Water Pollution Control - A Guide to the Use of Water Quality Management Principles
Edited by Richard Helmer and Ivanildo Hespanhol
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Case Study XIII* - Sana'a, Yemen

* *This case study was prepared by Mohamed Al-Hamdi*

XIII.1 Introduction

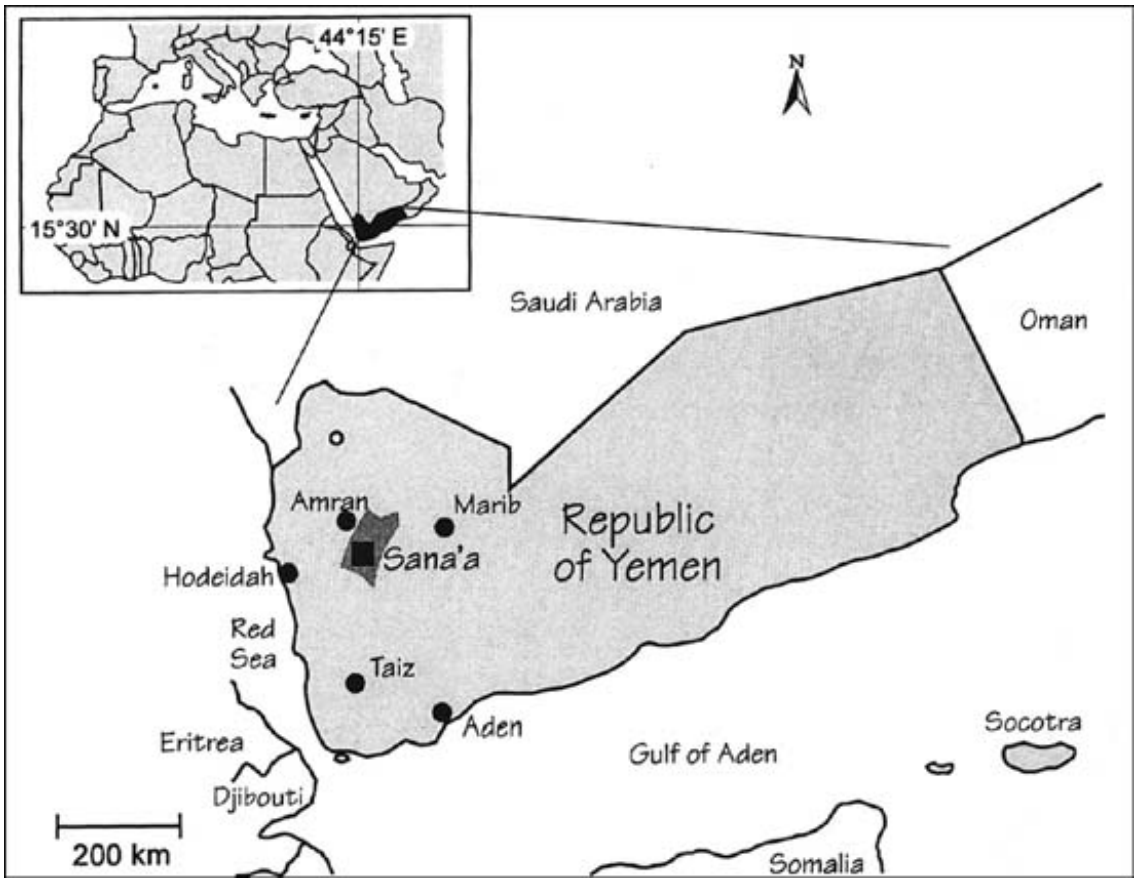
The Republic of Yemen (Arabia felix) is located in the south and southeastern part of the Arabian Peninsula and covers an area of 555,000 km^2 (Figure XIII.1). The country is surrounded from the west and south by the Red and the Arabian Seas. To the east and north it is bordered by the Sultanate of Oman and the Kingdom of Saudi Arabia respectively. In addition to Sana'a city, which is the capital, the country consists of 17 governorates of which 11 are located in the north (prior to 1990 known as North Yemen) and six in the south (prior to 1990 known as South Yemen). According to the High Water Council (HWC, 1992a) the total population was estimated to be 12.4 million in 1990 and 14 million in 1992. Eighty per cent are thought to live in the central and southern highlands which receives most of the erratic, limited rainfall. It is projected that the country's population will reach 23.4 million by the year 2010. Increasing water demand in recent years and the limited availability of surface water resources have increased the pressure on the available, mostly non-renewable, groundwater resources.

According to the *World Development Report* (World Bank, 1993), the per capita gross national product (GNP) of Yemen in 1991 was US$ 520. The major sectors that play important roles in the country's economy are agriculture, industry, services and mining. HWC (1992b) summarised the share of those sectors in the Gross Domestic Product (GDP) in 1990 as 20.6, 12.9, 58.1 and 8.4 per cent respectively. Although agriculture is not the largest contributor to the national economy, it employs around 60 per cent of the active labour force. In 1990, the total cultivated agricultural land was estimated to be 1.12 × 10 ha of which 61 per cent was rain-fed, 28 per cent was irrigated with groundwater, 2 per cent was irrigated with permanent springs and the remaining 9 per cent was cultivated by spate irrigation. In 1992, irrigated agriculture consumed about 90 per cent of the total water demand and accounted for about 50 per cent of the value of agricultural production. While total exports in 1990 amounted to YR 8.3 × 10^9 (the 1995 official exchange rate was US$ 1 = YR 12 and the parallel market rate for January 1995 was US$ 1 ≈ YR 100), of which crude oil and agricultural products had the largest shares (87 and 10 per cent respectively), agricultural trade registered a deficit of 88 per cent. Inflation in 1988 was around 16 per cent, but as a result of the Gulf crisis and the

return of more than a million labourers from the Gulf states, who previously provided hard currency, inflation increased to 50 per cent between 1990 and 1991.

Yemen depends mainly on external borrowing to implement its development programmes. As of 1990 the total debt stood at US$ 7.1×10^9, which was about 85 per cent of the GDP; 12 per cent of the debt comes from short-term commercial sources, 16 per cent from long-term multilateral sources, and the remaining 72 per cent from bilateral sources.

Figure XIII.1 Location map of Yemen indicating the Sana'a basin



XIII.1.1 Structure of the water sector

The two main institutions responsible for water in Yemen are the Ministry of Electricity and Water (MEW) and the Ministry of Agriculture and Water Resources (MAWR). The MEW is in charge of water supply and wastewater collection and treatment in urban centres, in addition to water supply in rural areas. Three organisations are directly attached to the MEW: the National Water and Sewerage Authority (NWSA), the General Directorate of Rural Water Supply (RWSD) and the High Water Council (HWC). The NWSA is a financially autonomous authority in charge of water supply and wastewater collection and treatment for the urban areas. Since the establishment of the authority in

1973, its jurisdiction has expanded to cover 12 cities in addition to Sana'a. The minister of MEW chairs the board of directors that runs the authority. The RWSD is mainly in charge of the rural water supply. The main role of this directorate has been the construction of small-scale water supply projects (mostly funded by external donors), which are usually handed to local councils for operation and maintenance. So far, rural sanitation has not received much attention, and on-site disposal facilities are the most common approach in the rural communities. The HWC was established under the same legislation that established the MEW in 1981, and its role is to co-ordinate the activities of all agencies in the water sector. The main task of the Council was to formulate national water plans and strategies and to prepare national water legislation. The Council consisted of deputy ministers of concerned ministries and was chaired by the Minister of Electricity and Water. As a result of under-staffing, the council was reformulated in 1986 to consist of concerned ministers and chaired by the Prime Minister. The Technical Secretariat of the HWC was also established in 1986 to assist the Council in the performance of its duties. Currently, no law had been passed to support the formulation of the Council as an independent agency and, therefore, it had been facing difficulties in meeting its obligations and duties.

After reunification of North and South Yemen in May 1990, the MAWR was formed from the previous Ministry of Agriculture and Fisheries in the north and the Ministry of Agriculture and Agrarian Reform in the south. These ministries had been in charge of development of water resources for agricultural purposes. However, since May 1990 the MAWR has been given the responsibility of managing national water resources, i.e. it has become a water manager and a major water user at the same time.

XIII. 1.2 Legislative framework

At present, there exists no national water legislation. Prior to May 1990, the HWC had prepared draft national water legislation and, because of the seriousness of groundwater depletion, the HWC also drafted a by-law on regulating groundwater extraction and a law to establish a National Water Authority. In the drafted law, the proposed National Water Authority was given the responsibility of allocating available water resources, specifying water use priorities and controlling annual consumption in order to ensure the sustainability of economic and social development. Due to the altered responsibilities for water resources management that occurred after May 1990, the MAWR drafted, independently, a second national water legislation in 1992 with a law to establish a National Water and Irrigation Authority.

However, neither of these laws were passed and the lack of water legislation has subsequently created an atmosphere of uncoordinated water use which is evident from the continuous decline of groundwater levels nation-wide. In short, the seriousness of the present water situation highlights the immediate need for water legislation and the establishment of a national agency to manage the scarce water resources in Yemen.

XIII.2 Water issues

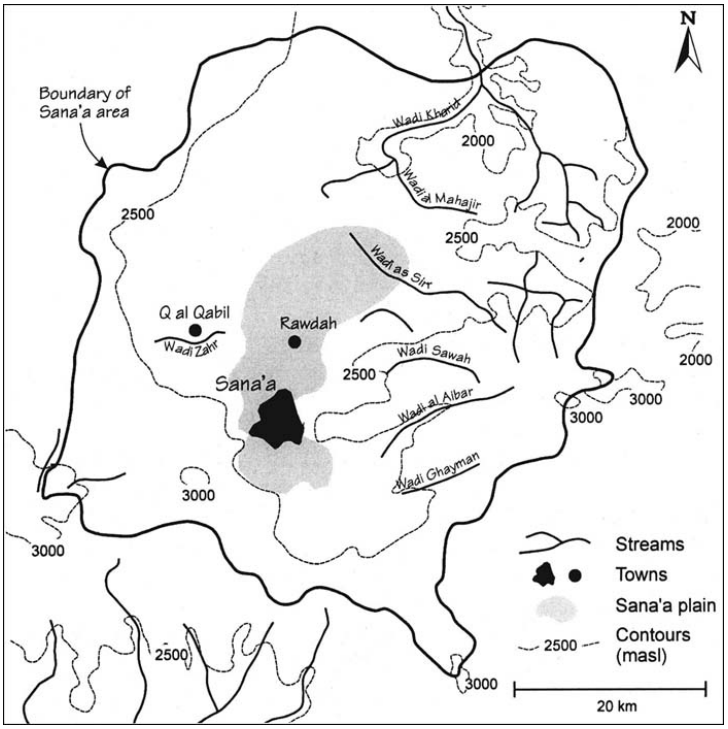
The Sana'a basin is located in the central highlands (Figure XIII.2) and covers approximately 3,200 km^2, ranging from less than 2,000 m to more than 3,200 m above sea level. The climate of the basin area is characterised by a low and erratic rainfall pattern with an average of 250 mm a^{-1}. Sana'a, the capital of Yemen, is located in the

Sana'a plain (Figure XIII.2) at an elevation of about 2,200 m above sea level. According to the first national census in 1975, the population of the city was 134,588 inhabitants and it had increased more than three-fold to 424,450 by 1986. Although the national population growth rate was around 3 per cent, the population of the city grew at an annual rate of 11 per cent and was then projected to continue at a similar rate. This rapid growth is mainly attributed to improved economic conditions which stimulated internal migration from the rural areas. At present, the population of the city is estimated to be over 1 million and is projected to increase to over 3.4 million by the year 2010.

XIII.2.1 Water resources

The principal source of water in the region is groundwater from three aquifer layers, namely alluvial deposits, volcanic units and the Tawilah sandstone. Of the three aquifers, the Tawilah is considered to be the most productive and has the best water quality. The capacity of the Tawilah is estimated at 2,230 × 10^6 m^3 (total storage) of which only 50 per cent is considered withdraw able. In addition to low recharge as a result of low rainfall in the recent past, increased extraction (mainly for agriculture) has resulted in a substantial drop in groundwater levels (3-4 m a^{-1}). It is important to realise that while the total water demand in the Sana'a basin area was estimated to be 220 × 10^6 m^3 a^{-1} in 1995, recharge estimates for the Tawilah aquifer vary between only 27 × 10^6 and 63 × 10^6 m^3 a^{-1}. The large difference between consumption and recharge is being filled with water from long-term storage, referred to as groundwater mining. The present pattern of water use in Sana'a is clearly unsustainable and, if allowed to continue, depletion of this valuable and scarce resource is inevitable.

Figure XIII.2 Map showing the major features of the Sana'a basin



XIII.2.2 Water use

Groundwater in the region is used exclusively to satisfy the water needs of the different water-using sectors, namely irrigated agriculture, municipal use and industrial use.

Prior to the Yemeni revolution in 1962, agriculture in the Sana'a basin area depended on dry farming practices and spate irrigation. The introduction of drilled boreholes in the 1970s, and the identification of the Tawilah as a highly productive aquifer, encouraged farmers to use groundwater for irrigation. Having realised the importance of the Tawilah, the government tried to regulate agricultural water use in the area by passing a law in 1973 which identified a local protection zone around the NWSA wellfields and prohibited further drilling of new wells or cesspits unless permitted. At present, agriculture in the basin area consumes about 175×10^6 m^3 a^{-1}, which accounts for 80 per cent of the total water demand in the basin area. Moreover, qat (a tree from which the leaves are chewed as a stimulant in Yemen) and grapes (a cash crop) are estimated to consume around 40 and 25 per cent respectively of the agricultural water demand in the region. The main reasons behind the over-use of groundwater for irrigation can be summarised as:

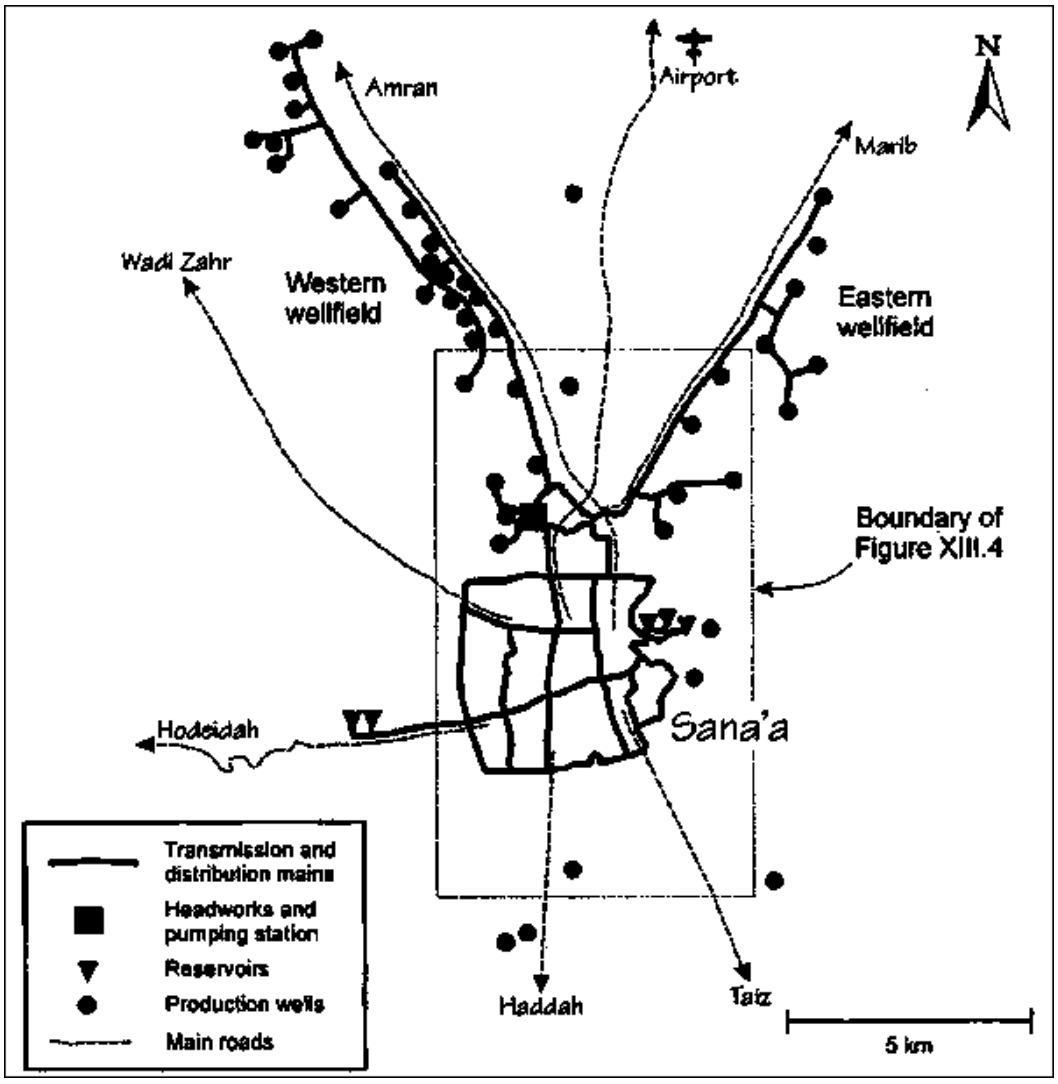
- Unclear water rights and thus unregulated extraction.
- Fuel subsidies and low import duties on agricultural equipment.
- High returns on cash crops.
- Inefficient irrigation practices.

Within the Sana'a basin, it is estimated that the present population is about 2.34 million, of which 1.4 million live in urban areas. Although the per capita consumption rate varies, it is estimated that the total municipal water demand in 1995 was 36.9×10^6 m^3 a^{-1}, of which about 29×10^6 m^3 a^{-1} was consumed in the urban areas. It was also projected that the total yearly municipal water demand would increase to 138×10^6 m^3 a^{-1} by the year 2010 (HWC, 1992c). The industrial water demand was estimated at 4.7×10^6 m^3 a^{-1} in 1990 and was projected to increase to 6.2×10^6 m^3 a^{-1} in 1995. Van der Gun *et al.* (1987) reported that the government of the Yemen Arab Republic (North Yemen prior to reunification in 1990) took measures to prevent the further establishment of major water-consuming industries in the Sana'a area and this could explain the low rate of increase in water use compared with the other sectors.

XIII.2.3 Sources of groundwater pollution

In the Sana'a basin area, unregulated direct disposal underground of municipal and industrial wastewater by means of on-site disposal facilities (cesspits) presents a potential threat of groundwater contamination. The thick, unsaturated zone, resulting from deep groundwater levels (100-170 m below ground level) suggests that groundwater pollution is unlikely. However, the complex geological structure and the presence of rock fractures could reduce the travel time of pollutants through this layer. The use of pesticides and chemical fertilisers in agriculture in Yemen is, however, still at a relatively low level and therefore groundwater contamination from this source is not of major concern at present.

Figure XIII.3 Map of the Sana'a area showing the location of pumping stations, reservoirs and the NWSA wells (After Al-Hamdi, 1994)



XIII.2.4 Water and wastewater in Sana'a city

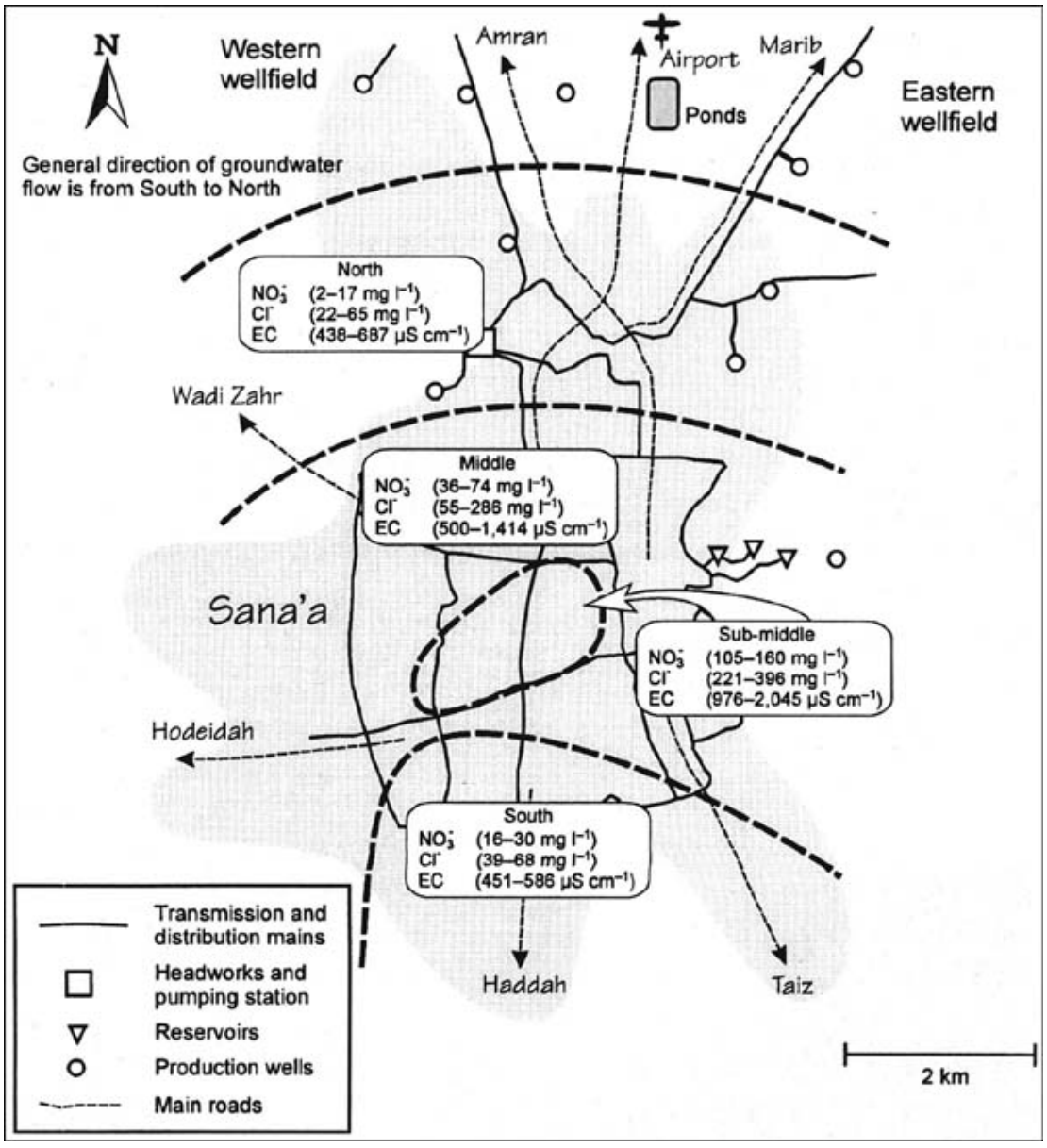
In the city of Sana'a, the municipal water supply consists of both public and private water supplies. In 1993, the public water supply produced around 17.8×10^6 m^3 providing 43 per cent of the city's population with a per capita consumption of about 120 l d^{-1}, including 35 per cent that was not accounted for. Groundwater from the NWSA wellfields (Figure XIII.3) is of good quality and meets the World Health Organization (WHO) drinking water guidelines. Nevertheless, chlorination is usually applied as a safety measure in the distribution network. Private water supplies, which depend on unmonitored private boreholes in the city, some of which also draw from the Tawilah, were estimated to have produced 6.7×10^6 m^3 in 1993. Although the private water supply is supposed to cover 57 per cent of the city's population, the high price of the water is suspected to reduce the per capita consumption to about 35 l d^{-1}.

As of 1993, only 12 per cent (10,000-12,000 m^3 d^{-1}) of the city was connected to the sewerage system which conveys wastewater to stabilisation ponds in Rowdda, north of Sana'a, for treatment (see Figure XIII.4). The rest of the city (35,000 m^3 d^{-1}) depended on cesspits with infiltration as the main mechanism of wastewater disposal. Al-Eryani *et al.* (1991) concluded that domestic wastewater had produced some changes in the quality of ground-water under the heavily populated area of the city and around the stabilisation ponds at Rowdda. Al-Shaik (1993) summarised an investigation of the water quality of some wells along the path of the effluent from the stabilisation ponds north of Rowdda. The study identified a contaminated area along the effluent channel and recommended continuous monitoring of the investigated area, as well as the NWSA wellfields. Al-Hamdi (1994) investigated the quality of groundwater in the city of Sana'a and classified the city into three quality zones: north, middle and south (Figure XIII.4). Groundwater in the middle zone contained more nitrate and chloride than the other zones, suggesting that wastewater disposal in this zone has had a negative effect on the quality of the groundwater. Furthermore, a polluted sub-area (sub-middle) was identified within the middle zone, which was characterised by NO_3^- concentrations within the range 100-160 mg l^{-1}, Cl^- concentrations within the range 220-400 mg l^{-1} and electrical conductivity within the range 975-2,045 mS cm^{-1}. It was argued that the present pollution could be attributed to wastewater disposal and that the polluted zone would expand towards the north, because the general direction of groundwater flow in the area is from south to north. No immediate risk was thought to exist for the NWSA wellfields but more than 50 per cent of the city's population depend on unmonitored private wells scattered within the city's perimeter.

The use of cesspits in the eastern and western parts of the city (Nokom and Allakama) has resulted in an overflow of wastewater to the ground surface because the local geology infiltration rates are very low. In addition to the potential health hazards resulting from direct human exposure, Al-Hamdi (1994) has suggested that intermittent de-pressurisation of the drinking water distribution network could induce some suction of wastewater into the network.

Based on groundwater samples taken near industrial activities, mainly large factories located outside the city, Al-Eryani *et al.* (1991) concluded that industrial wastewater in the Sana'a area was not presenting an immediate threat to the quality of the groundwater; however, no detailed information about the waste disposal methods and the characteristics of the industrial wastewaters was given. In addition to large factories, which are mostly located outside the city, many small workshops, oil-changing garages and car washes are located within the city. The results presented by Al-Hamdi (1994) suggest that direct disposal of wastewater from these activities could lead to serious groundwater contamination.

Figure XIII.4 Map showing the groundwater quality variation in the city of Sana'a. The general direction of groundwater flow is from South to North (After Al-Hamdi, 1994)



From the above discussion, it is evident that groundwater depletion is currently taking place, while at the same time the quality of groundwater under the city is threatened by extensive wastewater disposal. Water rights have not been settled with farmers and, therefore, they consider groundwater to be communal property whereby they have the right to fulfil their domestic and agricultural water needs. Competition for groundwater extraction could increase the rate of depletion of the aquifer leading to a subsequent decrease in irrigated agriculture in the area. In order to mitigate the possible future conflicts that could arise between farmers and the city over water resources, a

management plan acceptable to both parties must be concluded. In this context water conservation and wastewater reuse for irrigation could prove to be two key issues. Water conservation in irrigated agriculture, the largest groundwater user in the area, involves many aspects, including agricultural economy, governmental policies and the national legal conditions. Such aspects are beyond the scope of this case study. Wastewater reuse is, however, closely integrated with groundwater management and pollution control and this aspect is therefore discussed below.

Current estimates show that 18×10^6 m^3 a^{-1} of wastewater are generated by the city of Sana'a, of which about 20-25 per cent is collected through the sewerage system. It has been estimated by HWC (1992c) that the agricultural water requirements in the basin area were about 175×10^6 m^3 a^{-1} in 1995, of which 160×10^6 m^3 were accounted for by groundwater irrigation for cash crops. These estimates suggest that wastewater from the city could reduce agricultural water use by around 12 per cent if reused for irrigation at properly selected hydrogeological areas, i.e. at the NWSA wellfield region. This reuse could provide the city with substantial additional water supplies while also reducing the potential threat of groundwater contamination under the city. Farmers could be convinced to reuse wastewater because it would be cheaper than groundwater (collection and treatment would be paid for by the Government and by consumers) and more reliable (especially with the continuous decline in groundwater levels and the threat of complete exhaustion of the aquifer). Such reuse should be constrained by legal agreements where treated wastewater (the property of the city) is traded for undefined groundwater rights. Thus farmers involved in these agreements would receive treated wastewater, in addition to possible privileges, such as extra attention from relevant governmental agencies, awareness programmes for wastewater irrigation and certain financial incentives (i.e. loans and subsidies), in return for discontinuing groundwater irrigation. The increasing scarcity of groundwater in the area could make such agreements attractive to farmers especially when long-term (sustainable) agriculture in the area is most likely to be wastewater-irrigated.

With respect to pollution control, wastewater reuse could serve three objectives simultaneously:

- It would eliminate all adverse health effects that could result from drinking contaminated groundwater, from direct exposure to overflowing wastewater, and from direct contamination of the drinking water distribution network.

- The private sector could continue to provide part of the population with safe drinking water.

- The increased groundwater supplies, as a result of less groundwater irrigation, would allow the NWSA to increase the coverage of the regulated and monitored public water supply.

However, the absence of a co-ordinating agency and the present divided responsibilities for water resources are major constraints to the implementation of such management options.

XIII.2.5 Critical water issues

As indicated above Yemen in general, and Sana'a in particular, are facing a critical water shortage due to unregulated and uncoordinated water use. Moreover, there is a potential risk of groundwater contamination as a result of unregulated wastewater disposal. The risk of groundwater pollution could incur serious health problems because more than 50 per cent of the city's population rely on private wells for their water needs. In addition to adverse health effects, polluted groundwater becomes very costly to treat.

XIII.3 Planned interventions

The government of Yemen realised that there was a critical water shortage in Sana'a and initiated, with the assistance of the Dutch government, a project in the late 1980s to look for alternative water sources for the city, i.e. a supply orientated approach. The government also realised the need for water legislation and for a national agency to manage, regulate and co-ordinate the use of water resources in a manner that will ensure sustainable development.

With regard to the risk of groundwater contamination in the Sana'a area, the NWSA has appreciated that direct wastewater disposal and the overloaded stabilisation ponds are the main contributors to changing groundwater quality in certain areas of the city. Thus collection and proper treatment of wastewater is viewed as the key to protect the Tawilah aquifer from further quality degradation. If the sewerage system is expanded to cover the entire city and if wastewater is adequately treated so that it can be re-used in agriculture, the quality of the groundwater will be protected and some of the agricultural water demand should be reduced. Recently, land has been acquired for a new activated sludge treatment plant, but funds still need to be allocated for its construction. In response to continuous public complaints, the NWSA intends, in an emergency programme, to connect the eastern and western parts of the city (Nokom and Allakama) to the sewerage system in order to eliminate the overflow of wastewater and to reduce the threat of drinking water contamination in the distribution network.

XIII.4 Lessons learned and conclusions

In an effort to manage the current unsustainable use of the groundwater resources in the Sana'a area, the Government has focused on a supply orientated approach with a project to evaluate different water sources. At the same time, the Government has failed to address demand management measures as a viable option in water resources management. Importing water from other regions to Sana'a, given the scarcity of water nationwide, would be very costly and could face strong local resistance in the supplying regions. Implementation of demand management in Yemen requires an in-depth understanding of water rights. Settlement of those rights would become essential if the Government wished to set water-use priorities and to control the (re)allocation of water resources.

The 1973 law to protect the NWSA wellfields from depletion and from deterioration in water quality can be considered ineffective for the following reasons:

- Small ratio of protection zone to total basin area.

- Such regulations are difficult to monitor and to enforce.

• There was no other alternative for wastewater disposal and therefore permits for cesspits were always granted.

The quality of groundwater under the central part of the city of Sana'a and around the stabilisation ponds has deteriorated as a result of unregulated direct disposal of wastewater. Although immediate action is required, the availability of financial resources to expand the sewerage system and to construct proper treatment facilities seems to be the major constraint. To date, economic and financial incentives have been neglected in water management and pollution control in Yemen.

Five main points have been highlighted by this case study:

• Unregulated disposal of municipal and industrial wastewater could cause serious changes in the quality of groundwater and therefore could have the potential to result in adverse health effects and high treatment costs. Reuse of wastewater in a water-scarce regions like Sana'a can be considered as an attractive and effective opportunity because it reduces the threat of groundwater contamination while also providing a water source with a high nutrient content for irrigation. However, the success of a wastewater reuse programme depends on several conditions:
• The sewerage system should expand to cover the entire city (very costly).

• Reclaimed wastewater for irrigation should be free of toxic substances that may arise from industrial discharges, and the hygienic and agronomic quality of the water should be suitable for irrigation.

• Farmers should be amenable to the use of reclaimed wastewater for irrigation (wastewater irrigation of cash crops could reduce the market price of those crops).

• The present institutional arrangement of the water sector in Yemen, where there is no proper co-ordination in the use of scarce water resources or effective management of pollution control, can be viewed as a prime factor leading to the unsustainability of those water resources.

• A demand-orientated approach should be considered as an important element in water resource management. This is particularly important in arid and semi-arid areas where water resources are limited although demand, due to increased populations needing water and food, is always increasing.

• Economic and financial incentives should be considered seriously in water management and pollution control. Pricing could play an important role in demand reduction and pollution prevention.

• Sustainable use of scarce water resources should be included in the regional and national economic and social development plans and strategies.

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