New & Emergent ICTs and Climate Change in Developing Countries

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Executive Summary

Climate change impacts both the biophysical environment and human activity, and imposes a range of new challenges for research, technology development, and knowledge and information exchange. Over the last decade advances in ICT have emerged as a critical ingredient in the development process and can equally play a role in the climate change challenge. Based on a comprehensive review of the extant literature this paper outlines the range of new and emergent ICTs (e.g. wireless broadband and wireless sensor networks, geographic information systems and Web-based tools) being applied to climate change issues and investigates their use in developing countries. It also discusses innovative uses of established technologies such as mobile phones, but the main contribution will be to give those working on climate change an understanding of the technologies that will increasingly be used in their field: not just the identity of the technologies but their potential benefits and application areas.

The paper discusses three major application areas: (1) monitoring of climate change and the environment, (2) disaster management, and (3) climate change adaptation. A range of examples of the use of new and emergent ICTs in these areas in developing countries is described in order to demonstrate their utility and importance in assisting vulnerable communities to meet the climate change challenge. The review shows these technologies are predominately being deployed for disaster management and for localised monitoring activities. The technologies are not yet being employed much for adaptation purposes. A series of recommendations for researchers, NGOs and governments is provided in order to facilitate the widespread and effective application of new ICTs for climate change in developing countries.

1. Introduction

Climate change impacts both the biophysical environment and human activity, and imposes a range of new challenges for research, technology development, and knowledge and information exchange[1]. Over the last decade advances in ICT have led to widespread changes in human and economic activity, and emerged as a critical ingredient in the development process. Similarly, ICTs can play a catalytic role in adapting to climate change through collecting, analysing and disseminating information[2]. Advances, in particular, in space-based systems, geographical information systems (GIS), wireless broadband technologies, wireless sensor networks (WSN), mobile (cellular) technology and soft technologies such as Web-based tools (i.e. Web 2.0) and information systems have resulted in technologies that are well-suited to the climate change challenge.

Within the climate change domain there are a number of overall areas where ICTs can be useful to governments, vulnerable communities, scientists and other relevant actors in developing countries. This paper concentrates on the adoption of new and emergent technologies in three broad and interrelated activities: (1) monitoring of climate change and the environment, (2) disaster management, accounting for preparation, early warning systems (EWS), and response and recovery, and (3) climate change adaptation. Other pertinent activities such as mitigation, resource management, education and capacity building, networking, monitoring and evaluation, and climate modelling[3] are beyond the exposition of this paper. The frame of reference for this paper is graphically represented in Figure 1.

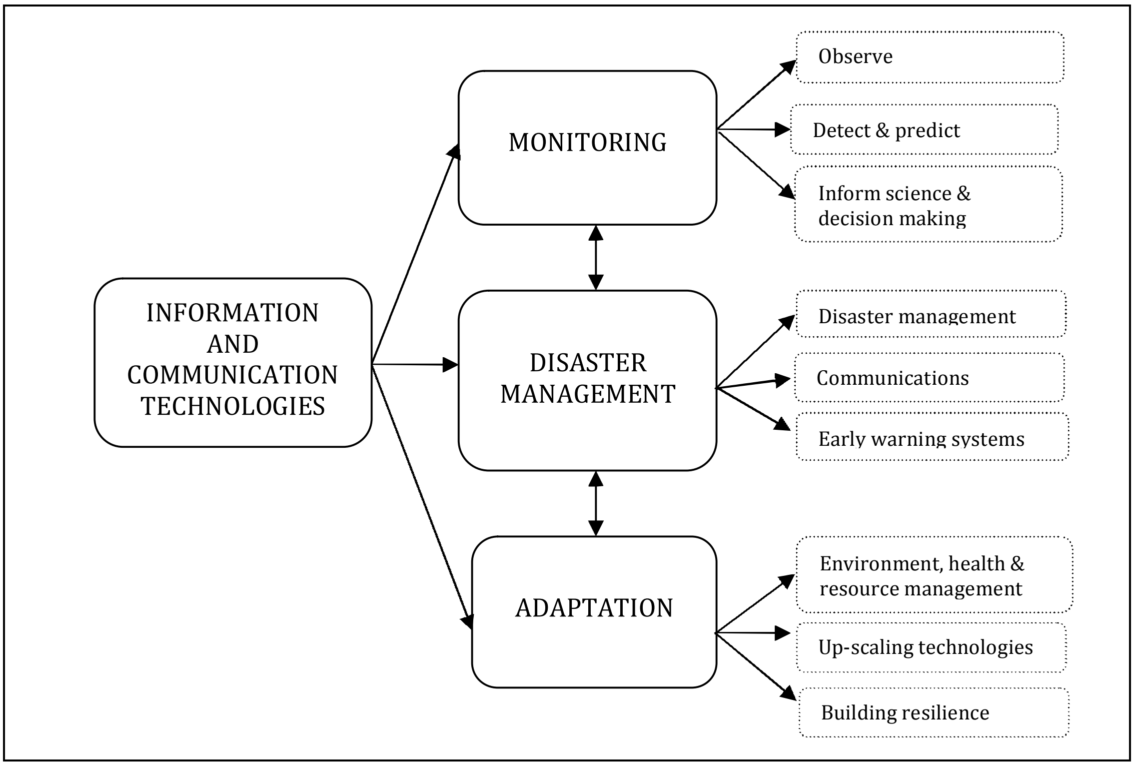

Figure 1: Conceptual Framework

[1] FAO (2010 p.282)
[2] ITU (2009b), FAO (2010)
[3] See FAO (2010), ITU (2008b), Sala (2009)

Within this frame of reference, the focus in this paper is on new and emergent ICTs. Primarily, it will focus on terrestrial technologies (wireless broadband and WSNs), geographical information systems and Web-based tools, and innovative use of mobile phone technology, providing a localised technological perspective on climate-related applications. Satellite/remote sensing technologies[4], while forming some of the underlying foundation of some of the technologies discussed, will not be addressed in detail and can be reviewed elsewhere[5].

This paper is one of few that examine new and emergent technologies in the context of developing countries and climate change. It draws on practical examples from developing countries but also developed countries (given the novelty of many of the applications), and it discusses some of the key issues in the field of ICT and climate change in developing countries. By doing so, this paper brings together literature from the fields of climate change, environment, development and ICT. Other authors have allocated importance to the role of ICT in climate change primarily in general statements, resulting in limited understanding of the mix of ICTs available, particularly new ICTs, and of the ICTs best suited to developing regions and climate change-specific scenarios. It is the intention of the paper to fill this gap.

The remainder of the paper is organised as follows. It begins with a discussion on monitoring activities and introduces emergent WSNs and wireless broadband technologies and presents a spectrum of climate change-related examples. A review of disaster management activities in the context of climate change and new ICT is then presented. Following this, a discussion on the scope of adaptation initiatives using emergent ICT in developing countries is provided. The final section looks at emerging patterns in the ICT, climate change and developing country domain and outlines a number of recommendations.

2. Monitoring Climate Change and Impacts

For developing countries to better understand their local climate and be able to anticipate climate change impacts, they must have adequate local and national observation networks, and access to the data captured from other global and regional networks. Systematic observations of the climate system are usually carried out by national meteorological centres and other specialised centres, which monitor atmosphere, ocean and terrestrial systems[6], typically using satellite technology. At the global level a number of established systems capture meteorological data using ICT, such as the World Meteorological Organisation’s (WMO) World Weather Watch (WWW)[7], which predominately makes use of satellite-based systems[8]. While, satellite technology is useful for large-scale phenomenon, it is limited in complex, cluttered environments where line of sight (LOS) paths are short[9]. Further, remote sensing is not ideal for a real-time continuous monitoring as the data is less accurate than ground sensors and the frequency and delay of the

[4] Earth observation satellites and remote sensing systems (sensors mounted on satellites or aircraft) are used to view areas over extended periods making it possible to monitor environmental change, human impact and natural processes, allowing for future projections. See www.un-spider.org
[5] Sammonds and Thompson (2007), Olla (2009b), ITU (2010b)
[6] UNFCCC (2007)
[7] See World Meteorological Organisation www.wmo.int
[8] ITU (2009b)
[9] Elson and Estrin (2004)

data depend on the satellite's orbit[10]. The cost of accessing this technology and procuring certain types of imagery is also typically beyond the financial capacity of many developing countries[11], necessitating the need for complementary technologies[12].

Beyond these satellite systems, then, a range of new and emergent technologies for monitoring localised climate change phenomenon exist that include ubiquitous wireless sensor networks, advanced next-generation wireless network technologies, and a mixture of existing and novel devices, such as mobile phones and other hand-held devices[13]. For instance, climate stations and small-scale WSNs can be set up in tropical forests, by following online instructions, in order to measure climate change and understand the effects on biodiversity and the ecosystem[14], allowing for inexpensive and bottom-up monitoring initiatives to take place.

As yet, much of the priority for wireless and WSN technologies has been in the area of volcanic and seismic activity[15] and pollution monitoring[16]. However, this has demonstrated the applicability of the technology to monitoring environmental phenomena in the developing country context. At the more advanced stage, many relevant state-of-the-art applications based on hybrid wireless mobile/broadband, space-based and WSN technologies are being developed and implemented in Europe[17].

These technologies and their relevance to climate change in developing countries are discussed next.

2.1. Wireless Broadband Technologies

Before discussing the application of wireless broadband technologies to climate change in developing countries, it is useful to establish the case for short-range (such as Wi-Fi) and long-range (such as WiMAX[18]) wireless broadband technology in developing countries as the technical infrastructure that would underpin such applications. Where traditional wired infrastructure has been avoided because of

[10] Panchard et al. (2007)
[11] ITU (2008b)
[12] Libatique et al. (2009)
[13] ITU (2008b)
[14] TEAM (2009)
[15] Mignanti et al. (2008), Linsey et al. (2010), Neves et al. (2009b), Musavi et al. (2010a, 2010b), Werner-Allen et al. (2006)
[16] Khedo et al. (2010)
[17] See the following examples:
- WIDENS http://www.chorist.eu/index.php?page=51&sel=51: Rapidly deployable and scalable wireless ad-hoc communication system, based on Wi-Fi (IEEE 802.11) for future public safety, emergency and disaster applications.
- ARMONIA http://www.eu-medin.org/%28S%28jihy52ycnre1pdy2macd5x55%29%29/EUMEDIN/StaticPage2.aspx?pagenb=20268: Spatial planning in environmentally prone areas .
- WIERD www.ist-weird.eu: Uses WiMAX to support novel application scenarios, such as environmental monitoring, telemedicine and fire prevention, making efficient use of WiMAX technology for the fixed/portable (IEEE 802.16d) and mobile (IEEE 802.16e) systems.

[18] IEEE 802.16d/e/m Worldwide Interoperability for Microwave Access (WiMAX). Based on the IEEE 802.16 standard WiMAX offers wireless transmission of data using a variety of modes supporting speeds as high as 40-70 Mbit/s, (however, the likelihood is that most users will experience speeds of one to five Mbit/s) and a range of up to 50 kilometres in LOS conditions and shorter ranges in non-line of sight (NLOS) conditions (although most WiMAX networks will have a 16 kilometre LOS range and eight kilometre NLOS range) (Etemad, 2008, Neves et al. 2009b). By contrast the Wi-Fi (IEEE 802.11) standard operates at somewhat slower data transmission speeds, typically over a few tens of metres, and at much lower cost.

the prohibitive costs and unsympathetic geography, wireless technologies are attractive to governments, NGOs and operators in developing countries because they can be deployed in an inexpensive, decentralised and effective manner, compared to other solutions[19].

Technologies such as WiMAX in particular have emerged as well suited to developing countries[20]. In 2008, Alvarion announced that it had 60 WiMAX networks deployed in 30 African countries and expected to reach more than 10 million subscribers over the next several years[21]. As an example of its utility, a hybrid WiMAX and satellite link was used to provide Internet access to Parintins, a small city located in the far east of the Amazonas state in Brazil, which has no roads and limited electricity[22]. Beyond development motivations, wireless broadband technology is essential for climate change applications such as climate scenario maps and images, which require high bandwidth[23]. Wireless broadband technologies also offer advantages for WSNs, especially when there is need for considerable bandwidth or mobile services such as GPRS[24] or GSM[25] coverage are not available[26]. Further, compared to other fixed technologies, it works better in remote locations, severe climates and difficult terrain[27].

Box 1: A note on Mobile Broadband

Mobile broadband (such as the standard IEEE 802.16m[28]) will further change the wireless communication landscape and has been applied and projected for future growth in disaster communications[29] and environmental monitoring[30]. HSPA[31] is forecast to remain the dominant technology in the short-term for mobile broadband, accounting for nearly 70 percent of total subscribers by 2012, while substantial growth in mobile WiMAX is expected after 2012 with developing markets projected to lead to way[32]. Given these projections, there is significant scope for development organisations to begin considering this technology as part of the climate change adaptation armoury.

[19] Dhawan (2007), WiMAX Forum (2005), Ibikunle and John (2008), Proenza (2006), Rao and Radhamani (2007), Galperin (2005)
[20] Frost & Sullivan (2008), Karanasios and Allen (2010), Rao and Radhamani (2007), Juniper Research (2007), EIU (2006), Pareek (2006)
[21] Alvarion (2008)
[22] Clendenning (2006)
[23] Apikul (2010)
[24] General Packet Radio Service, a 2G/GSM/3G mobile service that transmits data in packets
[25] Global System for Mobile Communications -the most popular standard for mobile telephone systems in the world
[26] Nissilä et al. (2008), Neves et al. (2009a). The capacity of GPRS and GSM for WSN is limited, GPRS communications costs are also high
[27] Sedoyeka and Hunaiti (2008), Rao and Radhamani (2007)
[28] Little distinction is made between fixed/mobile/true mobile broadband (for instance IEEE 802.16d, IEEE 802.16e, IEEE 802.16m) in this paper. For in depth discussion see Ergen (2009), Dahlman et al. (2007), Chen and de Marca (2008)
[29] Riegel et al. (2009)
[30] Ibikunle and John (2008), Linsey et al. (2010)
[31] High Speed Packet Access (HSPA), is a part of the group of high-speed 3G digital data services provided by mobile carriers worldwide that use GSM
[32] Juniper Research (2007)

2.2. Wireless Sensor Networks

WSNs are systems of intelligent sensor nodes deployed to monitor particular environmental cues, such as temperature, light intensity, water levels, local meteorological data and pollutant level[33]. They are well-suited to the application of collecting environmental data that will facilitate the study of the climate[34].

A WSN typically consists of large collections of nodes performing local processing, communicating wirelessly to form networks. Individually, each node is autonomous and has a short-range; collectively, they are cooperative and effective over a large area[35]. The typical elements are[36]:

- **Sensors:** Sensors with harvested or stored power sources for collecting and transmitting information about the surrounding environment
- **Access Network:** Sink nodes collecting information from a group of sensors and facilitating communication with a control centre or external entities
- **Network Infrastructure:** Typically based on 2G, GPRS, 3G or WiMAX/Zigbee[37]
- **Middleware:** Software for the collection and processing of the data
- **Applications Platform:** A technology platform for effective use of a WSN for a particular application

One of the main advantages of WSNs is that they can be deployed in almost any kind of terrain where it might be impossible to use traditional wired networks, require little human interaction, are scalable[38] and offer many advantages over long-range remote sensing technologies. Developing countries have been identified as major beneficiaries of WSNs in the field of environmental monitoring as they are most at risk from climate change[39].

2.3. Climate Change Applications in Developing Countries

2.3.1 Rainfall and Landslide Monitoring

Countries in temperate and tropical zones are likely to experience increased and increasingly-variable rainfall and exposure to extreme landslide events due to global warming[40]. Typical examples of existing landslide solutions involve a trip wire and alarm installed along landslide-prone areas, triggered by falling rocks[41]; but these are unreliable due to their margin for error.

In order to monitor rainfall and detect landslides a number of WSN initiatives have been deployed in developing countries. Amrita University deployed a landslide detection system using a WSN in Munnar, Idukki and Kerala in India; areas which are highly prone to landslides due to systemic monsoon-induced rainfall. The rainfall-induced landslide detection system used a WSN with Wi-Fi network and

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[33] Elson and Estrin (2004)
[34] Morshid (2009), Polastre (2003), ITU (2008d)
[35] Elson and Estrin (2004)
[36] ITU (2008d), Vassilaras and Yovanof (2010), Ganguly (2008), Townsend and Arms (2005), OECD (2009b)
[37] IEEE 802.15.4 A low-cost, low-power, wireless mesh networking standard
[38] Suri et al. (2006), Li et al. (2006), Pathan et al. (2006), ITU (2008d)
[39] ITU (2008d)
[40] Cruz et al. (2007)
[41] Sheth et al. (2007, 2005)

satellite technology. The deployment included 15 wireless sensor nodes and a total of 50 geophysical sensors (piezometers, tiltmeters, strain gauges, rain gauges, dielectric moisture sensors, geophones), which automatically collect and forward data via the WSN[42]. The real-time data from the deployment field is streamed to a central repository, providing a better understanding of landslides in the region than was previously possible and thus helping prevent the loss of human life[43].

Moving away from detection, SenSlide[44] - a distributed sensor system - predicts, rather than just detects landslides, in the hilly regions of western India, which occur frequently during the monsoon, rains causing significant damage. SenSlide makes use of a WSN and 2-axis strain gauges to predict landslides. The low maintenance WSN architecture consists of small sized, low cost, and wireless battery operated nodes deployed over a Wide Area Network with data sent to a base-station using Wi-Fi or GPRS[45]. Similar setups have been proposed in developing countries for tropical-rain monitoring using hybrid wireless broadband networks in conjunction with real-time acoustic rain rate point sensors and complementary rain gauges to monitor rain and rain-induced hazards. This approach leverages recent wireless communications infrastructure deployments in developing countries, even in regions where remote weather radar and climate monitoring systems are sparsely deployed, and will be critical for regions with undeveloped sensor systems[46].

2.3.2 Fire Monitoring

With global temperatures expected to rise, a major concern is the increased frequency of forest fires[47], which contribute 25 to 30 percent of carbon emissions[48]. Typical approaches to fire detection involve human spotters in towers or aircraft searching for smoke. These are costly: for instance, in Portugal a network of over 200 surveillance towers observes fire-sensitive areas[49]. But they are also relatively ineffective given the difficulties of providing total coverage and accurate location.

Wireless sensors or wireless broadband-supported video surveillance with automatic detection of smoke or heat sources can be used to monitor fires. These approaches can still require human interaction for confirmation, however they greatly enhance the efficiency of monitoring networks by reducing costs (only centrally-located operators would be required), provide more accurate location data, effective management of false alarms and 24/7 operation[50]. Technologies such as fixed broadband, mobile and radio links (e.g. ADSL or 3G/UMTS, GSM, GPRS) are not typically available in remote forests or cannot provide the bandwidth required for more automated fire detection[51]. Wireless broadband technologies can fill this gap by providing connectivity to remote sensors and monitoring systems, capable of effectively providing early detection of fire in an efficient and cost effective manner. In China, a forest WSN using the ZigBee wireless mesh standard was implemented to monitor temperature, humidity and fire, and was found to

[42] Ramesh et al. (2009b, 2009a)
[43] WINSOC (2007)
[44] http://www.cse.iitk.ac.in/users/cs725/lec_notes/senslide.html
[45] Sheth et al. (2007, 2005)
[46] Libatique et al. (2009)
[47] IPCC (2001)
[48] FAO (2010)
[49] Neves et al. (2009b)
[50] Neves et al. (2009b), Mignanti et al. (2008)
[51] Mignanti et al. (2008)

have technical advantages in terms of safety in data transmission, flexibility in the network build and low cost energy requirements[52].

A different approach can be to have cameras mounted in surveillance towers that can automatically scan a 360-degree area, within a 2,000 km^2 area, and send collected data (location data, meteorological data etc) to control centres, where prospective fires are further investigated (for instance remotely pointing and zooming the cameras to the suspect area)[53]. A similar forest fire system (FireHawk) of cameras with zoom lenses and microwave transmitters and receivers was implemented in mountainous and extreme temperate locations in South Africa. The system detected 153 fires, even at night, limiting the impact of damage[54], demonstrating the efficacy of ICT automation.

2.3.3 Flood Monitoring

Climate change is predicted to increase flooding frequency causing significant problems for vulnerable communities in developing countries[55]. The normal practice of flood monitoring typically involves taking readings from painted markers at certain points or water gauges[56]. There is a great deal of potential for WSNs to be deployed for flood and water level monitoring systems[57]. Figure 2 provides a simple graphical representation of a riverbank WSN for monitoring floods. In this example, sensors form clusters at certain points along a river bank to communicate with local base stations, which communicate with each other and the processing centre wirelessly.

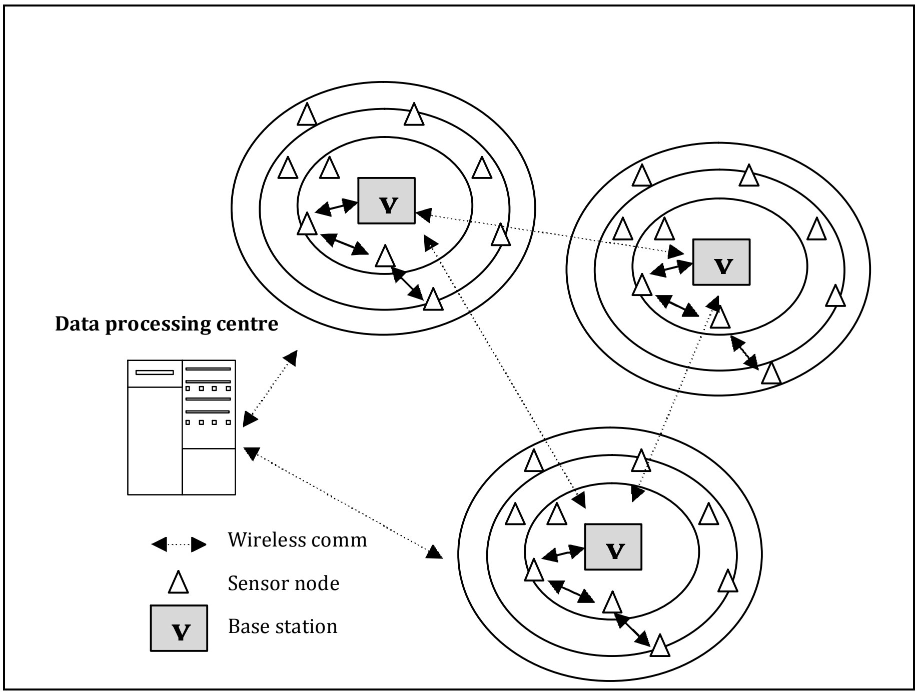

Figure 2: Simple Riverside Flood Monitoring WSN[58]

[52] Zhang et al. (2008)
[53] Mignanti et al. (2008), Linsey et al. (2010), Neves et al. (2009b)
[54] FireHawk (2004)
[55] Cruz et al. (2007), Magrin et al. (2007)
[56] Basha et al. (2008), Basha and Rus (2007)
[57] Pathan et al. (2006)
[58] Adapted from Pathan et al. (2006 p.708)

In Mérida, Venezuela, a WSN for flash flooding was designed in this way using hydrological nodes located along the river shore to monitor water level and water flow. In this design a geographic information system (GIS) constituted the basis for a data-collection and alarm generation station in the urban area. An Internet server published information about the current state of the environment[59], showing that these systems play a role in the path from data capture to information dissemination.

In Honduras, a WSN for flood monitoring was developed that was able to withstand river flooding and the severe storms causing the floods, communicate over a 10,000 km^2 river basin, predict flooding autonomously, and limit cost, allowing feasible implementation of the system in a developing country. A simplified version of the 9-node sensor network was deployed on the Aguán River basin in northern Honduras Experiments with the system confirmed the technical feasibility of a scalable, sensor network for use in a developing country[60].

2.3.4 Monitoring Impacts on Agriculture

In developing countries climate change is likely to affect agriculture, increasing risk of hunger and water and resource scarcity[61]. Existing systems have involved informing farmers of climate variability and better practices through radio and word of mouth and more recently mobile phones or telecentres. WSNs can provide risk assessment data such as alerting farmers at the onset of frost damage and provide better microclimate awareness[62] and inform climate science.

A number of examples demonstrate the use of ICTs for monitoring climate change and agriculture, such as wireless telemetric rain gauges, use of SMS to monitor rainfall and manage water in semi-arid areas[63], and strengthening drought preparation by using GIS for water allocation and contributing to improving micro-level drought preparedness[64]. In India a WSN-based agriculture management system, named COMMON-Sense Net[65], was deployed to support rain-fed agriculture and provide farmers with environmental data. Wireless sensors were deployed in geographical clusters, each with one base-station that was connected to a local server via a Wi-Fi link and organised in groups, each corresponding to a particular application, such as crop modelling, water conservation measures, or deficit irrigation management.

However, the monitoring system did not encourage the expected participation of the farmer population, making it difficult to develop the intended decision-support system. Based on the experience of this project it was proposed that the deployment of WSN technology in developing regions is more likely to be effective if targeted towards scientists and technical personnel, rather than farmers[66]. This suggests that although the technical feasibility of the solution is clear greater investigation into the needs and requirements of targeted communities is required.

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[59] Castillo-Effer et al. (2004)
[60] Basha et al. (2008), Basha and Rus (2007)
[61] Cruz et al. (2007), Boko et al. (2007)
[62] Edordu and Sacks (2006), Srivastava (2010)
[63] Pradeep (2004)
[64] Sreedhar et al. (2009)
[65] http://commonsense.epfl.ch
[66] Panchard et al. (2007)

2.3.5 Participatory Monitoring via Mobile

The previous examples relied on a high-level of automation and new and emergent ICTs. However, there are a number of localised monitoring techniques that involve a new type of convergence between mobile phones and human involvement, enabling 'citizen science', scaling up the monitoring process of climate change[67]. 'Mobile sensing', an emergent paradigm, enables data collection from large numbers of people by affixing sensory devices to a mobile phone allowing dynamic information to be collected about environmental trends[68]. Such a system was employed in Accra, Ghana to monitor pollution and air quality, leading to the adaptation of behaviours of people involved in the data collection[69] and presents an interesting means of monitoring and adapting to climate change in developing countries.

3. Disaster Management

Responding to natural disasters in a timely and effective manner has emerged as an important climate change theme particularly in developing countries; where in addition to the immediate crisis vulnerable communities suffer excessively from the secondary post-disaster effects that compound the tragedy. Disaster response in developing countries typically involves the military to stabilise the situation, medical staff, emergency services, officials, the media, a range of international and local NGOs, and other specialised agencies working together to manage particular situations. Coordination and communication becomes particularly imperative where contingencies cover expansive geographical areas, cross borders and require trans-border intra-agency cooperation[70].

In many cases, the existing telecommunication infrastructure will be significantly or completely destroyed by an extreme weather event, and hence rapidly deployable networks and other communication services need to be employed for disaster relief operations[71]. Communication technologies in such events typically have been limited to satellite communications, which are expensive to use, not sustainable beyond short-term use, and suffer from limited capacity for handling simultaneous calls, (although new satellite phones capable of terrestrial GSM wireless service are available)[72]. Wireless broadband technologies have filled this gap, allowing for rapidly deployable and flexible networks.

3.1 Preparation and Response: Emergency Communication Systems

Driven by the occurrence of large-scale disasters over the last decade, investment in rapidly deployable wireless communications is an area where there has been substantial allocation of resources by governments and international bodies in order to enhance response to disasters, signifying a commitment towards one element of climate change adaptation. During environmental contingencies wireless broadband

[67] OECD (2009a)
[68] Chaudhri et al. (2010)
[69] Kinkade and Verclas (2008)
[70] Paul-Morandini (2008)
[71] ITU (2008c)
[72] UN ESCAP (2008)

can support better communication between actors, allowing for instant data exchange between responders and the control centre (location of the event, meteorological data, instructions from the control centre etc)[73]. In Bangladesh an Integrated Information and Communication System is underway which will use satellite, wireless broadband, mobile phones and community radio services strengthening communication links between rescue and relief units and Emergency Operation Centres (EOC)[74]. In other parts of Asia and the Pacific it has been suggested that EOC's employ similar hybrid approaches[75] (converging satellite with terrestrial communication technologies), maximising the advantages of each technology[76]. It is realised that part of the disaster preparation approach involves establishing robust and reliable systems that will continue to allow for voice and data communication during and after disasters[77].

3.1.1 Rapidly Deployable Communications

One key portable infrastructure solution is Very Small Aperture Terminals (VSAT)[78], the only requirement being a direct line of sight to the satellite. VSAT networks can also support basic telecommunications infrastructure restoration requirements including the Public Switched Telephone Network (PSTN) and mobile and broadband wide area networks[79]. However, VSAT technology is known to be interference-prone especially in bad weather, expensive and have low bandwidth[80].

An alternative to satellite communications are wireless/mobile temporary/ad-hoc communication infrastructures[81]. Using wireless broadband technologies "nomadic" Relay Stations can be deployed temporarily to provide additional coverage or capacity where required[82]. Temporary-coverage WiMAX networks supported telecommunications destroyed in the 2004 tsunami in Indonesia and after hurricane Katrina in the Gulf Coast in 2005[83]. More recently, after the Haiti earthquake the ITU led a project that used WiMAX and Wi-Fi technology to rapidly set up wireless phone and Internet connectivity at 100 holding centres for displaced people[84].

A particularly interesting type of ad-hoc wireless typology in the context of developing counties is the fixed-mesh or mobile-ad hoc network (MANET)[85]. This is a network of mobile devices (subscriber stations) which interconnect in an ad-hoc

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[73] Mignanti et al. (2010)
[74] Hazarika et al. (2010)
[75] Apikul (2010)
[76] UN ESCAP (2008)
[77] Apikul (2010), ITU (2008a)
[78] A small antenna on the ground that allows two-way communication with a satellite-based communications system
[79] ITU (2008b)
[80] OECD (2009b)
[81] Jiang et al. (2008), Soldani and Dixit (2008), Abichar et al. (2006), Sithirasenan and Almahdouri (2010)
[82] Soldani and Dixit (2008). For state-of-the-art advances in rapid deployable networks see:

- WISECOM, http://www.wisecom-fp6.eu: Rapidly deployable communication infrastructures for emergency situations, involving a mixture of terrestrial mobile radio networks such as GSM, UMTS, Wi-Fi, WiMAX and TETRA over satellite.
- U-2010 www.efipsans.eu: provides the most capable means of communication and the most effective access to information to everybody required to act in case of an emergency.
- WIDENS, www.comlab.hut.fi/projects/WIDENS: a high-data rate, rapidly deployable and scalable wireless ad-hoc communication system for future emergency and disaster applications.
- CHORIST,http://www.ist-world.org/ProjectDetails.aspx?ProjectId=7374640a32574e15bedf55fb2d739195: Proposes a solution to increase rapidity and effectiveness of interventions following natural hazards

[83] Fitzgerald (2006)
[84] www.dailywireless.org (2010)
[85] Karanasios and Allen (2010), Sedoyeka et al. (2008), Kanchanasut et al. (2007b), Martikainen (2006)

manner to share data in a mesh network. Data is shared in a multi-hop manner by being passed between devices, with each device having the potential of routing data to another device. The devices in the network are self-configuring as the network automatically reconfigures when devices move in and out of range. Access to the Internet can be provided by just a single device in the network, which has Internet access on a wired or wireless basis. Mesh applications have been identified in developing countries as having important potential to bridge the digital divide[86] and deliver development outcomes including those that are climate change-related[87].

Box 2: Project DUMBO
Mesh Networks and Disaster Response in Thailand

DUMBO, a project initiated by the Asian Institute of Technology Internet Education and Research Laboratory, developed and tested a system for response to emergency scenarios in Thailand[88].

Making use of the concept of wireless mesh networks, DUMBO uses lightweight portable mobile nodes to broaden coverage and penetrate deep into areas not accessible by roads or where the telecommunication infrastructure has been destroyed. During the trials in Thailand, laptops were carried on elephants to extend the wireless mesh network coverage. On the networking side, the solution utilised hybrid Wi-Fi and satellite connectivity. The second application component involved sensors, which allowed for readings of environmental data such as temperature, humidity, pressure, wind-speed, wind-direction, rainfall and CO_2. The third application component involved facial recognition software that allowed rescuers to compare facial images captured from the site to the collection of known faces[89]. This is one of a few systems in developing countries that make use of emergent technologies and combine communications with integrated disaster applications.

3.1.2 The Role of Social Networking Media in Disaster Management

In addition to the communications infrastructure, information dissemination media, such as social network platforms have emerged as playing the multifaceted role of informing various actors and communities, often being used by locals who are at the site of the disaster. Radio remains the main channel for providing information to large sections of the population[90], however, Web 2.0 technologies such as social networking provide the added advantage of allowing direct community involvement.

During Typhoon Ondoy in the Philippines in 2009, local volunteers organised and disseminated information online through Web sites such as Facebook and Twitter.

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86 Karanasios and Allen (2010), Sedoyeka et al. (2008), Damsgaard (2006)
87 Kanchanasut et al. (2007b)
88 Kanchanasut et al. (2007b, 2007a) , Nouali et al. (2009), Myanmar Egress and MCPA (2008). DUMBO stands for Digital Ubiquitous Mobile Broadband Optimised link state routing (OLSR)
89 Kanchanasut et al. (2007b, 2007a)
90 UN ESCAP (2008), Chinese Radio Sports Association (2008), Coyle and Meier (2009)

Organisations and affected people used these sites for timely reports concerning the extent of damage, to provide information on the resources required and to allocate relief resources[91]. Likewise, during hurricanes Gustav and Ike, in the USA and Caribbean in 2008, volunteers used social network sites such as Ning to provide information on the hurricane. Newsfeeds were built in from other social networking media such as Twitter and Facebook and maps were created with information on shelters, evacuation routes and other relevant resources. Importantly, there is some emergent research that suggests local participation through these social media was beneficial to the hurricane victims, empowering them to play some role in the response[92].

3.1.3 The Role of GIS & Other Information Systems in Disaster Management

For managing disaster situations, which usually involve a large number of different agencies working in different but overlapping areas, geographic information systems have proven to be powerful visualisation and management tools. For mitigation GIS can visualise high risk zones; for preparedness they can visualise evacuation routes, shelters and the catalogue of available resources and their proximity; for response they facilitate the identification of priority search and rescue zones, delivery of supplies and medical help; and in recovery they can be used in reconstruction efforts[93]. GIS have been used in a number of countries to visualise critical data by location, for use in the coordination and implementation of relief efforts[94].

In conjunction with GIS, disaster management information systems that provide the basis for organising the response and relief effort are critical and there has been developing country-relevant innovation in this area. For instance, Sahana[95], which was used in the recent Pakistan flood disaster, can facilitate rapid and effective response efforts. Sahana has also been deployed for cyclone and earthquake management in Myanmar, Peru, Pakistan, Indonesia and Haiti[96]. It is a free and open source software-(FOSS-)based disaster management system consisting of a missing person registry, organisation registry, camp and shelter registry and request management system.

The downloadable software serves the needs of government agencies at the federal or local levels, NGOs, global agencies, communities and victims, and technology developers. From a technology standpoint it functions networked or standalone and can be installed on different platforms (Windows, Mac, Linux etc) and on a laptop for workers in the field or at a central command centre for overall coordination. This is one of a few examples of a new successfully-applied-in-practice information system made readily available for a range of actors in the response effort in developing countries.

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[91] Apikul (2010), See http://www.abs-cbnnews.com/nation/09/27/09/ondoy-situation-map-metro-manila-google-maps#Map
[92] Sutton (2009)
[93] Apikul (2010), Chanawongse (2009)
[94] Apikul (2010), Wattegama (2007)
[95] www.sahana.lk
[96] UN ESCAP (2008), Iglesias et al. (2010), n.a. (2009)

3.2. Early Warning Systems

Using ICT and traditional observation mechanisms coupled with climate data analysis, immediate and short/medium/long-term warnings can be made in order to minimise harm to vulnerable communities. Traditionally, most people in developing countries obtain climate contingency-related information through combined word-of-mouth, traditional knowledge and local media sources. However, the first two are often inefficient and arbitrary, whereas local media reports can be difficult for people to understand[97]. Radio and television are considered the most effective traditional media and are still being widely used for disaster warning in developing countries[98]. While they are effective for spreading a warning quickly to a broad population (even in rural environments where the teledensity is relatively low) the drawback is that their effectiveness is significantly reduced at night when they are normally switched off[99]. Proliferation of channels, and extension of warnings to those not listening/viewing are also issues.

Developing and implementing an effective EWS requires the contribution and coordination of a wide range of individuals and groups encompassing affected communities, national and local governments, regional institutions and organisations, international bodies, NGOs, the private sector and the scientific community. Each has a set of overlapping functions for which it is responsible[100]. In between these layers of actors ICT plays the crucial role of providing support to ensure the collection and dissemination of information and delivery of early warnings. In order to improve EWS at these levels there has been increasing focus on new ICTs for analysing and processing information and providing automated alerts to vulnerable populations. This involves the convergence of different information, risk assessment and disaster modelling and analysis systems, combined with multiple communication channels to send the alert[101].

3.2.1 Early Warning System Technologies

There is a wide range of new and emergent ICTs that can be used for receiving and disseminating alert messages to the public or central command posts[102]. For instance, trials are underway in 63 developing countries on a small two-way emergency messaging system named RANET Chatty Beetle, which can also be used to collect weather observations[103]. Many of its ICTs are subsets of the technologies already discussed and in some cases are already deployed and proven as well-suited to the developing country context, often in conjunction with non-ICT systems such as public address systems[104]. However, the range of technological EWS solutions introduces a tangle of conflicting requirements including cost and reliability, and raises several technological, social, and political problems[105].

Furthermore, no single technology has emerged as a fail-safe solution and little inquiry has been undertaken concerning the best channels to effectively warn

[97] UNFCCC (2006)
[98] AMARC (2008), t4cd (2006)
[99] Chanawongse (2009), Wattegama (2007)
[100] UN/ISDR (2006)
[101] UN ESCAP (2008), Wattegama (2007)
[102] ITU (2010a)
[103] RANET (2009)
[104] Subramanian (2005)
[105] Basha and Rus (2007)

vulnerable communities. In the context of cyclones on the East coast of India, a study of the public response to cyclone warning indicated that evacuation behaviour was not strongly related to the channel through which the warning was received or the timing and frequency of the warnings. Rather, evacuation behaviour was significantly related to prior warning experience, environmental cues, perception of safety during evacuation and perception of quality of stay at the relief camps, and the number of channels through which a person received the warning message[106]. This suggests that a multi-channel approach is the best strategy and that effective reliable systems are needed in order to develop a positive response pattern of behaviour among vulnerable communities.

Examples of key technologies are discussed next.

(a) Satellite Radio

A satellite radio is a digital radio that receives signals broadcast by a satellite, which covers a much larger geographical area than the traditional terrestrial radio antenna. Satellite radio can play a key role during both disaster warning and the recovery phase. Satellite audiences follow a single channel regardless of location within a given range, usually in areas not covered by terrestrial radio channels[107]. Bangladesh, India, Indonesia, Sri Lanka and Thailand have tested a Satellite Radios for Emergency Alerting (AREA) system that can be used to disseminate warnings to vulnerable communities. A GPS-enabled radio receiver set allows for warnings to be issued, in text and audio formats to specific areas[108].

(b) Mobile Phones

Fixed telephone lines suffer from congestion during disaster situations, exacerbated by the low penetration rate in developing countries. By contrast, mobile phone penetration rates are high in developing countries and there are many examples of how simple mobile phone warnings saved lives in environmental disasters[109]. SMS in particular are useful as an alert mechanism amongst family and friends[110] and are considered faster than conventional mass media[111]. In Wenling City in China, a sophisticated system to identify vulnerable buildings that could not withstand cyclone winds was implemented in order to warn residents. After identifying at risk buildings, residents were sent individual warning SMSs and relocated to safer places before a cyclone hit[112]. This acts as an example of not only an EWS, but also one of a few cases of understanding relevant infrastructural limitations and using ICT to adapt to it.

(c) Cell Broadcasting System

Cell broadcasting, which is being used increasingly in developing countries[113], is a geographically-specific public warning text message that can be sent to all mobile devices with such capability in any group of cells of any size, ranging from one

[106] Sharma et al. (2009)
[107] Chanawongse (2009), Wattegama (2007)
[108] Apikul (2010)
[109] Chanawongse (2009), Wattegama (2007)
[110] Chanawongse (2009)
[111] Samarajiva (2005)
[112] UN/ISDR (2008)
[113] Halder and Ahmed (2010), Wattegama (2007)

single cell (about 8 kilometres across) to a collection of cells covering a region or country. Different mobile phone system standards have this capability[114]. It has been examined as a coastal warning mechanism for fishing sites, to warn fishermen/women of impending extreme weather events[115] and village communities[116]. In Bangladesh, the Disaster Management Information Centre is piloting CBS-based early warnings for floods in Sirajgonj and cyclones in Cox's Bazar[117].

A critical issue with CBS is that it requires the use of private networks[118], which raises questions concerning the early warning as 'public good' and the private infrastructure required for its operation[119]. For instance, of concern, some network operators in developing countries have the CBS feature switched-off because they would have to pay a license fee to have it on[120].

(d) The Web

The effectiveness of the Web depends on the Internet penetration rate within the particular community, which is typically not high enough to expect it to play any critical role, particular for immediate EWS, in developing countries. Nonetheless, many new and continuously evolving Web-based EWS initiatives have been developed which can feed into immediate EWS and non-immediate EWS. For example, the Sharing Earth Observation Resources Website[121] provides a single access point for earth observation information and services including satellite imagery. Likewise, the Global Disaster Alert and Coordination System (GDACS)[122] a joint initiative of the United Nations and the European Commission provides real-time alerts about natural disasters around the world. The difference with this tool is that it enables the provision of warning messages (e-mail and SMS) and a secure virtual space for coordination efforts and maps and reports, and is directed more at disaster managers. These innovative systems are likely to inform part of the early warning decision-making process amongst politicians, scientists, and other local and international bodies. Amongst vulnerable communities Web 2.0 tools (Twitter, Facebook, etc) are likely to play some role[123], however they are better suited to coordinating relief and reporting casualties, damage, etc.

(e) Wireless Sensor Networks and Wireless Broadband

Many of the monitoring scenarios discussed above using WSN and wireless broadband can be used as a core element of an automated EWS. For instance, the infrastructure setup for monitoring can be used with other EWS tools to alert citizens and authorities to a particular contingency and allow for quicker response

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[114] Wattegama (2007), CDMA, D-AMPS, GSM and UMTS are popular mobile phone system standards used around the world. CDMA, D-AMPS and GSM are considered second-generation technologies, while UMTS is a newer third-generation system designed to replace GSM. Towards 4G (such as WiMAX and LTE/3GPP) Multicast Broadcast Services usage scenarios will be possible and include streaming of multimedia, file downloading, real-time monitoring amongst other applications (UN ESCAP., 2008).
[115] Torii et al. (2010)
[116] Waidyanatha et al. (2007a)
[117] Apikul (2010)
[118] Goswami (2005), Wattegama (2007)
[119] Goswami (2005)
[120] Mongi (2007)
[121] www.eoportal.org
[122] www.gdacs.org
[123] Wattegama (2007), Apikul (2010), Coyle and Meier (2009)

times and accurate data to be relayed[124]. However, the best method for using information gathering related to warnings from these systems to vulnerable communities has not been explored.

(f) The Common Alerting Protocol (CAP)

The Common Alerting Protocol (CAP) is an International Telecommunication Union (ITU) recommended international standard for public warnings. It is an XML-based data format for exchanging public warnings and emergency messages between alerting technologies. CAP allows a warning message to be consistently disseminated simultaneously over many warning systems to many applications, increasing warning effectiveness and simplifying the task of activating a warning for responsible officials[125]. CAP is useful for sharing alert information across multiple and dissimilar emergency information systems[126] and its benefits include cost reduction, reduced complexity, and the ability to convert messages to and from the native formats of all kinds of sensor and alerting technologies, forming a basis for a technology-independent national and international "warning Internet"[127]. It has been applied in the USA, Europe and developing countries in initiatives related to climate change such as the state-of-the-art OASIS project[128] and other EWS[129].

HazInfo - a project on last-mile hazard notification in Sri-Lanka involving 32 coastal villages - implemented the CAP content standard in order to provide a semantic structure for composing warning messages, which could then be relayed rapidly and accurately across multiple technology platforms in English, Tamil and Sinhalese (see Figure 3). The project also incorporated a cross-section of communication technologies and assessed their potential to distribute hazard information to rural and remote communities. The network consisted of mobile and fixed telephones (including a specialised remote alarm system based on GSM), addressable satellite radios, and a small number of Internet terminals[130].

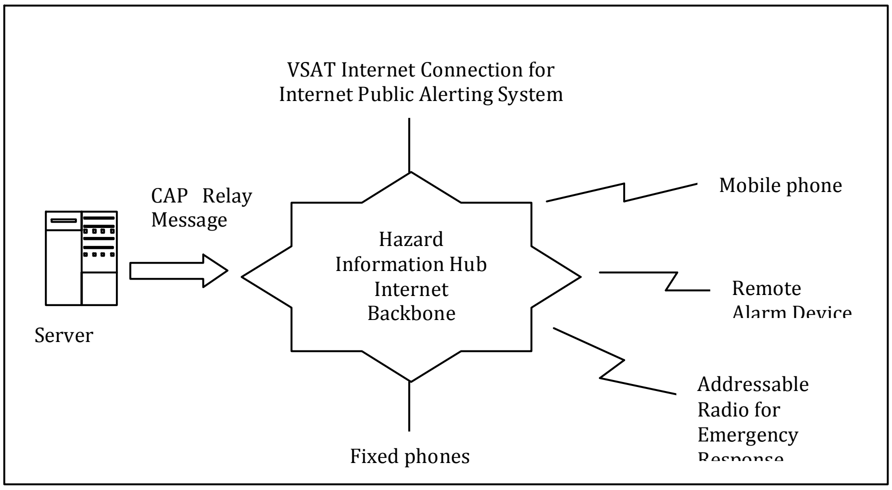

Figure 3: CAP Message Relay and the ICTs that Receive Alerts[131]

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124 Khadivi et al. (2009), Linsey et al. (2010)
125 ITU (2007)
126 OASIS (2006)
127 OASIS (2005)
128 Open Advanced System for Disaster & Emergency Management. See www.oasis-open.org and www.oasis-fp6.org
129 RANET (2009)
130 ITU (2009a)
131 Adapted from Waidyanatha et al. (2007b p.282)

During a trial of the HazInfo EWS, misinformation was received by the target group and as a result instead of reacting to a Category 4 Cyclone the target group executed tsunami evacuation plans, which involved running to higher grounds, when critically the community were meant to seek shelter at lower ground[132]. This demonstrates the importance of the ensuring accuracy of the technology each time it is used in order to build trust.

4. Climate Change Adaptation

To cope with current and future climate stress, communities - particularly those most vulnerable in developing countries - must build their resilience, including adopting appropriate technologies, while making the most of traditional knowledge, and diversifying their livelihoods[133].

The choice of adaptation interventions and ICT applications is dependent on the circumstance of each community or region. Bottom-up, local coping strategies are an important element of planning for adaptation[134] and ICTs can be used in a number of productive ways, particularly by leveraging existing ICT successes in developing countries such as telecentres and mobile phones, as well as introducing emergent ICTs in conjunction with existing sectoral policies, planning and budgeting[135].

While a review of the extant literature reveals relatively little to date in the field of adaptation in the context of new/emerging ICTs and developing countries, there are a number of positive examples of innovative uses of existing technologies and large potential for the application of the emergent technologies discussed in this paper.

Experience has shown that those best placed to prepare for and respond to climate change are local populations. Therefore, a key aim is obtaining community participation and providing relevant information to stakeholders. To date, such approaches have involved word of mouth and radio, primarily for disseminating information to vulnerable communities[136]. Participatory GIS (PGIS), which involve local people during data collection and in the verification of data has shown to have direct community benefits[137] and demonstrates how communities can be integrated with the use of newer ICTs.

Telecentres have featured heavily in ICT for development programmes and have emerged as important in climate change adaptation and resilience building[138]. Beyond their traditional use as an information and computer access centre, emergent examples of information to be made available through telecentres include digitised hazard maps that track the hazards to which the communities are vulnerable (for instance, propensity for heavy rainfall to cause flooding in a densely inhabited area), digitised resource maps that indicate the locations of the resources available to deal with the risks, and chronological logs of disasters that had

[132] Waidyanatha (2008)
[133] UNFCCC (2007)
[134] *ibid*
[135] *ibid*
[136] Solervicens (2009)
[137] Shrestha (2006), Aynekulu et al. (2006)
[138] Kumar et al. (2005), UN ESCAP (2009)

previously taken place in the area. These information bases can be created with input and involvement from the local community with technical support from disaster management authorities[139]. Therefore, telecentres can be a proxy to access new Web-based technologies, new information repositories, and information collected from advanced monitoring WSNs.

New technologies are increasingly being linked to telecentres. For instance, in addition to a telecentre based agrarian information system for use by farmers in Huaral Valley, Peru, portable terminals are also projected to be used in order to allow access to information outside of the telecentres[140]. Wireless broadband in particular has the potential to change the landscape of telecentres by connecting more remote locations, providing increased bandwidth[141] and therefore access to a range of new digital applications and new portable devices that can thereby be connected to telecentres.

4.1. Emergent Technologies and Adaptation

A number of ICTs have been described in this paper which can inform adaptation. For instance, monitoring networks can inform habitat location (provide information to house communities away from flood- or landslide-prone areas), better agriculture (based on informed climate information or water allocation) and provide early warnings, amongst other applications. Therefore, a key advantage of the wireless broadband and WSN examples provided in this paper is that they can span a range of activities. Further, as climate monitoring is an ongoing process many of the localised examples that have been described will over time provide longitudinal data that can inform global and local climate change science and adaptation.

A range of innovative Web-based tools and climate-related Web sites have also emerged as useful for informing the adaptation process. For instance, a range of online tools exist which can be used to present monitoring and prediction data[142] and inform communities on emergencies and disease outbreaks[143]. These are driven by NGOs, for instance, USAID's Famine Early Warning Systems Network[144] provides real-time updates on global weather hazards, food security and remote sensing data for a number of developing countries (Burundi, El Salvador, Nicaragua and Yemen).

By and large however, the main form of ICT applied in the adaptation process is mobile technology. The use of mobile technology in innovative ways in the context of adaptation is discussed next, covering topics such as health, environmental management and agriculture. A key focus is the expected diffusion of mobile broadband and its opening of a range of possibilities for climate change adaptation.

[139] UN ESCAP (2009)
[140] Novotný, (2009), APC (2007)
[141] Rao and Radhamani (2007), Sibanda et al. (2008), Clendenning (2006)
[142] See http://climateprediction.net/, http://www.eoportal.org/, http://www.eoportal.org/
[143] www.alertnet.org, http://medusa.jrc.it
[144] www.fews.net

4.1.1. Scaling–up Mobile Technology for Adaptation

Mobile phones are increasingly being examined as a means of transitioning citizens from mainly voice to more advanced applications, including agriculture, government, capacity building[145] and relevant monitoring[146] and climate change adaptation information/applications through connection to mobile broadband technology. For instance, it can also allow for e-health/telemedicine applications (discussed below) and Multicast Broadcast Services[147]. The latter would be particularly useful for NGOs for broadcasts on local climate related events, downloading climate relevant data, alert services, weather information and real-time monitoring. To date, such services have only begun to be realised in the developed world.

In the context of ICT and agriculture, environment related information ranks high in the needs of the rural populations in developing countries[148] and at the farmer/village level mobile phones are likely to remain the key information medium[149]. Mobile phones have been used to provide agricultural advice in the form of voice and text messages[150]. In India it was demonstrated that mKRISHI, a mobile based agro-advisory system, provided up-to-date weather and pricing information through text-messaging on mobile phones using sensors and GPS. The application can be prompted by text in farmers' local languages or via voice functions[151]. The pilot supported 20,000 farmers and was expected to reach 200,000 farmers[152]. The success of mobile phone innovations in the sphere of agriculture and adaptation suggest that they can be used to overcome some of the issues of farmer participation in the use of WSNs.

4.1.1.1 Mobile Health Application

Along with climate variability and extreme weather events, climate change is expected to increase the risk of disease, such as vector borne infectious diseases, to vulnerable communities[153]. In the process of adaptation and building resilience it is unequivocal that strengthening of health monitoring and information systems using ICT is required. As an example of mobile technology used for health purposes, TNokia launched a new software solution called Nokia Data Gathering to help the public sector and NGOs quickly and accurately collect data on critical issues such as disease outbreaks or disaster relief via mobile devices free of charge.

The Amazonas State Health Department in Brazil will be the first to use the solution as part of its fight against dengue fever in the city of Manaus in Northern Brazil. With the use of a regular mobile network, it can create tailored questionnaires and distribute them to multiple mobile phones. Field personnel surveying local conditions are able to quickly complete the questionnaires and immediately transmit findings to a central database. The system also allows organisations to

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145 Hopeton (2009)
146 Linsey et al. (2010), Ibikunle and John (2008)
147 Ergen (2009), Gur et al. (2008), Dahlman et al. (2007)
148 Panchard et al. (2007)
149 Kinkade and Verclas (2008), Dongtotsang and Sagun (2006), Tandon (2009)
150 Ramey (2009), Kinkade and Verclas (2008)
151 Joshi et al. (2008)
152 n.a., (2008)
153 IPCC (2001), Watson et al. (1997)

geo-tag data with GPS location information to build a more detailed picture of local conditions[154].

Other health monitoring/reporting systems such as EpiSurveyor[155] and OpenMRS[156] have successfully been implemented in a number of African countries and will be critical in the adaptation process as the impacts of global warming manifest in developing countries. This method of surveying and emergency reporting could also be extended to monitor environmental, disaster management or global warming-related issues[157].

This is another area where wireless and mobile broadband technologies in particular can play a role in the adaptation process and enhance e-health/telemedicine activities. Such technologies allow for remote diagnosis, where there is a need to transmit urgent data in order to make immediate basic diagnosis, a need to intervene on non-transportable patients, providing in-situ treatment and remote monitoring[158]. This would allow high-resolution video footage to complement the diagnosis and treatment of persons[159].

In the climate change adaptation process such technologies can be used when temporary medical sites/displacement sites are setup for responding to disease breakouts, when large numbers of displaced persons due to climate change lead to temporary location sites, and for responding to emergency disasters where there is a large number of distributed casualties and limited medical personal. Figure 4 illustrates some potential scenarios where this technology could be applied, particularly by NGOs.

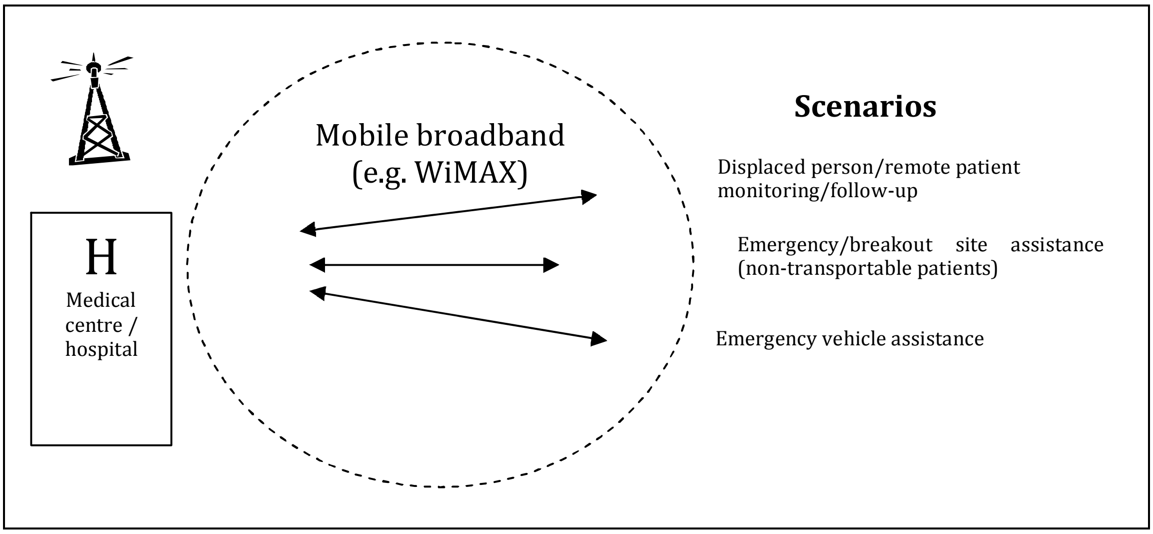

Figure 4: Examples of Telemedicine Application of Mobile Broadband[160]

[154] i4donline (2008)
[155] www.episurveyor.org
[156] www.openmrs.org
[157] Webersik and Wilson (2009)
[158] Neves et al. (2009a, 2009b)
[159] Mignanti et al. (2008)
[160] Adapted from Neves et al. (2009b p. 59)

5. Discussion

Several themes emerge from this review of the application of new and emergent ICTs to climate change in developing countries. The areas gaining the most currency are disaster management and early warning systems (EWS). This is linked to global and local level commitments to address environmental contingencies in the wake of recent large-scale environmental disasters. National disaster management systems and bodies and bottom-up initiatives have been established that have aligned their approaches with the use of new ICTs including Common Alerting Protocol (CAP)-based EWS, wireless broadband systems, wireless sensor networks (WSN), geographic information systems (GIS), disaster management information systems and even mobile ad-hoc networks (MANETs). The Sahana disaster response information system in particular is an instructive example of innovative use of ICTs in response to climate/environmental phenomena. On a global scale however, this is fragmented with many policymakers yet to acquire the knowledge needed to effectively plan for and operationalise new ICTs[161], and there appears to be little coordinated activity. As a point of reference, in the developed world there is a range of advanced environmental applications and coordinated regional activity[162], which has not been replicated to any significant extent in developing countries.

Unlike disaster management, the application of new ICTs to adaptation, particularly for longer-term climate change impacts, has not been addressed in a serious way and is mentioned as a priority in general statements, receiving low priority in terms of practical action. To this end, it is important that more funding is committed to making use of new and emergent ICTs for climate change adaptation and more attention is devoted to practical solutions, rather than broad-brush statements concerning the utility of ICT.

While research on new technologies to effectively deal with climate change in developing countries is beginning to take shape, many of the examples of new ICTs were embryonic, making it difficult to assign definitive benefits. This paper alluded to the technical feasibility of the solutions discussed as well as greater automation, accuracy, reduced cost, better response and information exchange made possible through the ICTs examined. Importantly, this level of automation and scalability allows for use of the technology across more than one application area. For instance, a tropical rain monitoring WSN can be used for observation, data capture, early warning and informing adaptation. Examples were also given on predicting, rather than just detecting certain climate change related events through monitoring networks[163].

These examples provide lessons for NGOs and governments interested in building effective resilience solutions for vulnerable communities. Of course the picture is not just skewed to benefits. Along with level of technical sophistication demanded by new ICTs a number of challenges are raised such as gaining community involvement and identifying solutions that are specifically relevant to vulnerable communities.

[161] Zengpei and Rhee (2010)
[162] For instance see http://ec.europa.eu/information_society/activities/sustainable_growth/funding/prj_climate/index_en.htm
[163] Sheth et al. (2007, 2005), Basha et al. (2008)

While local level monitoring systems are beginning to be developed and deployed, greater attention is needed concerning management of monitoring data. This involves mechanisms to use captured data to inform livelihood, resource management and other relevant decisions that affect vulnerable communities. This will require building interoperability and open standards, which is essential so that data that has been captured at one point can be shared with other platforms to ensure complete data is used to inform decision making. That is, can sensor networks, remote sensing, GIS, Web systems etc talk to each other in an effective manner? This will become an important issue with the scaling-up of the mix of new and established technologies used for climate change scenarios. At the Web level the Global Earth Observation System of Systems[164] will allow interoperability amongst hundreds of web portals[165], however at the infrastructure level few initiatives are taking place (an instructive exception being CAP). With the increasing use of sensor networks and rich data captured through wireless broadband monitoring systems and other hybrid systems a complex issue that emerges is ownership of the data. For instance, many of the examples described in this paper were small-scale and localised and it is unclear how data captured feeds into broader climate change data collection and then dissemination that would inform local communities. A fundamental question is: who owns the data[166]?

The potential of WSNs for climate change has only recently begun to be examined. There have been calls for WSNs to be deployed in developing countries on a community shared-model basis[167] (i.e. sharing the WSN across multiple application areas rather than rolling out one for rainfall, one for landslides, one for fire detection, etc), which would offer some benefits for grassroots applications. A number of relevant WSN applications have been discussed in this paper which should be leveraged as successful exemplars for governments, NGOs and other relevant bodies. These were predominately localised examples and a gap still exists between local and national/global monitoring. As an emergent technology a number of technical challenges remain that need to be addressed, such as being able to withstand extreme weather events, deployments in remote areas and power[168]. Another gap in understanding is how data that is captured by monitoring WSNs and other ICTs is presented, disseminated and acted upon.

As the impacts of global warming continue to mount, more robust communication networks will be required[169]. This paper presented the case for wireless broadband communications for climate observation systems, rapidly deployable communications and the underlying network infrastructure for WSNs. The implication of hybrid networks such as satellite with mobile WiMAX (and in the future other 4G technologies), will allow for more flexible architectures leading to improved climate, environmental and health forecasting and monitoring whilst reducing the digital divide[170].

Countries that have suffered from a lack of broadband connectivity should therefore continue to examine wireless communications in order to provide enhanced connectivity and a more climate resilient infrastructure for future climate related

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[164] www.earthobservations.org
[165] ITU (2008b)
[166] Houghton (2009)
[167] Ramanathan et al. (2006)
[168] Basha et al. (2008), Khadivi et al. (2009), Vassilaras and Yovanof (2010)
[169] Ghosh (2007)
[170] Olla (2009a)

applications. This is a key consideration for telecommunications policymakers in developing countries when deciding upon improving or implementing new infrastructure.

The use of the range of established low-tech ICTs (radio, television, mobile phone etc) and the convergence with new ICTs show the contextual compatibility of these technologies to vulnerable communities. Mobile phones and advances in mobile technology are likely to continue to play a large role in climate change adaptation. However, at present there is a clear disconnect between mobile phone uses (i.e. for agriculture, monitoring, and health) and the data captured through monitoring networks using new ICTs. A key question therefore is what is the potential for the convergence of mobile phones with advanced monitoring systems? The introduction of mobile broadband networks and the proliferation of smartphones present interesting avenues for future climate change applications. It is important that NGOs and governments begin to consider the range of climate change applications that can be made available with the projected increase of mobile broadband and devices.

The Web has also emerged as a promising climate change relevant technology, particularly for information dissemination and disaster management, and should continue to be researched and developed in order to understand and enhance its role in the climate change adaptation process. NGOs should embed these into their range of climate change activities to allow for greater community participation and additional information dissemination and collection channels.

A notable theme is that many of the examples in this paper have stemmed from South and South-East Asia and Latin America. Little application of ICT, new or otherwise, in Africa or Small Island Developing States (SIDS) in the context of climate change appears to have taken place, even though these countries are inhabited by the most vulnerable populations. This follows the broader pattern of ICT for development. There is a need for greater emphasis on ICT climate applications in Africa and the SIDS in order to prepare vulnerable communities.

5.1. Priorities for Future Research

This paper highlighted a number of gaps in the extant research and identified fruitful areas for further inquiry. Focusing on the impacts and outcomes of the use of new and emerging ICTs will augment understanding of the benefits and provide greater basis for advocating their diffusion.

From a technological position, looking ahead, the introduction of mobile broadband networks and the proliferation of smartphones present interesting avenues for research especially in the context of preparing for future climate change applications. There also needs to be a focus on researching the opportunities arising from the convergence of older and newer ICTs. Along with the mix of ICTs emerging for climate change applications a number of peripheral issues also need investigation, particularly, the ownership of data and information sharing across multiple technology platforms. The consequences of these issues particularly where a mix of public actors and private infrastructure is involved have barely been examined. Finally, and moving further from the technology, a critically underresearched area is the information requirements of vulnerable communities. Concentrating on community needs, rather than just technical issues, will ensure greater community participation and therefore improve the success of adaptation initiatives using new and emergent ICTs.

5.2. Recommendations

Based on the review of new and emergent ICTs and climate change in developing countries a number of recommendations are formed in order to facilitate greater understanding of how they may be applied. This will encompass expanding their application across climate change areas, building the underlying infrastructure that is required for the technology, and ensuring that communities, NGOs and governments can maximise the benefits of the ICTs available in order to meet the climate change challenge.

Recommendation 1

- Demonstrate the success and feasibility of new and emergent ICTs in relation to climate change in developing countries:
  - Review the benefits and outcomes of the use of new and emergent ICTs for climate change.
  - Develop a knowledge base of the lessons learnt in the deployment of new and emergent ICTs.
  - Leverage examples of successful deployments of new and emergent ICTs.
  - Deploy new ICTs in Africa and SIDS in order to demonstrate their success and feasibility even in the least developed countries and most demanding environments.

Recommendation 2

- Focus more on adaptation activities:
  - Using the technologies outlined for monitoring and disaster response, focus on longer-term adaptation activities. Possible initiatives involve bottom-up and participatory approaches facilitated by the use of new and emergent ICTs.

Recommendation 3

- Invest in wireless infrastructure:
  - Use wireless infrastructure as a backbone for future climate applications.
  - Examine the role of mobile broadband for use by NGOs, responders and other stakeholders.
  - Research future wireless/mobile broadband climate change applications.

Recommendation 4

- Build advanced terrestrial monitoring networks:
    - Continue technical development of monitoring networks for climate change scenarios that would improve precision of climate monitoring. and prediction of climate change impacts.
    - Establish how captured monitoring and prediction data can feed into local level information channels.
    - Research the best-suited technologies for communicating early warnings.

Recommendation 5

- Build upon established and successful technologies:
    - Use wireless broadband as a means to up-scale existing initiatives
    - Use mobile phones and telecentres to complement data captured by advanced monitoring systems and to act as dissemination channels.
    - Use FOSS for climate change relevant information systems deployment.
    - Research the role of the Web 2.0 for climate change action and its use as part of outreach, empowerment and adaptation strategies.

Recommendation 6

- Understand information requirements and build cross-platform interoperability:
    - Research how data gathered from observation systems using new and emergent ICTs can be integrated into broader climate change science.
    - Investigate and understand data ownership at the local, regional and national level.
    - Research the information needs of vulnerable communities and how these can be met by new ICTs.
    - Develop and promote interoperable standards for data exchange across multiple platforms.

Conclusions

This paper has reviewed new and emergent ICTs and developed an understanding of the new technologies relevant to developing countries and climate change. It augments understanding of the ways in which ICTs can be deployed to specific climate change issues and presents a number of recommendations to better allow for the effective use of ICTs. Within the frame of reference of development, climate change and ICTs it is impossible to escape the reality of related factors such as limited infrastructure, and technology, illiteracy, poverty and so forth, which complicate climate change adaptation. The challenge is building on the current momentum and using the appropriate and best mix of new and established ICTs to address climate change in developing counties, while balancing sustainable development, the digital divide, financial scarcity and the short-term well-being of citizens.

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ANNEX 1. Glossary

2G: Second generation wireless telephone technology.
3G: Third generation mobile telephone services.
4G: Fourth Generation technology.
ADSL: Asymmetric Digital Subscriber Line.
CAP: Common Alerting Protocol.
CBS: Cell Broadcasting System.
CDMA: Code Division Multiple Access.
EWS: Early Warning System.
FOSS: Free and Open Source Software.
GIS: Geographic Information System.
GPRS: General Packet Radio Service.
GPS: Global Positioning System.
GSM: Global System for Mobile Communications.
HSPA: High Speed Packet Access.
ITU: International Telecommunication Union.
LOS: Line of Sight.
MANET: Mobile ad-hoc network.
NLOS: Non Line of Sight.
PSTN: Public Switched Telephone Network.
SMS: Short Message Service.
Wi-Fi: Wireless Fidelity.
WiMAX: Worldwide Interoperability for Microwave Access.
WSN: Wireless Sensor Network.
WMO: World Meteorological Organisation.
WWW: World Weather Watch.
UMTS: Universal Mobile Telecommunications System.
VSAT: Very Small Aperture Terminals.
ZigBee: IEEE 802.15.4 wireless mesh networking standard.