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Environmental Management in Sana'a Basin: Urbanization and Degradation of Groundwater Quality

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Abstract

Sana'a Basin is one of the intermontane basins on the western semiarid highlands of Yemen. Average altitude of the land surface is about 2200 m.a.s.l., and the area is about 3200 km^2. Sana'a City, the capital of Yemen, is located at the southern part of the area. During the last three decades, rapid urbanization activities has been taking place within the basin, and mainly in the Capital which has already exceeded the two million mark in population. To meet the increasing water demands, groundwater abstraction has surpassed replenishment rates by several orders of magnitude. Effects of the decline in groundwater levels are remarkable on the natural environment. In addition, contamination of groundwater caused by untreated municipal wastewater has been very serious. Different contaminants have been traced in well waters. For example, high levels of nitrates were found in well waters. The water crisis in the basin has two dimensions; groundwater quantity depletion and quality degradation. Preservation of the quality of strategic groundwater reserves is a priority. Measures to tackle the problem of groundwater pollution are not adequate. Significant activities have been carried out regarding the control of groundwater abstraction, but little efforts has been devoted to control groundwater pollution. This paper will discuss the issue of groundwater pollution in the Basin and the management instruments to control it.

Background

Sana'a Basin is located on the western highlands of Yemen. Sana'a City, the capital of Yemen, is situated at the southern part of the Basin (Figure 1). During the past three decades the City has grown to be the largest urban center in the country. Rapid urbanization has raised the population of the City to about 2 million. Urbanization is mostly in the form of new residential areas. Industrial activities are still a small portion of urban development.

Groundwater, the major source of water in the basin, has been pumped at depleting rates since the mid 1980's, as a consequence of the rapid urbanization and population growth and a sharp increase in water demand for agricultural and municipal uses. Groundwater depletion has been accompanied with deterioration in water quality. Groundwater abstraction surpasses recharge to meet the escalating demand for water in the Basin. Groundwater pollution due to untreated domestic and industrial wastewater is escalating as the urban area expands. The water crisis in the basin has two dimensions; groundwater quantity depletion and quality degradation.

Significant activities have been carried out regarding the control of groundwater abstraction, but little efforts has been devoted to control groundwater pollution. Well licensing and monitoring has been reinforced by authorities for some time. Measures to tackle the problem of groundwater pollution should be given a priority to conserve the strategic reserves of groundwater.

Basin Characteristics

Sana'a Basin is one of the intermontane basins on the western semiarid highlands of Yemen (Figure 1). The range of absolute elevations is from 1900 to 3000 m.a.s.l. On the western boundary, a high mountain peak reaches an elevation of about 3760 m.a.s.l. (*Jabal An Nabi Shu'ayb*). On average the altitude of the land surface is about 2200 m.a.s.l., and the area is about 3200 km^2. Topography of the Basin is marked by different landscape forms. Four major physiographic units define the topography in the Basin; plateau, terraced hillslopes, peneplains and wadis. Precipitation is low and the pattern is erratic. Distinct temporal and spatial variations in precipitation are observed in the area. Average annual precipitation is about 220 mm. Average annual temperature is about 19 ºC. With these climate characteristics the Basin is classified as semiarid area.

Herbaceous and shrub-arboreal vegetation, which is poorly developed, cover parts of the Basin; a type and intensity of vegetation which is closely associated with topography and climate. The vegetative cover is directly related to the amount and seasonal distribution of precipitation.

Surface features are dominated by rigid relief that defines the morphology of the area. High peak mountains, mainly formed of volcanic rocks, surround a number of Alluvial peneplains and terraced hills. Sana'a Basin has developed on a large graben within a structurally high region (Yemen Horst). Tertiary Volcanics, mostly weathered, cover most of the southern part of the Basin, and form most of the rigid terrain. Cretaceous Sandstones (Tawilah Formation) outcrop at the north eastern part of the Basin, over about 15% of the area. Covered by thick Quaternary Alluvial deposits in the middle part of the Basin and Tertiary Volcanics in other parts, the Tawilah Sandstones form the main aquifer in the Basin. The Formation dips to substantial depths southward. On the northern part of the Basin, the outcrops of the

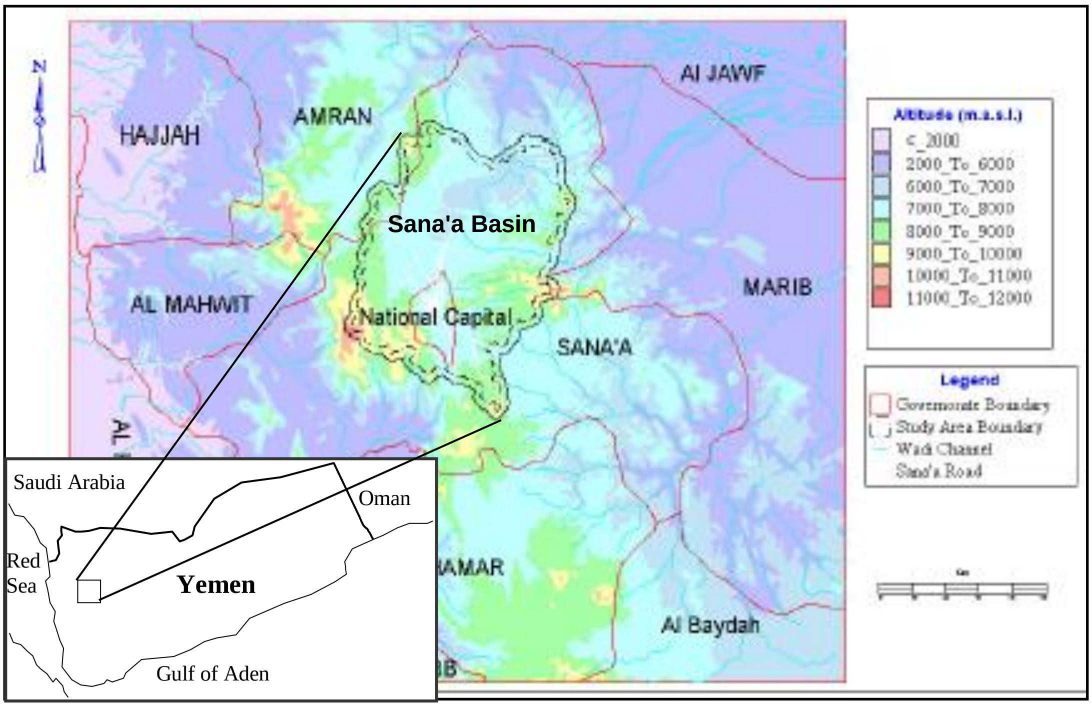

Figure 1: Location map of Sana'a Basin (WEC, 2004)

Jurassic Limestones (Amran Formation) are dominant. Outcrops of the Quaternary Volcanics prevail at the northwestern boundaries. Geukens (1966) concludes that the *"Sana'a Basin area is a large syncline…, which is the site of the old Jurassic Basin*."

Rain-fed agriculture has been the main economic activity in the rural area of the Basin for many years. About 110,000 hectares of arable land are available in the Basin, and about 20,000 of which are irrigated with groundwater, the major source of water in the basin.

Water Resources of the Basin

Sana'a Basin constitutes the watershed of *Wadi Al Kharid*. *Wadi Al Kharid* flows northwards, and eventually becomes part of *Al Jawf* surface water system, that debouches into the desert area of *Ramlat as Saba'atayn* eastwards. (Gun, van der and Ahmed, 1995). The general drainage pattern in the Basin is ephemeral; however, significant local differences observed at various parts. Differences are attributed to the complexity of the geological history of the Basin and to the variable climatic conditions. Based on these differences, the basin may be divided into separate hydrological units which can be divided into several groundwater zones, depending on the effective groundwater aquifers. Each groundwater zone includes a major wadi watershed.

Sana'a Basin is comprised of two hydrological units; *Wadi Al Kharid Hydrological Unit* and *Musyareka Hydrological Unit*. The northern *Wadi Al Kharid Hydrological Unit* constitutes about 30% of the area, while the southern *Musyareka Hydrological Unit* includes the balance. *Wadi Al Kharid Hydrological Unit* drainage pattern is along faults and fractures. *Musyareka Hydrological Unit* is a practically closed system, as runoff rarely crosses its northern boundary. Runoff waters infiltrate in the wadi channels. Within this unit is the main Alluvial plain, where Sana'a City is located. The main groundwater source in this unit is the Tawilah Sandstone aquifer.

In the Basin there are four aquifer types. The Tawilah Sandstones form the main aquifer in the Basin. The unsaturated Alluvial deposits convey recharge waters to the underlying aquifers. Although some wells in this layer are still productive, due to depletion this layer has become an insignificant aquifer. Weathered Volcanics are modest aquifers. Fractured layers of Amran Formation are considered very poor aquifer. The general trend of groundwater flow in towards the north.

Deep tube wells are constructed through the various aquifers to pump groundwater, which is mostly fossil water. About 9000 wells in the Basin are used to abstract groundwater for various uses. Most borehole depths in the Tawilah Sandstone aquifer vary from 100-400 m. Depth to water is between 50-150 m in most boreholes. Since the early 1970's the water level has been declining at a rate of 2-4 m/year (WEC 2004).

Most of the water is used for irrigation to produce cash crops. Municipal use comes in the next place. Industrial use is not significant when compared to the other two uses. The total annual abstraction for all uses is estimated at about 290 Mm^3. At best estimates, groundwater recharge is approximately 50 Mm^3. Mining fossil groundwater is underway, at an alarming rates, to fill the gap between abstraction and recharge. At present, the estimated exploitable strategic reserve of groundwater is 5212 Mm^3 (WEC, 2004). Table 1 shows the distribution of abstracted groundwater among different uses.

Table 1: Distribution of groundwater use in Sana'a Basin (Mm^3)

Use	1990	2000	2005	2010
Agricultural	113	205	240	283
Municipal	13.1	37.4	48.6	58.3
Industrial	-	4.2	5.6	7.7

Source: WEC (2001, 2004)

Groundwater, the major source of water in the basin, has been pumped at depleting rates since the mid 1980's, as a consequence of rapid urbanization and population growth. These conditions have lead to a sharp increase in water demand for agricultural and municipal uses. Groundwater depletion has been accompanied with deterioration in water quality.

Groundwater Quality

Prior research works have discussed groundwater contamination due to wastewater. According to Al-Eryani et al (1991), groundwater quality beneath the congested urban areas and in the vicinity of the stabilization ponds, north of the city, has deteriorated. At the wadis receiving effluent from the stabilization ponds, Al-Shaik (1993) identified the contaminated zones along the wadi channel that receives effluent from the stabilization ponds. At the middle part of the City of Sana'a, groundwater quality was found to be worse than other parts of the City. Well waters at this part contained high concentrations of nitrate (NO_3); in the range of 100-160 mg/l. Chloride (Cl) concentrations were found to be in the range of 220-400 mg/l and EC values ranged as from 975-2045 µs/cm, at the same zone (Al-Hamdi, 1994). These high values were attributed to wastewater contamination.

Regarding industrial wastewater, consistent data should be provided to derive realistic conclusions. Direct disposal of wastewater from vehicle maintenance shops into cesspits is a source of hydrocarbon pollution to groundwater. No reliable information is yet available on the extent and concentrations of hydrocarbons in groundwater. A considerable number of water samples from boreholes that range in depth from 100-400 m, in and around the City were analyzed. Different contaminants were identified in the samples, as shown in Table 2.

Groundwater quality in shallow wells in rural areas, where increasing development is

Table 2: Water quality in samples from boreholes that are 100-400 m deep in Sana'a Basin

	High	Average	WHO	FAO
Na	265	50	<200	<300
Cl mg/l	240	100	<250	<400
NO3 mg/l	272	15	<50	0-50
EC µs/cm	2499	800	1500	1500

Source: DHV Consultants (1996)

taking place, has been changing. Analysis of samples from a number of wells at the outskirts of the City ascertained this statement. Results of this analysis are shown in Table3.

Table 3 Water quality in shallow wells in rural areas in the northern part Sana'a Basin

Property \ Well Number	1	2	3	4	5
Depth m	43	43	22	18	14
pH	7.9	8	8.1	7.4	7.5
P mg/l	1.4	1.1	4.1	1.04	1.04
EC µs/cm	953	625	865	1222	1158
NO3 mg/l	9.6	52.7	4.2	49.7	49.7

Source: Boydell et al (2003)

Water quality in the middle area under the city is worse than other areas. Furthermore, the water quality north of the City, next to the treatment plant is even worse. A comparison of effluent and well water in the vicinity of the Wastewater Treatment Plant is summarized in Table 4.

Recently, analysis of groundwater samples in the area close to the Treatment Plant was carried out. The highest measured levels were: 2670 µS/cm for EC, 314 mg/l for nitrate (NO3)and 1628 mg/l for TDS. A value of 7.08 for pH was also found which indicated high acidity (NWRA-Sana'a Basin Division, 2006). Obviously, the levels are higher that what was reported in earlier studies, which confirm increasing contamination.

Table 4: Effluent and well water quality in the vicinity of the treatment plan north of Sana'a City

Property	Effluent	Well Water	FAO
pH	8.1 Alkaline	7.4 Neutral	6.5-8.3
EC µS/cm	2900 Saline	1000 Saline	<700
TDS	1750 Saline	700 Saline	<400
SAR	2.1 Med Sodium	2.7 Med. Sodium	<1.2
Chloride meq/l	7.7 High	4.2 Moderate	<10
Boron meq/l	2.5 High	0.3 Low	<0.5
Na meq/l	2.2	0.6	<0.3
Ca meq/1	19.0	3.7	0-20
Mg meq/l	7.3	1.4	0-5

Source: Yaseen (2001)

Urbanization and Environmental Issues

Sana'a City, the capital of Yemen, is located at the southern part of the Basin (Figure 1). During the last three decades the Sana'a City has grown from a small urban center to a 2-million metropolitan area. Rural population within the Basin is about 0.3 million inhabitants. Rate of population growth is 6% in the Basin and climbs to 10% in the City, due to migration from rural areas and other parts of the country. Urban population is projected to increase to about 5 million inhabitants by 2025 (WEC, 2001).

Groundwater pollution due to untreated domestic and industrial wastewater is escalating as the urban area expands. Urbanization is mostly in the form of new residential areas. Industrial activities are still a small portion of urban development. Around the city in the rural areas, irrigated agriculture is the main activity. It is growing to respond to the demands of the urban population. Less urbanization is taking place in the towns close to the City. Improving access to surrounding towns and villages would lead to mitigation of stress on the natural system around the City. Adopting an integrated approach to environmental management would help mitigate the adverse effects of quality degradation.

Furthermore, the rural areas at the outskirts of the city have developed their lifestyle and the domestic demand for water has also increased. As a result, more untreated wastewater is discharged underground. Pollution in the aquifer part under these areas should be monitored and data collected from well water samples.

About 40% of urban households are connected to the sewage network and the remainder are using cesspits to dispose of wastewater. A Wastewater treatment plant was constructed north of the City, which started operation around 2001. The plant was designed to serve a population of some 0.5 million; about 25 % of the present urban population. Wastewater BOD at the plant is about 1300 mg/l and SS 1100mg/l. Due to some technical problems, effluent quality is not up to the standards and bypassing raw wastewater to wadis is also frequent. Bypassed raw wastewater is used for irrigation or mixes with irrigation waters. Therefore, an alternate solution should be adopted for bypassing raw wastewater to wadis. The rate of urban growth surpasses the ability of the treatment plant to expand.

It is not possible to mitigate the problem without an appropriate wastewater treatment method. The water table beneath the city has not dropped, due to recharge with untreated wastewater from cesspits. Recharge with highly polluting wastewater is estimated at about 15 Mm3/year (WEC 2001). Thus, the deep aquifers are being recharged with polluted waters rather than natural waters. High concentrations of nitrates and chloride were found in waters of wells within the city. Furthermore, leaks from sewers and industrial wastes aggravate the situation. High concentrations of Cobalt were found in wastewater, which might indicate industrial pollution (Boydell et al, 2003). It might be viable to consider a form of wastewater treatment before the cesspits at building sites.

Abandoned quarries and borrow pits around the City are used as dump sites for different waste materials, including wastewater drawn from overflowing cesspits by vacuum tankers. Outcrops of the Tawilah Sandstones, the main aquifer rock in the Basin, are not protected against these practices. Furthermore, no accurate information is yet available about leaching from the solid waste dumping site north of the City.

Changes in the vegetative cover of the Basin were partly caused by the drop of the water table, especially at the southern part of the Basin. Topsoil on bare land has become susceptible to erosion (Gun, van der and Ahmed, 1995).

Thus, the environmental issues are more serious that quantity depletion. Strategies and management instruments for mitigating the problem should take priority over pumping control. Otherwise by the time the total amount was preserved it would have been already polluted. It is not a priority to deal with the problems of the quantity of water while the quality is deteriorating.

Required Actions and Management Instruments

The water crisis in the basin has two dimensions; groundwater quantity depletion and quality degradation. To deal with the aggravated situation in the Basin, groundwater quality degradation should take priority over other issues. Escalating depletion rates involves increasing contaminant load in geological strata. The Sana'a Basin Committee should give priority to gruondwater contamination. To protect the strategic reserves, pollution should be brought under control. Sana'a City is the largest urban area in the country that is situated on top of the water source that it uses. Since Sana'a City is the largest urban area in the country, special by-laws (executive regulations) should be adopted to confront the problem. Regional planning approach should be adopted to help in mitigating the pollution in the Basin. Population growth should be brought to a manageable level.

Pollution sources should be identified and monitored. Information about the levels and extent of pollution is required for decision making. Public awareness about the gravity of the problem is important. Centtral authorities should provide resources for local administrators to deal with pollution control issues. A watershed approach to identify sources of groundwater pollution may prove viable; especially that the Basin includes urban and rural areas.

Wastewater treatment facilities should be expanded by using an appropriate technology. It is worthwhile to consider using an appropriate septic system to provide a certain degree of wastewater treatment at building sites before discharging it into the natural system. Regarding soild waste dumping, proper management practices should adopted to control leaching to the aquifers.

It is urgently required to formulate a framework for analysis of possible management instruments to be used in enforcing regulatory actions. In addition to legal management instruments, customary law can provide an important reinforcement tool. To use this instrument, stakeholder awareness and participation are required. NGO's can play a significant role in this approach. Civil society organizations and Water User Assocaitions should be involved for awareness and public pressure. It might be an option to consider declaring Sana'a Basin an environmental protectorate.

Concluding Remarks

Serious environmental issues are emerging in Sana'a Basin as rapid urbanization is taking place there. Groundwater quality degradation has accompanied quantity depletion. Contamination due to untreated wastewater is the major issue to be considered. Formulation of a framework for analysis of possible management instruments to be used in enforcing regulatory actions is required. Proper planning and management practices are urgently required to protect groundwater strategic reserves against pollution.

References

Al-Eryani, M.; Ba-issa, A. and Al-Shuibi, Y. (1991) *Groundwater Pollution in the Sana'a Basin: a Preliminary Appraisal.* Environmental Protection Council, Sana'a, Republic of Yemen.

Al-Hamdi, M. (1994) *Groundwater Pollution due to Municipal Wastewater Disposal.* M.Sc. thesis, IHE, Delft, The Netherlands.

Al-Shaik, H. (1993) *Report on the Extent of Groundwater Pollution due to the Effluent of The Sana'a Stabilization Ponds at Rowdda.* National Water and Sewerage Authority, Sana'a, The Republic of Yemen.

Boydell, Robert A.; Al Hemyari, Amin Abdullah; Abdul Karim; Al Suleihi, Saba Taher; Al Dubai, Khalid Yasin; Iskandar, Mohamed Mahir; and Whitford, Peter W. (2003) *Sana'a Basin Water Management Program*, Project Phase I - Environmental Impact Assessment Report, Sana'a, Yemen.

DHV Consultants (1996) *Sources for Sana'a Water Supply (SAWAS) Project* Report.

Geukens, F (1966) *Geology of the Arabian Peninsula, Yemen.* U.S. Geological Survey Professional Paper 560-13:1-23.

Gun, van der, J. and Ahmed, Abdulaziz (1995) *The Water Resources of Yemen*, Report WRAY-35, MoMR/TNO, Sana'a, Yemen.

NWRA-Sana'a Basin Division (2006) Unpublished progress report, Sana'a, Yemen.

Water and Environment Center at Sana'a University (WEC) (2001) *The Sana'a Basin Characterization Study*, Sana'a, Yemen.

Water and Environment Center at Sana'a University (WEC) (2004) *The Sana'a Basin Study*, Volume 1, Main Report, Sana'a, Yemen.

Yaseen, B. (2001) *Preliminary Assessment of Pollution Due to Faulty Sewage System North of Sana'a,* Sana'a University, Sana'a, Yemen.