0.1 The Evolution of Groundwater Exploration Methods in the Moroccan Oases through History, and Managing Ecological Risk of their Present Pollution.

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Abstract

Moroccan Groundwater Systems in most oases are experiencing drastic changes due both to global scale stresses, and the cumulative effects of local and regional scale changes. The adaptive capacity and resilience of GW are severely affected because of the high magnitude of drivers.

The Tafilalt Oasis is located in the Sahara SE Morocco, with an area of about 1,370 km^2. Ramsar site no. 1483 which is part of UNESCO Biosphere Reserve is a site of Biological and Ecological Interest. It comprises a series of oases and the reservoir of one of the oldest dams in Morocco (Hassan Ad-Dakhil). Significant atmospheric and desert Saharan events such as sand invasion often occur in the region affecting the world's climate. Irrigation in the oases mostly depends on a dense and intricate network of canals distributed across the oasis. In the northern part of the Tafilalt oasis, water for irrigation canals has, since the late-14th century, also been provided by khettara (subterranean channels draining perched water tables). Starting from the early 1970s, the remaining active khettaras experienced a flow reduction, and over the next two decades many more khettaras dried up and were abandoned. The diminishing and abandonment of khettaras is attributed to the Hassan Adakhil dam and its new reservoir upstream from the Tafilalt oasis. The dam's control of downstream water releases has meant that many river channels downstream have water only during certain times of the year (thus affecting the Minimum Instream Flow), a phenomenon which is worsened by excessive water extraction for agriculture, human consumption and droughts that have become more common during the past two decades. Farmers are still not rapidly adopting techniques and equipment that economize water irrigation. The ground water (GW) mining in Tafilalt was enhanced by low-cost boring technology and cheaper imported and locally produced pumps. Pumps became a part and parcel of the green revolution and poverty alleviation but present development of uncontrolled GW markets threatens the sustainable use of GW reserves.

The valley's human growth is placing too many latrine systems too close to too many wells. The septic waste is seeping into drinking-water wells almost on every Kasbah, high levels of nitrates are showing up in water and most of sampled wells had bacteria contamination from septic wastes. Other poisons may be present, usually from septic waste that has polluted ground water.

Tafilalt Oases harbor important stenoendemic subterranean fauna. Major threats to regional freshwater biodiversity are: overexploitation; water pollution; flow modification; destruction or degradation of habitat; and invasion stygoxene species.

To the recent concept of the „new water culture“ involving a sustainable water use based on an integrated water management approach, we will consider the impact of man-induced contamination with regard to the different functions of the groundwater each with its own risk insight. Sustainable use can only be achieved if groundwater management is part of an integrated approach (surface water, environment, physical planning) and if instruments are available, providing information on the maintenance of potential functions and biodiversity.

Water management to date has been dominated by government agencies, and the necessary involvement of civil society (the general population, professional organizations, and selected non-governmental bodies) will take time to be organized.

0.1.1 Water resources and water management in the past and today

In southern Morocco, on the borders of the Sahara Desert, lies the Tafilalt oasis (Fig. 0.1.1, A), a historically important caravan crossroads and trading center. Sijilmassa (A.D. 757-1393), a great city whose remains lie in the center of the Tafilalt (near the modern town of Rissani), is one of the earliest Islamic cities established in Morocco. It used to play a crucial role in the gold trade from West Africa to the Islamic world during the medieval period. After the fall of Sijilmassa, the Tafilalt continued in a different form, ruled by the Alaouites who expanded the infrastructure through a large-scale irrigation network of dams and canals off the *oueds* (i.e., larger river channel) Ziz and Rheris (Lightfoot and Miller, 1996; Margat, 1959). Surface water for these canals is supplied by runoff from the Atlas Mountains, which increases during the Mediterranean-like winter experienced in the mountains, wanes in early summer, and is generally absent until autumn rain and winter snow return.

Irrigation has mostly been made possible through the use of earthen canals (seguias), and there is a very dense and intricate network of seguias in the Tafilalt. Most channels were traditionally filled with water diverted from the larger river channels (oueds or wadis), or from small reservoirs - intermittent pools of water - impounded behind a series of low-water dams across the Rheris and Ziz oueds. The channel which passes through the heart of the oasis, today called the Ziz oued, is

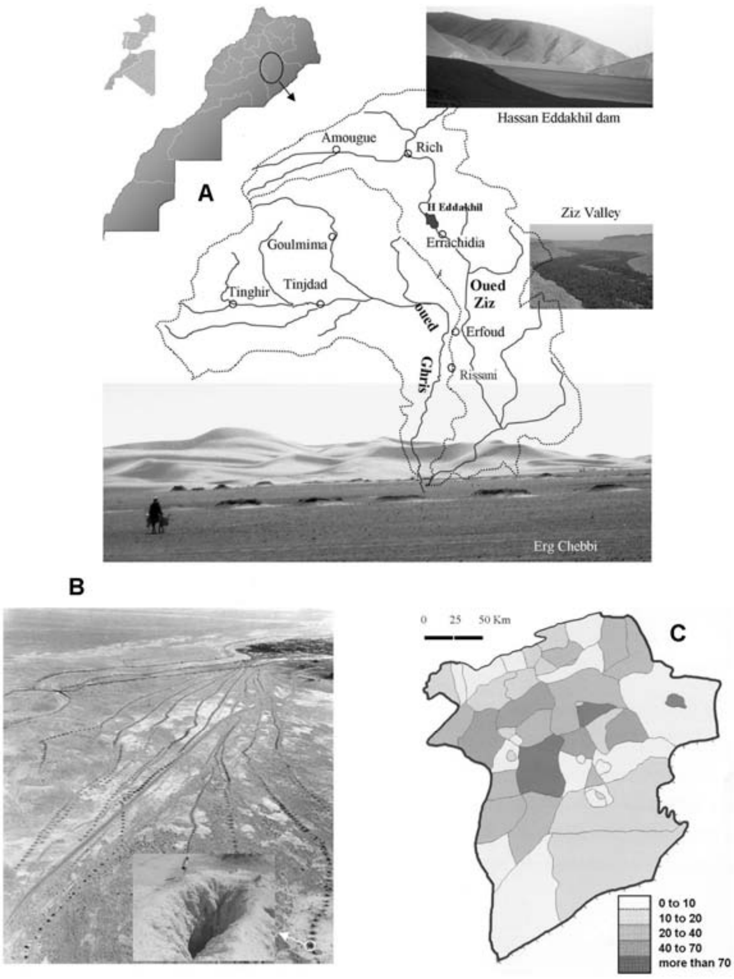

Fig. 0.1.1. **A**, Location of Ziz valley showing the hassan Eddakhil Dam the oasis and the sandy desert ,erg chebbi (photos Messouli);
B, System of khettara along the Tafilalet Valley (in Morocco, east of the High Atlas mountains) ; the water collected is used for irrigating the oasis visible in the background of the photograph.(source : www.francoravelli.it/cunicoli/images87/1.jpg);
C, percent of latrine use within the tafilalt oases (source: Atlas-Region Meknes-Tafilalet, MATEE).

itself a large primary channel built sometime after the mid-11th century by diverting water from the original Ziz, itself known as the Amerbouh in this stretch today (Lightfoot and Miller, 1996; Margat, 1959). Remains of the now- refashioned diversion dam lies in the Ziz channel near Erfoud. Eleven smaller dams on the Ziz, and two on the Rheris oued, were built and/or refashioned in this region by Sijilmassians, Alaouites, and the French empire. All of these ancient and historic dams have now silted up or breached and are useless for irrigation. In the northern part of the Tafilalt, water for irrigation canals was often provided by khettara, which will be discussed in detail in the next section. The availability and distribution of water in the Tafilalt changed dramatically after the 1971 opening of the Hassan Addakhil dam near Errachidia, impounding the Ziz Oued about 75 km north of the Tafilalt. Water from the Ziz oued used to flow unimpeded into the Tafilalt basin and provided the primary source of water for irrigation since the time of Sijilmassa. Floods were not uncommon. Now water from the reservoir is released through government canals only three to four times per year, depending on reservoir recharge, with each water release lasting 20 to 23 days (to allot 10-12 hr of water flow per village) and timed to correspond to more critical periods in the growing season. This water contributes to the irrigation of about 9400 ha, more than 75 % of all arable land currently used in the Tafilalt, but the water is so thinly spread that fields can no longer be irrigated with water from the Ziz oued only.

Because of their ubiquity, private and cooperatively owned diesel-pumped wells have now become most important to Tafilalt irrigation. The first private motor pump was installed on a well in 1965 (information from the Office Regional de Mise en Valeur Agricole du Rissani). Seven larger, public pumps, irrigating about 950 ha, had been installed by the French in the 1930s. Some of these public tube wells were deepened after the early 1970s when the water table began to fall.

History of Khettara

An impressive 300 km network of khettara (Fig. 0.1.1, B) was excavated in the Tafilalt basin starting from the late 14th century. Some of these wells tap into the aquifer at the base of mountains along the western edge of the oasis. Others exploit the shallow water tables adjacent to major stream channels which pass through the basin. Eighty of these chains provided perennial water for 28 qsour (i.e., villages; sing. qsar) in the northern part of the oasis. The qsour and khettara simultaneously developed following the breakup of Sijilmassa (Lightfoot and Miller, 1996). Qsour in the central and southern oasis-where the water table was and is still much deeper-continued to rely on the same sources of water (wells and surface channels) for irrigation and drinking water that sustained Sijilmassa.

It is possible that khettara first came to Morocco from the Middle East following the Islamic revolution; the pattern of diffusion closely follows the historic diffusion of Islam. However, it is not certain if this technology was introduced by Muslims first to Morocco and later to Islamic Spain, or whether it first swept into Islamic Spain from North Africa, and then diffused back into Morocco (Goblot, 1979; Joffe, 1992). It appears that qanat technology had been earlier introduced to Roman Spain from the Middle East where the Romans, presumably borrowing Persian technology, had built and used qanats in Jordan and Syria, so there could have been an Iberian precedent to Morocco's filtration gallery systems (Fleming and Barnes, 1993; Glick, 1979).

Networks of dispersed villages with associated khettara appear to have emerged in the Tafilalt in the late 14th through the 16th centuries; a few of the Sifa district (northwest Tafilalt) khettara being originally constructed as late as the 1730s (Margat, 1961).

Khettara continued to provide the only reliable irrigation water for north Tafilalt qsour until the early 1970s, when new technologies and government policies forced changes in traditional water management. Insufficient water (from the dam) and non-sustainable methods of groundwater use (overuse of diesel pumps) have, since the early 1970s, resulted in a dramatic lowering of the water table underlying the oasis. Because they are proffered and subsidized by the government, these modern water technologies, continue to replace the few remaining khettara, which are abandoned as the water table drops.

Khettara: water as a renewable resource

Khettaras were widely used throughout the dry lands of the Old World until recently for several reasons. First, khettara are made of local materials. Second, they tap aquifers using no source of power other than gravity. Third, water is transported for substantial distances in these subterranean conduits with minimal loss of water through evaporation and with little risk of pollution. Water loss through percolation is reduced by lining the tunnels with clay hoops when they pass through loose sand, and by infusing their beds with layers of impermeable clay.

The rate of flow of water in a khettara is controlled by the level of the underground water table. Thus a khettara cannot drain an aquifer, because its flow varies directly with the subsurface water supply. When properly maintained, a khettara is a sustainable system that provides water to settlements indefinitely. Khettaras exploit ground water as a renewable resource.

The self-limiting features of khettara that make them a sustainable technology can, however, be their main drawback, particularly when they are compared with the range of technologies available today. First, the flow of water in khettara varies from year to year depending on the recharge rate of the aquifer. Second, water flows continuously in a khettara, and although some winter water is used for domestic use, much larger amounts of irrigation water are needed during the daylight hours of the spring and summer growing seasons in villages. Although this continuous flow is frequently viewed as wasteful, it can, in fact, be controlled to a large degree. During periods of low water use in fall and winter, water-tight gates can seal off the khettara opening damming up and conserving groundwater for periods of high use. In spring and summer, night flow may be stored in small reservoirs at the mouth of the khettara and held there for daytime use. Moreover, much perceived seasonal water loss infiltrates the soil beneath the khettara tunnel and thus recharges the aquifer.

Khettara in a Modern World

The competition between traditional and modern water systems is both environmental and cultural. Environmentally, diesel-pumped wells and government channels have led to the abandonment of a sustainable technology in favor of systems which are capable of providing greater quantities of water but are not sustainable. Culturally, the adoption of newer technologies has led to the abandonment of traditional technologies like khettara, altering the land use patterns which evolved through the historical reliance of villages on khettara. There has been some loss of local control over water resources because much of the water villages need comes only from the Errachidia reservoir and drinking water pipes, both regulated by the government. Khettara are qsour operated and collectively maintained, and intricate relationships have evolved to manage them and distribute their benefits according to each shareholder's inputs of land, labor, tools, and money. Diesel-pumped wells are often privately owned and, as a result, the traditional ties that bind village society are breaking down. Non-farm sources of income continue to draw young men away from villages and out of the oasis, disrupting the social organization of khettara systems. Furthermore, the traditional source of wealth in the oasis through the trade in dates has been irreparably altered. Only 60 % of the palm trees in the Tafilalt still produce a date crop today. The others no longer produce dates or have died as a result of periodic date blight and/ or sustained desiccation.

0.1.2 Evidence of Climate Change in Morocco

Since 1970s, Morocco has experienced a general rainfall decline (Fig. 0.1.2). The Ziz-Gheris catchment is typical of a gradient from humid/sub-humid subtropical mountains to their arid foothills and finishing in the sandy desert (Sahara).

The trend toward a global warming of the Earth's atmosphere is an important environmental force with significant implication for the state of GW ecosystems. The Earth's surface temperature during the last two decades has increased by about 0.5° C and an ongoing rise with similar amplitude is expected up to 2025 (IPCC, 2001). The global warmth in 2001 was unusually high and is considered to be a consequence of anthropogenic greenhouse gases (Hansen *et al*. 2002).

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Fig. 0.1.2. Annual precipitation variability in Morocco throughout the 20 the century.

Table 0.1.1. Distributed changes on temperature and precipitation in Morocco.

Climatic zones	Representative stations	ΔT		Δp/p	
		range	mean	range	mean
		°C	°C	%	%
North-West	Tanger-Tetouan	0.6–0.8	0.7	-2.8 – -5.4	-3.3
Oriental	Oujda-Bouarfa	0.6 – 0.9 0.8 – 1.1	0.7 0.9	-1.8 – -5.5 -7 – 0	-2.3 -4.2
West	Kenitra	0.6 – 1	0.8	-7 – 0.1	-3.8
Oum er Rbia Tensift	Marrakech	0.8 – 1	0.9	-7 – 0.1	-4.3
Middle and High Atlas	Ifrane Beni Mellal	0.8 – 1.1	0.9	-7 – 0	-4.3
Sous-Draa	Agadir	0.8 – 1.1	0.9	-7 – 0.1 -11.7 – +2.8	-4.3 -10
South-East	Ouarzazate Errachidia	0.8 – 1.1	1	-7.5 – 0 -11.7 – +2.8	-4.3 -11
South	Laayoune, Dakhla	0.8 – 1.1	0.9	North: -8– -1 South:+1– +4	

Source: Bennani et al. 2001

These climate changes will act negatively on the GW reserves of many aquifers. In the semi-arid and arid zones the recharge of aquifers will be reduced through decrease in runoff and through higher human water consumption, especially for agriculture. The GW reserves will continue to shrink. In areas with a high net humidity, the surface run-off will increase, but because of fast flow the water will not optimally recharge the depleted aquifers.

Bennani *et al.* (2001) developed the climatic scenarios for Morocco following the IPCC methodology with „mid-range“ emissions scenario (scenario „IS92a“) and the MAGICC-SCENGEN software (Hulme *et al*. 2000). The software outputs are presented in Table 0.1.1 (Bennani *et al.* 2001)

The scenarios developed by Bennani *et al*. (2001) suggest that for Morocco as a whole:

- Mean annual temperature will increase by 0.6ºC to 1.1ºC between 2000 and 2020
- Annual precipitation volume will decrease by 4 percent between 2000 and 2020

The data indicates that the impact of future CC on water resources at smaller scales such as smaller river basins, specific water resources and irrigation systems has to date not been properly addressed and, therefore, constitutes a niche for immediate research. This is, especially relevant in areas such as the Mediterranean region, which is predicted to be particularly affected by CC in the future. The preliminary trend analysis of available rainfall data suggests that the possible future CC impacts will decrease the precipitation in parts of the Atlas Mountains, which is the main source of water supply in southern Morocco. (Chaponniere, A.; Smakhtin, V. 2006)

0.1.3 Water distribution, rights and conflict

Water as a vital but scarce resource determines the everyday-life in the Tafilalt Valley. Especially in the southern Oases, the arid environment is the limiting factor for economic development. The results of interdisciplinary research demonstrate that water resources are decreasing both as a consequence of environmental constraints and anthropogenic influences, while the degradation of soils and vegetation is increasing. The recent droughts have further aggravated these conditions.

In addition to the gravity of the scarcity of natural resources and the limited options for the local population to manage these resources, the increasing speed of social change due to external forces is one of the major problems in coping with the local conditions. Socio-economic changes on the national level alter modes of access to resources on the local level, particularly by modification of production systems and production relations, by technological innovation, and through new modes of commercialisation. On the local level, a rising demand for water, an increasing individualisation of property, and a weakening of social relations and social ties within the communities are consequences of this development.

Case studies from Tafilalt Valley point to a tendency towards smaller households, often accompanied by residence in „better“ equipped domiciles/ houses, and an increasing domestic water demand. A similar pattern can be found not only in urban centers like Errachidia and Erfoud, but also in rural settlements. This development is closely linked with labour-migration; which was identified as a major factor in the socially embedded negotiation about water use, with an increasing significance in recent years.

In Tafilalt local decision making structures are characterized by the co-existence of modern state institutions and local or tribal (q’bila) institutions. In order to understand patterns of emerging conflicts and conflict settlement concerning water rights and use, this co-existence must be analysed thoroughly before any recommendations can be made.

Technological innovation like the massive introduction of motor pumps, often financed by labour migrants, led to a barely controllable abstraction of groundwater and weakened traditional structures of water distribution and water ownership. The resulting modification of income distribution is one factor that will alter rural

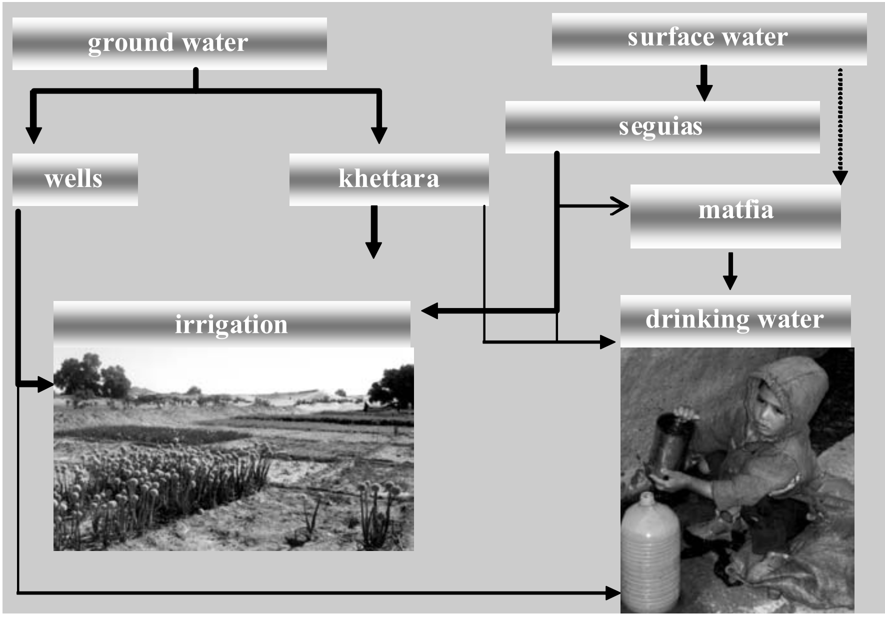

Fig. 0.1.3. Water distribution in main parts of the Ziz oasis (thick arrows indicate primary supply lines). Photos: M Messouli.

social structures. Yet, conservative kinship structures, group memberships, social status, and patterns of production that range from sedentariness associated with agricultural production to nomadic pastoralism, but also „non-traditional" economic activities, determine the handling of water resources. Therefore, to accomplish the task we are confronted with, it is essential to include social anthropological data. Otherwise, the impact of environmental and climatic change on the local populations cannot be investigated and understood fully. In addition, every intervention into an established setting needs a thorough understanding of the complexity of local traditions and the associated socio-cultural process of contemporary institutional changes. Any development cooperation can only be sustainable if the historically rooted cultural norms, values and strategies of survival are considered in the early stage of planning. Consequently, the social-anthropological work packages are investigating the embeddedness of indigenous systems of water use in the spheres of religion, economy and socio-political institutions.

Water taps are irregularly distributed along Ziz valley, but many wells are generally equipped with motor pumps. Together with the covered cisterns (matfiya), they supply the villages with water for drinking and irrigation. Water is distributed according to the pattern shown in Fig. 0.1.3.

0.1.4 Managing groundwater systems: Trends and developments

The danger global change and warming pose to oases is a concept familiar to many but understood by few. The life-sustaining benefits of oases are being altered by human activities and widespread disregard for the environment. Once this relationship has been clearly established, it is feared that global change will have a disastrous impact on local and regional weather patterns and on oases services. As a result, the oases as we know them today will be forever changed.

In addition, most of our knowledge in understanding linkages and feedbacks has to do with the physical, biological, and biogeochemical aspects of the Oasis system rather than with its human dimensions. As a rule, studies of complex water systems have included society either as a driver of change or as a recipient of negative impacts of changes. The aim of studies, however, must be to include human activities and institutions as one of the core components of the Oases water system, interacting with physical and biological / biogeochemical components.

Effects of contaminants on subsurface ecosystems are hardly considered in actual management of groundwater resources. Recent developments in groundwater management show growing attention for regional specific solutions and integrated environmental management including spatial planning. The role of ecology in groundwater remains unclear.

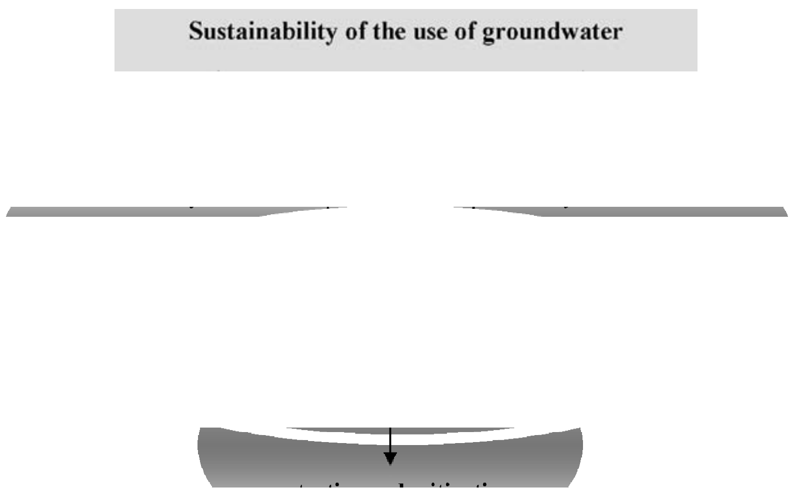

Fig. 0.1.4. Scheme for sustainable use of groundwater (modified after Notenboom, 2001).

Sustainability of the use of GW in Oases

The use of GW in a sustainable way is the maintenance of the integrity of structural and functional traits of groundwater ecosystems (Notenboom 2001). Within this framework we should consider not only the water aspects, but also the various species living within the subsurface. In order to achieve such a goal, we need to protect the environmental quality above and below the soil surface and apply a sound management strategy for the exploitation of water resources at relevant sites.

The problem of developing environmental policies for the implementation of sustainable GW systems and/ or for protection of such ecosystems requires two main approaches, one relying more on the socio-economic and political contexts and related to the sustainability of the water production, and the other insisting more on ecological criteria and related to the sustainability of the whole ecosystem (Fig. 0.1.4).

Analysis of environmental problems

Our paper follows the DPSIR framework (Driving forces, Pressures, State of Impact and Response), developed for environmental problems in the European Community (EEA [European Environment Agency] 1999; Notenboom 2001). This conceptual model encapsulates the idea that ecosystems, especially those impacted by human activities, change their structure and functions, leading to a diminution of ecosystem goods and services that they can offer to the biosphere.

The task of managers or decision-makers is to assess the driving forces, pressures, state and their ultimate impact. From the impact they must determine appropriate responses, in order to direct the final impact in the desired direction. These responses will influence the drivers, pressures and states, thus completing a feedback loop (Fig. 0.1.5).

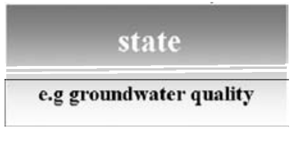

Fig. 0.1.5. The DPSIR framework applied to the impact of septic wells on the ecological properties of groundwater system onTafilalt oasis.

Table 0.1.2. Major global threats to the surface/ groundwater system in Oases and related issues (modified from Meybeck 1998 and Meybeck 2003). The scope and intersections of the numerous forcing and system impacts require an interdisciplinary and systematic research approach.
A : human health, B : water cycle, C : water quality, D : carbon balance, E : fluvial morphology, F : aquatic biodiversity, G : coastal zone impacts. Only the major links between issues and impacts are listed.

drivers	Major impacts	Global issues						
		A	B	C	D	E	F	G
	Change in flow regime (runoff volume and timing)		•	•		•		•
	Changes in wetland distribution	•	•	•	•		•	
climatic change	Changes in erosion and sedimentation				•	•		
	Change in chemical watering				•			•
	Accelerated salinization through evaporation	•	•				•	
	Development in non perennial rivers		•	•	•	•	•	•
	Nutrient and carbone retention				•			•
Water management	Retention of particulates				•	•		•
(including dams,	Change in flow regime (runoff volume and timing)		•	•		•		•
diversions, and channelization)	Stream flow variability and extremes		•					
	Loss of connectivity (L, V and H)						•	
	Wetland flling or draining		•	•	•		•	
	Change in sediment transport				•	•		•
Land use change	Change in vegetation cover		•					
	Alteration of first order streams					•	•	
	Nitrate and phosphate increase	•		•	•			•
	Pesticide increase	•		•				•
Irrigation & water transfer	Change in flow regime (runoff volume and timing)		•	•			•	•
	Salinization through evaporation		•	•				
Release of domestic wastes	Heavy metal increase	•		•				
(latrines, manners)	Eutrophication	•		•	•		•	•
	Development of water-borne diseases	•						
	Organic pollution	•		•			•	
	Persistent organic pollutants	•		•				•

Groundwater threats

Many of the driving forces, in Moroccan oases (Table 0.1.2), are leading to irreversible changes in the subsurface environment. The trend is that the subsurface is being used more and more for different functions. In densely populated areas in particular, along Ziz and Draa Rivers, these functions may conflict. Pressures are due to the presence of pollutants but also to changes in the natural physico-chemical conditions.

Latrines: groundwater contamination and impact on human health

It is important to distinguish point and diffuse sources of groundwater contamination. Environmental problems related to point sources are generally considered to be easier to bring under control, notwithstanding their seriousness. Diffuse sources are very difficult to bring under control and they need complex management solutions. Septic contamination is such a diffuse source of groundwater contamination. A basic threat assessment of this type of contamination for oases groundwater ecosystems is treated in the subsequent section

Drivers

Tafilalt valley's growth is placing too many septic systems too close to too many wells. In several parts of the oasis along the Ziz River (Fig. 0.1.1, C)), people are using the underground as a place for waste disposal and a very large number of subsurface sites are therefore now highly contaminated.

More than 80 percent of the people in sub-Saharan Moroccan oases use ground water as their source of drinking water, and about one-third of the rural and waterfront population uses tanks systems for wastewater disposal. Tanks serve primarily as settling „wells“ removing solids from the sewage. In sand and gravel aquifers characterized by large pore sizes that allow for relatively easy and rapid transport of water and contaminants, concentrated plumes of dissolved constituents from tanks septic systems can occur in the shallow part of the aquifer and can affect the quality of drinking water withdrawn from domestic wells. There is a slight general decrease in total constructing of latrine as responses to the demographic and tourism demand.

The number of **Concentrated Animal Feeding Operations (CAFOs)** often called „factory farms“, is growing. On these farms, animals are raised in a small space. The large amounts of animal wastes/ manures from these farms can threaten water supplies. Strict and careful manure management is needed to prevent pathogen and nutrient problems. Salts from high levels of manures can also pollute ground water.

Pressures

The quality of drinking water from shallow domestic wells potentially affected by seepage from septic systems was assessed by analyzing water samples for substances derived from septic systems. The effect of septic systems on water from domestic wells was demonstrated using a preliminary interdisciplinary approach involving the collection of physicochemical (Table 0.1.3), and biological data. Domestic wells seemed to be most vulnerable to septic-waste contamination when they were sand-point wells within 50m of a septic system and were less than 10 m deep in a shallow, thin aquifer.

Table 0.1.3. Range of some characterestic water quality parameters in groundwater of some wells in Errachidia.

Parameters		max	min	mean
temperature	°C	25	20	22.2
conductivity	$\mu S.cm^{-1}$	4383	1515	2120
pH		7.95	6.9	7.2
dissolved O_2	$mg.L^{-1}$	10.32	0.0	5.12
OM	$mg.L^{-1}$	4.41	0.77	2.44
NH^{4+}	$mg.L^{-1}$	0.326	0.005	0.116
Na^{+}	$mg.L^{-1}$	361.4	67.5	210.8
K^{+}	$mg.L^{-1}$	101.6	3.85	16.05
Ca^{2+}	$mg.L^{-1}$	525.0	88.2	163.58
Mg^{2+}	$mg.L^{-1}$	180	25.5	108.9
Mn^{2+}	$mg.L^{-1}$	0.018	0.012	0.014
Cl^{-}	$mg.L^{-1}$	634	131.3	369.1
NO^{2-}	$mg.L^{-1}$	9.220	0.03	0.75
NO^{3-}	$mg.L^{-1}$	69.76	4.82	18.26
HCO^{3-}	$mg.L^{-1}$	451.4	180.0	245.2
$SO4^{2-}$	$mg.L^{-1}$	1698	191.8	857.6
Fe (total)	$mg.L^{-1}$	0.106	0.064	0.079

States

The study illustrates that shallow wells, whether sand-point wells or cased wells, can be affected by septic waste if constructed near a septic field, the water table is shallow, and the saturated media consist mainly of sand and gravel. The study results also indicate that bacteria and nitrate concentrations may not always be the best indicators of contamination of drinking water with water and constituents from septic systems and that other indicators such as stygobites may be more valuable in some cases.

An impressive number of chemical and biological substances, mainly produced by human activities, accumulate in GW impairing the pristine quality of the water, producing changes in the structure and function of ecosystems and, very important, creating threats to human health. The spread of contaminants, especially nitrates and pathogens from septic tanks, is another widespread form of GW pollution that can impair the quality of drinking water and produce outbreaks of disease.

Impact

The study of the spatio-temporal distribution of meio- and micro-organisms was the only approach that provided evidence of the dispersion of contaminants throughout the less permeable parts of the aquifer during times of active groundwater recharge. This finding highlights the importance of integrating faunal investigations into the framework of interdisciplinary research programmes on groundwater contamination

Assessment of the impact of contaminants on biodiversity and ecosystem integrity is preferably based on system specific information on exposure, species sensitivity, population and community effects, and ecological recovery. This information is hardly available and no signs exist that applicable data and methods become available in nearby future.

Other human interventions in the subsurface

Acridian control: The Moroccan locust, *Dociostaurus maroccanus*, is an important pest in oases, affecting pasture and crops. Current control relies on broad spectrum chemical pesticides. Many thousands of hectares are sprayed each year, often in areas of major conservation value. Adverse effects on the environment have to be evaluated.

Fertilizers and Pesticides: Farmers use fertilizers and pesticides to promote growth and reduce insect damage. The chemicals in these products may end up in groundwater. Some underground agricultural drainage systems collect fertilizers and pesticides. This polluted water can cause problems to ground water and local streams and rivers.

Extraction of gravel creates GW pits through which contaminants (like nitrates) and pathogens pollute aquifers. Natural processes like climate change and polluted surface water infiltration put extra pressures on the GW. High amounts of phosphate and/ or nitrate infiltrate the subsurface water after drying out of streams and the rewetting of the channels under arid climate conditions (Stanley & Boulton 1995; Turner & Haygarth 2001). Infiltration of polluted water into the sediments along rivers also raises the concentration of dissolved organic matter and/or heavy metals in the shallow groundwater of riverbanks.

Deforestation: It is astonishing to notice that public baths (hammam) are still Morocco's largest consumer of fuel wood in spite of the negative impact of the deforestation. Landscape alteration, which can in the long term reduce the GW resources of an area, includes deforestation and reuse of the land for agriculture or urban activities, plantation of vegetation that extracts too much water from aquifers, dehydration of wetlands, and alteration of river courses through regulation of their channels and construction of dams, dykes and levies that contribute to isolation of the aquifer from riverbeds. In all these cases, the volume of recharged GW from surface run-off declines with time. UNDP Capacity 21 is supporting a number of projects focusing on more efficient use of fuel wood, including fuel-efficient stoves, solar water heaters for hammams, or public baths, as well as butane gas and rechargeable batteries.

Tourism: Tourism affects, and is affected by the environment. Mountains and Saharan tourism has grown and thus is expected to continue. In The High Atlas, the Isli and Tislit lakes are extremely sensitive mountain areas, represent important tourist destinations where water supply is rather scarce and sanitation poor. Tourism causes very high pressures on GW, especially because of the additional septic well, and water demand arising during the season when the GW situation may already be critical. In addition, tourism-associated waste and sewage represent a potential source of GW pollution in sensitive areas. This trend will certainly continue during the next decades and will extend to areas that, only recently, discovered the economic advantages of the tourism industry.

0.1.5 Oases groundwater ecosystems: structure and function

Wetlands on Tafilalt oases have close associations with groundwater. They depend on the outflow from an aquifer as a water source. In such case, the hydrology of the aquifer and the health of the wetland ecosystem are closely connected. Importantly, this relationship can be disrupted by changes either to the aquifer, such as by groundwater abstraction, or to the wetland, for example by reduced natural inundation of wetlands overlying aquifers.

One of the main functions of the water in the subterranean ecosystem is to transport energy and matter from the surface of the Earth and/or from underground and further distributes them through the subsurface. During the movement of the water through the subsurface, its chemical properties change due to physical, chemical and biological processes. The transport of water through the subsurface is studied mainly by hydrologists and hydro-chemists and is important for the understanding of the ecological dynamics of any GW system.

The groundwater of Ziz valley is inhabited by diverse micro-, meio- and macro-organisms (Fig. 0.1.6). They play an important role in the recycling of organic matter transported by water and in the redistribution of energy and matter; over areas ranging from few millimetres to metres (Ward *et al.* 1998) Secondary producers dominate GW ecosystems because of lack of light (Gibert *et al.* 1994). Primary producers are represented by chemoauthotrophic micro-organisms, namely Bacteria and Archea.

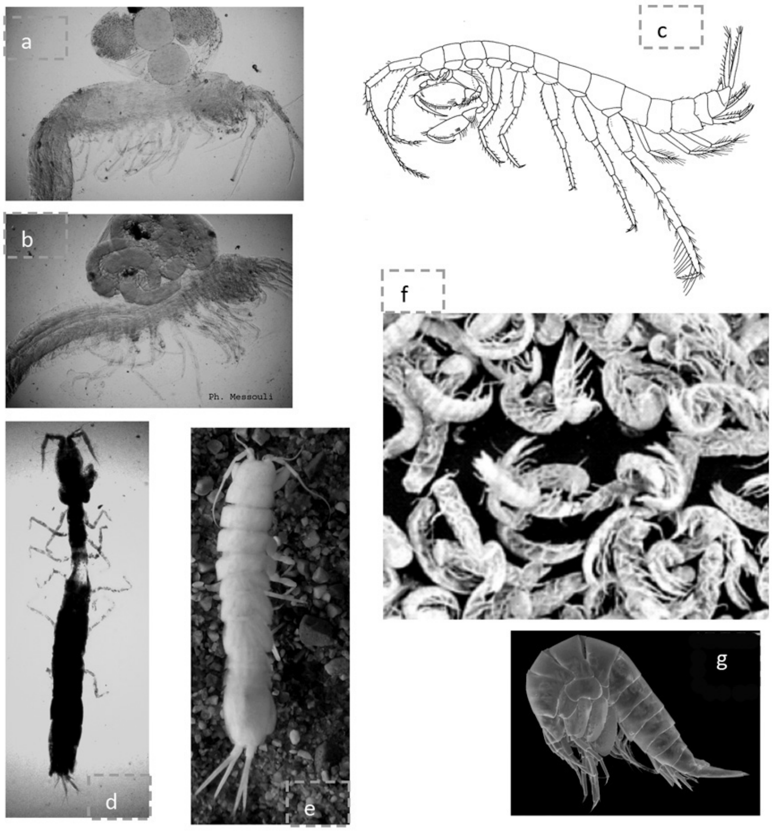

Fig. 0.1.6. Photographs and line drawing of representative unpigmented, blind, crustaceans from subterranean water of Tafilalt oases: (a) Thetysbaena cf. atlantomaroccana (1-1.5 mm) female carying larvae and (b) female with eggs on dorsal puch; (c) Maghrebidiella sp length 4.2 mm; (d) Microcerberus remyi; length 1.6 mm; (e) Magnezia gardei; length 10 mm; (f); Typhlocirolana sp; length 3-7 mm; (g) Salentinella sp ; length 1.2mm. (Photo and line drawing sources, a-d and f: Messouli; e: Messana; g: Messouli and Messana).

Many stygobitic species are relicts of animal groups that have disappeared from surface water systems. Such animals deserve protection within well functioning GW systems (Culver & Sket 2000). Shallow GW habitats, especially the hyporheal (the ecotonal zone connecting the surface-running water system to that of the deep subterranean) generally display high species richness, a mixture of surface dwelling and exclusively hypogean (stygobitic) taxa.

The key role of micro biota in the functioning of groundwater ecosystems

In pristine aquifers, micro-organisms are responsible for the major turnover of energy and matter. They play a key role in weathering and formation of minerals and they store in their biomass important quantities of carbon, nitrogen and phosphorus.

Moreover, they contribute to the development in the subsurface of microhabitats chemically distinguished by their redox reactions. In the context of strong human impacts on the environment, the high purification potential of GW ecosystems is of increasing interest and importance.

Understanding hydrological links between wetlands and groundwater

Hydrology controls the composition and functioning of aquatic and terrestrial subsurface ecosystems. The dynamic exchange processes between surface water and GW contribute much to the structure of subterranean communities.

Shallow subterranean ecosystems are directly connected to surface aquatic and terrestrial systems like rivers, lakes and wetlands. Hence the approach that ecologists now favour is to treat GW ecosystems within a holistic framework that integrates the connectivity between the subsurface and the surrounding terrestrial and aquatic systems. (Danielopol *et al*., 2003)

Into the relationships between GW and surface-water ecosystems it is important to integrate the ecological dimension played by human activities. In this enlarged ecological perspective we can better evaluate the actual ecological state of various GW systems viewed at different scales of generality from the local to worldwide.

0.1.6 Causes of Biodiversity Change

Groundwater ecosystems harbour an impressive number of animal species that are known exclusively from subterranean waters (referred to as stygobites), such as the crustacean species belonging to the orders Bathynellacea, Thermosbaenacea, Isopoda etc…. and family of Microparasellidae, Microcerberidae, and Salentinellidae. The ecological characteristics of subterranean animal assemblages offer in many cases information on the functional state of GW ecosystems and/or on the degree of connectivity, especially between above soil (epigean) and subsoil (hypogean) ecosystems (Malard *et al*. 1996; Boulton 2000). Many stygobitic species are relicts of animal groups that have disappeared from surface water systems (Humphreys 2000). Such animals deserve protection within well functioning GW systems (Culver & Sket 2000). Shallow GW habitats, especially the hyporheal (the ecotonal zone connecting the surface-running water system to that of the deep subterranean) generally display high species richness, a mixture of surface dwelling and exclusively hypogean (stygobitic) taxa.

The quantity and quality of the various kinds of pressures on GW systems are able to induce drastic changes in the diversity of organisms living underground. We assess two types of such changes, namely

1. decline in GW-dwelling organism populations leading to species extinctions and
2. penetration of alien species belonging to surface-water communities.

Both processes determine changes in the functioning of GW systems, generally reducing the efficiency of some ecosystem processes.

Comparative sampling of pristine and sewage-polluted wells showed that the contamination induced the disappearance of stygobites, promoted the colonisation of the aquifer by stygoxenes and modified the relative abundances of the different faunal groups. Wells of the unimpacted sites had faunal assemblages dominated by crustaceans, and they harbored a high number of stygobite species wich usually represented a major component of the total number of invertebrates. Polluted wells had significant relative abundances of oligochaetes and insects.

Hyporheic habitats along rivers, like the Draa or the Ziz, which are polluted especially by organic matter, display low biological diversity and are represented mainly by surface-dwelling taxa. River regulation combined with the negative effect of organic pollution alter GW habitats; for example, through stronger siltation and oxygen depletion of the interstitial voids, the free-moving crustaceans (such as stygobitic amphipods and isopods) are replaced by assemblages dominated by epigean animals such as insect larvae and oligochaetes .

Arid climates as well as damming rivers determine the drying of down streams and the interruption of water infiltration into adjacent-shallow subsurface areas. The fauna of hyporheic habitats in such cases is represented by a few epigean preadapted species that can survive the dry period until the next rewetting.

0.1.7 Concluding remarks

Khettara has a profound influence on the lives of the water users in Tafilalt oases. It allows those living in a desert environment adjacent to a mountain watershed to create a large oasis in an otherwise stark environment. The United Nations and other organizations are encouraging the revitalization of traditional water harvesting and supply technologies in arid areas because they feel it is important for sustainable water utilization.

GW ecosystems provide generally important services and goods to humans. The water filtration process in groundwater systems due to removal of microbial pathogens allows production of high-quality drinking water, a good of immense benefit to human welfare (Daily et al. 2000). The value of healthy GW systems has also to be seen as an intergenerational capital to which precautionary protective measures should be applied. The ecological consequences of natural and artificial recharges of aquifers need to be better understood for the effective management of GW reserves. Another ecological research area with important implications for the management of sustainable water resources lies in the protection measures required for GW systems.

Morocco's illiteracy rate and the poor school enrolment figures reflect higher poverty levels in rural areas and a large disregard toward environment. Consequences of inadequate supply of water and sanitation are very evident. However, they hit women most severely, as women are the traditional water carriers and family health care providers in many societies of the developing world.

Human population growth and increasing poverty will continuously exert pressure on the sustainable use of GW. Without fundamental changes in the relationship between man and environment, the possibilities for sustainable GW management programmes are limited. In the Tafilalt especially, urgent action is needed to reduce anthropogenic threats to GW systems and policy makers should tackle this problem at grass root level.

The irrigated agriculture has been the main economic drive in the Tafilalt. Sustainable use can only be achieved if groundwater management is part of an integrated approach (surface water, environment, physical planning) and if instruments are available providing information on the maintenance of potential functions and biodiversity.

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