Impact of urbanization on the Khash aquifer, an arid region of southeast Iran

E. KHAZAI

Department of Civil Engineering, University of Sistan and Baluchestan, Zahedan, Iran
e-mail: khazai@hamoon.usb.ac.ir

M. G. RIGGI

Sistan and Baluchestan Regional Water Authority, Zahedan, Iran

Abstract This paper investigates both the quantitative and the qualitative impacts of urbanization on the Khash aquifer. The results indicate a general fall in the groundwater level and deterioration of groundwater quality. However, there are cases of improvement in the groundwater quality owing to reductions in evaporation effects.

INTRODUCTION

Urbanization has a profound impact on groundwater hydrology. With increasing urbanization, both the quantitative and qualitative aspects of the hydrological cycle are affected by growth in population density and consequently an increase in the building density. Buildings and roads enlarge the impervious area and also modify the natural drainage system. Owing to the large impervious areas, a greater proportion of the incident rainfall appears as high velocity runoff and the volume of runoff increases (Hall, 1984; Oka, 1993). On the other hand, the runoff created may be ponded or conducted to an unlined sewage system which in turn may provide good conditions for recharge to take place (Rushton *et al.*, 1988). Furthermore, leakage from a water supply distribution system is a source of groundwater recharge (Lerner *et al.*, 1990). Urbanization may also cause radical changes in groundwater quality such as rising levels of salinity and nitrogen compounds as well as contamination by petroleum (Foster *et al.*, 1993). Hence urbanization influences groundwater level, flow regime and the quality of water in the underlying aquifer. The consequences of these influences, especially in developing countries where the urbanization expansion is not normally planned, may create serious difficulties. The difficulties are also enhanced by aridity. In such situations an efficient groundwater management is required to solve the existing problems and to prevent creation of further difficulties. This is only possible when the quantitative and qualitative impacts of urbanization on groundwater are known.

Several authors and organizations (e.g. Abu-Rizaiza *et al.*, 1989; Rushton, 1993; Foster *et al.*, 1993; Karimi, 1993; Zahedan Water Authorities, 1996) have investigated the consequences of urbanization impact on groundwater. Abu-Rizaiza *et al.* (1989) reported an annual rise of 0.5 m in groundwater level as well as potential health hazards in Jeddah, Saudi Arabia owing to urbanization effects. The rise of groundwater levels in Riyadh, Saudi Arabia, due to increasing urbanization has also been reported by Rushton *et al.* (1993). The main causes of the rise were recharge to the aquifer system due to losses from water mains, underground water tanks, septic tanks, garden irrigation and rainfall. Foster *et al.* (1993) analysed the various factors influencing flow systems within aquifers affected by urbanization. The analysis was supported by field data from five urban areas (Bermuda, Lima in Peru, Santa Cruz in Bolivia, Merida in Mexico and Hat Yai in Thailand) and other relevant literature. They clearly showed that the amount and nature of the influences depend on many factors such as the source of water supply, presence of stormwater drainage, type of sanitation and wastewater disposal system, hydrogeological conditions and climate.

Karimi (1993) has reported a fall of 5 m and a rise of about 1 m respectively outside and within urban developments in the Mashhad aquifer, northeast of Iran, during the period 1983–1993. He also reported bacteriological pollution of groundwater in this urban area. Zahedan Water Authorities (1996) have reported a general fall in groundwater level, a reduction in the areal extent of the aquifer, and deterioration of water quality due to urbanization in the Zahedan aquifer, southeast of Iran.

Therefore, the problems created in each aquifer are site specific which depend on conditions such as economy, climate, hydrology and hydrogeology. Therefore the groundwater management in an urban area can only be efficient if the nature and the extent of urban impacts on the groundwater in the area is known. In this paper, after a brief description of the study area, both the quantitative and qualitative impacts of urbanization on the Khash aquifer are investigated.

STUDY AREA

The 342 km^2 Khash aquifer underlies the Khash catchment which has a total surface area of about 2400 km^2 and occupies part of the Sistan and Baluchestan province in the southeastern part of Iran. The Khash catchment is made up of an alluvium plain surrounded by a steep mountain front. The thickness of the Khash aquifer varies owing to the undulating nature of the bedrock reducing to about 15–20 m in the central part but increasing to about 50–60 m in the northwest. The depth to groundwater varies in the aquifer area, from 58 m in the northwest and southeast to about 4.5 m at the aquifer outlet. The direction of groundwater flow is shown in Fig. 1. The value of transmissivity varies from 250 m^2 day^{-1} in the south east to about 2250 m^2 day^{-1} in the northwest part of the aquifer. The value of storativity in the northern parts is about 7% and in the other areas is estimated to be about 5%.

In the Khash catchment, as in other arid and semiarid regions, the indirect recharge mechanisms are the most important. Of the indirect recharge mechanisms, rainwater which infiltrates into the valley bed alluvium in the mountainous area drains down into the plain as subsurface flow and provides an important contribution to the groundwater. The magnitude of this contribution in some arid parts of southeast Iran may be about 60% of water reaching the aquifer as subsurface inflow (Khazai, 1997). The infiltration from the bed of ephemeral rivers in the plain as well as anthropogenic recharge are also valuable recharge mechanisms in the region. Table 1 shows the magnitude of the principle components of natural recharge to the Khash aquifer for the year 1992. The main source of groundwater recharge is upstream of the aquifer.

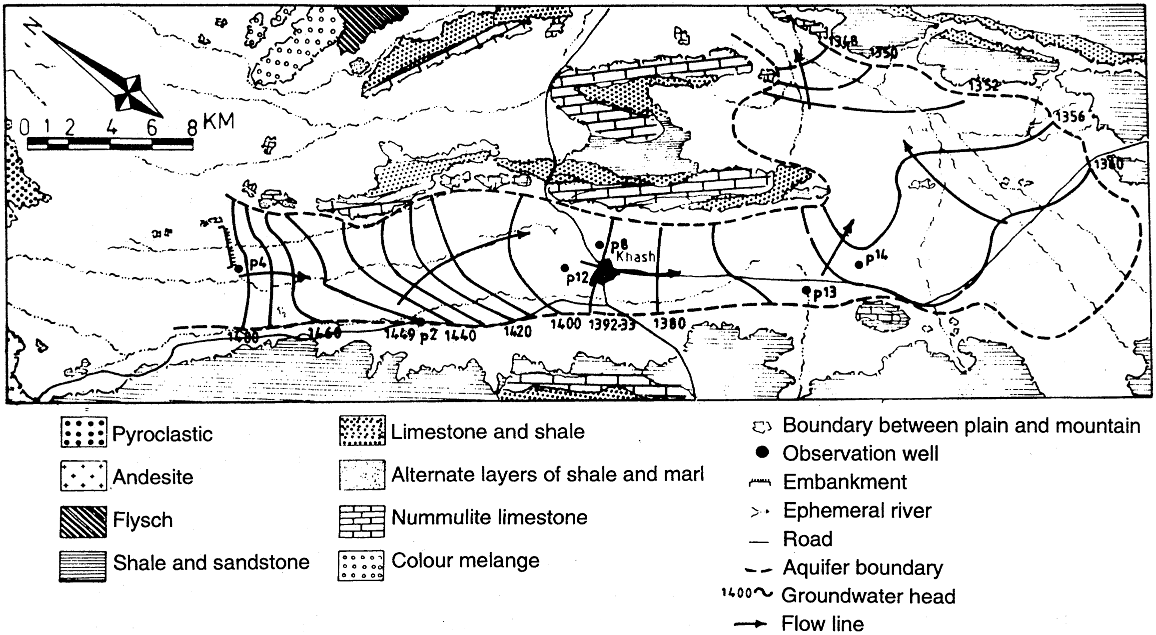

Fig. 1 Groundwater level contours in metres above mean sea level for November 1992 and the flow directions.

Table 1 Components of the natural recharge to the Khash aquifer for the year 1991 (after Tehran Sahab, 1992).

Subsurface inflow: Volume (Ml year^{-1})	% total natural recharge	Recharge from ephemeral rivers over the aquifer area (Ml year^{-1})	Total natural recharge (Ml year^{-1})
37 400	94%	2300	39 700

Therefore, the groundwater in this area has a better quality with an electrical conductivity of about 1000 µm. The quality deteriorates downstream of the aquifer so that the electrical conductivity may reach about 6000 µm.

QUANTITATIVE IMPACTS

Khash is one of the fastest growing cities in Iran. The groundwater from the Khash aquifer is the sole source of water supply to the city. The rapid growth of population has caused an increase in groundwater abstraction (Fig. 2) and an expansion of the city over the aquifer area has caused new conditions to be created.

Recharge from the city protection embankments In the Khash catchment rivers are ephemeral and the runoff has a "flashy" nature and may occur as damaging flood events. For this reason upstream of the city an embankment has been created for flood protection (Fig. 1) and the surface runoff gathered behind the embankment is a potential source for groundwater recharge.

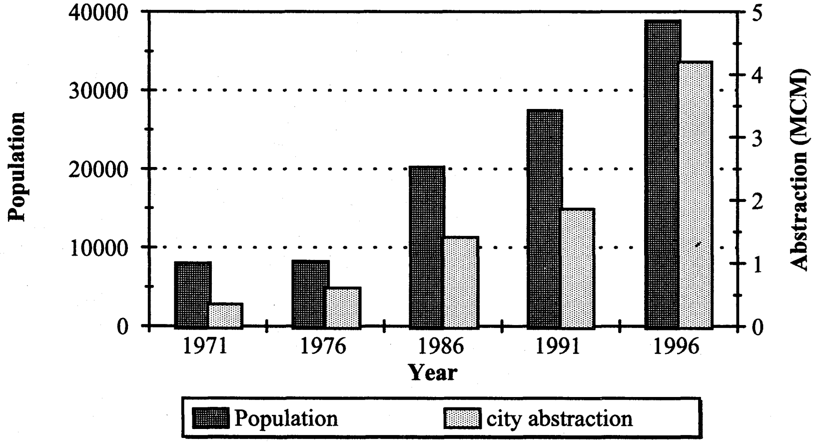

Fig. 2 Increase in groundwater abstraction from the Khash aquifer for urban use with urban population growth.

Recharge from the water collected in the roofs and yard of the houses In Khash rainwater from the roofs of buildings and the yards around houses is often conducted to absorber wells which provide a good source of groundwater recharge. The effects on recharge is more pronounced when there is a high intensity rainfall.

Through the water supply system The efficiency of the water supply distribution system in Khash is low (about 70%) owing to the bad quality of the water in the system which causes corrosion of the pipes. Hence the loss of about 30% may be considered as a source of groundwater recharge.

Through sanitation and wastewater disposal Since there is no main sewage system in the study area, the water which is used for washing and flushing is conducted to absorber wells, so again recharges groundwater but is also a source of pollution. According to Foster (1993) in such a situation about 90% of the water supply provided will end up as recharge to groundwater. However, considering the situation in the study area, recharge through sanitation and wastewater disposal according to the Khash Water Authority (personal communication) is about 80–85% of water used (metered).

Through domestic gardening and irrigation of amenity areas Usually some water from the distributed network is used for gardening and for irrigation of amenity areas. It is believed that, as the watering is done by unskilled persons, the quantity of watering is usually greater than that demanded by the vegetation, therefore some part of this water can move downward and recharge the aquifer.

Therefore the return water from urbanization effects is the sum of the returned water from the above sources. Riggi (1992) recommended a value of 50% of pumped water as a potential for groundwater recharge.

Irrigation A large amount of water is abstracted for agricultural uses from different parts in the aquifer outside the urban area. This produces changes both

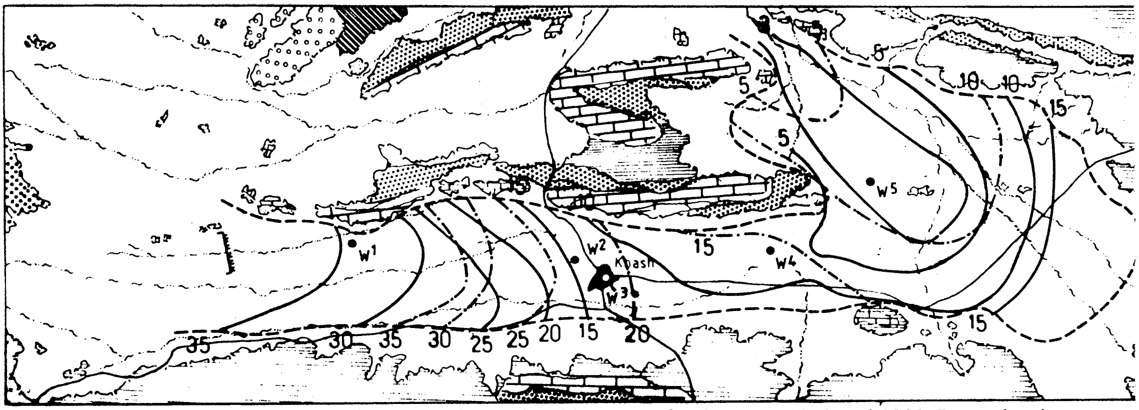

Fig. 3 Depth to groundwater level in metres for the years 1972 and 1992. Legend as in Fig. 1 except: 25—— depth to water table 1972, 25- - - - depth to water table 1992.

qualitatively and quantitatively in the groundwater system. Tehran Sahab (1992) recommended a value of 15% of the abstracted water as a recharge source. However, considering the situation of the study area and other similar areas, the authors believe that recharge from this source could be about 25%. The abstraction of groundwater from the aquifer as well as the introduction of new groundwater recharge due to urbanization has affected the groundwater level. There has been a general fall in groundwater level all over the aquifer area from 1972 to 1992 (Fig. 3). Figure 4 shows the change in depth to water table from 1987 to 1997 in six observation wells and the annual precipitation. Locations of the observation wells are shown in Fig. 1.

As can be seen in Fig. 4, in well P2 there was a sudden and continued rise in groundwater level from 1991 with water level responses clearly following the precipitation. The reason is that in this year an embankment was built upstream of the well which ponded surface runoff and provided a good source for recharging the

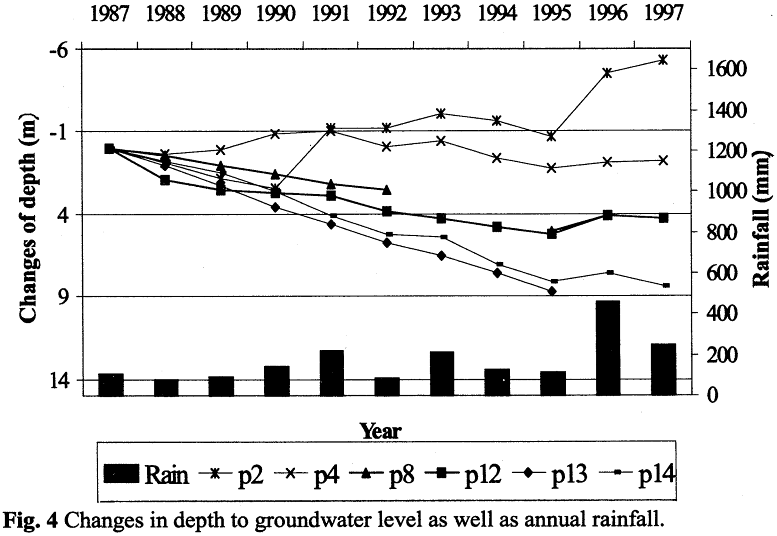

Fig. 4 Changes in depth to groundwater level as well as annual rainfall.

aquifer. Groundwater level in observation well P4 has a rising trend up to 1991 followed by a slight fall with the water level failing to respond even given the high precipitation in 1996. This well is also located downstream of an embankment which was built many years ago. The observed falling trend in water level and lack of rainfall response may be due to sedimentation of a clay layer behind this embankment. The groundwater levels in observation wells P8 and P12, which are located within the urban area, show less change than the observation wells P13 and P14 which are located outside and downstream of the urban area. The reason for this is that the new recharge mechanisms introduced following urbanization cause less change in groundwater level. The fall in groundwater level in the Khash aquifer has meant that some wells at the edge of the aquifer have become dry resulting in a reduction in the areal extent of the aquifer.

QUALITATIVE IMPACTS

Urban and agricultural development over the aquifer area have also affected groundwater quality. To show the nature of the effect, the electrical conductivity for five wells have been plotted in Fig. 5. Locations of the wells are shown in Fig. 3. As can be seen by reference to Fig. 5, except for well W5, the electrical conductivity has increased since 1972. The highest rise is seen in well W4 which is located downstream of Khash city. The cause for the increase is the circulation of groundwater generated by urban and agricultural development over the aquifer. However, the electrical conductivity shows a different behaviour in well W5 which is also located downstream of the aquifer. In this well the electrical conductivity reduced until 1987 and thereafter increased. The reason for the initial decrease is thought to be the reduction in evaporation losses due to the general fall in groundwater level, from less than 2 m to more than 5 m, in this area. However, the subsequent increase reflects the general deterioration of groundwater with time. Chloride trends show a similar behaviour to electrical conductivity.

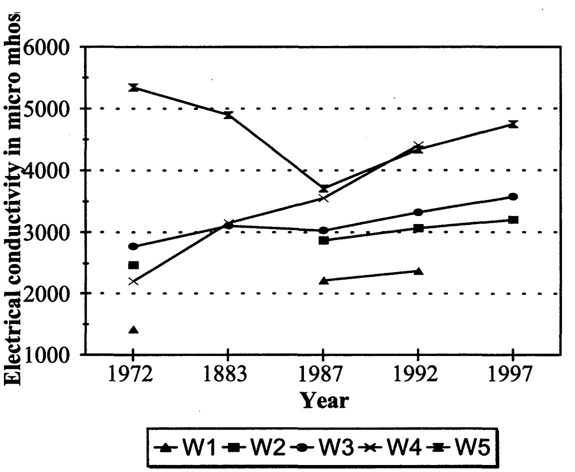

Fig. 5 The values of electrical conductivity in micro mhos.

Acknowledgements The University of Sistan and Baluchestan is gratefully acknowledged for sponsoring the first authors contribution. The authors thank Mr Noshavani, Mr K. Gorgij and other staff of the surface and groundwater division of Sistan and Baluchestan regional water authority in Zahedan and Khash for providing data and information.

REFERENCES

Abu-Rizaiza, O. S., Sarikaya, H. Z. & Ali Khan, M. Z. (1989) Urban groundwater rise control: case study. *J. Irrig. Drain. Div. ASCE* **115**(4), 588–607.

Foster, S. S. D., Morris B. L. & Lawrence A. R. (1993) Effects of urbanization on groundwater recharge. In: *Groundwater Problems in Urban Areas*. Instn Civil Engrs, Int. Conf. London.

Hall, M. J. (1984) *Urban Hydrology*. Elsevier Applied Science, London.

Karimi, H. (1993) Investigating the groundwater quality of Mashhad aquifer (in Persian). *Second Conference On Water Resources*. Ministry of Energy, Tehran, Iran.

Khazai, E. (1997) A conceptual model representing arid regions catchment with emphasis on groundwater recharge. PhD Thesis, University of Birmingham, UK.

Lerner, D. N., Issar, A. S. & Simmers, I. (1990) *Groundwater Recharge: A Guide to Understanding and Estimating Natural Recharge*. IAH no. 8. Verag Heinz Heise.

Oka, T. (1993) Changes of rainfall infiltration and runoff process due to urbanization. In: *Hydrology of Warm Humid Regions* (ed. by J. S. Gladwell) (Proc. Yokohama Symp., July 1993), 409–421. IAHS Publ. no. 216.

Riggi, M. G. (1992) Investigating the quality of groundwater in Khash aquifer (in Persian). MSc Thesis, University of Tehran, Iran.

Rushton K. R., Kawecki, M. W. & Brassington, F. C. (1988) Groundwater model of conditions in Liverpool sandstone aquifer. *J. Instn. Wat. Environ. Manage.* **2**(1), 65–84.

Rushton, K. R. & Al-Othman, A. A. R. (1993) Control of rising groundwater levels in Riyadh-Saudi Arabia. In: *Groundwater Problems In Urban Areas*. Instn Civil Engrs, Int. Conf. London.

Tehran Sahab (Consulting Engineers) (1992) *Artificial Recharge of Khash Aquifer*, Vol. 1 (in Persian).

Zahedan Water Authority (1996) Report about the groundwater situation in Zahedan (in Persian).