MODULE

10

GROUNDWATER AND ENVIRONMENT

CONTENT

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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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Picture: *IGRAC*

GROUNDWATER AND ENVIRONMENT

LEARNING OBJECTIVES

- To understand the link between groundwater and the environment
- To appreciate the main environmental threats that affect groundwater
- To appreciate the impacts that use or abuse of the groundwater resource can have on the environment.
- To understand the interactions between contaminants and aquifers
- To characterize groundwater-dependent ecosystems

10.1 Introduction

Groundwater is that part of the hydrologic cycle that lies below the surface of the Earth. Development of groundwater for various human uses has an impact on the environment. Similarly changes in the surface environment, whether of natural or anthropogenic origin, have the potential to affect the groundwater resource.

- There are two main interactions between the environment and groundwater: one is predicated on flows from the environment into the groundwater system and the other on flows from the groundwater system to the environment.
- The environment interfaces with groundwater by impacting on the recharge quantity and quality. Some of these interactions are entirely natural and others are modified by human activities. For example, various forms of land use and human waste management may result in groundwater contamination. Groundwater recharge may be increased or decreased by natural or human induced changes to the environment.
- Groundwater discharge to the environment occurs at Groundwater Dependent Ecosystems (GDE). A groundwater dependent ecosystem may be defined as a place where the groundwater surface intersects the land surface, giving rise to some form of usually perennial wetland environment. GDEs tend to host an entirely distinct suite of biota, and are generally highly bio-diverse and productive compared to the surrounding dry land. GDEs may arise from a number of different sets of groundwater conditions, giving rise to the differences between different types of GDEs and to their individual signatures. The varieties of GDEs are described in section 4 of this module.

10.2 Surface and groundwater interaction

Surface water and groundwater are linked as components in the hydrologic system. In humid climates, groundwater and surface water are frequently in direct contact, while in arid and semi-arid climates, the link is indirect since they are usually seperated by a thick unsaturated vadose zone. Excessive abstraction from and contamination of either one will in time most likely affect the other. Understanding the basic principles of interactions between surface water and groundwater is important for an effective management of the all water resources.

Water, whether surface or groundwater, flows in the direction of the hydaulic gradient.

Water flows from a high hydraulic head to a low hydraulic head. This fundamental principle governs all water flows. In order to determine the direction of flow, it is necessary to know the head at the either end of the flow path. Once the head dsitribution is know, it is straightforward to determine if flow is from the surface environment into the groundwater or vice versa.

Surface water and groundwater interact at many locations in all watersheds. Groundwater that is recharged from rainfall on upland interfluve areas could be discharged months or years later to streams, lakes, springs and wetlands. On the other hand, surface water that is derived from rainfall/runoff may be lost by seepage through the streambed, soil layer and fractures to mix with groundwater.

Surface water and groundwater interact on different physical scales and over long periods of time. The interactions of significant interest include (1) groundwater discharging as a baseflow to perennial streams throughout the year; (2) groundwater discharge as a source for springs, seeps, and cave systems; (3) streamflow supply of recharge to the groundwater system; (4) groundwater flow into and out of reservoirs, lakes, ponds and lagoons.

The larger-scale hydrologic exchange of groundwater and surface water in any landscape is controlled by: 1) the distribution and magnitude of hydraulic properties (hydraulic conductivity, transmissivity and storativity) 2) the relation of stream stage to the adjacent groundwater level, modified by the aquifer permeability; 3) the geometry and position of the stream channel within the alluvial plain (Woessner 2000); 4) the relative elevation of the water level in stream and groundwater table; and 5) climatic setting: high rainfall region favours abundant recharge into aquifers and rapid groundwater level fluctuation.

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What type of surface and groundwater interaction processes are you aware of in any of the catchments in your area? List the types and identify the links?

10.3 Groundwater Contamination

Any developmental activity (urbanization, industrial activity, mining and agriculture) by humans has an impact on both surface water and groundwater.

Surface water and groundwater both originate as precipitation. However, from the moment that precipitation reaches the soil and begins to infiltrate en route to becoming groundwater, its composition begins to change. Water that infiltrates into soils and rocks attain different water quality characteristics than the original preciptation water, and from the surface water component that does not infiltrate into the ground. On the other hand, surface water is open to contamination at the surface by waste mateirals and bacteria. Thus surface and groundwater tend to have different bio-chemical compositions. When they interact, the biochemistry of the resulting water is a product of the biochemistry of the two water sources.

Urbanization: Urbanization with large population concentrations in localized areas significantly increases the pollution load due to sewage discharge and solid waste disposal and hence risk of groundwater pollution. Urban populations generate huge volumes of sewage and discard vast volumes of solid and liquid waste every day containing plastics, chemicals, grease and oil, metals, glass, paper, organic wastes etc. Lack of water borne sewerage systems in most urban centres in Africa also forces people to use pit latrines and/or dispose untreated sewage into water bodies. This then creates a huge diffuse pollution of the groundwater system. Sewage contains salts, bacteria, phosphorus and many other chemicals. Overland flow from streets and buildings also carries pollutants such as bacteria, oil, and chemicals that can enter into the groundwater.

Urbanization also brings with it waste treatment and disposal sites such as solid waste landfill sites and sewage treatment plants. These point sources of pollution are sites where potentially there are concentrations of pollution entering the groundwater.

Industrial activity: Uncontrolled disposal of industrial effluent has a tremendous impact on groundwater especially from chemical and nuclear wastes. Industrial wastes are generated during manufacturing processes. Industrial wastes may be toxic, corrosive or reactive. Some examples are: oils, solvents, chemicals, radio active wastes, scrap metals and many others. If improperly managed, these wastes can pose dangerous consequences through pollution of groundwater upon which people depend. Waste water from manufacturing or chemical processes in industries contributes a lot to the groundwater pollution. Most large scale industries have treatment facilities but many small scale industries do not.

Mining: Prospecting and developing mineral and energy resources in Africa involve activities with the potential to significantly affect both the quantity and quality of groundwater resource associated with those areas.

Chemical pollution is often associated with mining. The main pollutant in both active and abandoned mining areas is acid mine drainage which is rich in heavy metals. Oxidation of sulphide minerals, such as pyrite, produces highly acidic water which then dissolves heavy metals and carries them into the aquatic environment, including the groundwater.

Dewatering of underground workings is a normal component of all mining. Dewatering around mine areas will significantly lower the water table, affecting surface water flows and drying out shallow aquifers. At a local scale, there may be water shortages for communities due to drying up of surface water bodies (streams, rivers, ponds, wetlands, lakes) and springs.

The impacts from mining can last for many decades. As a result, environmental impact assessment, environmental monitoring, contingency planning and financial assurance have to be in place for management. Geochemical conditions within the ore body, waste rock, and tailings can change over time and must be tracked. Flexibility, therefore, is needed to make necessary changes in water control and water treatment after mine closure.

Active management of the mine site and water management may be necessary for years or even decades after closure, depending on the type of mine, the size and nature of the area of disturbance, and the type of ore processing used. Permanent closure routinely includes some or all of the following: removal/disposal of chemicals; structure demolition; removal of unnecessary roadways and ditches; waste detoxification; capping of tailings and waste rock; backfilling pits; and active water management, including assuring that all applicable water-quality standards are met. In numerous cases, this has meant operating and maintaining a water-treatment facility in order to remove toxic chemicals. At sites where acid mine drainage is a problem, post-closure water treatment is necessary for several years, and in some cases, permanently.

Agriculture: Farming has direct and indirect impacts on groundwater quality. Direct impacts include dissolution and transport of excess quantities of fertilizers, pesticides, herbicides, antibiotics, hormones and associated materials and hydrologic alterations related to irrigation and drainage. Indirect impacts include changes in water–rock interactions in soils and aquifers caused by increased concentration of major ions and metals. Many studies indicate that agricultural practices have resulted in nitrate (NO3–) and pesticide contamination of groundwater with localized concentrations in shallow aquifers.

Sustainable agriculture is one of the greatest challenges to attain in the fast developing economies in Africa. According to FAO, sustainability implies that agriculture not only secures a food supply, but that its environmental, socio-economic and human health impacts are recognized and accounted for within national development plans. However, this is not priority in poor areas due to the attention to attain food security.

The potential groundwater contaminants due to agricultural activity are:

Nutrients: The risk of nutrients such as nitrogen and phosphorus reaching groundwater depends on the nutrient application method and extent, type of plantation and the type of soil. Phosphorus is not very soluble in water and rarely reaches groundwater except in highly permeable soil. In contrast, nitrogen is water soluble and rapidly converts to nitrate, which can contaminate groundwater unless it is used up by plants. High nitrate levels can lead to euthrophication of water bodies.

Pesticides are most likely to leach through sandy soils that contain little organic matter. Pesticide absorption and breakdown is inefficient in sandy soils with little organic matter because there are fewer microbes, and leaching can be rapid through the large soil pores. Since pesticides are designed to kill pests, excessive use will have far-reaching impact on people who consume groundwater underlying agricultural areas.

Microorganisms live in animal and human intestinal tracts and are excreted in faeces and manure. When they reach surface water, they can cause disease in humans and livestock. Groundwater is largely protected from such contamination because of the physical (filtration), chemical (adsorption) and biological (natural die-off) processes.

10.4 Groundwater-dependent ecosystems (GDEs)

Groundwater-dependent ecosystems (GDEs) vary from being marginally or only occasionally dependent on groundwater to being entirely groundwater dependent.

GDEs are communities of plants, animals and other organisms whose extent and life processes depend on groundwater. The following are some ecosystems that may depend on groundwater:

- Riverine environements where baseflow discharge maintains perennial streamflow.
- Wetlands in areas of groundwater discharge or shallow water table
- Terrestrial vegetation and fauna, in areas with a shallow water table or in riparian zones along streams/ rivers
- Aquatic ecosystems in groundwater-fed streams and lakes
- Karst systems
- Springs
- Estuarine and near-shore marine ecosystems

Threatening activities to GDEs:

The major threatening activities are:

- extensive groundwater resource development
- changes in land use – particularly change from indigenous vegetation to agricultural land
- agricultural development and expansion
- dewatering and acid mine decant associated with mining
- river diversion and daming
- commercial, urban or recreational developments.

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What are some of the threatening activities on GDEs in your watershed?

These activities have potential to alter the groundwater levels and the water quality enjoyed by GDEs. GDEs are, to a significant extent, reliant on groundwater and those that occupy a very narrow ecological range and those in arid and semi arid areas could be completely eliminated by even relatively small changes in water regime or water quality. In dry seasons, especially in less humid and semi-arid areas in Africa, the base flow of rivers is maintained entirely from groundwater. This makes management of this groundwater very important for both human and environment where wildlife, flora and people depend on surface water availability.

Many GDEs exist in environments that have been modified by human activity. Some have come into existence due to human activities, such as wetlands that may occur downstream of sewage treatment plants or mine decant sites. Others have dried up as a result of one or more threatening activities indicated above.

Some GDEs are vulnerable to slight groundwater declines due to excessive use and / or a decrease in recharge. Groundwater extraction by humans can lower groundwater levels in unconfined aquifers and the piezometric head in confined aquifers. The result can be alteration of the timing, availability, and volume of groundwater flow to GDEs.

Some of the planning and coordinated implementation methodologies that are appropriate to minimize adverse impacts on GDEs ecosystems are (1) maintaining natural patterns of recharge and discharge; (2) minimizing disruption to groundwater levels that are critical for ecosystems; (3) protecting groundwater quality by preventing the addition of toxic contaminants; and (4) rehabilitating degraded groundwater systems where possible.

Environmental flows

Environmental flows are the quantity and timing of surface and ground water flows required to maintain the components, functions, processes and resilience of aquatic ecosystems and the services they provide to people. Environmental flows are intended to mimic the patterns and ecological outcomes of the natural flow regime. In order to maintain a healthy environmental flow, coordinated management of surface water and groundwater is essential. There are flexible and iterative frameworks that can help in the environmental flow assessment in a given river basin. The following framework includes three levels of assessment: 1) Comprehensive hydrologic assessment: desk top and field (identifying hydrologic indicators, ecological limits of hydrological alterations); 2) Scientific interpretation of the processes and impacts: focus group discussion; and 3) examining trade-offs and prediction of impacts and recommendations.

Even though environmental flow assessment focuses on river water, the management solution will surely address sustainable use of groundwater in order to maintain base flow to streams.

Some goals for the management of GDE’s are suggested below:

- Manage GDEs to satisfy various legal mandates, including, but not limited to, those associated with floodplains, wetlands, water quality and quantity, acid mine drainage and decant, endangered species, and cultural areas.
- Manage GDEs under the principles of IWRM, while emphasizing protection and improvement of groundwater.
- Delineate and evaluate both groundwater and GDEs before implementing any project potentially adversely affecting the resources. Determine geographic boundaries of GDEs based on site-specific characteristics of water, geology, flora, and fauna.

- Establish maximum limits to which water levels can be drawn down at a specified distance from a GDE in order to protect the character and function of that ecosystem.
- During borehole development, establish a minimum distance from a connected river, stream, wetland

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What measures would you recommend?

10.5 Groundwater over-abstraction

Groundwater depletion is the inevitable and natural consequence of withdrawing water from an aquifer. Groundwater over-abstraction has a potential to affect the water balance in catchments of rivers and wetlands in hydraulic connection with groundwater and may lead to reductions in baseflow. However, 'over abstraction' is a value judgement. How much is 'over abstraction'? Over abstraction may be considered to occur if there are any irreversible impacts on the aquifer. Of course by this stage, it is already too late because permanent environmental damage has already taken place. Over abstraction might be considered to occur when the benefits of groundwater abstractions are overshadowed by the negative impacts arising from reduction to baseflow and spring flow.

Granting licenses for groundwater abstraction in sensitive areas requires comprehensive understanding of the interrelationship of the surface water and groundwater bodies. Such information will not be readily achieved without a suitably designed monitoring system and a good time series of data to assist in assessing this interrelationship, which may then be used as a basis for adjusting abstraction limits.

The response of the aquifers to over-pumping depends on characteristics of the aquifer, such as aquifer transmissivity and specific yield (if unconfined) or storativity (if confined) and the rate of recharge. Confined or leaky aquifers will show the most rapid and most significant head response to pumping and this can induce the most significant head differences and fluxes at a river. Land subsidence adjacent to developed aquifers can result from fluid pressure declines because of groundwater withdrawals.

It is important to be flexible when developing management solutions to such environmental challenges. Conserving groundwater by reducing pumping can be accomplished through administrative, legislative, or management controls, including economic incentives to reduce demand. It is important to target reductions that actually save water. In agricultural areas, for example, improved efficiency is sometimes sought through lining irrigation canals to reduce seepage. While this saves irrigation water, it also reduces return flows to the groundwater. A more effective strategy might be to plant a different crop that uses less water.

Conjunctive management of surface water and groundwater could help to reduce the pressure on both resources. Conjunctive management of surface and groundwater may be predicated on the feature that surface water abstraction, daming, diversion etc. have very significant upstream / downstream impacts. With groundwater abstraction, the impacts are centred around the abstraction points with much less significant upstream / downstream effects. Optimization methods may be used to position pumping centers to maximize withdrawals while minimizing upstream / downstream detrimental effects such as stream baseflow depletion. This may lead future water managers to implement appropriation zoning or to require well permits in which allowable pumping rates vary with location because of hydrogeological properties, distance from boundaries, and unit responses of surface water.

Reallocation between also economic sectors provides opportunities to optimize conjunctive use. For example potable groundwater resources may be substitued for untreated surface water, which may then be directed to irrigation demand.

10.6 Environmental aspects of groundwater management

Groundwater management is an important part of water resources management in order to sustain the livelihood of vast rural populations, rapidly growing urbanization, irrigation and industrial activity. The three main considerations for environmentally sound groundwater management are the following:

(i) Groundwater development must be sustainable on a long-term basis. This means that the rate of abstraction should be equal to or less than the rate of recharge. If the rate of abstraction is higher than the rate of recharge, it will result in groundwater mining, which may be carefully considered for some specific cases. If mining occurs, groundwater levels will continue to decline, which will steadily increase pumping costs, and then at a certain level it would no longer be economic to pump it for many uses such as agricultural production.

(ii) Human activities which could impair the quality of groundwater for potential future use should be controlled. This would include leaching of chemicals like nitrates and phosphates from extensive and intensive agricultural activities, contamination by toxic and other undesirable chemicals from landfills and other environmentally unsound waste disposal practices, bacterial and viral contamination due to inadequate sewage treatment and wastewater disposal practices, and increasing salinity content due to inefficient or improper irrigation practices, and salinization due to overpumping in coastal areas.

(iii) Improper groundwater management often contributes to other adverse environmental impacts such as dessication of wetlands, decrease in baseflow etc.

Environmental impact assessments may be considered to be as a planning tool to assist planners in anticipating potential future impacts of alternative groundwater development activities, both beneficial and adverse, with a view to selecting the ‘optimal’ alternative which maximizes beneficial effects and mitigates adverse impacts on the environment. It can be used not only for groundwater development projects but also for plans, programmes and policies (Biswas, 1992).

10.7 The role of basin organizations in environmental management of groundwater.

What are the roles that basin organizations can assume to make sure that the groundwater management carried out is sensitive to environmental needs?

Water availability:
This module has discussed the impact of groundwater abstraction on baseflow and on groundwater dependent ecosystems. BO's may carry out river hydrograph analyses to determine how much of total river flow in the catchment may be attributed to baseflow. Comparisons between river flow in areas with heavy groundwater use and similar rivers in areas without groundwater abstraction can provide some answers. However monitoring of both groundwater pumping, time series of groundwater levels and river stage levels will be essential to manage these interactions. Without data, such management becomes just guess work, and can have a negative economic impact without providing any benefits to river flow.

BO's may carry out an inventory of groundwater dependent ecosystems and quantify their economic and environmental value. If such ecosystems are potentially threatened by groundwater resource development or changes in land use, then the BO may institute monitoring and issue groundwater abstraction permits of short duration with regular review. A priority ranking system can be helpful to ensure the most vulnerable and the most valuable GDEs are protected. GDE's may start to change in unacceptable ways long before complete dessication, and thresholds for such changes need to be understood and defended.

BOs should also assess the economic and environmental value of maintaining baseflow. Groundwater that discharges as baseflow has significant downstream impacts, a factor that needs to be considered when allocating permits to abstract groundwater.

10.8 References & Further reading

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Web resources:
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