What can karstic organisms tell us about groundwater functioning and water quality?

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Abstract

Karst groundwater is an incredible natural resource. It provides drinking water for many of our residents, beautiful springs to feed our waterways and habitat for many unusual underground species. The quality of the groundwater is dependent upon how we use the land and how well we protect the quality of groundwater recharge.

Karst groundwater systems provide habitat for many fascinating animals. Most of the food for cave animals is washed in through discrete recharge zones. As a result, cave fauna is commonly concentrated around the points where these discrete recharge zones connect to caves. Some groundwater recharge seeps and oozes through the subsurface, and in so doing receives fairly good natural cleansing; the fauna is dominated by obligate cave dwelling. Other groundwater recharge occurs through a vast network of localized openings that are able to rapidly transport both water and contaminants; the fauna is especially composed of facultative cave-dweller or evenly accidental fauna.

Losing stream valleys are important groundwater recharge zones in the Middle-Atlas. Although valley areas represent about 10 percent of the land area, they are responsible for about 40 percent of the groundwater recharge to karst groundwater systems. Protection of water quality in these valleys is critical for protection of groundwater quality in wells and springs.

The groundwater fauna is generally ignored in the evaluation of global biodiversity. It is important from four points of views we aimed to demonstrate. It includes a part of regional biodiversity and natural patrimony; its local variations may indicate changes in water quality and biodiversity can be used for groundwater monitoring.

Cave and Well fauna from different parts of North Africa showed clear relationships between reduced biodiversity and level of water quality. Industries, mining, cattle farms and ranches are potential pollution sources, and fertilizer and pesticide use threatens the local water supply in many areas. Though poorly considered by public agencies, groundwater animal species have a potential scientific, practical and educational value. They may have good potential value to humans as “indicator species” since the decline of sensitive species number due to pests or pollution may be a natural alarm for regulators and public health agencies.

These contaminants can also affect people. Another unique feature of karst groundwater systems is that water entering the subsurface at a single point may sometimes discharge from multiple springs and wells. The discharge points are sometimes in different stream or river basins and may be separated from one another by a number of miles. Such complex flow systems help explain the relatively large ranges for some aquatic cave species.

Keywords: Karst, groundwater, recharge/discharge areas, biodiversity, resilience, management

Introduction

For a long time the study of the ecological environment represented by the underground water in the karstic massifs has been limited to the lotic or lentic water masses in the cave because only these were directly accessible. Research carried out in these habitats has led the ecologists to recognize discontinuous populations, not very dense, mostly monospecific, dominated by the oldest age-groups, and to describe this as an environment with an interspecific competition and predation of low intensity. These observations, although they are accurate and give an account of aquatic life in caves, cannot be considered representative for life within the karst massif (Rouch, 1986).

Changes in water karst system are difficult to understand with simple cause-effect relationships because of the intense and complex linkages also sometimes lead to abrupt changes in water system such as loss of biodiversity, the exceedence of safe water supply in urban areas and groundwater contamination. The surface and subsurface aquatic systems interact in various ways. A wide range of
contacts exist between the two environments. Within this diversity in mind four major characteristics of these ecotones emerge: 1) their elasticity in space and time, 2) their permeability to fluxes, 3) their frequent intermediate biodiversity and 4) their connectivity (Gibert et al. 1990).

Karst aquifers are hydrodynamic systems with heterogeneous structure. Various research methods are applied to define their characteristics. Very important are different analyses of karst springs which reflect the functioning of the whole system. Also the study of the recharge-discharge relations can give some further information about the characteristics of the flow and the storage in karst systems.

**Origin and derivation of troglobites**

Obligate cave organisms had lost features useful on the surface, including eyes, pigmentation and wings, but gained others that helped them cope with cave life, such as flattened, flexible bodies for squeezing through tight spaces, and well-developed senses for finding food in the dark. Aquatic troglobites (stygobionts) may be derived from marine, brakish or freshwater ancestors, depending on the environmental conditions under which the founding populations were living at the time of invasion of subterranean waters. Invasion of subterranean groundwater by organisms through active upstream migration into caves from spring resurgences, and passive introduction of organisms into subterranean waters when surface streams in which they dwell are captured through sinkholes into underground channels, have been discussed in detail (Mitchell et al., 1977; Culver, 1982; Sweet, 1982; Barr and Holsinger, 1985; Wilkens and Hüppop, 1986; Holsinger, 1988, 1994; Holsinger and Culver, 1988; Culver et al., 1995).

There have been two different approaches to the study of the distribution of cave organisms. The historical approach concentrates on the factors responsible for invasion and isolation of organisms in subterranean environment, such as the warming and drying associated with climatic changes, and the subsequent movements of cave organisms. The island biogeographic approach concentrates on the potential analogy between caves and islands, emphasizing the dynamics of migration and extinction (Culver, 1982).

**The karst system: structural and functional aspects**

Within caves a diverse biota may be found, exhibiting varying degrees of adaptation to the subterranean environment. Accidental species, which fall, wander, or are washed into caves, do not linger long in this environment. These animals either return to the surface, or die in the caves where they provide an important source of nutrients for the cave community. Trogloxenes occur commonly in caves, but must leave the cave at some point in their life cycle, typically for feeding. Species which occur in caves and can complete their entire life cycle there, but which are also found in similar habitats above ground, are referred to as troglophiles. And finally, troglobites are those species which are obligate cave dwellers adapted so completely to caves that they are restricted to this environment.

To confuse matters further, the current trend is to use the prefix 'troglo' with reference only to terrestrial fauna, and the prefix 'styro' for aquatic species (named after the river Styx, which in ancient Greek myth carries the souls of the dead to Hades). Thus, for aquatic species, trogloxene becomes stygoxene, troglophile becomes stygophile, and troglobite becomes stygobite.

Terrestrial habitats are often damp, but a few Moroccan caves, especially those with large entrances that face the west, may be very dry. Typical terrestrial habitats include flood debris (including logs, twigs and leaves from the surface), animal feces (often from bats) clay floors, rocky floors, and bedrock walls and ceilings. The predominant aquatic habitats in Chaara (Middle Atlas) are found in cave stream. Streams typically include shallow, fast flowing rocky sections, riffles, and slower moving, often silt-bottomed pools. Different animal species are dominant in these different parts of the stream.

Drip pools, sometimes found beneath active formations away from the cave stream, are another kind of aquatic habitat, where species typically found in narrow spaces in the bedrock and soil above may sometimes be found.

**Input to hypogean environment**

The number and size of openings strongly influence all epigean inputs, whether abiotic or biotic, to the hypogean environment. Curl (1966) has estimated that as few as five percent of limestone caves in temperate zones have “entrances” large enough to admit humans and flying bats. Many more caves have openings large enough for small trogloxenes such as squirrels, salamanders and crickets. But most have openings only large enough for bacteria and recalcitrant dissolved organic matter carried by flowing and seeping water.
Poulson and Lavoie (2000) have shown how organic matter gets into the hypogean environment, why it usually supports communities with low species diversity, and why it supports terrestrial communities of higher diversity than aquatic communities.

Cave ecosystems that depend on concentrated and episodic input of high amounts of relatively unleached particulate organic matter have a moderate number of troglobitic species. Some species can attain high densities in rocky streams with near-yearly renewal of input by sinking streams. Examples are the Gammarus sp in caves of the Middle Atlas.

Compared to aquatic habitats, terrestrial habitats have less leached particulate organic matter and higher species diversity. Partly leached leaf and twig litter deposited by flood irregular intervals in terrestrial habitats has some successional heterogeneity of species. In several karst regions of Morocco such flood-deposited leaf and twig debris supports oligochaetes and millipedes as the consumers with highest frequency, density and body size.

Colonization of karstic underground water is achieved by epigean forms in several places (springs, beds of perched, effluent or influent stream, and sinkholes) during low-water and high-water periods. However, highest input of epigean organisms into karst aquifers probably occurs during flood events through the sinking of surface streams. There is a massive migration of a high diverse epigean fauna at point inlets that are often directly connected to the drainage network. For example, drifting fauna at the main outlet of the Chaara karst system (Middle Atlas), must be partially fed by surface water of a sinking stream, include many insect larvae belonging to Plecoptera, Ephemeroptera, Diptera, Coleoptera and Hemiptera. Most epigean invertebrates do not pass from sinkholes to springs; rather they are trapped withing the aquifer. However, they do not survive in the aquifer and probably constitute a significant source of food for the autochthonous.

Fluxes of water, organisms and organic matter entering the subterranean environment show quantitative and qualitative temporal change. Therefore, in spite of the ecological inertia of the subterranean environment, epigean seasonal rhythms can influence the biological cycle of many stygobitic organisms.

Recent study (Datry et al 2005) showed that density and richness of invertebrate assemblages were higher at recharge sites for vadoze zone thickness < 10m. However, despite a strong increase in spatio-temporal variability at recharge sites with a vadoze zone thickness > 10m, density and richness were not different from reference sites. These results provided strong evidences that organic matter supply, rather than heterogeneity, was the primary driver of biodiversity in groundwater.

**Effect of floods**

The particular geological, hydrogeological and geomorphological setting of most of karst areas in the High Atlas mountains of Morocco cause them to be very vulnerable to hydrological extremes, in particular floods. Geological boundaries between limestone and basalt, steep landslide and debris flow prone slopes, coarsegrained, highly porous river beds, large subsurface reservoirs with high potential discharge rates and infrequent, high intensity rainfall or snow-melt cause these karst areas to be subject to a particularly high flood risk. Flood waves usually only develop after a long lag time due to the high infiltration and storage potential of channel beds and interflow areas such as scree slopes. Extensive scree slopes are a product of high weathering rates of limestone under both conditions of extreme temperatures, low humidity and frequent freeze-thaw cycles. In addition, agriculture and land use change have degraded the karst areas.

The karst groundwater reservoirs are very extensive and largely unknown in dimension, yet a large percentage (approx. estimated 70%) of surface water is directly lost to these. Especially after long lasting rainfall or extreme snow melt events, rapid discharge emerges from the karst aquifers. Once intermediary reservoirs such as scree slopes or river beds are filled, discharge emerging at the surface develops into sharp and short duration flood waves. After cessation of rainfall, the flood peaks diminish very rapidly again as the water rapidly infiltrates back into these interflow areas and the deeper karst reservoirs. In the northern Oulilimt catchment, there are large karst springs that emerge from the very steep and long sheets of limestone. They join to form larger rivers that are also fed by snowmelt. Under such circumstances, flood peaks can be augmented very rapidly (de Jong et al 2006).

Responses of aquatic communities to floods have been studied. During low-water period, subsurface water bodies undergo fragmentation and spatial reduction. The absence of surface-water inputs results in a poor connection between water bodies of the saturated zone (cave water or epikarstic aquifer) and groundwater. As groundwater drainage proceeds, hydraulic connections between regions of the saturated zone also become weaker. Such a low connectivity is partially observed in karst communities; as biological communities become isolated they respond increasingly to locally unique ecological factors.
Output of organisms

Springs are a natural source of groundwater discharge at a rate high enough to form a channel on the earth's surface. The physical and chemical composition of spring water reflects not only the mineral composition of the various rock strata with which the water has been in contact, but also the various chemicals that percolate into ground water. Even though springs provide a unique interface between ground water and surface water, they have only recently become a focal point of research.

Animal drift at the outlet of karst systems has been well studied by several authors (Rouch, 1970; Gibert and Laurant, 1982; Turquin, 1986; Vervier and Gibert, 1991). Drift involves epigean and hypogean invertebrates. Karst ecosystems lose a large number of organisms during floods. Aquatic fauna isolated in different habitats with no interconnections during low-water periods are likely to be in climax in a climax stage. During floods, increases in biological flux between these habitats modify, at least temporarily. The community structure characterizing this climatic stage; in the short term, therefore, floods maintain karst communities in a state of dynamic equilibrium. Finally, although the effect of floods in karst systems may seem comparable with those observed in river flood plains (Ward and Stanford, 1995), there exists at least one major difference: floods do not modify the structural characteristics of karstic milieu.

Along with their associated seeps and outflow brooks, springs provide a unique habitat for endemic species (organisms restricted to a localized area) of animals and plants because they usually provide a nearly constant physical and chemical environment. Until recently, little emphasis in Morocco had been given to the study of springs, particularly from the perspective of species richness and endemism in relation to water quality. Past studies of springs generally focused on a selected taxonomic group, but provided minimal water quality information other than water temperature, dissolved oxygen, hydrogen ion concentration (as pH) and alkalinity. Aquatic macroinvertebrates of temperate, cold water areas are dominated by either a non-insectan community (Turbellaria, Annelida, Amphipoda, Isopoda, Gastropoda) or an aquatic insect community (Odonata, Ephemeroptera, Plecoptera, aquatic Diptera, Trichoptera, and aquatic Coleoptera).

Human alteration of karst communities

Karstic groundwater is the major water source in Morocco, and had a major influence on the Moroccan culture. Farms and cattle ranches are a potential source of pollution, and use of fertilizers and pesticides threatens the local water supply in some areas. Solid waste is often dumped at the edges of towns or discarded into dry caves.

The most important driving forces for degradation include permanent over-grazing even during droughts and the use of firewood by a continually growing population. Large scale degradation of natural vegetation has occurred mainly in the oro-Mediterranean zone, i.e. between 2600 - 3400 m where there has been a particular decrease in the density of perennial grasses with a succession of cushion shrubs.

The combination of this degradation and deforestation in the higher zones has resulted in unimpeded erosion and the development of fast discharges on the highly exposed slopes, which in turn has increased the production of scree slopes and fluvial source material. Caves provide unique, productive and extensive field sites, because they allow direct observation and mapping of underground features and their relation to the surface and to groundwater flow. Furthermore, their origin, morphology and distribution patterns are the dominant factors in controlling the nature of the overlying land surface (e.g. distribution of sinkholes) and the directions of groundwater movement. Wells, borings and quarries are less useful as monitoring sites, because they provide only discontinuous points of information.

Karst processes are naturally occurring. They can be influenced by human activities such as land-use modification, waste disposal, and opening or blocking of cave entrances, all of which can substantially affect sedimentation, speleothem deposition and groundwater quality over the short term. These modification began several thousand years ago with deforestation and creation of pastures. In semiarid and arid lands, high rainfall intensities often are combined with high infiltration capacities of the rock.

Even if deforestation may have variable effects on soil erosion, water table elevation etc., it is always reduces water retention capacity of the catchment. Human impacts, which follow deforestation, accelerate erosion and transport of particulate matter out of the catchment through increased grazing pressure, the introduction of arable farming and irrigation. In semiarid region and other sensitive areas, these activities may easily lead to complete breakdown of soil structure and desertification of waste areas.
The experiment shows how rapidly caves and springs respond to surface runoff that enters the groundwater system through discrete recharge zones. Because intense rainstorms can cause rapid and lethal flash floods on cave streams, and water may totally fill passages, people should give careful consideration to the weather before entering caves.

Developing a Biotic Index for Subterranean Ecosystems

In general, moderate nutrient pollution results in a loss of biodiversity and an increase in the standing crop. In Cave Springs and wells, which may be impacted by both septic and animal waste, the *Metacrangonyx* well amphipods have apparently disappeared while the *Typhlocirolana* well isopods are numerous. The different pollution tolerances of amphipods and isopods could be useful in biomonitoring. Alternatively, the ratio between epigean and hypogean fauna in wells could be used as an indicator of ground water quality. *Danielopol and Roux, (1991)* found that in polluted, unprotected wells, where organic matter inputs and pumping rates are high, the fauna were epigean, cosmopolitan and more abundant than in protected wells, with lower organic inputs and pumping rates, where the fauna were primarily hypogean. This study will determine whether differences exist in the community structure of disturbed and undisturbed cave habitats, and an index of biotic integrity for cave ecosystems will be designed and tested using community structure factors such as alpha diversity, abundance and diversity of epigean and hypogean invertebrates, and nutrient inputs/trophic status.

Stygofauna and global changes

Karst responds with great sensitivity to environmental changes, and karst features (especially speleothems) contain many clues to past climatic and hydrological events and changes at a variety of time scales. Biological composant may also furnish great information. For instance, a stygobite amphipod (*Crangonyx africanus*) was recently recorded from a karstic area of Guelmim region (western Morocco). This marks the first record of freshwater subterranean Crangonyctidae in Africa. Other species of the genus are recorded from subterranean waters from Europe and Asia. Subterranean Crangonyx amphipods are believed to be limnocoide freshwater stygobionts, i.e derived from ancestors that lived first in epigean freshwaters and subsequently invaded and colonized subterranean freshwaters. The new record confirms the ancient origin of the family Crangonyctidae and especially of the genus *Crangonyx* which apparently originated and spread on the Pangea land mass prior to the separation of the Gondwana and the Laurasia by the Tethys Ocean rather than being a Laurasian group as stressed by many authors before.

The presence of troglobites and especially the subterranean isopod *Magnezia gardei* in Kehf aziza (sub-Saharan of Morocco) is astonishing. On the surface the landscape is harsh and dry. You wouldn’t think it was a hotspot for subterranean life. These ancient creatures must have colonised the underworld long before the Aziza cave had formed. We have no idea when or why they went. But whatever the reason, they must have gone underground somewhere else and moved in as the cave became available. That is strong evidence that the cave has never gone dry out since then.

The stygobiologists are making headway with some bigger questions about when and why these animals left the outside world and headed the underground. This circumstantial evidence to support the conviction that the spread of aridity that began in the Miocene was the main driving force: where stygobites have surface relatives in Morocco, they are confined to the wetter regions of the country, and where it is wet there are no subterranean species. As rivers began to dry, their faunas would have sought refuge in the waterlogged sands and gravels of the riverbed, where they adapted to life in the spaces between stones or sand grains. And when even that water disappeared, they went deeper, into the underlying groundwater, and some found their way into caves. Isolated in separated caves, they began to diverge, eventually evolving into the array of species living there today. There some surface organisms, such as *Proasellus*, many gammaridae, gastropoda and shrimps that seem to be going down this route even now. They live in sandy gravels of spring or alongside streams that dry out in summer, and show early signs of adapting to life below ground. In general areas experiencing global change and sensitive to climatic changes show a high animal tendency to colonize the underground.

The apparent lack of troglobites on most Moroccan caves appears to be correlated rather with the functioning of the karst than with the history of the region. In fact more than 90 % of Moroccan subterranean stygobites were collected in non karstic areas. Turbulent quickflows could have caused the extinction of any cave-adapted species that may have inhabited cave streams. In fact he identification of the turbidity mechanisms in two karstic springs (Ribaa and Bittit) located in the Middle...
Atlas Plateau in Morocco was performed by means of correlation and spectral analyses applied to time series of rainfall, flow rates, and turbidity. Time series analyses of rainfall and discharges revealed high inertia and storage capacities of the karstic systems. However, the occurrence of turbidity in the springs proved independent of discharges. Accordingly, turbidity was assumed to be related to the hydrodynamic conditions prevailing in the karst. Turbulent quickflows in the karst transmissive conduits, following heavy rainfall, are thought to provoke the resuspension of solid particles deposited in the conduits, as well as their transport towards outlets. An external origin has also been contemplated, concerning infiltration waters may be loaded with suspended matters washed from the watershed. (Amraoui et al. 2003)

Integrated conservation

Of all the natural habitats, underground habitats are undoubtedly the least known and probably the worst treated. Because of the extreme isolation, uniqueness, and harsh conditions of the cave environment, many of the species which occur here, especially obligate cavernicoles, are rare. Several merits threatened or endangered species status at the state or global level, or are stenoendemic to a small geographic area. In addition to providing a habitat for such forms of life as these, the karst underground system, with its caverns, underground rivers, and limestone aquifers, invariably displays interesting physical features as well as being of geological, mineralogical, geomorphological, and even archaeological interest.

It must be borne in mind that our knowledge of the fauna of underground's habitats is still only fragmentary, with a few notable exceptions. The state of underground environment and the importance of underground sites, habitats, and faunal species, vary considerably from region to region. For instance, mountainous karst territory far from any source of industrial or urban pollution is obviously better preserved than the cultivated karstic regions dotted with towns and villages, which are subject to intense human pressures.

Where underground waters are concerned, karstic ground-water, alluvial water-bodies, and underflows, are frequent victims today in many parts of the World of occasional or diffuse pollution by chemicals and Bacteria. The many practices that are responsible for pollution, such as direct discharges into crevices and the use of shallow-holes and former limestone quarries as dumps, are carried on today—most of the time in complete ignorance of the damage they cause to underground water, sites, and ecosystems. The same is true of water-regime modifications in karst territory and the consequences of river engineering works and streamflow regulation for the interstitial habitats associated with the underflow. Underground sites may also be threatened by quarrying operations, road building, or other infrastructure projects. Then again, far too many caves are damaged or otherwise adversely affected by non sustainable tourism, overcrowding, or vandalism.

Present Land Uses and Management

A management strategy of recharge area delineation and vulnerability mapping is recommended. The recharge area for a cave or spring is the area that contributes water to the cave or spring. In some cases the recharge area is little more than the land that overlies the cave. However, in many cases (and especially when the cave contains streams or lakes) the recharge area may be very large. Groundwater fauna may be a useful tool for recharge area delineation.

Vulnerability mapping is a land management tool that has been used effectively in a number of karst areas. It utilizes the fact that some lands in a karst area create appreciably greater groundwater contamination risks than other lands. Recharge area delineation, in concert with vulnerability mapping, is appropriate and necessary for sound land management in the karst of the study area. Such delineation and mapping will help insure that land use and land management actions in karst portions of the study area are appropriately tailored to site conditions. The study reached the following conclusions:

1. Karst attributes of national and international scale significance are being degraded by wood harvesting, pastoral activities; road location, construction, and operation;
2. Resource management in the study area must be conducted with adequate recognition of the area and its associated ecosystems;
3. Cave resource protection actions by the Forest Service have been laudable, but have commonly not provided adequate protection for cave features;
4. Management of karstlands should involve four key components: (i) inventories of karst features, (ii) recharge area delineations, (iii) vulnerability mapping, and (iv) incorporation of results from items (i) through (iii) into planning and land management decisions. It is well established that logging activities result in increased erosion and resulting sediment transport by runoff waters. There are dramatic differences in sediment transport conditions between karst areas and nonkarst areas.

In nonkarst portions of the study area sediment must move laterally to a stream, and then flow down the stream. Management efforts are made to protect riparian corridors from logging and its impacts. The large amounts of slash and cull materials remaining on the ground after logging, plus the heavy moss growths on the ground prior to logging, help trap and retain substantial amounts of the sediment. Vegetation can rapidly become established on trapped sediments. Karst areas transport sediment differently from nonkarst areas. The most important difference is that in many karst portions of the study area much of the sediment must move laterally for only a few feet before it is directly transported downward into conduit portions of the karst groundwater system. Once sediment is into the conduits there are no effective natural processes for trapping and retaining it within the system; as a result, it is delivered to a receiving spring or stream.

Features of the epikarst have previously been described. Areas with deep and well-developed epikarst have more closely spaced near-surface openings into which sediments can be flushed than is the case in areas with only shallow epikarst. As a result, sediment transport potential is typically much greater in areas underlain by deep and well-developed epikarst. The transport of suspended organic materials is similar to that for sediment. This is especially true for suspended organic material introduced into the karst groundwater system because of rapid subsurface travel rates and cold underground temperatures. Dissolved organic matter often creates foam at points where the water flow is particularly turbulent. Large amounts of foam attributable to dissolved organic matter are found in many of the stream caves of the study area; distinct lines of foam indicating peak flow elevations are often seen in such caves.

The potential impacts upon receiving streams of sediment and organic matter derived from logging activities in karst areas requires very careful management attention. The location of sinkholes, sinkhole areas, and linear karst valleys is of particular importance because of the hydrologic functioning of such features. The existence of a sinkhole is an ipso facto demonstration of the sinkhole’s ability to transport sediment and suspended organic material into the karst groundwater system. Furthermore, if the karst groundwater system could not also transport the introduced sediment and suspended organic material then the sinkholes would plug with introduced materials and either create small ponds or else ultimately lose their surface expression. Identification of sensitive habitats and features that might be adversely affected by land use changes in the area being investigated. These habitats and features must specifically include, among other things, streams important to fisheries and streams or springs used as domestic water supplies. The inventory work must recognize that many sensitive habitats and features are likely to be located appreciable distances away from points where waters enter the karst groundwater system. Troglobites may help to conduct groundwater tracing to determine the point(s) to which a particular karst area drains. Such tracing work will also provide useful insight into the responsiveness of the karst systems within the area under investigation. The tracing work is a crucial component of vulnerability mapping; you must know where the water goes if you are to credibly assess and characterize impacts. The intensity of the tracing work should be greatest in areas near recharge area boundaries and in areas which may contribute water to important caves, springs, and streams.

It is finally recommended to delineate the land under investigation into various vulnerability categories. We again emphasize that developing and testing a vulnerability mapping strategy for the study area is work that needs to be done, but that such an effort is outside of the scope of the present investigation.

References


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Groundwater quality refers to the state of water that is located beneath Earth’s surface. Groundwater can gather in cracks in subsurface rocks and in between soil particles. Since many compounds can dissolve in water and others can be suspended in water, there is a potential for contamination with toxic compounds. These include petroleum, hydrocarbons (oil), pesticides, minerals, and disease-causing (pathogenic) microorganisms. Groundwater tends to be less prone to contamination than surface waters such as streams, rivers, and lakes because the contaminants have to pass down through the ground to reach the water. Nevertheless, contamination can occur, especially if there are cracks in overlying soil and rock through which the toxic compounds can more easily flow. The effect of ground-water quality deterioration, notably increases of nitrate, ammonium or phosphate (even at low concentrations) and/or trace pesticide contamination, may lead to greater ecosystem impacts than groundwater flow diminution. What can be done to protect groundwater-dependent ecosystems? Two main lines of action are required for protection of GDEs and have been strongly advocated for all sites covered by the RAMSAR Convention: â€¢ increasing knowledge of their hydrogeo... The end product should be a conceptual model of GDE functioning, using GIS and other data management systems to display results clearly. US-EPA 2012 Identifying and protecting healthy watersheds: concepts, assessments and management... Continental water bodies are of various types including flowing water, lakes, reservoirs and groundwaters. All are inter-connected by the hydrological cycle with many intermediate water bodies, both natural and artificial. Wetlands, such as floodplains, marshes and alluvial aquifers, have characteristics that are hydrologically intermediate between those of rivers, lakes and groundwaters. Residence times in karstic aquifers may vary from days to thousands of years, depending on extent and recharge. Some karstic aquifers of the Arabian peninsula have water more than 10,000 years old. It is essential that all available hydrological data are included in a water quality assessment because water quality is profoundly affected by the hydrology of a water body. Unfortunately, when it comes to water quality problems, ignorance isn’t always bliss. If you go through your life drinking tap water without paying much attention to what might be in it, you run the risk of letting the pollution of ground water in your area make you and your family sick. In this article, you’ll learn all about the pollution of underground water and what it means for you. What Is Groundwater Pollution? Where does it Come From? How does it Affect Us? Potential Sources of Groundwater Pollution. Examples of Groundwater Pollutants. Groundwater itself is simply the water that can be found underground. This doesn’t include surface bodies of water, but instead includes the water that fills in spaces between sand, rocks, and soil beneath the surface of the earth. Ground water is free of pathogenic organisms. Ground water needs little treatment before use. Ground water has no turbidity and color. Ground water has distinct health advantage as art alternative for lower sanitary quality surface water. Ground water is usually universally available. Ground water resource can be instantly developed and used. There are not conveyance losses in ground water based supplies. Ground water has low vulnerability to drought.