Managed Aquifer Recharge Integration Potentiality In Arid Climate Conditions In The Jordan Rift Valley

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Abstract The Jordan Rift Valley (JRV) catchments are places of extreme water scarcity and continuing overexploitation of the Plio-Pleistocene aquifer system. The groundwater basin is overexploited and there exists a threat of groundwater quality deterioration and salinization. Tens of research projects have been conducted in the Eastern Basin catchments that drain into the JRV with the overall conclusion that integration of surface water and groundwater management into full-scale IWRM approaches are needed. Implementation processes by decision makers are hampered by the complexity of the water system and the political tensions in the region. Wastewater reuse and desalinisation will increase the amount of usable water, but do not affect the overall water balance. Managed Aquifer Recharge (MAR) projects would be beneficial to enhance productive water availability of the region. Dams and reservoirs that have been installed at the outlet of major wadis provide additional groundwater recharge but are characterised by high evaporation losses and progressive silting. Therefore, alternatives need to be evaluated. Due to fast hydraulic reactions and short residence times of contaminants in the aquifer system, karstic aquifers prevailing in the area are particularly vulnerable to contamination. For careful site selection for MAR schemes in the JRV, a site selection study is recommended that integrates existing knowledge with additional data collection and model calculations. At this point, major targets for MAR schemes are the alluvial aquifer system, as well as the Upper Carbonate Aquifers system, which is hydraulically connected with the alluvial aquifer in many locations.

Keywords MAR of carbonate and alluvial aquifer, Jordan Rift Valley

Introduction

Water resources in the Jordan Rift valley are scarce in nature. The increasing population growth in the Jordan Rift Valley has put more pressure on the existing limited resources in the region. The steep gradient of the Jordan Valley produces a shadow effect, which reduces the quantity of the rainfall in the Jordan Rift valley (Arad & Michaeli, 1967). This basin is of great tectonic complexity and the major movement is eastwards with a southerly component near the river Jordan (Guttman, 1995). The aquifer system in the study area includes the sub-aquifers of Quaternary and Neogene formations (Ghanem, 1999). This covers the formations of Jenin sub series (Eocene), Beida & Lisan (Neogene & Pleistocene) as well as alluvium. The Pleistocene sub-aquifer consists of unconsolidated sand, gravel, cobbles, and boulders of different sizes separated by impermeable layers of saline lacustrine marl deposits (Rofe and Raffetey, 1965). The Eocene deposits are composed of limestone, dolomite, chert, gravel with sand and clay filling the intersect ices and forming alluvial fans. The groundwater occurring in the alluvial fans differs quantitatively and qualitatively according to its location within the fan. Fresh water occurs around the apex of the fan, whereas saline water occurs at the fringes. Very steep deep faults in the Jordan Rift valley may cause deep circulation of the groundwater bringing it into contact with salty formations which appears as brackish springs near the Jordan river. Integrated Water resources management includes all water resources of the Lower Jordan River, namely ground water, waste water, saline water, and flood water.

These issues are explored with a series of test sites along the Jordan valley. Test sites are planned for infiltration of reclaimed wastewater, infiltration of water from flash floods, infiltration of urban surface runoff and irrigation of agricultural area with treated sewage. The test sites are embedded into several water balance studies and finally, a numerical groundwater flow model will be needed for the entire Lower Jordan Valley for verifications. The investigation area covers the Lower Jordan River Valley and reaches down to the northern part of the Dead Sea. It comprises an area of about 2000 km^2. The dominating tectonic element of the Jordan River Valley is the Dead Sea Transform (DST) a segment of the East African – Red Sea Rift System . At the northern shores of the Dead Sea the valley floor is at ca. -400 m below sea level whereas the surrounding highlands reach on average 800 m above sea level.

Materials and Methods

Water resources status in the Lower Jordan River Basin (LJRB): closed basin

The study area constitutes parts of a closed river basin with a pronounced water deficit. A progressive closure of the basin means in this case that almost no water is left to be mobilized and used while demand, notably in urban areas, keeps increasing (Venot, Molle et al., 2006). Figure 1 lists the key elements in the anthropogenic modified water cycle of the LJRB. The final sinks of water in the LJRB are evaporation and water exports, there is no surplus water running to the open sea. The area is characterised by severe water scarcity. Figure 2 shows the Schematic Hydrogelogical Profile of the Lower Jordan Valley. Aquifers are seriously overexploited and groundwater levels have been dropping during the last decades. As a result, the surface area of the sea has already shrunk by one-third, springs around the sea are drying up and sinkholes (areas of severe land subsidence) are forming, threatening historical sites and infrastructure.

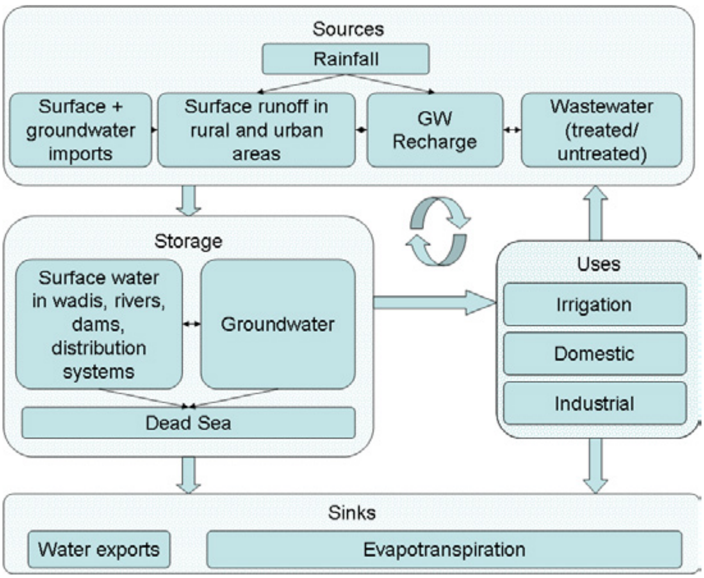

Figure 1 *Key elements of the water cycle in a closed river basin: the case of the lower Jordan River.*

Water quality of surface water is deteriorating due both due to reduction in natural flow volumes but also due to the many known and unknown releases of sewage into surface water. The situation is pronounced at the Lower Jordan River, whose waters were also historically more saline than the waters north of the Tiberias lake and of lower quality (Nissenbaum, 1969 in Farber et al., 2005). While flows of untreated wastewater in the wadis obviously constitute a pollution hazard, they still provide an augmentation of the Lower Jordan River base flow.

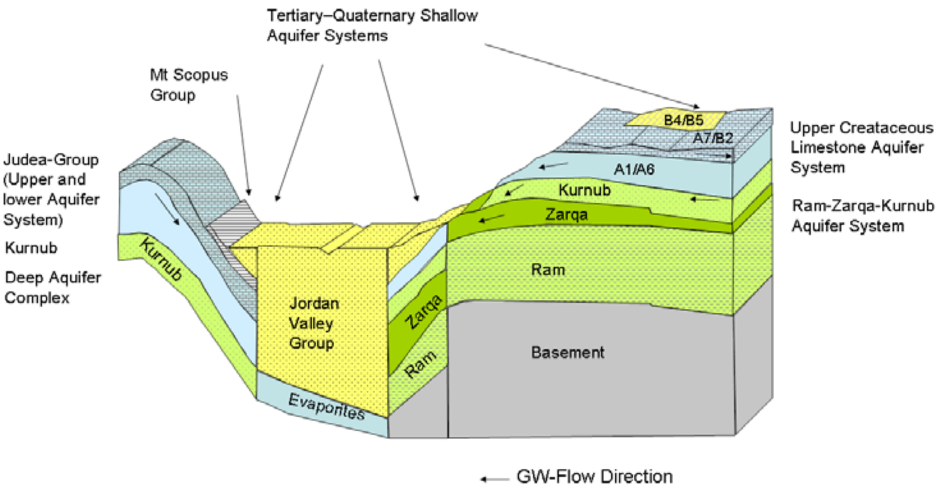

Figure 2 *Schematic Hydrogelogical Profile of the Lower Jordan Valley. Assembled from various sources (Salameh and Udluft, 1985; USGS, 1998; The Hashemite Kingdom of Jordan, 2004).*

Water resources status in the Lower Jordan River Basin (LJRB): Groundwater

As groundwater is the major source of drinking water in the Lower Jordan River basin, hydrogeological aspects exert a dominant influence on the water management. Especially on the west bank, groundwater is the most important source of fresh water supply in the area. The tectonically and sedimentologically complex setting in the LJRB produces a large number of local and regional aquifers. While major lithostratigraphic units were mapped in the region, hydrodynamic connections between aquifers and the borders of subsurface drainage basins are still a research topic. The various local aquifers may be grouped into three major aquifer systems:

(i) Tertiary-Quaternary Shallow Aquifer System: Alluvial aquifers are present at the floor of the Jordan Valley and the fans of the incoming wadis, where the alluvium is in contact with the aquifers of Upper Cretaceous age (Ailjun series). The alluvial aquifer extends from the northern shore of the Dead Sea in the south to the downstream part of the Yarmouk River in the north. The thickness of the alluvium in the Jordan Valley varies from zero along the eastern boundary to about 750 m in the deepest part of the basin near the Jordan River. An average thickness of

400 m may be reasonable for the purpose of hydrological considerations (The Hashemite Kingdom of Jordan, 2004). On the western side of the Jordan Valley, the term Shallow Aquifer Hydraulic Complex is used. It comprises Pleistocene sedimentary and alluvial deposits of the Quaternary age which receive localized annual recharge from wadi flows. The extent to which this aquifer is recharged from lower aquifers has not been determined and may be a function of faulting and fracturing.

(ii) Upper Cretaceous Limestone Aquifer System is known as the Judea Group and is subdivided into an upper and a lower aquifer system. In terms of extracted volumes, this is the most important aquifer system in the region. It receives the major part of the groundwater recharge in the area, occurring mainly in the high mountain regions on both sides.

(iii) Kurnub Group of Lower Cretaceous age consists mainly of sandstone. For the movement of groundwater the intergranular porosity of the sandstones is of minor importance, because most of the intergranular space is filled with siliceous cement.

Results and Discussions

Managed aquifer recharge (MAR) encompasses a whole suite of internationally used terms such as rainwater harvesting or artificial recharge. MAR describes intentional storage and treatment of water in aquifers. The term 'artificial recharge' has also been used to describe this, but adverse connotations of 'artificial', in a society where community participation in water resources management is becoming more prevalent, suggested that it was time for a new name. Managed recharge is intentional as opposed to the effects of land clearing, irrigation, and installing water mains where recharge increases are incidental (Gale, 2005). Figure 3 shows the basic types for MAR but the actual implementation of schemes is varying widely with different concepts in many cultures. Typical goals of managed aquifer recharge perceived in the region are (i) maintain and increase the natural groundwater as an economic resource. (ii) avoid further salinization and salt water intrusion (iii) decrease losses due to evaporation (iv) create a seasonal water storage (v) provide treatment and storage for reclaimed wastewater for subsequent reuse). Table 1 illustrates the methodologies for Managed Aquifer Recharge and their applications in the Jower Jordan River Basin.

While there is more than a millennium of experiences of using rainwater and surface runoff in rural areas by various forms of rainwater harvesting, the use of treated wastewater is young in comparison. Nowadays intentional replenishment of aquifers by highly treated reclaimed waters is increasingly being practised in developed countries with the full support of communities, and health and environment regulators, for aquifers that are under stress through imbalances between rates of extraction and natural recharge (Dillon, Toze et al., 2004; Dillon and Jimenez in press). With strong population growth in many urban centres and reduction of agricultural water demand by use of innovative irrigation technologies, the need to set up more sustainable urban water systems becomes obvious.

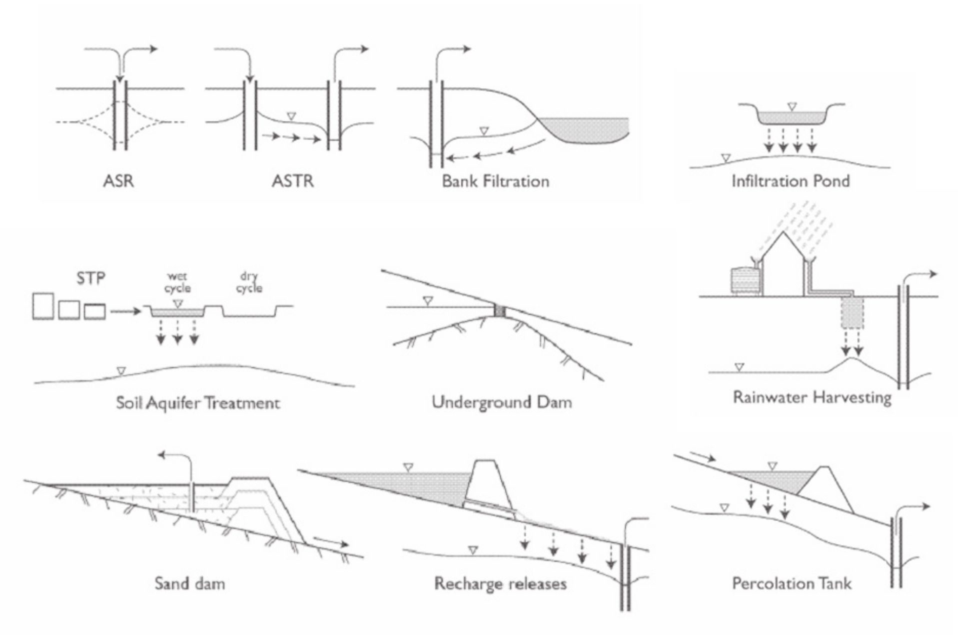

Figure 3 *Schematic of types of management of aquifer recharge (Dillon, 2005). Abbreviations: ASR=Aquifer Storage & Recovery, ASTR=Aquifer, Storage, Transfer & Recovery, STP = Sewage Treatment Plant.*

Table 1 *Methodologies for Managed Aquifer Recharge (Gale, 2005) and their applications in the Lower Jordan River Basin.*

General methodologies for MAR	
Spreading methods	Infiltration ponds and basins Soil Aquifer Treatment Controlled flooding Incidential recharge from irrigation
In-channel modifications	Percolation ponds behind check-dams, gabions, etc. Sand storage dams Subsurface dams Leaky dams and recharge releases
Well, shaft and borehole recharge	Open wells and shafts Aquifer storage and recovery (ASR) Aquifer storage, treatment and recovery (ASTR)
Induced bank filtration	Bank filtration Inter/-dune filtration
Rainwater harvesting	Field bunds, agricultural ponds Roof-top rainwater harvesting

Rainwater collection and storage schemes are traditionally carried out in Jordan and continued especially in rural villages. One of the techniques involves the filling of excavations close to wadi beds with a clay liner at the bottom, coarse rocks in the middle and a cover at the top. Due to the ongoing, unfavourable political situation in Palestine, there has been little scope for the construction of artificial recharge sites in the last decades. Current systems centre on rainwater harvesting, looking back upon long tradition and experience. Within the local context, managed aquifer recharge examples are grouped under the section “non conventional technologies”. Popular methods are (i) covered, underground reservoirs (locally called wells or cisterns) or (ii) pools made from earth or steel, covered with black plastic sheets to prevent algae growth (Carlo, 2007). The cisterns supply an estimated 6.6 mcm per year within the West Bank. Cisterns serve an essential purpose, meeting water needs left unfulfilled by the devastated infrastructure. In most cases, cisterns collect water from rooftops during the rainy season, which is then stored in subsurface containers, usually ranging in size from 60-100 cubic meters. A large percentage of water collected in cisterns is used for domestic purposes. Tankers are also used to fill cisterns, especially in the summer months when the cisterns dry up due to the lack of rainfall (Shehabadeen, 2007).

While these systems are effective in storing rainwater and securing the water supply during dry times, they are not recharging the groundwater directly. A direct recharge, however, is achieved through the numerous retaining walls on the agricultural fields. The retaining walls hinder surface runoff and enforce downward infiltration of water.

Incidential recharge occurs from a significant number of cesspits, but is associated with high nutrient and contaminant loads.

Conclusion

In general, the overexploitation of all aquifers in the region calls for recharge enhancement. Even without a recovery of the injected water close to the recharge site, a major environmental benefit will be achieved. Aquifers with high transmissivities are available close to the surface and successful examples are already implemented in the region. Mixing of injected water with saline groundwater bodies has proved to be low in international case studies. Beyond the hydrogeological constraints also the source of recharge water, the proximity to this source, the quality of the source and the availability of the source water has to be evaluated. Within the LJRB, both surface runoff and wastewater are available as sources. While significant amount of wastewater is produced in the urban areas, it is as far as possible used for irrigation following treatment. However, only a between 50% and 80% of the population are already served by sewerage systems. The alluvial fan aquifers at the inlets of the wadis to the Jordan valley offer a good potential for MAR due to their hydraulic conductivity, the gentle gradients and the long retention time. A major concern for the alluvial aquifers in the Jordan Valley is the mixing of the recharged water with saline groundwater. However, international studies have demonstrated that the mixing can be very low due to the slow groundwater movement and that efficient recovery is possible (Pavelic, Dillon et al., 2006). The Upper Cretaceous limestone aquifer system offers ample storage space but its use must be planned carefully due to the many fast discharge options via springs. Planning for MAR must take the local circumstances into account, such as the strong seasonality of rainfall, and high intensity peak rain events which require large reservoirs to provide temporal storage for runoff during flash floods. High technology options like ASR require significant experience in set-up and maintenance, especially with regard to the prevention of clogging and may not be suitable at this point. Furthermore, surface runoff from urban areas may be strongly polluted as no effective source control measures are currently in place. This review showed that a considerable potential in the lower Jordan River basin for managed aquifer recharge exists. However, MAR is not yet identified as a major goal in the national water master planning. Currently the main focus is on water demand management, water supply management and institutional reforms (Taha and Magiera, 2006). Considering the currently limited depth of this review of MAR activities in the Lower Jordan River basin, it is essential to increase the coverage by incorporating more of the locally available grey literature. In order to unlock the potential for MAR in the region, a series of background and feasibility studies on the following topics are recommended:

- Increase of groundwater recharge from reservoir structures by removal/disturbance of low permeability reservoir sediments.
- Artificial recharge from open reservoirs into alluvial fan aquifers
- Use of urban surface runoff for groundwater recharge
- Holistic urban water balances and construction of sustainable water systems in the fast growing urban areas
- Quantification of the impact of MAR in terms of evaporation prevention
- Cost-benefit analysis of MAR within the IWRM framework under the consideration that all the recharged water volumes (irrespective of the recovery possibilities on spot) are effectively adding up to the total water availability in the Jordan River basin.

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