and biofertilisers were found to buffer the shocks in agriculture by 10%, and buffer the GDP per capita by 3% (Arto et al., 2019).

Markandya and González-Eguino (2019) have estimated the adaptation costs and residual adaptation costs accrued due to insufficient adaptation using integrated assessment models. Using the residual damages as a measure of loss and damage, the authors have estimated adaptation costs and residual costs under scenarios of high damages–low discount rate and low damages–high discount rate. The estimates suggested adaptation costs of 182 and 193 billion USD by 2050, and 737 and 783 billion USD by 2100 for South Asia and East Asia, respectively, under the scenario of high damages–low discount rate. The residual costs for the same scenario were 289 and 76% for 2050 and 238 and 62% for 2100 for South Asia and East Asia, respectively. Estimates for low damages–high discount rate were significantly lower adaptation costs and residual costs for both of these sub-regions of Asia.

The CCA efforts can be characterised as fragmented, incoherent and lacking perspective (Ahmed et al., 2019a), and the picture on adaptation financing can be stated as similarly fragmented with very limited literature published in peer-reviewed journals. Adaptation financing is crucial for supporting vulnerable countries and enhances adaptation, as it is evident that the enhanced adaptation finance support has positively affected the pace of adaptation in low-income countries (Ford et al., 2015). At the organisational level, adaptation financing has provided multiple functions that include risk assessment functions, valuation functions and risk disclosure functions (Linnenluecke et al., 2016).

Of the total global public adaptation finance of 28 billion USD, East Asia and the Asia–Pacific attracted 46% of the total funding, while South Asian countries attracted only 9% of the total funding (UNEP, 2016). These differences reflect the capacity of countries to attract adaptation finance. Some of the important adaptation-targeted climate funds are Pilot Programmes for Climate Resilience, Green Climate Fund, and Least-Developed Countries Fund, and South Asian countries have significantly benefited from these dedicated climate funds. Due to the disaster implications of climate change, there is a need to allocate adaptation finances for DRR. Estimates suggest that East Asia and the Asia–Pacific in general allocated 27% of the total adaptation funds to DRR, while South Asia allocated 25% (Caravani, 2016). Low-income economies tend to allocate more adaptation funds to DRR (46%), while lower-middle-income economies allocated 22%.

The least developed countries lack the capacity to adapt to climate change and the Least Developed Country Fund (LDCF) has made significant contributions to adaptation in these countries (*High agreement, limited evidence*). Based on the interview-based field research in four least developed countries, Sovacool et al. (2017) opined that the LDCF projects are contributing to the adaptive capacity of these countries (Sovacool et al., 2017). They also found that these projects are taking a marginal approach, rather than a radical or transformational one, to adaptation.

Box 10.6 | Loss and Damage Across Asia: Mapping the Evidence and Knowledge Gaps

Losses and damages are climate impacts after implementing adaptation and mitigation actions, signifying the presence of residual risks (Chapter 1; Kugler and Sariego, 2016; Mechler et al., 2019). These residual risks indicate that despite adaptation, there are soft and hard adaptation limits (Mechler et al., 2019). This box reviews the adaptation literature across 51 countries in Asia on loss and damage (L&D), and adaptation barriers and limits, and identifies knowledge and regional gaps. The key messages are that (a) climate-induced L&D is already occurring across Asia (*medium evidence, high agreement*), (b) these L&D are *very likely* to increase at higher warming levels (*medium evidence, high agreement*) and (c) measuring and attributing non-economic and intangible L&D remains a challenge (*low evidence, high agreement*).

Findings on losses and damages in Asia: Evidence on climate-related L&D highlights tangible or material losses and damages such as loss to life, property, infrastructure and livelihoods (*medium evidence, high agreement*); and intangible or non-material losses and damages such as increasing conflict and civil unrest, erosion of sociocultural practices and decreased well-being (*low evidence, high agreement*). The main constraint in assessing past and future L&D is that this terminology is not used prominently or consistently in the disaster management and climate risk literature in Asia, which potentially leads to under-reporting. In contrast, there is *robust evidence* (*high agreement*) on adaptation constraints, notably on governance, informational and physical constraints, to adapting, but regional evidence is very uneven with gaps in Central, North and West Asia. Table 10.5 presents a summary of L&D but draws on national and subnational studies.

The knowledge gaps are as follows:

- Attribution studies linking anthropogenic climate change and L&D remain focused on rapid-onset extreme events, and evidence on L&D from slow-onset events, such as drought and water scarcity, is low (Pereira et al., 2019; Singh et al., 2021a).
- Regional evidence gaps in Central, North and West Asia; and *low evidence* of national-level projected L&D (Uchiyama et al., 2020; Singh et al., 2021a).
- Disproportionate emphasis on economic L&D while intangible, non-economic L&D are relatively less measured and reported (Chiba et al., 2017; Bahinipati, 2020). Economic loss estimates are largely approximations and therefore suffer from various methodological, assumption and data-related uncertainties.
- Insufficient literature differentiating L&D under future adaptation scenarios, which makes assessment of residual damages and future L&D difficult. The L&D projections are constrained by limited understanding on how vulnerabilities will evolve with economic and demographic changes. Most projected L&D are based on the population and GDP projections. More future projections are based on the RCP scenarios, and the least number of studies were conducted on the combination of RCP and SSPs.
- Mitigation will have L&D and adaptation co-benefits (Kugler and Sariego, 2016; Toussaint, 2020), especially at the lower temperature stabilisation 1.5°C (Nishiura et al., 2020), but the literature is currently insufficient to assess these L&D co-benefits of mitigation efforts.
- Negligible regional evidence on limits to adaptation.

Way forward: Developing robust metrics and institutions for measuring and reporting L&D at national and regional scales, especially non-economic damages and L&D due to slow-onset events, is critical. In addition to vulnerability assessments, assessing L&D and limits to adaptation can inform adaptation prioritisation and enhance adaptation effectiveness (e.g., Craft and Fisher, 2016; Leiter et al., 2019). Lessons are available from biodiversity and ecosystem services monitoring frameworks that have well-developed metrics and processes (e.g., Díaz et al., 2020).

Kissinger et al. (2019) have estimated the climate financing needs in the land sector under the Paris Agreement. The estimates suggested adaptation needs of 2.5 billion USD for Bangladesh, 40.5 million USD for Lao PDR and 31 million USD for Mongolia, for the forest sector alone (*Low agreement, limited evidence*).

Financing green growth and low-carbon development can provide resilience benefits (*high agreement*, *limited evidence*). Kameyama et al. (2016) have estimated the cost of low-carbon investments that can provide resilience benefits in Asia and reported that such low-carbon development will cost in the range of 125–149 billion USD annually. A combination of public, private, bilateral and multilateral funding sources, and carbon-market offsets, were suggested to achieve this level of funding. In terms of the total resources available, a combination of public, private and bi- and multi-lateral funding could help the region to raise as much as 222.3–412.5 billion USD annually, with a possibility to reach higher amounts depending on the future economic growth of countries in the region. Soil carbon sequestration in agricultural soils was found to be a win–win solution for both mitigation and adaptation as it can help improve soils while increasing farm yields and incomes of smallholders (Aryal et al., 2020a).

Table 10.5 | Tangible and intangible losses and damages across Asia[a]

Sub-region (no. of papers)	Key risks reported in L&D papers	Losses and damages					Adaptation constraints (bold ticks denote strong barrier)								Adaptation limits	
		Tangible				Intan-gible	E	S	H	G	F	I	P	B	Soft	Hard
		Past	RCP2.5	RCP4.5	RCP8.5											
East Asia (32)	Coastal flooding, heatwaves, SLR	***	*	**	**	*	✓			✓	✓	✓	✓		NE	NE
Southeast Asia (4)	Coastal flooding, SLR	*				*			✓	✓		✓			NE	NE
South Asia (18)	Coastal flooding, drought, SLR, heatwaves	***	*	**	**	**	✓			✓	✓	✓			*	**
Central Asia (3)	Snowmelt, heatwaves, drought	*			*	*						✓	✓		NE	NE
North Asia (2)	Permafrost thaw			*	*	*							✓		NE	NE
West Asia (9)	Heatwaves, drought	**		*	*	*							✓		*	**

Magnitude of losses and damages		Evidence		Adaptation constraints	
(dark orange)	High (>50% sector/ population affected relative to reported baseline)	***	High (≥10 papers)	E	Economic
				S	Sociocultural
(medium orange)	Medium (25–50% sector/ population affected)	**	Medium (5–9 papers)	H	Human capacity
				G	Governance
(light orange)	Low (<25% sector/ population affected)	*	Low (≤4 papers)	F	Financial
				I	Informational/technological
(grey)	Not assessed due to inadequate evidence	NE	No evidence	P	Physical
				B	Biological

Notes:

East Asia: Tezuka et al. (2014); Elliott et al. (2015); Lei et al. (2015); Li et al. (2015a); Li et al. (2015b); Kim et al. (2016a); Lee and Kim (2016); Yu (2016); Zhao et al. (2016b); Abadie et al. (2017); Chen et al. (2017a); Chen et al. (2017b); Chung et al. (2017b); Lee et al. (2017); Feng et al. (2018a); Lee et al. (2018b); Lee et al. (2018c); Udo and Takeda (2018); Yu et al. (2018a); Yu et al. (2018c); Lee et al. (2019); Liu et al. (2019c); Liu et al. (2019d); Wang et al. (2019b); Wu et al. (2019d); Kim and Lee (2020); Liu (2020); Liu and Chen (2020); Yu et al. (2020). **Southeast Asia:** Giuliani et al. (2016); Dau et al. (2017); Vu and Ranzi (2017); Mehvar et al. (2018). **South Asia:** Wijetunge (2014); Ahmed et al. (2016b); Jevrejeva et al. (2016); Patankar and Patwardhan (2016); Abadie et al. (2017); Aslam et al. (2017); Chiba et al. (2017); Mishra et al. (2017); van der Geest (2017); Chhogyel and Kumar (2018); Jevrejeva et al. (2018); Leng and Hall (2019); Bahinipati (2020); Bahinipati and Patnaik (2020); Khan et al. (2020); Bhowmik et al. (2021). **Central Asia:** Groll et al. (2015); Babagaliyeva et al. (2017); Otto et al. (2017). **North Asia:** Gleick (2014); Hjort et al. (2018); Tschakert et al. (2019). **West Asia:** Mantyka-Pringle et al. (2015); Pal and Eltahir (2016); Ghomian and Yousefian (2017); Gohari et al. (2017); Ashrafzadeh et al. (2019b); Bierkens and Wada (2019); Houmsi et al. (2019); Mosavi et al. (2020).

(a) For definitions on losses and damages and limits, see Cross-Chapter Box LOSS in Chapter 1.

10

New adaptation financing sources have been emerging which could provide country-specific adaptation financing suiting local-level adaptation needs in Asia. The newly established Asia Infrastructure Investment Bank (AIDB), and newly emerging developing-country finance institutions, are known to provide an additional adaptation finance (Neufeldt et al., 2018); however, despite these emerging financial sources, the region will fall short of the adaptation target in the Paris Agreement (Neufeldt et al., 2018).

10.5.4.3 Knowledge Gaps

Adaptation cost estimates can vary between various studies due to the differences in methodologies they adopt. Some studies have conducted cost assessments using a combination of stakeholder consultations and quantitative modelling of climate-change impacts and adaptation (Ahmed and Suphachalasai, 2014), while others depended solely on the quantitative modelling. Studies also differ in the coverage of sectors too: they either have focused on the multiple vulnerable sectors (Ahmed and Suphachalasai, 2014) or on a single sector (Hossain et al., 2019). Studies have differed in their estimates depending on their ability to take into consideration the transition costs of sudden adaptation (Hossain et al., 2019), the nature of social cost and/or damage functions employed (Arto et al., 2019), the discount rates applied (Markandya and González-Eguino, 2019) and consideration for the effects of GHG mitigation on adaptation needs (Duan et al., 2019a). In addition, the assumptions made on the pace of adaptation in estimating adaptation costs can make a difference in adaptation cost estimates. Adaptation at a slow or normal pace could require more adaptation finance, as large amounts of damage are not eliminated, than when adaptation is implemented at a faster rate (Markandya and González-Eguino, 2019). Although there have been improvements in adaptation cost estimates, there is a need to address the issue of endogeneity (Kousky, 2014; Samuel et al., 2019). The vast majority of studies that rely on databases, such as EM-DAT, tend to suffer from such endogeneity problems due to their inability to control the causality between GDP and damages (Kousky, 2014). Costs attributable to non-economic losses and damages are the least reported and least quantified in the adaptation costs literature due to lack of sufficient, robust and accessible methodologies (Chiba et al., 2017; Chiba et al., 2019; Serdeczny, 2019). This is a major limitation in assessing adaptation costs and financial needs, and it can lead to gross underestimation of adaptation costs. A detailed description of issues related to non-economic losses and damages, and its importance in strengthening adaptation, is provided in Box 10.6 and Table 10.5.

10.5.5 Risk Insurance

10.5.5.1 Point of Departure

Risk insurance approaches and tools have significantly evolved during recent years. The emphasis has been mainly on mitigating the adverse selection and moral hazard that have been the limitations of traditional area-based crop insurance approaches (He et al., 2019). This has been achieved by shifting the indemnity calculations on to the specific weather parameters and developing a weather index (Greatrex et al., 2015; Fischer, 2019). Technological applications in the development of insurance products have seen significant progress, including that of the blockchain and smart contracts (Gatteschi et al., 2018). There are technological developments in loss estimation, which has been a major limitation in the traditional insurance approaches in the past that either delayed the indemnity payment or misjudged the losses. Application of multi-model and multi-stage decision support systems has begun to make crop loss assessments for insurance more efficient (Aggarwal et al., 2020). Technological applications also include remote sensing (Di et al., 2017) and mobile phone app technologies (Meena et al., 2018) to provide accurate and quick damage assessments, and application of Internet-based indemnity approvals have enabled quick payment of indemnities (OECD, 2017b).

10.5.5.2 Findings

As against financing post-disaster relief and reconstruction, which has been the norm of disaster management for decades in Asia, the evolution of ex-ante risk financing in the form of risk insurance has seen a steady rise globally and in Asia. The rise in popularity for risk financing in general and insurance in specific stem from the observation that governments have recognised the burden of mainly financing the post-disaster relief and reconstruction only (Juswanto and Nugroho, 2017; UNESCAP, 2018c; ADB, 2019), and from the realisation of cost savings and efficiency that risk financing for risk mitigation brings overall risk reduction (*high agreement*, *medium evidence*). As a result, a gamut of risk-financing instruments have been introduced to finance DRR and CCA initiatives in Asia among which risk insurance has gained prominence for it provides a low-cost and easy option for individuals, provides an opportunity for the governments to effectively engage the private sector in implementation and has the ability to inculcate risk-aware decision making at various levels (*high agreement*, *medium evidence*) (Hazell and Hess, 2017; UNESCAP, 2018c).

Several Asian countries, including India, the Philippines and China, have a significant experience of offering agricultural insurance against typhoons, droughts and floods (Yang, 2018). For the most part, these insurance systems have followed a traditional indemnity-based insurance which faces several challenges in implementation including moral hazard and adverse selection, disagreements and delays in crop-damage assessments that relied upon crop-cutting experiments, often leading to a delay in processing indemnity payments, costly insurance premiums and poor insurance expansion (*high agreement*, *robust evidence*) (Patnaik and Swain, 2017; Ghosh et al., 2019). Other factors contributing to poor penetration of insurance include limited awareness on the importance of insurance, and poor access.

To tackle the problem of costly insurance premiums, governments have subsidised the premiums (Ghosh et al., 2019). Premium subsidies have been reported to undermine the ability to convey the real cost of risks by the insured (price distortion), and have encouraged adverse selection and moral hazard (Nguyen and Jolly, 2019). On the contrary, subsidies have been suggested to address the issue of adverse selection associated with the insurance (Zhao et al., 2017c).

Despite the fact that the insurance programmes are able to obtain high participation rates due to subsidised premiums, their impact on farmers' income seems to be insignificant especially under the conditions of low indemnities, low guarantee and wide coverage (Zhao et al., 2016a). The subsidy burden of insurance on national governments is found to be significant with an estimated equivalent of 6 billion USD spent by China alone on insurance (Hazell et al., 2017). In addition, the insurance programmes in Asian countries are reporting higher producer claim ratios, and often governments have to spend more than the money being transferred to the insured through the insurance programmes (Hazell et al., 2017).

To address the issues associated with traditional indemnity insurance, efforts have been made to develop weather-index insurance in Asia that bases the payouts on the rainfall or temperature index, rather than on the direct damage measurements. The parametric insurance products help avoid the delays in insurance payouts as they are based on modelled risks, rather than actual damage measurements, and control the adverse selection and moral hazard, although basis risks could be increased due to improper matching of payouts with the index (De Leeuw et al., 2014). Index insurance is known to promote public–private partnerships that in turn will enhance the efficiency of overall programme delivery (Hazell and Hess, 2017). Several countries, including India, Bangladesh, Thailand, Indonesia, Myanmar and the Philippines, either are currently piloting or expanding the weather-index insurance (Surminski and Oramas-Dorta, 2014; Tyagi and Joshi, 2019). Index insurance is constantly expanding with an estimated 194 million farmers already enrolled in China and India, which is much lower than the potential number of farmers it can reach (Hazell et al., 2017).

Few significant bottlenecks that are limiting the scaling up of weather-index insurance include lack of reliable weather data, low density of weather stations leading to high basis risk, and limited data on damage and hazard for parametric modelling of the insurance (Shirsath et al., 2019). Several innovations are being tried and tested to overcome the limitations associated with the index insurance which include developing multiscale index insurance, application of remote sensing, smartphone-based near-surface remote sensing and building insurance based on vegetation indices instead of relying on weather data alone (Hufkens et al., 2019). Alternative indices, such as the NDVI, are being tested for their applications in designing index-based insurance in India (IFAD, 2017). Agro-meteorology-based statistical analysis and crop growth modelling have been suggested to calibrate and rectify faulty weather indices (Shirsath et al., 2019; Zhu et al., 2019). Establishing automatic weather stations can improve data accuracy while preventing the delay in acquiring the weather data (Sinha and Tripathi, 2016). These technological applications have already started finding space within insurance programmes designed by national governments in Asia. For example, the government of India has released new operational guidelines for the application of new technologies such as drones, remote sensing and mobile phone apps in implementation of the national agricultural insurance, which is the third largest insurance in the world (Department of Agriculture, 2019).

10.5.5.3 Knowledge Gaps

Despite these developments, several issues still seem to hinder the penetration of insurance in Asia. Issues such as lack of sufficient choices, lack of clear model, lack of legal support, limited or absence of proper monitoring and evaluation, and limited data for underwriters to properly evaluate claims have been suggested (Nguyen and Jolly, 2019). Low interest among the potential buyers due to unaffordable insurance premiums, lack of provision for partial-loss claim settlement, big hassles in the claim settlement process and lack of timely settlement of claims are reported (Parappurathu et al., 2017). In addition, insurance has been reported to have expanded the coverage of cash crops at the expense of drought-resistant subsistence crops with effects on natural capital and a potential increase in farmer's vulnerability to market price fluctuations (Müller et al., 2017).

Regional catastrophic insurance pools have also received attention in Asia. With the formation of Southeast Asia Disaster Risk Insurance Facility (Haraguchi and Lall, 2019), the regional insurance pool has been introduced in Southeast Asia, initially being piloted in Lao PDR and Myanmar and to be expanded to the rest of the ASEAN region. Regional catastrophic insurance allows vulnerable countries to buffer climatic shocks by diversifying the risks beyond country boundaries.

10.5.6 Social Protection

10.5.6.1 Point of Departure

Social protection (SP) encompasses initiatives that involve transfer income or assets to the poor, protect the vulnerable against risks to their livelihood, and enhance the social status and rights of the marginalised (Béné et al., 2014; Kothari, 2014). Social protection offers a wide range of instruments (e.g., cash transfers, insurance products, pension schemes and employment guarantee schemes) that can be used to support households that are exposed to climate changes (Bank, 2015). It also presents an opportunity to develop inclusive comprehensive risk management strategies to address L&D from climate change as well as a means to CCA (Aleksandrova, 2019).

Social protection programmes assist individuals and families, especially the poor and vulnerable, cope with crises and shocks, finds jobs, improve productivity, invest in the health and education of their children, and protect the ageing population (Bank, 2018b). Social protection that is well designed and implemented in a more long-term approach can enhance human capital and productivity, reduce inequalities, build resilience and empowerment, and end the inter-generational cycle of poverty (*medium evidence, medium agreement*) as indicated from various experiences in the region such as (a) cash transfer programmes in Indonesia (Kwon and Kim, 2015), (b) the Benazir Income Support Programme in Pakistan (Watson et al., 2017), (c) the Chars Livelihoods Programme in Bangladesh (Pritchard et al., 2015) and (d) Minsei-in designated volunteer social workers in Japan (Boeckmann, 2016). A key consideration in strengthening resilience through SP programmes is to design with climate and disaster risk considerations in mind and implement in close synergy with existing programmes, such as on sustainable livelihoods, EWS and financial inclusion (Coirolo et al., 2013; Bank, 2018a).

10.5.6.2 Findings

Asia is already the most disaster-prone region in the world, with over 200,000 lives lost and almost 1 billion people affected by storms and floods alone between 2005 and 2014, while a heatwave in North and Central Asia in 2010 killed 56,000 people (United Nations, 2015). Climate change is increasing the frequency and intensity of these sudden and slow-onset disasters, among them, hydrological changes in major river basins where 1.5 billion people live (such as the Indus, Ganges, Brahmaputra, Mekong, Yellow, Yangtze, Tarim, Amu and Syr Darya rivers) (Bank, 2017a). According to the latest estimates of the International Labour Organisation (ILO), 55% of the global population (around 4 billion people) remain without any SP benefits, and the SP coverage gap is highest in Africa (82.2%) and the Asia–Pacific (61%) (ILO, 2017b).

Risks are generally amplified for people without SP or essential infrastructure and services, and for people with limited access to land and quality housing, especially those in exposed areas and informal settlements without secure tenure (ESCAP, 2017). Stateless people are disproportionately affected by climate change and disasters as they tend to reside in hazard-prone areas and their statues as non-citizens often limits access to assistance (Connell, 2015). The three main types of SP are: (a) social safety nets (also known as social assistance), which include conditional and unconditional cash transfers, public work programmes, subsidies and food stamps; (b) social insurance, which consists of contributory pensions and contributory health insurance; and (c) labour market measures, which include instruments such as unemployment compensation (Bank, 2018b). The potential for an integrated adaptive SP is not yet harnessed by policymakers in tackling the structural causes of vulnerability to climate change (Tenzing, 2019). Public works programmes (i.e., India's Mahatma Gandhi National Rural Employment Guarantee Act, MGNREGA) should take into account climate risk in planning and support development of community assets to increase collective resilience.

Aligning SP with climate-change interventions is an attempt to develop more durable pathways out of poverty and climate vulnerability; examples from MGNREGA depicting the attempt to align through a mainstreaming approach has helped women and their households (Adam, 2015; Steinbach et al., 2016). On another note, the Catastrophe Insurance Framework, the first model introduced in Shenzen, China, provides timely relief for citizens and operates as a safety net, particularly for the poorest residents who do not have disposable income to cover the costs associated with bodily injuries arising from disasters (Telesetsky and He, 2016). The Department of Labour and Employment's Integrated Livelihood and Emergency Employment Programme in the Philippines is part of the recovery efforts after Typhoon Haiyan, providing short-term wage employment, and facilitates entrepreneurship for people affected by natural calamities and economic shocks (Bank, 2018b).

In each of these instances, governments are using SP to protect populations suffering from climate change or are adversely affected by structural, pro-climate economic reforms (Hallegatte et al., 2015). However, additional research is still needed and new tools need to be developed to inform policy design and support the implementation of 'green' SP, as well as to measure the net-welfare impacts of such policies (Canonge, 2016). In order to enhance SP programmes, one of the cross-cutting issues is to discuss the linkages between gender roles and responsibilities, food security, agricultural productivity and the mediating role that SP programmes can have (Jones et al., 2017). Social protection has a potentially important role to play in contributing to food security and agricultural productivity in a gender-responsive way (Holmes and Jones, 2013). As such, experience from Challenging the Frontiers of Poverty Reduction: Targeting the Ultra Poor programme in Bangladesh has promoted social innovation by creating social and economic values, fostering microenterprises, increasing food security and fostering inclusive growth, all while empowering ultra-poor women (Emran et al., 2014; Mahmuda et al., 2014). Although there is increasing evidence that SP programmes are having a positive impact in terms of reducing vulnerability in women's everyday lives (Jones et al., 2017), the transformative impact of these programmes is rare due to limitations in recognising women's access to productive inputs and resources (Tanjeela and Rutherford, 2018; Cameron, 2019).

On the other hand, poor governance practices affect delivery of SP programmes and the ability of beneficiary households to reap the benefits from such support (Sijapati, 2017). In Nepal, a closer look at public expenditure shows that about 60% of the SP budget is used by social insurance programmes that predominantly consist of public-sector pensions (Babken Babajanian, 2014; Koehler, 2014). Towards this end, more effort is needed to improve its existing programmes so that there is an equality of opportunities, along with secured human rights. The example from Nepal's Child Grant is an indicative of an incremental approach to social policy (Garde et al., 2017). Meanwhile, in the Philippines, despite the existence of flagship national interventions that cover a significant number of people in need and have clear and robust implementation rules, there are still many programmes with overlapping mandates and target population, and several gaps in their monitoring systems (Bank, 2018b).

Having an integrated SP information system would allow policymakers to better monitor inputs, outputs and outcomes (e.g., who the beneficiaries are, what they are receiving, at what frequency, what the existing gaps are) (OECD, 2017a; Samad and Shahid, 2018). Based on evidence from the assessments of three countries (Mongolia, Nepal and Vietnam), the political and institutional arrangements (i.e., the software) is as important as the technical fixes (i.e., the hardware) in the success of using information and communication technology for delivering SP programmes (ADB, 2016). By 2050, climate-induced migration will *likely* be a major policy aspect of the rural–urban nexus as slow-onset impacts of climate change in sub-Saharan Africa, South Asia and Latin America will *likely* force over 143 million people to migrate within their national borders (Kumari Rigaud, 2018). This will have major implications for SP systems, and therefore national SP strategies should be designed to anticipate and address climate-induced internal mobility (Schwan and Yu, 2017). For instance, it does not offer a solution for maintaining Indigenous cultures which are often strongly affected by, or even disrupted by, climate change (Olsson, 2014). Hence, an effective approach needs to combine different policy instruments to support protection, adaptation and migration (O'Brien et al., 2018).

Evidently, SP has been financed typically through the combination of government tax revenues and official development assistance, and the challenges of the increasing frequency and intensity of natural and economic crises are straining these traditional financial sources (Durán-Valverde, 2020). In this context, innovative financing schemes are seen as critical to achieve the sustainable financing of SP (Asher, 2015; UNICEF, 2019) via social and solidarity economy, as seen in women's autonomous adaptation measures in precautionary savings and flood preparedness in Nepal (Banerjee et al., 2019), and self-help groups as development intermediaries (Anderson, 2019). Still, there are constraints of SP to reach those who are most vulnerable to climate change and other hazards due to their legal status, such as the fact that attention to forcibly displaced populations within the SP field has been limited (Sabates-Wheeler, 2019).

10.5.6.3 Knowledge Gaps

Government SP can attenuate the negative impacts in facing disasters, depending on the differences in political systems and the focus put on sociopolitical measures (*medium evidence, medium agreement*), not only in restoring livelihoods but also in easing mental burdens faced by rural households in developing countries (Dalton et al., 2016; Kosec and Mo, 2017; Liebenehm, 2018). However, limited government capacities and fiscal feasibility may impede the expansion and effective implementation of SP as developing countries need further support to design, adjust and implement SP schemes effectively (Klonner, 2014; Schwan and Yu, 2017). Most countries have comprehensive strategies for both SP and climate change, but few have attempted to align them, as in practice they remain in separate institutional homes, governed by their own intra-sector coordination groups and funding channels (Steinbach et al., 2016; Bank, 2018b). Thus, significant knowledge gaps remain in terms of understanding the potential of SP to build long-term resilience to climate change (Ulrichs et al., 2019). Future efforts should be geared to develop climate-responsive SP policies that consider a broad range of issues including urbanisation and migration, the impact of green policies on the poor, access to essential health care and risks to socially marginalised groups (Aleksandrova, 2019). Along with strengthening links to climate information and EWS, finance for enabling SP systems to address climate-related shocks and stresses dynamically needs to be scaled up (Kuriakose et al., 2013; Ulrichs et al., 2019).

10.5.7 Education and Capacity Development

10.5.7.1 Point of Departure

Asian areas with the least capacity to respond, such as the Himalayan region and densely populated deltas, are hit first and hardest by climate impacts (De Souza et al., 2015; Khan, 2017). Acknowledging the limitations in terms of capacity and coping mechanisms towards climate change, education, training and awareness building is central to sustaining long-term capacity building (Clemens et al., 2016). Education has a lot more to offer in terms of improvements in addressing climate change, particularly in the climate hotspots of Asia where mostly poor, disadvantaged communities vulnerable to climate change reside (Mani et al., 2018). In particular, when disseminated, climate-change awareness and information need more explanation (Steg et al., 2014; Wi and Chang, 2018; Cho, 2020). In addition, international and national support through institutions and financing is critical for successful capacity building (Hemachandra, 2019), which must be designed for the long term and be self-sustaining (Gustafson et al., 2018). National ownership by recipient countries and members of communities of capacity-building efforts is key to ensuring their success (Roberts and Pelling, 2016; Mikulewicz, 2017).

10.5.7.2 Findings

The need to develop tailored climate communication and education strategies for individual nations as public awareness and risk perceptions towards climate change vary greatly (*medium evidence, high agreement*) (Lee et al., 2015a). Improving on, and investing in, basic education, climate literacy and location-based strategies of climate change are vital to enhance public engagement, societies' adaptive capacity and support for climate action (Lutz et al., 2014c; Hu and Chen, 2016). As stated in the IPCC Special Report 1.5°C, sustainable development has the potential to significantly reduce systemic vulnerability, enhance adaptive capacity and promote livelihood security for poor and disadvantaged populations (Roy et al., 2018). Hence, various concepts are introduced to foster awareness, understanding, knowledge, participation as well as commitment towards managing climate change in a sustainable manner. One such concept is education for sustainable development (ESD), which is aimed at integrating the principles and practices of sustainable development in all aspects of education, and training individuals who will contribute to the realisation of a more sustainable society (Kitamura, 2017).

Climate-change education (CCE) is also now addressed in the context of ESD and allows for learners to understand the causes and consequences of climate change, and teaches them how to take action (Mochizuki and Bryan, 2015). Both ESD and CCE are gaining broader attention, for instance, in China (Han, 2015) and the Republic of Korea (Sung, 2015); however, development of policies and implementation of initiatives regarding ESD and CCE still face a handful of challenges which require a strong political will and consensus of key stakeholders (Læssøe and Mochizuki, 2015). Effective communication on CCE particularly for younger-generation engagement is also essential, as they are our future leaders as climate change is an inter-generational equity issue (Corner et al., 2015). Action for Climate Empowerment of Article 6 of the UNFCCC target youth as a major group for effective engagement in the formulation and implementation of decisions on climate change (UNFCCC, 2015). Increasing attention from countries in Asia, such as Thailand and India, will encourage innovative ways to provide adequately in educating and engaging youth in climate-change issues (Narksompong and Limjirakan, 2015; Dür and Keller, 2018).

An integrated approach to knowledge about climate change embraces both the importance in bridging knowledge of climate science and respecting IKLK, and should be at the heart of any effort to educate citizens to have a deeper understanding of the causes and consequence of climate change in a holistic manner (Aswani et al., 2018). Indigenous Peoples, comprising about 6% of the global population, play a crucial role in the fight against climate change for two interlinked reasons. First, they have a particular physical and spiritual relationship with land, water and associated ecosystems, and tend to be among the most vulnerable group to climate change (Magni, 2017). Second, they have a specialised ecological and traditional knowledge relevant to finding the best solutions to climate change (Rautela and Karki, 2015). Indigenous knowledge systems and resource management practices are important tools for both mitigating and adapting to climate change (Fernandez-Llamazares et al., 2015). Indigenous knowledge is increasingly recognised as a powerful tool for compiling evidence of climate change over time (Ahmed et al., 2016a). Knowledge of CCA and DRR provide a range of complementary approaches in building resilience and reducing the vulnerability of natural and human systems to the impacts of climate change and environmental hazards (Mall et al., 2019). The adaptation dimension involves developing knowledge and utilising existing IKLK, skills and dispositions to better cope with already evident and looming climate impacts (Aghaei et al., 2018). It is also important to ensure inclusive efforts in DRR across different nations and communities as well as increasing skills and capacities of women towards DRR efforts (Alam and Rahman, 2014; Drolet et al., 2015; Islam et al., 2016b; Reyes and Lu, 2016; Hemachandra et al., 2018). More effective and efficient teaching and learning strategies, as well as collaborative networks, are needed to increase preparedness and DRR activities across various levels of community (Oktari et al., 2015; Takahashi et al., 2015; Tuladhar et al., 2015b; Shiwaku et al., 2016; Gampell et al., 2017).

Table 10.6 shows education and capacity-building aspects affecting adaptation by sub-region examples.

10.5.7.3 Knowledge gaps

Capacity building at national and local levels still needs to address gaps in research and practice, such as impacts and results of different preparedness measures (Alcayna et al., 2016). Ad-hoc and localised documentations and monitoring of efforts to build adaptive capacities has rendered it difficult to assess success (Cinner et al., 2018). Recommendations for strengthened capacity building are sometimes made or understood in isolation from the underlying structural issues shaping vulnerability, or without adequately recognising the political relationships that mediate the ways in which particular technical interventions result in differentiated outcomes for different groups (Archer and Dodman, 2015). Thus, design- and decision-based tools, such as rapid assessment for community resilience to climate change as well as rapid approach to monitor the effectiveness of aid projects, support the community-based adaptation to climate change to analyse using a multi-dimensional approach, procedural, distributional, rights and responsibilities (Nkoana et al., 2018; Jacobson et al., 2019).

As a model of communication and engagement, citizen science has the potential to promote individual and collective climate-change action (Groulx et al., 2017). More than information provision is needed to mobilise public action on climate change (Kyburz-Graber, 2013). Citizen science links communication and engagement in a manner that holds important lessons on ways to promote collective responses to climate (Wals et al., 2014; Bonney et al., 2016). The power of science-based citizen engagement lies in citizen group contribution in drawing upon their local knowledge to enrich the knowledge base required for management decisions (Sayer et al., 2015). Scientific evidence may be less attuned to the complexity of local realities in managing climate change; thus, citizen science has the potential in bridging this gap and has many advantages for climate mitigation and adaptation practice and policy (Ford et al., 2016). While citizen science uses citizens as policy-passive objects for research in conducting measurements for big datasets, citizen social science is gaining momentum where it repositions citizens as central co-learners who can widen the climate-science evidence base to achieve a more holistic understanding for the benefit of all (Kythreotis et al., 2019).

10.6 Climate Resilient Development Pathways

10.6.1 Climate Resilient Development Pathways in Asia

Climate resilient development pathways (CRDPs) are ‘trajectories that strengthen sustainable development and efforts to eradicate poverty and reduce inequalities while promoting fair and cross-scalar adaptation to and resilience in a changing climate’ (Roy et al., 2018). Moving beyond a business-as-usual scenario, CRDPs involve not only adaptation and mitigation choices but also sustainable development implications and societal transformation (Roy et al., 2018). This basic understanding of CRDPs explicitly reflects that climate action (mitigation and adaptation) and sustainable development are fundamentally integrated and interdependent.

There is *high confidence* that currently implemented climate action in Asia (such as climate-smart agriculture, ecosystem-based DRR and investing in urban blue–green infrastructure) can meet adaptation, mitigation and SDGs simultaneously, presenting opportunities for climate resilient development (CRD). However, there also exist significant barriers to CRD such as fragmented, reactive governance; inadequate evidence on which actions to prioritise and how to sequence them; and finance deficits. Some Asian countries and regions offer solutions to overcome these barriers: through use of advanced technologies (*in situ* observation and remote sensing, a variety of new sensor technologies, citizen science, AI and machine learning tools); regional partnerships and learning; improved forecasting capabilities; and better risk awareness (*high confidence*).

Asian countries are repeatedly identified as the most vulnerable to climatic risks with key sectors such as agriculture, cities and infrastructure, and terrestrial ecosystems expected to see high exposure to multiple hazards (Section 10.3). Owing to rapid development and large populations, Asian countries have large and growing GHG emissions: in 2018, five of the top ten emitters in the world were Asian–China (1), India (3), Japan (5), the Republic of Korea (8) and Indonesia (10) (Friedlingstein et al., 2019)–although it is critical to note that per-capita emissions and cumulative emissions are relatively lower than in developed economies (Raupach et al., 2014). However, in the 2020 Sustainability Index and Dashboard, only two Asian countries made it into the top 30 countries in the world: Japan (17) and the Republic of Korea (20) (Sachs et al., 2020). Finally, Asia has varied capacities to adapt with high heterogeneity in adaptation progress across the region.

Given this context of high risks, growing emissions and varied adaptive capacities in Asia, CRDPs can enable (a) reducing existing vulnerability and inequality, (b) sustainable development and meeting the SDGs and

Table 10.6 | Education and capacity-building aspects affecting adaptation by sub-regions examples

Sub-region	Sectors	Adaptation interventions	Education and capacity-building factors affecting adaptation	Supporting references
North Asia	Human well-being	PEEX (Pan Eurasian Experiment) originating from a bottom-up approach by the science communities aiming at resolving major uncertainties in Earth system science and global sustainability issues concerning the Arctic and boreal pan-Eurasian regions, as well as China	Educating the next generation of multidisciplinary experts and scientists capable of finding tools in solving future environmental, socioeconomic and demographic development problems of the Arctic and boreal regions, as well as China	Pan Eurasian regions, as well as China (Kulmala et al., 2015)
West Asia	Agriculture	Smallholder farmers' vulnerability assessment	High level of education, more human capacity and adaptive capacity, less vulnerability	Iran (Jamshidi et al., 2019)
Central Asia	Agriculture, water resources and energy	Carrying out the selection and cultivation of drought-tolerant, salt-tolerant crops, preservation of the upper watershed of the rivers, improving climate resilience of hydro-facilities	Placing the focal point for the preparation and implementation of programmes for climate change at the regional level, increasing capacity of professionals in targeted areas and networking between them, and strengthening institutional, technical and human resources to promote adaptation and research in fields of climate and hydrological investigations, geographic information systems, environmental impact assessment, and protection and re-cultivation of lands	Kazakhstan, Tajikistan and Kyrgyzstan mountain societies in Central Asia (Schmidt-Vogt et al., 2016; Xenarios et al., 2019)
South Asia	Agriculture	Productivity, net crop income, improvement in livelihoods and food security	Farmers' education, easy access to farm advisory services, weather forecasting and marketing information	Pakistan (Abid et al., 2016)
		Passive adaptation in agricultural and farming practices implicitly to cope with climate change	Increasing knowledge on climate change so that concrete steps can be taken in dealing with perceived climate changes	India (Tripathi and Mishra, 2017)
		Having farmers' perceptions shape knowledge, and vice versa on climate change	Age, education, occupation, farming experience, knowledge about coping strategies (all significantly related to farmers' perceptions about climate change)	India (Aslam Ansari, 2018)
	Disaster risk reduction	Local institutions' preparedness and capacity for managing disaster at the local scale	Capacity building, technical support and financial capacity, as well as adopting a proactive approach, to achieve a higher level of disaster preparedness	Pakistan (Shah et al., 2019)
Southeast Asia	Agriculture	Farming cultural practices adopted to minimise production losses due to extreme weather	Small-scale farmers' attendance at climate-change training to enhance adaptive capacity	Vietnam (Trinh et al., 2018)
		Removing farmers' barriers to adopting adaptation measures, and provide funds and timely information	Knowledge of crop variety, increasing educational outreach and communicating climate-change-related information to increase the likelihood of employing adaptive strategies	China (Zhai et al., 2018)
		Making farmers in rural, under-resourced communities in the Lower Mekong basin aware of how climate change will affect them	Scientific findings which can be merged with local knowledge at a community level to help raise awareness, and knowledge gaps on both which can be filled for better understanding and adaptation planning	Cambodia, Lao PDR, Vietnam and Thailand (USAID, 2015; Gustafson et al., 2018)
	Coastal areas	Reducing households' vulnerability due to variation in socioeconomic and livelihoods assets	Increasing resilience by establishing effective an communication system, improving knowledge on climate change	Vietnam and Indonesia (Nanlohy et al., 2015; Huynh and Stringer, 2018)
	Disaster risk reduction	Capacity building through learning labs on disaster risk management for sustainable development (DRM-SD)	Transfer of learning initiatives to provide approach guidelines and innovative mechanisms for DRM practitioners who will have the know-how and potential for leadership in DRM-SD	Four ASEAN countries: Malaysia, Vietnam, Lao PDR and Cambodia (Ahmad Shabudin et al., 2017)
East Asia	Disaster risk reduction	Conducting community participation and disaster education so that people can take action in disaster management	Educational-resilience system tested and revised through experiences from past disasters; recognising and integrating gender perspectives into mainstream disaster management; 'school-based recovery concept' facilitating short-term recovery and the longer-term community building needs, which can also help communities in building new networks and solving chronic social problems	Japan (Matsuura and Shaw, 2014; Saito, 2014; Shiwaku et al., 2016)
	Bridging Indigenous knowledge and scientific knowledge	In efforts to solve real-world problems, engaging first with those local communities that are most affected, beginning with the perspective of Indigenous knowledge and then seeking relevant scientific knowledge	Paying attention to the Indigenous perception of a hazard and risk with the aim of increasing the effectiveness of projects implemented by practitioners who might need to communicate risks in the future; empowering the younger generation to ensure continuity of Indigenous cultures and their linked ecosystems	(Mistry and Berardi, 2016; Roder et al., 2016)

Table 10.7 | Adaptation options that can have mitigation and SDG synergies and trade-offs, providing opportunities for the triple wins necessary for climate resilient development pathways

Adaptation option	Mitigation impacts (H/M/L/NA)[a]	Implications on SDGs		References
		Positive	Negative	
Wetland protection, restoration	*Medium synergy* Carbon sequestration through mangroves	SDGs 8, 14, 15		Southeast Asia: Griscom et al. (2020)
Solar drip irrigation	*High synergy* Shift to cleaner energy	SDGs 2, 7, 12	SDG 10	South Asia: Alam et al. (2020)
Climate-smart agriculture	*High synergy* b No till practices and improved residue management can reduce soil carbon emissions.	SDGs 2, 12		South Asia: Aggarwal et al. (2019); Aryal et al. (2020b); Aryal et al. (2020a); Tankha et al. (2020) Southeast Asia: Chandra and McNamara (2018)
Integrated smart water grids	*High synergy* Reduced energy needs for supplying water	SDGs 6, 9, 11, 13		Asia: Kim (2017)
Disaster risk management (including early warning systems)[c]	Not applicable	SDGs 9, 11	SDGs 5, 10	South and Southeast Asia: Ajibade et al. (2019); Herbeck and Flitner (2019); Aryal et al. (2020b); Mishra (2020) Asia: Iturrizaga (2019) Bhutan: Sovacool et al. (2012) The Philippines: Grefalda et al. (2020)
Carefully planned resettlement and migration (including decongestion of urban areas)	Inadequate evidence to make an assessment	SDGs 8, 10, 11	SDGs 6, 10, 11	Asia: Arnall (2019) South Asia: Maharjan et al. (2020) The Philippines: Estoque et al. (2020) Nepal: Banerjee et al. (2019)
Aquifer storage and recovery	*Low synergy*	SDGs 6, 12		Saudi Arabia: Lopez et al. (2014) South and Southeast Asia: Hoque et al. (2016)
Nature-based solutions in urban areas: green infrastructure (including urban green space, blue–green infrastructure)	*High synergy* Blue–green infrastructure acts as a carbon sink	SDGs 3, 9, 11		Japan: Mabon et al. (2019) The Philippines: Estoque et al. (2020) China: Byrne et al. (2015); Zhang et al. (2020a) Taiwan, Province of China: Mabon and Shih (2018) Singapore: Liao (2019); Radhakrishnan et al. (2019)
Coastal green infrastructure	*High synergy*	SDGs 9, 11, 13, 14, 15		Bangladesh: Sovacool et al. (2012); Chow (2018); Zinia and (McShane, 2018) Southeast Asia: Koh and Teh (2019); Herbeck and Flitner (2019) Asia: Giffin et al. (2020)

Notes:

(a) Expert judgment.

(b) The CCA options in the agriculture sector include soil management, crop diversification, cropping system optimisation and management, water management, sustainable land management, crop pest and disease management, and direct seeding of rice (Aryal et al., 2020b). Other specific agricultural practices that have adaptation and mitigation synergies include between-tillage and residue management, alternate wetting and drying, site-specific nutrient management, crop diversification for less-water-intensive crops, such as maize, and improved livestock management (Aryal et al., 2020a).

(c) Risk management strategies in agriculture include crop insurance, index insurance, social networking and community-based adaptation, collective international action and integrated agro-meteorological advisory services (Aryal et al., 2020b).

(c) managing multiple and often concurrent risks, including climate-change and disaster risks. Potentially, combinations of adaptation and mitigation options will be required to lead to CRD (see Figure 18.1 on CRDPs), and some of them are shown in Table 10.7. For example, climate-smart agriculture strengthens food security (SDG 2, Zero Hunger) (Aggarwal et al., 2019); urban disaster management, such as the Jakarta Disaster Risk Reduction Education Initiative, contributes to SDG 11 (Sustainable Cities) (Ajibade et al., 2019).

The following subsections examine CRDPs through three approaches that are particularly important in Asia and have a large body of evidence to assess implications for adaptation, mitigation and sustainable development. The three illustrative approaches are: (a) disaster risk management and adaptation synergies, (b) the food–water–energy nexus and (c) poverty alleviation and meeting equity goals.

10.6.2 Disaster Risk Reduction and Climate-Change Adaptation Linkages

10.6.2.1 Point of Departure

There is growing evidence on the interconnectedness of extreme weather, climate change and disaster impacts (Asia, 2017; Reyer, 2017). In Asia, climate-related disasters have become more recurrent and destructive in terms of both economic and social impacts (Bhatt et al., 2015; Aich et al., 2017; Vij et al., 2017). Projections of increasing frequency, intensity and severity of climate-related disasters call for better integration of CCA and DRR (Sapountzaki, 2018) in policy development to address risks efficiently (Rahman et al., 2018) and to promote sustainable development pathways for reduced vulnerability and increased resilience (Seidler et al., 2018). Connecting CCA and DRR efforts in both policy and practice continue to be a challenge, however, because the convergence of national policy and planning processes on CCA and DRR within Asia is in its early stages (Cousins, 2014) and structural barriers persist (Mall et al., 2019). Both CCA and DRR have developed as separate policy domains because of the different temporal and spatial scales considered, the diversity of actors involved, the policies and institutional frameworks adopted and the differences in tools and methodological approaches used. This has resulted in the CCA and DRR communities, and the knowledge and research they produce to support planning and decision making, not always being well connected (Street et al., 2019).

10.6.2.2 Findings

Climate risk management in Asia is approached by focusing on hazards that are associated with extremes (i.e., extreme weather events with increased frequency and severity) as well as climate- and weather-related events. For example, farming has been affected by climatic variability and change in a wide variety of ways that include an increase in drought periods and intensity, a shortage of irrigation water availability, an increase in flooding and landslides, pest infestation of crops, a rising number of crop diseases, the introduction of invasive species and crop weeds, land degradation and an overall reduction in crop yields (Khanal et al., 2019). Estimation of the number of daily patients of heat-related illness based on the weather data and newly introduced metrics shows that the effects of age, successive days and heat adaptation are key variables (Kodera et al., 2019).

Because most developing countries in Asia are highly vulnerable to the impacts of climate change due to a number of factors, many studies have focused on understanding vulnerability, for instance, gendered vulnerability at the micro scale, which limits capacity to respond to both climatic and socioeconomic stressors (Ferdous and Mallick, 2019); vulnerability of urban poor communities due to the interaction of environmental and social factors (e.g., low incomes, gender, migrant status) and heightens the impacts of climate change on the poor (Porio, 2014); social–ecological vulnerability where a degraded environment influences hazard patterns and vulnerability of people (Depietri, 2020); and livelihood vulnerability due to perceived climate risks and adaptation constraints (Fahad and Wang, 2018; Hossain et al., 2020).

Risk assessments have been undertaken for different hazards such as flood (Al Saud, 2015; Al-Amin et al., 2019; Jha and Gundimeda, 2019; Mahmood et al., 2019; Zhang et al., 2019e), drought (Guo et al., 2019; Mainali et al., 2019), rainfall-induced landslide (Li et al., 2019b), SLR (Imaduddina and Subagyo, 2014; Suroso and Firman, 2018) and heat stress (Onosuka et al., 2019), among others, as well as environmental assessment, for example, in coastal zones (Islam and Zhang, 2019). Different types of strategies for climate risk management have also been studied including: (a) *in situ* adaptation through ecosystem- and community-based adaptation (Jamero et al., 2017); (b) managed retreat or relocation (Buchori et al., 2018; Doberstein et al., 2020); (c) planned sheltering in flood zones (Wu et al., 2019c); (d) sustainable livelihoods that consider long-term CCA measures of farmers and fishermen (Nizami et al., 2019; Shaffril et al., 2019); (e) coastal afforestation through mangrove plantation (Rahman et al., 2018); (f) management of ecosystem services to mitigate the effects of droughts (Tran and Brown, 2019); (g) pre-investments, including holistic assessment of the basin (Inaoka et al., 2019); (h) institutionalisation, where entry points are identified in efforts to build resilience (Lassa, 2019) and adaptive governance (Walch, 2019); and (i) linking science and local knowledge (Mehta et al., 2019; van Gevelt et al., 2019).

The sectors to which CCA and DRR have been linked are varied. For example, Filho et al. (2019) assessed adaptive capacity and resilience to climate change based on urban poverty, infrastructure and community facilities; Mabon et al. (2019) looked at adaptation via the built environment, green roofs, and citizen and private-sector involvement in smaller-scale greening actions; Lama and Becker (2019) focused on adaptation to reduce risk in conflicts; Banwell et al. (2018) studied the link between health, CCA and DRR; and Izumi et al. (2019) surveyed science, technology and innovation for DRR. Vulnerable groups have been given much attention, such as farmers (Afroz, 2017; Gupta et al., 2019; Jawid and Khadjavi, 2019; Khanal et al., 2019; Shi et al., 2019a), women (Goodrich et al., 2019; Hossain et al., 2019; Udas et al., 2019), and children, elderly and refugees (Asia, 2017). Finally, issues identified include water resource management (Bhatta et al., 2019; Sen et al., 2019; Zhang et al., 2019a); food security (Aleksandrova et al., 2016; Le, 2016); disaster governance (Blanco, 2015); climate boundary shifting wherein impacts of climate change are significant for crop production, soil management and DRR (Talchabhadel and Karki, 2019); and institutional dimensions of CCA (Cuevas, 2018; Islam et al., 2020).

Case studies on climate risk management and integrated CCA and DRR actions highlight some key lessons including: an integrated and transformative approach to CCA, which focuses on long-term changes in addressing climate impacts (Filho et al., 2019); adoption of an adaptive flood risk management framework incorporating both risk observation and public perceptions (Al-Amin et al., 2019); a holistic approach and non-structural and technological measures in flood control management (Chan, 2014); monitoring of changes in urban surface water in relation to changes in seasons, land covers, anthropogenic activities and topographic characteristics for managing watersheds and urban planning (Faridatul et al., 2019); removing 'gender blindness' in agrobiodiversity conservation and adaptation policies (Ravera et al., 2019); understanding uncertainties in CCA and DRR at the local level (van der Keur et al., 2016; Djalante and Lassa, 2019); promoting the use of IKLK alongside scientific knowledge

(Hiwasaki et al., 2014); and increasing information, education and communication activities, and capacity development on DRR at the local level (Tuladhar et al., 2015a).

Several studies also have identified enabling conditions to effectively implement CCA and DRR actions. In the Arab region of Asia (ARA), the following are critical: capacity building to develop knowledge and awareness; mainstreaming CCA and DRR in the national strategies and policies (e.g., water and environmental strategies); empowering the role of CCA and DRR actors, notably women and rural societies; adopting lessons learned from regions with physical characteristics similar to those of ARA; establishing forecasting and prediction platforms that are supported by advanced monitoring technologies (e.g., remote sensing); and encouraging universities and research centres to develop studies on CCA and DRR. In Southeast Asia, laws and policies, institutional and financial arrangements, risk assessment, capacity building, and planning and implementation are entry points in integrating CCA and DRR (Lassa and Sembiring, 2017; Agency, 2018). According to Cutter et al. (2015), holistic solutions and integrated approaches, rigorous risk research that shows coherent science-based assessment and knowledge transfer from research to practice, and aligned targets on disaster risk management, climate change and sustainable development targets, are critical. Social capital and SP measures could promote pro-poor and gender-responsive adaptation as well as socially inclusive policies (Dilshad et al., 2019; Yari et al., 2019). Community-based approaches could allow local perceptions of climate change and experience of place to be included in planning (Dujardin et al., 2018; Dwirahmadi et al., 2019; Widiati and Irianto, 2019), and multi-stakeholder participation could engage various actors such as the private sector in CCA and DRR. Furthermore, multi-level climate governance could benefit from vertical and horizontal interactions at different levels and layers in the city (Zen et al., 2019). To mainstream and secure funding commitments, CCA and DRR could be integrated into national development plans and sectoral long-term plans (Ishiwatari and Surjan, 2020; Rahayu et al., 2020; Rani et al., 2020b).

10.6.2.3 Knowledge Gaps

Adaptation follows knowledge on risks, and literature exists that systematically identifies and characterises exposure and vulnerability, but gaps still exist. Decision making under uncertainty is challenged by the lack of data for adapting to current and uncertain future climate, the different perceptions of risk, and the potential solutions across different cultures and languages (van der Keur et al., 2016). Lack of downscaled climatic data, diverse institutional structures, and missing links in policies, are among the challenges in South Asia (Mall et al., 2019). In agriculture, there are gaps in the use of advanced farming techniques such as drought-resistant crops, and information on climate change to support farming households in making adaptation decisions (Akhtar et al., 2019; Khanal et al., 2019; Ullah et al., 2019). Better understanding of effective water management is crucial due to conflicts for shared water in ARA (Shaban and Hamze, 2017; UNDP, 2018). For delta regions, gaps identified are methodologies and approaches appropriate for understanding social vulnerability at various scales, pathways required for adaptation policy and response in the deltas that transcend development, and the lessons from implemented policy and how practice can build on these lessons in the deltas, among others (Lwasa, 2015). Approaches in tackling the challenges of climate change and disasters in the cities of developing countries could be better understood, and shared between cities so they can learn from one another (Filho et al., 2019).

10.6.3 Food–Water–Energy Nexus

10.6.3.1 Point of Departure

Food, energy, water and land are vital elements for sustainable development as well as enhancing resilience to both climatic and non-climatic shocks. All these resources are highly vulnerable to climate change (Sections 10.3.1, 10.3.4). Poor people are most affected due to changes in resources availability and accessibility. Food, water and energy security are interconnected (Bizikova et al., 2013; Ringler et al., 2013; Rasul, 2014; Chang et al., 2016; Ringler et al., 2016). Although adapting to climate change is one of the core components of the global, regional, national and subnational agendas, the focus of adaptation action has remained sectoral. Undermining the interlinkages of food, energy and water security may increase trade-offs between sectors or places, which may lead to maladaptation (Barnett and O'Neill, 2010; Howells et al., 2013; Lele et al., 2013). Therefore, focusing on the nature of trade-offs and synergies across the food–water–energy nexus for integrated management of resources is a potential strategy for adaptation to both climatic and non-climatic challenges (Bhaduri et al., 2015; Zaman et al., 2017). Due to its importance to the Paris Agreement and SDGs, the food–water–energy nexus approach has gotten increasing attention in terms of capturing synergies and minimising trade-offs in this interconnected system, which is also critical for enhancing adaptation together (Bazilian et al., 2011; Lawford et al., 2013; UNESCAP, 2013; FAO, 2014; Rasul and Sharma, 2014; Taniguchi et al., 2017a; Sukhwani et al., 2019; Sukhwani et al., 2020).

10.6.3.2 Findings

The food–water–energy nexus can be evaluated in the two-way interactions between water–food, water–energy and food–energy (Taniguchi et al., 2017a). The water–energy nexus includes water for energy and energy for water (Rothausen and Conway, 2011; Hussey and Pittock, 2012; Byers et al., 2014), the water–food nexus includes water for food and the impact of food production on water (Hoekstra and Mekonnen, 2012) and the energy–food nexus includes energy consumption for food production and food crops for biofuel production (Tilman et al., 2009). The food–water–energy–land nexus has diverse implications at the sub-regional level in Asia. The increase in the water-supply gap raises questions about the sustainability of the main mode of electricity generation in South Asia. Thermal power generation and hydropower generation are both threatened by water shortages in South Asia (Luo, 2018b; Mitra et al., 2021). Furthermore, policy-mismatch-driven anthropogenic causes lead to unsustainable water use for food production in India. For example, subsidised electricity supply for watering agriculture plays a key role in losing groundwater's buffer capacity against the various changes including climate variabilities (Badiani et al., 2012; Mitra, 2017). In the Mekong River basin of Southeast Asia, massive and rapid export-oriented hydropower development will have direct implications on regional food security and livelihoods through a major negative effect on the aquatic ecosystem (Baran and Myschowoda, 2009; Dugan et al., 2010; Arias et al., 2014). Similarly, in Central Asia, the shifting of water storage for irrigation to power development has increased risks on reliable water supply and quality of water (Granit et al., 2012). Deforestation-driven agro-environmental changes have led to a decreased forest water supply, an increased irrigation water demand and a negative effect on cropland stability and productivity (Lim et al., 2017a; Lim et al., 2019b).

10.6.3.3 Knowledge gaps

Many challenges remain in both scientific research and policy actions at the global, regional, national and subnational levels. The scientific challenges include data, information and knowledge gaps in understanding the food, energy, water and land interlinkages, and lack of systematic tools to address trade-offs (Liu et al., 2017a). Until very recently, implementation of the food–energy–water nexus focused primarily on technical solutions, whereas governance (i.e., the institutions and processes governing the food–energy–water nexus) has not received much consideration (Scheyvens and Shivakoti, 2019). At the policy end, the common challenges for implementation of the water–energy–food–land nexus are absence of sectoral coordination (Pahl-Wostl, 2019), the influence of political priorities on decisions and lack of processes for scientific knowledge to shape decisions, lack of capacity to understand interlinkages between sectors, lack of multi-stakeholder engagement in planning and decision-making processes, and lack of incentive mechanisms and adequate finance to support the approach (Bao et al., 2018; Scheyvens and Shivakoti, 2019).

10.6.4 Social Justice and Equity

Social justice focuses on the justice-related implications of social and economic institutions, examined in different ways such as distributional justice (distribution of benefits and burdens across different societal groups), procedural justice (the design of just institutions and processes for decision making), inter-generational justice (duties of justice to future generations) and recognitional justice (recognition of historical inequality) (Thaler et al., 2017). Climate change is affecting every aspect of our society and economy; thus, it is pertinent to understand the interactions between social justice and climate-change impacts (Tol, 2018), in particular, focusing on how vulnerability to various impacts is created, maintained and distributed across geographic, social, demographic and economic dimensions (Bulkeley et al., 2014; Schlosberg and Collins, 2014; Van de Vliert, 2014; Burke et al., 2016). For instance, environmental and health consequences of climate change, which disproportionately affect low-income countries and poor people in high-income countries, profoundly affect human rights and social justice (Levy and Patz, 2015). Furthermore, great concern is expressed about the plight of the poor, disadvantaged and vulnerable populations when it comes to climate, but not in other policy domains (Winters, 2014).

Evidence is increasing on the importance of focusing on environmental sustainability, and relieving poverty and social injustice are not conflicting aims; in fact, there is a further need for mainstreaming such approaches in order to respond to the climate-change challenge in a socially just manner (Mayrhofer and Gupta, 2016). These non-conflicting aims are described as co-benefits as reiterated in the IPCC reports as a central concept that refers to 'the positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare' (IPCC, 2014b). Better understanding of how social justice affects, and is affected by, efforts to build adaptive capacity will be crucial to avoiding unintended, and even perverse, outcomes. For example, on the Andaman coast of Thailand, responses to climate-change trends and events tended to be reactive rather than proactive, making already vulnerable people even more vulnerable and undermining their capacity to adapt in the future (Bennett et al., 2014). Different forms of inequality, moreover, render some groups more vulnerable than others to damage from climate hazards. In Mumbai, India, for example, the houses of poorer families required repeated repairs to secure them against flood damage, and the cumulative cost of those repairs consumed a greater proportion of their income than for richer populations (UN, 2016). Building the resilience of vulnerable groups requires strong community and government institutions that can support efforts to cope with devastating events, offering SP and social development initiatives to support at-risk or vulnerable groups (Drolet et al., 2015). In addition, agencies need to consider how they can best work in ways which potentially support longer-term positive change to gender roles and relations. For example, post-disaster activities must build and resource women's resilience and adaptive capacity in practice and challenge the constraints that impinge on their lives (Sadia et al., 2016; Sohrabizadeh et al., 2016; Hadiyanto et al., 2018; Yumarni and Amaratunga, 2018; Alam and Rahman, 2019).

Insights from the environmental justice literature show that an overemphasis on emission reductions at national levels obscures the negative impacts on disadvantaged communities, including low-income communities (Burch and Harris, 2014). The issue of social justice and adaptation is particularly relevant because of the politics that drive how adaptation and recovery efforts, as well as investments, are targeted towards specific populations, places and capacities (Klinsky et al., 2017). Hence, climate justice and equity need to be highlighted more explicitly in integrative approaches to mitigation and adaptation (*medium evidence, high agreement*) (Moellendorf, 2015; Henrique KP, 2020).

The term 'climate justice' is used to problematise global warming in ethical and political contexts. It does so by employing the concepts of environmental justice and social justice to examine inequalities and violation of human collective rights in relation to climate-change impacts (Ghimire, 2016).

At the heart of climate-justice concerns lies the asymmetry that those who have contributed least to the problem of climate change (i.e., GHG emissions) are the ones who will be affected by its adverse impacts the most. It is about sharing the burden and benefits equitably (a) among developed and developing countries in the context of historical responsibility, and (b) within nations to uplift the marginalised and affected populations who have contributed the least to the problem in the contexts of per-capita equity and local vulnerability (Joshi, 2014; Chaudhuri, 2020; Shawoo, 2020).

An ethical analysis of the climate regime reveals an abidingly strong interconnection between economic circumstances, geopolitical power and the justice claims that nations can assert in negotiations (Okereke, 2016). Events within the climate regime highlight the importance of questioning the extent to which claims of justice can ever be truly realised in the context of international regimes of environmental governance, as well as how much concerns for justice are motivated by other concerns such as relative economic gains or geopolitical objectives (Sikor, 2014).

The global land rush and mainstream climate-change narratives have broadened the ranks of state and social actors concerned about land issues while strengthening those opposed to social-justice-oriented land policies (Borras, 2018). The five deep social reforms (redistribution, recognition, restitution, regeneration and resistance) of socially just land policy are necessarily intertwined. But the global land rush amid deepening climate change calls attention to the linkages, especially between the pursuit of agrarian justice, on the one hand, and climate justice, on the other. Here, the relationship is not without contradictions and warrants increased attention as both unit of analysis and object of political action. Understanding and deepening agrarian-justice imperatives in climate politics, and understanding and deepening climate-justice imperatives in agrarian politics, is needed more than ever in the ongoing pursuit of alternatives. For example, the intersection between land grabs and climate-change mitigation politics in Myanmar has created new political opportunities for scaling up, expanding and deepening the struggles towards 'agrarian climate justice'(Sekine, 2021).

Frequently Asked Questions

FAQ 10.1 | What are the current and projected key risks related to climate change in each sub-region of Asia?

Climate-change-related risks are projected to increase progressively at 1.5°C, 2°C and 3°C of global warming in many parts of Asia. Heat stress and water deficit are affecting human health and food security. Risks due to extreme rainfall and sea level rise are exacerbated in vulnerable Asia.

Climatologically, the summer surface air temperature in South, Southeast and Southwest Asia is high, and its coastal area is very humid. In these regions, heat stress is already a medium risk for humans. Large cities are warmer by more than 2°C compared with the surroundings due to heat island effects, exacerbating heat stress conditions. Future warming will cause more frequent temperature extremes and heatwaves especially in densely populated South Asian cities, where working conditions will be exacerbated and daytime outdoor work will become dangerous. For example, incidence of excess heat-related mortality in 51 cities in China is estimated to reach 37,800 deaths per year over a 20-year period in the mid-21st century (2041–2060) under the RCP8.5 scenario.

Asian glaciers are the water resources for local and adjacent regions. Glaciers are decreasing in Central, Southwest, Southeast and North Asia, but are stable or increased in some parts of the Hindu Kush Himalaya region. The glacier melt water in the southern Tibetan Plateau increased during 1998–2007, and the total amount and area of glacier lakes has increased during recent decades. In the future, maximum glacial runoff is projected in High Mountain Asia. Glacier collapses and surges, together with glacier lake outburst flood due to the expansion of glacier lakes, will threaten the securities of the local and down streaming societies.

With much of the Asian population living in drought-prone areas, water scarcity is a prevailing risk across Asia through water and food shortage leading to malnutrition. Populations vulnerable to impacts related to water are going to increase progressively at 1.5°C, 2°C and 3°C of global warming. Aggravating drought condition is projected in Central Asia. Water quality degradation also has profound impact on human health.

Extreme rainfall causes floods in vulnerable rivers. Observed changes in extreme rainfall vary considerably by region in Asia. Extreme rainfall events (such as heavy rainfall >100 mm per day) have been increasing in South and East Asia. In the future, most of East and Southeast Asia are projected to experience more intense rainfall events as soon as by the middle of the 21st century. In those regions, the flood risk will become more frequent and severe. It is estimated that over one-third of Asian cities and about 932 million urban dwellers are living in areas with high risk of flooding.

Sea level rise is continuing. Higher than the global mean sea level rise is projected on Asian coasts. Storm surge and high wave by tropical cyclones of higher intensity are high risk for a large number of Asian megacities facing the ocean: China, India, Bangladesh, Indonesia and Vietnam have the highest numbers of coastal populations exposed and thus are most vulnerable to disaster-related mortality.

Changes in terrestrial biome have been observed that are consistent with warming, such as an upward move of treeline position in mountains. Climate change, human activity, lightning and quality of forest governance and management have increased wildfire severity and area burned in North Asia in recent decades. Changes in marine primary production also have been observed: a decrease up to 20% over the past six decades in the western Indian Ocean, due to ocean warming and stratification, has restricted nutrient mixing. The risk of irreversible loss of many ecosystems will increase with global warming.

FAQ 10.1 (continued)

The likelihood of adverse impacts to agricultural and food security in many parts of developing Asia will progressively escalate with the changing climate. The potential of total fisheries production in South and Southeast Asia is also projected to decrease.

Figure FAQ10.1.1 | Key risks related to climate change in Asia.

Frequently Asked Questions

FAQ 10.2 | What are the current and emerging adaptation options across Asia?

Mirroring the heterogeneity across Asia, different countries and communities are undertaking a range of reactive and proactive strategies to manage risk in various sectors. Several of these adaptation actions show promise, reducing vulnerability and improving societal well-being. However, challenges remain around scaling up adaptation actions in a manner that is effective and inclusive while simultaneously meeting national development goals.

Asia exhibits tremendous variation in terms of ecosystems, economic development, cultures and climate risk exposure. Mirroring this variation, households, communities and governments have a wide range of coping and adaptation strategies to deal with changing climatic conditions, with co-benefits for various non-climatic issues such as poverty, conflict and livelihood dynamics.

Currently, Asian countries have rich evidence on managing risk, drawing on long histories of dealing with change. For example, to deal with erratic rainfall and shifting monsoons, farmers make incremental shifts such as changing what and when they grow or adjusting their irrigation practices. Communities living in coastal settlements are using Early warning systems to prepare for cyclones or raising the height of their houses to minimise flood impacts. These types of strategies, seen across all Asian sub-regions, based on local social and ecological contexts, are termed *autonomous adaptations* that occur incrementally and help people manage current impacts.

Currently and in the future, Asia is identified as one of regions most vulnerable to climate change, especially on extreme heat, flooding, sea level rise and erratic rainfall. All these climatic risks, when overlaid on existing development deficits, show us that incremental adaptation will not be enough; transformational change is required. Recognising this, at subnational and national levels, government and non-governmental actors are also prioritising *planned adaptation strategies* which include interventions like 'climate-smart agriculture' as seen in South and Southeast Asian countries, or changing labour laws to reduce exposure to heat as seen in West Asia. These are often sectoral priorities governments lay out through national or subnational policies and projects, drawing on various sources of funding: domestic, bilateral and international. Apart from these planned adaptation strategies in social systems, Asian countries also report and invest in adaptation measures in natural systems such as expanding nature reserves to enable species conservation or setting up habitat corridors to facilitate landscape connectivity and species movements across climatic gradients.

Overall, the fundamental challenges that Asia will see exacerbated under climate change are around water and food insecurity, poverty and inequality, and increased frequency and severity of extreme events. In some places and for some people, climate change, even at 1.5°C and more so at 2°C, will significantly constrain the functioning and well-being of human and ecological systems. Asian cities, villages and countries are rising to this current and projected challenge, albeit somewhat unevenly.

Some examples of innovative adaptation actions are China's 'Sponge Cities' which are trying to protect ecosystems while reducing risk for people, now and in the future. Another example is India's Heat Action Plans that are using 'cool roofs' technologies and awareness-building campaigns to reduce the impacts of extreme heat. Across South and Southeast Asia, climate-smart agriculture programmes are reducing GHG emissions associated with farming while helping farmers adapt to changing risks. Each country is experimenting with infrastructural, nature-based, technological, institutional and behavioural strategies to adapt to current and future climate change with local contexts shaping both the possibility of undertaking such actions as well as the effectiveness of these actions to reduce risk. What works for ageing cities in Japan exposed to heatwaves and floods may not work for pastoral communities in the highlands of Central Asia, but there is progress on understanding what actions work and for whom. The challenge is to scale current adaptation action, especially in the most exposed areas and for the most vulnerable populations, as well as move beyond adapting to single risks alone (i.e., adapt to multiple coinciding risks such as flooding and water scarcity in coastal cities across South Asia or extreme heat and flash floods in West Asia). In this context, funding and implementing adaptation is essential, and while Asian countries are experimenting with a range of autonomous and planned adaptation actions to deal with these multiple and often concurrent challenges, making current development pathways climate resilient is necessary and, some might argue, unavoidable.

FAQ 10.2 (continued)

Table FAQ10.2.1 | System transitions, sectors and illustrative adaptation options

System transitions	Sectors	Illustrative adaptation options
Energy and industrial systems	Energy and industries	Diversifying energy sources Improving energy access, especially in rural areas Improving resilience of power infrastructure Rehabilitation and upgrading of old buildings
Land and ecosystems	Terrestrial and freshwater ecosystems	Expanding nature reserves Assisted species migration Introducing species to new regions to protect them from climate-induced extinction risk Sustainable forest management including afforestation, forest fuel management, fire management
	Ocean and coastal ecosystems	Marine protected areas Mangrove and coral reef restoration Integrated coastal zone management Sand banks and structural technologies
	Freshwater	Integrated watershed management Transboundary water management Changing water access and use practices to reduce/manage water demand High-efficiency water-saving technology Aquifer storage and recovery
	Agriculture, fisheries and food	Changing crop type and variety, improving seed quality Water storage, irrigation and water management Climate-smart agriculture Early warning systems and use of climate information services Fisheries management plans (e.g., seasonal closures, limited fishing licenses, livelihood diversification)
Urban systems	Cities and settlements	Flood protection measures and sea walls sustainable land-use planning and regulation Protecting urban green spaces, improving permeability, mangrove restoration in coastal cities Planned relocation and migration Disaster management and contingency planning
	Key infrastructures	Climate-resilient highways and power infrastructure Relocating key infrastructure
Health systems		Reducing air pollution Changing dietary patterns

Frequently Asked Questions

FAQ 10.3 | How are Indigenous knowledge and local knowledge being incorporated in the design and implementation of adaptation projects and policies in Asia?

Indigenous People, comprising about 6% of the global population, play a crucial role in managing climate change for two important reasons. First, they have a physical and spiritual connection with land, water and associated ecosystems, thus making them most vulnerable to any environmental and climatic changes. Second, their ecological and local knowledge are relevant to finding solutions to climate change.

Indigenous knowledge and local knowledge (IKLK) play an important role in the formulation of adaptation governance and related strategies (IPCC 2007), and best quality, locality-specific knowledge can help address the serious lack of education on climate change and uncertainties surrounding quality, salience, credibility and the legitimacy of the available knowledge base.

Key findings across Asia underline the importance of building, sustaining and augmenting local capacity through addressing inadequacies in terms of resource base, climate-change awareness, government–community partnerships and vulnerability assessment. Furthermore, inclusion of as well as related practices will improve adaptation planning and decision-making processes concerning climate change.

FAQ 10.3 (continued)

In climate-sensitive livelihoods, an integrated approach informed by science that examines multiple stressors, along with IKLK, appears to be of immense value. For instance, in building farmers' resilience, enhancing CCA, ensuring cross-cultural communication and promoting local skills, Indigenous People's intuitive thinking processes and geographic knowledge of remote areas are very important.

There is also a widespread recognition that IKLK are important in ensuring successful ecosystem-based adaptation (EbA). However, this recognition requires more practical application and translation into IKLK-driven EbA projects. For instance, in the Coral Triangle region, creating historical timelines and mapping seasonal calendars can help to capture IKLK while also feeding this information into climate science and climate adaptation planning. Identifying indigenous crop species for agriculture by using IKLK is already identified as an important way to localise climate adaptation: an example is Bali's vital contribution of moral economies to food systems which have long built resilience among groups of communities in terms of food security and sovereignty, even with the challenges faced due to modernising of local food systems.

Many of the pressing problems of Asia, including water scarcity, rapid urbanisation, deforestation, loss of species, rising coastal hazards and agricultural loss can be effectively negated, or at least minimised, through proper adoption of suitable science and technological methods. Climate-change adaptation is greatly facilitated by science, technology and innovation. This ranges from application of existing science, new development on scientific tools and methods, application of IKLK and citizen sciences. Deploying Knowledge Quality Assessment Tool found significant co-relation between science-based and IKLK framing would help to address, acknowledge and utilise by an integrated approach the wisdom of IKLK, a valuable asset for climate adaptation governance. The IKLK-based environmental indicators need to be seen as part of a separate system of knowledge that coexists with, but is not submerged into, another conventional knowledge system.

In the context of education and capacity development of climate change, an integrated approach of embracing both the importance of climate science and IKLK is acknowledged. The IKLK is increasingly recognised as a powerful tool for compiling evidence of climate change over time. Such as knowledge of CCA and DRR provide a range of complementary approaches in building resilience and reducing the vulnerability of natural and human systems. Developing knowledge and utilising existing IKLK, skills and dispositions to better cope with already evident and looming climate impacts. Engaging communities in the process of documenting and understanding long-term trends and practices will enable both IKLK as well as Western scientific assessments of climate change to contribute in designing appropriate climate adaptation measures.

Frequently Asked Questions

FAQ 10.4 | How can Asia meet multiple goals of climate-change adaptation and sustainable development within the coming decades?

Asian countries are testing ways to develop in a climate-resilient manner to meet the goals related to climate change and sustainable development simultaneously. Some promising examples exist, but the window of opportunity to put some of these plans in place is small and closing fast, highlighting the need for urgent action across and within countries.

In order to achieve the multiple goals of CCA, mitigation and sustainable development, critical are rapid, system transitions across (a) energy systems, (b) land and ecosystems and (c) urban and infrastructural systems. This is especially important across Asia, which has the largest population exposed to current climate risks and high sub-regional diversity, and where risks are expected to rise significantly and unevenly under higher levels of global warming. However, such transformational change is deeply challenging because of variable national development imperatives; differing capacities and requirements of large, highly unequal and vulnerable populations; and socioeconomic and ecological diversity that requires very contextual solutions. Furthermore, issues such as growing transboundary risks, inadequate data for long-term adaptation planning, finance barriers, uneven institutional capacity and non-climatic issues, such as increasing conflict, political instability and polarization, constrain rapid, transformational action across systems.

FAQ 10.4 (continued)

Despite these challenges, there are increasing examples of actions across Asia that are meeting climate adaptation goals and SDGs simultaneously, such as through climate-smart agriculture, disaster risk management and NbS. To enable these system transitions, vertical and horizontal policy linkages, active communication and cooperation between multiple stakeholders, and attention to the root causes of vulnerability are essential. Furthermore, rapid systemic transformation can be enabled by policies and finances to incentivise capacity building, new technological innovation and diffusion. The effectiveness of such technology-centred approaches can be maximised by combining them with attention to behavioural shifts such as by improving education and awareness, building local capacities and institutions, and leveraging IKLK.

Obviously, time is of the essence. If system transitions are delayed, there is *high confidence* that climatic risks will increase human and natural system vulnerability, as well as increase inequality and erode the achievements of multiple SDGs. Thus, urgent systemic change that is suited to national and subnational social–ecological contexts across Asia is imperative.

Adaptatation option	Mitigation impacts	Implications on SDGs	
		Positive	Negative
Wetland protection, restoration	Medium synergy (carbon sequestration through mangroves)	8 DECENT WORK AND ECONOMIC GROWTH; 14 LIFE BELOW WATER; 15 LIFE ON LAND	
Solar drip irrigitation	High synergy (shift to cleaner energy)	2 ZERO HUNGER; 7 AFFORDABLE AND CLEAN ENERGY; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	10 REDUCED INEQUALITIES
Climate-smart agriculture	High synergy (no till practices and improved residue management can reduce soil carbon emissions)	2 ZERO HUNGER; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	
Integrated smart water grids	High synergy (reduced energy needs for supplying water)	6 CLEAN WATER AND SANITATION; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES	
Disaster risk management (including early warning systems)	Not applicable	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES	5 GENDER EQUALITY; 10 REDUCED INEQUALITIES
Aquifer storage and recovery	Low synergy	6 CLEAN WATER AND SANITATION; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	
Nature-based solutions in urban areas: green infrstructure	High synergy (blue-green infrastructure act as carbon sinks)	3 GOOD HEALTH AND WELL-BEING; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES	
Coastal green infrastructure	High synergy	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES; 14 LIFE BELOW WATER; 15 LIFE ON LAND	

Figure FAQ10.4.1 | Adaptation options, mitigation impacts and implications on Sustainable Development Goals.

References

Aayog, N., 2017: *Inventory and Revival of Springs in the Himalayas for Water Security*. Dept. of Science and Technology, Government of India, New Delhi.

Abadie, L.M., I. Galarraga and E.S. de Murieta, 2017: Understanding risks in the light of uncertainty: low-probability, high-impact coastal events in cities. *Environ. Res. Lett.*, **12**(1), doi:10.1088/1748-9326/aa5254.

Abadie, L.M., et al., 2020: Comparing urban coastal flood risk in 136 cities under two alternative sea-level projections: RCP 8.5 and an expert opinion-based high-end scenario. *Ocean. Coast. Manag.*, **193**, 105249, doi:10.1016/j.ocecoaman.2020.105249.

Abbas, A., T.S. Amjath-Babu, H. Kächele and K. Müller, 2015: Non-structural flood risk mitigation under developing country conditions: an analysis on the determinants of willingness to pay for flood insurance in rural Pakistan. *Nat. Hazards*, **75**(3), 2119–2135, doi:10.1007/s11069-014-1415-x. SpringerLink.

Abbas, A., et al., 2019: Participatory adaptation to climate extremes: an assessment of households' willingness to contribute labor for flood risk mitigation in Pakistan. *J. Water Clim. Chang.*, **7**(3), 621–636, doi:10.2166/wcc.2016.002.

Abe, M. and L. Ye, 2013: Building resilient supply chains against natural disasters: The cases of Japan and Thailand. *Glob. Bus. Rev.*, **14**(4), 567–586.

Abid, M., U.A. Schneider and J. Scheffran, 2016: Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan. *J. Rural Stud.*, **47**, 254–266, doi:10.1016/j.jrurstud.2016.08.005.

Abolmaali, S.M.-R., M. Tarkesh and H. Bashari, 2018: MaxEnt modeling for predicting suitable habitats and identifying the effects of climate change on a threatened species, Daphne mucronata, in central Iran. *Ecol. Inform.*, **43**, 116–123, doi:10.1016/j.ecoinf.2017.10.002.

Abubakar, I., et al., 2018: The UCL–Lancet Commission on Migration and Health: the health of a world on the move. *Lancet*, **392**(10164), 2606–2654.

Acharya, A. and A. Prakash, 2019: When the river talks to its people: Local knowledge-based flood forecasting in Gandak River basin, India. *Environ. Dev. Elsevier*, **31**, 55–67, doi:10.1016/j.envdev.2018.12.003.

Acharya, P., B. Boggess and K. Zhang, 2018: Assessing heat stress and health among construction workers in a changing climate: A review. *Int. J. Environ. Res. Public Health*, **15**(2), 247.

Ackerman, K., et al., 2014: Sustainable Food Systems for Future Cities: The Potential of Urban Agriculture. *Econ. Soc. Rev.*, **45**(2).

Adaev, V., 2018: Smoke over taiga and tundra: fire in the culture of Northern peoples of Western Siberia as a means of environmental management. *Vest. Arheol. Antropol. Etnogr.*, 138–147, doi:10.20874/2071-0437-2018-41-2-138-147.

Adam, H.N., 2015: Mainstreaming adaptation in India – the Mahatma Gandhi National Rural Employment Guarantee Act and climate change. *Clim. Dev.*, **7**(2), 142–152, doi:10.1080/17565529.2014.934772.

ADB, 2013: *Investing in Resilience: Ensuring a Disaster-Resistant Future*. ISBN 978-9290929499. 188 pp.

ADB, 2014: *Climate proofing ADB investment in the transport sector: initial experience*.

ADB, 2016: *Integrating Information and Communication Technology in Social Protection Programs* ADB Briefs. ADB, Manila.

ADB, 2017a: *Meeting Asia's Infrastructure Needs*.

ADB, 2017b: *A region at risk: The human dimensions of climate change in Asia and the Pacific*. Asian Development Bank, Mandalyong City, Metro Manila, https://www.adb.org/sites/default/files/publication/325251/region-risk-climate-change.pdf.

ADB, 2019: *The Enabling Environment for Disaster Risk Financing in Sri Lanka: Country Diagnostics Assessment*, 56.

Adger, W.N., et al., 2021: Perceived environmental risks and insecurity reduce future migration intentions in hazardous migration source areas. *One Earth*, **4**(1), 146–157.

Adhikari, P., et al., 2018: Potential impact of climate change on the species richness of subalpine plant species in the mountain national parks of South Korea. *J. Ecol. Environ.*, **42**(4), 298–307, doi:10.1186/s41610-018-0095-y.

Adler, C., C. Huggel, B. Orlove and A. Nolin, 2019: *Climate change in the mountain cryosphere: impacts and responses*. Springer, Berlin.

Afroz, R., 2017: Determinants of Malaysian farmers' choice of adaptation strategies for adapting to climate change in Kedah Malaysia. *Asian J. Agric. Res.*, **11**, 120–127, doi:10.3923/ajar.2017.120.127.

Agency, J.I.C., 2018: *Project for Strengthening Institutional and Policy Framework on Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) Integration (ASEAN)*. JICA.

Aggarwal, P., et al., 2020: Application note: Crop-loss assessment monitor–A multi-model and multi-stage decision support system. *Comput. Electron. Agric.*, **175**, 105619.

Aggarwal, P., S. Vyas, P. Thornton and B.M. Campbell, 2019: How much does climate change add to the challenge of feeding the planet this century? *Environ. Res. Lett.*, **14**(4), 43001, doi:10.1088/1748-9326/aafa3e.

Aghaei, N., H. Seyedin and H. Sanaeinasab, 2018: Strategies for disaster risk reduction education: A systematic review. *J. Educ. Health Promot.*, **7**, 98, doi:10.4103/jehp.jehp_31_18.

Agung, P., G. Galudra, M. Van Noordwijk and R. Maryani, 2014: Reform or reversal: the impact of REDD+ readiness on forest governance in Indonesia. *Clim. Policy*, **14**(6), 748–768, doi:10.1080/14693062.2014.941317.

Ahluwalia, R.S., et al., 2016: Towards the understanding of the flash flood through isotope approach in Kedarnath valley in June 2013, Central Himalaya, India. *Nat Hazards*, **82**(1), 321–332, doi:10.1007/s11069-016-2203-6.

Ahmad, M., et al., 2015: *Chapter 7: Impact of Climate Change on the Rice–Wheat Cropping System of Pakistan* Cynthia Rosenzweig, D. H. 219–258.

Ahmad, I., et al., 2019: *Climate change impacts and adaptation strategies for agronomic crops*. IntechOpen, London, UK, ISBN 978-1789856675.

Shabudin, A., S. Azhar and T.F. Ng, 2017: Learning lab on disaster risk management for sustainable development (DRM-SD). *Int. J. Clim. Chang. Strateg. Manag.*, **9**(5), 600–625, doi:10.1108/ijccsm-08-2016-0114.

Ahmadi, M., P. Chatrchi and A.A. Dadashi Rodbari, 2018: Modeling the precipitation trend in the West Asia region under climate change. *Res. Earth Sci.*, **9**(35), P479.

Ahmed, A.U., A.N. Appadurai and S. Neelormi, 2019a: Status of climate change adaptation in South Asia region. In: *Status of Climate Change Adaptation in Asia and the Pacific*. Springer, Berlin Heidelberg, pp. 125–152.

Ahmed, C.I., W.B. Hu and S. Kumar, 2016a: Indigenous knowledge about prediction in climate change. *Int. J. Human. Soc. Sci.*, **5**(1), 45–62.

Ahmed, I., et al., 2019b: Opportunities and challenges of compliance to safe building codes: Bangladesh and Nepal. *APN Sci. Bull.*, **9**(1), doi:10.30852/sb.2019.834.

Ahmed, M. and S. Suphachalasai, 2014: *Assessing the costs of climate change and adaptation in South Asia*. Asian Development Bank.

Ahmed, N. and J.S. Diana, 2015: Threatening "white gold": Impacts of climate change on shrimp farming in coastal Bangladesh. *Ocean. Coast. Manag.*, **114**, 42–52, doi:10.1016/j.ocecoaman.2015.06.008.

Ahmed, N. and M. Glaser, 2016: Coastal aquaculture, mangrove deforestation and blue carbon emissions: Is REDD+ a solution? *Mar. Policy.*, **66**, 58–66, doi:10.1016/j.marpol.2016.01.011.

Ahmed, N., S. Thompson and M. Glaser, 2018: Integrated mangrove-shrimp cultivation: Potential for blue carbon sequestration. *Ambio*, **47**(4), 441–452, doi:10.1007/s13280-017-0946-2.

Ahmed, N., S. Thompson and M. Glaser, 2019c: Global aquaculture productivity, environmental sustainability, and climate change adaptability. *Environ. Manage.*, **63**(2), 159–172, doi:10.1007/s00267-018-1117-3.

Ahmed, S., et al., 2016b: A comparative review of China, India and Pakistan renewable energy sectors and sharing opportunities. *Renew. Sustain. Energy Rev.*, **57**, 216–225, doi:10.1016/j.rser.2015.12.191.

Ahmed, S. and J. Stepp, 2016: Beyond yields: Climate change effects on specialty crop quality and agroecological management. *Elem. Sci. Anthropocene*, **4**, 92, doi:10.12952/journal.elementa.000092.

Ahmedabad Municipal, C., 2018: *Ahmedabad heat action plan 2018. guide to extreme heat planning in Ahmedabad, India*.

Aich, V., et al., 2017: Climate Change in Afghanistan Deduced from Reanalysis and Coordinated Regional Climate Downscaling Experiment (CORDEX)—South Asia Simulations. *Climate*, **5**(2), doi:10.3390/cli5020038.

Ajibade, I. and E. Michael, 2019: SDGs and climate change adaptation in Asia megacities: Synergies and opportunities for transformation. In: *Achieving the Sustainable Development Goals: Global Governance Challenges* [Dalby, A., S. Horton, R. Mahon and D. Thomaz)](eds.)]. Routledge, London, pp. 100–116.

Ajibade, I., 2019: Planned retreat in Global South megacities: disentangling policy, practice, and environmental justice. *Clim. Change*, **157**(2), 299–317.

Akbari, H. and D. Kolokotsa, 2016: Three decades of urban heat islands and mitigation technologies research. *Energy Build.*, **133**, 834–842, doi:10.1016/j.enbuild.2016.09.067.

Akber, M.A., et al., 2017: Changes of shrimp farming in southwest coastal Bangladesh. *Aquac. Int.*, **25**(5), 1883–1899, doi:10.1007/s10499-017-0159-5.

Akhtar, R., M.M. Masud and R. Afroz, 2019: Perception of Climate Change and the Adaptation Strategies and Capacities of the Rice Farmers in Kedah, Malaysia. *Environ. Urban. Asia*, **10**(1), 99–115, doi:10.1177/0975425318822338.

Akhtar, S., K. Zahedi and T. Bonapace, 2018: *Sand and dust storms in Asia and the Pacific: opportunities for regional cooperation and action., United Nations Economic and Social Commission for Asia and the Pacific, Bangkok*. https://www.unescap.org/sites/default/files/UNESCAP%20SDS%20Report_1.pdf. Accessed 2021.

Al-Amin, A.Q., et al., 2019: Evaluating the impacts of climate disasters and the integration of adaptive flood risk management. *Int. J. Disaster Risk Reduct.*, **39**, doi:10.1016/j.ijdrr.2019.101241.

Al-Zahrani, K.H., M.B. Baig and G.S. Straquadine, 2019: Food Waste in the Kingdom of Saudi Arabia: Implications for Extension Education. In: *Climate Change, Food Security and Natural Resource Management : Regional Case Studies from Three Continents* [Behnassi, M., O. Pollmann and H. Gupta)](eds.)]. Springer International Publishing, Cham, pp. 73–101. ISBN 978-3319970912.

Al Saud, M., 2015: *Flood Control Management for the City and Surroundings of Jeddah, Saudi Arabia*, 1st edn., Vol. XIII. Springer Natural Hazards, Springer Netherlands, Dortrecht. 169 pp.

Alam, G.M.M., K. Alam and S. Mushtaq, 2017: Climate change perceptions and local adaptation strategies of hazard-prone rural households in Bangladesh. *Clim. Risk Manag.*, **17**, 52–63, doi:10.1016/j.crm.2017.06.006.

Alam, K. and M.H. Rahman, 2014: Women in natural disasters: A case study from southern coastal region of Bangladesh. *Int. J. Disaster Risk Reduct.*, **8**, 68–82, doi:10.1016/j.ijdrr.2014.01.003.

Alam, K. and M.H. Rahman, 2019: Post-disaster recovery in the cyclone Aila affected coastline of Bangladesh: women's role, challenges and opportunities. *Nat. Hazards*, doi:10.1007/s11069-019-03591-7.

Alam, M.F., et al., 2020: *Convergence and co-financing opportunities for climate-resilient water management*. Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH; Water Security and Climate Adaptation in Rural India (WASCA), Bonn, Germany and New Delhi, India. 109 pp.

Alamgir, M., S.A. Mukul and S.M. Turton, 2015: Modelling spatial distribution of critically endangered Asian elephant and Hoolock gibbon in Bangladesh forest ecosystems under a changing climate. *Appl. Geogr.*, **60**, 10–19.

Alauddin, M. and M.A.R. Sarker, 2014: Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation. *Ecol. Econ.*, **106**, 204–213, doi:10.1016/j.ecolecon.2014.07.025.

Alauddin, S. and K.F. Rahman, 2013: Vulnerability to climate change and adaptation practices in Bangladesh. *J. Sub*, **4**(2), 25–42.

Albright, R. and B. Mason, 2013: Projected Near-Future Levels of Temperature and pCO(2) Reduce Coral Fertilization Success. *Plos One*, **8**(2), 8, doi:10.1371/journal.pone.0056468.

Alcayna, T., V. Bollettino, P. Dy and P. Vinck, 2016: Resilience and Disaster Trends in the Philippines: Opportunities for National and Local Capacity Building. *PLoS Curr.*, **8**, doi:10.1371/currents.dis.4a0bc960866e53bd6357ac135d740846.

Aleksandrova, M., 2019: Principles and considerations for mainstreaming climate change risk into national social protection frameworks in developing countries. *Clim. Dev.*, 1–10, doi:10.1080/17565529.2019.1642180.

Aleksandrova, M., A.K. Gain and C. Giupponi, 2016: Assessing agricultural systems vulnerability to climate change to inform adaptation planning: an application in Khorezm, Uzbekistan. *Mitig. Adapt. Strateg. Glob. Change*, **21**(8), 1263–1287.

Ali, A. and O. Erenstein, 2017: Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Clim. Risk Manag.*, **16**, 183–194, doi:10.1016/j.crm.2016.12.001.

Ali, H., V. Mishra and D.S. Pai, 2014: Observed and projected urban extreme rainfall events in India. *J. Geophys. Res. Atmos.*, **119**(22), 12,621–12,641, doi:10.1002/2014JD022264.

Ali, J., et al., 2018: Centennial heat wave projections over Pakistan using ensemble NEX GDDP data set. *Earth Syst. Environ.*, **2**(3), 437–454.

Ali, S., et al., 2020: Identifying hotspots cities vulnerable to climate change in Pakistan under CMIP5 climate projections. *Int. J. Climatol.*, doi:10.1002/joc.6638.

Ali, S., et al., 2017: Climate Change and Its Impact on the Yield of Major Food Crops: Evidence from Pakistan. *Foods*, **6**(6), doi:10.3390/foods6060039.

Aliagha, U.G., et al., 2014: Factors affecting flood insurance purchase in residential properties in Johor, Malaysia. *Nat. Hazards Earth Syst. Sci.*, **14**(12), 3297–3310, doi:10.5194/nhess-14-3297-2014.

Aliagha, U.G., M. Iman, H.M. Ali, N. Kamaruddin and K.N. Ali, 2013: Discriminant factors of flood insurance demand for flood-hit residential properties: a case for Malaysia. *J. Flood Risk Manag.*, **8**, 39–51, doi:10.1111/jfr3.12065.

Alizadeh-Choobari, O., P. Ghafarian and E. Owlad, 2016: Temporal variations in the frequency and concentration of dust events over Iran based on surface observations. *Int. J. Climatol.*, **36**(4), 2050–2062, doi:10.1002/joc.4479.

Allen, S.K., et al., 2018: Translating the concept of climate risk into an assessment framework to inform adaptation planning: Insights from a pilot study of flood risk in Himachal Pradesh, Northern India. *Environ. Sci. Policy*, **87**, 1–10.

Allen, S.K., et al., 2016: Lake outburst and debris flow disaster at Kedarnath, June 2013: hydrometeorological triggering and topographic predisposition. *Landslides*, **13**(6), 1479–1491, doi:10.1007/s10346-015-0584-3.

Almaden, C.R.C., et al., 2019a: *Meso-Level Analysis on Rice-Farmers' Adaptive Measures for Slow Onset Hazard: The Case of Saltwater Intrusion in the Philippines and Vietnam*.

Almaden, C.R.C., et al., 2019b: Determinants of Adaptation for Slow-Onset Hazards: The Case of Rice-Farming Households Affected by Seawater Intrusion in Northern Mindanao, Philippines. *Asian J. Agric. Dev. Southeast Asian Reg. Cent. Graduate Study Res. Agric.*, **16**(1), 117–132, doi:10.22004/ag.econ.289833.

Alshehri, S.A., Y. Rezgui and H. Li, 2013: Public perception of the risk of disasters in a developing economy: the case of Saudi Arabia. *Nat Hazards*, **65**(3), 1813–1830, doi:10.1007/s11069-012-0445-5.

Altman, J., et al., 2020: Tree growth response to recent warming of two endemic species in Northeast Asia. *Clim. Change*, **162**(3), 1345–1364, doi:10.1007/s10584-020-02718-1.

Alvi, S. and U. Khayyam, 2020: Mitigating and adapting to climate change: attitudinal and behavioural challenges in South Asia. *Int. J. Clim. Chang. Strateg. Manag.*, **12**(4), 477–493, doi:10.1108/ijccsm-08-2019-0054.

Amjath-Babu, T., P.K. Aggarwal and S. Vermeulen, 2019: Climate action for food security in South Asia? Analyzing the role of agriculture in nationally determined contributions to the Paris agreement. *Clim. Policy*, **19**(13), 283–298.

Anderson, M.K.G.P.B.C.L., 2019: Delivering development? Evidence on self-help groups as development intermediaries in South Asia and Africa. *Dev. Policy Rev.*, **37**(1), 129–151.

Andreeva, M.V., Y.N. Kurochkin, M.V. Syromyatina and K.V. Chistyakov, 2019: Factors of Spatial and Temporal Variability of Siberian Larch Growth in the Mountain Regions of Altai, Tuva, and Mongolia. *Russ. J. Ecol.*, **50**(5), 453–459, doi:10.1134/S1067413619040040.

Anguelovski, I., E. Chu and J. Carmin, 2014: Variations in approaches to urban climate adaptation: Experiences and experimentation from the global South. *Glob. Environ. Chang.*, **27**, 156–167, doi:10.1016/j.gloenvcha.2014.05.010.

Anisimov, O., V. Kokorev and Y. Zhiltcova, 2017: Arctic Ecosystems and their Services Under Changing Climate: Predictive-Modeling Assessment. *Geogr. Rev.*, **107**(1), 108–124, doi:10.1111/j.1931-0846.2016.12199.x.

Anthopoulos, L., 2017: Smart utopia VS smart reality: Learning by experience from 10 smart city cases. *Cities*, **63**, 128–148.

Apraku, A., W. Akpan and P. Moyo, 2018: Indigenous knowledge, global ignorance? Insights from an Eastern Cape climate change study. *South Afr. Rev. Soc.*, **49**(2), 1–21.

Araos, M., et al., 2016: Climate change adaptation planning in large cities: A systematic global assessment. *Environ. Sci. Policy*, **66**, 375–382, doi:10.1016/j.envsci.2016.06.009.

Archer, D., et al., 2014: Moving towards inclusive urban adaptation: approaches to integrating community-based adaptation to climate change at city and national scale. *Clim. Dev.*, **6**(4), 345–356, doi:10.1080/17565529.2014.918868.

Archer, D. and D. Dodman, 2015: Making capacity building critical: Power and justice in building urban climate resilience in Indonesia and Thailand. *Urban Clim.*, **14**, 68–78, doi:10.1016/j.uclim.2015.06.007.

Arfanuzzaman, M., 2018: Economics of transboundary water: an evaluation of a glacier and snowpack-dependent river basin of the Hindu Kush Himalayan region. *Water Policy*, **20**(1), 90–108.

Arias, M. E., et al., 2014: Impacts of hydropower and climate change on drivers of ecological productivity of Southeast Asia's most important wetland. *Ecol. Model.*, **272**, 252–263.

Arias, P.A., N. Bellouin, E. Coppola, R.G. Jones, G. Krinner, J. Marotzke, V. Naik, M.D. Palmer, G.-K. Plattner, J. Rogelj, M. Rojas, J. Sillmann, T. Storelvmo, P.W. Thorne, B. Trewin, K. Achuta Rao, B. Adhikary, R.P. Allan, K. Armour, G. Bala, R. Barimalala, S. Berger, J.G. Canadell, C. Cassou, A. Cherchi, W. Collins, W.D. Collins, S.L. Connors, S. Corti, F. Cruz, F.J. Dentener, C. Dereczynski, A. Di Luca, A. Diongue Niang, F.J. Doblas-Reyes, A. Dosio, H. Douville, F. Engelbrecht, V. Eyring, E. Fischer, P. Forster, B. Fox-Kemper, J.S. Fuglestvedt, J.C. Fyfe, N.P. Gillett, L. Goldfarb, I. Gorodetskaya, J.M. Gutierrez, R. Hamdi, E. Hawkins, H.T. Hewitt, P. Hope, A.S. Islam, C. Jones, D.S. Kaufman, R.E. Kopp, Y. Kosaka, J. Kossin, S. Krakovska, J.-Y. Lee, J. Li, T. Mauritsen, T.K. Maycock, M. Meinshausen, S.-K. Min, P.M.S. Monteiro, T. Ngo-Duc, F. Otto, I. Pinto, A. Pirani, K. Raghavan, R. Ranasinghe, A.C. Ruane, L. Ruiz, J.-B. Sallée, B.H. Samset, S. Sathyendranath, S.I. Seneviratne, A.A. Sörensson, S. Szopa, I. Takayabu, A.-M. Tréguier, B. van den Hurk, R. Vautard, K. von Schuckmann, S. Zaehle, X. Zhang, and K. Zickfeld, 2021: Technical Summary. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. University Press, Cambridge.

Arifanti, V.B., et al., 2019: Carbon dynamics and land use carbon footprints in mangrove-converted aquaculture: The case of the Mahakam Delta, Indonesia. *For. Ecol. Manag.*, **432**, 17–29, doi:10.1016/j.foreco.2018.08.047.

Arifwidodo, S.D. and O. Chandrasiri, 2020: Urban heat stress and human health in Bangkok, Thailand. *Environ. Res.*, **185**, 109398.

Arifwidodo, S.D., O. Chandrasiri, R. Abdulharis and T. Kubota, 2019: Exploring the effects of urban heat island: A case study of two cities in Thailand and Indonesia. *APN Sci. Bull.* https://doi.org/10.30852/sb.2019.539.

Arnall, A., 2019: Resettlement as climate change adaptation: what can be learned from state-led relocation in rural Africa and Asia? *Clim. Dev.*, **11**(3), 253–263.

Arnell, N.W., et al., 2016: The impacts of climate change across the globe: a multi-sectoral assessment. *Clim. Change*, **134**(3), 457–474.

Arshad, A., et al., 2020: Vulnerability assessment of urban expansion and modelling green spaces to build heat waves risk resiliency in Karachi. *Int. J. Disaster Risk Reduct.*, **46**, 101468.

Artemov, I. A., 2018: Changes in the Altitudinal Distribution of Alpine Plants in Katunskiy Biosphere Reserve (Central Altai) Revealed on the Basis of Multiyear Monitoring Data. *Contemp. Probl. Ecol.*, **11**(1), 1–12, doi:10.1134/S1995425518010018.

Arto, I., et al., 2019: The socioeconomic future of deltas in a changing environment. *Sci. Total. Environ.*, **648**, 1284–1296.

Arunrat, N., et al., 2017: Farmers' intention and decision to adapt to climate change: A case study in the Yom and Nan basins, Phichit province of Thailand. *J. Clean. Prod.*, **143**, 672–685, doi:10.1016/j.jclepro.2016.12.058.

Aryal, J.P., et al., 2020a: Climate change mitigation options among farmers in South Asia. *Environ. Dev. Sustain.*, **22**(4), 3267–3289, doi:10.1007/s10668-019-00345-0.

Aryal, J.P., et al., 2020b: Climate change and agriculture in South Asia: adaptation options in smallholder production systems. *Environ. Dev. Sustain.*, **22**(6), 5045–5075, doi:10.1007/s10668-019-00414-4.

Asher, A., 2015: Public Pension Programs in Southeast Asia: An Assessment. *Asian Econ. Policy Rev.*, doi:10.10.1111/aepr.12100.

Ashrafzadeh, M.R., A.A. Naghipour, M. Haidarian and I. Khorozyan, 2019a: Modeling the response of an endangered flagship predator to climate change in Iran. *Mammal Res*, **64**(1), 39–51, doi:10.1007/s13364-018-0384-y.

Ashrafzadeh, M.R., et al., 2019b: Effects of climate change on habitat and connectivity for populations of a vulnerable, endemic salamander in Iran. *Glob. Ecol. Conserv.*, **19**, doi:10.1016/j.gecco.2019.e00637.

Asia, E. a. S. C. f. W, 2017: *ESCWA Water Development Report 7* Climate Change and Disaster Risk Reduction in the Arab Region. 64 pp.

Ansari, A., 2018: Understanding farmers perceptions about climate change: a study in a North Indian State. *Adv. Agric. Environ. Sci. Open Access*, **1**(2), doi:10.30881/aaeoa.00015.

Aslam, A.Q., et al., 2017: Vulnerability and impact assessment of extreme climatic event: A case study of southern Punjab, Pakistan. *Sci. Total. Environ.*, **580**, 468–481, doi:10.1016/j.scitotenv.2016.11.155.

Asmiwyati, I.G.A.A.R., M.S. Mahendra, N.H.S. Arifin and T. Ichinose, 2015: Recognizing Indigenous Knowledge on Agricultural Landscape in Bali for Micro Climate and Environment Control. *Procedia Environ. Sci.*, **28**, 623–629, doi:10.1016/j.proenv.2015.07.073.

Assaf, H., 2009: *Infrastructure* Arab Environment: Impact of Climate Change on Arab Countries. AFED Report, 113–120.

Aswani, S., A. Lemahieu and W.H.H. Sauer, 2018: Global trends of local ecological knowledge and future implications. *PLoS ONE*, **13**(4), e195440, doi:10.1371/journal.pone.0195440.

Auffhammer, M. and M. E. Kahn, 2018: Chapter 5 - The farmer's climate change adaptation challenge in least developed countries. In: *Handbook of Environmental Economics* [Dasgupta, P., S.K. Pattanayak and V.K. Smith(eds.)]. Elsevier, pp. 193–229. ISBN 15740099.

Ayeb-Karlsson, S., 2020: 'I do not like her going to the shelter': Stories on gendered disaster (im) mobility and wellbeing loss in coastal Bangladesh. *Int. J. Disaster Risk Reduct.*, **50**, 101904.

Ayeb-Karlsson, S., D. Kniveton and T. Cannon, 2020: Trapped in the prison of the mind: Notions of climate-induced (im) mobility decision-making and wellbeing from an urban informal settlement in Bangladesh. *Palgrave Commun.*, **6**(1), 1–15.

Azad, S.A., 2017: *Yearbook of Fisheries Statistics of Bangladesh (July 2015 - June 2016)*. https://drive.google.com/file/d/0B6XjGVIRbmt0bHhjcVl2UWNCbmM/view, accessed on October 1, 2021.

Babagaliyeva, Z., A. Kayumov, N. Mahmadullozoda and N. Mustaeva, 2017: *Migration, remittances and climate resilience in Tajikistan*. (CAREC), R. E. C. f. C. A, https://carececo.org/eng_P2%20WP1%20Migration,%20remittances_FIN.pdf, accessed on October 1, 2021.

Babel, M.S., V.R. Shinde, D. Sharma and N.M. Dang, 2020: Measuring water security: A vital step for climate change adaptation. *Environ. Res.*, **185**, 109400.

Babajanian, J. Hagen-Zanker and R. Holmes, 2014: *How do social protection and labour programmes contribute to social inclusion?* Evidence from Afghanistan, Bangladesh, India and Nepal. March 2014. ODI. https://areu.org.af/wp-content/areu_publications/2016/02/E-How-do-Social-Protection-Synthesis-11.pdf, accessed on October 1, 2021.

Badiani, R., K.K. Jessoe and S. Plant, 2012: Development and the environment: the implications of agricultural electricity subsidies in India. *J. Environ. Dev.*, **21**(2), 244–262.

Bae, Y. J., H. J. Lee, B. W. Jung and H.-C. Jung, 2020: *Climate Change Impact and Adaptation. Korean Climate Change Assessment Report 2020. Summary for Policymakers*, Ministry of Environment. Sejong-si, Republic of Korea, 43 pp.

Bahinipati, C.S., 2020: Assessing the costs of droughts in rural India: a comparison of economic and non-economic loss and damage. *Curr. Sci.*, **118**, 1832–1841, doi:10.18520/cs/v118/i11/1832-1841.

Bahinipati, C.S. and U. Patnaik, 2020: Does development reduce damage risk from climate extremes? Empirical evidence for floods in India. *Water Policy*, **22**(5), 748–767, doi:10.2166/wp.2020.059.

Bai, J., et al., 2018: Snowmelt Water Alters the Regime of Runoff in the Arid Region of Northwest China. *Water*, **10**(7), doi:10.3390/w10070902.

Baig, M.B., A.M. Qureshi, G.S. Straquadine and A. Hajiyev, 2019: Realizing Food Security Through Sustainable Agriculture in the Republic of Yemen: Implications for Rural Extension. In: *Climate Change, Food Security and Natural Resource Management : Regional Case Studies from Three Continents* [Behnassi, M., O. Pollmann and H. Gupta)](eds.)]. Springer International Publishing, Cham, pp. 19–60. ISBN 978-3319970912.

Bailey, H. and D.H. Secor, 2016: Coastal evacuations by fish during extreme weather events. *Sci. Rep.*, **6**, 9, doi:10.1038/srep30280.

Bajpai, R., S. Mishra, S. Dwivedi and D.K. Upreti, 2016: Change in atmospheric deposition during last half century and its impact on lichen community structure in Eastern Himalaya. *Sci. Rep.*, **6**, doi:10.1038/srep30838.

Bajracharya, A.R., S.R. Bajracharya, A.B. Shrestha and S.B. Maharjan, 2018: Climate change impact assessment on the hydrological regime of the Kaligandaki Basin, Nepal. *Sci. Total. Environ.*, **625**, 837–848.

Bajracharya, S.R., et al., 2014: *Glacier status in Nepal and decadal change from 1980 to 2010 based on Landsat data*. International Centre for Integrated Mountain Development, ISBN 978-9291153114.

Baker, J.L. and G.U. Gadgil, 2017: *East Asia and Pacific Cities: Expanding Opportunities for the Urban Poor*. ISBN 978-1464810930.

Balke, T. and D.A. Friess, 2016: Geomorphic knowledge for mangrove restoration: a pan-tropical categorization. *Earth Surf. Process. Landforms*, **41**(2), 231–239, doi:10.1002/esp.3841.

Banerjee, S., R. Black, A. Mishra and D. Kniveton, 2018: Assessing vulnerability of remittance-recipient and non-recipient households in rural communities affected by extreme weather events: Case studies from south-west China and northeast India. *Popul Space Place*, **25**(2), e2157, doi:10.1002/psp.2157.

Banerjee, S., A. Hussain, S. Tuladhar and A. Mishra, 2019: Building capacities of women for climate change adaptation: Insights from migrant-sending households in Nepal. *Clim Change*, **157**(3), 587–609, doi:10.1007/s10584-019-02572-w.

Bank, A.D., 2017a: *A region at risk: The human dimension of climate change in Asia and the Pacific*. ADB, Manila. https://doi.org/10.22617/TCS178839-2.

Bank, A.D., 2018a: *Strengthening resilience through social protection programs : guidance note*. Manila, https://www.adb.org/documents/strengthening-resilience-social-protection-guidance-note. accessed on October 1, 2021.

Bank, W., 2015: *The state of social safety nets 2015*. The World Bank, Washington, DC.

Bank, W., 2017b: *Tracking universal health coverage : 2017 global monitoring report*. World Bank, Washington, D.C. English.

Bank, W., 2018b: *Philippines: Social Protection Review and Assessment*. Bank, W.

Banu, S., et al., 2014: Projecting the impact of climate change on dengue transmission in Dhaka, Bangladesh. *Environ Int.*, **63**, 137–142, doi:10.1016/j.envint.2013.11.002.

Banwell, N., S. Rutherford, B. Mackey and C. Chu, 2018: Towards Improved Linkage of Disaster Risk Reduction and Climate Change Adaptation in Health: A Review. *Int. J. Environ. Res. Public Health*. 2018, 15(4), 793. https://doi.org/10.3390/ijerph15040793.

Bao, P.N., et al., 2018: *Governing the Water-Energy-Food Nexus Approach for Creating Synergies and Managing Trade-offs*. Institute for Global Environmental Strategies. http://www.jstor.com/stable/resrep21799.

Bao, Z., et al., 2019: The impact of climate variability and land use/cover change on the water balance in the Middle Yellow River Basin, China. *J. Hydrol. Reg. Stud.*, **577**, 123942.

Baran, E. and C. Myschowoda, 2009: Dams and fisheries in the Mekong Basin. *Aquat. Ecosyst. Health Manag.*, **12**(3), 227–234.

Barange, M., et al., 2014: Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nat. Clim. Change*, **4**, 211, doi:10.1038/nclimate2119. https://www.nature.com/articles/nclimate2119#supplementary-information.

Barinova, S., M. Boboev and H. Hisoriev, 2015: Freshwater algal diversity of the South-Tajik Depression in a high-mountainous extreme environment, Tajikistan. *Turk. J. Bot.*, **39**, 535–546, doi:10.3906/bot-1406-45.

Barkdull, J. and P.G. Harris, 2018: Emerging responses to global climate change: ecosystem-based adaptation. *Glob. Chang. Peace Secur.*, **31**(1), 19–37, doi:10.1080/14781158.2018.1475349.

Barnett, C. and S. Parnell, 2016: Ideas, implementation and indicators: epistemologies of the post-2015 urban agenda. *Environ. Urban.*, **28**(1), 87–98.

Barnett, J. and S. O'Neill, 2010: Maladaptation. *Glob. Environ. Chang.*, **20**(2), 211–213, doi:10.1016/j.gloenvcha.2009.11.004.

Bateman, I., et al., 2016: Spatially explicit integrated modeling and economic valuation of climate driven land use change and its indirect effects. *J. Environ. Manage*, **181**, 172–184, doi:10.1016/j.jenvman.2016.06.020.

Bauer, N., et al., 2017: Shared Socio-Economic Pathways of the Energy Sector – Quantifying the Narratives. *Glob. Environ. Chang.*, **42**, 316–330, doi:10.1016/j.gloenvcha.2016.07.006.

Baul, T.K. and M. McDonald, 2015: Integration of Indigenous knowledge in addressing climate change. *integr. Indig. Knowl. Addr. Clim. Chang.*, **1**(1), 20–27.

Bazaz, A., et al., 2018: *Summary for Urban Policymakers – What the IPCC Special Report on 1.5C Means for Cities*. IHHS Indian Institute for Human Settlements, Bengaluru.

Bazilian, M., et al., 2011: Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy*, **39**(12), 7896–7906, doi:10.1016/j.enpol.2011.09.039.

Bechtel, B., et al., 2019: SUHI analysis using Local Climate Zones—A comparison of 50 cities. *Urban Clim.*, **28**, doi:10.1016/j.uclim.2019.01.005.

Beermann, J., A. Damodaran, K. Jörgensen and M. A. Schreurs, 2016: Climate action in Indian cities: an emerging new research area. *J. Integr. Environ. Sci.*, **13**(1), 55–66, doi:10.1080/1943815x.2015.1130723.

Bell, A.R., et al., 2021: Migration towards Bangladesh coastlines projected to increase with sea-level rise through 2100. *Environ. Res. Lett.*, **16**(2), 24045, doi:10.1088/1748-9326/abdc5b.

Béné, C., et al., 2014: *Social Protection and Climate Change*. doi:10.1787/5jz2qc8wc1s5-en.

Bennett, N.J., P. Dearden, G. Murray and A. Kadfak, 2014: The capacity to adapt?: communities in a changing climate, environment, and economy on the northern Andaman coast of Thailand. *Ecol. Soc.*, **19**(2), doi:10.5751/es-06315-190205.

Bento, R., et al., 2016: The implications of recurrent disturbances within the world's hottest coral reef. *Mar. Pollut. Bull.*, **105**(2), 466–472, doi:10.1016/j.marpolbul.2015.10.006.

Bernasconi, R., M. Stat, A. Koenders and M.J. Huggett, 2019: Global Networks of Symbiodinium-Bacteria Within the Coral Holobiont. *Microb. Ecol.*, **77**(3), 794–807, doi:10.1007/s00248-018-1255-4.

Berner, L.T., P.S. Beck, A.G. Bunn and S.J. Goetz, 2013: Plant response to climate change along the forest-tundra ecotone in northeastern Siberia. *Glob. Chang Biol.*, **19**(11), 3449–3462, doi:10.1111/gcb.12304.

Best, J., 2018: Anthropogenic stresses on the world's big rivers. *Nat. Geosci.*, **1**.

Bhaduri, A., et al., 2015: Sustainability in the water–energy–food nexus. *Water Int.*, **40**(5-6), 723–732, doi:10.1080/02508060.2015.1096110.

Bhambri, R., K. Hewitt, P. Kawishwar and B. Pratap, 2017: Surge-type and surge-modified glaciers in the Karakoram. *Sci. Rep.*, **7**, doi:10.1038/s41598-017-15473-8.

Bhanja, S.N., et al., 2016: Validation of GRACE based groundwater storage anomaly using in-situ groundwater level measurements in India. *J. Hydrol.*, **543**, 729–738.

Bhatt, R.K., T. Mall and Banerjee, 2015: Climate change, climate extremes and disaster risk reduction. *Nat. Hazards*, **78**, 775–778, doi:10.1007/s11069-015-1874-8.

Bhatta, B., et al., 2019: Evaluation and application of a SWAT model to assess the climate change impact on the hydrology of the Himalayan River Basin. *Catena*, **181**, doi:10.1016/j.catena.2019.104082.

Bhatta, K.P., J.-A. Grytnes and O.R. Vetaas, 2018: Downhill shift of alpine plant assemblages under contemporary climate and land-use changes. *Ecosphere*, **9**(1), doi:10.1002/ecs2.2084.

Bhowmik, J., H.M. Irfanullah and S.A. Selim, 2021: Empirical evidence from Bangladesh of assessing climate hazard-related loss and damage and state of adaptive capacity to address them. *Clim. Risk Manag.*, **31**, 100273, doi:10.1016/j.crm.2021.100273.

Bi, X., et al., 2019: The potential suitable area of Galinsoga Parviflora in China in response to climate change. *J. Shaanxi Norm. Univ. Nat. Sci. Ed.*, **47**(2), 70–75.

Biemans, H., et al., 2019: Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. *Nat. Sustain.*, **2**(7), 594.

Bierkens, M.F.P. and Y. Wada, 2019: Non-renewable groundwater use and groundwater depletion: a review. *Environ. Res. Lett.*, **14**, doi:10.1088/1748-9326/ab1a5 f.

Bindoff, N.L., W.W.L. Cheung, J.G. Kairo, J. Arístegui, V.A. Guinder, R. Hallberg, N. Hilmi, N. Jiao, M.S. Karim, L. Levin, S. O'Donoghue, S.R. Purca Cuicapusa, B. Rinkevich, T. Suga, A. Tagliabue, and P. Williamson, 2019: Changing Ocean, Marine Ecosystems, and Dependent Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Birkmann, J., N. Setiadi and G. Fiedler, 2019: A culture of resilience and preparedness: The 'last mile' case study of tsunami rise in Padang, Indonesia. In: *Cultures and Disasters: Understanding Cultural Framings in Disaster Risk Reduction* [Kruger, F., G. Bankoff, T. Cannon, B. Orlowski and L.F. Schipper)](eds.)]. Routledge, London New York.

Biskaborn, B.K., et al., 2019: Permafrost is warming at a global scale. *Nat. Commun*, **10**(1), 264, doi:10.1038/s41467-018-08240-4.

Bizikova, L., et al., 2013: *The water-energy-food security nexus: Towards a practical planning and decision-support framework for landscape investment and risk management*. International Institute for Sustainable Development, Winnipeg.

Black, K.P., et al., 2017: *Climate change adaptation guidelines for coastal protection and management in India*. Bank, A. D. Manila. http://resolver.tudelft.nl/uuid:01b3e6da-7f41-4174-945c-6e70a901fd21.

Blanco, D.V., 2015: Disaster Governance in the Philippines: Issues, Lessons Learned, and Future Directions in the Post-Yolanda Super Typhoon Aftermath. *Int. J. Public Adm.*, **38**(10), 743–756, doi:10.1080/01900692.2014.979198.

Blasiak, R., et al., 2017: Climate change and marine fisheries: Least developed countries top global index of vulnerability. *PLoS ONE*, **12**(6), e179632, doi:10.1371/journal.pone.0179632.

Blok, A. and R. Tschötschel, 2015: World port cities as cosmopolitan risk community: Mapping urban climate policy experiments in Europe and East Asia. *Environ. Plan. C Polit.*, doi:10.1177_0263774X15614673.

Blondin, S., 2019: Environmental migrations in Central Asia: A multifaceted approach to the issue. *Centr. Asian. Surv.*, **38**(2), 275–292.

Blunden, J. and D.S. Arndt, 2017: State of the Climate in 2016. *Bull. Am. Meteorol. Soc.*, **98**(8), Si-S280, doi:10.1175/2017BAMSStateoftheClimate.1.

Boas, I., et al., 2019: Climate migration myths. *Nat. Clim. Chang.*, **9**(12), 901–903.

Bobojonov, I. and A. Aw-Hassan, 2014: Impacts of climate change on farm income security in Central Asia: An integrated modeling approach. *Agric. Ecosyst. Environ.*, **188**, 245–255, doi:10.1016/j.agee.2014.02.033.

Bobojonov, I., et al., 2016: Income and irrigation water use efficiency under climate change: An application of spatial stochastic crop and water allocation model to Western Uzbekistan. *Clim. Risk Manag.*, **13**, 19–30, doi:10.1016/j.crm.2016.05.004.

Bobrowski, M., et al., 2018: Application of Thermal and Phenological Land Surface Parameters for Improving Ecological Niche Models of Betula utilis in the Himalayan Region. *Remote Sens.*, **10**(6), doi:10.3390/Rs10060814.

Boeckmann, M., 2016: Exploring the health context: A qualitative study of local heat and climate change adaptation in Japan. *Geoforum*, **73**, 1–5, doi:10.1016/j.geoforum.2016.04.006.

Bogard, J.R., et al., 2015: Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes. *J. Food. Compost Anal.*, **42**, 120–133, doi:10.1016/j.jfca .2015.03.002.

Bolch, T., 2017: HYDROLOGY: Asian glaciers are a reliable water source. *Nature*, **545**(7653), 161–162, doi:10.1038/545161a.

Bolch, T., 2019: Past and future glacier changes in the Indus River Basin. In: *Indus River Basin*, pp. 85–97.

Bonney, R., T.B. Phillips, H.L. Ballard and J.W. Enck, 2016: Can citizen science enhance public understanding of science? *Public Underst. Sci.*, **25**(1), 2–16.

Borodavko, P.S., et al. (ed.), 2018: *Climate change impact on high-altitude geomorphological systems*. IOP Conference Series: Earth and Environmental Science. IOP Publishing, ISBN 17551315. 012004 pp. Tomsk, Russian Federation.

Borras, S.M.F. and C. Jennifer, 2018: The challenge of locating land-based climate change mitigation and adaptation politics within a social justice perspective: towards an idea of agrarian climate justice. *Third World Q.*, doi: 10.1080/01436597.2018.1460592.

Bourne, D.G., K.M. Morrow and N.S. Webster, 2016: Insights into the Coral Microbiome: Underpinning the Health and Resilience of Reef Ecosystems. In: *Annual Review of Microbiology* [Gottesman, S.(ed.)], Annual Reviews, Vol. 70, Palo Alto, pp. 317. ISBN 978-0824311704. https://doi.org/10.1146/annurev-micro-102215-095440.

BP, *Statistical Review of World Energy*. http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html, accessed on October 1, 2021..

BP, 2019: *BP Energy Outlook: 2019 edition*.

Brammer, H., 2014: Bangladesh's dynamic coastal regions and sea-level rise. *Clim. Risk Manag.*, **1**, 51–62, doi:10.1016/j.crm.2013.10.001.

Brazhnik, K., C. Hanley and H.H. Shugart, 2017: Simulating changes in fires and ecology of the 21st century Eurasian boreal forests of Siberia. *Forests*, **8**(2), doi:10.3390/f8020049.

Brazhnik, K. and H.H. Shugart, 2015: 3D simulation of boreal forests: structure and dynamics in complex terrain and in a changing climate. *Environ. Res. Lett.*, **10**(10), doi:10.1088/1748-9326/10/10/105006.

Brink, E., et al., 2016: Cascades of green: A review of ecosystem-based adaptation in urban areas. *Glob. Environ. Chang.*, **36**, 111–123, doi:10.1016/j.gloenvcha.2015.11.003.

Briones, R. and J. Felipe, 2013: *Agriculture and structural transformation in developing asia: Review and utlook*. Asian Development Bank, Manduluyong City.

Brito-Morales, I., et al., 2018: Climate Velocity Can Inform Conservation in a Warming World. *Trends Ecol. Evol.*, **33**(6), 441–457, doi:10.1016/j.tree.2018.03.009.

Bruno, J.F. and A. Valdivia, 2016: Coral reef degradation is not correlated with local human population density. *Sci. Rep.*, **6**, 8, doi:10.1038/srep29778.

Buchanan, J.R., et al., 2019: Regional extinction risks for marine bony fishes occurring in the Persian/Arabian Gulf. *Biol. Conserv.*, **230**, 10–19, doi:10.1016/j.biocon.2018.11.027.

Buchori, I., et al., 2018: Adaptation to coastal flooding and inundation: Mitigations and migration pattern in Semarang City, Indonesia. *Ocean. Coast. Manag.*, **163**, 445–455, doi:10.1016/j.ocecoaman.2018.07.017.

Bulkeley, H., G.A.S. Edwards and S. Fuller, 2014: Contesting climate justice in the city: Examining politics and practice in urban climate change experiments. *Glob. Environ. Chang.*, **25**, 31–40, doi:10.1016/j.gloenvcha.2014.01.009.

Bunting, P., et al., 2018: The global mangrove watch—a new 2010 global baseline of mangrove extent. *Remote Sens.*, **10**(10), 1669.

Burch, S.L. and S.E. Harris, 2014: A Massive Open Online Course on climate change: the social construction of a global problem using new tools for connectedness. *Wiley Interdiscip. Rev. Clim. Chang.*, **5**(5), 577–585, doi:10.1002/wcc.300.

Burke, L., K. Reytar, M. Spalding and A. Perry, 2011: *Reefs at risk revisited*. World Resources Institute. Washington DC.

Burke, M., et al., 2016: CLIMATE ECONOMICS. Opportunities for advances in climate change economics. *Science*, **352**(6283), 292–293, doi:10.1126/science.aad9634.

Burnham, M. and Z. Ma, 2017: Climate change adaptation: factors influencing Chinese smallholder farmers' perceived self-efficacy and adaptation intent. *Reg. Environ. Change*, **17**(1), 171–186, doi:10.1007/s10113-016-0975-6.

Burt, J.A., et al., 2019: Causes and consequences of the 2017 coral bleaching event in the southern Persian/Arabian Gulf. *Coral Reefs*, **38**(4), 567–589, doi:10.1007/s00338-019-01767-y.

Burt, H. and D. Feary, 2014: Persian Gulf Reefs: An Important Asset for Climate Science in Urgent Need of Protection. *Ocean. Chall.*, **20,** 49-56.

Byers, E., et al., 2018: Global exposure and vulnerability to multi-sector development and climate change hotspots. *Environ. Res. Lett.*, **13**(5), 55012, doi:10.1088/1748-9326/aabf45.

Byers, E.A., J.W. Hall and J.M. Amezaga, 2014: Electricity generation and cooling water use: UK pathways to 2050. *Glob. Environ. Chang.*, **25**, 16–30, doi:10.1016/j.gloenvcha.2014.01.005.

Byrne, J.A., A.Y. Lo and Y. Jianjun, 2015: Residents' understanding of the role of green infrastructure for climate change adaptation in Hangzhou, China. *Landsc. Urban. Plan.*, **138**, 132–143, doi:10.1016/j.landurbplan.2015.02.013.

Cadiz, N.R., 2018: UP NOAH in Building Resilient Philippines; Multi-hazard and Risk Mapping for the Future. *Procedia Eng.*, **212**, 1018–1025, doi:10.1016/j.proeng.2018.01.131.

Cai, Y., J.S. Bandara and D. Newth, 2016: A framework for integrated assessment of food production economics in South Asia under climate change. *Environ. Model. Softw.*, **75**, 459–497, doi:10.1016/j.envsoft.2015.10.024.

Cameron, L., *Social protection programs for women in developing countries*. IZA World of Labor, Cameron.

Canadell, J.G., P.M.S. Monteiro, M.H. Costa, L. Cotrim da Cunha, P.M. Cox, A.V. Eliseev, S. Henson, M. Ishii, S. Jaccard, C. Koven, A. Lohila, P.K. Patra, S. Piao, J. Rogelj, S. Syampungani, S. Zaehle, and K. Zickfeld, 2021: Global Carbon and other Biogeochemical Cycles and Feedbacks. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge.

Canonge, J., *Social protection and climate change: Greener economies and just societies*. ILO, social-protection.org, accessed on October 1, 2021.

Cao, A., et al., 2021: Future of Asian Deltaic Megacities under sea level rise and land subsidence: current adaptation pathways for Tokyo, Jakarta, Manila, and Ho Chi Minh City. *Curr. Opin. Environ. Sustain.*, **50**, 87–97.

Cao, H., F. Amiraslani, J. Liu and N. Zhou, 2015: Identification of dust storm source areas in West Asia using multiple environmental datasets. *Sci. Total. Environ.*, **502**, 224–235.

Cao, R.W., et al., 2018: Seawater Acidification Reduced the Resistance of Crassostrea gigas to Vibrio splendidus Challenge: An Energy Metabolism Perspective. *Front. Physiol.*, **9**, 14, doi:10.3389/fphys.2018.00880.

Caprotti, F., F. Springer and N. Harmer, 2015: 'Eco' For Whom? Envisioning Eco-urbanism in the Sino-Singapore Tianjin Eco-city, China. *Int. J. Urban. Reg.*, doi:10.1111/1468-2427.12233.

Caravani, A., 2016: *Does adaptation finance invest in disaster risk reduction?* 21.

Carleton, T.A., 2017: Crop-damaging temperatures increase suicide rates in India. *Proc. Natl. Acad. Sci. U.S.A.*, **114**(33), 8746–8751, doi:10.1073/pnas.1701354114.

Carleton, T.A. and S.M. Hsiang, 2016: Social and economic impacts of climate. *Science*, **353**(6304), aad9837.

Carleton, T.A., et al., 2020: *Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits*. National Bureau of Economic Research, Cambridge, MA, USA.

Carley, K.M., et al., 2016: Crowd sourcing disaster management: The complex nature of Twitter usage in Padang Indonesia. *Saf. Sci.*, **90**, 48–61.

Carlton, E.J., et al., 2016: A systematic review and meta-analysis of ambient temperature and diarrhoeal diseases. *Int. J. Epidemiol.*, **45**(1), 117–130, doi:10.1093/ije/dyv296.

Carrão, H., G. Naumann and P. Barbosa, 2016: Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure and vulnerability. *Glob. Environ. Chang.*, **39**, 108–124, doi:10.1016/j.gloenvcha.2016.04.012.

Castillo, J.A.A., A.A. Apan, T.N. Maraseni and S.G. Salmo, 2018: Tree biomass quantity, carbon stock and canopy correlates in mangrove forest and land uses that replaced mangroves in Honda Bay, Philippines. *Reg. Stud. Mar. Sci.*, **24**, 174–183, doi:10.1016/j.rsma.2018.08.006.

Cazzolla Gatti, R., et al., 2019: Accelerating upward treeline shift in the Altai Mountains under last-century climate change. *Sci. Rep.*, **9**(1), 7678, doi:10.1038/s41598-019-44188-1.

Cha, E.J., et al., 2020: Third assessment on impacts of climate change on tropical cyclones in the Typhoon Committee Region – Part II: Future projections. *Trop. Cyclone Res. Rev.*, **9**(2), 75–86, doi:10.1016/j.tcrr.2020.04.005.

Chacko, N., 2019: Differential chlorophyll blooms induced by tropical cyclones and their relation to cyclone characteristics and ocean pre-conditions in the Indian Ocean. *J. Earth Syst. Sci.*, **128**(7), 11, doi:10.1007/s12040-019-1207-5.

Chakraborty, T., R. Kar, P. Ghosh and S. Basu, 2010: Kosi megafan: Historical records, geomorphology and the recent avulsion of the Kosi River. *Quat. Int.*, **227**(2), 143–160.

Chalise, S. and A. Naranpanawa, 2016: Climate change adaptation in agriculture: A computable general equilibrium analysis of land-use change in Nepal. *Land Use Policy*, **59**, 241–250, doi:10.1016/j.landusepol.2016.09.007.

Chan, E.Y.Y., et al., 2018: Association between Ambient Temperatures and Mental Disorder Hospitalizations in a Subtropical City: A Time-Series Study of Hong Kong Special Administrative Region. *Int. J. Environ. Res. Public Health*, **15**(4), doi:10.3390/ijerph15040754.

Chan, N.W., 2014: Impacts of Disasters and Disaster Risk Management in Malaysia: The Case of Floods. In: *Resilience and Recovery in Asian Disasters*, pp. 239–265. doi:10.1007/978-4-431-55022-8_12.

Chandler, M., et al., 2017: Contribution of citizen science towards international biodiversity monitoring. *Biol. Conserv.*, **213**, 280–294, doi:10.1016/j.biocon.2016.09.004.

Chandra, A., et al., 2017: A study of climate-smart farming practices and climate-resiliency field schools in Mindanao, the Philippines. *World Dev.*, **98**, 214–230.

Chandra, A. and K.E. McNamara, 2018: Chapter 13 - Climate-Smart Agriculture in Southeast Asia: Lessons from Community-Based Adaptation Programs in the Philippines and Timor-Leste. In: *Resilience* [Zommers, Z. and K. Alverson(eds.)]. Elsevier, pp. 165–179. ISBN 978-0128118917. https://doi.org/10.1016/B978-0-12-811891-7.00013-X.

Chang, Y., et al., 2016: Quantifying the Water-Energy-Food Nexus: Current Status and Trends. *Energies*, **9**(2), doi:10.3390/en9020065.

Chapman, S., et al., 2017: The impact of urbanization and climate change on urban temperatures: a systematic review. *Landscape Ecol.*, **32**(10), 1921–1935.

Chartres, C., 2014: Is water scarcity a constraint to feeding Asia's growing population? *Int. J. Water Resour. Dev.*, **30**(1), 28–36, doi:10.1080/07900627.2013.846713.

Chaudhuri, N.R., 2020: *Social movements and grassroots discourse of climate justice in the context of droughts in semi-arid regions: A case study in India*. Climate Justice in the Anthropocene, Oñati Socio-Legal Series. doi:10.35295/osls.iisl/0000-0000-0000-1157. forthcoming.

Chen, D. and T.V. Loboda, 2018: Surface forcing of non-stand-replacing fires in Siberian larch forests. *Environ. Res. Lett.*, **13**(4), doi:10.1088/1748-9326/aab443.

Chen, D., et al., 2018a: Strong cooling induced by stand-replacing fires through albedo in Siberian larch forests. *Sci. Rep.*, **8**, doi:10.1038/s41598-018-23253-1.

Chen, G., et al., 2018b: Top-meter soil organic carbon stocks and sources in restored mangrove forests of different ages. *For. Ecol. Manag.*, **422**, 87–94, doi:10.1016/j.foreco.2018.03.044.

Chen, G., et al., 2020a: Global projections of future urban land expansion under shared socioeconomic pathways. *Nat. Commun.*, **11**(1), 537, doi:10.1038/s41467-020-14386-x.

Chen, H., Y. Zhang, Y. Peng and R.T. Corlett, 2018c: Latitudinal effects on phenology near the northern limit of figs in China. *Sci. Rep*, **8**, doi:10.1038/s41598-018-22548-7.

Chen, J., S. Yin, H. Gebhardt and X. Yang, 2018d: Farmers' livelihood adaptation to environmental change in an arid region: A case study of the Minqin Oasis, northwestern China. *Ecol. Indic.*, **93**, 411–423, doi:10.1016/j.ecolind.2018.05.017.

Chen, K., et al., 2015a: Influence of heat wave definitions to the added effect of heat waves on daily mortality in Nanjing, China. *Sci. Total Environ.*, **506-507**, 18–25, doi:10.1016/j.scitotenv.2014.10.092.

Chen, K., et al., 2017a: Impact of climate change on heat-related mortality in Jiangsu Province, China. *Environ. Pollut.*, **224**, 317–325, doi:10.1016/j.envpol.2017.02.011.

Chen, K., et al., 2016a: Urbanization Level and Vulnerability to Heat-Related Mortality in Jiangsu Province, China. *Environ. Health Perspect.*, **124**(12), 1863–1869, doi:10.1289/ehp204.

Chen, L.-L., C.-H. Tseng and Y.-H. Shih, 2017b: Climate-related economic losses in Taiwan. *Int. J. Glob. Warming*, **11**(4), doi:10.1504/IJGW.2017.083670.

Chen, Q., et al., 2020b: Unpacking the black box: How to promote citizen engagement through government social media during the COVID-19 crisis. *Comput. Human Behav.*, https://doi.org/10.1016/j.chb.2020.106380.

Chen, R., et al., 2018e: Association between ambient temperature and mortality risk and burden: time series study in 272 main Chinese cities. *BMJ*, **363**, k4306, doi:10.1136/bmj.k4306.

Chen, S., X. Chen and J. Xu, 2016b: Impacts of climate change on agriculture: Evidence from China. *J. Environ. Econ. Manage.*, **76**, 105–124, doi:10.1016/j.jeem.2015.01.005.

Chen, X., et al., 2017c: Improved modeling of snow and glacier melting by a progressive two-stage calibration strategy with GRACE and multisource data: How snow and glacier meltwater contributes to the runoff of the Upper Brahmaputra River basin? *Water Resour. Res.*, **53**(3), 2431–2466, doi:10.1002/2016wr019656.

Chen, Y. and Y. Li, 2017: An Inter-comparison of Three Heat Wave Types in China during 1961–2010: Observed Basic Features and Linear Trends. *Sci. Rep.*, **7**(1), 45619, doi:10.1038/srep45619.

Chen, Y., Z. Li, G. Fang and W. Li, 2018 f: Large Hydrological Processes Changes in the Transboundary Rivers of Central Asia. *J. Geophys. Res. Atmos.*, doi:10.1029/2017JD028184.

Chen, Y., et al., 2015b: Urban flood risk warning under rapid urbanization. *Environ. Res.*, **139**, 3–10.

Chhogyel, N. and L. Kumar, 2018: Climate change and potential impacts on agriculture in Bhutan: a discussion of pertinent issues. *Agric. Food Secur.*, **7**(79), doi:10.1186/s40066-018-0229-6.

Chi, C.-F., S.-Y. Lu and J.-D. Lee, 2020: Ostensibly Effective Adaptive Measures Could Potentially Be Maladaptations: A Case Study of the Jiadung Coastal Area, Pingtung County, Taiwan. *Coast. Manag.*, **48**(6), 643–676.

Chiba, Y., S.V.R.K. Prabhakar and M. A. Islam, 2019: Addressing non-economic loss and damage associated with climatic events: Cases of Japan and Bangladesh. *APN Sci. Bull.* https://www.apn-gcr.org/bulletin/article/addressing-non-economic-loss-and-damage-associated-with-climatic-events-cases-of-japan-and-bangladesh/.

Chiba, Y., R. Shaw and S. Prabhakar, 2017: Climate change-related non-economic loss and damage in Bangladesh and Japan. *Int. J. Clim. Chang. Strateg. Manag.*, **9**(2), 166–183, doi:10.1108/IJCCSM-05-2016-0065.

Cho, H., 2020: Climate Change Risk Assessment for Kurunegala, Sri Lanka: Water and Heat Waves. *Climate*, **8**, 140, doi:10.3390/cli8120140.

Choi, Y.-Y., M.-S. Suh and K.-H. Park, 2014: Assessment of Surface Urban Heat Islands over Three Megacities in East Asia Using Land Surface Temperature Data Retrieved from COMS. *Remote Sens*, **6**(6), doi:10.3390/rs6065852.

Choi, Y., et al., 2021: Forest management can mitigate negative impacts of climate and land-use change on plant biodiversity: Insights from the Republic of Korea. *J. Environ Manage*, **288**, 112400, doi:10.1016/j.jenvman.2021.112400.

Choi, Y., et al., 2019: Novel Index for bioclimatic zone-based biodiversity conservation strategies under climate change in Northeast Asia. *Environ. Res. Lett.*, **14**(12), doi:10.1088/1748-9326/ab5237.

Choi, Y., et al., 2016: Effects of weather factors on dengue fever incidence and implications for interventions in Cambodia. *BMC Public Health*, **16**, 241, doi:10.1186/s12889-016-2923-2.

Chow, J., 2018: Mangrove management for climate change adaptation and sustainable development in coastal zones. *J. Sustain. For.*, **37**(2), 139–156, doi:10.1080/10549811.2017.1339615.

Chu, E., I. Anguelovski and D. Roberts, 2017: Climate adaptation as strategic urbanism: assessing opportunities and uncertainties for equity and inclusive development in cities. *Cities*, **60**, 378–387, doi:10.1016/j.cities.2016.10.016.

Chua, P.L., et al., 2021: Global projections of temperature-attributable mortality due to enteric infections: a modelling study. *Lancet Planet. Health*, **5**(7), e436–e445.

Chuah, C.J., B.H. Ho and W.T.L. Chow, 2018: Trans-boundary variations of urban drought vulnerability and its impact on water resource management in Singapore and Johor, Malaysia. *Environ. Res. Lett.*, **13**(7), 74011.

Chung, I.K., C.F.A. Sondak and J. Beardall, 2017a: The future of seaweed aquaculture in a rapidly changing world. *Eur. J. Phycol.*, **52**(4), 495–505, doi:10.1080/09670262.2017.1359678.

Chung, S.E., et al., 2017b: Current and projected burden of disease from high ambient temperature in Korea. *Epidemiology*, 98–105, doi:10.1097/EDE.0000000000000731.

Chung, Y., et al., 2017c: Temporal Changes in Mortality Related to Extreme Temperatures for 15 Cities in Northeast Asia: Adaptation to Heat and Maladaptation to Cold. *Am. J. Epidemiol.*, **185**(10), 907–913, doi:10.1093/aje/kww199.

Chung, Y., et al., 2018: Changing Susceptibility to Non-Optimum Temperatures in Japan, 1972-2012: The Role of Climate, Demographic, and Socioeconomic Factors. *Environ. Health Perspect.*, **126**(5), 57002, doi:10.1289/ehp2546.

Central Intelligence Agency, 2017: *The World Factbook*. https://www.cia.gov/library/publications/download/download-2017/index.html, accessed on October 1, 2021.

Cinco, T.A., et al., 2016: Observed trends and impacts of tropical cyclones in the Philippines. *Int. J. Climatol.*, **36**(14), 4638–4650, doi:10.1002/joc.4659.

Cinner, J.E., et al., 2018: Building adaptive capacity to climate change in tropical coastal communities. *Nat. Clim. Change*, **8**(2), 117–123, doi:10.1038/s41558-017-0065-x.

Clayton, S., et al., 2015: Psychological research and global climate change. *Nat. Clim. Change*, **5**(7), 640–646, doi:10.1038/nclimate2622.

Clemens, M., et al., 2016: Social learning for adaptation to climate change in developing countries: insights from Vietnam. *J. Water Clim. Chang.*, **7**(2), 365–378.

Clement, F., 2018: Climate Change Governance and Adaptation. In: *Climate Change Governance and Adaptation*. CRC Press, Boca Raton, FL, USA, pp. 29–50.

Cohen, J.M., M.J. Lajeunesse and J.R. Rohr, 2018: A global synthesis of animal phenological responses to climate change. *Nat. Clim. Change*, **8**(3), 224–228, doi:10.1038/s41558-018-0067-3.

Coirolo, C., S. Commins, I. Haque and G. Pierce, 2013: Climate change and social protection in Bangladesh: are existing programmes able to address the impacts of climate change? *Dev. Policy Rev.*, **31**, o74–o90.

Coles, S.L., E. Looker and J.A. Burt, 2015: Twenty-year changes in coral near Muscat, Oman estimated from manta board tow observations. *Mar. Environ. Res.*, **103**, 66–73, doi:10.1016/j.marenvres.2014.11.006.

Coles, S.L. and B.M. Riegl, 2013: Thermal tolerances of reef corals in the Gulf: A review of the potential for increasing coral survival and adaptation to climate change through assisted translocation. *Mar. Pollut. Bull.*, **72**(2), 323–332, doi:10.1016/j.marpolbul.2012.09.006.

Commission, B.P., 2018: *Bangladesh Delta Plan 2100* Abridged Version.

Comte, A. and L.H. Pendleton, 2018: Management strategies for coral reefs and people under global environmental change: 25 years of scientific research. *J. Environ. Manag.*, **209**, 462–474, doi:10.1016/j.jenvman.2017.12.051.

Connell, J., 2015: Statelessness and environmental displacement. *Forced Migr. Rev.*, **49**, 46-47.

Cook, K.L., et al., 2018: Glacial lake outburst floods as drivers of fluvial erosion in the Himalaya. *Science*, **362**(6410), 53–57.

Cook, M. and E. Chu, 2019: *Between Policies, Programs, and Projects: How Local Actors Steer Domestic Urban Climate Adaptation Finance in India*. Springer, Berlin Heidelberg, doi:10.1007/978-3-319-65003-6_13.

Corner, A., et al., 2015: How do young people engage with climate change? The role of knowledge, values, message framing, and trusted communicators. *Wiley Interdiscip. Rev. Clim. Chang.*, **6**(5), 523–534, doi:10.1002/wcc.353.

Cousins, S., 2014: *Can't Afford to Wait: Why Disaster Risk Reduction and Climate Change Adaptation plans in Asia are still failing millions of people*. Oxfam GB, Oxford, UK.

Craft, B. and S. Fisher, 2016: Measuring effective and adequate adaptation. *IIED*, London.

CRED and UNISDR, 2019: *2018 Review of Disaster Events: Centre for Research on the Epidemiology of Disasters*.

Crost, B., C. Duquennois, J.H. Felter and D.I. Rees, 2018: Climate change, agricultural production and civil conflict: Evidence from the Philippines. *J. Environ. Econ. Manage.*, **88**, 379–395, doi:10.1016/j.jeem.2018.01.005.

Cruz, R.V.O., et al., 2017: *2017 Philippine Climate Change Assessment: Impacts, Vulnerabilities and Adaptation*. The Oscar M. Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation, Inc. and Climate Change Commission, Pasig City, Metro Manila.

Cuevas, S.C., 2018: Institutional dimensions of climate change adaptation: insights from the Philippines. *Climate Policy*, **18**(4), 499–511, doi:10.1080/14693062.2017.1314245.

Cuevas, S.C., A. Peterson, C. Robinson and T.H. Morrison, 2016: Institutional capacity for long-term climate change adaptation: evidence from land use planning in Albay, Philippines. *Reg. Environ. Change*, **16**(7), 2045–2058, doi:10.1007/s10113-015-0909-8.

Cullen, A.C. and C.L. Anderson, 2016: Perception of Climate Risk among Rural Farmers in Vietnam: Consistency within Households and with the Empirical Record. *Risk Anal.*, doi:10.1111/risa.12631.

Cullet, P., 2016: Governing Water to Foster Equity and Conservation: Need for New Legal Instruments. *Econ. Polit. Wkly.*, **51**(53).

Cundill, G., et al., 2021: Toward a climate mobilities research agenda: intersectionality, immobility, and policy responses. *Glob. Environ. Chang.*, **69**, doi:10.1016/j.gloenvcha.2021.102315.

Cutter, S.L., et al., 2015: Pool knowledge to stem losses from disasters. *Nature*, **522**, 277–279.

D'Aloia, C.C., et al., 2019: Coupled Networks of Permanent Protected Areas and Dynamic Conservation Areas for Biodiversity Conservation Under Climate Change. *Front. Ecol. Evol.*, **7**, doi:10.3389/Fevo.2019.00027.

d'Amour, C.B., et al., 2017: Future urban land expansion and implications for global croplands. *Proc. Natl. Acad. Sci.*, **114**(34), 8939–8944.

d'Amour, C.B., et al., 2016: Teleconnected food supply shocks. *Environ. Res. Lett.*, **11**(035007), 10.1088.

Dahal, N.M., et al., 2021: Spatiotemporal analysis of drought variability based on the standardized precipitation evapotranspiration index in the Koshi River Basin, Nepal. *J. Arid Land*, **13**, 433–454.

Dai, G.H., et al., 2018: The potential impact of invasive woody oil plants on protected areas in China under future climate conditions. *Sci. Rep.*, **8**, doi:10.1038/S41598-018-19477-W.

Dalton, P.S., S. Ghosal and A. Mani, 2016: Poverty and Aspirations Failure. *Econ. J.*, **126**(590), 165–188, doi:10.1111/ecoj.12210.

Dang, T.N., et al., 2016: Characterizing the relationship between temperature and mortality in tropical and subtropical cities: a distributed lag non-linear model analysis in Hue, Viet Nam, 2009-2013. *Glob. Health Action*, **9**, 28738, doi:10.3402/gha.v9.28738.

Das, S., N.S. Kar and S. Bandyopadhyay, 2015: Glacial lake outburst flood at Kedarnath, Indian Himalaya: a study using digital elevation models and satellite images. *Nat. Hazards*, **77**(2), 769–786.

Dasgupta, P., D. Bhattacharjee and A. Kumari, 2013a: Socio-economic analysis of climate change impacts on foodgrain production in Indian states. *Environ. Dev.*, **8**, 5–21, doi:10.1016/j.envdev.2013.06.002.

DasGupta, R., S. Hashimoto, T. Okuro and M. Basu, 2018: Scenario-based land change modelling in the Indian Sundarban delta: an exploratory analysis of plausible alternative regional futures. *Sustain. Sci.*, **14**(1), 221–240, doi:10.1007/s11625-018-0642-6.

Dasgupta, S., et al., 2015: River salinity and climate change: evidence from coastal Bangladesh. In: *World Scientific Reference on Asia and the World Economy*. World Scientific, Singapore, pp. 205–242.

Dasgupta, S., et al., 2013b: A megacity in a changing climate: the case of Kolkata. *Clim. Change*, **116**(3), 747–766.

Dasgupta, S., M.M. Hossain, M. Huq and D. Wheeler, 2014a: *Facing the Hungry Tide: Climate Change, Livelihood Threats, and Household Responses in Coastal Bangladesh*. Policy Research Working Papers. The World Bank, Washington, DC. 30 pp.

Dasgupta, S., et al., 2014b: Cyclones in a changing climate: the case of Bangladesh. *Clim. Dev.*, **6**(2), 96–110, doi:10.1080/17565529.2013.868335.

Dasgupta, S., et al., 2017a: The impact of aquatic salinization on fish babitats and poor communities in a changing climate: Evidence from Southwest coastal Bangladesh. *Ecol. Econ.*, **139**, 128–139, doi:10.1016/j.ecolecon.2017.04.009.

Dasgupta, S., et al., 2014c: *River Salinity and Climate Change : Evidence from Coastal Bangladesh* Policy Research Working Paper No. 6817. World Bank, Washington, DC.

Dasgupta, S., F.A. Kamal, Z.H. Khan, S. Choudhury and A. Nishat, 2015: River Salinity and Climate Change: Evidence from Coastal Bangladesh. In: *Asia and the World Economy - Actions on Climate Change by Asian Countries* [Pan, J.W.(ed.)]. World Scientific Press, Singapore, pp. 205–242.

Dasgupta, S., I. Sobhan and D. Wheeler, 2017b: The impact of climate change and aquatic salinization on mangrove species in the Bangladesh Sundarbans. *Ambio*, **46**(6), 680–694, doi:10.1007/s13280-017-0911-0.

Dasgupta, S., et al., 2020: *Coping with Climate Change in the Sundarbans : Lessons from Multidisciplinary Studies* International Development in Focus. World Bank, Washington, DC.

Dastagir, M.R., 2015: Modeling recent climate change induced extreme events in Bangladesh: A review. *Weather. Clim. Extrem.*, **7**, 49–60, doi:10.1016/j.wace.2014.10.003.

Dastorani, M. and M. Jafari, 2019: Analysis of the Trend of Dust Changes in Ardestan Region, Iran. *Desert Ecosyst. Eng. J.*, **2**(1), 45–54, doi:10.22052/jdee.2019.173755.1049.

Dau, Q.V., K. Kuntiyawichai and V. Plermkamon, 2017: Quantification of flood damage under potential climate change impacts in Central Vietnam. *Irrigation Drain.*, **66**(5), 842–853, doi:10.1002/IRD.2160.

Davis, K.F., A. Bhattachan, P. D'Odorico and S. Suweis, 2018: A universal model for predicting human migration under climate change: examining future sea level rise in Bangladesh. *Environ. Res. Lett.*, doi:10.1088/1748-9326/aac4d4.

de Coninck, H., A. Revi, M. Babiker, P. Bertoldi, M. Buckeridge, A. Cartwright, W. Dong, J. Ford, S. Fuss, J.-C. Hourcade, D. Ley, R. Mechler, P. Newman, A. Revokatova, S. Schultz, L. Steg, and T. Sugiyama, 2018: Strengthening and Implementing the Global Response. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press

De Leeuw, J., et al., 2014: The potential and uptake of remote sensing in insurance: A review. *Remote Sens.*, 6(11), 10888–10912.

de Leon, E. G. and J. Pittock, 2017: Integrating climate change adaptation and climate-related disaster risk-reduction policy in developing countries: A case study in the Philippines. *Clim. Dev.*, **9**(5), 471–478, doi:10.1080/17565529.2016.1174659.

De Souza, K., et al., 2015: Vulnerability to climate change in three hot spots in Africa and Asia: key issues for policy-relevant adaptation and resilience-building research. *Reg. Environ. Change*, **15**(5), 747–753, doi:10.1007/s10113-015-0755-8.

Dehghani, M., et al., 2010: Recreation Value of Hara Biosphere Reserve using Willingness-to-pay method. *Int. J. Environ Res.*, **4**(2), 271–280.

de la Cruz, D.W. and P.L. Harrison, 2020: Optimising conditions for in vitro fertilization success of Acropora tenuis, A. millepora and Favites colemani corals in northwestern Philippines. *J. Exp. Mar. Biol. Ecol.*, **524**, 8, doi:10.1016/j.jembe.2019.151286.

Dell, M., B.F. Jones and B.A. Olken, 2014: What do we learn from the weather? The new climate-economy literature. *J. Econ. Lit.*, **52**(3), 740–798.

Demin, A., 2014: Water resources and food program. *Water Resour.*, **41**(3), 232–241.

Demuzere, M. and al e, 2014: Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *J. Environ. Manag.*

Deng, X. and C. Zhao, 2015: Identification of Water Scarcity and Providing Solutions for Adapting to Climate Changes in the Heihe River Basin of China. *Adv. Meteorol.*, **13**.

Deng, Y., M. Wang and R. Yousefpour, 2017: How do people's perceptions and climatic disaster experiences influence their daily behaviors regarding adaptation to climate change? — A case study among young generations. *Sci. Total. Environ.*, **581-582**, 840–847, doi:10.1016/j.scitotenv.2017.01.022.

Deng, Z., et al., 2015: Impacts of tropical cyclones and accompanying precipitation on infectious diarrhea in cyclone landing areas of Zhejiang Province, China. *Int. J Environ. Res. Public Health*, **12**(2), 1054–1068, doi:10.3390/ijerph120201054.

Department of Agriculture, 2019: *Operational Guidelines: Pradhan Mantri Fasal Bima Yojana*. Department of Agriculture, Cooperation and Farmers Welfare. Ministry of Agriculture and Farmers Welfare, New Delhi, India.

Department of Fisheries (Thailand), 2015: *Marine Fisheries Management Plan of Thailand*. Department of Fisheries, Ministry of Agriculture and Cooperatives (Thailand), Bangkok.

Depietri, Y., 2020: The Social-Ecological Dimension of Vulnerability and Risk to Natural Hazards. *Sustain. Sci.*, **15**, 587–604.

Derocher, A.E., et al., 2013: Rapid ecosystem change and polar bear conservation. *Conserv. Lett.*, **6**(5), 368–375, doi:10.1111/conl.12009.

Deshpande, T., K. Michael and K. Bhaskara, 2018: Barriers and enablers of local adaptive measures: a case study of Bengaluru's informal settlement dwellers. *Local Environ.*, **24**(3), 167–179, doi:10.1080/13549839.2018.1555578.

Devkota, S., et al., 2019: Climate change-induced range shift of the endemic epiphytic lichen *Lobaria pindarensis* in the Hindu Kush Himalayan region. *Lichenologist*, **51**(2), 157–173, doi:10.1017/S002428291900001x.

Dhar, T.K. and L. Khirfan, 2016: *Climate change adaptation in the urban planning and design research: missing links and research agenda*. doi:10.1080/09640568.2016.1178107.

Dhiman, R.C. and S. Sarkar, 2017: El Nino Southern Oscillation as an early warning tool for malaria outbreaks in India. *Malar. J.*, **16**(1), 122, doi:10.1186/s12936-017-1779-y.

Di, L., et al., 2017: RF-CLASS: A remote-sensing-based flood crop loss assessment cyber-service system for supporting crop statistics and insurance decision-making. *J. Integr. Agric.*, **16**(2), 408–423.

Díaz, S., et al., 2020: *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science*. Policy Platform on Biodiversity and Ecosystem Services, Argentina.

Didovets, I., et al., 2021: Central Asian rivers under climate change: Impacts assessment in eight representative catchments. *J. Hydrol. Reg. Stud.*, **34**, 100779, doi:10.1016/j.ejrh.2021.100779.

Dilshad, T., et al., 2019: Growing social vulnerability in the river basins: Evidence from the Hindu Kush Himalaya (HKH) Region. *Environ. Dev.*, **31**, 19–33, doi:10.1016/j.envdev.2018.12.004.

Dineshbabu, A.P., et al., 2020: Assessment of stock vulnerability of Indian marine fishes to past changes in climate and options for adaptation. *Clim. Res.*, **79**, 175–192, doi:10.3354/cr01586.

Ding, M., et al., 2018: Surge-type glaciers in Karakoram Mountain and possible catastrophes alongside a portion of the Karakoram Highway. *Nat. Hazards*, **90**(2), 1017–1020, doi:10.1007/s11069-017-3063-4.

Ding, Y., et al., 2019: Global warming weakening the inherent stability of glaciers and permafrost. *Sci. Bull.*, **64**(4), 245–253, doi:10.1016/j.scib.2018.12.028.

Dissanayake, S., J. Asafu-Adjaye and R. Mahadeva, 2017: Addressing climate change cause and effect on land cover and land use in South Asia. *Land Use Policy*, **67**, 352–366, doi:10.1016/j.landusepol.2017.06.003.

Dittrich, R., A. Wreford and D. Moran, 2016: A survey of decision-making approaches for climate change adaptation: Are robust methods the way forward? *Ecol. Econ.*, **122**, 79–89.

Djalante, R. and S. Lassa, 2019: *Governing Complexities and Its Implication on the SFDRR Priority 2 on Governance*.

Doan, N.X., et al., 2018: Temperature-and sex-specific grazing rate of a tropical copepod Pseudodiaptomus annandalei to food availability: Implications for live feed in aquaculture. *Aquac. Res.*, **49**(12), 3864–3873, doi:10.1111/are.13854.

Doan, N.X., et al., 2019: Extreme temperature impairs growth and productivity in a common tropical marine copepod. *Sci. Rep.*, **9**, 9, doi:10.1038/s41598-019-40996-7.

Doberstein, B., A. Tadgell and A. Rutledge, 2020: Managed Retreat for Climate Change Adaptation in Coastal Megacities: A Comparison of Policy and Practice in Manila and Vancouver. *J. Environ. Manag.*, **253**.

Doblas-Reyes, F.J., A.A. Sörensson, M. Almazroui, A. Dosio, W.J. Gutowski, R. Haarsma, R. Hamdi, B. Hewitson, W.-T. Kwon, B.L. Lamptey, D. Maraun, T.S. Stephenson, I. Takayabu, L. Terray, A. Turner, and Z. Zuo, 2021: Linking Global to Regional Climate Change. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, UK.

Dodman, D., D. Archer and D. Satterthwaite, 2019: Editorial: Responding to climate change in contexts of urban poverty and informality. *Environ. Urban.*, doi:10.1177/0956247819830004.

Doswald, N., et al., 2014: Effectiveness of ecosystem-based approaches for adaptation: review of the evidence-base. *Climate and Development*. doi:10.1080/17565529.2013.867247.

Douville, H., K. Raghavan, J. Renwick, R.P. Allan, P.A. Arias, M. Barlow, R. Cerezo-Mota, A. Cherchi, T.Y. Gan, J. Gergis, D. Jiang, A. Khan, W. Pokam Mba, D. Rosenfeld, J. Tierney, and O. Zolina, 2021: Water Cycle Changes. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, UK.

Drolet, J., et al., 2015: Women rebuilding lives post-disaster: innovative community practices for building resilience and promoting sustainable development. *Gend. Dev.*, **23**(3), 433–448, doi:10.1080/13552074.2015.1096040.

Du, S., et al., 2020: Hard or soft flood adaptation? Advantages of a hybrid strategy for Shanghai. *Glob. Environ. Chang.*, **61**, 102037.

Duan, H., G. Zhang, S. Wang and Y. Fan, 2019a: Integrated benefit-cost analysis of China's optimal adaptation and targeted mitigation. *Ecol. Econ.*, **160**, 76–86.

Duan, H., G. Zhang, S. Wang and Y. Fan, 2019b: Robust climate change research: a review on multi-model analysis. *Environ. Res. Lett.*, **14**(3), doi:10.1088/1748-9326/aaf8 f9.

Duan, W., et al., 2016: Floods and associated socioeconomic damages in China over the last century. *Nat. Hazards*, **82**(1), 401–413.

Duane, A., M. Castellnou and L. Brotons, 2021: Towards a comprehensive look at global drivers of novel extreme wildfire events. *Clim. Change*, **165**(3), 43, doi:10.1007/s10584-021-03066-4.

Duarte, C.M., et al., 2017: Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? *Front. Mar. Sci.*, **4**(100), doi:10.3389/fmars.2017.00100.

Duffy, J.E., et al., 2019: Toward a Coordinated Global Observing System for Seagrasses and Marine Macroalgae. *Front. Mar. Sci.*, **6**(317), doi:10.3389/fmars.2019.00317.

Dugan, P.J., et al., 2010: Fish migration, dams, and loss of ecosystem services in the Mekong basin. *Ambio*, **39**(4), 344–348.

Dujardin, S., J. Hermesse and N. Dendoncker, 2018: Making space for experiential knowledge in climate change adaptation? Insights from municipal planning officers in Bohol, Philippines. *Jamba J. Disaster Risk Stud.*, **10**(1), 433, doi:10.4102/jamba.v10i1.433.

Dulal, H.B., 2019: Cities in Asia: how are they adapting to climate change? *J. Environ. Stud. Sci.*, **9**(1), 13–24, doi:10.1007/s13412-018-0534-1.

Dulamsuren, C., M. Khishigjargal, C. Leuschner and M. Hauck, 2014: Response of tree-ring width to climate warming and selective logging in larch forests of the Mongolian Altai. *J. Plant Ecol.*, **7**(1), 24–38, doi:10.1093/jpe/rtt019.

Dulamsuren, C., et al., 2016: Carbon pool densities and a first estimate of the total carbon pool in the Mongolian forest-steppe. *Glob. Change Biol.*, **22**(2), 830–844, doi:10.1111/gcb.13127.

Dulamsuren, C., et al., 2013: Increased Summer Temperatures Reduce the Growth and Regeneration of *Larix sibirica* in Southern Boreal Forests of Eastern Kazakhstan. *Ecosystems*, **16**(8), 1536–1549, doi:10.1007/s10021-013-9700-1.

Duncan, C., et al., 2016: Rehabilitating mangrove ecosystem services: A case study on the relative benefits of abandoned pond reversion from Panay Island, Philippines. *Mar. Pollut Bull.*, **109**(2), 772–782, doi:10.1016/j.marpolbul.2016.05.049.

Dür, M. and L. Keller, 2018: Education for Sustainable Development through International Collaboration. A Case Study on Concepts and Conceptual Change of School-Students from India and Austria on Gender Equality and Sustainable Growth. *Educ. Sci.*, **8**(4), doi:10.3390/educsci8040187.

Durán-Valverde, F., J. Pacheco-Jiménez, T. Muzaffar and H. Elizondo-Barboza, 2020: *Financing gaps in social protection: Global estimates and strategies for developing countries in light of the COVID-19 crisis and beyond*. International Labour Organization. ISBN 9789220328712. https://www.ilo.org/secsoc/information-resources/publications-and-tools/Workingpapers/WCMS_758705/lang--en/index.htm.

Duy, P.N., L. Chapman, M. Tight and L.V. Thuong, 2019: Urban Resilience to Floods in Coastal Cities: Challenges and Opportunities for Ho Chi Minh City and Other Emerging Cities in Southeast Asia. *J. Urban Plan. Dev.*, **144**(1). https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29UP.1943-5444.0000419.

Dwirahmadi, F., S. Rutherford, D. Phung and C. Chu, 2019: Understanding the Operational Concept of a Flood-Resilient Urban Community in Jakarta, Indonesia, from the Perspectives of Disaster Risk Reduction, Climate Change Adaptation, and Development Agencies. *Int. J. Environ. Res. Public Health*, **16**.(20), 3993. doi: 10.3390/ijerph16203993.

Eakin, C.M., H.P.A. Sweatman and R.E. Brainard, 2019: The 2014-2017 global-scale coral bleaching event: insights and impacts. *Coral Reefs*, **38**(4), 539–545, doi:10.1007/s00338-019-01844-2.

Eco, M.E.N., https://www.ecomena.org/ecomena/. accessed on October 1, 2021.

Edmonds, D.A., R.L. Caldwell, E.S. Brondizio and S.M.O. Siani, 2020: Coastal flooding will disproportionately impact people on river deltas. *Nat. Commun.*, **11**(1), 1–8.

Eilander, D., et al., 2020: The effect of surge on riverine flood hazard and impact in deltas globally. *Environ. Res. Lett.* **15**(10), 104007. https://iopscience.iop.org/article/10.1088/1748-9326/ab8ca6.

Elalem, S. and I. Pal, 2015: Mapping the vulnerability hotspots over Hindu-Kush Himalaya region to flooding disasters. *Weather. Clim. Extrem.*, **8**, 46–58, doi:10.1016/j.wace.2014.12.001.

Elliott, R.J.R., E. Strobl and P. Sun, 2015: The local impact of typhoons on economic activity in China: A view from outer space. *J. Urban Econ.*, **88**, 50–66, doi:10.1016/j.jue.2015.05.001.

Ellis, P. and M. Roberts, 2016: *Leveraging urbanization in South Asia: managing spatial transformation for prosperity and livability*. ISBN 978-1464806629.

Elum, Z.A., D.M. Modise and A. Marr, 2017: Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa. *Clim. Risk Manag.*, **16**, 246–257, doi:10.1016/j.crm.2016.11.001.

Emran, M.S., V. Robano and S.C. Smith, 2014: Assessing the frontiers of ultrapoverty reduction: evidence from challenging the frontiers of poverty reduction/targeting the ultra-poor, an innovative program in Bangladesh. *Econ. Dev. Cult. Change.*, **62**(2), 339–380.

Environment, U. A. E. M. o. C. C, 2015: *National Climate Change Plan of the United Arab Emirates 2017-2050*.

ESCAP, U, 2017: *Migration and climate change in Asia and the Pacific*. ESCAP, U, Bangkok.

Escarcha, J., J. Lassa and K. Zander, 2018a: Livestock Under Climate Change: A Systematic Review of Impacts and Adaptation. *Climate*, **6**(3), doi:10.3390/cli6030054.

Escarcha, J.F., J.A. Lassa, E.P. Palacpac and K.K. Zander, 2018b: Understanding climate change impacts on water buffalo production through farmers' perceptions. *Clim. Risk Manag.*, **20**, 50–63, doi:10.1016/j.crm.2018.03.003.

ESCWA, 2020: *Impact of COVID-19 on Migrants and Refugees in the Arab Region* Technical Paper. United Nations Economic and Social Commission for Western Asia (ESCWA), Beirut, Lebanon.

Esham, M., B. Jacobs, H.S.R. Rosairo and B.B. Siddighi, 2018: Climate change and food security: a Sri Lankan perspective. *Environ. Dev. Sustain.*, **20**(3), 1017–1036, doi:10.1007/s10668-017-9945-5.

Eslamian, S., et al., 2017: A Review of Drought Indices. *Int. J. Constr. Res. Civ. Eng.*, **3**(4), doi:10.20431/2454-8693.0304005.

Estoque, R.C., Y. Murayama and S.W. Myint, 2017: Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia. *Sci. Total. Environ.*, **577**, 349–359.

Estoque, R.C., et al., 2019: The future of Southeast Asia's forests. *Nat Commun*, **10**(1), 1829, doi:10.1038/s41467-019-09646-4.

Estoque, R.C., et al., 2020: Heat health risk assessment in Philippine cities using remotely sensed data and social-ecological indicators. *Nat. Commun.*, **11**(1), 1581, doi:10.1038/s41467-020-15218-8.

Etchart, L., 2017: The role of indigenous peoples in combating climate change. *Palgrave Commun.*, **3**, doi:10.1057/palcomms.2017.85.

EUEI-PDF, 2017: *Energy and Climate Change Adaptation in Developing Countries*.

Evers, J. and A. Pathirana, 2018: Adaptation to climate change in the Mekong River Basin: introduction to the special issue. *Clim. Change*, **149**(1), 1–11, doi:10.1007/s10584-018-2242-y.

Evertsen, K.F. and K. van der Geest, 2020: Gender, environment and migration in Bangladesh. *Clim. Dev.*, **12**(1), 12–22.

Fahad, S. and J. Wang, 2018: Farmers' risk perception, vulnerability, and adaptation to climate change in rural Pakistan. *Land Use Policy*, **79**, 301–309, doi:10.1016/j.landusepol.2018.08.018.

Fan, J.T., et al., 2014: Assessing the impact of climate change on the habitat distribution of the giant panda in the Qinling Mountains of China. *Ecol. Model.*, **274**, 12–20, doi:10.1016/j.ecolmodel.2013.11.023.

Fant, C., et al., 2016: Projections of water stress based on an ensemble of socioeconomic growth and climate change scenarios: a case study in Asia. *PLoS ONE*, **11**(3), e150633.

FAO, 2001: *The state of food insecurity in the world*. Food and Agriculuture Organization of the United Nations, Rome.

FAO (ed.), *Actions to Adapt to and Mitigate Climate Change Impacts on Natural Resources: the Case of Fisheries and Aquaculture, Forestry, and Livestock in the Near East*. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2014: *The Water-Energy-Food Nexus: A new approach in support of food security and sustainable agriculture*. Food and Agriculture Orgnization, Rome.

FAO, 2015: *FAO Statistical Pocketbook*. Food and Agricultural Organization (FAO), Rome, Italy.

FAO, 2018a: *The impact of disasters and crises on agriculture and food security 2017*. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2018b: *Impacts of climate change on fisheries and aquaculture Synthesis of current knowledge, adaptation and mitigation options*. http://www.fao.org/3/i9705en/i9705en.pdf. accessed on October 1, 2021.

FAO, 2018c: *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals*. http://www.fao.org/3/i9540en/i9540en.pdf. accessed on October 1, 2021.

FAO, 2019: *FAO Fisheries & Aquaculture - Statistics - Introduction*.

FAO, 2020: *The state of world fisheries and aquaculture 2020 - sustainability in action*. Food and Agriculture Organization, Rome.

FAO, UNICEF, WFP and WHO, 2018d: *The State of Food Security and Nutrition in the World 2018* Building climate resilience for food security and nutrition. FAO, UNICEF, WFP and WHO, Rome.

Farajalla, N., 2013: *Impact of Climate Change on the Arab World*.

Faridatul, M.I., B. Wu and X. Zhu, 2019: Assessing long-term urban surface water changes using multi-year satellite images: A tale of two cities, Dhaka and Hong Kong. *J. Environ. Manag.*, **243**, 287–298, doi:10.1016/j.jenvman.2019.05.019.

Farrington, J. and J. Li, 2016: Climate Change Impacts on Snow Leopard Range. In: *Snow Leopards: Biodiversity of the World: Conservation from Genes to Landscapes* [Nyhus, P., T. McCarthy and D. Mallon)](eds.)]. Elsevier, London, pp. 85–95. ISBN 978-0128022139.

Felberg, K., P. Mellen and D. Puig, 1999: Environment in the European Union at the Turn of the Century: Co-author of 3.12. Urban areas. In: *Environment in the European Union at the Turn of the Century*. European Environment Agency, Copenhagen.

Feliciano, G.N.R., L.M.F. Gagalac, A. Nava and W.Y. Licuanan, 2018: Size structure and possible bleaching susceptibility of mushroom corals in the Philippines following a bleaching event. *Reg. Stud. Mar. Sci.*, **24**, 288–295, doi:10.1016/j.rsma.2018.09.003.

Feng, A., et al., 2018a: Assessing the inundation risk resulting from extreme water levels under sea-level rise: a case study of Rongcheng, China. *Geomatics Nat. Hazards Risk*, **9**(1), 456–470, doi:10.1080/19475705.2018.1447026.

Feng, J., et al., 2018b: Changes of Extreme Sea Level in 1.5 and 2.0°C Warmer Climate Along the Coast of China. *Front. Earth Sci.*, **6**, doi:10.3389/feart.2018.00216.

Feng, X., M. Liu, X. Huo and W. Ma, 2017: What Motivates Farmers' Adaptation to Climate Change? The Case of Apple Farmers of Shaanxi in China. *Sustainability*, **9**(4), 519, doi:10.3390/su9040519.

Fengqing, J., et al., 2005: Magnification of Flood Disasters and its Relation to Regional Precipitation and Local Human Activities since the 1980s in Xinjiang, Northwestern China. *Nat. Hazards*, **36**(3), 307–330, doi:10.1007/s11069-005-0977-z.

Fenner, D., et al., 2017: Intra and inter 'local climate zone' variability of air temperature as observed by crowdsourced citizen weather stations in Berlin, Germany. *Meteorol. Z.*, **26**(5), 525–547, doi:10.1127/metz/2017/0861.

Ferdous, J. and D. Mallick, 2019: Norms, practices, and gendered vulnerabilities in the lower Teesta T basin, Bangladesh. *Environ. Dev.*, **31**, 88–96, doi:10.1016/j.envdev.2018.10.003.

Fernandes, J.A., et al., 2016: Projecting marine fish production and catch potential in Bangladesh in the 21st century under long-term environmental change and management scenarios. *ICES J. Mar. Sci. J. Conseil*, **73**(5), 1357–1369, doi:10.1093/icesjms/fsv217.

Fernandez-Llamazares, A., et al., 2015: Rapid ecosystem change challenges the adaptive capacity of Local Environmental Knowledge. *Glob. Environ. Change.*, **31**, 272–284, doi:10.1016/j.gloenvcha.2015.02.001.

Filho, W.L., et al., 2019: Assessing the impacts of climate change in cities and their adaptive capacity: Towards transformative approaches to climate change adaptation and poverty reduction in urban areas in a set of developing countries. *Sci. Total. Environ.*, **692**, 1175–1190, doi:10.1016/j.scitotenv.2019.07.227.

Fink, H.S., 2016: Human-nature for climate action: Nature-based solutions for urban sustainability. *sustainability*, **8**(3), doi:10.3390/su8030254.

Fischer, E., J. Hellin, H. Greatrex and N. Gensen, 2019: Index insurance and climate risk management: Addressing social equity. *Dev. Policy Rev.*, **37**(5), 581–602.

Fomin, V.V., A.P. Mikhailovich and S.G. Shiyatov, 2020: Trees in the Upper Treeline Ecotone in the Polar Urals: Centuries-Old Change and Spatial Patterns. *Mt. Res. Dev.*, **40**(2), R32.

Ford, J.D., et al., 2015: The status of climate change adaptation in Africa and Asia. *Reg. Environ. Change*, **15**(5), 801–814.

Ford, J.D., et al., 2016: Opinion: Big data has big potential for applications to climate change adaptation. *Proc. Natl. Acad. Sci. U. S. A.*, **113**(39), 10729–10732, doi:10.1073/pnas.1614023113.

Fortes, M.D., 2018: Seagrass ecosystem conservation in Southeast Asia needs to link science to policy and practice. *Ocean. Coast. Manag.*, **159**, 51–56, doi:10.1016/j.ocecoaman.2018.01.028.

Fourqurean, J.W., et al., 2012: Seagrass ecosystems as a globally significant carbon stock. *Nat. Geosci.*, **5**(7), 505–509, doi:10.1038/ngeo1477.

Francaviglia, R., et al., 2020: Probability assessment of climate change impacts on soil organic carbon stocks in future periods: a case study in Hyrcanian forests (Northern Iran). *Eur. J. For. Res.*, **139**(1), 1–16, doi:10.1007/s10342-019-01228-9.

Francisco, H.A. and N.A. Zakaria, 2019: Understanding Climate Change Adaptation Needs and Practices of Households in Southeast Asia: Lessons from Five Years of Research | SpringerLink. In: *Handbook of Climate Mitigation and Adaptation*.

Freeman, B.G. and A.M.C. Freeman, 2014: Rapid upslope shifts in New Guinean birds illustrate strong distributional responses of tropical montane species to global warming. *Proc. Natl. Acad. Sci. USA*, **111**(12), 4490–4494, doi:10.1073/pnas.1318190111.

Friedlingstein, P., et al., 2019: Global Carbon Budget 2019. *Earth Syst. Sci. Data*, **11**(4), 1783–1838, doi:10.5194/essd-11-1783-2019.

Frieler, K., et al., 2013: Limiting global warming to 2 degrees C is unlikely to save most coral reefs. *Nat. Clim. Change*, **3**(2), 165–170, doi:10.1038/nclimate1674.

Friend, R., et al., 2014: Mainstreaming urban climate resilience into policy and planning; reflections from Asia. *Urban Clim.*, **7**, 6–19.

Friess, D.A., et al., 2019: The State of the World's Mangrove Forests: Past, Present, and Future. In: *Annual Review of Environment and Resources*. Annual Review of Environment and Resources. [Gadgil, A. and T.P. Tomich(eds.)] Vol.44, In, Palo Alto, pp. 89–115. ISBN 978-0824323448.

Froehlich, H.E., R.R. Gentry and B.S. Halpern, 2018: Global change in marine aquaculture production potential under climate change. *Nat. Ecol. Evol.*, **2**(11), 1745–1750, doi:10.1038/s41559-018-0669-1.

Frölicher, T.L. and C. Laufkötter, 2018: Emerging risks from marine heat waves. *Nat. Commun.*, **9**(1), 650, doi:10.1038/s41467-018-03163-6.

Fuhr, H., T. Hickmann and K. Kern, 2018: The role of cities in multi-level climate governance: local climate policies and the 1.5°C target. *Curr. Opin. Environ. Sustain.*, **30**, 1–6, doi:10.1016/j.cosust.2017.10.006.

Fujisawa, M. and K. Kobayashi, 2011: Climate change adaptation practices of apple growers in Nagano, Japan. *Mitig. Adapt. Strateg. Glob. Change*, **16**(8), 865–877.

Fujisawa, M., K. Kobayashi, P. Johnston and M. New, 2015: What drives farmers to make top-down or bottom-up adaptation to climate change and fluctuations? A comparative study on 3 cases of apple farming in Japan and South Africa. *PLoS ONE*, **10**(3), e120563.

Fünfgeld, H., 2015: Facilitating local climate change adaptation through transnational municipal networks. *Curr. Opin. Environ. Sustain.*, **12**, 67–73, doi:10.1016/j.cosust.2014.10.011.

Gaire, N.P., M. Koirala, D.R. Bhuju and M. Carrer, 2017: Site- and species-specific treeline responses to climatic variability in eastern Nepal Himalaya. *Dendrochronologia*, **41**, 44–56, doi:10.1016/j.dendro.2016.03.001.

Gaisin, I.K., et al., 2020: Expansion of Tree Vegetation in the Forest-Mountain Steppe Ecotone on the Southern Urals in Relation to Changes in Climate and Habitat Moisture. *Russ. J. Ecol.*, **51**(4), 306–318, doi:10.1134/S1067413620040074.

Gajjar, S.P., C. Singh and T. Deshpande, 2018: Tracing back to move ahead: a review of development pathways that constrain adaptation futures. *Clim. Dev.*, 1–15, doi:10.1080/17565529.2018.1442793.

Gallagher, J.B., C.H. Chuan, T.K. Yap and W.F.F. Dona, 2019: Carbon stocks of coastal seagrass in Southeast Asia may be far lower than anticipated when accounting for black carbon. *Biol. Lett.*, **15**(5), 5, doi:10.1098/rsbl.2018.0745.

Gama, M., D. Crespo, M. Dolbeth and P.M. Anastacio, 2017: Ensemble forecasting of *Corbicula fluminea* worldwide distribution: Projections of the impact of climate change. *Aquat. Conserv.*, **27**(3), 675–684, doi:10.1002/aqc.2767.

Gamble, J.L., et al., 2016: *The Impacts of Climate Change on Human Health in The United States A Scientific Assessment*.

Gampell, A.V., J.C. Gaillard, M. Parsons and K. Fisher, 2017: Beyond stop disasters 2.0: an agenda for exploring the contribution of video games to learning about disasters. *Environ. Hazards*, **16**(2), 180–191, doi:10.1080/17477891.2016.1275502.

Gandhi, S. and T.G. Jones, 2019: Identifying Mangrove Deforestation Hotspots in South Asia, Southeast Asia and Asia-Pacific. *Remote Sens.*, **11**(6), 27, doi:10.3390/rs11060728.

Ganguly, D., et al., 2017: Seagrass metabolism and carbon dynamics in a tropical coastal embayment. *Ambio*, **46**(6), 667–679, doi:10.1007/s13280-017-0916-8.

Gao, G., A.S. Clare, C. Rose and G.S. Caldwell, 2017: Eutrophication and warming-driven green tides (Ulva rigida) are predicted to increase under future climate change scenarios. *Mar. Pollut. Bull.*, **114**(1), 439–447, doi:10.1016/j.marpolbul.2016.10.003.

Gao, G., A.S. Clare, C. Rose and G.S. Caldwell, 2018a: Ulva rigida in the future ocean: potential for carbon capture, bioremediation and biomethane production. *Glob. Change Biol. Bioenergy*, **10**(1), 39–51, doi:10.1111/gcbb.12465.

Gao, G., et al., 2018b: Global warming interacts with ocean acidification to alter PSII function and protection in the diatom Thalassiosira weissflogii. *Environ. Exp. Bot.*, **147**, 95–103, doi:10.1016/j.envexpbot.2017.11.014.

Gao, G., Z.H. Zhong, X.H. Zhou and J.T. Xu, 2016: Changes in morphological plasticity of Ulva prolifera under different environmental conditions: A laboratory experiment. *Harmful Algae*, **59**, 51–58, doi:10.1016/j.hal.2016.09.004.

Gao, J., et al., 2019: Collapsing glaciers threaten Asia's water supplies. *Nature*, **565**(7737), 19–21, doi:10.1038/d41586-018-07838-4.

Gao, X., C.A. Schlosser, C. Fant and K. Strzepek, 2018c: The impact of climate change policy on the risk of water stress in southern and eastern Asia. *Environ. Res. Lett.*, **13**(6), 64039.

Garde, M., N. Mathers and T. Dhakal, 2017: The evolution of Nepal's child grant: From humble beginnings to a real driver of change for children? *Glob. Soc. Policy.*, **17**(3), 359–364, doi:10.1177/1468018117729911.

Garrick, D., et al., 2019: Rural water for thirsty cities: A systematic review of water reallocation from rural to urban regions. *Environ. Res. Lett.*, **14**(4), 43003.

Garschagen, M. and D. Marks, 2019: Towards an Agenda for Profound Urban Climate Resilience in Southeast Asia. In: *Urban Climate Resilience in Southeast Asia*. Springer, Berlin Heidelberg, pp. 223–228.

Gasparrini, A., et al., 2017: Projections of temperature-related excess mortality under climate change scenarios. *Lancet Planet Health*, **1**(9), e360–e367, doi:10.1016/S2542-5196(17)30156-0.

Gatteschi, V., et al., 2018: Blockchain and smart contracts for insurance: Is the technology mature enough? *Future Internet*, **10**(2), 20.

Gavonel, M.F., et al., 2021: The migration-sustainability paradox: transformations in mobile worlds. *Curr. Opin. Environ. Sustain.*, **49**, 98–109.

Garcia, G., B. Gonzalez and B. Bastien-Olvera, 2017: An Agent-based Model of Food-borne Diseases Under Climate Change Scenarios in Mexico City - The Risk of Street-food in a Warming City. In: *Proceedings of the 7th International Conference on Simulation and Modeling Methodologies, Technologies and Applications*, pp. 474–479. doi:10.5220/0006484404740479.

Gaydon, D.S., et al., 2017: Evaluation of the APSIM model in cropping systems of Asia. *Field Crop. Res.*, **204**, 52–75, doi:10.1016/j.fcr.2016.12.015.

Ge, Z.M., et al., 2015: Future vegetation patterns and primary production in the coastal wetlands of East China under sea level rise, sediment reduction, and saltwater intrusion. *J. Geophys. Res.*, **120**(10), 1923–1940, doi:10.1002/2015JG003014.

Gemenne, F., et al., 2015: How climate extremes are affecting the movement of populations in the Asia Pacific region. In: *Global Implications of Development, Disasters and Climate Change: Responses to Displacement from Asia Pacific*, pp. 21–40.

Georgeson, L., M. Maslin, M. Poessinouw and S. Howard, 2016: Adaptation responses to climate change differ between global megacities. *Nat. Clim. Change*, **6**(6), 584–588, doi:10.1038/nclimate2944.

Ghasem, A., A. Shamsipour, M. Miri and T. Safarrad, 2012: Synoptic and remote sensing analysis of dust events in southwestern Iran. *Nat. Hazards*, **64**(2), 1625–1638.

Ghimire, D.P., 2016: Interconnection of climate change, agriculture and climate justice: Complexities for feeding the world under changing climate. *Development*, **59**(4), 270, doi:10.1057/s41301-017-0118-5.

Ghomian, Z. and S. Yousefian, 2017: Natural disasters in the Middle-East and North Africa with a focus on Iran: 1900 to 2015. *Health Emerg. Dis. Q.*, **2**(2), 53–62, doi:10.18869/nrip.hdq.2.2.53.

Ghosh, R.K., S. Gupta, V. Singh and P.S. Ward, 2019: *Is there a market for multi-peril crop insurance in developing countries moving beyond subsidies? Evidence from India*. Vol. 1820. Intl Food Policy Res Inst, Chicago, IL, USA.

Ghosh, S., et al., 2018: Exploitation of social media for emergency relief and preparedness: Recent research and trends. *Inf. Syst. Front.*, 1–7, doi:10.1007/s10796-018-9878-z.

Giang, P.N., et al., 2014: The effect of temperature on cardiovascular disease hospital admissions among elderly people in Thai Nguyen Province, Vietnam. *Glob. Health Action*, **7**, 23649, doi:10.3402/gha.v7.23649.

Giffin, A.L., et al., 2020: Marine and coastal ecosystem-based adaptation in Asia and Oceania: review of approaches and integration with marine spatial planning. *Pac. Conserv. Biol.*

Gilfillan, D., 2018: Regional organisations supporting health sector responses to climate change in Southeast Asia. *Global Health*, **14**(1), 80, doi:10.1186/s12992-018-0388-z.

Gilfillan, D., T.T. Nguyen and H.T. Pham, 2017: Coordination and health sector adaptation to climate change in the Vietnamese Mekong Delta. *Ecol. Soc.*, **22**(3), doi:10.5751/es-09235-220314.

Ginbo, T., L. Di Corato and R. Hoffmann, 2020: Investing in climate change adaptation and mitigation: A methodological review of real-options studies. *Ambio*.

Girishkumar, M.S., et al., 2019: Quantifying Tropical Cyclone's Effect on the Biogeochemical Processes Using Profiling Float Observations in the Bay of Bengal. *J. Geophys. Res. Oceans*, **124**(3), 1945–1963, doi:10.1029/2017jc013629.

Giuliani, M., et al., 2016: Large storage operations under climate change: expanding uncertainties and evolving tradeoffs. *Environ. Res. Lett.*, **11**(3), doi:10.1088/1748-9326/11/3/035009.

Gleick, P. and C. Iceland, 2018: *Water, Security, and Conflict*. World Resource Institute. https://openresearch.amsterdam/nl/page/76697/water-security-and-conflict.

Gleick, P.H., 1993: Water and conflict: Fresh water resources and international security. *Int. Secur.*, **18**(1), 79–112.

Gleick, P.H., 2014: Water, Drought, Climate Change, and Conflict in Syria. *Weather. Clim. Soc.*, **6**(3), 331–340, doi:10.1175/wcas-d-13-00059.1.

IPBES, 2019: *Glossary*. https://www.ipbes.net/sites/default/files/ipbes_global_assessment_glossary_unedited_31may.pdf. accessed on October 1, 2021.

Godber, O.F. and R. Wall, 2014: Livestock and food security: vulnerability to population growth and climate change. *Glob. Chang. Biol.*, **20**(10), 3092–3102, doi:10.1111/gcb.12589.

Goel, S., K. Singh and N.K. Singh, 2017: Wheat Improvement in India: Present and Future. In: *Wheat Biotechnology: Methods and Protocols* [Bhalla, P.L. and M.B. Singh(eds.)]. Springer, New York, NY, pp. 61–82. ISBN 978-1493973378.

Gohari, A., A. Mirchi and K. Madani, 2017: System dynamics evaluation of climate change adaptation strategies for water resources management in Central Iran. *Water Resour. Manag.*, **31**, 1413–1434, doi:10.1007/s11269-017-1575-z.

Gong, S.Q., et al., 2019: Differences in Symbiodiniaceae communities and photosynthesis following thermal bleaching of massive corals in the northern part of the South China Sea. *Mar. Pollut. Bull.*, **144**, 196–204, doi:10.1016/j.marpolbul.2019.04.069.

Gong, Y., J. Yang and X. Shi, 2020: Towards a comprehensive understanding of digital transformation in government: Analysis of flexibility and enterprise architecture. *Gov. Inf. Q.*, **37**(3), 101487.

Goodrich, C.G., A. Prakash and P.B. Udas, 2019: Gendered vulnerability and adaptation in Hindu-Kush Himalayas: Research insights. *Environ. Dev.*, **31**, 1–8, doi:10.1016/j.envdev.2019.01.001.

Grainger, S. and D. Conway, 2014: Climate change and International River Boundaries: fixed points in shifting sands. *Wiley Interdiscip. Rev. Clim. Chang.*, **5**(6), 835–848, doi:10.1002/wcc.306.

Granit, J., et al., 2012: Regional options for addressing the water, energy and food nexus in Central Asia and the Aral Sea Basin. *Int. J. Water Resour. Dev.*, **28**(3), 419–432.

Gray, T.N.E., et al., 2014: Population size estimation of an Asian elephant population in eastern Cambodia through non-invasive mark-recapture sampling. *Conserv. Genet.*, **15**(4), 803–810, doi:10.1007/s10592-014-0579-y.

Greatrex, H., et al., 2015: *Scaling up index insurance for smallholder farmers: Recent evidence and insights*.

Grebenets, V., D. Streletskiy and N. Shiklomanov, 2012: Geotechnical safety issues in the cities of Polar Regions. *Geogr. Environ. Sustain.*, **5**(3), 104–119.

Green, P.A., et al., 2015: Freshwater ecosystem services supporting humans: Pivoting from water crisis to water solutions. *Glob. Environ. Chang.*, **34**, 108–118, doi:10.1016/j.gloenvcha.2015.06.007.

Grefalda, L.B., et al., 2020: Building institutional resilience in the context of climate change in Aurora, Philippines. *Environ. Res.*, **186**, 109584, doi:10.1016/j.envres.2020.109584.

Grigor'ev, A.A., et al., 2019: Structure and dynamics of tree stands at the upper timberline in the western part of the Putorana Plateau. *Russ. J. Ecol.*, **50**(4), 311–322, doi:10.1134/s1067413619040076.

Griscom, B.W., et al., 2020: National mitigation potential from natural climate solutions in the tropics. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, **375**(1794), 20190126, doi:10.1098/rstb.2019.0126.

Groll, M., et al., 2015: Water quality, potential conflicts and solutions—an upstream–downstream analysis of the transnational Zarafshan River (Tajikistan, Uzbekistan). *Environ. Earth Sci.*, **73**, 743–763, doi:10.1007/S12665-013-2988-5.

Grothmann, T. and A. Patt, 2005: Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Glob. Environ. Chang.*, **15**(3), 199–213, doi:10.1016/j.gloenvcha.2005.01.002.

Groulx, M., et al., 2017: A Role for Nature-Based Citizen Science in Promoting Individual and Collective Climate Change Action? A Systematic Review of Learning Outcomes. *Sci. Commun.*, **39**(1), 45–76, doi:10.1177/1075547016688324.

Gruffudd, H.R., T.A.R. Jenkins and H.F. Evans, 2016: Using an evapo-transpiration model (ETpN) to predict the risk and expression of symptoms of pine wilt disease (PWD) across Europe. *Biol. Invasions*, **18**(10), 2823–2840, doi:10.1007/s10530-016-1173-7.

Gu, D., P. Gerland, F. Pelletier and B. Cohen, 2015: *Risks of Exposure and Vulnerability to Natural Disasters at the City Level: A Global Overview*. Technical Paper, No. 2015/2. UN Population Division, New York, USA.

Gulakhmadov, A., et al., 2020: Long-Term Hydro-Climatic Trends in the Mountainous Kofarnihon River Basin in Central Asia. *Water*, **12**, doi:10.3390/w12082140.

Gunathilaka, R.P.D., J.C.R. Smart and C.M. Fleming, 2018: Adaptation to climate change in perennial cropping systems: Options, barriers and policy implications. *Environ. Sci. Policy*, **82**, 108–116, doi:10.1016/j.envsci.2018.01.011.

Güneralp, B., I. Güneralp and Y. Liu, 2015: Changing global patterns of urban exposure to flood and drought hazards. *Glob. Environ. Change*, **31**, 217–225, doi:10.1016/j.gloenvcha.2015.01.002.

Guo, X., L. Wang, L. Tian and X. Li, 2017a: Elevation-dependent reductions in wind speed over and around the Tibetan Plateau. *Int. J. Climatol.*, **37**(2), 1117–1126, doi:10.1002/joc.4727.

Guo, X.Y., et al., 2016: Early development of undulated surf clam, Paphia undulate under elevated pCO(2). *J. Exp. Mar. Biol. Ecol.*, **484**, 23–30, doi:10.1016/j.jembe.2016.08.002.

Guo, Y., et al., 2017b: Heat Wave and Mortality: A Multicountry, Multicommunity Study. *Environ. Health Perspect.*, **125**(8), 87006, doi:10.1289/ehp1026.

Guo, Y., et al., 2019: Dynamic Evaluation and Regionalization of Maize Drought Vulnerability in the Midwest of Jilin Province. *Sustainability*, **11**, 4234, doi:10.3390/su11154234.

Gupta, A.K., et al., 2019: Assessing the vulnerability of socio-environmental systems to climate change along an altitude gradient in the Indian Himalayas. *Ecol. Indic.*, **106**, doi:10.1016/j.ecolind.2019.105512.

Gupta, D. and T.M. Koontz, 2019: Working together? Synergies in government and NGO roles for community forestry in the Indian Himalayas. *World Dev.*, **114**, 326–340.

Gurung, D.R., et al., 2017: Lemthang Tsho glacial Lake outburst flood (GLOF) in Bhutan: cause and impact. *Geoenviron. Dis.*, **4**(1), 17, doi:10.1186/s40677-017-0080-2.

Gustafson, S., A.J. Cadena and P. Hartman, 2018: Adaptation planning in the Lower Mekong Basin: Merging scientific data with local perspective to improve community resilience to climate change. *Clim. Dev.*, **10**(2), 152–166.

Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I. V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon, 2021: Atlas. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, UK.

Haag, I., P.D. Jones and C. Samimi, 2019: Central Asia's changing climate: How temperature and precipitation have changed across time, space, and altitude. *Climate*, **7**(10), 123.

Haasnoot, M., et al., 2019: Generic adaptation pathways for coastal archetypes under uncertain sea-level rise. *Environ. Res. Commun.*, **1**(7), 71006.

Haasnoot, M., 2021: Long-term sea-level rise necessitates a commitment to adaptation: a first order assessment. *Clim. Risk Manag.* https://doi.org/10.1016/j.crm.2021.100355.

Hadiyanto, et al., 2018: Relation of social capital to women's proactive participation in the community for sustainability of river in urban areas. *E3S Web Conf.*, **73**, doi:10.1051/e3sconf/20187303003.

Hadwen, W.L., et al., 2015: Putting WASH in the water cycle: Climate change, water resources and the future of water, sanitation and hygiene challenges in Pacific Island Countries. *J. Water Sanitation Hyg. Dev.*, **5**(2), 183–191.

Haeberli, W., et al., 2016: New lakes in deglaciating high-mountain regions - opportunities and risks. *Clim. Change*, **139**(2), 201–214, doi:10.1007/s10584-016-1771-5.

Halbrendt, J., et al., 2014: Differences in farmer and expert beliefs and the perceived impacts of conservation agriculture. *Glob. Environ. Chang.*, **28**(1), 50–62, doi:10.1016/j.gloenvcha.2014.05.001.

Hallegatte, S., 2012: A Framework to Investigate the Economic Growth Impact of Sea Level Rise. *Environ. Res. Lett.*, **7**(1), doi:10.1088/1748-9326/7/1/015604.

Hallegatte, S., et al., 2015: *Shock waves: managing the impacts of climate change on poverty*. The World Bank, Washington, DC, USA. ISBN 978-1464806735.

Hallegatte, S., C. Green, R.J. Nicholls and J. Corfee-Morlot, 2013: Future flood losses in major coastal cities. *Nat. Clim. Change*, **3**(9), 802–806.

Hallegatte, S., J. Rentschler and J. Rozenberg, 2019: *Lifelines : The Resilient Infrastructure Opportunity: Sustainable Infrastructure Series*. https://elibrary.worldbank.org/doi/abs/10.1596/978-1-4648-1430-3. accessed on October 1, 2021.

Hallegatte, S., J. Rentschler and B. Walsh, 2018: *Building back better: achieving resilience through stronger, faster, and more inclusive post-disaster reconstruction*. World Bank, Washington, DC, USA.

Hamal, K., et al., 2020: Assessment of drought impacts on crop yields across Nepal during 1987–2017. *Meteorol. Appl.*, **27**(5), e1950.

Hamid, A. and M. A. Raouf, 2009: Climate change in the Arab world: Threats and responses. In: *Troubled Waters; Climate Change, Hydro politics, and Transboundary Resources* [Michel, D. and A. Pandya(eds.)]. The Henry L. Stimson Center, Washington, D.C., US.

Hamidazada, M., A.M. Cruz and M. Yokomatsu, 2019: Vulnerability Factors of Afghan Rural Women to Disasters. *Int. J. Disaster Risk Sci.*, **10**(4), 573–590, doi:10.1007/s13753-019-00227-z.

Han, Q., 2015: Education for Sustainable Development and Climate Change Education in China: A Status Report. *J. Educ. Sustain. Dev.*, **9**(1), 62–77, doi:10.1177/0973408215569114.

Handisyde, N., T.C. Telfer and L.G. Ross, 2017: Vulnerability of aquaculture-related livelihoods to changing climate at the global scale. *Fish. Fish.*, **18**(3), 466–488, doi:10.1111/faf.12186.

Hansen, J., et al., 2013: Assessing "dangerous climate change": Required reduction of carbon emissions to protect young people, future generations and nature. *PLoS ONE*, **8**(12), e81648.

Hao, X.M., et al., 2019: Response of ecosystem water use efficiency to climate change in the Tianshan Mountains, Central Asia. *Environ Monit Assess*, **191**(9), doi:10.1007/S10661-019-7673-Z.

Haque, M.M., S. Bremer, S.B. Aziz and J.P. van der Sluijs, 2017: A critical assessment of knowledge quality for climate adaptation in Sylhet Division, Bangladesh. *Clim. Risk Manag.*, **16**, 43–58, doi:10.1016/j.crm.2016.12.002.

Haraguchi, M. and U. Lall, 2019: Concepts, Frameworks, and Policy Tools for Disaster Risk Management: Linking with Climate Change and Sustainable Development. *Sustain. Dev. Africa Concepts Methodol. Approaches*, **5**, 57.

Hashizume, M., et al., 2020: Health Effects of Asian Dust: A Systematic Review and Meta-Analysis. *Environ. Health Perspect.*, **128**(6), 66001, doi:10.1289/EHP5312.

Hassan, B., et al., 2020: Impact of Climate Change on Freshwater Ecosystem and Its Sustainable Management. In: *Fresh Water Pollution Dynamics and Remediation* [Qadri, H., R.A. Bhat, M. A. Mehmood and G.H. Dar(eds.)]. Springer, Singapore, pp. 105–121. ISBN 978-9811382772.

Hauck, M., C. Dulamsuren and C. Leuschner, 2016: Anomalous increase in winter temperature and decline in forest growth associated with severe winter smog in the Ulan Bator basin. *Water Air Soil Pollut.*, **227**(8), 1–10.

Hauer, M. E., E. Fussell and V. Mueller, 2020: Sea-level rise and human migration. *Nat. Rev. Earth Environ.*, **1**, 28–39, doi:10.1038/s43017-019-0002-9.

Hayat, H., et al., 2019: Simulating Current and Future River-Flows in the Karakoram and Himalayan Regions of Pakistan Using Snowmelt-Runoff Model and RCP Scenarios. *Water*, **11**(4), 761.

Hazell, P. and U. Hess, 2017: Beyond hype: Another look at index-based agricultural insurance. In: *Agriculture and Rural Development in a Globalizing World*. Routledge, London, UK, pp. 211–226.

Hazell, P., R. Sberro-Kessler and P. Varangis, 2017: *When and how should agricultural insurance be subsidized? Issues and good practices*. World Bank, Washington DC, USA.

He, J., X. Zheng, R.M. Rejesus and J.M. Yorobe Jr, 2019: Moral hazard and adverse selection effects of cost-of-production crop insurance: evidence from the Philippines. *Aust. J. Agric. Resour. Econ.*, **63**(1), 166–197.

Heery, E.C., et al., 2018: Urban coral reefs: Degradation and resilience of hard coral assemblages in coastal cities of East and Southeast Asia. *Mar. Pollut. Bull.*, **135**, 654–681, doi:10.1016/j.marpolbul.2018.07.041.

Heino, M., et al., 2020: A multi-model analysis of teleconnected crop yield variability in a range of cropping systems. *Earth Syst. Dynam.*, **11**(1), 113–128, doi:10.5194/esd-11-113-2020.

Heino, M., et al., 2018: Two-thirds of global cropland area impacted by climate oscillations. *Nat. Commun.*, **9**(1), 1257, doi:10.1038/s41467-017-02071-5.

Hemachandra, K., 2019: Regional cooperation multihazards early warning systems in Asia. *Int. J. Adv. Sci. Eng. Inf. Technol.*, **9**(1), 287–292.

Hemachandra, K., D. Amaratunga and R. Haigh, 2018: Role of women in disaster risk governance. *Proc. Eng.*, **212**, 1187–1194, doi:10.1016/j.proeng.2018.01.153.

Hendrix, C.S. and S. Haggard, 2015: Global food prices, regime type, and urban unrest in the developing world. *J. Peace Res.*, **52**(2), 143–157, doi:10.1177/0022343314561599.

Hennige, S.J., et al., 2010: Acclimation and adaptation of scleractinian coral communities along environmental gradients within an Indonesian reef system. *J. Exp. Mar. Biol. Ecol.*, **391**(1-2), 143–152, doi:10.1016/j.jembe.2010.06.019.

Henriksson, P., et al., 2019: Indonesian aquaculture futures — identifying interventions for reducing environmental impacts. *Environ. Res. Lett.*, **14**, doi:10.1088/1748-9326/ab4b79.

Henrique, K.P., P. Tschakert, 2020: Pathways to urban transformation: From dispossession to climate justice. *Prog. Hum. Geogr.*, doi:10.1177/0309132520962856.

Hens, L., et al., 2018: Sea-level rise and resilience in Vietnam and the Asia-Pacific: A synthesis. *Vietnam J. Earth Sci.*, **40**(2), 126–152.

Herbeck, J. and M. Flitner, 2019: Infrastructuring coastal futures: Key trajectories in Southeast Asian megacities. *Erde J. Geogr. Soc. Berl.*, **150**(3), doi:10.12854/erde-2019-451.

Hijioka, Y., E. Lin, J.J. Pereira, R.T. Corlett, X. Cui, G.E. Insarov, R.D. Lasco, E. Lindgren, and A. Surjan, 2014: Asia. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1327–1370.

Hilmi, N., et al., 2019: Socio-economic tools to mitigate the impacts of ocean acidification on economies and communities reliant on coral reefs - a framework for prioritization. *Reg. Stud. Mar. Sci.*, **28**, 10, doi:10.1016/j.rsma.2019.100559.

Himes-Cornell, A., L. Pendleton and P. Atiyah, 2018: Valuing ecosystem services from blue forests: a systematic review of the valuation of salt marshes, sea grass beds and mangrove forests. *Ecosyst. Serv.*, **30**, 36–48, doi:10.1016/j.ecoser.2018.01.006.

Hirata, A., et al., 2017: Potential distribution of pine wilt disease under future climate change scenarios. *PLoS ONE*, **12**(8), e182837, doi:10.1371/journal.pone.0182837.

Hirota, T. and K. Kobayashi, 2019: The Roles of Farmers, Scientists, and Extension Staff in Technology Development for Soil Frost Control as an Adaptation to Climate Change in Tokachi, Hokkaido, Japan. In: *Adaptation to Climate Change in Agriculture: Research and Practices* [Iizumi, T., R. Hirata and R. Matsuda(eds.)]. Springer, Singapore, pp. 211–228. ISBN 978-9811392351.

Hiwasaki, L., L. Syamsidik and R. Shaw, 2014: Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities. *Int. J. Dis. Risk Reduct.*, **10**, 15–27, doi:10.1016/j.ijdrr.2014.07.007.

Hjort, J., et al., 2018: Degrading permafrost puts Arctic infrastructure at risk by mid-century. *Nat. Commun.*, **91**(9), 1–9, doi:10.1038/s41467-018-07557-4.

Ho, P.L., et al., 2017: Adaptation to Sea Level Rise: A Multidisciplinary Analysis for Ho Chi Minh City, Vietnam. *Water Resour. Res.*, **53**(12), 10841–10857, doi:10.1002/2017wr021344.

Hoang, L.P., et al., 2016: Mekong River flow and hydrological extremes under climate change. *Hydrol. Earth Syst. Sci.*, **20**(7), 3027–3041.

Hochman, Z., et al., 2017: Smallholder farmers managing climate risk in India: 2. Is it climate-smart? *Agric. Syst.*, **151**, 61–72, doi:10.1016/j.agsy.2016.11.007.

Hochrainer-Stigler, S., R. Mechler, G. Pflug and K. Williges, 2014: Funding public adaptation to climate-related disasters. Estimates for a global fund. *Glob. Environ. Chang.*, **25**, 87–96.

Hock, R., G. Rasul, C. Adler, B. Cáceres, S. Gruber, Y. Hirabayashi, M. Jackson, A. Kääb, S. Kang, S. Kutuzov, Al. Milner, U. Molau, S. Morin, B. Orlove, and H. Steltzer, 2019: High Mountain Areas. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Hoegh-Guldberg, O., D. Jacob, M. Taylor, M. Bindi, S. Brown, I. Camilloni, A. Diedhiou, R. Djalante, K.L. Ebi, F. Engelbrecht, J. Guiot, Y. Hijioka, S. Mehrotra, A. Payne, S.I. Seneviratne, A. Thomas, R. Warren, and G. Zhou, 2018: Impacts of 1.5°C global warming on natural and human systems. In: *Global Warming of 1.5 C an IPCC special report on the impacts of global warming of 1.5 C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

Hoegh-Guldberg, O., L. Pendleton and A. Kaup, 2019: People and the changing nature of coral reefs. *Reg. Stud. Mar. Sci.*, **30**, 20, doi:10.1016/j.rsma.2019.100699.

Hoegh-Guldberg, O., E.S. Poloczanska, W. Skirving and S. Dove, 2017: Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Front. Mar. Sci.*, **4**, doi:10.3389/fmars.2017.00158.

Hoekstra, A.Y. and M.M. Mekonnen, 2012: The water footprint of humanity. *Proc. Natl. Acad. Sci. U. S. A.*, **109**(9), 3232–3237, doi:10.1073/pnas.1109936109.

Hoelzle, M., et al., 2019: The status and role of the alpine cryosphere in Central Asia. In: *The Aral Sea Basin*. Taylor & Francis, London, UK.

Holland, G. and A. I. L. G. S. I. M. Grozdanic Cox Kennedy Agabekian Vergara Pitterle Ng Poh Podolski, 2019: *World Economic Situation and Prospects as of mid-2019*. United Nations, New York.

Holmes, R. and N. Jones, 2013: *Gender and social protection in the developing world: Beyond mothers and safety nets*. Zed Books, London.

Hong, C., et al., 2019a: Impacts of climate change on future air quality and human health in China. *Proc. Natl. Acad. Sci.*, **116**(35), 17193–17200.

Hong, E.-M., W.-H. Nam, J.-Y. Choi and Y.A. Pachepsky, 2016: Projected irrigation requirements for upland crops using soil moisture model under climate change in South Korea. *Agric. Water Manag.*, **165**, 163–180, doi:10.1016/j.agwat.2015.12.003.

Hong, H., J. Liu and A.-X. Zhu, 2019b: Landslide susceptibility evaluating using artificial intelligence method in the Youfang district (China). *Environ. Earth Sci.*, **78**(15), 488, doi:10.1007/s12665-019-8415-9.

Hong, J.-W., J. Hong, E.E. Kwon and D.K. Yoon, 2019c: Temporal dynamics of urban heat island correlated with the socio-economic development over the past half-century in Seoul, Korea. *Environ. Pollut.*, **254**, 112934, doi:10.1016/j.envpol.2019.07.102.

Hoque, M. A., et al., 2016: Drinking water vulnerability to climate change and alternatives for adaptation in coastal South and South East Asia. *Clim. Change*, **136**(2), 247–263, doi:10.1007/s10584-016-1617-1.

Hori, K., et al., 2020: Projecting population distribution under depopulation conditions in Japan: scenario analysis for future socio-ecological systems. *Sustain. Sci.*, doi:10.1007/s11625-020-00835-5.

Hossain, B., M.S. Sohel and C.M. Ryakitimbo, 2020: Climate Change Induced Extreme Flood Disaster in Bangladesh: Implications on People's Livelihoods in the Char Village and Their Coping Mechanisms. *Prog. Dis. Sci.*, **6**.

Hossain, M.S., et al., 2019: Economic impact of climate change on crop farming in Bangladesh: An application of Ricardian method. *Ecol. Econ.*, **164**, 106354.

Hossain, M.S., et al., 2018: Climate change and crop farming in Bangladesh: an analysis of economic impacts. *Int. J. Clim. Chang. Strateg. Manag.*

Hou, L., J. Huang and J. Wang, 2017: Early warning information, farmers' perceptions of, and adaptations to drought in China. *Clim. Change*, **141**(2), 197–212, doi:10.1007/s10584-017-1900-9.

Houmsi, M.R., et al., 2019: Spatial shift of aridity and its impact on land use of Syria. *Sustainability*, **11**(24), doi:10.3390/su11247047.

Howells, M., et al., 2013: Integrated analysis of climate change, land-use, energy and water strategies. *Nat. Clim. Change*, **3**(7), 621–626.

Hu, F. and D. Tan, 2018: *No water, no growth: Does Asia have enough water to develop*. China Water Risk, Hong Kong.

Hu, S. and J. Chen, 2016: Place-based inter-generational communication on local climate improves adolescents' perceptions and willingness to mitigate climate change. *Clim. Change*, **138**(3-4), 425–438.

Hu, X., et al., 2019: *Methodology and Findings for the Exposure Analysis of the Chinese Wastewater Sector to Flooding and Earthquakes Hazards*.

Hu, Z., et al., 2017: Variations and changes of annual precipitation in Central Asia over the last century. *Int. J. Climatol.*, **37**(S1), 157–170, doi:10.1002/joc.4988.

Huang, C., et al., 2016: Effects of snow thickness on the abundance of archaeal and bacterial amoA genes and gene transcripts during dwarf bamboo litter decomposition in an alpine forest on the eastern Tibetan Plateau. *Russ. J. Ecol.*, **47**(4), 419–429, doi:10.1134/s106741361604010x.

Huang, D.W., et al., 2015a: Extraordinary diversity of reef corals in the South China Sea. *Mar. Biodivers.*, **45**(2), 157–168, doi:10.1007/s12526-014-0236-1.

Huang, Y., et al., 2020: Nature-based solutions for urban pluvial flood risk management. *Wiley Interdiscip. Rev. Water*, **7**(3), e1421.

Huang, Z., et al., 2015b: Individual-level and community-level effect modifiers of the temperature-mortality relationship in 66 Chinese communities. *BMJ Open*, **5**(9), e9172, doi:10.1136/bmjopen-2015-009172.

Hufkens, K., et al., 2019: Monitoring crop phenology using a smartphone based near-surface remote sensing approach. *Agric. For. Meteorol.*, **265**, 327–337.

Hughes, T.P., et al., 2017: Global warming and recurrent mass bleaching of corals. *Nature*, **543**(7645), 373, doi:10.1038/nature21707.

Hughes, T.P., et al., 2018: Global warming transforms coral reef assemblages. *Nature*, **556**(7702), 492, doi:10.1038/s41586-018-0041-2.

Hung, H.-C., Y.-T. Lu and C.-H. Hung, 2018: The determinants of integrating policy-based and community-based adaptation into coastal hazard risk management: a resilience approach. *J. Risk Res.*, 1–19, doi:10.1080/13669877.2018.1454496.

Husnayaen, et al., 2018: Physical assessment of coastal vulnerability under enhanced land subsidence in Semarang, Indonesia, using multi-sensor satellite data. *Adv. Space Res.*, **61**(8), 2159–2179, doi:10.1016/j.asr.2018.01.026.

Huss, M. and R. Hock, 2018: Global-scale hydrological response to future glacier mass loss. *Nat. Clim. Change*, **8**(2), 135–140.

Hussain, A., B. Mahapatra and G. Rasul, 2019: Adaptation in Mountain Agriculture: Food Security in the Hindu-Kush Himalayan (HKH) Region. In: *Status of Climate Change Adaptation in Asia and the Pacific*, pp. 211–236.

Hussey, K. and J. Pittock, 2012: The Energy–Water Nexus: Managing the Links between Energy and Water for a Sustainable Future. *Ecol. Soc.*, **17**(1), doi:10.5751/es-04641-170131.

Hutchison, J., et al., 2014: Predicting Global Patterns in Mangrove Forest Biomass. *Conservation Lett.*, **7**(3), 233–240, doi:10.1111/conl.12060.

Huynh, L.T.M. and L.C. Stringer, 2018: Multi-scale assessment of social vulnerability to climate change: An empirical study in coastal Vietnam. *Clim. Risk Manag.*, **20**, 165–180, doi:10.1016/j.crm.2018.02.003.

Ibarbalz, F.M., et al., 2019: Global Trends in Marine Plankton Diversity across Kingdoms of Life. *Cell*, **179**(5), 1084, doi:10.1016/j.cell.2019.10.008.

Ichii, T., et al., 2017: Impacts of extensive driftnet fishery and late 1990s climate regime shift on dominant epipelagic nekton in the Transition Region and Subtropical Frontal Zone: Implications for fishery management. *Prog. Oceanogr.*, **150**, 35–47, doi:10.1016/j.pocean.2015.03.007.

22, 09 and 2020 (eds.), 2011: *Glacial Lakes and Glacial Lake Outburst Floods in Nepal*. International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal. 99 pp.

ICLEI, 2014a: *Urban NEXUS Case Study 2014 - 02*. *Nashik, India*., http://old.iclei.org/fileadmin/PUBLICATIONS/Case_Studies/Urban_NEXUS_cs02_Nashik_ICLEI-GIZ_2014.pdf. accessed on October 1, 2021.

ICLEI, 2014b: *Urban NEXUS Case Study 2014 - 05*. Tianjin Eco-City, China, http://old.iclei.org/fileadmin/PUBLICATIONS/Case_Studies/Urban_NEXUS_cs05_Tianjin_ICLEI-GIZ_2014.pdf. accessed on October 1, 2021.

Ide, T., A. Kristensen and H. Bartusevičius, 2021: First comes the river, then comes the conflict? A qualitative comparative analysis of flood-related political unrest. *J. Peace Res.*, **58**(1), 83–97, doi:10.1177/0022343320966783.

IDMC, 2019: *GRID Report*.

IDMC, 2020: *Global Report on Internal Displacement 2020*. IDMC, https://www.internal-displacement.org/global-report/grid2020/. accessed on October 1, 2021.

IEA, 2017: *Southeast Asia Energy Outlook 2017*. World Energy Outlook Special Report. https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_SoutheastAsiaEnergyOutlook.pdf. accessed on October 1, 2021.

IEA, 2018: *World Energy Outlook 2018 Paris*.

IEEJ, 2018: *IEEJ Outlook 2019: Energy transition and a thorny path for 3E challenges*.

IFAD, 2017: *Remote sensing for index insurance: Findings and lessons learned for smallholder agriculture*, 174.

IGES (ed.), 2019: *1.5 Degree Lifestyles: Targets and options for reducing lifestyle carbon footprints*. ISBN 978-4887882201.

Iizuka, K., et al., 2017: Modeling Future Urban Sprawl and Landscape Change in the Laguna de Bay Area, Philippines. *Land*, **6**(2), doi:10.3390/land6020026.

Iizumi, T., 2019: Emerging Adaptation to Climate Change in Agriculture. In: *Adaptation to Climate Change in Agriculture: Research and Practices* [Iizumi, T., R. Hirata and R. Matsuda(eds.)]. Springer, Singapore, pp. 3–16. ISBN 978-9811392351.

Iizumi, T. and N. Ramankutty, 2015: How do weather and climate influence cropping area and intensity? *Glob. Food Sec.*, **4**, 46–50, doi:10.1016/j.gfs.2014.11.003.

ILO, 2015: *Value chain analysis and competitiveness strategy: Marine capture fisheries*. International Labour Organization, Myeik and Yangon, https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_446510.pdf. accessed on October 1, 2021.

ILO, 2017a: *World of work report 2014: Developing with jobs*. International Labour Organization, Geneva, https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms_243961.pdf. accessed on October 1, 2021.

ILO, 2017b: *World Social Protection Report 2017-19: Universal social protection to achieve the Sustainable Development Goals*. International Labour Office, Geneva.

Im, E.-S., J.S. Pal and E.A. Eltahir, 2017: Deadly heat waves projected in the densely populated agricultural regions of South Asia. *Sci. Adv.*, **3**(8), e1603322.

Imada, Y., et al., 2018: Climate Change Increased the Likelihood of the 2016 Heat Extremes in Asia. *Bull. Am. Meteorol. Soc.*, **99**(1), S97–S101, doi:10.1175/bams-d-17-0109.1.

Imada, Y., et al., 2019: The July 2018 high temperature event in Japan could not have happened without human-induced global warming. *SOLA*, **15A**. https://doi.org/10.2151/sola.15A-002.

Imaduddina, A.H. and W.W.H. Subagyo, 2014: Sea Level Rise Flood Zones: Mitigating Floods in Surabaya Coastal Area. *Proc. Soc. Behav. Sci.*, **135**, 123–129, doi:10.1016/j.sbspro.2014.07.335.

Imai, K.S. and B. Malaeb, 2018: *Asia's rural-urban disparity in the context of growing inequality*. IFAD Research Series. 30 pp.

IMF, 2018: *IMF Annual Report 2018*.

Immerzeel, W.W., et al., 2020: Importance and vulnerability of the world's water towers. *Nature*, doi:10.1038/s41586-019-1822-y.

Inaoka, M., K. Takeya and S. Akiyama, 2019: JICA's policies, experiences and lessons learned on impacts of urban floods in Asia. *Int. J. Water Resour. Dev.*, **35**(2), 343–363, doi:10.1080/07900627.2018.1444980.

Inaotombi, S. and P.C. Mahanta, 2018: Pathways of socio-ecological resilience to climate change for fisheries through indigenous knowledge. *Hum. Ecol. Risk Assess. Int. J.*, 1–13, doi:10.1080/10807039.2018.1482197.

Ingole, V., J. Rocklov, S. Juvekar and B. Schumann, 2015: Impact of Heat and Cold on Total and Cause-Specific Mortality in Vadu HDSS--A Rural Setting in Western India. *Int J Environ Res Public Health*, **12**(12), 15298–15308, doi:10.3390/ijerph121214980.

IPBES, 2018: *The IPBES regional assessment report on biodiversity and ecosystem services for Asia and the Pacific*.

IPCC, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Parry, M. L. Cambridge University Press, Cambridge, UK, ISBN 978-0521880107. 976 pp.

IPCC, 2014a: *Climate change 2014: Impacts, adaptation, and vulnerability*. IPCC, Geneva.

IPCC, 2014b: Climate Change 2014: *Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 1132 pp.

IPCC, 2014c: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects* Barros, V. R., C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White. Cambridge University Press, Cambridge, UK and New York, NY. 688 pp.

IPCC, 2018a: Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. (In Press).

IPCC, 2018b: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* V. Masson-Delmotte, P. Z., H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield.

IPCC, 2021: *Climate Change 2021: The Physical Science Basis* Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Iqbal, M.W., S. Donjadee, B. Kwanyuen and S. Liu, 2018: Farmers' perceptions of and adaptations to drought in Herat Province, Afghanistan. *J. Mt. Sci.*, **15**(8), 1741–1756, doi:10.1007/s11629-017-4750-z.

Isaev, A.S. and G.N. Korovin, 2013: Forests as a national treasure of Russia. *Contemp. Probl. Ecol.*, **6**(7), 677–682, doi:10.1134/S1995425513070056.

Iseman, T. and F. Miralles-Wilhelm, 2021: *Nature-based solutions in agriculture – The case and pathway for adoption. FAO and The Nature Conservancy, Virginia*. http://www.fao.org/3/cb3141en/cb3141en.pdf.

Ishigooka, Y., et al., 2017: Large-scale evaluation of the effects of adaptation to climate change by shifting transplanting date on rice production and quality in Japan. *Journal of Agricultural Meteorology*, **73**(4), 156–173, doi:10.2480/agrmet.D-16-00024.

Ishiwatari, M. and A. Surjan, 2020: Good Enough Today is Not Enough Tomorrow: Challenges of Increasing Investments in Disaster Risk Reduction and Climate Change Adaptation. *Prog. Dis. Sci. DOI:10.1016/j.pdisas.2019.100007*

Isik, O., et al., 2015: Are women in Turkey both risks and resources in disaster management? *Int. J. Environ. Res. Public Health*, **12**(6), 5758–5774, doi:10.3390/ijerph120605758.

Islam, A., S. Islam and A. Wahab, 2016a: Impacts of climate change on shrimp farming in the South-West coastal region of Bangladesh. *Res. Agric. Likestock Fish.*, **3**(1), 227–239.

Islam, A.R.M.T., S.-H. Shen and S.-B. Yang, 2018: Predicting design water requirement of winter paddy under climate change condition using frequency analysis in Bangladesh. *Agric. Water Manag.*, **195**, 58–70, doi:10.1016/j.agwat.2017.10.003.

Islam, M.R., V. Ingham, J. Hicks and I. Manock, 2016b: The changing role of women in resilience, recovery and economic development at the intersection of recurrent disaster: A case study from Sirajgang, Bangladesh. *J. Asian Afr. Stud.*, **52**(1), 50–67, doi:10.1177/0021909614560244.

Islam, M.S. and Y. Zhang, 2019: The Potential of Strategic Environmental Assessment to Reduce Disaster Risks Through Climate Change Adaptation in the Coastal Zone of Bangladesh. *Int. J. Clim. Chang. Strateg. Manag.*, **11**(1), 137–153.

Islam, S., C. Chu and J. Smart, 2020: Challenges in integrating disaster risk reduction and climate change adaptation: exploring the Bangladesh case. *Int. J. Dis. Risk Reduct.* DOI:10.1016/j.ijdrr.2020.101540.

Ito, A., K. Nishina and H.M. Noda, 2016: Evaluation of global warming impacts on the carbon budget of terrestrial ecosystems in monsoon Asia: a multi-model analysis. *Ecol. Res.*, **31**(3), 459–474, doi:10.1007/s11284-016-1354-y.

Iturrizaga, L., 2019: Historical beacon fire lines as early warning systems for glacier lake outbursts in the Hindu Kush–Karakoram Mountains. *Nat. Hazards*, **99**(1), 39–70.

IUC, *FutureCity Yokohama - Yokohama Smart City Project*. http://www.iuc.eu/japan-en/bestpractice/yokohama/. accessed on October 1, 2021.

Ivanova, G.A., V.A. Ivanov, E.A. Kukavskaya and A.J. Soja, 2010: The frequency of forest fires in Scots pine stands of Tuva, Russia. *Environ. Res. Lett.*, **5**(1), doi:10.1088/1748-9326/5/1/015002.

Izumi, T., et al., 2019: Disaster Risk Reduction and Innovations. *Prog. Dis. Sci.*, **2**.

Jacobson, C., S. Crevello, C. Chea and B. Jarihani, 2019: When is migration a maladaptive response to climate change? *Reg. Environ. Change*, **19**(1), 101–112, doi:10.1007/s10113-018-1387-6.

Jafari, A., A. Torabi and S. Sohrabi, 2016: The study of temperature increases effects due to global climate change on the Mean Sea Level (MSL) in the north coasts of Persian Gulf (Hormozgan province). *J. Environ. Sci. Technol.*, **18**(3), 81–97.

Jain, G., 2013: *The Role of Private Sector for Disaster Risk Reduction in Large Scale Infrastructure and Real Estate Development - The Case of Delhi*. Indian Institute for Human Settlements, Bangalore.

Jain, G., C. Singh and T. Malladi, 2021: (Re)creating disasters – A case of post-disaster resettlements in Chennai. In: *Rethinking Urban Risk and Relocation* [Johnson, C., G. Jain and A. Lavell(eds.)]. UCL Press, London (forthcoming).

Jamero, M.L., et al., 2017: Small-Island Communities in the Philippines Prefer Local Measures to Relocation in Response to Sea-Level Rise. *Nat. Clim. Change*, **7**, 581–586.

James, H., 2019: *Women, Water and 'Wicked Problems': Community Resilience and Adaptation to Climate Change in Northern Pakkoku, Myanmar.*

10

Population, Development, and the Environment. Palgrave Macmillan, Singapore.

Jamodiong, E.A., et al., 2018: Coral spawning and spawn-slick observation in the Philippines. *Mar. Biodivers.*, **48**(4), 2187–2192, doi:10.1007/s12526-017-0680-9.

Jamshidi, O., et al., 2019: Vulnerability to climate change of smallholder farmers in the Hamadan province, Iran. *Clim. Risk Manag.*, **23**, 146–159, doi:10.1016/j.crm.2018.06.002.

Jat, M.L., et al., 2016: Chapter Three - Climate Change and Agriculture: Adaptation Strategies and Mitigation Opportunities for Food Security in South Asia and Latin America. In: *Advances in Agronomy* [Sparks, D.L.(ed.)]. Vol 137, pp. 127–235. ISBN 00652113.

Jawid, A. and M. Khadjavi, 2019: Adaptation to climate change in Afghanistan: Evidence on the impact of external interventions. *Econ. Anal. Policy.*, **64**, 64–82, doi:10.1016/j.eap.2019.07.010.

Jayanthi, M., et al., 2018: Spatial and temporal changes in mangrove cover across the protected and unprotected forests of India. *Estuar. Coast. Shelf Sci.*, **213**, 81–91, doi:10.1016/j.ecss.2018.08.016.

Jenny, J.-P., et al., 2020: Scientists' warning to humanity: rapid degradation of the world's large lakes. *J. Gt. Lakes Res.*, **46**(4), 686–702.

Jenssen, B.M., et al., 2015: Anthropogenic flank attack on polar bears: interacting consequences of climate warming and pollutant exposure. *Front. Ecol. Evol.*, **3**(16), doi:10.3389/fevo.2015.00016.

Jevrejeva, S., et al., 2018: Flood damage costs under the sea level rise with warming of 1.5°C and 2°C. *Environ. Res. Lett.*, **17**(7), doi:10.1088/1748-9326/aacc76.

Jevrejeva, S., et al., 2016: Coastal sea level rise with warming above 2°C. *Proc. Natl. Acad. Sci.*, **113**(47), 13342–13347, doi:10.1073/pnas.1605312113.

Jeyabaskaran, R., et al., 2018: Conservation of seagrass beds with special reference to associated species and fishery resources. *J. Mar. Biol. Assoc. India*, 62–70. DOI:10.6024/jmbai.2018.60.1.2038-10.

Jha, C.K., V. Gupta, U. Chattopadhyay and B.A. Sreeraman, 2018: Migration as adaptation strategy to cope with climate change. *Int. J. Clim. Chang. Strateg. Manag.* https://doi.org/10.1108/IJCCSM-03-2017-0059.

Jha, R.K. and H. Gundimeda, 2019: An integrated assessment of vulnerability to floods using composite index – A district level analysis for Bihar, India. *Int. J. Disaster Risk Reduct.*, **35**, doi:10.1016/j.ijdrr.2019.101074.

Jia, G., E. Shevliakova, P. Artaxo, N. De Noblet-Ducoudré, R. Houghton, J. House, K. Kitajima, C. Lennard, A. Popp, A. Sirin, R. Sukumar, L. Verchot, 2019: Land–climate interactions. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press. https://www.ipcc.ch/site/assets/uploads/2019/08/2c.-Chapter-2_FINAL.pdf. Accessed 2019-08-16.

Jiang, L., et al., 2019: Assessment of frozen ground organic carbon pool on the Qinghai-Tibet Plateau. *J Soils Sediments*, **19**(1), 128–139, doi:10.1007/s11368-018-2006-3.

Jiang, T-t., et al., 2015: Current status of coastal wetlands in China: degradation, restoration, and future management. *Estuar. Coast. Shelf Sci.*, **164**, 265–275.

Jiang, X., et al., 2016: Estimation of property loss and business interruption loss caused by storm surge inundation due to climate change: a case of Typhoon Vera revisit. *Nat. Hazards*, **84**(1), 35–49.

Jiang, Y., Y. Luo and Z. Zhao, 2013: Maximum wind speed changes over China. *Acta Meteorol. Sinica*, **27**(1), 63–74, doi:10.1007/s13351-013-0107-x.

Jiang, Y., C. Zevenbergen and Y. Ma, 2018: Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy. *Environ. Sci. Policy*, **80**, 132–143, doi:10.1016/j.envsci.2017.11.016.

Jianjun, J., G. Yiwei, W. Xiaomin and P.K. Nam, 2015: Farmers' risk preferences and their climate change adaptation strategies in the Yongqiao District, China. *Land Use Policy*, **47**, 365–372, doi:10.1016/j.landusepol.2015.04.028.

Jiao, F., X.R. Shi, F.P. Han and Z.Y. Yuan, 2016: Increasing aridity, temperature and soil pH induce soil C-N-P imbalance in grasslands. *Sci.. Rep*, **6**, doi:10.1038/Srep19601.

JMA, 2018: *Climate Change Monitoring Report*. Japan Meteorological Agency, Tokyo, Japan.

Jogesh, A. and N.K. Dubash, 2015: State-led experimentation or centrally-motivated replication? A study of state action plans on climate change in India. *J. Integr. Environ. Sci.*, **12**(4), 247–266, doi:10.1080/1943815x.2015.1077869.

Johnson, B.A. and K. Iizuka, 2016: Integrating OpenStreetMap crowdsourced data and Landsat time-series imagery for rapid land use/land cover (LULC) mapping: Case study of the Laguna de Bay area of the Philippines. *Appl. Geogr.*, **67**, 140–149, doi:10.1016/j.apgeog.2015.12.006.

Johnson, B.A., A.D. Mader, R. Dasgupta and P. Kumar, 2020: Citizen science and invasive alien species: An analysis of citizen science initiatives using information and communications technology (ICT) to collect invasive alien species observations. *Glob. Ecol. Conserv.*, **21**, doi:10.1016/j.gecco.2019.e00812.

Johnson, C., et al., 2013: *Understanding the nature and scale of urban risk in low- and middle- income countries and its implications for humanitarian preparedness, planning and response*. ISBN 978-1843699156.

Jones, N., R. Holmes, E. Presler-Marshall and M. Stavropoulou, 2017: Transforming gender constraints in the agricultural sector: The potential of social protection programmes. *Glob. Food Sec.*, **12**, 89–95, doi:10.1016/j.gfs.2016.09.004.

Jordan, K., *Hashemite Kingdom of Jordan Intended Nationally Determined Contribution (INDC)*. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Jordan%20First/Jordan%20INDCs%20Final.pdf. (Arabic & English). accessed on October 1, 2021.

Jörgensen, K., A. Jogesh and A. Mishra, 2015: Multi-level climate governance and the role of the subnational level. *J. Integr. Environ. Sci.*, **12**(4), 235–245, doi:10.1080/1943815x.2015.1096797.

Joshi, N., et al., 2016: A Review of the Application of Optical and Radar Remote Sensing Data Fusion to Land Use Mapping and Monitoring. *Remote Sens.*, **8**(1), doi:10.3390/rs8010070.

Joshi, S., 2014: Environmental justice discourses in Indian climate politics. *GeoJournal*, doi:10.1007/s10708-014-9545-y.

Ju, H., et al., 2013: Climate Change Modelling and Its Roles to Chinese Crops Yield. *J. Integr. Agric.*, **12**(5), 892–902, doi:10.1016/S2095-3119(13)60307-X.

Jung, M.-P., K.-M. Shim, Y. Kim and I.-T. Choi, 2015: Change of Climatic Growing Season in Korea. *Korean J. Environ. Agric.*, **34**(3), 192–195.

Juswanto, W. and S.A. Nugroho, 2017: *Promoting Disaster Risk Financing in Asia and the Pacific*.

Kääb, A., et al., 2018: Massive collapse of two glaciers in western Tibet in 2016 after surge-like instability. *Nat Geosci*, **11**(2), 114, doi:10.1038/s41561-017-0039-7.

Kaczan, D.J. and J. Orgill-Meyer, 2020: The impact of climate change on migration: a synthesis of recent empirical insights. *Clim. Change*, **158**(3), 281–300.

Kafash, A., et al., 2016: Ensemble distribution modeling of the Mesopotamian spiny-tailed lizard, Saara loricata (Blanford, 1874), in Iran: an insight into the impact of climate change. *Turk J Zool*, **40**(2), 262–271, doi:10.3906/zoo-1504-10.

Kais, S.M. and M.S. Islam, 2018: Impacts of and resilience to climate change at the bottom of the shrimp commodity chain in Bangladesh: A preliminary investigation. *Aquaculture*, **493**, 406–415, doi:10.1016/j.aquaculture.2017.05.024.

Kameyama, Y., K. Morita and I. Kubota, 2016: Finance for achieving low-carbon development in Asia: the past, present, and prospects for the future. *J. Clean. Prod.*, **128**, 201–208.

Kanak Pervez, A., Q. Gao and M. E. Uddin, 2015: Rural women's awareness on indigenous technical knowledge: case of northern Bangladesh. *Anthropologist*, **21**(3), 415–426.

Kanamori, Y., A. Takasuka, S. Nishijima and H. Okamura, 2019: Climate change shifts the spawning ground northward and extends the spawning period of chub mackerel in the western North Pacific. *Mar. Ecol. Prog. Ser.*, **624**, doi:10.3354/meps13037.

Kang, S. and E.A.B. Eltahir, 2018: North China Plain threatened by deadly heatwaves due to climate change and irrigation. *Nat. Commun.*, **9**(1), 1–9.

Karanth, A. and D. Archer, 2014: Institutionalising mechanisms for building urban climate resilience: experiences from India. *Dev. Pract.*, **24**(4), 514–526, doi:10.1080/09614524.2014.911246.

Karthe, D., et al., 2017: *Water in Central Asia: an integrated assessment for science-based management*. Springer, Berlin Heidelberg.

Brickell, K., et al., 2020: Compounding crises of social reproduction: Microfinance, over-indebtedness and the COVID-19 pandemic. *World Dev*, **136**, doi:10.1016/j.worlddev.2020.105087.

Kato, A., et al. (ed.), *Tropical forest disaster monitoring with multi-scale sensors from terrestrial laser, UAV, to satellite radar*. 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 23-28 July 2017, 2883–2886. ISBN 21537003.

Kattsov, V.M. and S.M. Semenov, 2014: *Second Roshydromet assessment report on climate change and its consequences in Russian Federation* General Summary. Federal Service for Hydrometeorology and Environmental Monitoring of Russia (Roshydromet), Moscow, Russia.

Kelley, C.P., et al., 2015: Climate change in the Fertile Crescent and implications of the recent Syrian drought. *Proc. Natl. Acad. Sci.*, **112**(11), 3241, doi:10.1073/pnas.1421533112.

Keshavarz, M. and E. Karami, 2016: Farmers' pro-environmental behavior under drought: Application of protection motivation theory. *J. Arid Environ.*, **127**, 128–136, doi:10.1016/j.jaridenv.2015.11.010.

Khaling, S., et al., 2018: Progress on integrating climate change adaptation and disaster risk reduction for sustainable development pathways in South Asia: Evidence from six research projects. *Int. J. Disaster Risk Reduct.*, **31**, 92–101, doi:10.1016/j.ijdrr.2018.04.023.

Khan, A.M., et al., 2020: Economic Effects of Climate Change-Induced Loss of Agricultural Production by 2050: A Case Study of Pakistan. *Sustainability*, **12**(3), doi:10.3390/su12031216.

Khan, M.R., 2017: Capacity building for climate change: lessons from other regimes. AdaptationWatch Brief. AdaptationWatch.

Khanal, S., et al., 2021: Variable 21st century climate change response for rivers in High Mountain Asia at seasonal to decadal time scales. *Water Resour. Res.* https://doi.org/10.1029/2020WR029266.

Khanal, U. and C. Wilson, 2019: Derivation of a climate change adaptation index and assessing determinants and barriers to adaptation among farming households in Nepal. *Environ. Sci. Policy*, **101**, 156–165, doi:10.1016/j.envsci.2019.08.006.

Khanal, U., C. Wilson, V.-N. Hoang and B. Lee, 2018: Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. *Ecol. Econ.*, **144**, 139–147.

Khanna, A., 2020: Impact of Migration of Labour Force due to Global COVID-19 Pandemic with Reference to India. *J. Health. Manag.*, **22**(2), 181–191, doi:10.1177/0972063420935542.

Khansaritoreh, E., et al., 2017: Higher climate warming sensitivity of Siberian larch in small than large forest islands in the fragmented Mongolian forest steppe. *Glob. Change Biol.*, **23**(9), 3675–3689, doi:10.1111/gcb.13750.

Kharuk, V.I., et al., 2017a: Tree wave migration across an elevation gradient in the Altai Mountains, Siberia. *J. Mt. Sci.*, **14**(3), 442–452, doi:10.1007/s11629-016-4286-7.

Kharuk, V.I., S.T. Im, K.J. Ranson and M.N. Yagunov, 2017b: Climate-Induced Northerly Expansion of Siberian Silkmoth Range. *Forests*, **8**(8), doi:10.3390/f8080301.

Kharuk, V.I., S.T. Im and V.V. Soldatov, 2020: Siberian silkmoth outbreaks surpassed geoclimatic barrier in Siberian Mountains. *J. Mt. Sci.*, **17**(8), 1891–1900, doi:10.1007/s11629-020-5989-3.

Kharuk, V.I., et al., 2018: Comparative Reaction of Larch (*Larix sibirica Ledeb.*) Radial Increment on Climate Change in the Forest Steppe and Highlands of Southern Siberia. *Contemp. Probl. Ecol.*, **11**(4), 388–395, doi:10.1134/S1995425518040042.

Kharuk, V.I. and E.I. Ponomarev, 2017: Spatiotemporal characteristics of wildfire frequency and relative area burned in larch-dominated forests of Central Siberia. *Russ. J. Ecol.*, **48**(6), 507–512, doi:10.1134/s1067413617060042.

Khatri-Chhetri, A., P.K. Aggarwal, P.K. Joshi and S. Vyas, 2017: Farmers' prioritization of climate-smart agriculture (CSA) technologies. *Agric. Syst.*, **151**, 184–191, doi:10.1016/j.agsy.2016.10.005.

Khishigjargal, M., et al., 2013: Contrasting responses of seedling and sapling densities to livestock density in the Mongolian forest-steppe. *Plant Ecol.*, **214**(11), 1391–1403, doi:10.1007/s11258-013-0259-x.

Khormi, H. and L. Kumar, 2016: Future malaria spatial pattern based on the potential global warming impact in South and Southeast Asia. *Geospat. Health*, **11**(3), 416, doi:10.4081/gh.2016.416.

Khosla, R. and A. Bhardwaj, 2019: Urbanization in the time of climate change: Examining the response of Indian cities. *Wiley. Interdiscip. Rev. Clim. Change.*, **10**(e560), doi:10.1002/wcc.560.

Kicklighter, D.W., et al., 2014: Potential influence of climate-induced vegetation shifts on future land use and associated land carbon fluxes in Northern Eurasia. *Environ. Res. Lett.*, **9**(3), doi:10.1088/1748-9326/9/3/035004.

Kilroy, G., 2015: A review of the biophysical impacts of climate change in three hotspot regions in Africa and Asia. *Reg. Environ. Change*, **15**(5), 771–782, doi:10.1007/s10113-014-0709-6.

Kim, B.-T., C.L. Brown and D.-H. Kim, 2019a: Assessment on the vulnerability of Korean aquaculture to climate change. *Mar. Policy.*, **99**, 111–122, doi:10.1016/j.marpol.2018.10.009.

Kim, D.-W., R.C. Deo, J.-H. Chung and J.-S. Lee, 2016a: Projection of heat wave mortality related to climate change in Korea. *Nat. Hazards*, **80**(1), 623–637.

Kim, D., et al., 2019b: Comparing effects of untreated and treated wastewater on riverine greenhouse gas emissions. *APN Sci. Bull.*, doi:10.30852/sb.2019.872.

Kim, D. and J. Lee, 2020: Spatial changes in work capacity for occupations vulnerable to heat stress: Potential regional impacts from global climate change. *Saf. Health. Work.*, **11**(1), 1–9, doi:10.1016/j.shaw.2019.10.004.

Kim, E.-S., J.-S. Lee, G.-E. Park and J.-H. Lim, 2019c: Change of Subalpine Coniferous Forest Area over the Last 20 Years. *J. Korean Soc. For. Sci.*, **108**(1), 10–20, doi:10.14578/JKFS.2019.108.1.10.

Kim, E.J. and H. Kim, 2017: Effect modification of individual- and regional-scale characteristics on heat wave-related mortality rates between 2009 and 2012 in Seoul, South Korea. *Sci. Total Environ.*, **595**, 141–148, doi:10.1016/j.scitotenv.2017.03.248.

Kim, J.-Y. and I.-S. Han, 2017: Sea Surface Temperature Time Lag Due to the Extreme Heat Wave of August 2016. *J. Korean Soc. Mar. Environ. Saf.*, **23(6)**, 6677–683.

Kim, J., S. Jeong and S. Son, 2019d: *A National-level Study on Plant Phenology across Forest Region of South Korea during the last decade* December 01, 2019. B33K–2628.

Kim, J., H. Jung and Y.H. Park, 2016b: Predicting Potential Distribution of Monochamus alternatus Hope responding to Climate Change in Korea. *Korean J. Appl. Entomol.*, 501–511, doi:10.5656/KSAE.2016.11.0.053.

Kim, K.-G., 2017: Development of an integrated smart water grid model as a portfolio of climate smart cities. *J. Smart Cities*, **3**, 23–34.

Kim, S.E., et al., 2020: Air quality co-benefits from climate mitigation for human health in South Korea. *Environ. Int.*, **136**, 105507, doi:10.1016/j.envint.2020.105507.

Kim, Y., et al., 2016c: Suicide and Ambient Temperature in East Asian Countries: A Time-Stratified Case-Crossover Analysis. *Environ. Health Perspect.*, **124**(1), 75–80, doi:10.1289/ehp.1409392.

Kimura, F. and H. Phoumin, 2013: *Energy Market Integration in EAST Asia: Energy Trade, Cross Border Electricity, and Price Mechanism*.

Kirby, J., et al., 2016: The impact of climate change on regional water balances in Bangladesh. *Clim. Change*, **135**(3-4), 481–491.

Kirdyanov, A.V., et al., 2012: 20th century tree-line advance and vegetation changes along an altitudinal transect in the Putorana Mountains, northern Siberia. *Boreas*, **41**(1), 56–67, doi:10.1111/j.1502-3885.2011.00214.x.

Kiseleva, N.V., 2020: Long-term Population Dynamics of the Bank Vole in the Ilmen Nature Reserve. *Russ. J. Ecol.*, **51**(2), 188–194, doi:10.1134/S1067413620020071.

Kissinger, G., A. Gupta, I. Mulder and N. Unterstell, 2019: Climate financing needs in the land sector under the Paris Agreement: An assessment of developing country perspectives. *Land Use Policy*, **83**, 256–269.

Kitamura, Y., 2017: *Education for Sustainable Development (ESD) in Asia*.

Kittipongvises, S. and T. Mino, 2015: *Perception and Communication of Flood Risk: Lessons Learned about Thailand's Flood Crisis of 2011. 37(1)*. https://www.tci-thaijo.org/index.php/aer/article/view/30895. accessed on October 1, 2021.

Klinge, M., et al., 2018: Climate effects on vegetation vitality at the treeline of boreal forests of Mongolia. *Biogeosciences*, **15**(5), 1319–1333, doi:10.5194/bg-15-1319-2018.

Klinsky, S., et al., 2017: Why equity is fundamental in climate change policy research. *Glob. Environ. Chang.*, **44**, 170–173, doi:10.1016/j.gloenvcha.2016.08.002.

Klonner, S., C. Oldiges, 2014: *Safety Net for India's Poor or Waste of Public Funds? Poverty and Welfare in the Wake of the World's Largest Job Guarantee Program*. doi:10.11588/heidok.00016875.

Klorvuttimontara, S., C. Tumpeesuwan and S. Tumpeesuwan, 2017: Distribution range and extinction risk of tree snail subgenus Amphidromus (Pulmonata: Camaenidae) in Thailand. *Raffles B Zool.*, **65**, 189–197.

Knowlton, K., et al., 2014: Development and implementation of South Asia's first heat-health action plan in Ahmedabad (Gujarat, India). *Int. J. Environ. Res. Public Health*, **11**(4), 3473–3492, doi:10.3390/ijerph110403473.

Knutson, T.R., et al., 2015: Global projections of intense tropical cyclone activity for the late twenty-first century from dynamical downscaling of CMIP5/RCP4.5 scenarios. *J. Clim.*, **28**(18), 7203–7224, doi:10.1175/jcli-d-15-0129.1.

Ko, C.-H., et al., 2017: Carbon sequestration potential via energy harvesting from agricultural biomass residues in Mekong River basin, Southeast Asia. *Renew. Sustain. Energy Rev.*, **68**, 1051–1062, doi:10.1016/j.rser.2016.03.040.

Kobayashi, S., et al., 2015: The JRA-55 Reanalysis: General Specifications and Basic Characteristics. *J. Meteorol. Soc. Japan. Ser. Ii*, **93**(1), 5–48, doi:10.2151/jmsj.2015-001.

Kobori, H., et al., 2012: The effects of climate change on the phenology of winter birds in Yokohama, Japan. *Ecol. Res.*, **27**(1), 173–180, doi:10.1007/s11284-011-0891-7.

Kodera, S., et al., 2019: Estimation of heat-related morbidity from weather data: A computational study in three prefectures of Japan over 2013–2018. *Environ. Int.*, **130**, doi:10.1016/j.envint.2019.104907.

Kodikara, K.A.S., et al., 2017: Have mangrove restoration projects worked? An in-depth study in Sri Lanka. *Restor. Ecol.*, **25**(5), 705–716, doi:10.1111/rec.12492.

Koehler, G., 2014: Introduction: Preliminary Reflections on Development and Welfare Policy. In: *Development and Welfare Policy in South Asia*. Routledge, Abingdon.

Koh, H.L. and S.Y. Teh, 2019: Climate Change Mitigation and Adaptation: Role of Mangroves in Southeast Asia. In: *Climate Action* [Filho, L., A.M. Azul, L. Brandli, P.G. Özuyar and T. Wall(eds.)]. Springer, Cham, pp. 1–13. ISBN 978-3319710631.

Kohler, T. and D. Maselli, 2009: *Mountains and climate change. From understanding to action*. Geographica Bernensia, Bern, ISBN 978-3905835168.

Koks, E.E., et al., 2019: A global multi-hazard risk analysis of road and railway infrastructure assets. *Nat. Commun.*, **10**(1), 1–11.

Kongsager, R., B. Locatelli and F. Chazarin, 2016: Addressing climate change mitigation and adaptation together: A global assessment of agriculture and forestry projects. *Environ. Manage.*, **57**(2), 271–282.

Koo, K. A., et al., 2018: Future distributions of warm-adapted evergreen trees, Neolitsea sericea and *Camellia japonica* under climate change: ensemble forecasts and predictive uncertainty. *Ecol. Res.*, **33**(2), 313–325, doi:10.1007/s11284-017-1535-3.

Korznikov, K. A., D.E. Kislov and P.V. Krestov, 2019: Modeling the bioclimatic range of tall herb communities in northeastern Asia. *Russ. J. Ecol.*, **50**(3), 241–248, doi:10.1134/s1067413619030093.

Kosec, K. and C.H. Mo, 2017: Aspirations and the role of social protection: Evidence from a natural disaster in rural Pakistan. *World Dev.*, **97**, 49–66, doi:10.1016/j.worlddev.2017.03.039.

Kothari, J., 2014: A Social Rights Model for Social Security: Learnings from India. *Verfass. Recht Übersee Law Polit. Afr. Asia Lat. Am.*, **47**(1), 5–21.

Kotharkar, R., A. Ramesh and A. Bagade, 2018: Urban Heat Island studies in South Asia: A critical review. *Urban Clim.*, **24**, 1011–1026, doi:10.1016/j.uclim.2017.12.006.

Kottawa-Arachchi, J. and M. Wijeratne, 2017: Climate climate change impacts on biodiversity and ecosystems in Sri Lanka: A REVIEW. *Nat. Conserv. Res.*, **2**, 2–22, doi:10.24189/ncr.2017.042.

Kousky, C., 2014: Informing climate adaptation: A review of the economic costs of natural disasters. *Energy Econ.*, **46**, 576–592.

Kraaijenbrink, P., M. Bierkens, A. Lutz and W. Immerzeel, 2017: Impact of a global temperature rise of 1.5 degrees Celsius on Asia's glaciers. *Nature*, **549**(7671), 257.

Kripa, V., et al., 2018: Overfishing and Climate Drives Changes in Biology and Recruitment of the Indian Oil Sardine Sardinella longiceps in Southeastern Arabian Sea. *Front. Mar. Sci.*, **5**, doi:10.3389/fmars.2018.00443.

Krishnan, R., et al., 2019: Unravelling Climate Change in the Hindu Kush Himalaya: Rapid Warming in the Mountains and Increasing Extremes. In: *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* [Wester, P., A. Mishra, A. Mukherji and A.B. Shrestha(eds.)]. Springer, Cham, pp. 57–97. ISBN 978-3319922881.

Kubicek, A., B. Breckling, O. Hoegh-Guldberg and H. Reuter, 2019: Climate change drives trait-shifts in coral reef communities. *Sci. Rep.*, **9**, 10, doi:10.1038/s41598-019-38962-4.

Kuemmerlen, M., et al., 2015: An attack on two fronts: predicting how changes in land use and climate affect the distribution of stream macroinvertebrates. *Freshw. Biol.*, **60**(7), 1443–1458, doi:10.1111/fwb.12580.

Kuenzer, C. and V.Q. Tuan, 2013: Assessing the ecosystem services value of Can Gio Mangrove Biosphere Reserve: Combining earth-observation- and household-survey-based analyses. *Appl. Geogr.*, 167–184. DOI:10.1016/j.apgeog.2013.08.012.

Kugler, N.R. and P.M. Sariego, 2016: "Climate change damages", conceptualization of a legal notion with regard to reparation under international law. *Clim. Risk Manag.*, **13**, 103–111.

Kuhl, L., et al., 2021: Transformational Adaptation in the Context of Coastal Cities. *Annu. Rev. Environ. Resour.*, **46**, 449-479. https://doi.org/10.1146/annurev-environ-012420-045211.

Kulmala, M., et al., 2015: Introduction: The Pan-Eurasian Experiment (PEEX) – multidisciplinary, multiscale and multicomponent research and capacity-building initiative. *Atmos. Chem. Phys.*, **15**(22), 13085–13096, doi:10.5194/acp-15-13085-2015.

Kulp, S.A. and B.H. Strauss, 2019: New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nat. Commun.*, **10**(1), 1–12.

Kumar, P., 2019: Numerical quantification of current status quo and future prediction of water quality in eight Asian megacities: challenges and opportunities for sustainable water management. *Environ. Monit. Assess.*, **191**(6), 319, doi:10.1007/s10661-019-7497-x.

Kumar, P., et al., 2020: Participatory Approach for More Robust Water Resource Management: Case Study of the Santa Rosa Sub-Watershed of the Philippines. *Water*, **12**(4), doi:10.3390/w12041172.

Rigaud, K., et al., 2018: *Groundswell: Preparing for Internal Climate Migration*. The World Bank, Washington DC.

Jung, K., et al., 2017: The influence of climate regime shifts on the marine environment and ecosystems in the East Asian Marginal Seas and their mechanisms. *Deep. Sea Res. Part Ii: Top. Stud. Oceanogr.*, **143**, 110–120, doi:10.1016/j.dsr2.2017.06.010.

Kuriakose, A.T., et al., 2013: Climate-responsive social protection. *Dev Policy Rev*, **31**, o19–o34.

Kuwait, G. o, 2015: *Kuwait's Intended Nationally Determined Contribution (INDC)*.

Kwan, S.C., et al., 2017: The carbon savings and health co-benefits from the introduction of mass rapid transit system in Greater Kuala Lumpur, Malaysia. *J. Transp. Health*, **6**, 187–200, doi:10.1016/j.jth.2017.06.006.

Kwon, H.-J. and W.-R. Kim, 2015: The evolution of cash transfers in Indonesia: policy transfer and national adaptation. *Asia Pac. Policy Stud.*, **2**(2), 425–440, doi:10.1002/app5.83.

Kwon, J.-W., et al., 2016: Emergency Department Visits for Asthma Exacerbation due to Weather Conditions and Air Pollution in Chuncheon, Korea: A Case-Crossover Analysis. *Allergy Asthma Immunol. Res.*, **8**(6), 512–521.

Kwon, T.-S., et al., 2021: Habitat change has greater effects than climate change on butterfly occurrence in South Korea. *Glob. Ecol. Conserv.*, **26**, e1464, doi:10.1016/j.gecco.2021.e01464.

Kyburz-Graber, R.S., 2013: Socio-ecological approaches to environmental education and research. *: a paradigmatic response to behavioral change orientations.* In: *International handbook of research on environmental education* [Brody, M., J. Dillon and A. Wals(eds.)]. Routledge, New York, pp. 310–330.

Kythreotis, A.P., et al., 2019: Citizen Social Science for More Integrative and Effective Climate Action: A Science-Policy Perspective. *Front. Environ. Sci.*, **7**, doi:10.3389/fenvs.2019.00010.

Læssøe, J. and Y. Mochizuki, 2015: Recent Trends in National Policy on Education for Sustainable Development and Climate Change Education. *J. Educ. Sustain. Dev.*, **9**(1), 27–43, doi:10.1177/0973408215569112.

Lam, H.C.-Y., A.M. Li, E.Y.-Y. Chan and W.B. Goggins, 2016: The short-term association between asthma hospitalisations, ambient temperature, other meteorological factors and air pollutants in Hong Kong: a time-series study. *Thorax*, **71**(12), 1097, doi:10.1136/thoraxjnl-2015-208054.

Lam, V.W.Y., et al., 2019: Dealing with the effects of ocean acidification on coral reefs in the Indian Ocean and Asia. *Reg. Stud. Mar. Sci.*, **28**, 10, doi:10.1016/j.rsma.2019.100560.

Lama, P.D. and P. Becker, 2019: Conflicts in adaptation: case studies from Nepal and the Maldives. *Disaster Prev. Manag.*, **28**(3), 304–318, doi:10.1108/DPM-12-2018-0393.

Lassa, J.A., 2019: Negotiating Institutional Pathways for Sustaining Climate Change Resilience and Risk Governance in Indonesia. *Climate*, **7**(95), doi:10.3390/cli7080095.

Lassa, J.A. and M. Sembiring, 2017: *Towards Policy Integration of Disaster Risk, Climate Adaptation, and Development in ASEAN: A Baseline Assessment*.

Lasslop, G., et al., 2019: Influence of fire on the carbon cycle and climate. *Curr Clim Change Rep*, **5**(2), 112–123, doi:10.1007/s40641-019-00128-9.

Lauvset, S.K., et al., 2015: Trends and drivers in global surface ocean pH over the past 3 decades. *Biogeosciences*, **12**(5), 1285–1298, doi:10.5194/bg-12-1285-2015.

Lawford, R., et al., 2013: Basin perspectives on the water–energy–food security nexus. *Curr. Opin. Environ. Sustain.*, **5**(6), 607–616.

Le Dang, H., E. Li, I. Nuberg and J. Bruwer, 2014: Farmers' perceived risks of climate change and influencing factors: A study in the Mekong Delta, Vietnam. *Environ. Manage.*, **54**(2), 331–345, doi:10.1007/s00267-014-0299-6.

Le, M.-H., K.V. Dinh, M.V. Nguyen and I. Rønnestad, 2020: Combined effects of a simulated marine heatwave and an algal toxin on a tropical marine aquaculture fish cobia (Rachycentron canadum). *Aquac. Res.*, **51**(6), 2535–2544, doi:10.1111/are.14596.

Le, T.T.H., 2016: Effects of climate change on rice yield and rice market in Vietnam. *J. Agric. Appl. Econ.*, **48**(4), 366–382, doi:10.1017/aae.2016.21.

Lebel, L., S. Wattana, and P. Talerngsri, 2015: Assessments of ecosystem services and human well-being in Thailand build and create demand for coproductive capacity. *Ecol. Soc.*, **20**(1), 12. http://dx.doi.org/10.5751/ES-06527-200112.

Lee, E., R. Jayakumar, S. Shrestha and Z. Han, 2018a: Assessment of transboundary aquifer resources in Asia: Status and progress towards sustainable groundwater management. *J. Hydrol. Reg. Stud.*, **20**, 103–115.

Lee, J.Y., et al., 2018b: Projection of future mortality due to temperature and population changes under representative concentration pathways and shared socioeconomic pathways. *Int. J. Environ. Res. Public Health*, **15**(4), doi:10.3390/ijerph15040822.

Lee, J.Y. and H. Kim, 2016: Projection of future temperature-related mortality due to climate and demographic changes. *Environ. Int.*, **94**, 489–494, doi:10.1016/j.envint.2016.06.007.

Lee, J.Y., H.S. Lee, S.-C. Hong and H. Kim, 2017: Projecting future summer mortality due to ambient ozone concentration and temperature changes. *Atmospheric. Environ.*, **156**, 88–94, doi:10.1016/j.atmosenv.2017.02.034.

Lee, J.Y., W.-S. Lee, K.L. Ebi and H. Kim, 2019: Temperature-related summer mortality under multiple climate, population, and adaptation scenarios. *Int. J. Environ. Res. Public Health*, **16**(6), doi:10.3390/ijerph16061026.

Lee, J.-Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J.P. Dunne, F. Engelbrecht, E. Fischer, J.C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, and T. Zhou: 2021, Future Global Climate: Scenario-Based Projections and Near-Term Information. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge.

Lee, M. and R.C. Asuncion, 2020: Impacts of Sea Level Rise on Economic Growth in Developing Asia. *Resour. Environ. Econ.*, **2**(1), 102–111, doi:10.25082/ree.2020.01.002.

Lee, S.-W., K. Lee and B. Lim, 2018c: Effects of climate change-related heat stress on labor productivity in South Korea. *Int. J. Biometeorol.*, **62**, 2119–2129, doi:10.1007/s00484-018-1611-6.

Lee, S., H. Jung and J. Choi, 2021b: Projecting the Impact of Climate Change on the Spatial Distribution of Six Subalpine Tree Species in South Korea Using a Multi-Model Ensemble Approach. *Forests*, **12**, 37, doi:10.3390/f12010037.

Lee, S., et al., 2018d: Mental disease-related emergency admissions attributable to hot temperatures. *Sci. Total. Environ.*, **616-617**, 688–694, doi:10.1016/j.scitotenv.2017.10.260.

Lee, T.-C., et al., 2020a: Third assessment on impacts of climate change on tropical cyclones in the Typhoon Committee Region – Part I: Observed changes, detection and attribution. *Trop. Cyclone Res. Rev.*, **9**(1), 1–22, doi:10.1016/j.tcrr.2020.03.001.

Lee, T. and M. Painter, 2015: Comprehensive local climate policy: The role of urban governance. *Urban Clim.*, **14**, 566–577, doi:10.1016/j.uclim.2015.09.003.

Lee, T.M., et al., 2015a: Predictors of public climate change awareness and risk perception around the world. *Nat. Clim. Change*, **5**(11), 1014.

Lee, W.K., H.A. Lee, Y.H. Lim and H. Park, 2016: Added effect of heat wave on mortality in Seoul, Korea. *Int. J. Biometeorol.*, **60**(5), 719–726, doi:10.1007/s00484-015-1067-x.

Lee, Y.-C., J. Ahern and C.-T. Yeh, 2015b: Ecosystem services in peri-urban landscapes: The effects of agricultural landscape change on ecosystem services in Taiwan's western coastal plain. *Landsc. Urban Plan.*, **139**, 137–148, doi:10.1016/j.landurbplan.2015.02.023.

Lee, Y.-J., 2017: A synthesized biophysical and social vulnerability assessment for Taiwan. *IOP Conf. Series Earth Environ. Sci.*, **94**, 12161, doi:10.1088/1755-1315/94/1/012161.

Lee, Y.H., et al., 2020b: Transgenerational acclimation to changes in ocean acidification in marine invertebrates. *Mar. Pollut. Bull.*, **153**, 18, doi:10.1016/j.marpolbul.2020.111006.

Lei, J., L. Chen and H. Li, 2017: Using ensemble forecasting to examine how climate change promotes worldwide invasion of the golden apple snail (Pomacea canaliculata). *Environ. Monit. Assess.*, **189**(8), 404, doi:10.1007/s10661-017-6124-y.

Lei, J., S. Wang, J. Wang and J. Wu, 2016: Potential effects of future climate change on suitable habitat of Muntiacus crinifrons, an endangered and endemic species in China. *Biodivers. Sci.*, **24**, 1390–1399, doi:10.17520/biods.2016152.

Lei, Y., et al., 2015: Adaptive governance to typhoon disasters for coastal sustainability: A case study in Guangdong, China. *Environ. Sci. Policy*, **54**, 281–286, doi:10.1016/j.envsci.2015.07.016.

Leiter, T., et al., 2019: *Adaptation Metrics. Current Landscape and Evolving Practices*.

Leith, P. and F. Vanclay, 2017: Placing Science for Natural Resource Management and Climate Variability: Lessons from Narratives of Risk, Place and Identity. *Sociol. Rural.*, **57**(2), 155–170, doi:10.1111/soru.12124.

Lele, S., V. Srinivasan, B.K. Thomas and P. Jamwal, 2018: Adapting to climate change in rapidly urbanizing river basins: insights from a multiple-concerns, multiple-stressors, and multi-level approach. *Water Int.*, **43**(2), 281–304.

Lele, U., M. Klousia-Marquis and S. Goswami, 2013: Good Governance for Food, Water and Energy Security. *Aquat. Proc.*, **1**, 44–63, doi:10.1016/j.aqpro.2013.07.005.

Leng, G. and J. Hall, 2019: Crop yield sensitivity of global major agricultural countries to droughts and the projected changes in the future. *Sci. Total. Environ.*, **654**(1), 811–821, doi:10.1016/j.scitotenv.2018.10.434.

Lenoir, J. and J.-C. Svenning, 2015: Climate-related range shifts – a global multidimensional synthesis and new research directions. *Ecography*, doi:10.1111/ecog.00967.

Leong, C.M.L., S.L. Pan, P. Ractham and L. Kaewkitipong, 2015: ICT-enabled community empowerment in crisis response: social media in Thailand Flooding 2011. *J. Assoc. Inf. Syst.*, **16**(3), 1–39.

Leung, J.Y.S., B.D. Russell and S.D. Connell, 2020: Linking energy budget to physiological adaptation: How a calcifying gastropod adjusts or succumbs to ocean acidification and warming. *Sci. Total. Environ.*, **715**, 8, doi:10.1016/j.scitotenv.2020.136939.

Levy, B.S. and J.A. Patz, 2015: Climate Change, Human Rights, and Social Justice. *Ann. Glob. Health.*, **81**(3), 310–322, doi:10.1016/j.aogh.2015.08.008.

Levy, K., A.P. Woster, R.S. Goldstein and E.J. Carlton, 2016: Untangling the Impacts of Climate Change on Waterborne Diseases: a Systematic Review of Relationships between Diarrheal Diseases and Temperature, Rainfall, Flooding, and Drought. *Environ. Sci. Technol.*, **50**(10), 4905–4922, doi:10.1021/acs.est.5b06186.

Li, B., et al., 2018a: Comparative Analysis of Urban Heat Island Intensities in Chinese, Russian, and DPRK Regions across the Transnational Urban Agglomeration of the Tumen River in Northeast Asia. *Sustainability*, **10**(8), doi:10.3390/su10082637.

Li, C., Y. Lu, J. Liu and X. Wu, 2018b: Climate change and dengue fever transmission in China: Evidences and challenges. *Sci. Total Environ.*, **622-623**, 493–501, doi:10.1016/j.scitotenv.2017.11.326.

Li, G., et al., 2020: Algal density mediates the photosynthetic responses of a marine macroalga Ulva conglobata (Chlorophyta) to temperature and pH changes. *Algal. Res.*, **46**, 7, doi:10.1016/j.algal.2020.101797.

Li, H.-C., et al., 2015a: Applying risk analysis to the disaster impact of extreme typhoon events under climate change. *J. Dis. Res.*, **10**(3), 513–526, doi:10.20965/jdr.2015.p0513.

Li, J., et al., 2021: Work Resumption Rate and Migrant Workers' Income During the COVID-19 Pandemic. *Front. Public Health*, **9**(464), doi:10.3389/fpubh.2021.678934.

Li, J.M. and Z.H. Li, 2014: Physical limitations and challenges to Grain Security in China. *Food Secur.*, **6**(2), 159–167, doi:10.1007/s12571-013-0326-0.

Li, K., et al., 2016a: Effects of temperature variation between neighbouring days on daily hospital visits for childhood asthma: a time-series analysis. *Public Health*, **136**, 133–140, doi:10.1016/j.puhe.2016.04.002.

Li, L., et al., 2019a: Twenty-first-century glacio-hydrological changes in the Himalayan headwater Beas River basin. *Hydrol. Earth Syst. Sci.*, **23**(3), 1483–1503.

Li, Q., et al., 2019b: Debris Flow Risk Assessment Based on a Water–Soil Process Model at the Watershed Scale Under Climate Change: A Case Study in a Debris-Flow-Prone Area of Southwest China. *Sustainability*, **11**, 3199, doi:10.3390/su11113199.

Li, T., et al., 2015b: Heat-related mortality projections for cardiovascular and respiratory disease under the changing climate in Beijing, China. *Sci. Rep.*, **5**, doi:10.1038/srep11441.

Li, T., et al., 2018c: Long-term projections of temperature-related mortality risks for ischemic stroke, hemorrhagic stroke, and acute ischemic heart disease under changing climate in Beijing, China. *Environ. Int.*, **112**, 1–9, doi:10.1016/j.envint.2017.12.006.

Li, X., Y. Gao, Y. Pan and Y. Xu, 2018d: Evaluation of near-surface wind speed simulations over the Tibetan Plateau from three dynamical downscalings based on WRF model. *Theor. Appl. Climatol.*, **134**(3), 1399–1411, doi:10.1007/s00704-017-2353-9.

Li, X., et al., 2016b: *Case Studies of the Sponge City Program in China*, 295–308.

Li, X., T. Takahashi, N. Suzuki and H.M. Kaiser, 2014a: Impact of Climate Change on Maize Production in Northeast and Southwest China and Risk Mitigation Strategies. *APCBEE Proc.*, **8**, 11–20, doi:10.1016/j.apcbee.2014.01.073.

Li, Y., et al., 2014b: Extremely cold and hot temperatures increase the risk of diabetes mortality in metropolitan areas of two Chinese cities. *Environ. Res.*, **134**, 91–97, doi:10.1016/j.envres.2014.06.022.

Liang, E., B. Dawadi, N. Pederson and D. Eckstein, 2014: Is the growth of birch at the upper timberline in the Himalayas limited by moisture or by temperature? *Ecology*, **95**, 2453–2465, doi:10.1890/13-1904.1.

Liao, K.-H., 2019: The socio-ecological practice of building blue-green infrastructure in high-density cities: what does the ABC Waters Program in Singapore tell us? *Soc. Ecol. Pract. Res.*, **1**(1), 67–81, doi:10.1007/s42532-019-00009-3.

Liebenehm, S., 2018: Temporal Stability of Risk Attitudes and the Impact of Adverse Shocks—A Panel Data Analysis from Thailand and Vietnam. *World Dev.*, **102**, 262–274, doi:10.1016/j.worlddev.2017.07.020.

Lim, C.-H., et al., 2017a: Impact of Deforestation on Agro-Environmental Variables in Cropland, North Korea. *Sustainability*, **9**(8), doi:10.3390/su9081354.

Lim, C.-H., et al., 2017b: Estimation of the Virtual Water Content of Main Crops on the Korean Peninsula Using Multiple Regional Climate Models and Evapotranspiration Methods. *Sustainability*, **9**, 1172, doi:10.3390/su9071172.

Lim, C.-H., et al., 2019a: Assessment of Agricultural Drought Considering the Hydrological Cycle and Crop Phenology in the Korean Peninsula. *Water*, **11**(5), 1105.

Lim, C.H., J.H. An, S.H. Jung and C.S. Lee, 2018: Allogenic succession of Korean fir (*Abies koreana* Wils.) forests in different climate condition. *Ecol. Res.*, **33**(2), 327–340, doi:10.1007/s11284-018-1592-2.

Lim, C.H., et al., 2019b: Decoupling of forest water supply and agricultural water demand attributable to deforestation in North Korea. *J. Environ. Manage.*, **248**, 109256, doi:10.1016/j.jenvman.2019.07.027.

Lin, C., K. Yang, J. Qin and R. Fu, 2013: Observed Coherent Trends of Surface and Upper-Air Wind Speed over China since 1960. *J. Climate*, **26**, 2891–2903, doi:10.1175/JCLI-D-12-00093.1.

Lin, I., et al., 2003: New evidence for enhanced ocean primary production triggered by tropical cyclone. *Geophys. Res. Lett.*, **30**(13), 4, doi:10.1029/2003gl017141.

Lin, W.-Y., et al., 2018: Filtering disaster responses using crowdsourcing. *Autom. Constr.*, **91**, 182–192, doi:10.1016/j.autcon.2018.03.016.

Lin, Y.K., A.T. Maharani, F.T. Chang and Y.C. Wang, 2019: Mortality and morbidity associated with ambient temperatures in Taiwan. *Sci. Total Environ.*, **651**(Pt 1), 210–217, doi:10.1016/j.scitotenv.2018.09.161.

Lincke, D. and J. Hinkel, 2021: Coastal Migration due to 21st Century Sea-Level Rise. *Earths Future*, **9**(5), e2020EF001965.

Ling, F.H., et al., 2015: Reducing flood risks in rural households: survey of perception and adaptation in the Mekong delta. *Clim. Change*, **132**(2), 209–222.

Linnenluecke, M.K., et al., 2016: Emerging trends in Asia-Pacific finance research: A review of recent influential publications and a research agenda. *Pacific Basin Finance J.*, **36**, 66–76.

Liu, D., et al., 2018a: Flood risk perception of rural households in western mountainous regions of Henan Province, China. *Int. J. Dis. Risk Reduct.*, **27**, 155–160.

Liu, H., et al., 2019a: Recent lake area changes in Central Asia. *Sci. Rep.*, **9**(1), 1–11.

Liu, J., et al., 2018b: Large observational bias on discharge in the Indus River since 1970s. *Sci. Rep.*, **8**(1), 1–10.

Liu, J., et al., 2017a: Challenges in operationalizing the water–energy–food nexus. *Hydrol. Sci. J.*, **62**(11), 1714–1720, doi:10.1080/02626667.2017.1353695.

Liu, M., et al., 2016a: Do Climate Change Policies Promote or Conflict with Subjective Wellbeing: A Case Study of Suzhou, China. *Int. J. Environ. Res. Public Health*, **13**(3), 344.

Liu, M., et al., 2017b: Estimating health co-benefits of greenhouse gas reduction strategies with a simplified energy balance based model: The Suzhou City case. *J. Clean. Prod.*, **142**, 3332–3342, doi:10.1016/j.jclepro.2016.10.137.

Liu, P.J., S.J. Ang, A.B. Mayfield and H.J. Lin, 2020a: Influence of the seagrass Thalassia hemprichii on coral reef mesocosms exposed to ocean acidification and experimentally elevated temperatures. *Sci. Total. Environ.*, **700**, 11, doi:10.1016/j.scitotenv.2019.134464.

Liu, Q. and S. Liu, 2015: Response of glacier mass balance to climate change in the Tianshan Mountains during the second half of the twentieth century. *Clim. Dyn.*, **46**, 301–316, doi:10.1007/s00382-015-2585-2.

Liu, W., W. Chen and C. Peng, 2014a: Assessing the effectiveness of green infrastructures on urban flooding reduction: A community scale study. *Ecol. Model.*, **291**(C), 6-14. DOI: 10.1016/j.ecolmodel.2014.07.012.

Liu, X., 2020: Reductions in labor capacity from intensified heat stress in China under future climate change. *Int. J. Environ. Res. Public Health*, **17**(4), doi:10.3390/ijerph17041278.

Liu, X., et al., 2017c: A future land use simulation model (FLUS) for simulating multiple land use scenarios by coupling human and natural effects. *Landsc. Urban Plan.*, **168**, 94–116, doi:10.1016/j.landurbplan.2017.09.019.

Liu, X., et al., 2019b: Multimodel assessments of human and climate impacts on mean annual streamflow in China. *Hydrol. Earth Syst. Sci.*, **23**(3), 1245–1261.

Liu, X., et al., 2019c: The value of China's coastal wetlands and seawalls for storm protection. *Ecosyst. Serv.*, **36**, doi:10.1016/j.ecoser.2019.100905.

Liu, X., et al., 2019d: The value of China's coastal wetlands and seawalls for storm protection. *Ecosyst. Serv.*, **36**, doi:10.1016/j.ecoser.2019.100905.

Liu, X., X. Zhang, Q. Tang and X. Zhang, 2014b: Effects of surface wind speed decline on modeled hydrological conditions in China. *Hydrol. Earth Syst. Sci.*, **18**, 2803–2813, doi:10.5194/hess-18-2803-2014.

Liu, Y. and J. Chen, 2020: Socioeconomic risk of droughts under a 2.0°C warmer climate: Assessment of population and GDP exposures to droughts in China. *Int. J. Climatol.*, doi:10.1002/joc.6691.

Liu, Y., et al., 2016b: A community-based disaster risk reduction system in Wanzhou, China. *Int. J. Dis. Risk Reduct.*, **19**, 379–389, doi:10.1016/j.ijdrr.2016.09.009.

Liu, Y.P., et al., 2014c: The potential effects of climate change on the distribution and productivity of *Cunninghamia lanceolata* in China. *Environ. Monit. Assess.*, **186**(1), 135–149, doi:10.1007/s10661-013-3361-6.

Liu, Z.-J., S. Minobe, Y.N. Sasaki and M. Terada, 2016c: Dynamical downscaling of future sea level change in the western North Pacific using ROMS. *J. Oceanogr.*, **72**(6), 905–922, doi:10.1007/s10872-016-0390-0.

Liu, Z.Q., et al., 2020b: Ocean acidification inhibits initial shell formation of oyster larvae by suppressing the biosynthesis of serotonin and dopamine. *Sci. Total. Environ.*, **735**, 12, doi:10.1016/j.scitotenv.2020.139469.

Lkhagvadorj, D., M. Hauck, C. Dulamsuren and J. Tsogtbaatar, 2013a: Pastoral nomadism in the forest-steppe of the Mongolian Altai under a changing economy and a warming climate. *J. Arid Environ.*, **88**, 82–89.

Lkhagvadorj, D., M. Hauck, C. Dulamsuren and J. Tsogtbaatar, 2013b: Twenty Years After Decollectivization: Mobile Livestock Husbandry and Its Ecological Impact in the Mongolian Forest-Steppe. *Hum. Ecol.*, **41**(5), 725–735, doi:10.1007/s10745-013-9599-3.

Lopez, O., G. Stenchikov and T.M. Missimer, 2014: Water management during climate change using aquifer storage and recovery of stormwater in a dunefield in western Saudi Arabia. *Environ. Res. Lett.*, **9**(7), 75008, doi:10.1088/1748-9326/9/7/075008.

Lorenzoni, I. and L. Whitmarsh, 2014: Climate change and perceptions, behaviors, and communication research after the IPCC 5th Assessment Report - a WIREs Editorial. *Wiley Interdiscip. Rev. Clim. Chang.*, **5**(6), 703–708, doi:10.1002/wcc.319.

Lough, J.M., K.D. Anderson and T.P. Hughes, 2018: Increasing thermal stress for tropical coral reefs: 1871-2017. *Sci. Rep*, **8**, 8, doi:10.1038/s41598-018-24530-9.

Lovelock, C.E., et al., 2015: The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature*, **526**(7574), 559–563, doi:10.1038/nature15538.

Lu, X., 2019: *Building Resilient Infrastructure for the Future: Background paper for the G20 Climate Sustainability Working Group*. Asian Development Bank, Metro Manila, Philippines, https://www.adb.org/sites/default/files/publication/519821/sdwp-061-building-resilient-infrastructure-future.pdf. accessed on October 1, 2021.

Lu, X.M., et al., 2015: Climate warming increases biological control agent impact on a non-target species. *Ecol. Lett.*, **18**(1), 48–56, doi:10.1111/ele.12391.

Lu, Y., et al., 2018: Interaction between pollution and climate change augments ecological risk to a coastal ecosystem. *Ecosyst. Health Sustain.*, **4**(7), 161–168.

Luan, G., P. Yin, L. Wang and M. Zhou, 2019: Associations between ambient high temperatures and suicide mortality: a multi-city time-series study in China. *Environ. Sci. Pollut. Res.*, doi:10.1007/s11356-019-05252-5.

Luo, M. and N.-C. Lau, 2018a: Increasing heat stress in urban areas of eastern China: Acceleration by urbanization. *Geophys. Res. Lett.*, **45**(13), doi:10.1029/2018GL080306.

Luo, M., et al., 2019: Identifying climate change impacts on water resources in Xinjiang, China. *Sci. Total. Environ.*, **676**, doi:10.1016/j.scitotenv.2019.04.297.

Luo, T., D. Krishnan and S. Sen, 2018b: *Parched Power: Water Demands, Risks, and Opportunities for India's Power Sector*. World Resources Institute, Washington, DC.

Luo, X.-S., et al., 2017: Inclusive development and agricultural adaptation to climate change. *Curr. Opin. Environ. Sustain.*, **24**, 78–83.

Lutz, A., W. Immerzeel, A. Shrestha and M. Bierkens, 2014a: Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nat. Clim. Change*, **4**(7), 587.

Lutz, A. F., et al., 2016: Climate change impacts on the upper indus hydrology: Sources, shifts and extremes. *PLoS ONE*, **11**(11), e165630.

Lutz, A. F., W.W. Immerzeel, A.B. Shrestha and M.F.P. Bierkens, 2014b: Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nat. Clim. Change*, **4**(7), 587–592, doi:10.1038/nclimate2237.

Lutz, A. F., et al., 2019: South Asian river basins in a 1.5 C warmer world. *Reg. Environ. Change*, **19**(3), 833–847.

Lutz, W., R. Muttarak and E. Striessnig, 2014c: Universal education is key to enhanced climate adaptation. *Science*, **346**(6213), 1061–1062.

Lwasa, S., 2015: A systematic review of research on climate change adaptation policy and practice in Africa and South Asia deltas. *Reg. Environ. Change*, **15**, 815–824, doi:10.1007/s10113-014-0715-8.

Ma, S., et al., 2019: Interannual to decadal variability in the catches of small pelagic fishes from China Seas and its responses to climatic regime shifts. *Deep. Sea Res. Part Ii: Top. Stud. Oceanogr.*, **159**, 112–129, doi:10.1016/j.dsr2.2018.10.005.

Ma, W., et al., 2015: The short-term effect of heat waves on mortality and its modifiers in China: an analysis from 66 communities. *Environ. Int.*, **75**, 103–109, doi:10.1016/j.envint.2014.11.004.

Mabon, L., et al., 2019: Fukuoka: Adapting to climate change through urban green space and the built environment? *Cities*, **93**, 273–285, doi:10.1016/j.cities.2019.05.007.

Mabon, L. and W.-Y. Shih, 2018: What might 'just green enough' urban development mean in the context of climate change adaptation? The case of urban greenspace planning in Taipei Metropolis, Taiwan. *World Dev.*, **107**, 224–238, doi:10.1016/j.worlddev.2018.02.035.

Mabon, L. and W.-Y. Shih, 2021: Urban greenspace as a climate change adaptation strategy for subtropical Asian cities: A comparative study across cities in three countries. *Glob. Environ. Chang.*, **68**, 102248.

Mack, T.J., 2018: Groundwater Availability in the Kabul Basin, Afghanistan. In: *Groundwater of South Asia*. Springer, Berlin Leipzig, pp. 23–35.

Magni, G., 2017: Indigenous knowledge and implications for the sustainable development agenda. *Eur. J. Educ.*, **52**(4), 437–447, doi:10.1111/ejed.12238.

Maharjan, A., R. Safra de Caompos, C. Singh, et al., 2020: Migration and Household Adaptation in Climate-Sensitive Hotspots in South Asia. *Curr Clim Change Rep*, **6**, doi:10.1007/s40641-020-00153-z.

Mahmood, S., A.U. Rahman and R. Shaw, 2019: Spatial appraisal of flood risk assessment and evaluation using integrated hydro-probabilistic approach in Panjkora River Basin, Pakistan. *Environ. Monit. Assess.*, **191**, 573, doi:10.1007/s10661-019-7746-z.

Mahmuda, I., A. Baskaran and J. Pancholi, 2014: Financing social innovation for poverty reduction: A case study of microfinancing and microenterprise development in Bangladesh. *Sci. Technol. Soc.*, **19**(2), 249–273.

Mainali, J. and N.G. Pricope, 2019: Mapping the need for adaptation: assessing drought vulnerability using the livelihood vulnerability index approach in a mid-hill region of Nepal. *Clim. Dev.*, **11**(7), 607–622, doi:10.1080/17565529.2018.1521329.

Majumdar, S.D., et al., 2018: Threats to coral reef diversity of Andaman Islands, India: a review. *Reg. Stud. Mar. Sci.*, **24**, 237–250, doi:10.1016/j.rsma.2018.08.011.

Makondo, C.C. and D.S.G. Thomas, 2018: Climate change adaptation: Linking indigenous knowledge with western science for effective adaptation. *Environ. Sci. Policy*, **88**, 83–91, doi:10.1016/j.envsci.2018.06.014.

Mall, R.K., et al., 2019: Disaster Risk Reduction Including Climate Change Adaptation Over South Asia: Challenges and Ways Forward. *Int. J. Disaster Risk Sci.*, **10**, 14–27, doi:10.1007/s13753-018-0210-9.

Mallari and C.A. Ezra, 2016: Climate Change Vulnerability Assessment in the Agriculture Sector: Typhoon Santi Experience. *Proc. Soc. Behav. Sci.*, **216**, 440–451, doi:10.1016/j.sbspro.2015.12.058.

Mani, M., et al., 2018: *South Asia hotspots*. World Bank Group, Washington.

Mannakkara, S. and S. Wilkinson, 2013: Build Back Better principles for post-disaster structural improvements. *Struct. Surv.*, **31**(4), 314–327, doi:10.1108/SS-12-2012-0044.

Mantyka-Pringle, C.S., et al., 2015: Climate change modifies risk of global biodiversity loss due to land-cover change. *Biol. Conserv.*, **187**, 103–111, doi:10.1016/j.biocon.2015.04.016.

Mao, H., Y.-Y. Ahn, B. Bhaduri and G. Thakur, 2017: Improving land use inference by factorizing mobile phone call activity matrix. *J. Land. Use Sci.*, **12**(2-3), 138–153, doi:10.1080/1747423x.2017.1303546.

Markandya, A. and M. González-Eguino, 2019: Integrated Assessment for Identifying Climate Finance Needs for Loss and Damage: A Critical Review. In: *Loss and Damage from Climate Change*. Springer, Berlin Heidelberg, pp. 343–362.

Mason-D'Croz, D., et al., 2016: Multi-factor, multi-state, multi-model scenarios: Exploring food and climate futures for Southeast Asia. *Environ. Model. Softw.*, **83**, 255–270, doi:10.1016/j.envsoft.2016.05.008.

Masood, M., P.-F. Yeh, N. Hanasaki and K. Takeuchi, 2015: Model study of the impacts of future climate change on the hydrology of Ganges–Brahmaputra–Meghna basin. *Hydrol. Earth Syst. Sci.*, **19**(2), 747–770.

Masud, M.M., et al., 2016: Climate change issue and theory of planned behaviour: relationship by empirical evidence. *J Clean Prod*, **113**(1), 613–623.

Masutomi, Y., et al., 2019: Rice grain quality degradation and economic loss due to global warming in Japan. *Environ. Res. Commun.*, **1**(12), 121003, doi:10.1088/2515-7620/ab52e7.

Matheswaran, K., N. Alahacoon, R. Pandey and G. Amarnath, 2019: Flood risk assessment in South Asia to prioritize flood index insurance applications in Bihar, India. *Geomat. Nat. Hazards Risk*, **10**(1), 26–48, doi:10.1080/19475705.2018.1500495.

Matsuhashi, S., et al., 2020: Developing a point process model for ecological risk assessment of pine wilt disease at multiple scales. *For. Ecol. Manag.*, **463**, 118010, doi:10.1016/j.foreco.2020.118010.

Matsui, T., et al., 2018: Potential impact of climate change on canopy tree species composition of cool-temperate forests in Japan using a multivariate classification tree model. *Ecol. Res.*, **33**(2), 289–302, doi:10.1007/s11284-018-1576-2.

Matsumoto, K., 2019: Climate change impacts on socioeconomic activities through labor productivity changes considering interactions between socioeconomic and climate systems. *J. Clean. Prod.*, **216**, 528–541, doi:10.1016/j.jclepro.2018.12.127.

Matsushita, N., et al., 2018: The non-linear and lagged short-term relationship between rainfall and leptospirosis and the intermediate role of floods in the Philippines. *PLoS Negl. Trop. Dis.*, **12**(4), e6331, doi:10.1371/journal.pntd.0006331.

Matsuura, S. and R. Shaw, 2014: Exploring the possibilities of school-based recovery and community building in Toni District, Kamaishi. *Nat. Hazards*, **75**(1), 613–633, doi:10.1007/s11069-014-1344-8.

Matthews, T.K.R., R.L. Wilby and C. Murphy, 2017: *Communicating the deadly consequences of global warming for human heat stress*. Proc Natl Acad Sci USA. doi:10.1073/pnas.1617526114.

Maung Saw Htoo, T., et al., 2017: Seasonal dynamics influencing coastal primary production and phytoplankton communities along the southern Myanmar coast. *J. Oceanogr.*, **73**(3), 345–364, doi:10.1007/s10872-016-0408-7.

Mavrodieva, A.V. and R. Shaw, 2020: Disaster and Climate Change Issues in Japan's Society 5.0—A Discussion. *Sustainability*, **12**(5), doi:10.3390/su12051893.

Maynard, J., et al., 2015: Projections of climate conditions that increase coral disease susceptibility and pathogen abundance and virulence. *Nat. Clim. Change*, **5**(7), 688, doi:10.1038/nclimate2625.

Mayrhofer, J.P. and J. Gupta, 2016: The science and politics of co-benefits in climate policy. *Environ. Sci. Policy*, **57**, 22–30, doi:10.1016/j.envsci.2015.11.005.

Mazangi, A., et al., 2016: Effects of climate change on the distribution of endemic Ferula xylorhachis Rech.f. (Apiaceae: Scandiceae) in Iran: Predictions from ecological niche models. *Russ. J. Ecol.*, **47**(4), 349–354, doi:10.1134/s1067413616040123.

McDowell, G., et al., 2013: Climate-related hydrological change and human vulnerability in remote mountain regions: a case study from Khumbu. *Nepal. Reg. Environ. Chang.*, **13**(2), 299–310.

McGill, N., 2016: Vulnerable populations at risks from effects of climate change: Public health working to find solutions. *Nations Health*, **46**(9), 1–14.

McIlreavy, C., 2015: *East Asia's Changing Urban Landscape: Measuring a Decade of Spatial Growth*. The World Bank, Washton DC, USA. 1–26. ISBN 978-1464803635.

McKinnon, A.D., et al., 2003: Rapid changes in shelf waters and pelagic communities on the southern Northwest Shelf, Australia, following a tropical cyclone. *Cont. Shelf Res.*, **23**(1), 93–111, doi:10.1016/s0278-4343(02)00148-6.

McLeman, R., 2019: International migration and climate adaptation in an era of hardening borders. *Nat. Clim. Chang.*, **9**, 911–918, doi:10.1038/s41558-019-0634-2.

McLeman, R.A., 2014: *Climate and human migration: Past experiences, future challenges*. Cambridge University Press, Cambridge, UK, ISBN 978-1107022652.

McLeod, E., et al., 2019: The future of resilience-based management in coral reef ecosystems. *J. Environ. Manag.*, **233**, 291–301, doi:10.1016/j.jenvman.2018.11.034.

McVicar, T.R., et al., 2012: Global review and synthesis of trends in observed terrestrial near-surface wind speeds: Implications for evaporation. *J. Hydrol. Reg. Stud.*, **416-417**, 182–205, doi:10.1016/j.jhydrol.2011.10.024.

Mechler, R., et al., 2019: Science for loss and damage. Findings and propositions. In: *Loss and damage from climate change*. Springer, Berlin Heidelberg, pp. 3–37.

Meena, R., B. Jirli, M. Kanwat and N. Meena, 2018: Mobile applications for agriculture and allied sector. *Int. J. Curr. Microbiol. Appl. Sci.*, **7**(2), 2317–2326.

Meerow, S., 2017: Double exposure, infrastructure planning, and urban climate resilience in coastal megacities: A case study of Manila. *Environ. Plan. A Economy Space*, **49**(11), 2649–2672, doi:10.1177/0308518X17723630.

Mehar, M., S. Mittal and N. Prasad, 2016: Farmers coping strategies for climate shock: Is it differentiated by gender? *J. Rural Stud.*, **44**, 123–131.

Mehta, J., et al., 2019: Climate change and uncertainty from 'above' and 'below': perspectives from India. *Reg. Environ. Change*, **19**, 1533–1547, doi:10.1007/s10113-019-01479-7.

Mehvar, S., et al., 2019: Quantitative assessment of the environmental risk due to climate change-driven coastline recession: A case study in Trincomalee coastal area, Sri Lanka. *Clim. Risk Manag.*, **25**, doi:10.1016/j.crm.2019.100192.

Mehvar, S., et al., 2018: Developing a framework to quantify potential Sea level rise-driven environmental losses: A case study in Semarang coastal area, Indonesia. *Environ. Sci. Policy*, **89**, 216–230, doi:10.1016/J.ENVSCI.2018.06.019.

Meier, F., et al., 2017: Crowdsourcing air temperature from citizen weather stations for urban climate research. *Urban Clim.*, **19**, 170–191, doi:10.1016/j.uclim.2017.01.006.

Mendelsohn, R., 2014: The Impact of Climate Change on Agriculture in Asia. *J. Integr. Agric.*, **13**(4), 660–665, doi:10.1016/s2095-3119(13)60701-7.

Menéndez, P., et al., 2018: Valuing the protection services of mangroves at national scale: The Philippines. *Ecosyst. Serv.*, **34**, 24–36, doi:10.1016/j.ecoser.2018.09.005.

Mercure, J.-F., et al., 2018: Macroeconomic impact of stranded fossil fuel assets. *Nat. Clim. Change*, **8**(7), 588–593, doi:10.1038/s41558-018-0182-1.

Michael, K., T. Deshpande and G. Ziervogel, 2018: Examining vulnerability in a dynamic urban setting: the case of Bangalore's interstate migrant waste pickers. *Clim. Dev.*, 1–12, doi:10.1080/17565529.2018.1531745.

Mikulewicz, M., 2017: Politicizing vulnerability and adaptation: on the need to democratize local responses to climate impacts in developing countries. *Clim. Dev.*, **10**(1), 18–34, doi:10.1080/17565529.2017.1304887.

Miller, D.D., et al., 2018: Adaptation strategies to climate change in marine systems. *Glob. Change Biol.*, **24**(1), e1–e14, doi:10.1111/gcb.13829.

Milner, J., et al., 2017: Projected health effects of realistic dietary changes to address freshwater constraints in India: a modelling study. *Lancet Planet Health*, **1**(1), e26–e32, doi:10.1016/S2542-5196(17)30001-3.

Miralles-Wilhelm, F., 2021: *Nature-based solutions in agriculture – Sustainable management and conservation of land, water, and biodiversity*. FAO and The Nature Conservancy, Virginia.

Mirzabaev, A., J. Wu, J. Evans, F. García-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Türkeş, R.J. Vázquez, M. Weltz, 2019: Desertification. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Mischke, S., 2020: *Large Asian Lakes in a Changing World: Natural State and Human Impact*. Springer, Berlin Heidelberg, ISBN 978-3030422547.

Mishra, A., et al., 2019: Adaptation to climate change in the Hindu Kush Himalaya: Stronger action urgently needed. In: *The Hindu Kush Himalaya Assessment*. Springer, Cham, pp. 457–490.

Mishra, B., A. Mansoor, C. Saraswat and A. Gautam, 2019: Climate change adaptation through optimal stormwater capture measures. *APN Sci Bull*, **9**(1). https://doi.org/10.30852/sb.2019.590.

Mishra, D. and N.C. Sahu, 2014: Economic Impact of Climate Change on Agriculture Sector of Coastal Odisha. *APCBEE Proc.*, **10**, 241–245, doi:10.1016/j.apcbee.2014.10.046.

Mishra, H.S., 2020: Sustainable Development Goals and Disaster Risk Reduction, Targets and Challenges for India. In: *Disaster Management for 2030 Agenda of the SDG* [Malhotra, V.K., R.L.S. Fernando and N.P. Haran(eds.)]. Springer, Singapore, pp. 59–76. ISBN 978-9811543241.

Mishra, V., A.R. Ganguly, B. Nijssen and D.P. Lettenmaier, 2015: Changes in observed climate extremes in global urban areas. *Environ. Res. Lett.*, **10**(2), 24005, doi:10.1088/1748-9326/10/2/024005.

Mishra, V. and R. Lilhare, 2016: Hydrologic sensitivity of Indian sub-continental river basins to climate change. *Glob. Planet. Change.*, **139**, 78–96.

Mishra, V., S. Mukherjee, R. Kumar and D.A. Stone, 2017: Heat wave exposure in India in current, 1.5°C, and 2.0°C worlds. *Environ. Res. Lett.*, **12**(12), doi:10.1088/1748-9326/aa9388.

Mistry, J. and A. Berardi, 2016: Bridging indigenous and scientific knowledge. *Science*, **352**(6291), 1274, doi:10.1126/science.aaf1160.

Mitchell, D., S. Enemark and P. van der Molen, 2015: *Climate resilient urban development: Why responsible land governance is important*.

Mitra, B.K., D. Sharma, X. Zhou and R. Dasgupta, 2021: Assessment of the Impacts of Spatial Water Resource Variability on Energy Planning in the Ganges River Basin under Climate Change Scenarios. *Sustainability*, **13**(13), 7273.

Mitra, S., A. Markandya and N. B. Pham, 2017: *Improving Irrigation Water Use Efficiency Holds the Key to Tackling Water Scarcity in South Asia: Technical Potential and Financing Options*. Institute for Global Environmental Strategies, Hayama.

Mochizuki, Y. and A. Bryan, 2015: Climate Change Education in the Context of Education for Sustainable Development: Rationale and Principles. *J. Educ. Sustain. Dev.*, **9**(1), 4–26, doi:10.1177/0973408215569109.

Modarres, R. and S. Sadeghi, 2018: Spatial and temporal trends of dust storms across desert regions of Iran. *Nat. Hazards*, **90**(1), 101–114, doi:10.1007/s11069-017-3035-8.

Moellendorf, D., 2015: Climate change justice. In: *Philosophy Compass*, pp. 173–186.

Mohanty, B., M. Scherfler and V. Devatha, 2012: *Lifestyle Choices and Societal Behavior Changes as Local Climate Strategy*. ADBI Working Paper Series 398.

Moiseev, P.A., I.K. Gaisin, M.O. Bubnov and O.O. Moiseeva, 2018: Dynamics of Tree Vegetation in Steppificated Areas on the Slopes of the Southern Kraka Massif during the Past 80 Years. *Russ. J. Ecol.*, **49**(2), 190–195, doi:10.1134/S1067413618020108.

Moniruzzaman, S., 2015: Crop choice as climate change adaptation: Evidence from Bangladesh. *Ecol. Econ.*, **118**, 90–98, doi:10.1016/j.ecolecon.2015.07.012.

Montesclaros, J.M.L. and P.S. Teng, 2021: Agriculture and Food Security in Asia. In: *Climate Change, Disaster Risks, and Human Security: Asian Experience and Perspectives* [Pulhin, J.M., M. Inoue and R. Shaw(eds.)]. Springer, Singapore, pp. 137–168. ISBN 978-9811588525.

Mora, C., et al., 2018: Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions. *Nat. Clim. Change*, **8**(12), 1062.

Morchain, D., G. Prati, F. Kelsey and L. Ravon, 2015: What if gender became an essential, standard element of Vulnerability Assessments? *Gend. Dev.*, **23**(3), 481–496, doi:10.1080/13552074.2015.1096620.

Mordkovich, V.G., S. Khudyaev, I. Lyubechanskii and D.R. Yu, 2020: Zoological Indication of Climate Change in the Central Kazakh Steppe Compared to the Middle of the 20th Century Using the Example of Carabid and Tenebrionid Beetles. *Contemp. Probl. Ecol.*, **13**, 443–468, doi:10.1134/S1995425520050078.

Mori, N., et al., 2021a: Future projection of maximum potential storm surge height at three major bays in Japan using the maximum potential intensity of a tropical cyclone. *Clim. Change*, **164**(3), 1–18.

Mori, N., S. Nakajo, S. Iwamura and Y. Shibutani, 2018: Projection of decrease in Japanese beaches due to climate change using a geographic database. *Coast. Eng. J.*, 239–246.

Mori, N. and T. Takemi, 2016: Impact assessment of coastal hazards due to future changes of tropical cyclones in the North Pacific Ocean. *Weather. Clim. Extrem.*, **11**, 53–69, doi:10.1016/j.wace.2015.09.002.

Mori, N., et al., 2021b: Recent nationwide climate change impact assessments of natural hazards in Japan and East Asia. *Weather. Clim. Extrem.*, **32**, 100309, doi:10.1016/j.wace.2021.100309.

Morita, S., H. Wada and Y. Matsue, 2016: Countermeasures for heat damage in rice grain quality under climate change. *Plant. Prod. Sci.*, **19**(1), 1–11, doi:10.1080/1343943x.2015.1128114.

Mortreux, C. and J. Barnett, 2017: Adaptive capacity: exploring the research frontier. *WIREs Clim. Chang.*, 1–12, doi:10.1002/wcc.467.

Mosavi, S.H., S. Soltani and S. Khalilian, 2020: Coping with climate change in agriculture: Evidence from Hamadan-Bahar plain in Iran. *Agric. Water Manag.*, **241**, doi:10.1016/j.agwat.2020.106332.

Moskovchenko, D.V., S.P. Aref'ev, M.D. Moskovchenko and A.A. Yurtaev, 2020: Spatiotemporal Analysis of Wildfires in the Forest Tundra of Western Siberia. *Contemp. Probl. Ecol.*, **13**(2), 193–203, doi:10.1134/S1995425520020092.

Motone, K., et al., 2018: Protection of Coral Larvae from Thermally Induced Oxidative Stress by Redox Nanoparticles. *Mar. Biotechnol.*, **20**(4), 542–548, doi:10.1007/s10126-018-9825-5.

Motone, K., et al., 2020: A Zeaxanthin-Producing Bacterium Isolated from the Algal Phycosphere Protects Coral Endosymbionts from Environmental Stress. *mBio*, **11**(1), 13, doi:10.1128/mBio.01019-19.

Mubaya, C.P. and P. Mafongoya, 2017: The role of institutions in managing local level climate change adaptation in semi-arid Zimbabwe. *Clim. Risk Manag.*, **16**, 93–105, doi:10.1016/j.crm.2017.03.003.

Mukherjee, A., 2018: Overview of the groundwater of South Asia. In: *Groundwater of South Asia*. Springer, Berlin Heidelberg, pp. 3–20.

Mukherjee, K., et al., 2017: Surge-type glaciers in the Tien Shan (Central Asia). *Arct. Antarct. Alp. Res.*, **49**(1), 147–171, doi:10.1657/aaar0016-021.

Mukul, S.A., et al., 2019: Combined effects of climate change and sea-level rise project dramatic habitat loss of the globally endangered Bengal tiger in the Bangladesh Sundarbans. *Sci. Total. Environ.*, **663**, 830–840, doi:10.1016/j.scitotenv.2019.01.383.

Müller, B., L. Johnson and D. Kreuer, 2017: Maladaptive outcomes of climate insurance in agriculture. *Glob. Environ. Chang.*, **46**, 23–33.

Müller, M., et al., 2016: How do soil properties affect alpine treelines? General principles in a global perspective and novel findings from Rolwaling Himal, Nepal. *Prog. Phys. Geogr. Environ.*, **40**(1), 135–160, doi:10.1177/0309133315615802.

Murari, K.K., et al., 2015: Intensification of future severe heat waves in India and their effect on heat stress and mortality. *Reg. Environ. Change*, **15**(4), 569–579.

Nabavi, S.O., L. Haimberger and C. Samimi, 2016: Climatology of dust distribution over West Asia from homogenized remote sensing data. *Aeolian Res.*, **21**, 93–107.

Nahiduzzaman, K.M., A.S. Aldosary and M.T. Rahman, 2015: Flood induced vulnerability in strategic plan making process of Riyadh city. *Habitat Int.*, **49**, 375–385, doi:10.1016/j.habitatint.2015.05.034.

Nakamura, H., H. Umeki and T. Kato, 2017: Importance of communication and knowledge of disasters in community-based disaster-prevention meetings. *Saf. Sci.*, **99**, 235–243, doi:10.1016/j.ssci.2016.08.024.

Nakano, M., M. Matsueda and M. Sugi, 2013: Future projections of heat waves around Japan simulated by CMIP3 and high-resolution Meteorological Research Institute atmospheric climate models. *J. Geophys. Res. Atmos.*, **118**(8), 3097–3109.

Nakayama, S.-I., A. Takasuka, M. Ichinokawa and H. Okamura, 2018: Climate change and interspecific interactions drive species alternations between anchovy and sardine in the western North Pacific: Detection of causality by convergent cross mapping. *Fish. Oceanogr.*, **27**(4), 312–322, doi:10.1111/fog.12254.

Nanajkar, M., K. De and B. Ingole, 2019: Coral reef restoration - A way forward to offset the coastal development impacts on Indian coral reefs. *Mar. Pollut. Bull.*, **149**, 110504, doi:10.1016/j.marpolbul.2019.110504.

Nandi, I., A. Tewari and K. Shah, 2016: Evolving human dimensions and the need for continuous health assessment of Indian rivers. *Curr. Sci.*, **111**, 263–271.

Nangia, R., 2019: Securing Asia's energy future with regional integration. *Energy Policy*, **132**, 1262–1273.

Nanlohy, H., A.N. Bambang, Ambariyanto and S. Hutabarat, 2015: Coastal Communities Knowledge Level on Climate Change as a Consideration in Mangrove Ecosystems Management in the Kotania Bay, West Seram Regency. *Procedia Environ. Sci.*, **23**, 157–163, doi:10.1016/j.proenv.2015.01.024.

Nara, P., G.-G. Mao and T.-B. Yen, 2014: Climate Change Impacts on Agricultural Products in Thailand: A Case Study of Thai Rice at the Chao Phraya River Basin. *APCBEE Proc*, **8**, 136–140, doi:10.1016/j.apcbee.2014.03.015.

Narender, A. and M. Sethi, 2018: Mainstreaming co-benefits in urban policy, governance and finance. In: *Mainstreaming Climate Co-Benefits in Indian Cities*. Springer, Berlin Heidelberg, pp. 341–373.

Narksompong, J. and S. Limjirakan, 2015: Youth Participation in Climate Change for Sustainable Engagement. *Rev. Eur. Comp. Int. Environ. Law*, **24**(2), 171–181, doi:10.1111/reel.12121.

NASA, *Powerful Dust Storms in Western Asia*. NASA earth observatory, https://earthobservatory.nasa.gov/images/92212/powerful-dust-storms-in-western-asia. accessed on October 1, 2021.

Nasim, W., et al., 2018: Future risk assessment by estimating historical heat wave trends with projected heat accumulation using SimCLIM climate model in Pakistan. *Atmos. Res.*, **205**, 118–133.

Nations, U., 2019: *Climate action and support trends*. 40 pp.

Nehru, P. and P. Balasubramanian, 2018: Mangrove species diversity and composition in the successional habitats of Nicobar Islands, India: A post-tsunami and subsidence scenario. *For. Ecol. Manag.*, **427**, 70–77, doi:10.1016/j.foreco.2018.05.063.

Nepal, S., 2016: Impacts of climate change on the hydrological regime of the Koshi river basin in the Himalayan region. *J. Hydro Environ. Res.*, **10**, 76–89.

Nepal, S., W.-A. Flügel and A.B. Shrestha, 2014: Upstream-downstream linkages of hydrological processes in the Himalayan region. *Ecol. Proc.*, **3**(1), 19.

Nepal, S., et al., 2019: Achieving water security in Nepal through unravelling the water-energy-agriculture nexus. *Int. J. Water Resour. Dev.*, 1–27.

Nepal, S., et al., 2021: Space–time variability in soil moisture droughts in the Himalayan region. *Hydrol. Earth Syst. Sci.*, **25**(4), 1761–1783.

Nepal, S. and A.B. Shrestha, 2015: Impact of climate change on the hydrological regime of the Indus, Ganges and Brahmaputra river basins: a review of the literature. *Int. J. Water Resour. Dev.*, **31**(2), 201–218, doi:10.1080/07900627.2015.1030494.

Neufeldt, H., et al., 2018: *The Adaptation Gap Report 2018*.

Neumann, B., A.T. Vafeidis, J. Zimmermann and R.J. Nicholls, 2015: Future coastal population growth and exposure to sea-level rise and coastal flooding-a global assessment. *PLoS ONE*, **10**(3), e118571.

Newell, R., B. Prest and S. Sexton, 2018: *The GDP-Temperature Relationship: Implications for Climate Change Damages*. RFF Working Paper.

Ngin, C., C. Chhom and A. Neef, 2020: Climate change impacts and disaster resilience among micro businesses in the tourism and hospitality sector: The case of Kratie, Cambodia. *Environ. Res.*, **186**, 109557.

Nguyen, K.A.T. and C.M. Jolly, 2019: Steps Toward the Establishment of a Commercial Aquaculture Insurance Program: Lessons from an Assessment of the Vietnamese Pilot Insurance Program. *Rev. Fish. Sci. Aquac.*, **27**(1), 72–87.

Nguyen, T.P.L., et al., 2016: Perceiving to learn or learning to perceive? Understanding farmers' perceptions and adaptation to climate uncertainties. *Agric. Syst.*, **143**, 205–216, doi:10.1016/j.agsy.2016.01.001.

Nguyen, T.Q., A.K. Das and L.T. Tran, 2019: *NEO Smart Contract for Drought-Based Insurance*, 1–4.

Nicholls, R.J., J. Hinkel, D. Lincke and T. van der Pol, 2019: *Global investment costs for coastal defense through the 21st century*. The World Bank, Washington DC, USA. ISBN 18139450.

Nicholls, R.J., et al., 2021: A global analysis of subsidence, relative sea-level change and coastal flood exposure. *Nat. Clim. Chang.*, **11**(4), 338–342.

Nie, X.Q., et al., 2019: Storage, patterns and controls of soil organic carbon in the alpine shrubland in the Three Rivers Source Region on the Qinghai-Tibetan Plateau. *Catena*, **178**, 154–162, doi:10.1016/j.catena.2019.03.019.

Nie, Y., et al., 2021: Glacial change and hydrological implications in the Himalaya and Karakoram. *Nat. Rev. Earth Environ.*, **2**(2), 91–106.

Niggol Seo, S. and L.A. Bakkensen, 2017: Is Tropical Cyclone Surge, Not Intensity, What Kills so Many People in South Asia? *Weather. Clim. Soc.*, **9**(2), 171–181, doi:10.1175/WCAS-D-16-0059.1.

Nishiura, O., et al., 2020: An Assessment of Global Macroeconomic Impacts Caused by Sea Level Rise Using the Framework of Shared Socioeconomic Pathways and Representative Concentration Pathways. *Sustainability*, **12**(9), 3737.

Nizami, A., J. Ali and M. Zulfiqar, 2019: Climate Change, Hydro-Meteorological Hazards and Adaptation for Sustainable Livelihood in Chitral Pakistan. *Sarhad J. Agric.*, **35**(2), 432–441, doi:10.17582/journal.sja/2019/35.2.432.441.

Nkoana, E., A. Verbruggen and J. Hugé, 2018: Climate change adaptation tools at the community level: An integrated literature review. *Sustainability*, **10**(3), 796.

NOAA, 2010: *NOAA Large Marine Ecosystem Program Report*.

Nong, D., 2019: Potential economic impacts of global wild catch fishery decline in Southeast Asia and South America. *Econ. Anal. Policy.*, **62**, doi:10.1016/j.eap.2019.04.004.

Nordgren, J., M. Stults and S. Meerow, 2016: Supporting local climate change adaptation: Where we are and where we need to go. *Environ. Sci. Policy*, **66**, 344–352, doi:10.1016/j.envsci.2016.05.006.

Nordlund, L.M., R.K.F. Unsworth, M. Gullstrom and L.C. Cullen-Unsworth, 2018: Global significance of seagrass fishery activity. *Fish. Fish.*, **19**(3), 399–412, doi:10.1111/faf.12259.

Nüsser, M., et al., 2019: Socio-hydrology of "artificial glaciers" in Ladakh, India: assessing adaptive strategies in a changing cryosphere. *Reg. Environ. Change*, **19**(5), 1327–1337.

Nüsser, M. and S. Schmidt, 2017: Nanga Parbat revisited: Evolution and dynamics of sociohydrological interactions in the Northwestern Himalaya. *Ann. Am. Assoc. Geogr.*, **107**(2), 403–415.

O'Brien, C., et al., 2018: *Shock-Responsive Social Protection Systems Research Synthesis Report*. Oxford Policy Management, Oxford, UK.

Ober, K., 2019: *The links between climate change, disasters, migration, and social resilience in Asia: A literature review*. Asian Development Bank Economics Working Paper Series, (586).

OECD, 2017a: *Social Protection System Review of Cambodia*. OECD Development Pathways. Paris, France.

OECD, 2017b: *Technology and innovation in the insurance sector*. OECD, Paris, France.

Ogasahara, M., H. Kawashima and H. Fujishiro, 2019: How Did Rumors on Twitter Diffuse and Change in Expression? An Investigation of the Process of Spreading Rumors on Twitter during the 2011 Great East Japan Earthquake. *Adv. Human. Comp. Interact.*, 8, doi:10.1155/2019/5103840.

Ohba, M., 2019: The Impact of Global Warming on Wind Energy Resources and Ramp Events in Japan. *Atmosphere*, **10**, 265, doi:10.3390/atmos10050265.

Ohba, M. and H. Kawase, 2020: Rain-on-Snow events in Japan as projected by a large ensemble of regional climate simulations. *Clim. Dyn.*, **55**(9), 2785–2800, doi:10.1007/s00382-020-05419-8.

Ohba, M. and S. Sugimoto, 2020: Impacts of climate change on heavy wet snowfall in Japan. *Clim. Dyn.*, **54**(5), 3151–3164, doi:10.1007/s00382-020-05163-z.

Ojha, H.R., et al., 2014: Is South Asian agriculture adapting to climate change? Evidence from the Indo-Gangetic Plains. *Agroecol. Sustain. Food Syst.*, **38**(5), 505–531.

Okereke, P., 2016: Climate justice and the international regime: before, during and after Paris. *Wiley Interdiscip. Rev. Clim. Chang.*, doi:10.1002/wcc.419.

Oktari, R.S., et al., 2015: A conceptual model of a school–community collaborative network in enhancing coastal community resilience in Banda Aceh, Indonesia. *Int. J. Dis. Risk Reduct.*, **12**, 300–310, doi:10.1016/j.ijdrr.2015.02.006.

Oliver, E.C.J., et al., 2017: The unprecedented 2015/16 Tasman Sea marine heatwave. *Nat. Commun.*, **8**, 12, doi:10.1038/ncomms16101.

Oliver, E.C.J., et al., 2019: Projected Marine Heatwaves in the 21st Century and the Potential for Ecological Impact. *Front. Mar. Sci.*, **6**, 12, doi:10.3389/fmars.2019.00734.

Olson, D.M., et al., 2001: Terrestrial Ecoregions of the World: A New Map of Life on EarthA new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience*, **51**(11), 933–938.

Olsson, L., et al., 2014: *Livelihoods and poverty Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, NY, 793–832.

Omer, A., et al., 2020: Water scarcity in the Yellow River Basin under future climate change and human activities. *Sci. Total. Environ.*, **749**, 141446.

Ong, R.T., M.S. Rodriguez, E.V. Epino, J.A.G. Aying and G. L. B. L Lamparas, R. Bagares (eds.), *Automated waterlevel monitoring using real-time observation (AleRTO)*.

Onosuka, D., et al., 2019: Future projections of temperature-related excess out-of-hospital cardiac arrest under climate change scenarios in Japan. *Sci. Total. Environ.*, **682**, 333–339, doi:10.1016/j.scitotenv.2019.05.196.

Onozuka, D., et al., 2019: Modeling Future Projections of Temperature-Related Excess Morbidity due to Infectious Gastroenteritis under Climate Change Conditions in Japan. *Environ. Health Perspect.*, **127**(7), 77006, doi:10.1289/EHP4731.

Onozuka, D. and A. Hagihara, 2015: All-Cause and Cause-Specific Risk of Emergency Transport Attributable to Temperature: A Nationwide Study. *Medicine*, **94**(51), e2259, doi:10.1097/md.0000000000002259.

Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-Elgawad, R. Cai, M. Cifuentes-Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac and Z. Sebesvari, 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska,

K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Otoda, T., et al., 2013: Frequent fires may alter the future composition of the boreal forest in northern Mongolia. *J. For. Res.*, **18**(3), 246–255, doi:10.1007/s10310-012-0345-2.

Otto, I.M., et al., 2017: Social vulnerability to climate change: a review of concepts and evidence. *Reg. Environ. Change*, **17**, 1651–1662, doi:10.1007/S10113-017-1105-9.

Owen, G., 2020: What makes climate change adaptation effective? A systematic review of the literature. *Glob. Environ. Chang.*, **62**, 102071.

Padgham, J., Jason and K. Dietrich, 2015: Managing change and building resilience: A multi-stressor analysis of urban and peri-urban agriculture in Africa and Asia. *Urban Clim.*, **12**, 183–204.

Pahl-Wostl, C., 2019: Governance of the water-energy-food security nexus: A multi-level coordination challenge. *Environ. Sci. Policy*, **92**, 356–367, doi:10.1016/j.envsci.2017.07.017.

Pal, J.S. and E.A.B. Eltahir, 2016: Future temperature in southwest Asia projected to exceed a threshold for human adaptability. *Nat. Clim. Change*, **6**(2), 197.

Paling, a. F. M. a. K. M. a. v. K. M, 2009: Seagrass restoration. In: *Coastal wetlands: an integrated ecosystems approach*, pp. 687–713.

Palmer, M. A., et al., 2015: Water security: Gray or green? *Science*, **349**(6248), 584–585.

Pan, S.L., M. Cui and J. Qian, 2020: Information resource orchestration during the COVID-19 pandemic: A study of community lockdowns in China. *Int. J. Inf. Manage*, **102143**.

Panda, D.K., A. AghaKouchak and S.K. Ambast, 2017: Increasing heat waves and warm spells in India, observed from a multiaspect framework. *J. Geophys. Res. Atmos.*, **122**(7), 3837–3858, doi:10.1002/2016JD026292.

Panda, R.M. and M.D. Behera, 2019: Assessing harmony in distribution patterns of plant invasions: a case study of two invasive alien species in India. *Biodivers. Conserv.*, **28**(8-9), 2245–2258, doi:10.1007/s10531-018-1640-9.

Pang, Y., et al., 2018: Variability of coastal cephalopods in overexploited China Seas under climate change with implications on fisheries management. *Fish. Res.*, **208**, 22–33, doi:10.1016/j.fishres.2018.07.004.

Panpeng, J. and M. Ahmad, 2017: Vulnerability of Fishing Communities from Sea-Level Change: A Study of Laemsing District in Chanthaburi Province, Thailand. *Sustainability*, **9**(8), doi:10.3390/su9081388.

Panthi, S., A. Bräuning, Z.-K. Zhou and Z.-X. Fan, 2017: Tree rings reveal recent intensified spring drought in the central Himalaya, Nepal. *Glob. Planet. Change.*, **157**, 26–34.

Parappurathu, S., et al., 2017: What ails fisheries insurance in India? An assessment of issues, challenges and future potential. *Mar. Policy.*, **86**, 144–155.

Parazoo, N.C., et al., 2018: Detecting the permafrost carbon feedback: talik formation and increased cold-season respiration as precursors to sink-to-source transitions. *Cryosphere*, **12**(1), 123–144.

Park, J.J., et al., 2014: Predicting the potential geographic distribution of Thrips palmi in Korea, using the CLIMEX model. *Entomol. Res.*, **44**(2), 47–57, doi:10.1111/1748-5967.12049.

Parkinson, S., et al., 2019: Balancing clean water-climate change mitigation trade-offs. *Environ. Res. Lett.*, **14**(1), 14009.

Patankar, A. and A. Patwardhan, 2016: Estimating the uninsured losses due to extreme weather events and implications for informal sector vulnerability: a case study of Mumbai, India. *Nat. Hazards*, **80**, 285–310, doi:10.1007/s11069-015-1968-3.

Patil, S., B. Dhanya, R.S. Vanjari and S. Purushothaman, 2019: Urbanisation and new agroecologies: The story of Bengaluru's peripheries. *Econ. Polit. Wkly.*, **53**(41), 71–77.

Patnaik, S. and M. Swain, 2017: Agrarian Distress and Crop Insurance in Odisha: Some Empirical Findings from Kalahandi District of Odisha. *J. Rural Dev.*, **36**(3), 353–378.

Paul, A., R. Ray, A Kamila, S. Jana, 2017: *Mangrove Degradation in the Sundarbans*, 357–392. doi:10.1007/978-3-319-56179-0_11.

Peixoto, R.S., et al., 2017: Beneficial Microorganisms for Corals (BMC): Proposed Mechanisms for Coral Health and Resilience. *Front. Microbiol.*, **8**, 16, doi:10.3389/fmicb.2017.00341.

Peng, W., J.N. Yang, X. Lu and D.L. Mauzerall, 2018: Potential co-benefits of electrification for air quality, health, and CO2 mitigation in 2030 China. *Appl. Energ.*, **218**, 511–519, doi:10.1016/j.apenergy.2018.02.048.

Pereira, J.J., et al., 2019: Appraising slow onset hazards for loss and damage: Case studies in Southeast Asia. *Arch. Psychiatr. Nurs.*, **9**(1), 45–51.

Perera, N.G.R. and R. Emmanuel, 2018: A "Local Climate Zone" based approach to urban planning in Colombo, Sri Lanka. *Urban Clim.*, **23**, 188–203, doi:10.1016/j.uclim.2016.11.006.

Perkins-Kirkpatrick, S.E. and S.C. Lewis, 2020: Increasing trends in regional heatwaves. *Nat. Commun.*, **11**(3357), doi:10.1038/s41467-020-16970-7.

Pervin, I. A., et al., 2020: Adapting to urban flooding: a case of two cities in South Asia. *Water Policy*, **22**(S1), 162–188, doi:10.2166/wp.2019.174.

Phan, S.M., H.T.T. Nguyen, T.K. Nguyen and C. Lovelock, 2019: Modelling above ground biomass accumulation of mangrove plantations in Vietnam. *For. Ecol. Manag.*, **432**, 376–386, doi:10.1016/j.foreco.2018.09.028.

Phuong, L.T.H., G.R. Biesbroek, L.T.H. Sen and A.E. Wals, 2018a: Understanding smallholder farmers' capacity to respond to climate change in a coastal community in Central Vietnam. *Clim. Dev.*, **10**(8), 701–716.

Phuong, L.T.H., G.R. Biesbroek and A.E. Wals, 2018b: Barriers and enablers to climate change adaptation in hierarchical governance systems: the case of Vietnam. *J. Environ. Policy Plan.*, **20**(4), 518–532.

Piao, S.L., et al., 2015: Detection and attribution of vegetation greening trend in China over the last 30 years. *Glob. Change Biol.*, **21**(4), 1601–1609, doi:10.1111/gcb.12795.

Pimm, S.L., et al., 2015: Emerging Technologies to Conserve Biodiversity. *Trends Ecol. Evol.*, **30**(11), 685–696, doi:10.1016/j.tree.2015.08.008.

Piya, L., K.L. Maharjan and N.P. Joshi, 2013: Determinants of adaptation practices to climate change by Chepang households in the rural Mid-Hills of Nepal. *Reg. Environ. Change*, **13**(2), 437–447, doi:10.1007/s10113-012-0359-5.

Ponomarev, E.I., V.I. Kharuk and K.J. Ranson, 2016: Wildfires dynamics in Siberian larch forests. *Forests*, **7**(6), doi:10.3390/f7060125.

Ponomarev, E.I., E. G. Shvetsov and V.I. Kharuk, 2018: The intensity of wildfires in fire emissions estimates. *Russ. J. Ecol.*, **49**(6), 492–499, doi:10.1134/s1067413618060097.

Popova, E.N., 2014: The Influence of Climatic Changes on Range Expansion and Phenology of the Colorado Potato Beetle (Leptinotarsa Decemlineata, Coleoptera, Chrysomelidae) in the Territory of Russia. *Zool Zh*, **93**(4), 537–548, doi:10.7868/S0044513414020093.

Popova, E.N., S.M. Semenov and I.O. Popov, 2016: Assessment of possible expansion of the climatic range of Italian locust (*Calliptamus italicus* L.) in Russia in the 21st century at simulated climate changes. *Russ. Meteorol. Hydro.*, **41**(3), 213–217, doi:10.3103/S1068373916030079.

Porio, E., 2014: Climate Change Vulnerability and Adaptation in Metro Manila: Challenging Governance and Human Security Needs of Urban Poor Communities. *Asian J. Soc. Sci.*, **42**, 75–102, doi:10.1163/15685314-04201006.

Porst, L. and P. Sakdapolrak, 2020: Gendered translocal connectedness: Rural–urban migration, remittances, and social resilience in Thailand. *Popul. Space Place*, **26**(4), e2314.

Pörtner, H.O., et al., 2021: *Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change*. IPBES secretariat, Bonn, Germany, doi:10.5281/zenodo.4659158.

Pospelova, E.B., I.N. Pospelov and M.V. Orlov, 2017: Climate change in Eastern Taimyr over the last 80 years and the warming impact on biodiversity and ecosystem processes in its territory. *Nat. Conserv. Res.*, **2**(3), 48–60.

Poudel, S. and R. Shaw, 2015: Demographic changes, economic changes and livelihood changes in the HKH Region. In: *Mountain hazards and disaster risk reduction*. Springer, Berlin Heidelberg, pp. 105–123.

Poudel, S. and R. Shaw, 2016: The Relationships between Climate Variability and Crop Yield in a Mountainous Environment: A Case Study in Lamjung District, Nepal. *Climate*, **4**(1), doi:10.3390/cli4010013.

Prabhakar, S., et al., 2018: Benefits and costs of risk insurance in selected countries of Asia. *APN Sci. Bull.*, **8**(1. Asia-Pacific Network for Global Change Research. https://doi.org/10.30852/sb.2018.265.

Prabnakorn, S., S. Maskey, F.X. Suryadi and C. de Fraiture, 2018: Rice yield in response to climate trends and drought index in the Mun River Basin, Thailand. *Sci. Total. Environ.*, **621**, 108–119, doi:10.1016/j.scitotenv.2017.11.136.

Prasad, R.S. and R. Sud, 2019: Implementing climate change adaptation: lessons from India's national adaptation fund on climate change (NAFCC). *Clim. Policy*, **19**(3), 354–366.

Pritchard, H.D., 2019: Asia's shrinking glaciers protect large populations from drought stress. *Nature*, **569**(7758), 649–654, doi:10.1038/s41586-019-1240-1.

Pritchard, M., A. Rahman and M. Alam, 2015: Empowering Women on the Chars: Increasing Resilience to Disasters and Building Sustainable Livelihoods. *J. Agric. Sci. Technol. A*, **5**(4), doi:10.17265/2161-6256/2015.04.003.

Prokosheva, I. V., 2017: Dynamics of phenology process in mountain taiga zone of Vishera nature reserve (Northern Urals) under the influence of climatic changes. *Probl. Ecol. Monit. Ecosyst. Model.*, **28**, 40–55, doi:10.21513/0207-2564-2017-2-40-55.

Prudhomme, C., et al., 2014: Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. *Proc. Natl. Acad. Sci.*, **111**(9), 3262–3267.

Puan, C.L., et al., 2019: Influence of landscape matrix on urban bird abundance: evidence from Malaysian citizen science data. *J. Asia Pacific Biodivers.*, **12**(3), 369–375, doi:10.1016/j.japb.2019.03.008.

Pulhin, J., R.J. Peras, F. Pulhin and D. Gevaña, 2016: Farmers' Adaptation to Climate Variability: Assessment of Effectiveness and Barriers Based on Local Experience in Southern Philippines. *J. Environ. Sci. Manag.*

Puma, M.J., S. Bose, S.Y. Chon and B.I. Cook, 2015: Assessing the evolving fragility of the global food system. *Environ. Res. Lett.*, **10**(2), 24007.

Puspa, A., T. Osawa and I.W. Arthana, 2018: Quantitative assessment of vulnerability in aquaculture: climate change impacts on whiteleg shrimp (Litopenaeus vannamei) farming in East Java Province. *IOP Conf. Series Earth Environ. Sci.*, **162**, 12027, doi:10.1088/1755-1315/162/1/012027.

Pycroft, J., J. Abrell and J.C. Ciscar, 2016: The Global Impacts of Extreme Sea-Level Rise: A Comprehensive Economic Assessment. *Environ. Resour. Econ.*, **64**(2), 225–253, doi:10.1007/s10640-014-9866-9.

Pyhälä, A., et al., 2016: Global environmental change: local perceptions, understandings, and explanations. *Ecol. Soc.*, **21**(3), art25, doi:10.5751/ES-08482-210325.

Qin, W., et al., 2018: Comparison of deterministic and data-driven models for solar radiation estimation in China. *Renew. Sustain. Energy Rev.*, **81**, 579–594, doi:10.1016/j.rser.2017.08.037.

Qin, Z., A. DiTommaso, R.S. Wu and H.Y. Huang, 2014: Potential distribution of two Ambrosia species in China under projected climate change. *Weed Res.*, **54**(5), 520–531, doi:10.1111/wre.12100.

Qiu, G.Y., X. Zhang, X. Yu and Z. Zou, 2018: The increasing effects in energy and GHG emission caused by groundwater level declines in North China's main food production plain. *Agric. Water Manag.*, **203**, 138–150, doi:10.1016/j.agwat.2018.03.003.

Quach, A.V., F. Murray and A. Morrison-Saunders, 2015: Perspectives of Farmers and Experts in Ca Mau, Vietnam on the Effects of Climate Change on Shrimp Production. *Int. J. Environ. Sci. Dev.*, **6**(10), 718–726, doi:10.7763/ijesd.2015.V6.687.

Quach, A.V., F. Murray and A. Morrison-Saunders, 2017: The vulnerability of shrimp farming income to climate change events. *Int. J. Clim. Chang. Strateg. Manag.*, **9**(2), 261–280, doi:10.1108/ijccsm-05-2015-0062.

Radhakrishnan, M., et al., 2019: Development of context specific sustainability criteria for selection of plant species for green urban infrastructure: The case of Singapore. *Sustain. Prod. Consum.*, **20**, 316–325, doi:10.1016/j.spc.2019.08.004.

Rafaj, P., et al., 2021: Air quality and health implications of 1.5°C–2°C climate pathways under considerations of ageing population: a multi-model scenario analysis. *Environ. Res. Lett.*, **16**(4), 45005, doi:10.1088/1748-9326/abdf0b.

Rafiq, M., S.A. Romshoo, A.K. Mishra and F. Jalal, 2019: Modelling Chorabari Lake outburst flood, Kedarnath, India. *J. Mt. Sci.*, **16**(1), 64–76.

Ragettli, S., W.W. Immerzeel and F. Pellicciotti, 2016: Contrasting climate change impact on river flows from high-altitude catchments in the Himalayan and Andes Mountains. *Proc. Natl. Acad. Sci.*, **113**(33), 9222–9227.

Rahayu, H.P., et al., 2020: A Micro Scale Study of Climate Change Adaptation and Disaster Risk Reduction in Coastal Urban Strategic Planning for the Jakarta. *Int. J. Dis. Resil. Built Environ.*, **11**(1), 119–133.

Rahman, M.T., A.S. Aldosary, K.M. Nahiduzzaman and I. Reza, 2016: Vulnerability of flash flooding in Riyadh, Saudi Arabia. *Nat. Hazards*, **84**(3), 1807–1830, doi:10.1007/s11069-016-2521-8.

Rahman, S., et al., 2018: Climate change adaptation and disaster risk reduction (DRR) through coastal afforestation in South-Central Coast of Bangladesh. *Manag. Environ. Qual. Int. J.*, **30**(3), 498–517, doi:10.1108/MEQ-01-2018-0021.

Rahut, D.B. and A. Ali, 2018: Impact of climate-change risk-coping strategies on livestock productivity and household welfare: empirical evidence from Pakistan. *Heliyon*, **4**(10), e797, doi:10.1016/j.heliyon.2018.e00797.

Rajan, S.I., 2020: Migrants at a crossroads: COVID-19 and challenges to migration. *Migr. Dev.*, **9**(3), 323–330, doi:10.1080/21632324.2020.1826201.

Raju, E., 2019: Gender as Fundamental to Climate Change Adaptation and Disaster Risk Reduction: Experiences from South Asia. In: *Climate Hazards, Disasters, and Gender Ramifications* [Kinvall, C. and H. Rydstrom. (ed.)]. Routledge, London, pp. 122–137. ISBN 978-1138354364.

Ramaswami, A., et al., 2017: Urban cross-sector actions for carbon mitigation with local health co-benefits in China. *Nat. Clim. Change*, **7**(10), 736, doi:10.1038/Nclimate3373.

Ramesh, R., et al., 2019: Chapter 14 - *Importance of Seagrass Management for Effective Mitigation of Climate Change,* pp.283–299. In: Coastal Management (pp.283-299) doi:10.1016/B978-0-12-810473-6.00015-7.

Ran, L., W. Chun-Jing, H.E. Jian and Z. Zhi-Xiang, 2018: Analysis of geographical distribution of Abies in China under climate change. *Bull. Bot. Res.*, **38**(1), 37–46.

Rana, S.K., et al., 2017: Predicting the impact of climate change on the distribution of two threatened Himalayan medicinal plants of Liliaceae in Nepal. *J. Mt. Sci.*, **14**(3), 558–570, doi:10.1007/s11629-015-3822-1.

Ranagalage, M., R.C. Estoque and Y. Murayama, 2017: An Urban Heat Island Study of the Colombo Metropolitan Area, Sri Lanka, Based on Landsat Data (1997–2017). *ISPRS Int. J. Geo Inform*, **6**(7), doi:10.3390/ijgi6070189.

Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz Carrascal, J. Sillmann, M.B. Sylla, C. Tebaldi, W. Wang, and R. Zaaboul, 2021: Climate Change Information for Regional Impact and for Risk Assessment. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK.

Rani, S., et al., 2020a: Economic valuation and conservation, restoration & management strategies of Saint Martin's coral island, Bangladesh. *Ocean. Coast. Manag.*, **183**, 17, doi:10.1016/j.ocecoaman.2019.105024.

Rani, W.N.M.W.M., K.H. Kamarudin, K. A. Razak and Z.M. Asmawi (eds.), 2020: *Climate Change Adaptation and Disaster Risk Reduction in Urban Development Plans for Resilient Cities*. The First International Conference on Urban Design and Planning. IOP Publishing, Bristol, UK.

Ranith, R. and V. Kripa, 2019: Post-bleaching benthic status on reef sites of Mandapam group of islands and Palk Bay, Indian Ocean following the 2016 bleaching events. *Reg. Stud. Mar. Sci.*, **27**, doi:10.1016/j.rsma.2019.100525.

Rao, N., et al., 2019: Gendered vulnerabilities to climate change: insights from the semi-arid regions of Africa and Asia. *Clim. Dev.*, **11**(1), 14–26.

Rao, N., et al., 2020: Managing risk, changing aspirations and household dynamics: Implications for wellbeing and adaptation in semi-arid Africa and India. *World Dev.*, **125**, 104667.

Rashid, I., et al., 2015: Projected climate change impacts on vegetation distribution over Kashmir Himalayas. *Clim. Change*, **132**(4), 601–613, doi:10.1007/s10584-015-1456-5.

Rasul, G., 2014: Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region. *Environ. Sci. Policy*, **39**, 35–48, doi:10.1016/j.envsci.2014.01.010.

Rasul, G., 2016: Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environ. Dev.*, **18**, 14–25.

Rasul, G. and D. Molden, 2019: The Global Social and Economic Consequences of Mountain Cryospheric Change. *Front. Environ. Sci.* https://doi.org/10.3389/fenvs.2019.00091.

Rasul, G., B. Pasakhala, A. Mishra and S. Pant, 2020: Adaptation to mountain cryosphere change: issues and challenges. *Clim. Dev.*, **12**(4), 297–309.

Rasul, G. and B. Sharma, 2014: Water, Food, and Energy Nexus in South Asia: Implications for Adaption to Climate Change. In: *Handbook of Climate Change Adaptation*, pp. 1–18. ISBN 978-3642404559.

Rataj, E., K. Kunzweiler and S. Garthus-Niegel, 2016: Extreme weather events in developing countries and related injuries and mental health disorders - a systematic review. *BMC Public Health*, **16**(1), 1020, doi:10.1186/s12889-016-3692-7.

Rauf, S., et al., 2017: How hard they hit? Perception, adaptation and public health implications of heat waves in urban and peri-urban Pakistan. *Environ. Sci. Pollut. Res. Int.*, **24**(11), 10630–10639, doi:10.1007/s11356-017-8756-4.

Raupach, M.R., et al., 2014: Sharing a quota on cumulative carbon emissions. *Nat. Clim. Change*, **4**(10), 873–879, doi:10.1038/nclimate2384.

Rautela, P. and B. Karki, 2015: Weather Forecasting: Traditional Knowledge of the People of Uttarakhand Himalaya. *J. Geogr. Environ. Earth Sci. Int.*, **3**(3), 1–14, doi:10.9734/jgeesi/2015/19016.

Ravera, F., et al., 2019: Gendered agrobiodiversity management and adaptation to climate change: differentiated strategies in two marginal rural areas of India. *Agric. Hum. Values*, **36**, 455–474, doi:10.1007/s10460-018-09907-w.

Ray, B. and R. Shaw, 2019: *Urban Drought - Emerging Water Challenges in Asia*. Springer, Berlin Heidelberg.

Reddy, C.S., et al., 2020: Identification and characterization of spatio-temporal hotspots of forest fires in South Asia. *Environ. Monit. Assess.*, **191**(S3), doi:10.1007/s10661-019-7695-6.

Reed, S.O., et al., 2015: Resilience projects as experiments: implementing climate change resilience in Asian cities. *Clim. Dev.*, **7**(5), 469–480.

Rees, W.G., et al., 2020: Is subarctic forest advance able to keep pace with climate change? *Glob. Change Biol.*, **26**(7), 3965–3977, doi:10.1111/gcb.15113.

Ren, C., et al., 2018: Creating breathing cities by adopting urban ventilation assessment and wind corridor plan – The implementation in Chinese cities. *J. Wind. Eng. Ind. Aerodyn.*, **182**, 170–188.

Rentschler, J., M. Obolensky and M. Kornejew, 2019: *Candle in the wind? Energy system resilience to natural shocks*. The World Bank, Washington DC, USA. ISBN 18139450.

Revi, A., 2017: Re-imagining the United Nations' Response to a Twenty-first-century Urban World. *Urbanisation*. https://doi.org/10.1177/2455747117740438.

Revi, A., et al., 2014: Towards transformative adaptation in cities: the IPCC's Fifth Assessment. *Environ. Urban.*, **26**(1), 11–28.

Reyer, C., I.M. Otto, S. Adams, et al., 2017: Climate change impacts in Central Asia and their implications for development. *Reg. Environ. Change*, **17**, 1639–1650, doi:10.1007/s10113-015-0893-z.

Reyes, D.D. and J.L. Lu, 2016: Gender dimension in disaster situations: A case study of flood prone women in Malabon City, Metro Manila. *Int. J. Disaster Risk Reduct.*, **15**, 162–168, doi:10.1016/j.ijdrr.2015.11.001.

Reynaud, A., C. Aubert and M.H. Nguyen, 2013: Living with floods: Protective behaviours and risk perception of vietnamese households. *Geneva Pap. Risk Insur. Issues Pract.*, **38**(3), 547–579, doi:10.1057/gpp.2013.16.

Rezaei, E.E. and A. Lashkari, 2018: The consequences of change in management practices on maize yield under climate warming in Iran. *Theor. Appl. Climatol.*, doi:10.1007/s00704-018-2637-8.

Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang, 2013: *Observations: Ocean. In: Climate Change 2013*: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA

Ricart, A.M., et al., 2020: High variability of Blue Carbon storage in seagrass meadows at the estuary scale. *Sci. Rep.*, **10**(1), 12, doi:10.1038/s41598-020-62639-y.

Richards, D.R. and D.A. Friess, 2016: Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012. *Proc. Natl. Acad. Sci. U. S. A.*, **113**(2), 344–349, doi:10.1073/pnas.1510272113.

Riegl, B., et al., 2018: Population collapse dynamics in Acropora downingi, an Arabian/Persian Gulf ecosystem-engineering coral, linked to rising temperature. *Glob. Change Biol.*, **24**(6), 2447–2462, doi:10.1111/gcb.14114.

Rigaud, K.K., et al., 2018: *Groundswell: Preparing for Internal Climate Migra Organisations.* World Banktion. Washington DC, USA.

Ringler, C., A. Bhaduri and R. Lawford, 2013: The nexus across water, energy, land and food (WELF): potential for improved resource use efficiency? *Curr. Opin. Environ. Sustain.*, **5**(6), 617–624, doi:10.1016/j.cosust.2013.11.002.

Ringler, C., et al., 2016: Global linkages among energy, food and water: an economic assessment. *J. Environ. Stud. Sci.*, **6**(1), 161–171, doi:10.1007/s13412-016-0386-5.

Ritphring, S., C. Somphong, K. Udo and S. Kazama, 2018: Projections of future beach loss due to sea level rise for sandy beaches along Thailand's coastlines. *J. Coast. Res.*, 541–545.

Roberts, E. and M. Pelling, 2016: Climate change-related loss and damage: translating the global policy agenda for national policy processes. *Clim. Dev.*, **10**(1), 4–17, doi:10.1080/17565529.2016.1184608.

Roberts, S.L., et al., 2018: Diatom evidence of 20th century ecosystem change in Lake Baikal, Siberia. *PLoS ONE*, **13**(12), doi:10.1371/journal.pone.0208765.

Rode, K.D., C.T. Robbins, L. Nelson and S.C. Amstrup, 2015a: Can polar bears use terrestrial foods to offset lost ice-based hunting opportunities? *Front. Ecol. Environ.*, **13**(3), 138–145, doi:10.1890/140202.

Rode, K.D., et al., 2015b: Increased land use by Chukchi Sea polar bears in relation to changing sea ice conditions. *PLoS ONE*, **10**(11), doi:10.1371/journal.pone.0142213.

Rodell, M., et al., 2018: Emerging trends in global freshwater availability. *Nature*, **557**, 651–659, doi:10.1038/s41586-018-0123-1.

Rodell, M., I. Velicogna and J.S. Famiglietti, 2009: Satellite-based estimates of groundwater depletion in India. *Nature*, **460**(7258), 999.

Roder, G., T. Ruljigaljig, C.-W. Lin and P. Tarolli, 2016: Natural hazards knowledge and risk perception of Wujie indigenous community in Taiwan. *Nat. Hazards*, **81**(1), 641–662, doi:10.1007/s11069-015-2100-4.

Rogelj, J., et al., 2018: The many possible climates from the Paris Agreement's aim of 1.5°C warming. *Nature*, **558**(7708), 41–49, doi:10.1038/s41586-018-0181-4.

Rohini, P., M. Rajeevan and A.K. Srivastava, 2016: On the Variability and Increasing Trends of Heat Waves over India. *Sci. Rep.*, **6**(1), 26153, doi:10.1038/srep26153.

Rojas-Downing, M.M., A.P. Nejadhashemi, T. Harrigan and S.A. Woznicki, 2017: Climate change and livestock: Impacts, adaptation, and mitigation. *Clim. Risk Manag.*, **16**, 145–163.

Romañach, S.S., et al., 2018: Conservation and restoration of mangroves: Global status, perspectives, and prognosis. *Ocean. Coast. Manag.*, **154**, 72–82, doi:10.1016/j.ocecoaman.2018.01.009.

Rosendo, S., L. Celliers and M. Mechisso, 2018: Doing more with the same: A reality-check on the ability of local government to implement Integrated Coastal Management for climate change adaptation. *Mar. Policy.*, **87**, 29–39.

Ross, R.S., T.N. Krishnamurti, S. Pattnaik and D.S. Pai, 2018: Decadal surface temperature trends in India based on a new high-resolution data set. *Sci. Rep.*, **8**(1), 7452–7452, doi:10.1038/s41598-018-25347-2.

Roth, D., et al., 2019: Climates of urbanization: local experiences of water security, conflict and cooperation in peri-urban South-Asia. *Clim. Policy*, **19**(sup1), S78–S93.

Rothausen, S.G. and D. Conway, 2011: Greenhouse-gas emissions from energy use in the water sector. *Nat. Clim. Change*, **1**(4), 210.

Routledge, P., 2015: Engendering Gramsci: Gender, the philosophy of praxis, and spaces of encounter in the climate caravan, Bangladesh. *Antipode*, **47**(5), 1321–1345.

Roxy, M.K., et al., 2016: A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean. *Geophys. Res. Lett.*, **43**(2), 826–833, doi:10.1002/2015gl066979.

Roy, A. and M.Z. Haider, 2019: Stern review on the economics of climate change: implications for Bangladesh. *Int. J. Clim. Chang. Strateg. Manag.*, **11**(1), 100–117.

Roy, J., P. Tschakert, H. Waisman, S. Abdul Halim, P. Antwi-Agyei, P. Dasgupta, B. Hayward, M. Kanninen, D. Liverman, C. Okereke, P.F. Pinho, K. Riahi, and A.G. Suarez Rodriguez, 2018: Sustainable Development, Poverty Eradication and Reducing Inequalities. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. (In Press).

Roy, M., D. Hulme and F. Jahan, 2013: Contrasting adaptation responses by squatters and low-income tenants in Khulna, Bangladesh. *Environment and Urbanization.* doi:10.1177/0956247813477362.

Roy, S.S., 2018: *Linking Gender to Climate Change Impacts in the Global South*. Springer, Berlin Heidelberg, ISBN 978-3319757766.

Rozenberg, J. and M. Fay, 2019: *Beyond the gap: How countries can afford the infrastructure they need while protecting the planet*. The World Bank, Washington DC, USA. ISBN 978-1464813634.

Ruane, A.C., et al., 2013: Multi-factor impact analysis of agricultural production in Bangladesh with climate change. *Glob. Environ. Chang.*, **23**(1), 338–350, doi:10.1016/j.gloenvcha.2012.09.001.

Ruckelshaus, M., et al., 2013: Securing ocean benefits for society in the face of climate change. *Mar. Policy.*, **40**, 154–159, doi:10.1016/j.marpol.2013.01.009.

Rumbach, A. and M. Shirgaokar, 2017: Predictors of household exposure to monsoon rain hazards in informal settlements. *Nat. Hazards*, **85**(2), 709–728, doi:10.1007/s11069-016-2599-z.

Rumiantsev, V.Y., S.M. Malkhazova, N.B. Leonova and M.S. Soldatov, 2013: Forecasting possible changes in zonal vegetation boundaries in European Russia and Western Siberia in connection with global warming. *Contemp. Probl. Ecol.*, **6**(4), 343–349, doi:10.1134/S1995425513040094.

Russell, M., *Water in Central Asia An increasingly scarce resource, European Parliamentary Research Service*. http://www.europarl.europa.eu/RegData/etudes/BRIE/2018/625181/EPRS_BRI(2018)625181_EN.pdf. accessed on October 1, 2021.

Ruzol, C., L.L. Lomente and J. Pulhin, 2021: Cultural consensus knowledge of rice farmers for climate risk management in the Philippines. *Clim. Risk Manag.*, **32**, 100298, doi:10.1016/j.crm.2021.100298.

Ruzol, C.D. and J.M. Pulhin, 2021: Cultural Dimensions of Human Security. In: *Climate Change, Disaster Risks, and Human Security: Asian Experience and Perspectives* [Pulhin, J.M., M. Inoue and R. Shaw(eds.)]. Springer, Singapore, pp. 169–192. ISBN 978-9811588525.

Ryzhanovskiy, V.N., 2019a: Ecology of thrush birds (Passeriformes, Turdidae) in northwestern Siberia under effects of climate and landscape changes. *Contemp. Probl. Ecol.*, **12**(3), 220–230, doi:10.1134/s1995425519030107.

Ryzhanovskiy, V.N., 2019b: The phenology of seasonal phenomena and the territorial distribution of gray crow (*Corvus cornix*) from the Lower Ob region. *Russ. J. Ecol.*, **50**(1), 88–92, doi:10.1134/s1067413618060103.

Sabates-Wheeler, 2019: Mapping differential vulnerabilities and rights: 'opening' access to social protection for forcibly displaced populations. *Comp. Migr. Stud.*, **7**, 38, doi:10.1186/s40878-019-0142-6.

Sachs, J., et al., 2018: SDG Index and. *Dashboards*. Report 2018. New York: Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN).

Sachs, J., et al., 2020: *The Sustainable Development Goals and COVID-19*. Sustainable Development Report 2020. Cambridge University Press, Cambridge, 508.

Sadia, H., et al., 2016: Gender-sensitive public health risks and vulnerabilities' assessment with reference to floods in Pakistan. *Int. J. Dis. Risk Reduct.*, **19**, 47–56, doi:10.1016/j.ijdrr.2016.08.024.

Safronov, V.M., 2016: Climate change and mammals of Yakutia. *Biol. Bull.*, **43**(9), 1256–1270, doi:10.1134/s1062359016110121.

Sahani, M., et al., 2014: A case-crossover analysis of forest fire haze events and mortality in Malaysia. *Atmospheric Environ.*, **96**, 257–265, doi:10.1016/j.atmosenv.2014.07.043.

Said, F., U. Afzal and G. Turner, 2015: Risk taking and risk learning after a rare event: Evidence from a field experiment in Pakistan. *J. Econ. Behav. Organ.*, **118**, 167–183.

Sailor, D., 2001: Relating residential and commercial sector electricity loads to climate - Evaluating state level sensitivities and vulnerabilities. *Energy*, **26**, 645–657, doi:10.1016/S0360-5442(01)00023-8.

Saito, N., 2013: Mainstreaming climate change adaptation in least developed countries in South and Southeast Asia. *Mitig. Adapt. Strateg. Glob. Change*, **18**(6), 825–849.

Saito, Y., 2014: Progress or repetition? Gender perspectives in disaster management in Japan. *Dis. Prev. Manag. Int. J.*, **23**(2), 98–111, doi:10.1108/dpm-08-2013-0134.

Sajjad, M., et al., 2018: Assessing Hazard Vulnerability, Habitat Conservation, and Restoration for the Enhancement of Mainland China's Coastal Resilience. *Earths Future*, **6**(3), 326–338, doi:10.1002/2017ef000676.

Sakaki, T., M. Okazaki and Y. Matsuo, 2013: Tweet Analysis for Real-Time Event Detection and Earthquake Reporting System Development. *IEEE Trans. Knowl. Data Eng.*, **25**(4), 919–931, doi:10.1109/TKDE.2012.29.

Sakamoto, D., et al., 2017: Application of Livestock Waste Compost as a Source of Nitrogen Supplementation during the Fall-winter Season Causes Dead Flower Buds in Japanese Pear 'Kosui. *Hortic. J.*, doi:10.2503/hortj.MI-134.

Sakamoto, Y., 2000: Snow accretion on overhead wires. *Philos. Trans. Royal Soc. A: Math. Phys. Eng. Sci.*, **358**, 2941–2970, doi:10.1098/rsta.2000.0691.

Sakurai, M. and H. Chughtai, 2020: Resilience against crises: COVID-19 and lessons from natural disasters. *Eur. J. Inf. Syst.*, **29**(5), 585-594. https://doi.org/10.1080/0960085X.2020.1814171.

Sakurai, M. and D. Thapa, 2017: Building resilience through effective disaster management: An information ecology perspective. *Int. J. Inf. Syst. Crisis Response Manag.*, **9**(1), 11–26, doi:10.4018/IJISCRAM.2017010102.

Sakurai, M., R. Watson, C. Abraham and J. Kokuryo, 2014: Sustaining life during the early stages of disaster relief with a frugal information system: learning from the great east Japan earthquake. *Commun. Mag. IEEE*, **52**(1), 176–185, doi:10.1109/MCOM.2014.6710081.

Salik, K.M., S. Jahangir, W. Zafar Zahdi and S. Hasson, 2015: Climate change vulnerability and adaptation options for the coastal communities of Pakistan. *Ocean. Coast. Manag.*, **112**, 61–73, doi:10.1016/j.ocecoaman.2015.05.006.

Salim, W., K. Bettinger and M. Fisher, 2019: Maladaptation on the waterfront: Jakarta's growth coalition and the Great Garuda. *Environ. Urban. Asia*, **10**(1), 63–80.

Samad, S.A. and K.M. Shahid, 2018: Social protection programme in Malaysia. *Int. J. Stud. Child. Women Elder. Disabl.*, **5**(Oct.), 71-79.

Samaddar, S., R. Chatterjee, B. Misra and H. Tatano, 2014: Outcome-expectancy and self-efficacy: Reasons or results of flood preparedness intention? *Int. J. Disaster Risk Reduct.*, **8**, 91–99, doi:10.1016/j.ijdrr.2014.02.002.

Samuel, O.O., T.S. Sylvia and S.R. Casadevall, 2019: Establishing the nexus between climate change adaptation strategy and smallholder farmers' food security status in South Africa: A bi-casual effect using instrumental variable approach. *Cogent Soc. Sci.*, **5**(1), 1656402.

Sancholi, N., 2018: Effects of Climate Change on *Paralaudakia lehmanni* (Nikolsky, 1896) (Reptilia: Agamidae) in Central Asia. *Contemp. Probl. Ecol.*, **11**(6), 682–686, doi:10.1134/s199542551806015x.

Sang, S., et al., 2014: Predicting local dengue transmission in Guangzhou, China, through the influence of imported cases, mosquito density and climate variability. *Plos One*, **9**(7), e102755, doi:10.1371/journal.pone.0102755.

Sangoony, H., M. Vahabi, M. Tarkesh and S. Soltani, 2016: Range Shift of Bromus Tomentellus Boiss. As a Reaction to Climate Change in Central Zagros, Iran. *Appl. Ecol. Env. Res.*, **14**(4), 85–100, doi:10.15666/aeer/1404_085100.

Sannikov, S.N., N.V. Tantsyrev and I. V. Petrova, 2018: Invasion of Siberian Pine populations in mountain tundra in the Northern Urals. *Contemp. Probl. Ecol.*, **11**(4), 396–405, doi:10.1134/s1995425518040078.

Santamouris, M., 2015: Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions. *Sci. Total Environ.*, **512-513C**, 582–598, doi:10.1016/j.scitotenv.2015.01.060.

Sapkota, T.B., et al., 2015: Climate change adaptation, greenhouse gas mitigation and economic profitability of conservation agriculture: Some examples from cereal systems of Indo-Gangetic Plains. *J. Integr. Agric.*, **14**(8), 1524–1533, doi:10.1016/S2095-3119(15)61093-0.

Sapountzaki, K., 2018: Boundaries, Overlaps and Conflicts between Disaster Risk Reduction and Adaptation to Climate Change: Are There Prospects of Integration? In: *Smart, Reslient and Transition Cities*, pp. 237.

Saraswat, C., 2016: Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo. *Environ. Sci. Policy*.

Sarathchandra, C., et al., 2018: Significance of Mangrove Biodiversity Conservation in Fishery Production and Living Conditions of Coastal Communities in Sri Lanka. *Diversity*, **10**(2), doi:10.3390/d10020020.

Sarma, R.R., M. Munsi and A.N. Ananthram, 2015: Effect of Climate Change on Invasion Risk of Giant African Snail (Achatina fulica Ferussac, 1821: Achatinidae) in India. *PLoS ONE*, **10**(11), doi:10.1371/journal.pone.0143724.

Satoh, Y., et al., 2017: Multi-model and multi-scenario assessments of Asian water futures: The Water Futures and Solutions (WFaS) initiative. *Earths Future*, **5**(7), 823–852.

Sawamura, Y., Y. Suesada, T. Sugiura and H. Yaegaki, 2017: Chilling Requirements and Blooming Dates of Leading Peach Cultivars and a Promising Early Maturing Peach Selection, Momo Tsukuba 127. *Hortic. J.*, **86**(4), 426–436, doi:10.2503/hortj.OKD-052.

Sayer, J., et al., 2015: The Role of Citizen Science in Landscape and Seascape Approaches to Integrating Conservation and Development. *Land*, **4**(4), doi:10.3390/land4041200.

Schaefer, K., et al., 2014: The impact of the permafrost carbon feedback on global climate. *Environ. Res. Lett.*, **9**(8), 85003.

Schaer, C. and A. Pantakar, 2018: Promoting private sector engagement in climate change adaptation and flood resilience—a case study of innovative approaches applied by MSMEs in Mumbai, India. In: *Theory and Practice of Climate Adaptation*. Springer, Berlin Heidelberg, pp. 175–191.

Schamm, K., et al., 2014: Global gridded precipitation over land: a description of the new GPCC First Guess Daily product. *Earth Syst. Sci. Data*, **6**(1), 49–60, doi:10.5194/essd-6-49-2014.

Schaphoff, S., et al., 2016: Tamm review: observed and projected climate change impacts on Russia's forests and its carbon balance. *For. Ecol. Manag.*, **361**, 432–444, doi:10.1016/j.foreco.2015.11.043.

Scheelbeek, P.F.D., et al., 2016: Drinking Water Sodium and Elevated Blood Pressure of Healthy Pregnant Women in Salinity-Affected Coastal Areas. *Hypertension*, **68**(2), 464–470, doi:10.1161/HYPERTENSIONAHA.116.07743.

Scheyvens, H. and B.R. Shivakoti, 2019: *Asia-Pacific Landscape Transformations, Solutions for Sustainability*. (IGES), I. f. G. E. S, Hayama, Japan.

Schickhoff, U., et al., 2015: Do Himalayan treelines respond to recent climate change? An evaluation of sensitivity indicators. *Earth Syst. Dyn.*, **6**(1), 245–265, doi:10.5194/esd-6-245-2015.

Schlenker, W. and M. Auffhammer, 2018: *The cost of a warming climate*. Nature Publishing Group, London, New York, Berlin, Shanghai and Tokyo.

Schleussner, C.-F., et al., 2016: Differential climate impacts for policy-relevant limits to global warming: the case of 1.5°C and 2°C. *Earth Syst. Dyn.*, **7**(2), 327–351, doi:10.5194/esd-7-327-2016.

Schlosberg, D. and L.B. Collins, 2014: From environmental to climate justice: climate change and the discourse of environmental justice. *Wiley Interdiscip. Rev. Clim. Chang.*, **5**(3), 359–374, doi:10.1002/wcc.275.

Schmidt-Vogt, D., M. Foggin and C. Hergarten, 2016: Strengthening Mountain Societies in Central Asia in a Context of Multidimensional Change. *Mt. Res. Dev.*, **36**(3), 380–383, doi:10.1659/mrd-journal-d-16-00101.1.

Schwan, S. and X. Yu, 2017: Social protection as a strategy to address climate-induced migration. *Int. J. Clim. Chang. Strateg. Manag.*, doi:10.1108/ijccsm-01-2017-0019.

Scott, C.A., et al., 2019: Water in the Hindu Kush Himalaya. In: *The Hindu Kush Himalaya Assessment*. Springer, Berlin Heidelberg, pp. 257–299.

Seidler, R., et al., 2018: Progress on integrating climate change adaptation and disaster risk reduction for sustainable development pathways in South Asia: Evidence from six research projects. *Int. J. Disaster Risk Reduct.*, **31**, 92–101.

Sekine, Y., 2021: Emerging 'agrarian climate justice' struggles in Myanmar. *J Peasant Stud*, **48**(3), 517–540, doi:10.1080/03066150.2020.1839054.

Semenov, S.M., I.O. Popov and V.V. Yasyukevich, 2020: Statistical Model for Assessing the Formation of Climate-related Hazards Based on Climate Monitoring Data. *Russ. Meteorol. Hydro.*, **45**(5), 339–344, doi:10.3103/S1068373920050040.

Sen, S.M. and A. Kansal, 2019: Achieving water security in rural Indian Himalayas: A participatory account T of challenges and potential solutions. *J. Environ. Manag.*, **245**, 398–408, doi:10.1016/j.jenvman.2019.05.132.

Senapati, S. and V. Gupta, 2017: Socio-economic vulnerability due to climate change: Deriving indicators for fishing communities in Mumbai. *Mar. Policy.*, **76**, 90–97, doi:10.1016/j.marpol.2016.11.023.

Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satoh, S.M. Vicente-Serrano, M. Wehner, and B. Zhou, 2021: Weather and Climate Extreme Events in a Changing Climate. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK.

Sengupta, S. and M.K. Jha, 2020: Social policy, COVID-19 and impoverished migrants: challenges and prospects in locked down India. *Int. J. Community Soc. Dev.*, **2**(2), 152–172.

Seposo, X.T., T.N. Dang and Y. Honda, 2015: Evaluating the Effects of Temperature on Mortality in Manila City (Philippines) from 2006-2010 Using a Distributed Lag Nonlinear Model. *Int. J. Environ. Res. Public Health*, **12**(6), 6842–6857, doi:10.3390/ijerph120606842.

Serdeczny, O., 2019: Non-economic loss and damage and the Warsaw international mechanism. In: *Loss and damage from climate change*. Springer, Berlin Heidelberg, pp. 205–220.

Servadio, J.L., S.R. Rosenthal, L. Carlson and C. Bauer, 2018: Climate patterns and mosquito-borne disease outbreaks in South and Southeast Asia. *J Infect Public Health*, **11**(4), 566–571, doi:10.1016/j.jiph.2017.12.006.

Setiawati Martiwi Diah, J.M.P., M. Gomez-Garcia and K. Fukushi, 2021: Accelerating Urban Heating Under Land-Cover and Climate Change Scenarios in Indonesia: Application of the Universal Thermal Climate Index. *Front. Built Environ.*, **7**, 65, doi:10.3389/fbuil.2021.622382.

Sha, Z., et al., 2016: Spatio-temporal patterns of satellite-derived grassland vegetation phenology from 1998 to 2012 in Inner Mongolia, China. *J. Arid Land*, **8**(3), 462–477, doi:10.1007/s40333-016-0121-9.

Shaban, A. and M. Hamze, 2017: *Shared Water Resources of Lebanon. Water Resource Planning, Development and Management*. 174 pp.

Shabani, F., L. Kumar and R. Hamdan Saif Al Shidi, 2018: Impacts of climate change on infestations of Dubas bug (Ommatissus lybicus Bergevin) on date palms in Oman. *Peer J.*, **6**, e5545, doi:10.7717/peerj.5545.

Shaffril, H.A.M., A.A. Samah, S.F. Samsuddin and Z. Ali, 2019: Mirror-mirror on the wall, what climate change adaptation strategies are practiced by the Asian's fishermen of all? *J. Clean. Prod.*, **232**, doi:10.1016/j.jclepro.2019.05.262.

Shaffril, H.A.M., A. Samah and J.L. D'Silva, 2017: Adapting towards climate change impacts: Strategies for small-scale fishermen in Malaysia. *Mar. Policy.*, **81**, 196–201, doi:10.1016/j.marpol.2017.03.032.

Shaffril, H.A.M., S.E. Krauss and S.F. Samsuddin, 2018: A systematic review on Asian's farmers' adaptation practices towards climate change. *Sci. Total Environ.*, **644**, 683–695, doi:10.1016/j.scitotenv.2018.06.349.

Shah, A.A., et al., 2019: Current capacities, preparedness and needs of local institutions in dealing with disaster risk reduction in Khyber Pakhtunkhwa, Pakistan. *Int. J. Disaster Risk Reduct.*, **34**, 165–172, doi:10.1016/j.ijdrr.2018.11.014.

Shah, T., et al., 2018: Solar pumps and South Asia's energy-groundwater nexus: exploring implications and reimagining its future. *Environ. Res. Lett.*, **13**(11), 115003.

Shahid, S., et al., 2016: Climate variability and changes in the major cities of Bangladesh: observations, possible impacts and adaptation. *Reg. Environ. Change*, **16**(2), 459–471.

Sharma, B., et al., 2016: *Springs, storage towers, and water conservation in the midhills of Nepal*. International Centre for Integrated Mountain Development., ISBN 978-9291153954.

Sharma, E., et al., 2019: Introduction to the hindu kush himalaya assessment. In: *The Hindu Kush Himalaya Assessment*. Springer, pp. 1–16.

Sharma, V., 2019: Access for adaptation? Reviewing the linkages between energy, disasters, and development in India. *Energy Res. Soc. Sci.*, **52**, 10–19.

Shaw, R., 2019: Role of private sectors in disaster risk reduction: Potential and challenges. *J. Dis. Res.*, **13**(7), 1207–1212, doi:10.20965/jdr.2018.p1207.

Shaw, R., Atta-ur-Rahman, A. Surjan and G.A. Parvin, 2016a: *Urban Disasters and Resilience in Asia*.

Shaw, R., T. Izumi and P. Shi, 2016b: Perspectives of Science and Technology in Disaster Risk Reduction of Asia. *Int. J. Disaster Risk Sci.*, **7**(4), 329–342, doi:10.1007/s13753-016-0104-7.

Shawoo, Z. and C.L. McDermott, 2020: Justice through polycentricity? A critical examination of climate justice framings in Pakistani climate policymaking. *Clim. Policy*, **20**(2), 199–216, doi:10.1080/14693062.2019.1707640.

Shen, Y.-J., et al., 2020: Review of historical and projected future climatic and hydrological changes in mountainous semiarid Xinjiang (northwestern China), central Asia. *Catena*, **187**, 104343.

Sherman, K., 1994: Sustainability, Biomass Yields, and Health of Coastal Ecosystems - An Ecological Perspective. *Mar. Ecol. Prog. Ser.*, **112**(3), 277–301, doi:10.3354/meps112277.

Shi, W., et al., 2020: Modification Effects of Temperature on the Ozone–Mortality Relationship: A Nationwide Multicounty Study in China. *Environ. Sci. Technol.*, **54**(5), 2859–2868, doi:10.1021/acs.est.9b05978.

Shi, X., et al., 2019a: Farmers' perceived efficacy of adaptive behaviors to climate change in the Loess Plateau, China. *Sci. Total. Environ.*, **697**, doi:10.1016/j.scitotenv.2019.134217.

Shi, Y., T. Sayama, K. Takara and K. Ohtake, 2019b: Detecting flood inundation information through Twitter: The 2015 Kinu River flood disaster in Japan. *J. Nat. Disaster Sci.*, **40**(1), 1–13.

Shiklomanov, N. I., D. A. Streletskiy, T. B. Swales, V. A. Kokorev, 2016: Climate Change and Stability of Urban Infrastructure in Russian Permafrost Regions: Prognostic Assessment based on GCM Climate Projections. *Geogr. Rev.*, doi:10.1111/gere.12214.

Shiklomanov, N.I., D.A. Streletskiy, V.I. Grebenets and L. Suter, 2017a: Conquering the permafrost: urban infrastructure development in Norilsk, Russia. *Polar Geogr.*, **40**(4), 273–290, doi:10.1080/1088937X.2017.1329237.

Shiklomanov, N.I., D.A. Streletskiy, T.B. Swales and V.A. Kokorev, 2017b: Climate Change and Stability of Urban Infrastructure in Russian Permafrost Regions: Prognostic Assessment based on GCM Climate Projections. *Geogr. Rev.*, **107**(1), 125–142, doi:10.1111/gere.12214.

Shirsath, P., S. Vyas, P. Aggarwal and K.N. Rao, 2019: Designing weather index insurance of crops for the increased satisfaction of farmers, industry and the government. *Clim. Risk Manag.*, **25**, 100189.

Shirsath, P.B., P.K. Aggarwal, P.K. Thornton and A. Dunnett, 2017: Prioritizing climate-smart agricultural land use options at a regional scale. *Agric. Syst.*, **151**, 174–183, doi:10.1016/j.agsy.2016.09.018.

Shitara, T., et al., 2018: Formation of disjunct plant distributions in Northeast Asia: a case study of Betula davurica using a species distribution model. *Plant Ecol.*, **219**(9), 1105–1115, doi:10.1007/s11258-018-0862-y.

Shiwaku, K., A. Sakurai and R. Shaw (eds.), 2016: *Disaster resilience of education system : experiences from Japan*. Springer, Japan.

Shiyatov, S.G. and V.S. Mazepa, 2015: Contemporary expansion of Siberian larch into the mountain tundra of the Polar Urals. *Russ. J. Ecol.*, **46**(6), 495–502, doi:10.1134/s1067413615060168.

Shrestha, A., et al., 2010: Glacial lake outburst flood risk assessment of Sun Koshi basin, Nepal. *Geomatics Nat. Hazards Risk*, **1**(2), 157–169.

Shrestha, S., S. Neupane, S. Mohanasundaram and V.P. Pandey, 2020: Mapping groundwater resiliency under climate change scenarios: A case study of Kathmandu Valley, Nepal. *Environ. Res.*, **183**, 109149.

Shrestha, S., V.P. Pandey, S. Thatikonda and B.R. Shivakoti, 2016: *Groundwater environment in Asian cities: concepts, methods and case studies*. Butterworth-Heinemann, Oxford, UK, ISBN 978-0128031674.

Shuaib, M., et al., 2018: Impact of rapid urbanization on the floral diversity and agriculture land of district Dir, Pakistan. *Acta Ecol. Sinica*, **38**(6), 394–400, doi:10.1016/j.chnaes.2018.04.002.

Shukla, A.K., K. Sudhakar and P. Baredar, 2017: Renewable energy resources in South Asian countries: Challenges, policy and recommendations. *Resour. Efficient Technol.*, **3**(3), 342–346.

Shuman, J.K., et al., 2015: Forest forecasting with vegetation models across Russia. *Can. J. For. Res.*, **45**(2), 175–184, doi:10.1139/cjfr-2014-0138.

Shyam, S.S., K.S. Mohamed, P.K. Safeena and R. Remya, 2017: Effect of declining oil sardine landings on the livelihoods of traditional fishers in Kerala. *J. Indian Fish. Assoc.*, **44**(2), 7.

Siddiqui, T., et al., 2019: Migration in the Hindu Kush Himalaya: Drivers, Consequences, and Governance. In: *The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People* [Wester, P., A. Mishra, A. Mukherji and A.B. Shrestha(eds.)]. Springer, Cham, pp. 517–544. ISBN 978-3319922881.

Sigdel, S.R., et al., 2020: Tree-to-tree interactions slow down Himalayan treeline shifts as inferred from tree spatial patterns. *J. Biogeogr.*, **47**(8), 1816–1826, doi:10.1111/jbi.13840.

Sigdel, S.R., et al., 2018: Moisture-mediated responsiveness of treeline shifts to global warming in the Himalayas. *Glob. Change Biol.*, **24**(11), 5549–5559, doi:10.1111/gcb.14428.

Sijapati, B., 2017: The quest for achieving universal social protection in Nepal: Challenges and opportunities. *Indian J. Hum. Dev.*, **11**(1), 17–36.

Sikor, T., P. Newell, 2014: Globalizing environmental justice? *Geoforum*, **54**, 151–157.

Silva, R.A., et al., 2016: The effect of future ambient air pollution on human premature mortality to 2100 using output from the ACCMIP model ensemble. *Atmos. Chem. Phys.*, **16**(15), 9847–9862, doi:10.5194/acp-16-9847-2016.

Simons, W.J.F., et al., 2019: Vertical motion of Phuket Island (1994-2018) due to the Sumatra-Andaman mega-thrust earthquake cycle: impact on sea-level and consequences for coral reefs. *Mar. Geol.*, **414**, 92–102, doi:10.1016/j.margeo.2019.05.008.

Singh, C., 2019: Migration as a driver of changing household structures: Implications for local livelihoods and adaptation. *Migr. Dev.*, **8**(3), 301–319.

Singh, C. and R. Basu, 2020: Moving in and out of vulnerability: Interrogating migration as an adaptation strategy along a rural–urban continuum in India. *Geogr. J.*, **186**(1), 87–102.

Singh, C., et al., 2018a: The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India. *Clim. Dev.*, **10**(5), 389–405, doi:10.1080/17565529.2017.1318744.

Singh, C., P. Dorward and H. Osbahr, 2016: Developing a holistic approach to the analysis of farmer decision-making: Implications for adaptation policy and practice in developing countries. *Land Use Policy*, **59**, 329–343, doi:10.1016/j.landusepol.2016.06.041.

Singh, C., G. Jain, V. Sukhwani and R. Shaw, 2021a: Losses and damages associated with slow-onset events: urban drought and water insecurity in Asia. *Curr. Opin. Environ. Sustain.*, **50**, 72–86.

Singh, C., M. Madhavan, J. Arvind and A. Bazaz, 2021b: Climate change adaptation in Indian cities: A review of existing actions and spaces for triple wins. *Urban Clim.*, **36**, 100783, doi:10.1016/j.uclim.2021.100783.

Singh, C., H. Osbahr and P. Dorward, 2018b: The implications of rural perceptions of water scarcity on differential adaptation behaviour in Rajasthan, India. *Reg. Environ. Change*, **18**(8), 2417–2432, doi:10.1007/s10113-018-1358-y.

Singh, C., et al., 2019a: Exploring methodological approaches to assess climate change vulnerability and adaptation: reflections from using life history approaches. *Reg. Environ. Change*, **19**(8), 2667–2682.

Singh, S.P., I. Bassignana-Khadka, B. Singh Karky and E. Sharma, 2011: *Climate change in the Hindu Kush-Himalayas: the state of current knowledge*. International Centre for Integrated Mountain Development (ICIMOD).

Singh, S.P., S. Sharma and P.P. Dhyani, 2019b: Himalayan arc and treeline: distribution, climate change responses and ecosystem properties. *Biodivers. Conserv.*, **28**(8-9), 1997–2016, doi:10.1007/s10531-019-01777-w.

Singh, U., et al., 2018c: Static tree line of Himalayan silver fir since last several decades at Tungnath, western Himalaya. *Trop. Ecol.*, **59**(2), 351–363.

Sinha, R., et al., 2019: Basin-scale hydrology and sediment dynamics of the Kosi river in the Himalayan foreland. *J. Hydrol. Reg. Stud.*, **570**, 156–166.

Sinha, S. and N. Tripathi, 2016: Assessing the challenges in successful implementation and adoption of crop insurance in Thailand. *Sustainability*, **8**(12), 1306.

Slodowicz, D., et al., 2018: Areas of high conservation value at risk by plant invaders in Georgia under climate change. *Ecol. Evol.*, **8**(9), 4431–4442, doi:10.1002/ece3.4005.

Smale, D.A., et al., 2019: Marine heatwaves threaten global biodiversity and the provision of ecosystem services. *Nat. Clim. Change*, **9**(4), 306, doi:10.1038/s41558-019-0412-1.

Smeets Kristkova, Z., M. Van Dijk and H. Van Meijl, 2016: Projections of long-term food security with R&D driven technical change—A CGE analysis. *NJAS Wageningen J. Life Sci.*, **77**, 39–51, doi:10.1016/j.njas.2016.03.001.

Smith, K.R., et al., 2014: *Human Health: Impacts, Adaptation, and Co-Benefits*.

Smith, M.R. and S.S. Myers, 2018: Impact of anthropogenic CO2 emissions on global human nutrition. *Nat. Clim, Change*, **8**(9), 834–839, doi:10.1038/s41558-018-0253-3.

Sohel, S.I., et al., 2016: Predicting impacts of climate change on forest tree species of Bangladesh: evidence from threatened Dysoxylum binectariferum (Roxb.) Hook. f. ex Bedd. (Meliaceae). *Iforest*, **10**, 154–160, doi:10.3832/ifor1608-009.

Sohrabizadeh, S., D.S. Tourani and H.R. Khankeh, 2016: Women and health consequences of natural disasters: Challenge or opportunity? *Women Health*, **56**(8), 977–993, doi:10.1080/03630242.2016.1176101.

Soleimani, A., et al., 2019: Influence of land use and land cover change on soil organic carbon and microbial activity in the forests of northern Iran. *Catena*, **177**, 227–237, doi:10.1016/j.catena.2019.02.018.

Son, J.Y., K.J. Lane, J.T. Lee and M.L. Bell, 2016: Urban vegetation and heat-related mortality in Seoul, Korea. *Environ. Res.*, **151**, 728–733, doi:10.1016/j.envres.2016.09.001.

Son, J.Y., J.T. Lee and M.L. Bell, 2017: Is ambient temperature associated with risk of infant mortality? A multi-city study in Korea. *Environ. Res.*, **158**, 748–752, doi:10.1016/j.envres.2017.07.034.

Song, C.L., et al., 2019: Importance of active layer freeze-thaw cycles on the riverine dissolved carbon export on the Qinghai-Tibet Plateau permafrost region. *Peer J.*, **7**, doi:10.7717/peerj.7146.

Song, G., et al., 2017: Dietary changes to mitigate climate change and benefit public health in China. *Sci. Total. Environ.*, **577**, 289–298, doi:10.1016/j.scitotenv.2016.10.184.

Song, Y., et al., 2016: Spatial distribution estimation of malaria in northern China and its scenarios in 2020, 2030, 2040 and 2050. *Malar. J.*, **15**(1), 345, doi:10.1186/s12936-016-1395-2.

Kreft, S., D. Eckstein and I. Melchior, 2016: *GLOBAL CLIMATE RISK INDEX 2017: Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2015*.

Sovacool, B.K., A.L. D'Agostino, A. Rawlani and H. Meenawat, 2012: Improving climate change adaptation in least developed Asia. *Environ. Sci. Policy*, **21**, 112–125, doi:10.1016/j.envsci.2012.04.009.

Sovacool, B.K., B.-O. Linnér and R.J. Klein, 2017: Climate change adaptation and the Least Developed Countries Fund (LDCF): Qualitative insights from policy implementation in the Asia-Pacific. *Clim. Change*, **140**(2), 209–226.

Spalding, M., et al., 2017: Mapping the global value and distribution of coral reef tourism. *Mar. Policy.*, **82,** 104–113.

Spalding, M. and C.L. Parret, 2019: Global patterns in mangrove recreation and tourism. *Mar. Policy.* https://doi.org/10.1016/j.marpol.2019.103540.

Springmann, M., H.C.J. Godfray, M. Rayner and P. Scarborough, 2016: Analysis and valuation of the health and climate change cobenefits of dietary change. *Proc. Natl. Acad. Sci.*, **113**(15), 4146–4151, doi:10.1073/pnas.1523119113.

Rao, S., et al., 2016: Chapter Four - Climate Resilient Villages for Sustainable Food Security in Tropical India: Concept, Process, Technologies, Institutions, and Impacts. In: *Advances in Agronomy* [Sparks, D.L.(ed.)]. Academic Press, San Diego, pp. 101–214. ISBN 00652113.

Stankovic, M., N. Tantipisanuh and A. Prathep, 2018: Carbon storage in seagrass ecosystems along the Andaman coast of Thailand. *Bot. Mar.*, **61**(5), 429–440, doi:10.1515/bot-2017-0101.

Steg, L., J.W. Bolderdijk, K. Keizer and G. Perlaviciute, 2014: An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. *J. Environ. Psychol.*, **38**, 104–115, doi:10.1016/j.jenvp.2014.01.002.

Steinbach, D., et al., 2016: *Aligning social protection and climate resilience*. IIED, London, UK.

Stevenson, L.A., M.L. Shrestha and A. Sterin, 2013: *Climate Change Adaptation Strategies of Selected Smallholder Upland Farmers in Southeast Asia: Philippines and Indonesia*.

Stip, C., et al., 2019: *Water Infrastructure Resilience*.

Storch, H. and N.K. Downes, 2011: A scenario-based approach to assess Ho Chi Minh City's urban development strategies against the impact of climate change. *Cities*, **28**(6), 517–526, doi:10.1016/j.cities.2011.07.002.

Stott, C. and S. Huq, 2014: Knowledge flows in climate change adaptation: exploring friction between scales. *Clim. Dev.*, **6**(4), 382–387.

Street, R.B., et al., 2019: How could climate services support disaster risk reduction in the 21st century. *Int. J. Disaster Risk Reduct.*, **34**, 28–33, doi:10.1016/j.ijdrr.2018.12.001.

Streletskiy, D.A., A.B. Sherstiukov, O.W. Frauenfeld and F.E. Nelson, 2015: Changes in the 1963–2013 shallow ground thermal regime in Russian permafrost regions. *Environ. Res. Lett.*, **10**(12), 125005.

Streletskiy, D.A., N.I. Shiklomanov and F.E. Nelson, 2012: Permafrost, infrastructure, and climate change: a GIS-based landscape approach to geotechnical modeling. *Arct. Antarct. Alp. Res.*, **44**(3), 368–380.

Streletskiy, D.A., L.J. Suter, N.I. Shiklomanov, B.N. Porfiriev and D.O. Eliseev, 2019: Assessment of climate change impacts on buildings, structures and infrastructure in the Russian regions on permafrost. *Environ. Res. Lett.*, doi:10.1088/1748-9326/aaf5e6.

Stringer, L.C., et al., 2020: Adaptation and development pathways for different types of farmers. *Environ. Sci. Policy*, **104**, 174–189, doi:10.1016/j.envsci.2019.10.007.

Sugiura, T., H. Ogawa, N. Fukuda and T. Moriguchi, 2013: Changes in the taste and textural attributes of apples in response to climate change. *Sci. Rep.*, **3**, 2418, doi:10.1038/srep02418.

Sugiura, T., et al., 2014: Predicted changes in locations suitable for Tankan cultivation due to global warming in Japan. *J. Jpn. Soc. Hortic. Sci.*, **83**(2), 117–121, doi:10.2503/jjshs1.CH-094.

Sugiura, T., M. Shiraishi, S. Konno and A. Sato, 2019: Assessment of deterioration in skin color of table grape berries due to climate change and effects of two adaptation measures. *J. Agric. Meteorol.*, doi:10.2480/agrmet.D-18-00032.

Sukhwani, V., R. Shaw, B.K. Mitra and W. Yan, 2019: Optimizing Food-Energy-Water (FEW) nexus to foster collective resilience in urban-rural systems. *Prog. Dis. Sci.*, **1**, 100005, doi:10.1016/j.pdisas.2019.100005.

Sukhwani, V., et al., 2020: Addressing Urban–Rural Water Conflicts in Nagpur through Benefit Sharing. *Water*, **12**(11), 2979, doi:10.3390/w12112979.

Sullivan-Wiley, K.A. and A.G. Short Gianotti, 2017: Risk Perception in a Multi-Hazard Environment. *World Dev.*, **97**, 138–152, doi:10.1016/j.worlddev.2017.04.002.

Sultana, F., 2021: Climate change, COVID-19, and the co-production of injustices: a feminist reading of overlapping crises. *Soc. Cult. Geogr.*, **22**(4), 447–460.

Sun, F., W. Kuang, W. Xiang and Y. Che, 2016: Mapping water vulnerability of the Yangtze River Basin: 1994–2013. *Environ. Manage.*, **58**(5), 857–872.

Sun, H., et al., 2017: Exposure of population to droughts in the Haihe River Basin under global warming of 1.5 and 2.0 C scenarios. *Quat. Int.*, **453**, 74–84.

Sun, Q.H., et al., 2019: Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming. *Environ. Int.*, **128**, 125–136, doi:10.1016/j.envint.2019.04.025.

Sun, Y. and Z. Han, 2018: Climate change risk perception in Taiwan: Correlation with individual and societal factors. *Int. J. Environ.Res. Public Health*, **15**(1), doi:10.3390/ijerph15010091.

Sung, J., 2015: Climate change education and education for sustainable development in the Republic of Korea : a status report. *J. Educ. Sustain. Dev.*, **9**(1), 78–89, doi:10.1177/0973408215569116.

Supari, et al., 2020: Multi-model projections of precipitation extremes in Southeast Asia based on CORDEX-Southeast Asia simulations. *Environ. Res.*, **184**, 109350, doi:10.1016/j.envres.2020.109350.

Surasinghe, T., 2011: Conservation and distribution status of amphibian fauna in Sri Lanka. *Biodiversity*, **10**, doi:10.1080/14888386.2009.9712632.

Surie, M. and S. Prasai, 2015: *Strengthening transparency and access to information on transboundary rivers in South Asia*. The Asia Foundation, New Delhi.

Surminski, S. and D. Oramas-Dorta, 2014: Flood insurance schemes and climate adaptation in developing countries. *Int. J. Disaster Risk Reduct.*, **7**, 154–164.

Suroso, D.S.A. and T. Firman, 2018: The role of spatial planning in reducing exposure towards impacts of global sea level rise case study: Northern coast of Java, Indonesia. *Ocean. Coast. Manag.*, **153**, 84–97, doi:10.1016/j.ocecoaman.2017.12.007.

Sutthacheep, M., et al., 2013: Impacts of the 1998 and 2010 mass coral bleaching events on the Western Gulf of Thailand. *Deep. Res. II Top. Stud. Ocean.*, **96**, 25–31, doi:10.1016/j.dsr2.2013.04.018.

Sutton, W.R., J.P. Srivastava and J.E. Neumann, 2013: *Looking Beyond the Horizon How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia*. Bank, W, http://documents.worldbank.org/curated/en/676601468249642651/pdf/Looking-beyond-the-horizon-how-climate-change-impacts-and-adaptation-responses-will-reshape-agriculture-in-Eastern-Europe-and-Central-Asia.pdf. accessed on October 1, 2021

Suwal, M.K., et al., 2016: Land-use change under a warming climate facilitated upslope expansion of Himalayan silver fir (*Abies spectabilis* (D. Don) Spach). *Plant. Ecol.*, **217**(8), 993–1002, doi:10.1007/s11258-016-0624-7.

Suzuki-Ohno, Y., et al., 2017: Factors restricting the range expansion of the invasive green anole Anolis carolinensis on Okinawa Island, Japan. *Ecol. Evol.*, **7**(12), 4357–4366, doi:10.1002/ece3.3002.

Suzuki, S.N., M.I. Ishihara and A. Hidaka, 2015: Regional-scale directional changes in abundance of tree species along a temperature gradient in Japan. *Glob. Change Biol.*, **21**(9), 3436–3444, doi:10.1111/gcb.12911.

Swe, L.M.M., R.P. Shrestha, T. Ebbers and D. Jourdain, 2015: Farmers' perception of and adaptation to climate-change impacts in the Dry Zone of Myanmar. *Clim. Dev.*, **7**(5), 437–453.

Szabo, S., W.N. Adger and Z. Matthews, 2018: Home is where the money goes: migration-related urban-rural integration in delta regions. *Migr. Dev.*, **7**(2), 163–179.

Szabo, S., et al., 2016a: Population Dynamics, Delta Vulnerability and Environmental Change: Comparison of the Mekong, Ganges–Brahmaputra and Amazon Delta Regions. *Sustain. Sci.*, **11**(4), 539–554, doi:10.1007/s11625-016-0372-6.

Szabo, S., et al., 2016b: Making SDGs work for climate change hotspots. *Environ. Sci. Policy Sustain. Dev.*, **58**(6), 24–33, doi:10.1080/00139157.2016.1209016.

Takahashi, K., et al., 2015: School Health: an essential strategy in promoting community resilience and preparedness for natural disasters. *Glob. Health Action*, **8**, 29106, doi:10.3402/gha.v8.29106.

Takama, T., E. Aldrian, S.D.A. Kusumaningtyas and W. Sulistya, 2016: Identified vulnerability contexts for a paddy production assessment with climate change in Bali, Indonesia. *Clim. Dev.*, **9**(2), 110–123, doi:10.1080/17565529.2016.1167658.

Takano, K.T., et al., 2017: Detecting latitudinal and altitudinal expansion of invasive bamboo Phyllostachys edulis and Phyllostachys bambusoides (Poaceae) in Japan to project potential habitats under 1.5 degrees C-4.0 degrees C global warming. *Ecol. Evol.*, **7**(23), 9848–9859, doi:10.1002/ece3.3471.

Takao, S., et al., 2015: Projecting the impacts of rising seawater temperatures on the distribution of seaweeds around Japan under multiple climate change scenarios. *Ecol. Evol.*, **5**(1), 213–223, doi:10.1002/ece3.1358.

Talchabhadel, R. and R. Karki, 2019: Assessing climate boundary shifting under climate change scenarios across Nepal. *Environ. Monit. Assess.*, **191**, 520, doi:10.1007/s10661-019-7644-4.

Tambe, S., et al., 2012: Reviving dying springs: climate change adaptation experiments from the Sikkim Himalaya. *Mt. Res. Dev.*, **32**(1), 62–73.

Tanaka, Y., Y. Sakamoto and H. Honda (eds.), 2014: *The impact of posting URLs in disaster-related tweets on rumor spreading behavior*. 47th Hawaii International Conference on System Sciences, IEEE, 520–529. ISBN 978-1479925049.

Tang, C.Q., et al., 2018: Identifying long-term stable refugia for relict plant species in East Asia. *Nat. Commun.*, **9**(1), 4488, doi:10.1038/s41467-018-06837-3.

Taniguchi, M., A. Endo, J.J. Gurdak and P. Swarzenski, 2017a: Water-Energy-Food Nexus in the Asia-Pacific Region. *J. Hydrol. Reg. Stud.*, **11**, 1–8, doi:10.1016/j.ejrh.2017.06.004.

Taniguchi, M., N. Masuhara and K. Burnett, 2017b: Water, energy, and food security in the Asia Pacific region. *J. Hydrol. Reg. Stud.*

Tanjeela, M. and S. Rutherford, 2018: The Influence of Gender Relations on Women's Involvement and Experience in Climate Change Adaptation Programs in Bangladesh. *Sage Open*, **8**(4), doi:10.1177/2158244018812620.

Tankha, S., D. Fernandes and N.C. Narayanan, 2020: Overcoming barriers to climate smart agriculture in India. *Int. J. Clim. Chang. Strateg. Manag.*, **12**(1), 108–127, doi:10.1108/IJCCSM-10-2018-0072.

Taremwa, N.K., D. Gashumba, A. Butera and T. Ranganathan, 2017: Climate Change Adaptation in Rwanda through Indigenous Knowledge Practice. *Kamla Raj Enterp.*, doi:10.1080/09718923.2016.11893524.

Tasgaonkar, P., M. D'Souza, R. Bendapudi and C. Jacobs, 2018: *Vulnerability to heat stress: A case study of Yavatmal, Maharashtra, India*. ASSAR (Adaptation at Scale in Semi-Arid Regions). Cape Town, South Africa.

Taylor, A.L., 2019: General and specific motivations. *Nat. Clim. Change*, **9**(2), 89–90, doi:10.1038/s41558-018-0395-3.

Tchebakova, N.M., et al., 2016: Assessment of climatic limits of needle cast-affected area under climate change in Central Siberia. *Contemp. Probl. Ecol.*, **9**(6), 721–729, doi:10.1134/s1995425516060135.

Teh, L.S.L., L.C.L. Teh and U.R. Sumaila, 2013: A Global Estimate of the Number of Coral Reef Fishers. *Plos One*, **8**(6), 10, doi:10.1371/journal.pone.0065397.

Teixeira, E.I., et al., 2013: Global hot-spots of heat stress on agricultural crops due to climate change. *Agric. For. Meteorol.*, **170**, 206–215, doi:10.1016/j.agrformet.2011.09.002.

Telesetsky, A. and Q. He, 2016: Climate Change Insurance and Disasters: Is the Shenzhen Social Insurance Program a Model for Adaptation. *BC Envtl. Aff. L. Rev.*, **43**, 485.

Telwala, Y., B.W. Brook, K. Manish and M.K. Pandit, 2013: Climate-Induced Elevational Range Shifts and Increase in Plant Species Richness in a Himalayan Biodiversity Epicentre. *Plos One*, **8**(2), doi:10.1371/journal.pone.0057103.

Tenzing, J.D., 2019: Integrating social protection and climate change adaptation: A review. *WIREs Clim. Chang.*, **11**(2), doi:10.1002/wcc.626.

Tezuka, S., et al., 2014: Estimation of the effects of climate change on flood-triggered economic losses in Japan. *Int. J. Dis. Risk Reduct.*, **9**, 58–67, doi:10.1016/J.IJDRR.2014.03.004.

Thakur, B.K. and V. Gupta, 2019: Valuing health damages due to groundwater arsenic contamination in Bihar, India. *Econ. Hum. Biol.*, **35**, 123–132.

Thaler, T., S. Fuchs, S. Priest and N. Doorn, 2017: Social justice in the context of adaptation to climate change—reflecting on different policy approaches to distribute and allocate flood risk management. *Reg. Environ. Change*, **18**(2), 305–309, doi:10.1007/s10113-017-1272-8.

Thapa, S., et al., 2018: Understanding the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *PLoS ONE*, **13**(4), doi:10.1371/journal.pone.0195752.

Thinesh, T., et al., 2019: Differential bleaching and recovery pattern of southeast Indian coral reef to 2016 global mass bleaching event: Occurrence of stress-tolerant symbiont Durusdinium (Clade D) in corals of Palk Bay. *Mar. Pollut. Bull.*, **145**, 287–294, doi:10.1016/j.marpolbul.2019.05.033.

Thirumalai, K., P.N. DiNezio, Y. Okumura and C. Deser, 2017: Extreme temperatures in Southeast Asia caused by El Nino and worsened by global warming. *Nat. Commun.*, **8**, 15531, doi:10.1038/ncomms15531.

Thomas, K., et al., 2019: Explaining differential vulnerability to climate change: A social science review. *Wiley Interdiscip. Rev. Clim. Chang.*, **10**(2).

Tian, J. and Y. Zhang, 2019: Detecting changes in irrigation water requirement in Central Asia under CO2 fertilization and land use changes. *J. Hydrol. Reg. Stud.*, **583**, 124315, doi:10.1016/j.jhydrol.2019.124315.

Tian, X.R., W.B. Cui and L.F. Shu, 2020: Evaluating fire management effectiveness with a burn probability model in Daxing'anling, China. *Can. J. For. Res.*, **50**(7), 670–679, doi:10.1139/cjfr-2019-0413.

Tilman, D., et al., 2009: Beneficial biofuels—the food, energy, and environment trilemma. *Science*, **325**(5938), 270–271.

Tishkov, A., et al., 2020: Regional biogeographic effects of "fast" climate changes in the Russian Arctic in the 21st century. *Arctic Ecol. Econ.*, 31–44, doi:10.25283/2223-4594-2020-2-31-44.

Tiwari, A., Z.X. Fan, A.S. Jump and Z.K. Zhou, 2017: Warming induced growth decline of Himalayan birch at its lower range edge in a semi-arid region of Trans-Himalaya, central Nepal. *Plant. Ecol.*, **218**(5), 621–633, doi:10.1007/s11258-017-0716-z.

Tiwari, A. and P.K. Jha, 2018: An overview of treeline response to environmental changes in Nepal Himalaya. *Trop. Ecol.*, **59**(2), 273–285.

Tiwari, P.C. and B. Joshi, 2014: Environmental changes and their impact on rural water, food, livelihood, and health security in Kumaon Himalaya. *Int. J. Urban Reg. Stud. Contemp. India*, **1**, 1–12.

Tiwari, V., J. Wahr and S. Swenson, 2009: Dwindling groundwater resources in northern India, from satellite gravity observations. *Geophys. Res. Lett.*, **36**(18).

Tol, R.S.J., 2018: The Economic Impacts of Climate Change. *Rev. Environ. Econ. Policy*, **12**(1), 4–25, doi:10.1093/reep/rex027.

Torralba, V., F.J. Doblas-Reyes and N. Gonzalez-Reviriego, 2017: Uncertainty in recent near-surface wind speed trends: a global reanalysis intercomparison. *Environ. Res. Lett.*, **12**(11), 114019, doi:10.1088/1748-9326/aa8a58.

Torzhkov, I., et al., 2019: The economic consequences of future climate change in the forest sector of Russia. *IOP Conf. Ser. Earth Environ. Sci.*, **226**, 12032, doi:10.1088/1755-1315/226/1/012032.

Toussaint, P., 2020: Loss and damage and climate litigation: The case for greater interlinkage. *Rev. Eur. Comp. Int. Environ. Law*.

Tran, L. and K. Brown, 2019: The importance of ecosystem services to smallholder farmers in climate change adaptation: learning from an ecosystem-based adaptation pilot in Vietnam. *Agrofor. Syst.*, **93**, 1949–1960, doi:10.1007/s10457-018-0302-y.

Tran, N., et al., 2020: Profitability and perceived resilience benefits of integrated shrimp-tilapia-seaweed aquaculture in North Central Coast, Vietnam. *Mar. Policy.*, **120**, 104153, doi:10.1016/j.marpol.2020.104153.

Trang, P.M., et al., 2016: Heatwaves and Hospital Admissions for Mental Disorders in Northern Vietnam. *PLoS ONE*, **11**(5), e155609, doi:10.1371/journal.pone.0155609.

Trinh, T.Q., R.F. Rañola, L.D. Camacho and E. Simelton, 2018: Determinants of farmers' adaptation to climate change in agricultural production in the central region of Vietnam. *Land Use Policy*, **70**, 224–231, doi:10.1016/j.landusepol.2017.10.023.

Tripathi, A. and A.K. Mishra, 2017: Knowledge and passive adaptation to climate change: An example from Indian farmers. *Clim. Risk Manag.*, **16**, 195–207, doi:10.1016/j.crm.2016.11.002.

Trisurat, Y., A. Aekakkararungroj, H.O. Ma and J.M. Johnston, 2018: Basin-wide Impacts of Climate Change on Ecosystem Services in the Lower Mekong Basin. *Ecol. Res.*, **33**(1), 73–86, doi:10.1007/s11284-017-1510-z.

Truelove, H.B., A.R. Carrico and L. Thabrew, 2015: A socio-psychological model for analyzing climate change adaptation: A case study of Sri Lankan paddy farmers. *Glob. Environ. Chang.*, **31**, 85–97, doi:10.1016/j.gloenvcha.2014.12.010.

Tschakert, P., et al., 2019: One thousand ways to experience loss: A systematic analysis of climate-related intangible harm from around the world. *Glob. Environ. Chang.*, **55**, 58–72, doi:10.1016/j.gloenvcha.2018.11.006.

Tseng, W.W., S.H. Hsu and C.C. Chen, 2015: Estimating the willingness to pay to protect coral reefs from potential damage caused by climate change--The evidence from Taiwan. *Mar. Pollut. Bull.*, **101**(2), 556–565, doi:10.1016/j.marpolbul.2015.10.058.

Tucker, J., et al., 2015: Social vulnerability in three high-poverty climate change hot spots: What does the climate change literature tell us? *Reg. Environ. Change*, **15**(5), 783–800.

Tuladhar, G., et al., 2015a: Disaster risk reduction knowledge of local people in Nepal. *Geoenviron. Dis.*, **2**(5), doi:10.1186/s40677-014-0011-4.

Tuladhar, G., R. Yatabe, N. Bhandary and R. Dahal, 2015b: Assessment of disaster risk reduction knowledge of school teachers in Nepal. *Int. J. Health Syst. Dis. Manag.*, **3**(1), doi:10.4103/2347-9019.147142.

Tyagi, N.K. and P.K. Joshi, 2019: Index-Based Insurance for Mitigating Flood Risks in Agriculture: Status, Challenges and Way Forward. In: *Climate Smart Agriculture in South Asia*. Springer, Berlin Heidelberg, pp. 183–204.

Uchiyama, C., L.A. Stevenson and E. Tandoko, 2020: Climate change research in Asia: A knowledge synthesis of Asia-Pacific Network for Global Change Research (2013–2018). *Environ. Res.*, **188**, 109635.

Udas, P.B., et al., 2019: Basin level gendered vulnerabilities and adaptation: A case of Gandaki River Basin. *Environ. Dev.*, **31**, 43–54, doi:10.1016/j.envdev.2019.05.002.

Uddin, M. A. R. Shah, S. Khanom, M. K. Nesha, 2014: Climate change impacts on the Sundarbans mangrove ecosystem services and dependent livelihoods in Bangladesh. *Asian J. Conserv. Biol.*, **2**, 152–156.

Udo, K. and Y. Takeda, 2018: Projections of future beach loss in Japan due to sea-level rise and uncertainties in projected beach loss. *Coast. Eng. J.*, **59**(2), doi:10.1142/S057856341740006X.

Ullah, W., M. Nafees, M. Khurshid and T. Nihei, 2019: Assessing farmers' perspectives on climate change for effective farm-level adaptation measures in Khyber Pakhtunkhwa, Pakistan. *Environ. Monit. Assess.*, **191**, 547, doi:10.1007/s10661-019-7651-5.

Ulrichs, M., R. Slater and C. Costella, 2019: Building resilience to climate risks through social protection: from individualised models to systemic transformation. *Disasters*, **43**, S368–S387.

10

Umapathy, G., et al., 2016: Ranging, Activity and Habitat Use by Tigers in the Mangrove Forests of the Sundarban. *PLoS ONE*, **11**(4), doi:10.1371/journal.pone.0152119.

UN-HABITAT and UNESCAP, 2018: *Climate Change and National Urban Policies in Asia and The Pacific: A regional guide for integrating climate change concerns into urban-related policy, legislative, financial and institutional frameworks*. https://www.fukuoka.unhabitat.org/projects/asian_subregion/pdf/RegionalGuide_Print_NEWVersion.pdf, accessed on October 1, 2021.

UN-Water, 2018: *The United Nations World Water Development Report 2018: Nature-Based Solutions for Water*. UNESCO, Paris.

UN, 2016: *World Economic and Social Survey 2016.* **(E/2016/50/Rev.1)**. Nations, U, New York.

UN, 2018: *Towards Safe, Orderly and Regular Migration in the Asia-Pacific Region Challenges and Opportunities*.

UNDESA, 2017: *World Population Prospects: Key findings & advance tables*. New York, https://reliefweb.int/organization/un-desa, accessed on October 1, 2021.

UNDESA, 2018: *World Urbanization Prospects: The 2018 Revision*. https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf, accessed on October 1, 2021.

UNDP ESCAP OCHA RIMES APCC, 2017: *Enhancing Resilience to Extreme Climate Events: Lessons from the 2015-2016 El Niño Event in Asia and the Pacific*. https://www.unescap.org/sites/default/files/El%20Nino%20report-%20finalized%20ESCAP07082017.pdf, accessed on October 1, 2021.

UNDP, G, 2018: *Climate Change Adaptation in the Arab States: Best practices and lessons learned*. UNDP, G., Bangkok. 90 pp.

UNEP, 2016: *The Adaptation Finance Gap Report 2016*.

UNEP, 2019: *Air Pollution in Asia and the Pacific: Science-based solutions*. https://www.ccacoalition.org/en/resources/air-pollution-asia-and-pacific-science-based-solutions-summary-full-report, accessed on October 1, 2021.

UNEP, 2020: *Out of the Blue: The Value of Seagrasses to the Environment and to People*. https://www.unenvironment.org/resources/report/out-blue-value-seagrasses-environment-and-people, accessed on October 1, 2021.

UNESCAP, 2013: *The status of the water-energy-food nexus in Asia and the Pacific*. UNESCAP, Thailand.

UNESCAP, 2018a: *Economic and Social Commission for Asia and the Pacific Committee on Environment and Development*. Fifth session, Bangkok, 21–23 November 2018. Item 2 of the provisional agenda* Environmental challenges in the context of the implementation of the 2030 Agenda for Sustainable Development, 21pp pp.

UNESCAP, 2018b: *Energy Transition Pathways for the 2030 Agenda in Asia and the Pacific: Regional Trends Report on Energy for Sustainable Development 2018*.

UNESCAP, 2018c: *Opportunities for Regional Cooperation in Disaster Risk Financing*, 70.

UNESCAP, 2019: *Asia-Pacific Disaster Report 2019. The Disaster Riskscape Across Asia-Pacific*. (ESCAP), Bangkok, Thailand, https://www.unescap.org/sites/default/files/publications/Asia-Pacific%20Disaster%20Report%202019_full%20version.pdf, accessed on October 1, 2021.

UNFCCC, 2015: *Article 6 Climate education and training*.

Ung, M., I. Luginaah, R. Chuenpagdee and G. Campbell, 2015: Perceived Self-Efficacy and Adaptation to Climate Change in Coastal Cambodia. *Climate*, **4**(1), 1, doi:10.3390/cli4010001.

UNICEF, 2015: *The impact of climate change on children*. UNICEF, New York: USA.

UNICEF, 2019: *Social Protection in Asia and the Pacific: Inventory of non-contributory programmes*. International Policy Centre for Inclusive Growth, Brasília.

UNISDR, 2017: *GAR Atlas: Unveiling Global Disaster Risk*.

United Nations, 2015: *Transforming our world : 2030 Agenda for Sustainable Development. General Assembly on 25 September 2015*. United Nation, New York, https://www.preventionweb.net/publications/view/45418, accessed on October 1, 2021.

United Nations Climate Change Secretariat, 2019: *Climate action and support trends*. United Nations Climate Change Secretariat, Bonn, Germany, 33.

United Nations, D. o. E. a. S. A., Population Division (UNDESA), 2019: *World Urbanization Prospects: The 2018 Revision*. United Nations, New York.

United Nations, E. a. S. C. f. A. a. t. P. E, 2020: *Asia-Pacific Migration Report 2020: Assessing Implementation of the Global Compact for Migration*. United Nations, Bangkok.

Unsworth, R.K.F., et al., 2018: Indonesia's globally significant seagrass meadows are under widespread threat. *Sci. Total. Environ.*, **634**, 279–286, doi:10.1016/j.scitotenv.2018.03.315.

Unsworth, R.K.F., et al., 2019a: Global challenges for seagrass conservation. *Ambio*, **48**(8), 801–815, doi:10.1007/s13280-018-1115-y.

Unsworth, R.K.F., L.M. Nordlund and L.C. Cullen-Unsworth, 2019b: Seagrass meadows support global fisheries production. *Conserv. Lett.*, **12**(1), 8, doi:10.1111/conl.12566.

Upadhyay, H., 2014: *Migrating to adapt?: contesting dominant narratives of migration and climate change; case of Maldives and Lakshadweep*.

USAID, 2015: *USAID Mekong Adaptation and Resilience to Climate Change (USAID Mekong ARCC) : Lessons on Integrating Scientific and Community Knowledge of Climate Change to Develop Adaptation Plans in Lower Mekong Basin*. https://www.weadapt.org/, accessed on October 1, 2021.

Vadigi, S., 2017: Indigenous Knowledge Systems and Formal Scientific Research for Climate Change. *Kamla Raj Enterp.*, doi:10.1080/09709274.2016.11906967.

Vaghefi, S.A., et al., 2019: Author Correction: The future of extreme climate in Iran. *Sci. Rep.*, **9**(1), 17420, doi:10.1038/s41598-019-53784-0.

Van Cuong, C., M. Russell, S. Brown and P. Dart, 2015: Using Shoreline Video Assessment for coastal planning and restoration in the context of climate change in Kien Giang, Vietnam. *Ocean Sci. J.*, **50**(2), 413–432, doi:10.1007/s12601-015-0038-9.

Van de Vliert, E.T.R.S.J., 2014: Harsh climate promotes harsh governance (except in cold-dry-weathy environments). *Clim. Res.*, **61**(1), 19–28, doi:10.3354/cr01246.

van der Geest, K., 2017: Landslide Loss and Damage in Sindhupalchok District, Nepal: Comparing Income Groups with Implications for Compensation and Relief. *Int. J. Disaster Risk Sci.*, **9**, 157–166, doi:10.1007/s13753-018-0178-5.

van der Heijden, J., A. Cherkasheva and O. Luckman, 2019: Urban climate governance in Russia: Critical insights from Moscow and St Petersburg. *J. Urban. Aff.*, doi:10.1080/07352166.2019.1617036.

van der Keur, P., et al., 2016: Identification and Analysis of Uncertainty in Disaster Risk Reduction and Climate Change Adaptation in South and Southeast Asia. *Int. J. Dis. Risk Reduct.*, **16**, 208–214.

van der Zande, R.M., et al., 2020: Paradise lost: End-of-century warming and acidification under business-as-usual emissions have severe consequences for symbiotic corals. *Glob. Change Biol.*, **26**(4), 2203–2219, doi:10.1111/gcb.14998.

van Gevelt, T., et al., 2019: Indigenous perceptions of climate anomalies in Malaysian Borneo. *Glob. Environ. Chang.*, **58**, doi:10.1016/j.gloenvcha.2019.101974.

van Katwijk, M.M., et al., 2016: Global analysis of seagrass restoration: the importance of large-scale planting. *J. Appl. Ecol.*, **53**(2), 567–578, doi:10.1111/1365-2664.12562.

Van Luong, C., et al., 2012: Status and threats on seagrass beds using GIS in Vietnam. Proc. SPIE **8525**, Remote Sensing of the Marine Environment II, 852512 (11 December 2012), 214–226, https://doi.org/10.1117/12.977277.

van Valkengoed, A. and L. Steg, 2019a: The Psychology of Climate Change Adaptation. In: *Elements in Applied Social Psychology* [Clayton, S.(ed.)]. Cambridge University Press, Cambridge, UK, ISBN 978-1108724456.

van Valkengoed, A.M. and L. Steg, 2019b: Meta-analyses of factors motivating climate change adaptation behaviour. *Nat. Clim. Change*, **9**(2), 158–163, doi:10.1038/s41558-018-0371-y.

Van Vliet, M.T.H., F. Ludwig and P. Kabat, 2013: Global streamflow and thermal habitats of freshwater fishes under climate change. *Clim. Change*, **121**(4), 739–754, doi:10.1007/s10584-013-0976-0.

Varma, N. and S. Hazarika, 2018: Bridges and Barriers for Governance of Water Resources in South Asia—Insights from Brahmaputra Basin in India. In: *Climate Change Governance and Adaptation*. CRC Press, Boca Raton, FL, USA. pp. 161–182.

Veettil, B.K., et al., 2019: Mangroves of Vietnam: historical development, current state of research and future threats. *Estuar. Coast. Shelf Sci.*, **218**, 212–236, doi:10.1016/j.ecss.2018.12.021.

Veh, G., O. Korup, S. Roessner and A. Walz, 2018: Detecting Himalayan glacial lake outburst floods from Landsat time series. *Remote. Sens. Environ.*, **207**, 84–97.

Veh, G., et al., 2019: Unchanged frequency of moraine-dammed glacial lake outburst floods in the Himalaya. *Nat. Clim. Chang.*, **9**(5), 379, doi:10.1038/s41558-019-0437-5.

Vij, S., R. Biesbroek, A. Groot and K. Termeer, 2018: Changing climate policy paradigms in Bangladesh and Nepal. *Environ. Sci. Policy*, **81**, 77–85.

Vij, S., et al., 2017: Climate adaptation approaches and key policy characteristics: Cases from South Asia. *Environ. Sci. Policy*, **78**, 58–65.

Vinh, T.V., et al., 2019: Allometric models to estimate above-ground biomass and carbon stocks in Rhizophora apiculata tropical managed mangrove forests (Southern Viet Nam). *For. Ecol. Manag.*, **434**, 131–141, doi:10.1016/j.foreco.2018.12.017.

Visvanathan, C., 2018: *Water Quality and Security in Asia and the Pacific ~What 3R and Circular Economy can Offer?* United Nations Centre for Regional Development, Indore, Madhya Pradesh, India.

Vivekanandan, E., R. Hermes and C. O'Brien, 2016: Climate change effects in the Bay of Bengal Large Marine Ecosystem. *Environ. Dev.*, **17**, 46–56, doi:10.1016/j.envdev.2015.09.005.

von Stechow, C., et al., 2016: 2 C and SDGs: united they stand, divided they fall? *Environ. Res. Lett.*, **11**(3), 34022.

Vu, T.T. and R. Ranzi, 2017: Flood risk assessment and coping capacity of floods in central Vietnam. *J. Hydro Environ. Res.*, **14**, 44–60, doi:10.1016/J.JHER.2016.06.001.

Wabnitz, C.C.C., et al., 2018: Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf. *PLoS ONE*, **13**(5), 26, doi:10.1371/journal.pone.0194537.

Wada, Y. and L. Heinrich, 2013: Assessment of transboundary aquifers of the world—vulnerability arising from human water use. *Environ. Res. Lett.*, **8**(2), 24003.

Wagner, B., et al., 2015: Carbon pools of semi-arid *Picea crassifolia* forests in the Qilian Mountains (north-eastern Tibetan Plateau). *For. Ecol. Manag.*, **343**, 136–143, doi:10.1016/j.foreco.2015.02.001.

Walch, C., 2018: Evacuation ahead of natural disasters: Evidence from cyclone Phailin in India and typhoon Haiyan in the Philippines. *Geo Geogr. Environ.*, **5**(1), 1–16, doi:10.1002/geo2.51.

Walch, C., 2019: Adaptive Governance in the Developing World: Disaster Risk Reduction in the State of Odisha, India. *Clim. Dev.*, **11**(3), 238–252.

Wals, A.E., M. Brody, J. Dillon and R.B. Stevenson, 2014: Convergence between science and environmental education. *Science*, **344**(6184), 583–584.

Wan, J.Z., C.J. Wang, J.F. Tan and F.H. Yu, 2017: Climatic niche divergence and habitat suitability of eight alien invasive weeds in China under climate change. *Ecol Evol*, **7**(5), 1541–1552, doi:10.1002/ece3.2684.

Wan, X., et al., 2019: Historical records reveal the distinctive associations of human disturbance and extreme climate change with local extinction of mammals. *Proc. Natl. Acad. Sci.*, **116**(38), 19001, doi:10.1073/pnas.1818019116.

Wang, C., et al., 2018a: Different response of human mortality to extreme temperatures (MoET) between rural and urban areas: A multi-scale study across China. *Health Place*, **50**, 119–129, doi:10.1016/j.healthplace.2018.01.011.

Wang, G., P. Yang and X. Zhou, 2017a: Identification of the driving forces of climate change using the longest instrumental temperature record. *Sci. Rep.*, **7**, 46091, doi:10.1038/srep46091.

Wang, H., C. Mei, J. Liu and W. Shao, 2019a: *A new strategy for integrated urban water management in China: Sponge city*. Springer, Berlin Heidelberg, doi:10.1007/s11431-017-9170-5.

Wang, H., et al., 2019b: Tropical cyclone damages in Mainland China over 2005–2016: Losses analysis and implications. *Environ. Dev. Sustain.*, **21**, 3077–3092, doi:10.1007/s10668-019-00481-7.

Wang, J.-X., J.-K. Huang and J. Yang, 2014: Overview of Impacts of Climate Change and Adaptation in China's Agriculture. *J. Integr. Agric.*, **13**(1), 1–17, doi:10.1016/S2095-3119(13)60588-2.

Wang, J., Y. Yang, J. Huang and K. Chen, 2015: Information provision, policy support, and farmers' adaptive responses against drought: An empirical study in the North China Plain. *Ecol. Model.*, **318**, 275–282, doi:10.1016/j.ecolmodel.2014.12.013.

Wang, K., et al., 2021a: Understanding the impacts of climate change and socio-economic development through food-energy-water nexus: A case study of mekong river delta. *Resour. Conserv. Recycl.*, **167**, 105390, doi:10.1016/j.resconrec.2020.105390.

Wang, L., et al., 2020: Assessment of soil erosion risk and its response to climate change in the mid-Yarlung Tsangpo River region. *Environ. Sci. Pollut. Res.*, **27**(1), 607–621.

Wang, M., et al., 2018b: Assessing changes of mangrove forest in a coastal region of southeast China using multi-temporal satellite images. *Estuar. Coast. Shelf Sci.*, **207**, 283–292, doi:10.1016/j.ecss.2018.04.021.

Wang, P., W.B. Goggins and E.Y.Y. Chan, 2018c: A time-series study of the association of rainfall, relative humidity and ambient temperature with hospitalizations for rotavirus and norovirus infection among children in Hong Kong. *Sci. Total Environ.*, **643**, 414–422, doi:10.1016/j.scitotenv.2018.06.189.

Wang, P., et al., 2021b: Potential role of permafrost thaw on increasing Siberian river discharge. *Environ. Res. Lett.*, **16**(3), 34046.

Wang, P., L. Liu and T. Wu, 2017b: A review of China's climate governance: state, market and civil society. *Clim. Policy*, **18**(5), 664–679, doi:10.1080/14693062.2017.1331903.

Wang, X., et al., 2017c: No consistent evidence for advancing or delaying trends in spring phenology on the Tibetan Plateau. *J. Geophys. Res.*, **122**(12), 3288–3305, doi:10.1002/2017jg003949.

Wang, Y., et al., 2019c: The stability of spruce treelines on the eastern Tibetan Plateau over the last century is explained by pastoral disturbance. *For. Ecol. Manag.*, **442**, 34–45, doi:10.1016/j.foreco.2019.03.058.

Wang, Y. and M. Wild, 2016: A new look at solar dimming and brightening in China. *Geophys. Res. Lett.*, **43**(22), 11,777–711,785, doi:10.1002/2016GL071009.

Wani, K. A. and L. Ariana, 2018: *Impact of Climate Change on Indigenous People and Adaptive Capacity of Bajo Tribe, Indonesia*. doi:10.1080/10406026.2018.1504380.

Ward, P.J., et al., 2017: A global framework for future costs and benefits of river-flood protection in urban areas. *Nat. Clim. Change*, **7**(9), 642–646.

Ward, R., et al., 2016a: Improved modelling of the impacts of sea level rise on coastal wetland plant communities. *Hydrobiologia*, **774**(1), 203–216.

Ward, R.D., D.A. Friess, R.H. Day and R.A. Mackenzie, 2016b: Impacts of climate change on mangrove ecosystems: a region by region overview. *Ecosyst. Health Sustain.*, **2**(4), doi:10.1002/ehs2.1211.

Warren, R., et al., 2018: The implications of the United Nations Paris Agreement on climate change for globally significant biodiversity areas. *Clim. Change*, **147**(3-4), 395–409, doi:10.1007/s10584-018-2158-6.

Wassmann, R., et al., 2019a: High-resolution mapping of flood and salinity risks for rice production in the Vietnamese Mekong Delta. *Field Crop. Res.*, **236**, 111–120, doi:10.1016/j.fcr.2019.03.007.

Wassmann, R., et al., 2019b: Adaptation, mitigation and food security: Multi-criteria ranking system for climate-smart agriculture technologies illustrated for rainfed rice in Laos. *Glob. Food Sec.*, **23**, 33–40, doi:10.1016/j.gfs.2019.02.003.

Water, U., 2020: *UN world water development report 2020: Water and climate change*.

Watson, C., et al., 2017: *Shock responsive and social protection Pakistan Management*.

Watts, N., et al., 2015: *Strengthening Health Resilience to Climate Change*.

Waycott, M., et al., 2009: Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proc. Natl. Acad. Sci. USA*, **106**(30), 12377–12381, doi:10.1073/pnas.0905620106.

WEC, 2018: *World Energy Trilemma Index 2018*. https://www.worldenergy.org/assets/downloads/World-Energy-Trilemma-Index-2018.pdf, accessed on October 1, 2021.

WEF, 2018: *The Global Competitiveness Report 2017–2018: 2.01 Quality of overall infrastructure*. World Economic Forum.

Weindl, I., et al., 2015: Livestock in a changing climate: production system transitions as an adaptation strategy for agriculture. *Environ. Res. Lett.*, **10**(9), doi:10.1088/1748-9326/10/9/094021.

Werg, J., T. Grothmann and P. Schmidt, 2013: Assessing social capacity and vulnerability of private households to natural hazards - Integrating psychological and governance factors. *Nat. Hazards Earth Syst. Sci.*, **13**(6), 1613–1628, doi:10.5194/nhess-13-1613-2013.

Wester, P., A. Mishra, A. Mukherji and A.B. Shrestha (eds.), 2019: *The Hindu Kush Himalaya Assessment – Mountains, Climate Change, Sustainability and People*. Springer, Cham, ISBN 978-3319922874. 627 pp.

Westermann, O., et al., 2018: Scaling up agricultural interventions: Case studies of climate-smart agriculture. *Agric. Syst.*, **165**, 283–293, doi:10.1016/j.agsy.2018.07.007.

Weststrate, J., et al., 2019: The sustainable development goal on water and sanitation: learning from the millennium development goals. *Soc. Indic. Res.*, **143**(2), 795–810.

Wheater, H.S. and P. Gober, 2015: Water security and the science agenda. *Water Resour. Res.*, **51**, 5406–5424, doi:10.1002/2015WR016892@10.1002/(ISSN)1944-7973.WRR50.

Wi, A. and C.-H. Chang, 2018: Promoting pro-environmental behaviour in a community in Singapore – from raising awareness to behavioural change. *Environ. Educ. Res.*, 1–19, doi:10.1080/13504622.2018.1528496.

Widiati, I.R. and Irianto, 2019: Mitigation and adaptation to climate change on among stakeholder for sustainability: Evaluation a regional multistakeholder for an approach of the role of disaster risk management. *IOP Conf. Series: Earth Environ. Sci.*, **235**, doi:10.1088/1755-1315/235/1/012103.

Wijetunge, J.J. (ed.), *Disaster risk assessment and mitigation strategy for tropical cyclone induced storm surge hazard and coastal impacts of climate change in Sri Lanka*. International Conference on Hydroinformatics. City University of New York, New York.

Wijngaard, R.R., et al., 2018: Climate change vs. socio-economic development: understanding the future South Asian water gap. *Hydrol. Earth Syst. Sci.*, **22**(12), 6297–6321.

Wijngaard, R.R., et al., 2017: Future changes in hydro-climatic extremes in the Upper Indus, Ganges, and Brahmaputra River basins. *PLoS ONE*, **12**(12), e190224.

Winkler, D.E., et al., 2016: Seasonal dry-down rates and high stress tolerance promote bamboo invasion above and below treeline. *Plant. Ecol.*, **217**(10), 1219–1234, doi:10.1007/s11258-016-0649-y.

Winters, L.A.A. and M. Antonio, 2014: Trade Liberalization and Poverty: What Have We Learned in a Decade? *Annu. Rev. Resour. Econ.*, **6**(1), 493–512.

Wodon, Q., A. Liverani, G. Joseph and N. Bougnoux, 2014: *Climate change and migration: evidence from the Middle East and North Africa*. The World Bank, Washington DC, USA. ISBN 978-0821399712.

Wong, J., et al., 2020: Preparing for a COVID-19 pandemic: a review of operating room outbreak response measures in a large tertiary hospital in Singapore. *Can. J. Anesth.*, 67(6), 732-745. doi: 10.1007/s12630-020-01620-9.

Woolway, R.I., et al., 2020: Global lake responses to climate change. *Nat. Rev. Earth Environ.* 1(8). DOI:10.1038/s43017-020-0067-5.

World Health Organization, 2014: *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s* Simon Hales, Sari Kovats, Simon Lloyd and D. Campbell-Lendrum.

World Meteorological Organization, 2017: *TAHAK, A meteorological application services initiated by IRIMO to support end users*.

World Bank, 2016: *Emerging Trends in Mainstreaming Climate Resilience in Large Scale, Multi-sector Infrastructure PPPs*. accessed on October 1, 2021.

World Bank, 2017: *Resilient Infrastructure Public-Private Partnerships (PPPs): Contracts and Procurement Resilient - The Case of Japan*. https://www.globalinfrafacility.org/sites/gif/files/Resilient%20Infrastrcuture%20PPP%20Japan%20Case%20Study%20FINAL_web.pdf, accessed on October 1, 2021.

Wu, G., Z. Han, W. Xu and Y. Gong, 2018a: Mapping individuals' earthquake preparedness in China. *Nat. Hazards Earth Syst. Sci.*, **18**(5), 1315–1325, doi:10.5194/nhess-18-1315-2018.

Wu, G., et al., 2012: Revisiting Asian monsoon formation and change associated with Tibetan Plateau forcing: I. Formation. *Clim. Dyn.*, **39**(5), 1169–1181, doi:10.1007/s00382-012-1334-z.

Wu, H., J. Carrillo and J.Q. Ding, 2016: Invasion by alligator weed, Alternanthera philoxeroides, is associated with decreased species diversity across the latitudinal gradient in China. *J. Plant Ecol.*, **9**(3), 311–319, doi:10.1093/jpe/rtv060.

Wu, H., et al., 2019a: Spatio-temporal analysis of drought variability using CWSI in the Koshi River Basin (KRB). *Int. J. Environ.Res. Public Health*, **16**(17), 3100.

Wu, H.L., et al., 2019b: Effects of increased CO2 and temperature on the physiological characteristics of the golden tide blooming macroalgae Sargassum horneri in the Yellow Sea, China. *Mar. Pollut. Bull.*, **146**, 639–644, doi:10.1016/j.marpolbul.2019.07.025.

Wu, J., et al., 2018b: Disaster Monitoring and Emergency Response Services in CHINA. Int. Arch. Photogramm.*Remote. Sens. Spatial Inf. Sci*, **XLII-3**, 1879–1881, doi:10.5194/isprs-archives-XLII-3-1879-2018.

Wu, J., et al., 2019c: Planned Sheltering as an Adaptation Strategy to Climate Change: Lessons Learned from the Severe Flooding in Anhui Province of China in 2016. *Sci. Total. Environ.*, **694**. DOI: 10.1016/j.scitotenv.2019.133586.

Wu, J., J. Zha and D. Zhao, 2017a: Evaluating the effects of land use and cover change on the decrease of surface wind speed over China in recent 30 years using a statistical downscaling method. *Clim. Dyn.*, **48**(1), 131–149, doi:10.1007/s00382-016-3065-z.

Wu, J., J. Zha, D. Zhao and Q. Yang, 2018c: Changes in terrestrial near-surface wind speed and their possible causes: an overview. *Clim. Dyn.*, **51**(5), 2039–2078, doi:10.1007/s00382-017-3997-y.

Wu, N., et al., 2018d: Chapter 4: Direct and indirect drivers of change in biodiversity and nature's contributions to people. In: *IPBES (2018): The IPBES regional assessment report on biodiversity and ecosystem services for Asia and the Pacific* [Karki, M., S. Senaratna Sellamuttu, S. Okayasu and W. Suzuki(eds.)]. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, pp. 265–370.

Wu, S., L. Liu, J. Gao and W. Wang, 2019d: Integrate risk from climate change in China under global warming of 1.5°C and 2.0°C. *Earths Future*, **7**(12), 1307–1322, doi:10.1029/2019EF001194.

Wu, X., et al., 2021: Snow cover loss compounding the future economic vulnerability of western China. *Sci. Total. Environ.*, **755**, 143025.

Wu, Y., et al., 2017b: Describing interaction effect between lagged rainfalls on malaria: an epidemiological study in south-west China. *Malar. J.*, **16**(1), 53, doi:10.1186/s12936-017-1706-2.

Wu, Z.W., et al., 2014: Relative effects of climatic and local factors on fire occurrence in boreal forest landscapes of northeastern China. *Sci. Total. Environ.*, **493**, 472–480, doi:10.1016/j.scitotenv.2014.06.011.

Xenarios, S., et al., 2019: Climate change and adaptation of mountain societies in Central Asia: uncertainties, knowledge gaps, and data constraints. *Reg. Environ. Change*, **19**(5), 1339–1352, doi:10.1007/s10113-018-1384-9.

Xia, J., et al., 2019: Shifts in timing of local growing season in China during 1961-2012. *Theor. Appl. Climatol.*, **137**(3-4), 1637–1642, doi:10.1007/s00704-018-2698-8.

Xia, J., K. Tu, Z. Yan and Y. Qi, 2016: The super-heat wave in eastern China during July–August 2013: a perspective of climate change. *Int. J. Climatol.*, **36**(3), 1291–1298, doi:10.1002/joc.4424.

Xiang, J., et al., 2018: Association between malaria incidence and meteorological factors: a multi-location study in China, 2005-2012. *Epidemiol. Infect.*, **146**(1), 89–99, doi:10.1017/s0950268817002254.

Xie, B., et al., 2020: Global health crises are also information crises: A call to action. *J. Assoc. Inf. Sci. Technol.*

Xie, J., et al., 2017: An integrated assessment of urban flooding mitigation strategies for robust decision making. *Environ. Model. Softw.*, **95**, 143–155.

Xu, J. and R.E. Grumbine, 2014: Integrating local hybrid knowledge and state support for climate change adaptation in the Asian Highlands. *Clim. Change*, **124**(1-2), 93–104, doi:10.1007/s10584-014-1090-7.

Xu, L., et al., 2017: Climate variation drives dengue dynamics. *Proc. Natl. Acad. Sci. U. S. A.*, **114**(1), 113–118, doi:10.1073/pnas.1618558114.

Xu, L., et al., 2019: Identifying the trade-offs between climate change mitigation and adaptation in urban land use planning: An empirical study in a coastal city. *Environ. Int.*, **133**, 105162.

Xu, Z.L., H.H. Peng, Z.D. Feng and N. Abdulsalih, 2014: Predicting Current and Future Invasion of Solidago Canadensis: A Study from China. *Pol. J. Ecol.*, **62**(2), 263–271, doi:10.3161/104.062.0207.

Yadav, S.S. and R. Lal, 2018: Vulnerability of women to climate change in arid and semi-arid regions: The case of India and South Asia. *J. Arid Environ.*, **149**, 4–17, doi:10.1016/j.jaridenv.2017.08.001.

Yamamoto, T., et al., 2021: Evaluation of flood damage reduction throughout Japan from adaptation measures taken under a range of emissions mitigation scenarios. *Clim. Change*, **165**(3), 60, doi:10.1007/s10584-021-03081-5.

Yamanaka, M.D., et al., 2018: Maritime continent coastlines controlling Earth's climate. *Prog. Earth Planet. Sci.*, **5**(1), doi:10.1186/s40645-018-0174-9.

Yamane, T., 2014: Foliar Calcium Applications for Controlling Fruit Disorders and Storage Life in Deciduous Fruit Trees. *Jpn. Agric. Res. Q.*, **48**, 29–33, doi:10.6090/jarq.48.29.

Yamazaki, S., et al., 2015: Exposure to air pollution and meteorological factors associated with children's primary care visits at night due to asthma attack: case-crossover design for 3-year pooled patients. *BMJ Open*, **5**(4), e5736, doi:10.1136/bmjopen-2014-005736.

Yan, H.Q., et al., 2019: Regional coral growth responses to seawater warming in the South China Sea. *Sci. Total. Environ.*, **670**, 595–605, doi:10.1016/j.scitotenv.2019.03.135.

Yan, Y., et al., 2018: Diatom response to climatic warming over the last 200 years: A record from Gonghai Lake, North China. *Geol. Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **495**, 48–59, doi:10.1016/j.palaeo.2017.12.023.

Yang, B., et al., 2017: New perspective on spring vegetation phenology and global climate change based on Tibetan Plateau tree-ring data. *Proc. Natl. Acad. Sci. U.S.A.*, **114**(27), 6966–6971, doi:10.1073/pnas.1616608114.

Yang, J., et al., 2012a: Daily temperature and mortality: a study of distributed lag non-linear effect and effect modification in Guangzhou. *Environ. Health.*, **11**, 63, doi:10.1186/1476-069x-11-63.

Yang, L., G. Su and H. Yuan, 2012b: Design principles of integrated information platform for emergency responses: The case of 2008 Beijing Olympic Games. *Inf. Syst. Res.*, **23**(3-part-1), 761–786, doi:10.1287/isre.1110.0387.

Yang, R., 2018: Agricultural Insurance: Theory, Empirical Research and Experience–Based on Farmers Household Data. *China Agric. Econ. Rev.*, **10**(1), 173–175.

Yang, S., X. Wang and M. Wild, 2018a: Homogenization and trend analysis of the 1958-2016 in-situ surface solar radiation records in China. *J. Climate*, **31**, doi:10.1175/JCLI-D-17-0891.1.

Yang, X., et al., 2012c: The decreasing wind speed in southwestern China during 1969–2009, and possible causes. *Quat. Int.*, **263**, 71–84, doi:10.1016/j.quaint.2012.02.020.

Yang, Y.B., et al., 2018b: Where will Invasive Plants Colonize in Response to Climate Change: Predicting the Invasion of Galinsoga quadriradiata in China. *Int. J. Environ. Res.*, **12**(6), 929–938, doi:10.1007/s41742-018-0146-3.

Yao, L., L. Chen, W. Wei and R. Sun, 2015: *Potential reduction in urban runoff by green spaces in Beijing: A scenario analysis*. doi:10.1016/j.ufug.2015.02.014.

Yari, A., et al., 2019: Underlying factors affecting death due to flood in Iran: A qualitative content analysis. *Int. J. Dis. Risk Reduct.*, **40**, doi:10.1016/j.ijdrr.2019.101258.

Yati, E., et al., 2020: Marine ecosystem variations over the North Pacific and their linkage to large-scale climate variability and change. *Front. Mar. Sci.*, **7**(925), doi:10.3389/fmars.2020.578165.

Ye, G., et al., 2015: Is integrated coastal management an effective framework for promoting coastal sustainability in China's coastal cities? *Mar. Policy.*, **56**, 48–55, doi:10.1016/j.marpol.2015.02.009.

Ye, H., Z. Huang, L. Huang, L. Lin and M. Luo, 2018: Effects of urbanization on increasing heat risks in South China. *Int. J. Climatol.*, doi:10.1002/joc.5747.

Yin, H., A. Khamzina, D. Pflugmacher and C. Martius, 2017: Forest cover mapping in post-Soviet Central Asia using multi-resolution remote sensing imagery. *Sci. Rep.*, **7**(1), doi:10.1038/s41598-017-01582-x.

Yin, J., et al., 2020: Flood Risks in Sinking Delta Cities: Time for a Reevaluation? *Earths Future*, **8**(8), e2020EF001614, doi:10.1029/2020ef001614.

Yin, J., et al., 2012: Using Social Media to Enhance Emergency Situation Awareness. *IEEE Intell. Syst.*, **27**(6), 52–59, doi:10.1109/MIS.2012.6.

Yin, P., et al., 2018: The added effects of heatwaves on cause-specific mortality: A nationwide analysis in 272 Chinese cities. *Environ. Int.*, **121**(Pt 1), 898–905, doi:10.1016/j.envint.2018.10.016.

Yong-Jian, R., et al., 2013: Climate Change Impacts on Central China and Adaptation Measures. *Adv. Clim. Chang. Res.*, **4**(4), 215–222, doi:10.3724/sp.J.1248.2013.215.

Yoseph-Paulus, R. and R. Hindmarsh, 2016: Addressing inadequacies of sectoral coordination and local capacity building in Indonesia for effective climate change adaptation. *Clim. Dev.*, **10**(1), 35–48, doi:10.1080/17565529.2016.1184609.

Yoshida, K., et al., 2017: Future Changes in Tropical Cyclone Activity in High-Resolution Large-Ensemble Simulations. *Geophys. Res. Lett.*, **44**(19), 9910–9917, doi:10.1002/2017gl075058.

You, Q.-L., et al., 2017: An overview of studies of observed climate change in the Hindu Kush Himalayan (HKH) region. *Adv. Clim. Chang. Res.*, **8**(3), 141–147.

You, W.H., et al., 2014: Responses of the invasive aquatic plant water hyacinth to altered nutrient levels under experimental warming in China. *Aquat. Bot.*, **119**, 51–56, doi:10.1016/j.aquabot.2014.06.004.

Yousefi, M., A. Jouladeh-Roudbar and A. Kafash, 2020: Using endemic freshwater fishes as proxies of their ecosystems to identify high priority rivers for conservation under climate change. *Ecol. Indic.*, **112**, doi:10.1016/j.ecolind.2020.106137.

Yousefi, M., et al., 2019: Climate Change is a Major Problem for Biodiversity Conservation: A Systematic Review of Recent Studies in Iran. *Contemp. Probl. Ecol.*, **12**(4), 394–403, doi:10.1134/S1995425519040127.

Yu, C., et al., 2018a: Assessing the impacts of extreme agricultural droughts in China under climate and socioeconomic changes. *Earths Future*, **6**(5), 689–703, doi:10.1002/2017EF000768.

Yu, L., 2016: Agro-pastoralism under climate change: Institutions and local climate adaptations in northern China. *Land Use Policy*, **58**, 173–182, doi:10.1016/j.landusepol.2016.07.022.

Yu, L., et al., 2020: Impacts of 1.5°C and 2°C global warming on net primary productivity and carbon balance in China's terrestrial ecosystems. *Sustainability*, **12**(7), doi:10.3390/su12072849.

Yu, M., C. Yang and Y. Li, 2018b: Big data in natural disaster management: a review. *Geosciences*, **8**(5), 165.

Yu, Q., A.K.H. Lau, K.T. Tsang and J.C.H. Fung, 2018c: Human damage assessments of coastal flooding for Hong Kong and the Pearl River Delta due to climate change-related sea level rise in the twenty-first century. *Nat. Hazards*, **92**, 1011–1038, doi:10.1007/S11069-018-3236-9.

Yu, R., P. Zhai and Y. Chen, 2018d: Facing climate change-related extreme events in megacities of China in the context of 1.5°C global warming. *Curr. Opin. Environ. Sustain.*, **30**, 75–81, doi:10.1016/j.cosust.2018.03.008.

Yu, R., P. Zhai and Y. Lu, 2018e: Implications of differential effects between 1.5 and 2°C global warming on temperature and precipitation extremes in China's urban agglomerations. *Int. J. Climatol.*, **38**(5), 2374–2385, doi:10.1002/joc.5340.

Yu, W., et al., 2015: Variability of Suitable Habitat of Western Winter-Spring Cohort for Neon Flying Squid in the Northwest Pacific under Anomalous Environments. *PLoS ONE*, **10**(4), e122997, doi:10.1371/journal.pone.0122997.

Yuan, W.B., et al., 2018: Combined effects of ocean acidification and warming on physiological response of the diatom Thalassiosira pseudonana to light challenges. *Mar. Environ. Res.*, **135**, 63–69, doi:10.1016/j.marenvres.2018.01.016.

Yuan, X., et al., 2019: Coral responses to ocean warming and acidification: Implications for future distribution of coral reefs in the South China Sea. *Mar. Pollut. Bull.*, **138**, 241–248, doi:10.1016/j.marpolbul.2018.11.053.

Yumarni, T. and D. Amaratunga, 2018: Gender mainstreaming as a strategy to achieve sustainable post-disaster reconstruction. *Built Environ. Proj. Asset Manag.*, **8**(5), 544–556, doi:10.1108/bepam-10-2017-0086.

Yun, J.H., et al., 2018: Vulnerability of subalpine fir species to climate change: using species distribution modeling to assess the future efficiency of current protected areas in the Korean Peninsula. *Ecol. Res.*, **33**(2), 341–350, doi:10.1007/s11284-018-1581-5.

Yun, X., et al., 2020: Impacts of climate change and reservoir operation on streamflow and flood characteristics in the Lancang-Mekong River Basin. *J. Hydrol. Reg. Stud.*, **590**, 125472.

Zakharov, V.D., 2016: The influence of climate change on the dates of bird arrival to the Ilmen State Reserve (Southern Urals). *Russ. J. Ecol.*, **47**(6), 546–551, doi:10.1134/s1067413616060138.

Zakharov, V.D., 2018: Long-Term Dynamics of Winter Communities of Forest Birds in the Ilmen Nature Reserve. *Russ. J. Ecol.*, **49**(4), 332–337, doi:10.1134/s106741361803013x.

Zakharova, E.Y., A.O. Shkurikhin and T.S. Oslina, 2017: Morphological variation of *Melanargia russiae* (Esper, 1783) (Lepidoptera, Satyridae) from the main part of the range and in case of its expansion to the north under climate change conditions. *Contemp. Probl. Ecol.*, **10**(5), 488–501, doi:10.1134/S1995425517050146.

Zaman, K., S. Shamsuddin and M. Ahmad, 2017: Energy-water-food nexus under financial constraint environment: good, the bad, and the ugly sustainability reforms in sub-Saharan African countries. *Environ. Sci. Pollut. Res.*, **24**(15), 13358–13372, doi:10.1007/s11356-017-8961-1.

Zanzanaini, C., et al., 2017: Integrated landscape initiatives for agriculture, livelihoods and ecosystem conservation: An assessment of experiences from South and Southeast Asia. *Landsc. Urban Plan.*, **165**, 11–21, doi:10.1016/j.landurbplan.2017.03.010.

Zemp, M., et al., 2019: Global glacier mass changes and their contributions to sea-level rise from 1961 to 2016. *Nature*, **568**(7752), 382, doi:10.1038/s41586-019-1071-0.

Zen, I.S., A.Q. Al-amin and B. Doberstein, 2019: Mainstreaming climate adaptation and mitigation policy: Towards multi-level climate governance in Melaka, Malaysia. *Urban Clim.*, **30**, doi:10.1016/j.uclim.2019.100501.

Zeng, Z., et al., 2019: A reversal in global terrestrial stilling and its implications for wind energy production. *Nat. Clim. Chang.*, **9**(12), 979–985, doi:10.1038/s41558-019-0622-6.

Zevenbergen, C., D. Fu and A. Pathirana, 2018: *Transitioning to sponge cities: challenges and opportunities to address urban water problems in China*. Multidisciplinary Digital Publishing Institute, Basel, Switzerland.

Zha, J., J. Wu and D. Zhao, 2016: Changes of probabilities in different wind grades induced by land use and cover change in Eastern China Plain during 1980-2011. *Atmospheric Sci. Lett.*, **17**, doi:10.1002/asl.653.

Zhai, S-y., et al., 2018: Climate change and Chinese farmers : perceptions and determinants of adaptive strategies. *J. Integr. Agric.*, **17**(4), 949–963, doi:10.1016/s2095-3119(17)61753-2.

Zhan, Y.Y., et al., 2020: CO2-driven ocean acidification repressed the growth of adult sea urchin Strongylocentrotus intermedius by impairing intestine function. *Mar. Pollut. Bull.*, **153**, 9, doi:10.1016/j.marpolbul.2020.110944.

Zhang, C. and W. Ren, 2017: Complex climatic and CO2 controls on net primary productivity of temperate dryland ecosystems over central Asia during 1980–2014. *J. Geophys. Res. Biogeosci.*, **122**(9), 2356–2374, doi:10.1002/2017JG003781.

Zhang, C., Y. Huang, A. Javed and G.B. Arhonditsis, 2019a: An ensemble modeling framework to study the effects of climate change on the trophic state of shallow reservoirs. *Sci. Total. Environ.*, **697**, doi:10.1016/j.scitotenv.2019.134078.

Zhang, F., C.K.L. Chung and Z. Yin, 2020a: Green infrastructure for China's new urbanisation: A case study of greenway development in Maanshan. *Urban Stud.*, **57**(3), 508–524, doi:10.1177/0042098018822965.

Zhang, G., et al., 2015: An inventory of glacial lakes in the Third Pole region and their changes in response to global warming. *Glob. Planet. Change.*, **131**, 148–157, doi:10.1016/j.gloplacha.2015.05.013.

Zhang, G., G. Zeng, X.-Z. Liang and C. Huang, 2021: Increasing heat risk in China's urban agglomerations. *Environ. Res. Lett.* **16**(6), 064073.

Zhang, H.X., M.L. Zhang and Y. Wang, 2017a: Distribution pattern of poisonous plant species in arid grasslands: a case from Xinjiang, Northwestern China. *Rangel. J.*, **39**(3), 279–287, doi:10.1071/RJ16018.

Zhang, L., et al., 2016a: Toward optimal soil organic carbon sequestration with effects of agricultural management practices and climate change in Tai-Lake paddy soils of China. *Geoderma*, **275**, 28–39, doi:10.1016/j.geoderma.2016.04.001.

Zhang, M., H. Yu, A.D. King and al e, 2020b: Greater probability of extreme precipitation under 1.5°C and 2°C warming limits over East-Central Asia. *Clim. Change*, doi:10.1007/s10584-020-02725-2.

Zhang, M.L., et al., 2017b: Spatial and temporal variability in the net primary production of grassland in China and its relation to climate factors. *Plant. Ecol.*, **218**(9), 1117–1133, doi:10.1007/s11258-017-0756-4.

Zhang, N., et al., 2019b: The impact of the 2016 flood event in Anhui Province, China on infectious diarrhea disease: An interrupted time-series study. *Environ. Int.*, **127**, 801–809, doi:10.1016/j.envint.2019.03.063.

Zhang, N.N., et al., 2017c: Opposite polarities of ENSO drive distinct patterns of coral bleaching potentials in the southeast Indian Ocean. *Sci. Rep.*, **7**, 10, doi:10.1038/s41598-017-02688-y.

Zhang, P., et al., 2019c: Thermal tolerance traits of the undulated surf clam Paphia undulata based on heart rate and physiological energetics. *Aquaculture*, **498**, 343–350, doi:10.1016/j.aquaculture.2018.08.037.

Zhang, Q., et al., 2016b: Flood-induced agricultural loss across China and impacts from climate indices. *Glob. Planet. Change.*, **139**, 31–43, doi:10.1016/j.gloplacha.2015.10.006.

Zhang, Q., et al., 2016c: Magnitude, frequency and timing of floods in the Tarim River basin, China: Changes, causes and implications. *Glob. Planet. Change.*, **139**, 44–55.

Zhang, X., et al., 2020c: Evaluating the vulnerability of physical and virtual water resource networks in China's megacities. *Resour. Conserv. Recycl.*, **161**, 104972.

Zhang, Y., et al., 2019d: Identifying refugia and corridors under climate change conditions for the Sichuan snub-nosed monkey (Rhinopithecus roxellana) in Hubei Province, China. *Ecol. Evol.*, **9**(4), 1680–1690, doi:10.1002/ece3.4815.

Zhang, Y., et al., 2017d: Land surface phenology of Northeast China during 2000-2015: temporal changes and relationships with climate changes. *Environ. Monit. Assess.*, **189**(11), doi:10.1007/s10661-017-6247-1.

Zhang, Y., et al., 2018: Rising levels of temperature and CO2 antagonistically affect phytoplankton primary productivity in the South China Sea. *Mar. Environ. Res.*, **141**, 159–166, doi:10.1016/j.marenvres.2018.08.011.

Zhang, Y., et al., 2019e: Assessment of future flash flood inundations in coastal regions under climate change scenarios—A case study of Hadahe River basin in northeastern China. *Sci. Total. Environ.*, **693**, doi:10.1016/j.scitotenv.2019.07.356.

Zhang, Y.B., Y.Z. Wang, M.G. Zhang and K.P. Ma, 2014: Climate change threats to protected plants of China: an evaluation based on species distribution modeling. *Chin. Sci. Bull.*, **59**(34), 4652–4659, doi:10.1007/s11434-014-0642-6.

Zhang, Y.Y., et al., 2019 f: Ulva prolifera green-tide outbreaks and their environmental impact in the Yellow Sea, China. *Natl. Sci. Rev.*, **6**(4), 825–838, doi:10.1093/nsr/nwz026.

Zhanqiang, Z., J. Ren and L. Xuan, 2019: Green Infrastructure Provision for Environmental Justice: Application of the Equity Index in Guangzhou, China. *Urban For. Urban Green.* 126443.

Zhao, H., et al., 2020: Virtual water scarcity risk in China. *Resour. Conserv. Recycl.*, **160**, 104886.

Zhao, J., H.Y. Du, Y.F. Shi and Y.J. Che, 2017a: A GIS simulation of potential vegetation in China under different climate scenarios at the end of the 21st century. *Contemp. Probl. Ecol.*, **10**(3), 315–325, doi:10.1134/s1995425517030131.

Zhao, X.G., et al., 2017b: Ocean acidification adversely influences metabolism, extracellular pH and calcification of an economically important marine bivalve, Tegillarca granosa. *Mar. Environ. Res.*, **125**, 82–89, doi:10.1016/j.marenvres.2017.01.007.

Zhao, Y.-F., Z.-H. Chai, M.S. Delgado and P.V. Preckel, 2017c: A test on adverse selection of farmers in crop insurance: Results from Inner Mongolia, China. *J. Integr. Agric.*, **16**(2), 478–485.

Zhao, Y., Z. Chai, M.S. Delgado and P.V. Preckel, 2016a: An empirical analysis of the effect of crop insurance on farmers' income: results from inner Mongolia in China. *China Agric. Econ. Rev.*, **8**(2), 299–313.

Zhao, Y., et al., 2016b: Potential escalation of heat-related working costs with climate and socioeconomic changes in China. *Proc. Natl. Acad. Sci.*, **113**(17), 4640–4645, doi:10.1073/pnas.1521828113.

Zheng, X., F. Kuo, K. Pan, H. Huang and R. Lin, 2019: *Different calcification responses of two hermatypic corals to CO 2 -driven ocean acidification*.

Zheng, Y. and M. Dallimer, 2016: What motivates rural households to adapt to climate change ? *Clim. Dev.*, **8**(2), 110–121, doi:10.1080/17565529.2015.1005037.

Zhu, W., L. Porth and K.S. Tan, 2019: A credibility-based yield forecasting model for crop reinsurance pricing and weather risk management. *Agric. Finance Rev.*, **79**(1), 2–26.

Zhupankhan, A., K. Tussupova and R. Berndtsson, 2018: Water in Kazakhstan, a key in Central Asian water management. *Hydrol. Sci. J.*, **63**(5), 752–762, doi:10.1080/02626667.2018.1447111.

Zickgraf, C., 2019: Keeping People in Place: Political Factors of (Im) mobility and Climate Change. *Soc. Sci.*, **8**(8), 228.

Zinia, N.J. and P. McShane, 2018: Ecosystem services management: An evaluation of green adaptations for urban development in Dhaka, Bangladesh. *Landsc. Urban Plan.*, **173**, 23–32.

Zolotareva, N.V. and M.P. Zolotarev, 2017: The phenomenon of forest invasion to steppe areas in the Middle Urals and its probable causes. *Russ. J. Ecol.*, **48**(1), 21–31, doi:10.1134/s106741361606014x.

Zomer, R.J., et al., 2014: Projected climate change impacts on spatial distribution of bioclimatic zones and ecoregions within the Kailash Sacred Landscape of China, India, Nepal. *Clim. Change*, **125**(3-4), 445–460, doi:10.1007/s10584-014-1176-2.