15th Iranian Hydraulic Conference, 14-15 December 2016
Faculty of Engineering and Technology, Imam Khomeini International University,
Qazvin, Iran

On the Contribution of Hydrogeology to the Integrated Water Resources Management of Arid Environments based on Studies from the Middle East

Randolf Rausch[1], Heidi Megerle[2]
Water Resources Management - University of Applied Forest Sciences
Schadenweilerhof
D-72108 Rottenburg am Neckar / Germany

randolf_rausch@yahoo.de

Abstract

Arid environments are characterized by low rainfall, high evapotranspiration and rarely perennial surface water bodies. Groundwater is often the only important water resource. Therefore the knowledge of hydrogeology is a prerequisite for the sustainable use and management of the groundwater resources in these regions. However, almost all hydrogeological investigation and modeling tools had been primarily developed for application in humid areas. As the hydrological situation of arid areas differs significantly from humid regions the investigation methods must be adapted to local circumstances. More than twelve years of field research and consulting in the Middle East using the latest technologies showed clearly the importance of hydrogeology for IWRM in arid regions. The publication points out different approaches and methods with examples from the Middle East especially from the Arabian Peninsula.

Keywords: Arid environments, integrated water resources management, groundwater resources assessment, groundwater management, Middle East.

1. INTRODUCTION

Arid environments are characterized by low but intense rainfall, high temperature yielding to a high evapotranspiration, scarce vegetation, thin or missing soil cover and rarely perennial surface water bodies. Therefore groundwater often is the only important water resource. As arid areas cover approximately one third of the land surface and are actual home to about one billion people, with a dramatic increase in population, a sustainable water management is not only vital for local population, agriculture and livestock, but also for the political stability of these regions. The impacts of climate change and the finite nature of fossil groundwater exacerbate the already critical situation. More than twelve years of field research and consulting in the Middle East using the latest technologies showed clearly the importance of hydrogeology for IWRM (Integrated Water Resources Management) in arid regions.

2. CRUCIAL ROLE OF HYDROGEOLOGY FOR IWRM IN ARID REGIONS

As groundwater is often the only important water resource in arid regions hydrogeology plays a crucial role for integrated water resources management. The hydrogeologist is responsible for the provision of a sound data base for water authorities and political decision makers. The most important items include:

- Establishment of a precise and reliable groundwater balance (especially in- and outflows of the aquifer system).
- Assessment of groundwater resources (especially availability and quality).
- Management plan for groundwater resources (best practice, sustainability).

3. ASSESSMENT OF GROUNDWATER BUDGET

The assessment of the groundwater budget in arid regions comprises firstly the identification and secondly the quantification of the different water budget components. Furthermore, we have to distinguish between two different states, the so called predevelopment state and the present state. The predevelopment state is defined by a site which is in its natural condition prior to any major human activity, e.g. prior to the introduction of motor pumps. During this time a more or less sustainable water use took place, which was controlled by the natural water supply. The present state is normally characterized by an unsustainable groundwater abstraction (see Figure 1). As arid environments have a high proportion of fossil groundwater, Groundwater mining takes place, meaning that more water is taken from storage than is actually recharged. Results are declining groundwater levels, large groundwater drawdowns, drying up of wells, in some places land subsidence, and often a deterioration of groundwater quality. This leads to a conflict between the different users (agriculture, industry and domestic users) as well as between the present and future generation.

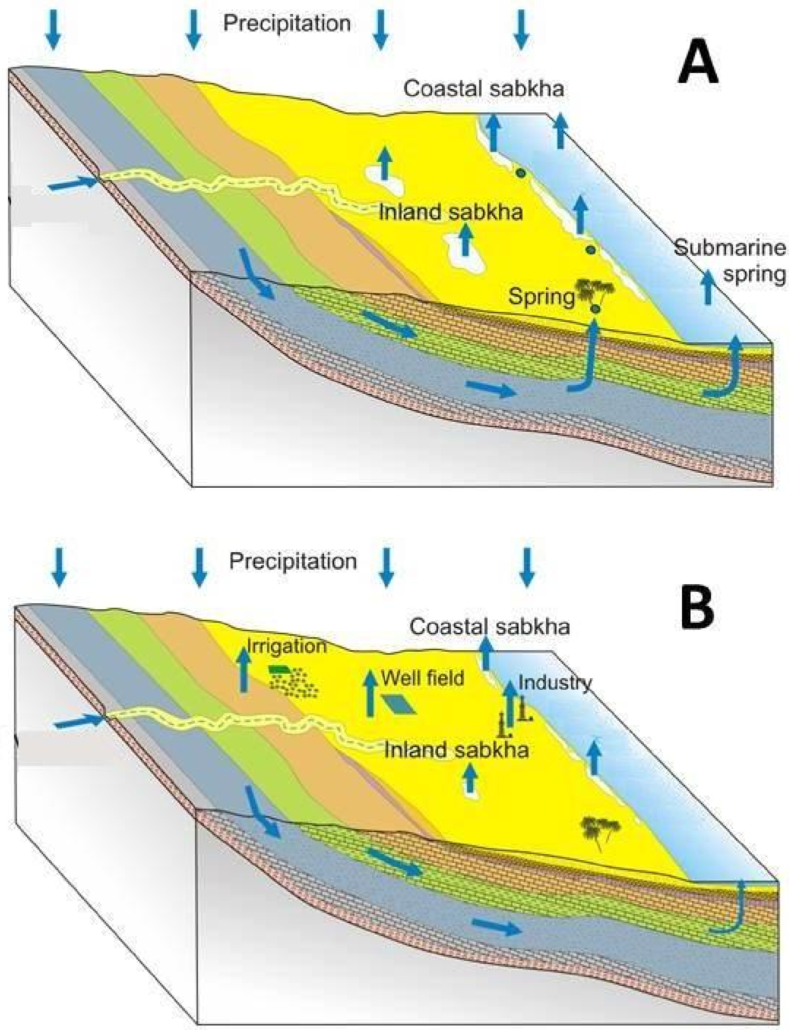

Figure 1. Schematic sketch showing the different groundwater budget components for (A) the predevelopment state and (B) the present state for the aquifer system on the Arabian Platform (Arabian Peninsula). Modified from [1].

Considering the water budget components we see that the main inflow component is the groundwater recharge from precipitation. The outflow components are spring discharge, groundwater discharge to inland and coastal sabkhas and finally groundwater discharge directly into the sea in coastal areas. In some areas submarine springs exist [2]. In the present state the outflow is dominated by abstraction for agricultural, industrial, and domestic water use.

Groundwater recharge from precipitation depends essentially on the amount and intensity of precipitation, evaporation rate, soil condition, plant cover, and topography. Due to the high intensity and spatial variability of the rainfall and low infiltration capacities of the soils indirect groundwater recharge prevails in arid region. Nevertheless, for the quantification of the recharge rate standard hydrological methods can be used. These methods include direct on site measurement of groundwater recharge [3], [4], [5], [6] or different indirect methods, e.g. by calculating the recharge rate from climate and soil data. However, we have to keep in mind that most of these methods are developed for humid regions and their accuracy is often in the range of the actual groundwater recharge in arid regions. Figure 2 shows a graph of annual groundwater recharge versus precipitation for selected countries in the Middle East. Figure 2 illustrates that the annual groundwater recharge rates are in the range from 1 to 10 mm per year [1].

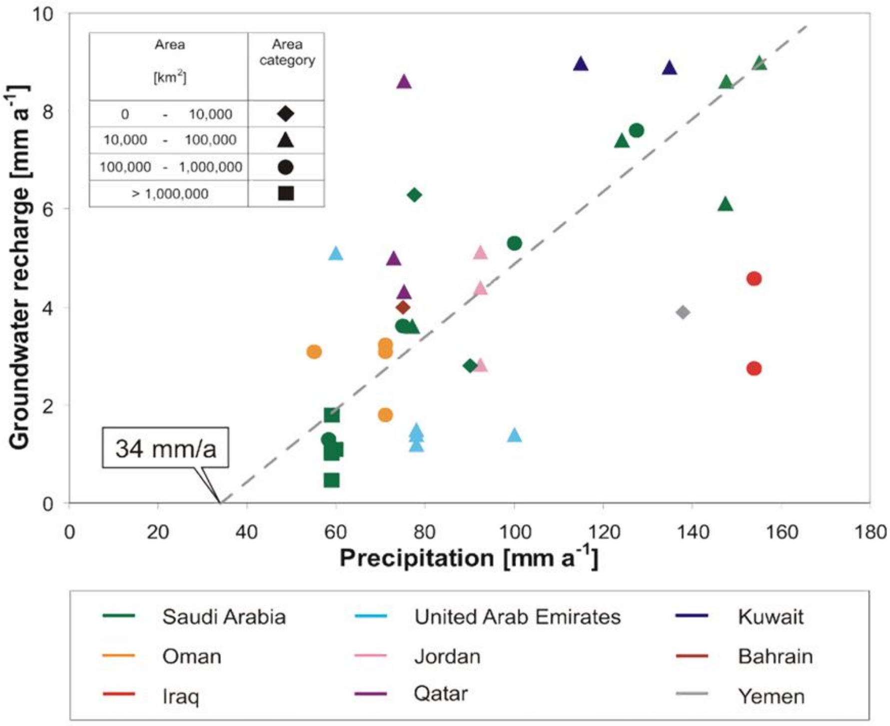

Figure 2. Annual groundwater recharge versus precipitation in millimeter per year for selected countries in the Middle East. The symbols are an indicator for the area size of the corresponding catchments for which the groundwater recharge was estimated.

Recent spring discharge is easy to measure while historic discharge from old files often requires corrections and interpolation. The discharge from inland and coastal sabkhas is difficult to measure on site. Indirect methods using remote sensing techniques for the identification of active and inactive sabkhas combined with ground truth offer an alternative [7]. While for the domestic and industrial water demand often reliable information are available, data from agricultural water consumption is rare. In many cases no metering of the irrigation water is made. As an alternative the estimation can be done by a combination of remote sensing (interpretation of satellite images) combined with ground truth investigations. From satellite imagery the irrigated areas can be identified by calculating the Normalized Difference Vegetation Index (NDVI). Whereby high NDVI values indicate healthy and well irrigated vegetation, low positive value stressed respectively natural vegetation and a negative value no vegetation. This information is then linked to ground truth information from the farms which consists of the actual crops and their individual water demand. Table 1 gives a list with the corresponding uncertainties in the quantification of the different water budget components. Furthermore, a qualitative assessment of the process understanding is given.

Table 1- Components of water budget, assessment of uncertainty, and process understanding (from [1])

Inflow components:	Uncertainty (%)	Process understanding
Groundwater recharge	>100	poor
Outflow components:		
Natural discharge:		
Spring discharge	20	good
Inland and coastal sabkhas	75	moderate
Discharge to sea	>100	poor
Groundwater abstraction:		
Agriculture	20	good
Industry	15	good
Domestic water demand	15	good

It must be mentioned that for the interpretation of the water budget of a catchment area not only the uncertainties of the different budget components should be taken into consideration. Furthermore, the size of the catchment area is important. For example if we consider a small area, groundwater recharge often can be neglected or set to zero. However, this approach is no longer valid if we consider a large aquifer system. Even in case of small groundwater recharge rates big water volumes are obtained by multiplying the recharge rate with the corresponding recharge area.

4. ASSESSMENT OF GROUNDWATER RESOURCES

The estimation of the groundwater resources in storage can be made either by calculating the static groundwater resources in a traditional way or by calculating the dynamic resources by using mathematical groundwater models.

For the estimation of the static ground water volumes in storage, the knowledge of the geometry and the storage properties of the aquifer are required. While the determination of the aquifer geometry respectively the aquifer volume is relatively simple, reliable and accurate, the determination of the aquifer properties (storage coefficient, specific yield) is generally less accurate. As the evaluation of pumping tests shows, the error in the determination of the storage coefficient can easily be up to a factor of ten. Furthermore, it must be mentioned that groundwater volumes estimated with this approach are often academically. That means that only a small part of the predicted amount of water can be technically and economically extracted. This figures lead often to wrong expectations when they are presented to laymen. Using this method we have to distinguish between the total groundwater resources in storage and the exploitable groundwater resources. The exploitable groundwater resources are restricted by constraints like groundwater quality as well as technical and economic constraints like drilling depth, pumping height, and distance to consumer.

The other approach is the use of a regional groundwater model that will be continuously updated. The estimation of reliable aquifer parameters can be improved by the analysis of so called mega-pumping tests. Mega-pumping tests are large-scale groundwater withdrawals that took place in agricultural centers. The long-term abstraction of groundwater for irrigation and the corresponding groundwater drawdown can be regarded like a long term pumping test [1]. The evaluation of these tests shows that this approach allows a sufficiently accurate determination of the storage properties on a regional scale. - Thus enables an optimal estimation of groundwater volumes. For the calibration of these models all information about the aquifer should be compiled. This approach is highly recommended to reduce the degrees of freedom during the calibration process. It is recommended to make a joint use of head and flow and if available concentration measurements. This approach includes not only information about groundwater heads, and in- and outflows. Information about the geology, sedimentology, tectonics, landscape development, water quality, and information from environmental isotopes should be included in the model. Examples of this approach are given for example in [8], [9], [10], [11]. For the transient groundwater flow simulation information about the climate development during the past are needed. These data can be obtained from the analysis of climate archives which give us an idea about the temporal climate development in the past.

5. MANAGEMENT OF GROUNDWATER RESOURCES

The major challenge of the smart management of the groundwater resources is: (1) to mitigate the user conflict between municipal and agricultural users, (2) to protect the dwindling resources, and (3) to implement an economic view on the water sector. Facing these challenges ensures the best use of the non-renewable resources, turning them into economic and social welfare for the population [12], [13].

The tools for the IWRM are the above mentioned

- Groundwater models, furthermore,
- Economic models for costs and infrastructure, and
- Prognostic models for water demand.

The calibrated groundwater model serves as the prediction tool for the simulation of future possible scenarios. For example we can use the groundwater model as a decision tool for the planning of new well fields, for the optimization of groundwater abstraction strategies especially with respect to groundwater mining or the simulation of the upconing or intrusion of salt water. Experiences showed that intelligent schemes make a huge economic difference. Furthermore, the groundwater model will be coupled with prognostic water demand models for different future scenarios. The impact of climate change can be included easily, e.g. by incorporating regional climate model predictions for precipitation changes and calculating the corresponding groundwater recharge.

6. CONCLUSIONS

The IWRM of arid environments needs a profound knowledge about the hydrogeology of the region of interest. Robust data about the groundwater budget and the groundwater resources in storage are necessary. These data are the basis of a smart management water management.

7. REFERENCES

1. Rausch, R., Dirks, H., Al-Ajmi, H. (2013): Zur Hydrogeologie des „Oberen Mega-Aquifer-Systems“ auf der Arabischen Halbinsel. – *Jh. Ges. Naturkunde. Württemberg, Sonderband*, S. 119-145, 22 Abb., 2 Tab.; Stuttgart.

2. Rausch, R., Dirks, H., Kallioras, A., Schüth, C. (2014): The riddle of the springs of Dilmun – Does the Gilgamesh epic tell the truth? – Historical note. – *Groundwater*, Vol. 52, No. 4, pp. 640-644, 4. Fig.

3. Kallioras, A., Khan, A., Reshid, M., Todoroff, P., Pfletschinger, H., Schüth, C., Rausch, R., Al Saud, M. (2011): Investigation of groundwater recharge through unsaturated zone studies in arid regions. – *Geophysical Research Abstracts*, Vol. 13, EGU2011-13475.

4. Kallioras, A., Piepenbrink, M., Khan, A., Reshid, M., Rausch, R., Dietrich, P., Schüth, C. (2012): Investigation of isotopic signals in the unsaturated zone with the use of direct push technology and azaeotropic distillation. – *Acque Soutterranee* - *Italian Journal of Groundwater*, p. 39-46, 10 fig.

5. Schüth, C., Kallioras, A., Piepenbrink, M., Pfletschinger, H., Al-Ajmi, H., Engelhardt, I., Rausch, R., Al Saud, M. (2010): New Approaches to Quantify Groundwater Recharge in Arid Areas. - *The 4th International Conference on Water Resources and Arid Environments (ICWRAE)*, 7 p., 4 fig.; Riyadh.

6. Schulz, S., De Rooij, G., Michelsen, N., Rausch, R., Siebert, C., Schüth, C., Al Saud, M., Merz, R. (2015): Estimating groundwater recharge for an arid karst system using a combined approach of time lapse camera monitoring and water balance modeling. – *Hydrological Processes*; Wiley.

7. Schott, U., Faber, P., Jensen, H., Rausch, R. (2008): Groundwater Evaporation from Sabkhas in the Northern Rub' Al Khali Desert – Identification and Characterization of Active Sabkha Areas. – FH-DGG-Tagung 2008. *Schriftenreihe der Deutschen Geol. Gesellschaft für Geowissenschaften*, Heft 57, S. 170; Hannover.

8. Schüth, C., Rausch, R. (2009): Modeling and Managing Regional Aquifers in Arid Countries. – *AGU Fall Meeting 2009*; San Francisco.

9. Kalbus, E., Oswald, S., Wang, W., Kolditz, O., Engelhardt, I., Al-Saud, M., Rausch, R. (2010): Large-scale Modelling of the Groundwater Resources on the Arabian Platform. - *The 4th International Conference on Water Resources and Arid Environments (ICWRAE)*, 17 p., 4 fig., 1 tab.; Riyadh.

10. Engelhardt, I., Rausch, R. Lang, U., Al Saud, M., Schüth, C. (2013a): Impact of Pre-boreal to Subatlantic shifts in climate on groundwater resources on the Arabian Peninsula. - *Environmental Earth Sciences*, 69 (2), pp 557-570; Springer.

11. Engelhardt, I., Rausch, R. Keim, B., Al Saud, M., Schüth, C. (2013b): Surface and sub-surface conceptual model of an arid environment with respect to mid- and late Holocene climate changes. - *Environmental Earth Sciences*, 69 (2), pp 537-555; Springer.

12. Dirks, H., Rausch, R., Fuest, T., Holtkemper, S., Schüth, C. (2013): Integrated Water Management in Arid and Semiarid Countries – Experiences of GIZ IS and Dornier Consulting in the MENA Region. – Abstract Book, *3rd International Conference of Ecosystems*, p. 46; Tirana.

13. Siebert, C., Rödiger, T., Schulz, S., Horovitz, M., Merz, R., Friesen, J., Dietrich, P., Michelsen, N., Kallioras, A., Rausch, R., Engelhardt, I., Al-Saud, M., Schüth, C. (2016): New Tools for Coherent Information Base for IWRM in Arid Regions: The Upper Mega Aquifer System on the Arabian Peninsula. - *Integrated Water Resources Management: Concept, Research and Implementation*, p. 85 – 106, 14 fig.; Springer.