MODULE

8

GROUNDWATER HAZARDS

CONTENT

MODULE 8

Groundwater Hazards

Imprint

A4A – aqua for all
AGW-Net – Africa Groundwater Network
ANBO – African Network of Basin Organisations
BGR – Federal institute for geosciences and natural resources
UNDP-Cap-Net
BMZ – Federal Ministry for Economic Cooperation and Development
GWP – Global Water Partnership
IGRAC – International Groundwater Resources Assessment Centre
imawesa – Improved Management of Agricultural Water in Eastern and Southern Africa
IWMI - International Water Management Insitute

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GROUNDWATER HAZARDS

LEARNING OBJECTIVES

The objectives of this module are to:

- Assess the risk of groundwater pollution and quantity impairment
- Protect groundwater from pollution and over-exploitation

8.1 Introduction

Under natural conditions, groundwater is usually potable and needs almost no treatment before distribution and use. The good water quality is a result of the protection of the soil and rocks in the unsaturated zone above the water table. They filter out bacteria and protect groundwater from contaminants on the surface. But the massive input of pollutants generated by modern agriculture, industry and lack of sanitation facilities can overburden the ability of the unsaturated zone to filter out contaminants and protect groundwater. Once a groundwater aquifer is polluted, rehabilitation is a very expensive and long-lasting task. Because of the very long time lags that might take place before a pollution impact on the resource is noticeable, good management of the aquifers, including pollution prevention activities, are of great importance.

In the case of transboundary aquifers, the sustainable use of groundwater is often hindered by the lack of legal and institutional mechanisms, hence a lack of common management of these aquifers. To enable cooperation between neighboring countries, necessary legal and institutional mechanisms as well as capacities at national level have to be put in place first. The development and implementation of appropriate legal instruments and management tools for catchment-based resource protection still constitute some of the challenging aspects regarding transboundary aquifer management. First steps to follow are the identification of these aquifers and formulation of appropriate instruments to enhance cooperation for sustainable and integrated management and use of these resources for socio-economic benefits.

This module examines groundwater quantity and quality aspects and identifies water management options to preserve and protect groundwater resources.

8.2 Groundwater Quantity: Over-exploitation

High population growth results in an increased need for water for agricultural production and industrial development, which in terms leads to more groundwater pumping globally (UNEP, 2003; FAO, 2003; Burke and Moench, 2000). Increased pumping can leads to extreme lowering of water tables. The impacts of groundwater over-exploitation are numerous and often irreversible (Figure 8.1). Direct impacts are:

1. Lowering of groundwater levels/pressures;
2. Reduction of groundwater discharge to springs, stream base flow and aquatic ecosystems;
3. Deterioration of groundwater quality (salinization) as a result of sea water intrusion in coastal aquifers and up-coning of deep saline water;
4. Land-surface subsidence;

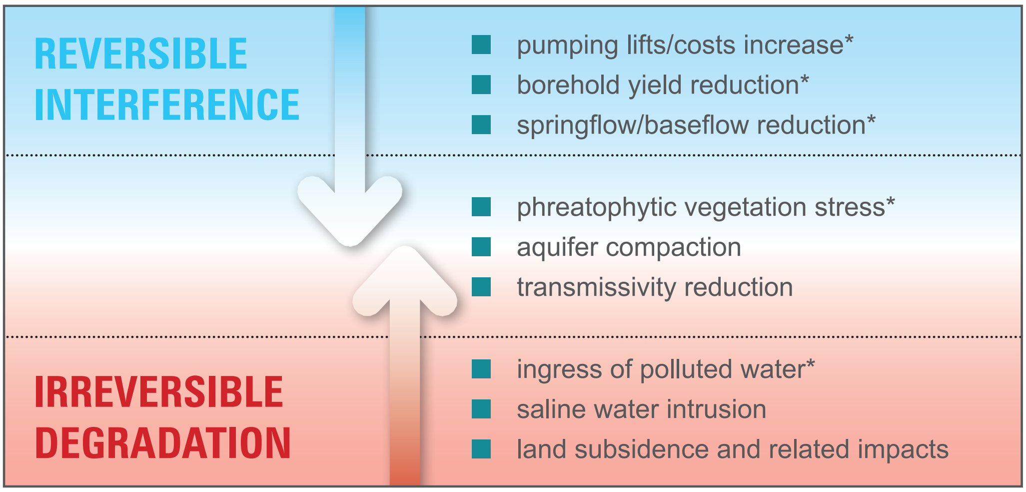


Figure 8.1: Consequences of excessive groundwater abstraction. Source: GW-Mate

* consequences vary widely in impact depending on aquifer susceptibility to change under intensive pumping – and some impacts commence well before the level at which total groundwater abstraction rate exceeds long-term average aquifer replenishment rate

Impacts of groundwater over-exploitation

Physically, aquifer overexploitation is reached whenever abstraction rates overcome the long-term recharge rate. In practice however, over-exploitation is invariably much more concerned with the consequences of intensive groundwater abstraction (Figure 8.1) than about its absolute level. Thus the most appropriate definition for over-exploitation is probably that it is reached when the overall costs of the negative impacts of groundwater exploitation exceed the net benefits of groundwater use, although these impacts are not always easy to predict and/or to quantify in monetary terms. It is also important to stress that some of these negative impacts can arise well before the groundwater abstraction rate exceeds long-term average recharge. Therefore the way in which over-exploitation is interpreted varies with the type of aquifer system involved, the key issues being the volume of exploitable storage and aquifer susceptibility to irreversible side-effects during short-term overdraft.

Lowering of groundwater levels/pressures

Lowering of the water table is a relatively slow process. In contrast to a surface water body, the water table is not lowered simultaneously within the whole aquifer but in the immediate surroundings of the well. Groundwater travel time is much slower than in surface water because of its movement through pores and fissures. When wells pump water from these aquifers, the water table near the wells is lowered in the form of a cone of depression. Within this cone of depression, the groundwater flows towards the well. If two cones of depression overlap, there is interference between the wells and the volume of water available to each well reduces. Well interference can be a problem when many wells are competing for the water from the same aquifer, particularly at the same depth.

Long-lasting pumping at high rates might cause irreversible lowering of water tables reducing the aquifer discharge to surface water bodies (Figure 8.2).

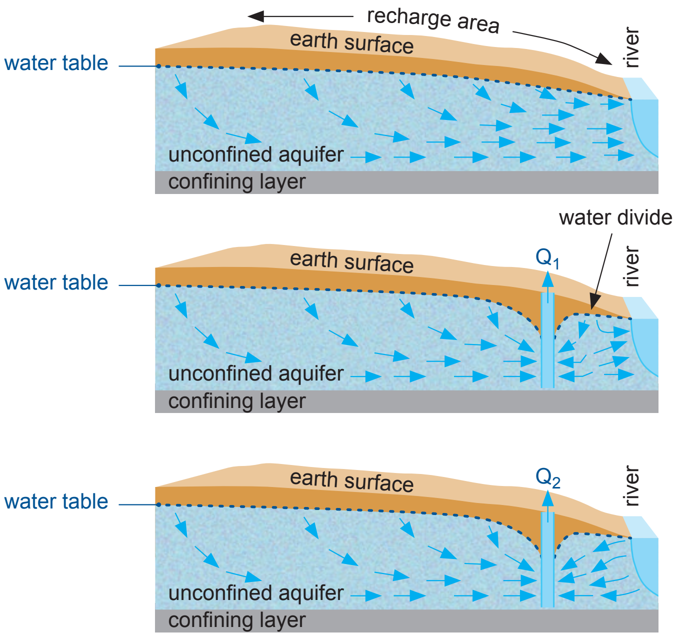
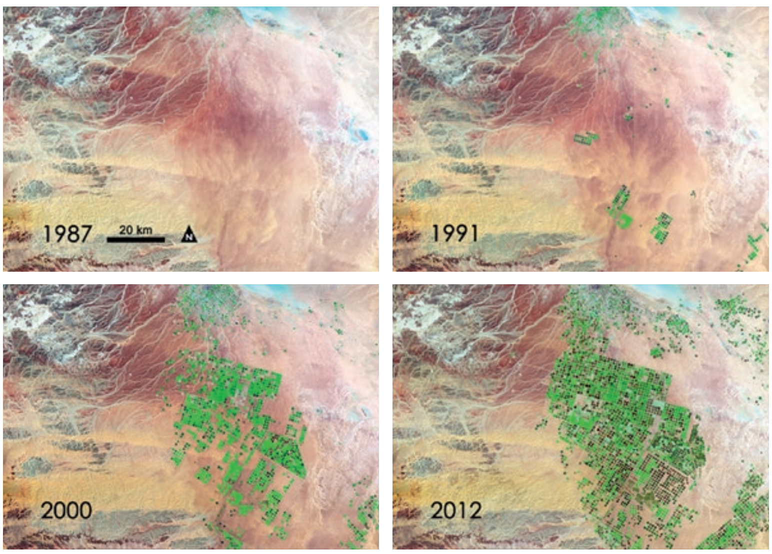


Figure 8.2 : Continuous pumping at high rates lowers the water table reducing the aquifer discharge into the river (middle). It can also lead to a change of the flow situation in which the river water reaches the well. Source: modified from US Geological Survey

Cones of depression only appear in unconfined aquifers, which are aquifers that have direct hydraulic connection to the atmosphere. In the case of confined aquifers, it is the pressure in the aquifer that reduces in the surounding of the pumped well.

In the case of transboundary aquifers, the problem of groundwater depletion applies predominantly to deep aquifer systems, which are mostly confined. This is a major problem because generally these aquifers receive little or no recharge, e.g. in North Africa and the Middle East. Large abstraction, as is necessary for irrigation, over long periods of time leads to ever decreasing groundwater levels. This problem can be observed quite impressively in the desert of Saudi Arabia. Landsat satellite images reveal an increase of the agricultural area from 1987 to 2012 (Figure 8.3). Due to the lack of recharge, the increased irrigation has caused dropping groundwater tables (FAO, 2009). On the long term, this will also affect the groundwater resources in the neighbour countries, like Jordan. Recently Jordan also started pumping from the same aquifer to provide water for the city of Amman, and this is exacerbating the situation.

Figure 8.3: Extent of agricultural area in the desert of Saudi Arabia at the border to Jordan from 1987 to 2012. The green dots are irrigated areas using groundwater. Source: USGS



Reduction of groundwater discharge to springs, stream base flow and aquatic ecosystems

Ground- and surface water systems often interact closely (see module 3 “Aquifer characterisation”). Groundwater provides river base flow even in dry periods and supplies freshwater ecosystems (module 3). When groundwater is pumped excessively, surface discharges as springs, base flows and seepages tend to dry out, sometimes permanently, damaging groundwater dependent ecosystems and reducing groundwater to user communities.

Subsidence

Subsidence is yet another particularly widespread impact of excessive over-pumping, with some notable examples in a number of major cities in China, Japan, Mexico and the US (Figure 8.4). Land subsidence occurs when excessive amounts of groundwater have been withdrawn from a porous aquifer. As a result, the porous aquifer materials compact and settle, resulting in a lowering of the ground surface in the area (www.sjra.net). Land subsidence can lead to many problems such as: changes in land surface elevation; damage to structures such as storm drains, sanitary sewers, roads, railroads, canals, levees and bridges; structural damage to public and private buildings; and damage to wells. Most commonly, though, subsidence is known for causing the potential for flooding.

Figure 8.4: Land Subsidence in the San Joaquin Valley, California, USA Source: www.sjra.net

Salinisation

Over-pumping fresh water aquifers in coastal areas may cause saline waters to intrude into the freshwater zones of aquifers. This occurs by up-coning of saline water and mixing with fresh water, giving rise to an irreversible aquifer salinization (see section 8.3 and Fig 8.7). It is a major problem for a great number of coastal cities around the world.

8.3 Groundwater Quality: Pollution

When considering groundwater quality and deterioration, one has to distinguish between natural and anthropogenic contamination. Under most natural conditions groundwater is potable without any treatment. There are some exceptions worldwide, where the natural groundwater has concentrations of various soluble materials at levels that are harmful to health, human, animal or plant. A very well known case is the high arsenic concentration of the porous aquifer in Bangladesh. Salinization is also an example of natural contamination, but is very often intensified by human activities. It seems that in the African context, most groundwater quality concerns are related to:

- Declining urban groundwater quality due to a combination of leaking pit latrines / septic tanks and uncontrolled effluent discharge from industry and municipal wastewater and landfill facilities.
- Salinization of groundwater due to over abstraction for irrigation leading to declining groundwater quality
- Saline water intrusion due to lowering of water table by water supply wells near / along coastal areas.

Naturally-occurring groundwater quality hazards

Groundwater becomes mineralized to varying degrees due to soil/rock-water interactions, which result in the dissolution of certain minerals and chemical elements. Nine major chemical constituents (Na, Ca, Mg, K, HCO3, Cl, SO4, NO3, Si) make up 99% of the solute content of natural groundwater.

The degree of dissolution depends on the length along flow path, the travel time, the solubility of soil/rock minerals and the amount of dilution by fresh recharge water. Reactions of rainwater in the soil/rock profile during infiltration provide groundwater with its essential mineral composition. Groundwater in the recharge areas of humid regions is likely to be low in overall mineralization, compared to arid or semi-arid regions where the combination of evaporative concentration and slower groundwater movement can produce much higher concentrations.

Under certain conditions and in some geo-environments, naturally occurring but hazardous elements are taken into solution at excessive concentrations:

- Arsenic (As) is the trace element currently giving greatest concern in groundwater, being both toxic and carcinogenic at low concentrations
- Fluoride (F) is an element that is sometimes deficient, but in excessive concentrations it can be a problem, especially in arid climates and in volcanic and granitic rocks
- Manganese (Mn) and iron (Fe) in soluble form occur widely where anaerobic groundwater conditions arise. When water is extracted, manganese and iron oxidize, giving rise to unacceptable groundwater taste and/or color. While Fe is not a health hazard, consumption of water with high manganese concentrations might have neurological effects on humans. The WHO has set the upper limit for Mn concentration in groundwater at 0.4 mg/l

Various other trace elements (including notably Ni, U and Al) can occur under natural conditions in groundwater and are listed by World Health Organization (WHO) as potentially hazardous in drinking water.

If excessive toxic trace elements are present in a potential groundwater supply, then an emergency plan should be implemented and a longer-term strategy identified. The emergency plan is likely to comprise the following:

- Hydro-geochemical evaluation of the aquifer at an appropriate scale
- Community guidance on use restrictions and safe locations of water wells
- Community health programs to look for symptoms related to drinking water.

Anthropogenic Pollution

Worldwide, aquifers are experiencing an increasing threat of pollution from urbanization, industrial development, agricultural activities and mining enterprises (Figure 8.5). In some cases, it may take many years before the impact of pollution by a persistent contaminant becomes fully apparent. Groundwater from deep wells, or from springs or groundwater dependent ecosystems often has a long flow path and may take decades or longer to move from recharge to discharge area. This can lead to complacency over the pollution threat. The unfortunate implication is that once people become aware that a groundwater source has become polluted, large volumes of the aquifer are usually already contaminated. Mitigation measures then tend to be very costly and remediation is technically problematic and time consuming. Such contaminated aquifers may be unsuitable for use for decades or centuries. This is why prevention measures such as groundwater protection have to be integrated into land-use planning activities.

Groundwater pollution occurs if the subsurface contaminant load generated by man-made emissions (waste dumping, discharges and leakages) is inadequately controlled, and exceeds the natural attenuation capacity of underlying soils and strata. Natural subsoil profiles actively attenuate many water pollutants and have long been considered potentially effective for the safe disposal of human excreta and domestic wastewater. The auto-elimination of contaminants during subsurface transport within the rock/soil is the result of biochemical degradation and chemical reaction, but contaminant retardation (due to sorption on clay minerals and/or organic matter) is also important, since it greatly increases the time available for processes resulting in contaminant elimination. However, not all subsoil profiles and underlying strata are equally effective in contaminant attenuation, and this leads to the hazard of contaminating unconfined (phreatic) shallow aquifers.

Threats of groundwater pollution arise from a variety of different point and non-point contaminant sources (Figure 8.5 and Table 8.1) originating from industrial, agricultural, domestic (inadequate sanitation), fuel storage, medical and other common sources.

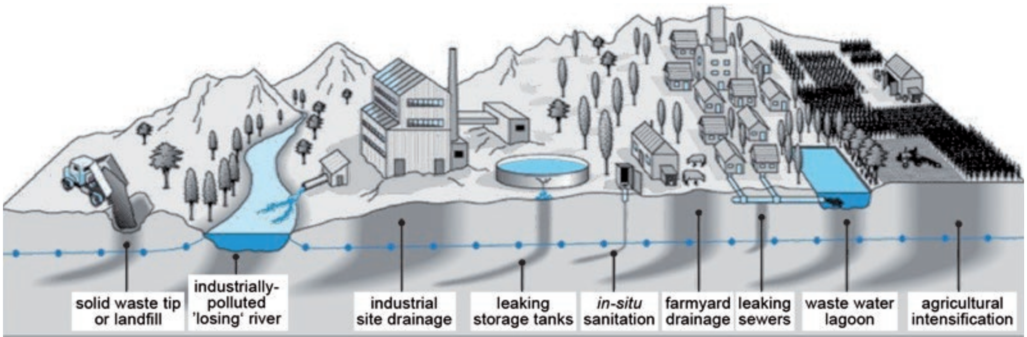


Figure 8.5: Different land-use activities that commonly generate groundwater pollution threats. Source: GW-MATE Briefing Note Series, Note 8, 2002-2006

Table 8.1: Some common groundwater contaminants and associated pollution sources.

Pollution Source	Type of contaminant
Agricultural Activity	nitrates, ammonium, pesticides, faecal organisms
On-site Sanitation	nitrates, faecal organisms, trace synthetic hydrocarbons
Gasoline Filling Stations & Garages	benzene, other aromatic hydrocarbons, phenols, some halogenated hydrocarbons
Solid Waste Disposal	ammonium, salinity, some halogenated hydrocarbons, heavy metals
Metal Industries	trichloroethylene, tetrachloroethylene, other halogenated hydrocarbons, heavy metals, phenols, cyanide
Painting and Enamel Works	alkylbenzene, tetrachloroethylene, other halogenated hydrocarbons, metals, some aromatic hydrocarbons
Timber Industry	pentachlorophenol, some aromatic hydrocarbons
Dry Cleaning	trichloroethylene, tetrachloroethylene,
Pesticide Manufacture	various halogenated hydrocarbons, phenols, arsenic
Sewage Sludge Disposal	nitrates, various halogenated hydrocarbons, lead, zinc
Leather Tanneries	chromium, various halogenated hydrocarbons, phenols
Oil and Gas Exploration/Extraction	salinity (sodium chloride), aromatic hydrocarbons
Metalliferous and Coal Mining	acidity, various heavy metals, iron, sulphates

Source: GW-MATE Briefing Note Series, Note 8, 2002-2006

Groundwater salinisation

The existence of saline groundwater and the process of groundwater salinisation can come about by a number of distinctive mechanisms, only some of which are pumping-related and/or associated with the seawater intrusion.

The main mechanisms of groundwater salinization are indicated schematically in Figure 8.6, and range from the mobilisation of paleo-saline or connate waters[1] at depth to essentially surface processes related to soil water-logging due to rising water-tables. In-depth investigations are required to diagnose existing occurrences of saline groundwater, and to assess the potential that such processes might occur during a major or progressive change of groundwater abstraction. The importance of this cannot be over-stressed since once a major rise in salinity or intrusion of saline water has occurred, it may take a very long-time (decades or even millenia) and considerable cost to remediate — and will destroy the groundwater resources for both potable water-supply and many agricultural irrigation uses.

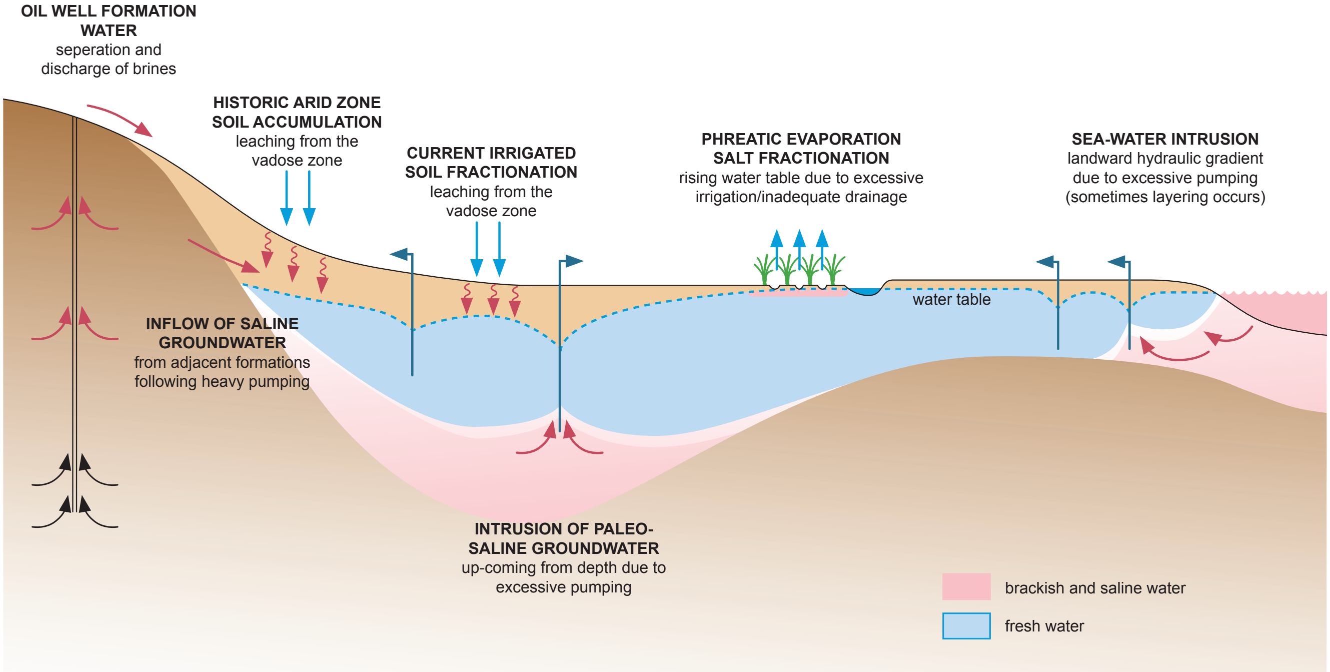


Figure 8.6: Salinisation as possible effect of groundwater over-abstraction. Source: GW-MATE

[1] Groundwater recharged in the past, thousands of years ago, that stagnates in channels or depressions and has thus time to interact with the surrounding rocks. It is generally high saline and as such cannot be used for water supply without treatment

8.3 Assessment of groundwater pollution, aquifer vulnerability and over-exploitation

To protect groundwater from pollution and overexploitation, it is essential to assess the hydrogeological setting and the anthropogenic impact.

Groundwater extraction and recharge rates

In the light of all the above considerations, it will be evident that water resource managers need to have an estimate of the acceptable abstraction[2] from a groundwater system. Although in reality such estimates can also be misleading because to make them it is necessary to have value judgements about what is 'acceptable'. In this case ecosystems also have to be considered as stakeholders that are aquifer dependent.

To assess a safe yield, the quantities of input (recharge) and output (discharge) to the groundwater system have to be estimated. An important component of the output, abstraction by pumping, varies according to human demand. However there is often substantial scientific uncertainty of the quantification of individual recharge and discharge components due to the inherent complexity of natural geo-systems and wide spatial and temporal variability of rainfall and runoff events (including climatic cycles) as well as of groundwater abstraction. Therefore groundwater balance calculations in many regions always should be treated with caution. Nevertheless, for most practical purposes, it is sufficient to make approximate estimates, and refine these subsequently through groundwater level monitoring and analysis of aquifer response to abstraction over the medium-term.

It is always essential when attempting to evaluate contemporary groundwater recharge rates to appreciate the significance of the intimate linkages between land-use and groundwater recharge, which is an essential input for integrated water resources management. The common paradigm of 'constant average rates of present-day aquifer recharge' is false. In reality the contemporary rate of aquifer recharge varies considerably with:

- Changes in land-use and vegetation cover, notably the introduction of irrigated agriculture, but also vegetation clearance and soil compaction
- Urbanisation processes, and in particular the level of water-mains leakage and the degree of land-surface impermeabilisation;
- Widespread water-table lowering by groundwater abstraction and/or land drainage, which leads to increased areas and/or rates of infiltration in some aquifer systems;
- Changes in surface water regime, especially the diversion of riverflow.

Moreover groundwater abstraction data is almost unavailable, since direct monitoring of groundwater abstraction is costly because meters have to be fitted to all pump outlets, and this requires the full cooperation of water users, which is not always easy to achieve. Intensive groundwater use for domestic water supply is also encountered in fast growing cities where the water service provision is inadequate. This is the case

2 Acceptable extraction or safe yield is the rate at which a well can be pumped in a long-term without causing harm either to the well construction (water level falls below the screen) or to the aquifer (irreversible lowering of the water table)

in many African cities and has led to massive and indiscriminate private groundwater development. Indirect monitoring of groundwater use can be done using demographic data in combination with satellite images and urban planning maps that show the urban expansion and estimating water use per household.

Pollution sources and vulnerability

Groundwater is vulnerable to many different sources of pollution. The location, nature and amount of pollution sources have to be known to assess the pollution load to land surface and hence potentially to the groundwater. The pollution loads are relatively easy to identify, especially point source pollution, but it is the vulnerability of the aquifer system in combination with the pollution load that translates the into groundwater hazard.

Hydrogeological data such the thickness and hydraulic properties, such as permeability, of the unsaturated zone are necessary to assess the vulnerability of aquifers to pollution loads. The groundwater hazard can be determined by overlaying pollution load maps onto aquifer vulnerability maps.

There are a number of aquifer vulnerability assessment methods that consider a variety of factors that contribute to an aquifer's vulnerability. Two of the better known assessment schemes are known by their acronyms: DRASTIC and GOD. To provide a general insight into aquifer vulnerability characterization it is useful to consider the elements considered in the eg. Drastic method. Each element in the vulnerability assessment is allocated a relative score, and the final score is rannked against a ranking chart which may characterize the aquifer from: very high vulnerability to very low vulnerability.

- D = depth to the groundwater (the deeper, the less vulnerable)
- R = net recharge (the greater the recharge rate, the more vulnerable)
- A = aquifer medium (low permeability aquifers are less vulnerable)
- S = soil medium (permeability, adsorbtion capacity)
- I = impact of the vadose zone (combination of S and D)
- C = hydraulic conductivity (similar to A)

Due to the repetition of some of the parameters, hydrogeologists have tended to modify Drastic and come up with more stream-lined vulnerabilty assessment methods.

Once the aquifer vulnerability has been assessed, then the risk to the groundwater can also be assessed. The definition of groundwater pollution hazard is the interaction between aquifer pollution vulnerability and the contaminant load applied on the subsurface environment as a result of human activity at the land-surface. Contaminant load can be controlled, but aquifer vulnerability is fixed by the natural hydrogeological setting.

Systematic groundwater pollution hazard assessments should be integrated into groundwater quality protection measures and should become an essential component of environmental best practice.

Management of groundwater pollution.
As expressed earlier, prevention of pollution is far preferable to trying to cure it. The key management options for preventing groundwater pollution are:

- Seperation: keep waste materials and productive aquifers far apart. This usually takes place during the planning phase of any development, especially where there is a high level of waste generated. Environmental impact assessments are designed specifically to ensure that such separation occurs in a timely manner.
- Containment: Where waste is generated in proximity of groundwater or surface water supplies, then containment of the waste in impermeable ponds is a management option. Solid waste landfills should be designed such that there is an impermeable base, which may be some form of high density polyethelyne liner or a compacted clay base.
- Waste management: the sorting of waste into different components is highly successful and allows the reuse / recycling of some wastes (plastic, metal, glass, paper and cardboard) and composting of organic waste. This reduces the overall waste load and allow the seperation of toxic waste which can be treated or contained in high level waste facilities. Waste sorting and seperation is often commercially viable.
- Remediation: finally there is remediation of polluted aquifers. As expressed earlier, this is technically complex, long duration and expensive. Methods such as pump, treat and reinject treated water; aquifer flushing with fresh water etc. have been used with limited success. Insoluble pollutants, the so-called LNAPL and DNAPL (Light and dense non-aqueous phase liquids) are particularly difficult to treat.

8.5 Groundwater protection

Whether a given pollution hazard will result in a threat to a groundwater supply-source depends primarily on its location with respect to the source water-capture area and secondarily on the mobility of the contaminant(s) concerned. A number of groundwater protection zones should normally be defined (Figure 8.7) based on hydrogeological data about the local groundwater flow regime. Various analytical and numerical models are available for this purpose. The scale and intensity at which the survey, mapping and analyses of various components needed to assess groundwater pollution hazard are undertaken, will vary with the importance and sensitivity of the groundwater resource: water-supply protection or aquifer resource conservation.

A primary focus of groundwater quality monitoring is usually public water supply networks from water wells and springs via piped distribution systems. Two key components involve (i) regular sampling of the water, and (ii) chemical analysis in the laboratory.

Groundwater pollution hazard assessments should prompt municipal authorities or environmental regulators to take both preventive actions (to avoid future pollution) and corrective measures (to control the existing threats). To protect aquifers against pollution it is essential to constrain land-use, effluent discharge and waste disposal practices.

Simple and robust zones need to be established, based on aquifer pollution vulnerability and source protection perimeters. For each zone certain activities have to be defined that give an acceptable risk to groundwater. Groundwater protection zoning also has a key role in setting priorities for groundwater quality monitoring, environmental audit of industrial premises, and pollution control within the agricultural advisory system.

A sensible balance needs to be struck between the protection of groundwater resources (aquifers as a whole) and specific sources (boreholes, wells and springs). While both approaches to groundwater pollution control are complementary, the emphasis placed on one or other (in a given area) will depend on the resource development situation and on the prevailing hydrogeological conditions.

In dealing with threats to groundwater, communities and stakeholders need information about the resource. Groundwater protection can best be accomplished by controlling potential contaminant sources and by managing landuse in prime recharge areas. Using knowledge of local geology and groundwater flow directions, estimates can be made of land areas that contribute to recharge a particular aquifer. Controls can then be established to ensure appropriate land uses and chemical practices within the recharge areas. In many instances, recharge areas cannot be set-aside in their natural states.

Within certain basins, domestic, industrial, agricultural and commercial operations discharge different forms of potential contaminants, which can contaminate groundwater with bacterial matter, pesticides, chemical spills, toxic wastes, etc. In this regard, groundwater protection efforts must focus instead on management of the diverse potential contaminant sources. Some possible management techniques include public education, inventory and monitoring of potential contaminant sources, and zoning of local land use activities (Figure 8.7) in order to protect community groundwater supplies.

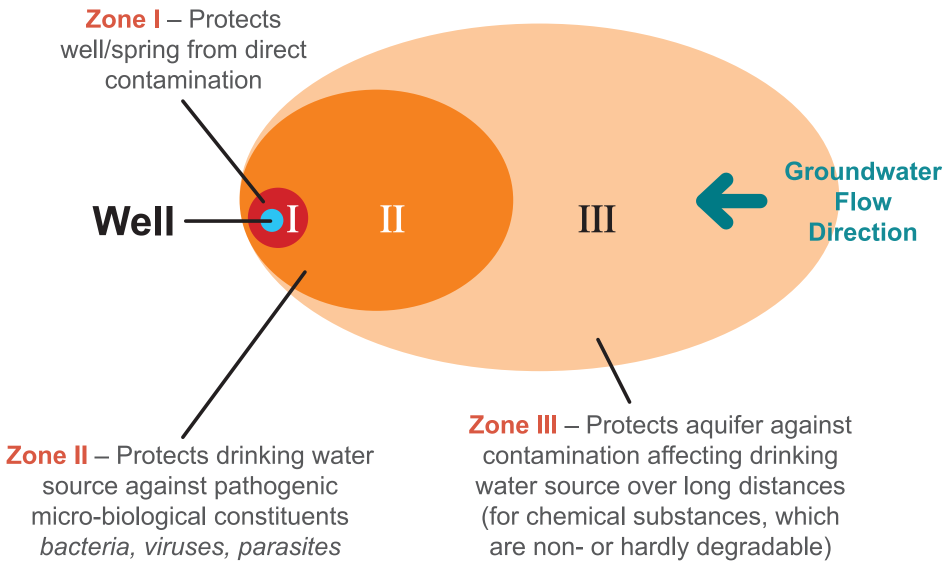


Figure 8.7: Idealized schematic zones for protection of a well in an unconfined aquifer. Source: Modified after GW-Mate, 2006

For groundwater protection zones to be effective, they need:

- To be embedded in the regulatory framework and enforced
- Stakeholders to be aware about them and adhere to them
- To be regularly monitored
- Land-use restrictions to balance competing user-interests.

8.6 Summary

In discussing groundwater hazards, it can be helpful to consider them in the context of generic hazard management. Since we are concerned with the management of groundwater hazards, the question to ask is: "How does a catchment manager protect the groundwater resources and the aquifers in his catchment against hazards?"

The measurement of groundwater recharge, groundwater flows and even mapping of the aquifers and abstraction potential are expensive and complex. Faced with such a large information lack, how does the manager start to make decisions? Box 8.1 presents terms that are used in disaster studies and their interactions. Such a framework can be helpful for a catchment manager tasked with protecting groundwater resources.

The manager first has to identify the important groundwater sources being used in their catchment / basin, then assess the hazards for each, look at the vulnerability to each hazard to determine the risk. The hazards (pollution hot spots) are relatively easy to identify but it is the aquifer vulnerability that translates the hazard into risk.

Once the catchment managers have an assessment of risk, they then have a basis for action (mitigation) that may include control of specific polluting agents or practices, adjusting abstraction or other interventions. If managers use a structured approach on disaster management (Box 8.1), this can provide a framework for identifying risk and thereby targeting effective response / remediation. Managers, despite the complexity and unknowns in groundwater, still have a framework for management steps that they can take to protect the groundwater resource from pollution.

BOX 8.1: SOME TERMINOLOGIES USED IN DISASTER STUDIES

i) Hazard - A potentially damaging physical event, human activity or phenomenon that has potential to cause loss of life or injury, property damage, socio-economic disruption of life and environmental degradation, among others.

ii) Vulnerability - A set of conditions resulting from physical, social, economic and environmental factors that increase the susceptibility of a community to the impact of disasters or the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard.
Disaster = Hazard + Vulnerability

iii) Risk - The probability of harmful consequences or loss resulting from the interaction between natural hazards and vulnerable conditions of people and property.
Risk = (Hazard X Vulnerability)/Capacity

iv) Mitigation - Short and long term actions, programmes or policies in advance of a natural hazard or in its early stages, to reduce the degree of risk to people, property and productive capacity.

v) Impacts - Specific effects, consequences or outcomes of hazards or disasters.

vi) Preparedness - Pre-disaster activities designed to increase the level of readiness or improve operational capabilities for responding to an emergency.

vii) Response - Actions taken immediately before, during or directly after a disaster to reduce the impacts and improve recovery.

viii) Resilience/Capacity – The capability of the community to cope with disasters.

Source: Report on the Status of Disaster Risk Reduction in Sub-Saharan Africa Region, 2008.

8.7 References

Burke, J.J. and Moench, M.H. (2000):
Groundwater and Society: Resources, Tensions and Opportunities.
United Nations. Publications, Sales No. E.99.II.A.1, ISBN 92-1-104485-5.

FAO (2003):
Groundwater Management – The Search for Practical Approaches.
Water Reports 25. FAO (Food and Agricultural Organization), ISBN 92-5-104908-4.

FAO (2009):
Irrigation in the middle east region in figures. Aquastat survey 2008.
FAO Water Report 34, Country
Report Saudi Arabia, Food and Agriculture Organization of the United Nations, Rome.

UNEP (2003):
Groundwater and its Susceptibility to Degradation.
UNEP/DEWA, Nairobi.

Ponce V. M., Lohani A. K. & Huston P. T. (1997):
Surface albedo and water resources: Hydroclimatological impact of human activities.
Journal of Hydrologic Engineering, ASCE, Vol. 2, No. 4, October, 197-203.

Web Readings
http://www.eea.europa.eu/publications/92-9167-056-1/page007.html
http://www.greenfacts.org/en/water-resources/l-3/4-effect-human-actions.htm
http://www.lenntech.com/images/gw-sewater-intrusion2.gif
http://psep.cce.cornell.edu/facts-slides-self/facts/gr-wh-hw-grw85.aspx
http://ponce.sdsu.edu/albedo197.html
http://www.sjra.net

8.8 Exercise

Exercise 1

Title: Water Quality Management

Issue:

Mining impact on water quality in the West Rand: Calculation and interpretation

The West Rand area of Johannesburg is one of the largest gold producing regions in South Africa. The area is underlain by quartzites and dolomites. Some of the mines were closed in 1980's and since 2002 acidic mine water is decanting into the environment. Local farmers depend on the dolomitic aquifer for water supply. The discharge of toxic-rich effluent from gold mines and the proximity of slimes dams, tailings and rock dumps can also cause chemical and biological damage to aquatic ecosystems through flooding, clogging, altering streams and wetlands and deposition of radioactive and toxic metals within the drainage of the karst system. The run-off from slimes dams enters the drainage network that feeds into the surface water, karst system and groundwater.

During the mining process, rocks which are situated far below the surface are brought to the surface, where they are crushed and processed. Gold is extracted through chemical processing and the barren material is stored in slimes dams. The crushing and chemical processing expose and mobilize pyrite (FeS_2), a natural sulphur-rich component of the rock that is then exposed to the atmosphere and water. The oxidized sulphates in combination with water and bacterial breakdown produce sulphuric acid that in turn reacts with the rocks and soils to release and mobilize the metals. The acids and metals which are released are found in the rivers and groundwater that is contaminated by the runoff from slimes dams, tailings, rock dumps and mine effluent. This is known as Acid Mine Drainage (AMD).

Question:

Acid mine decant flows downstream into dolomitic terrain in the West Rand. Discharge measurement was undertaken at six stations in two different months (February and August). February is a rainy month, while August is dry. Station P1 exclusively contains acid mine decant and the measured values change downstream. Calculate the seepage rate/amount of acid mine water into dolomitic aquifer. Give possible reasons for the loss, the impact and increase at some stations. Recommend mitigation measures.

Acid mine decent in the West Rand, Johannesburg							
Discharge		**February**	**August**		**Seepage in Feb**	**Seepage in Aug**	
Q (m^3/s)	P1	2.214	1.075				
Q (m^3/s)	P2	1.2177	0.7				
Q (m^3/s)	P3	1.014	0.588				
Q (m^3/s)	P4	0.3	0.28				
Q (m^3/s)	P5	0.9	0.3				
Q (m^3/s)	P6	0.45	0.207				
				Total			m^3/s
				Total			m^3/year

Exercise 2

Purpose: To share experience of groundwater quantity problems.

Activity: Break into groups of 4 or 5.

Each group to (in 1 hour):

a) Identify a common groundwater quantity problem in your country.
b) Discuss the nature and scale of the problem – is it anthropogenic or natural?
c) How is the problem being managed, and who is responsible for the management?
d) What have been the aims of the management and how successful has it been?
e) What would you change to improve management of the problem?

Implemented by

Led by: