Assessing water supplies for irrigation - availability of natural resources and sustainability indices

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Abstract

Sustainability indices should indicate the renewability of water resources compared to consumption in commonly known units. Simple quantitative concepts are proposed for their evaluation. The applied indices express water demand in terms of water supply areas and water supply periods required for the replenishment of water resources by natural or artificial recharge. A comparison of estimated present day recharge rates to the actual consumption in a case study (Disi aquifer, Jordan) highlights the urgent need to re-assess management policies.

Keywords: Irrigation, sustainability, groundwater, Disi aquifer

Introduction

In several countries of the eastern Mediterranean severe over-exploitation of groundwater resources took place and still takes place. Some coastal aquifers have been heavily affected by seawater intrusion or have been destroyed due to over-exploitation. The main reason for high abstraction rates are high water demands for irrigation during the summer season. The increasing competition between water uses for the agricultural sector on the one hand and demands for drinking water supplies, industrial uses and the tourist sector on the other hand requires political or market oriented regulation and adequate decision indicators.

The impacts of over-exploitation on groundwater availability and on groundwater quality are often experienced only after long time periods due to long turn-over times of groundwater reservoirs. Still, in many cases the knowledge that severe over-exploitation took place did not prevent such practice. This may be due to the missing clarity and preciseness of terms in which groundwater renewal and sustainability were described so far. Water requirements for irrigation are often given in per capita volumes or in volumes of water per crop unit. However, these ratios are not related to the **availability of groundwater**. A novel approach integrating climatic data and the increasingly important potential of treated water into a *Water Poverty Index* (WPI) was proposed by Salameh (1998).

Following this line of thinking simple indices providing direct and quantitative information on the sustainability of irrigation (and any other abstraction or consumption) schemes as a function of available resources were introduced. These indices were chosen so as to show the degree of over-exploitation directly in concrete terms, implying also an ideal state of system utilisation. Their application was tested in a case study on the Disi aquifer, Jordan.

Concept

The evaluation of sustainability of groundwater exploitation schemes is based on the comparison of natural and artificial renewal of groundwater resources on the one hand with the sum of abstraction and system outflow on the other hand.

Groundwater renewal may take place through rainfall recharge, losses from streams/canals or lakes/pans. A wealth of estimation techniques exists, also for drylands (Simmers, 1997 for further reference). Water balance approaches, indicators related to solute transport (chloride method) and isotope methods have been used successfully for the estimation of groundwater recharge.

It must be taken into account that also lateral groundwater inflows from other areas may contribute to the balance if the study area is not a closed system. In general groundwater systems also have groundwater outflow on the negative side of the balance. Although groundwater and baseflow discharge is unproductive in terms of quantities, it is essential for the removal of solutes from the system. Hydrochemical mixing modelling has been used successfully for the evaluation of lateral groundwater in- and outflow (Adar et al., 1988). If more detailed information on the aquifer properties are available also hydraulic estimations or discrete groundwater flow models may be applied.

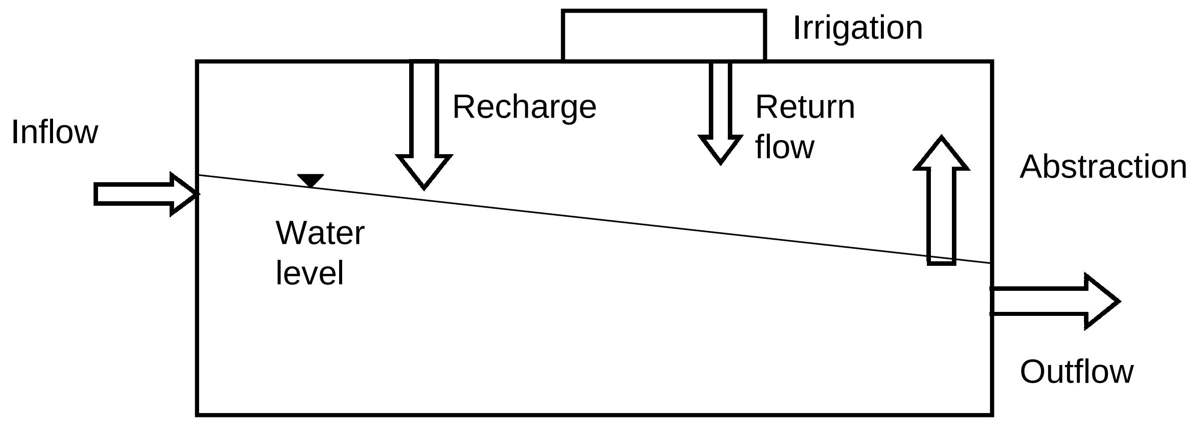

Figure 1 Components of the water balance to be considered for the assessment of sustainability indices

The difference between recharge and groundwater inflow on the one hand and groundwater outflow on the other hand is the quantitative safe yield of the system that can be abstracted without affecting the long-term water balance. In fact, inflow, outflow and recharge may also **depend** on the amount of abstraction and on the storage of the system. This feed-back is caused by the dependency of in- and outflow on water-levels. An extreme case is given if groundwater levels reach the capillary fringe. In this case the outflow of water by evaporation increases dramatically and the outflow of solutes decreases proportionally causing severe salinization. Such feed-back mechanisms resulting in critical cases of system failure must be considered conceptually but are not amenable to inclusion into the proposed quantitative indices.

Still, an integral part of the assessment of sustainability is groundwater quality (Salameh, 1996). Here, the recycling of return flow from the irrigation area into the aquifer is a crucial parameter as it results in an enrichment of solutes in the groundwater system. Therefore also the degree to which groundwater is recycled must be included into the assessment of sustainability.

Methodology

The above concept implies the following procedure for the assessment of sustainability indices:

1. balancing the total annual amount of consumption
2. delimiting the area of the hydrological/hydrogeological system that contributes to the abstraction scheme
3. estimating recharge within the system boundaries of the hydrological/hydrogeological system
4. building sustainability indices as consumption/recharge ratios in terms of supply area or supply period

Information on the first two items is taken from topographical maps and from previous hydrogeological investigations. The water balance approach (Udluft & Kuells, 2000) and the chloride method (Allison et al., 1994) have been used to assess natural recharge. The water balance model uses daily meteorological variables (rainfall, temperature and relative humidity), soil and vegetation parameters for the prediction of fluxes within the soil. It calculates runoff, actual evaporation and groundwater recharge. The actual evaporation concentrates chloride in the soil water. This effect can be used as a secondary indicator of groundwater recharge. The chloride method is based on the principles of water movement in soils and concomitant solute transport. The combination of these methods is straightforward and offers the additional advantage of cross-validation.

By dividing total groundwater consumption by recharge per unit area we obtain a **water supply area** (WSA, here given in km²). It corresponds to the area sustaining water consumption by natural recharge generation. A **water supply period** (WSP) is obtained if we divide total consumption by the total annual recharge of the hydrogeological system. It corresponds to the time (in years) that is needed to replenish the water resources consumed by a production unit without allowing for lateral water import. If we cumulate the water supply period over time it immediately indicates the water dept or the time that is needed to fully restore water resources by natural recharge. Finally, a water recycling index is proposed relating return flow to the estimated sum of groundwater inflow and direct recharge. The higher this index becomes the higher the degree of salt accumulation will be.

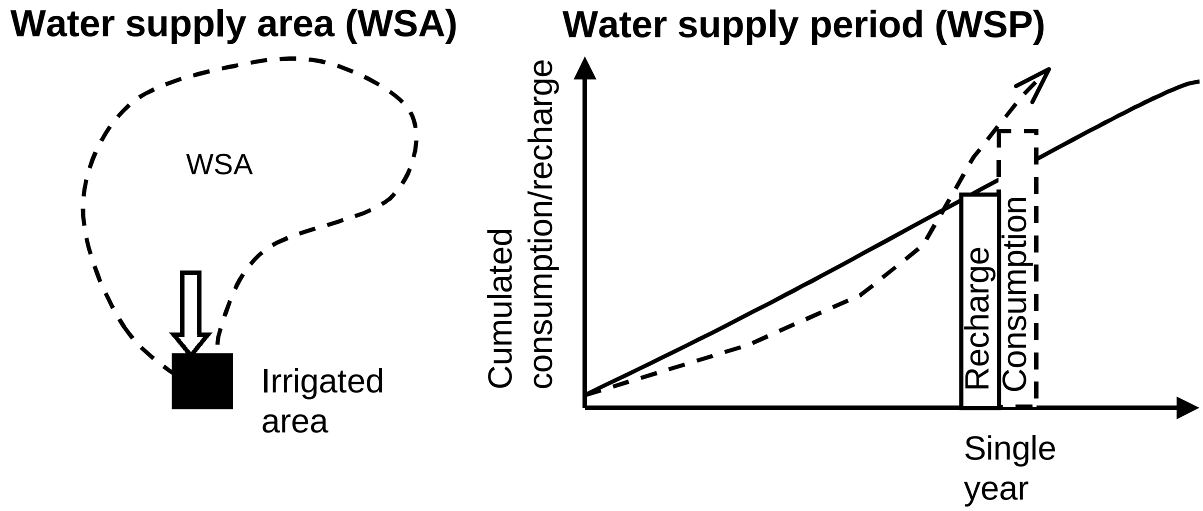

Figure 2 Water supply area and water supply period as indices of sustainability, the dashed line (right) indicates the cumulated consumption, the full line (right) shows the cumulated recharge

Two state variables of the groundwater system indicate system trends: Water levels and halogen concentrations respond directly to over-exploitation and recycling and should be monitored in any case on a long-term basis.

Results

The estimation of groundwater recharge in several study areas in Jordan showed a strong temporal and spatial variability of recharge rates (Udluft & Kuells, 1999). Recharge rates of up to 28 litre/y*m² were determined for the Disi aquifer by the chloride method (Salameh, personal communication). The total area is approximately 1,800 km². By integrating recharge over the estimated intake area, the total natural replenishment could reach up to 50 MCM (10^6 m³) per year. Previous estimates of inflow into the Disi area gave approximately 30 MCM (Salameh, 1996). The total sustainable yield including groundwater inflow vary accordingly between 17 and 28 l/y*m².

The evolution of consumption from the Disi aquifer between 1969 and today is given in Table 1. It also shows the water supply areas and the water supply periods needed to sustain consumption at different times. Without brackets the indices are given compared to direct recharge, within brackets the indices are calculated based on the total natural supply including lateral inflow.

Table 1 The development of abstraction from the Disi aquifer compared to recharge and inflow with water supply areas and water supply periods

Year	1969-82	1982-85	1985-?
Abstraction (MCM)	~ 0.3	15	85
WSA (km²)	11 - 17	536 - 882	3,035 - 5,000
WSP (years)	< 1	<1	1.7-2.8

Compared to estimated recharge the consumption in this area resulted in an increase of the water supply area (WSA) from 11 to 17 km² in 1969 to 3,035 to 5,000 km² for abstraction after 1985. This is the recharge area that would be needed to sustain abstraction by direct natural recharge, only. However, taking into account the possibility that the hydraulic calculation of lateral inflow was over-estimated due to fossil groundwater level gradients the later figure should be used with care. In terms of water supply periods (WSP) there has been an increase from < 1 year to 1.7 to 2.8 years compared to natural recharge. Hence, the equivalent of about 2 to 3 year’s annual recharge was pumped from the aquifer after 1985. This deficit has accumulated to a deficit of at least 25 years of recharge.

Conclusions

Since 1985 the equivalent of **25 to more than 40 times** the annual recharge has been pumped from the Disi aquifer (depending on the amount of estimated recharge per year). Neglecting feed-back and storage effects this represents also the range of years needed for a natural recovery of the system. It is possible that recharge is actually lower and time for recovery even longer. No data for the estimation of water recycling indices were available. But it is known that some recharge from irrigation return flow takes place. This might alleviate the situation quantitatively but creates problems of increasing salinity. In conclusion, the study highlights the need to adapt the abstraction from the Disi aquifer to available recharge in view of sustainable management.

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