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Urbanization effects on groundwater quantity and quality in the Zahedan aquifer, an arid region in southeast Iran

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Abstract This paper investigates the quantitative and qualitative impacts of urban growth on the Zahedan aquifer (southeast Iran). Investigation revealed that the decline in groundwater level may reach about 15 m in some places, and that the direction of groundwater flow changes towards the heavily abstracted area. The EC in some places shows a rise from 2030 to 5799 μmho cm^{-1}. The level of nitrates has increased to 143 mg l^{-1} in the populated area owing to return of wastewater through the absorption wells. In general it can be said that unplanned development of urbanization in the area has created a very difficult situation.

Key words groundwater quality; groundwater quantity; groundwater pollution; urbanization and groundwater; Zahedan aquifer (Iran)

STUDY AREA

The Zahedan aquifer is located within the Zahedan catchment. The Zahedan catchment is about 1280 km^2 (29°9′41″–29°43′19″N and 60°35′00″–61°1′42″E) and occupies part of the Sistan and Baluchestan province in the southeastern part of Iran. The Zahedan catchment is composed of an alluvial plain surrounded by mountains. Within the plain, several outcrops coincide with individual hills. The Zahedan aquifer, which is about 146 km^2, lies in the plain. The thickness of the Zahedan aquifer varies with the maximum in the central part 20–40 m thick. The depth to groundwater in the aquifer varies from 70 m in the northwest and southwest, to about 10 m in the northeast.

In the Zahedan catchment, as in the other arid regions, indirect recharge is the primary input to the aquifer. Infiltration of rainwater into valley bed alluvium in the mountains and subsequent subsurface drainage into the plain is the main component of natural groundwater recharge (Khazai, 1997). In addition, the bed infiltration of ephemeral rivers is an important recharge mechanism.

URBANIZATION EFFECT

The city of Zahedan, the capital of the Sistan and Baluchestan province, was established in 1942 at the downstream end of the Zahedan plain (the northern part). Groundwater from the aquifer is the only water supply for the city. Zahedan city is one of the fastest growing cities in Iran. From 1976 to 1986, population growth was more than 11% (from 90 668 to 281 923 people, Fig. 1). The city has expanded to accommodate the rapid population growth. The expansion of the city (from 16 km^2 in 1955 to 126 km^2 in 1989, and about 160 km^2 at present, has created new hydrological

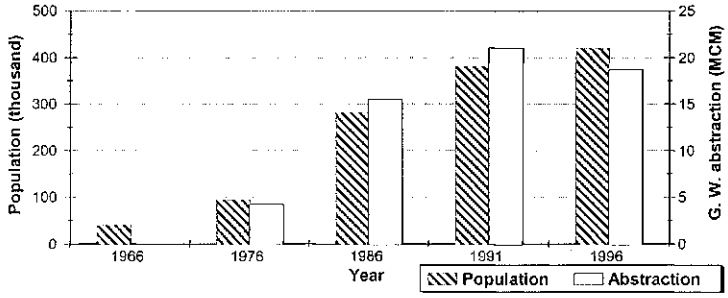

Fig. 1 Change of groundwater abstraction from the Zahedan aquifer for urban use, with population growth.

and hydrogeological condition. New recharge mechanisms have developed including: (a) recharge from city protection embankments; (b) recharge from the water collected on the roofs and yards of the houses; (c) leakage from the main water supply system, which is 26–38% (Ministry of Power, 1999); (d) recharge through sanitation of wastewater disposal (absorbing well system), which is 50–70% of used or metered water (Bandab Consulting Engineers, 1987); and (e) recharge through domestic gardening and irrigation of amenity areas. Groundwater recharge to the Zahedan aquifer from the urbanized area is about 65% of the pumped water (Bandab Consulting Engineers, 1987; Khazai, 1997). Urbanization, however, has affected the aquifer both quantitatively and qualitatively as discussed below.

Quantitative impact

The change in groundwater abstraction has accompanied the rapid population growth (Fig. 1), because groundwater is the only water supply for domestic, industrial, and agricultural uses for the Zahedan city. In 1996, despite an increase of population, groundwater abstraction decreased compared to 1991. The groundwater levels have fallen so much due to overexploitation that it is not possible to abstract more water from the aquifer, even with an increasing number of wells. In 1991, about 21×10^6 m^3 was abstracted from 25 wells, whereas in 2000, only 18×10^6 m^3 was abstracted from 33 wells. The change in groundwater level from 1977 to 1997 is shown in Fig. 2 and it follows that:

- groundwater levels throughout the aquifer have declined by a maximum of 15 m depth;
- the pre-urbanization direction of groundwater flow from all parts of the aquifer is towards the northeast. However, groundwater flow in 1997 has changed, especially in the southeast, where the flow is towards the central and northern part of the plain.

Water-quality impact

Urbanization has affected the quality of the groundwater in the Zahedan aquifer. The groundwater chloride concentration in 1977 was compared to that in 1997 (Fig. 3).

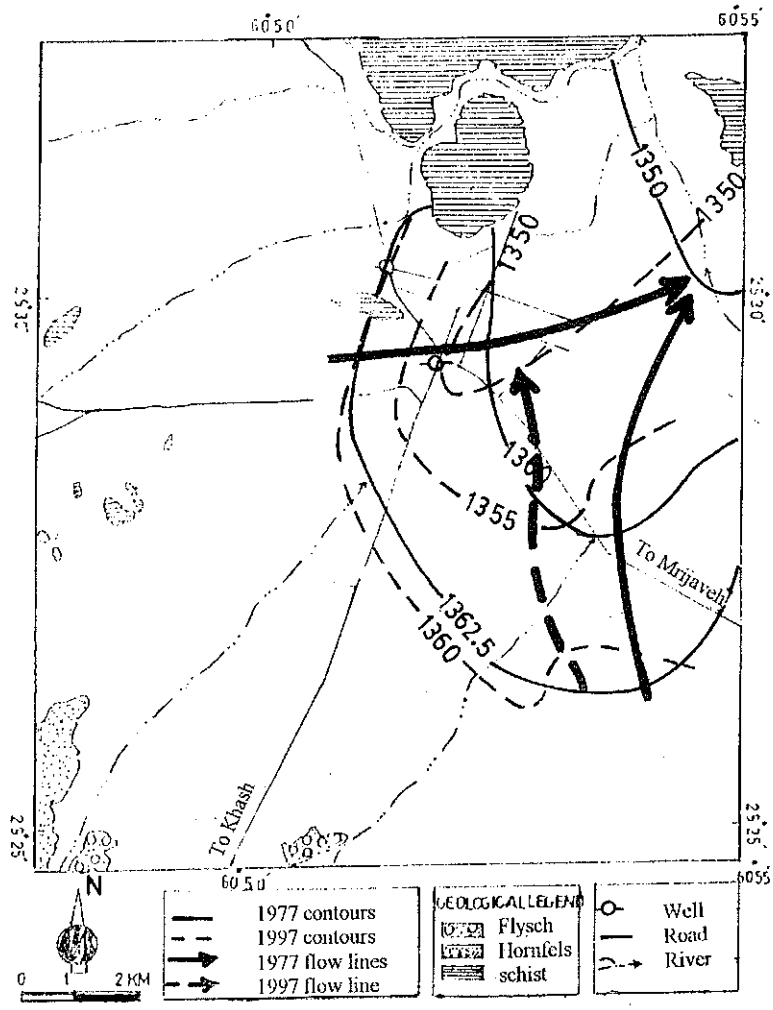

Fig. 2 Changes in groundwater level of the Zahedan aquifer from 1977 to 1997.

Groundwater salinity (chloride concentration) has increased markedly over all the aquifer area and the increase is attributed to:

- a cone of depression near Zahedan city has changed the flow direction (as discussed earlier), causing the encroachment of saline water from the southeast;
- recirculation of water through the absorbing wells in the unconfined alluvial aquifer is an important source for deterioration of groundwater quality. In Zahedan there is no main sewage system and untreated wastewater recharges the aquifer through absorber wells

The chemical composition of the groundwater and associated temporal changes are listed in Table 1. Groundwater quality of one of the main supply wells for Zahedan city (W2, for location see Fig. 3) degraded between 1974 and 1999 and exceeded the WHO health limit for Na^+, SO_4^{2-}, and NO_3^- (Table 1). Moreover, the rate of degradation resulted in an almost threefold increase in EC from 2033 μmho cm^{-1} in 1974

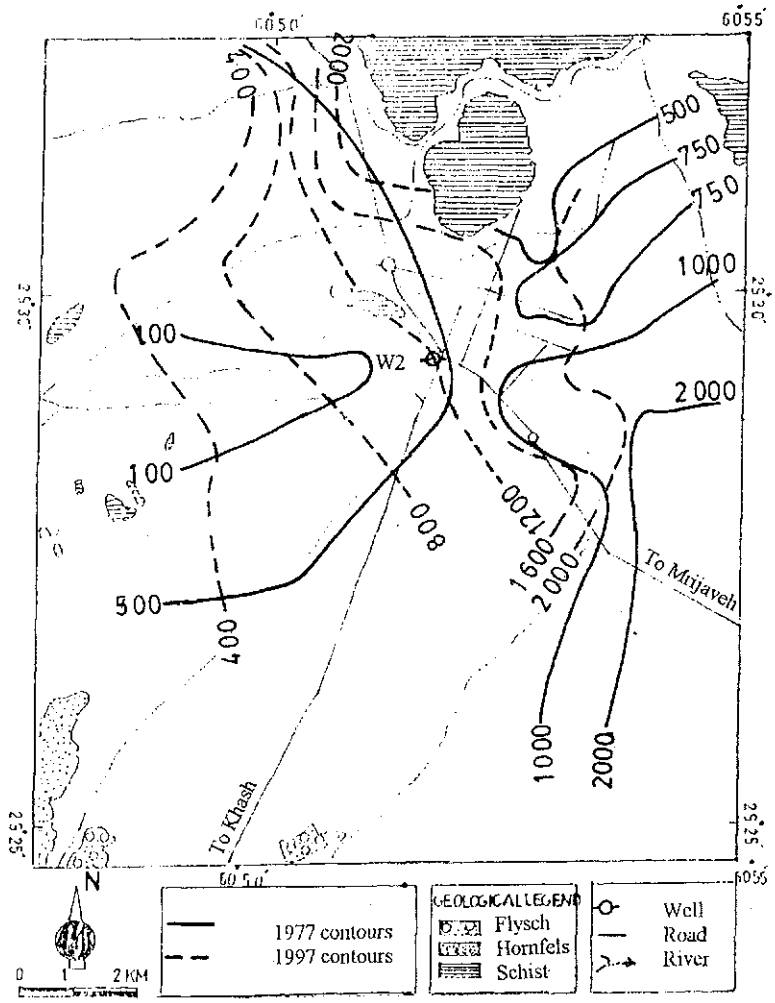

Fig. 3 Comparison of the groundwater Cl concentration in 1977 to that in 1997.

Table 1 Chemistry of groundwater from the main water supply well for Zahedan city (Well W2), compared with maximum admissible according to the World Health Organization (Appelo & Postma, 1996).

Collection year	Na^+ (mg l^{-1})	SO_4^{2-} (mg l^{-1})	NO_3^- (mg l^{-1})	EC (μmho cm^{-1})
1974	346.84	166	–	2033
1999	800.4	696	143	5799
WHO health limit	175	250	50	–

to 5799 μmho cm^{-1} in 1999. The high NO_3^- concentration (143 mg l^{-1}) is indicative of groundwater pollution by waste disposal through absorbing wells. However, the water quality degradation associated with the urbanization has become critical and groundwater can no longer be used for drinking. Even if the abstracted groundwater is rationed, water is not available for long periods because the demand far exceeds the supply. For example, if water resides in the supply system for eight hours there will be

none for about the following 72 h. Drinking water is supplied by public taps located in seven areas of the city. The drinking water is transported to the city from some local aquifers in the valley bed alluvium and about 25 tanker trucks bring drinking water from Mirjaveh, 60 km from Zahedan city.

Unplanned urbanization, in general, has caused this crisis, which should be a warning to authorities in similar regions, especially in developing countries. It is critically important that urban development be restricted and appropriate management strategies be implemented before a major health crisis occurs.

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