Groundwater Quality: Pakistan

This is one of a series of information sheets prepared for each country in which WaterAid works. The sheets aim to identify inorganic constituents of significant risk to health that may occur in groundwater in the country in question. The purpose of the sheets is to provide guidance to WaterAid Country Office staff on targeting efforts on water-quality testing and to encourage further thinking in the organisation on water-quality issues.

Background

Pakistan lies in southern Asia, bordered to the east by India, the west by Iran and Afghanistan and to the north by China (Figure 1). The total area is 803,940 square kilometres. Terrain consists of the flat-lying Indus Plain in the east, mountains of the Himalaya, Karakoram and Hindukush ranges in the north, hill regions (up to 4761 m) in the north-west, and the upland Baluchistan plateau in the west. Elevation ranges are extreme, from K2 (8611 m) to the Indian Ocean (0 m).

The climate is mostly arid to semi-arid, although conditions are temperate in the north-west and arctic in the mountains of the north. Average annual rainfall varies from less than 125 mm in the south-west (western Baluchistan) to in excess of 1000 mm in Islamabad, but becomes again low (less than 125 mm) in the northern mountains (Muzaffar, 1997). Monsoon rains fall dominantly in July–August. The mean annual temperature in the Indus Plain is around 18ºC (with monthly maxima over 40ºC) but decreases significantly in the mountains of the north.

Figure 1. Map of Pakistan (source: CIA WorldFactbook).

The Indus, the main river of Pakistan, has its source in the mountains of the Karakoram range and flows southwards through the Provinces of Punjab and Sindh to the Arabian Sea (Figure 1). Major tributaries of the Indus in Punjab are the Sutlej, Ravi, Chenab and Jhelum Rivers. Relatively abundant water and fertile soils of the Indus Plain have encouraged a major proportion of the population to settle in the region, including those in the main cities of Karachi, Islamabad, Lahore and Hyderabad. However, flooding along the Indus valley is a frequent problem after heavy rains.

Agriculture forms a major part of the national economy. Land-use is approximately 27% arable and around 50% of the workforce is employed in the agricultural sector. Principal crops include cotton, wheat, rice, sugarcane and maize. Most of the agricultural development is along the Indus Plain. Irrigation is a major aspect of the agricultural development, much being from canal-fed river water. Numerous major canals have been constructed along the Indus in Punjab and Sindh. Tubewell irrigation is also important in the Indus Plain. Fertilisers and pesticides have been used widely in the plain.

Industrial developments have grown in many of the urban centres. Most important is the textiles industry. Tanneries are also particularly abundant in the town of Kasur, south-east of Lahore, as well as in Karachi.

Geology

The geology of Pakistan is dominated by young (Quaternary) sediments which outcrop over large parts of the Indus Plain and Baluchistan Basins and are often hundreds of metres thick. The Indus sediments are mainly alluvial and deltaic deposits, consisting mainly of fine-medium sand, silt and clay. Coarser sands and gravels occur in parts however, especially on the margins of the plain abutting upland areas (WAPDA/EUAD, 1989). Wind-blown sands occur in to the east of the Indus Plain (Thar and Cholistan desert areas). Sediments of the Baluchistan Basin are mainly recent wind-blown deposits with some lake sediments, many associated with playas. These often also have surface salt deposits caused by evaporation. Unconsolidated Quaternary deposits also occur in North West Frontier Province in the Dera Ismail Khan Plain, Bannu Basin and the Peshawar Valley. These are usually sands, silts and gravels with variable thicknesses and extent. In the Dera Ismail Khan Plain, they attain a thickness of over 300 m (WAPDA/EUAD, 1989).

Mesozoic and Cenozoic sedimentary rocks occur in a north-south tract to the west of the Indus Plain stretching from Peshawar to the coast. Older (Palaeozoic) sediments and crystalline basement rocks (granites, metamorphic rocks) are mainly restricted to the north, including North West Frontier Province, Gilgit and Jammu & Kashmir.

Groundwater Availability

As a result of the arid climate of large parts of Pakistan, groundwater availability is limited and poses a severe problem for water supply. Water shortage has meant that access to potable drinking water is limited in many areas. Worst affected are the most arid regions of Baluchistan and the south-east. Additional problems have arisen through poor tubewell design, construction and maintenance. The problems are exacerbated in the major cities by overabstraction of groundwater and resulting falling water tables. As a result, groundwater quantity has traditionally been a priority over quality issues in Pakistan.

Of the aquifers available, by far the most productive are the Quaternary alluvial aquifers of the Indus Plain. Groundwater yields from these sediments are typically around 100–300 m^3/hour down to 150 m depth. Lower yields (typically 10–50 m^3/hour) are obtained from the sediments of the Thar and Cholistan desert regions on the eastern fringes of the Plain (south-eastern border with India). Yields are also restricted in the fine-grained Quaternary tidal and deltaic deposits in the southern coastal area (Shamsi, 1989). Permeable gravels occur in intermontane valleys in Baluchistan and North West Frontier Province, but these are typically of limited extent.

Prior to the development of irrigation systems, groundwater tables in the Indus Plain were typically 20–30 m below surface. More recently, water levels have risen significantly as a result of irrigation inputs to the aquifers. Waterlogging with accompanying salinisation of groundwater has therefore become a major problem in parts of the Indus Plain, with large investment in remediation measures having been undertaken over the last few decades.

Older (pre-Quaternary) sedimentary rocks and crystalline basement rocks in the western and northern parts of Pakistan have limited tubewell yields with patchy groundwater availability. Indurated sedimentary rocks such as the Siwalik Sandstone (Potwar Plateau), Multana conglomerate (Zhob River Basin) and Ketch Conglomerate (Rakhshan River Basin), also have fairy high groundwater yields but their productivity is limited to areas with favourable recharge (WAPDA/ EUAD, 1989). Older crystalline rocks are generally poorly permeable, and groundwater yields are controlled by the availability of fractures. In the northern mountains, groundwater availability is limited further by the cold climate and the presence of glaciers.

Groundwater Quality

Overview

Recent missions to Pakistan to investigate groundwater quality and monitoring strategy have indicated a distinct paucity of chemical data (Chilton et al., 2001). From the limited data available, it appears that the most recognised water-quality problem is poor microbial quality within distribution systems which can lead to severe health problems (e.g. Hina, 2001). High salinity is also of major importance and leads to restrictions in resource availability. Excessive fluoride is an additional common problem. Recent well testing of sources within the Indus Plain has also identified some groundwaters with unacceptably high concentrations of arsenic. The numbers of affected wells recognised is so far small, but screening has been initiated in priority areas to ascertain the scale of the problem and the necessity for remedial measures.

Nitrogen species

Increases in the concentrations of nitrogen species in groundwater are likely in many areas of Pakistan as a result of pollution from sewage and/or agricultural sources. Pollution of groundwater from sewage disposal is severe in some parts of the country and the quality of many shallow groundwaters and river waters is impaired, especially in urban areas. Sewage seepage to groundwater occurs from poorly constructed, poorly maintained or incomplete sewerage systems and from latrines and septic tanks. The contamination is manifested especially by the presence of pathogenic organisms, which have often been tested and are found in many drinking-water supplies in the major cities such as Karachi (Hina, 2000), Lahore, Rawalpindi and Islamabad (Chilton et al., 2001).

Pollution from agricultural sources is also marked in some areas. Applications of NPK fertilisers have been increasing in Pakistan over the last few decades, with applications of nitrogen reaching in excess of 2 million tonnes by the late 1990s (Chandio, 1999). Agricultural inputs are likely to be worst in Punjab and Sindh where agricultural productivity is highest. Concentrations of nitrate may also be increased in the saline groundwaters by evaporation.

As a result of these pollutnat sources, exceedances of nitrate above the WHO guideline value for drinking water of 11.3 mg/l (as NO_3-N) are expected to be relatively widespread in urban and agricultural areas. High concentrations of NO_3-N were reported to be common in water sources in Karachi (Mahmood et al., 1997). Tasneem et al. (1999) found NO_3-N concentrations ranging from 1–171 mg/l in the Kasur area of Punjab. Tahir et al. (1999) noted concentrations up to 111 mg/l NO_3-N in groundwater from Rawalpindi District. Chandio (1999) found concentrations of NO_3-N mostly less than 6 mg/l in dug wells and tubewells from canal-irrigated areas of Pakistan, although concentrations up to 210 mg/l (as N) were found where directly contaminated by sewage. Latif et al. (1999) found concentrations in groundwater from irrigated areas mostly less than 8 mg/l, although concentrations were observed to be highest in shallow groundwater which is more vulnerable to fertiliser leaching.

In contrast, concentrations of nitrate in water supplies from the North-West Frontier Province were found by Khan et al. (1993) to be mostly below the WHO guideline value. These authors reported often high concentrations of nitrite (NO_2) in the water samples analysed, although the results are suspect, especially given the overall low concentrations of nitrate observed.

Nitrite may be present in some polluted shallow groundwaters and river waters from Pakistan but concentrations are not expected to exceed the WHO guideline value in significant numbers of tubewells. The presence of ammonium in groundwater from some polluted sources is not likely to pose a health risk, but may give rise to complaints from consumers (due to adverse smell or taste).

Salinity

As noted above, one of the main problems with groundwater quality in Pakistan is high salinity which results from waterlogging of salinised soils due to irrigation, dissolution of salts in the sediments, evaporation under the arid conditions, industrial pollution and in coastal areas from seawater intrusion. The distribution of groundwater salinity is relatively well known. The problem affects the groundwaters in large parts of Sindh, Punjab, Baluchistan and southern North West Frontier Province. In Punjab and Sindh, groundwater salinity is related closely to the river morphology. Many shallow groundwaters in Punjab are of low salinity. However, concentrations of total dissolved solids (TDS) are generally higher, often >3000 mg/l, in groundwaters from the interfluve ('Doab') areas between the major river and canal tracts. TDS values are typically lower (<1000 mg/1) in groundwaters from below the active river channels as a result of dilution by local river and canal recharge to the aquifers (PHED, 1999). The fresh groundwater bodies occur as lenses below the rivers, the lens thicknesses decreasing with distance away from the river courses (Nazir, 1974). Particularly saline waters are present in the Thal desert (Sibi–Jacobabad; Dera Ismail Khan) region which forms one of the interfluves to the west of the Indus. Salinity is also a problem in Cholistan region. Occasional zones of saline groundwater in Punjab contain dissolved salts of 20,000 mg/l or more (Nazir, 1974).

Salinity is even more widespread in the lower reaches of the Indus Plain in Sindh. As in Punjab, salinity increases away from the course of the lower Indus and large parts of the aquifers of southern Pakistan have groundwater of unsuitable quality for development as a result of high salinity (Thar-Thatta-Karachi areas). Additional severe salinity problems related to seawater intrusion occur in coastal areas of Sindh, especially to the north and west of Karachi (Shamsi, 1989).

Saline groundwaters (TDS >3000 mg/l) are also present in the Quaternary aquifers of arid western Baluchistan (sandy desert of the Nok Kundi and Hamun-e-Mashkhel playa lake areas and the Makran coastal zone). However, groundwater in many parts of the North West Frontier Province tends to be fresher.

In the saline groundwaters, the dominant ions are likely to be sodium and chloride, although sulphate, magnesium and potassium are also likely to be major constituents present in concentrations above WHO guideline values for drinking water. However, these groundwaters are typically too saline to be of use for drinking water.

Fluoride

Under the arid climatic conditions of large parts of Pakistan, high fluoride concentrations in the groundwater are to be expected at least in some areas. Excessive fluoride concentrations are a problem in parts of Punjab, Sindh and Baluchistan (Tariq, 1981). Ayyaz (pers. comm.) has noted the incidence of dental fluorosis in communities in Thaparkar, Thar desert, Makran area, the Mastung Valley (Baluchistan), Pattoki and Manga Mandi (Punjab), Nowshera (North West Frontier Province), the Salt Range, Kasur–Mianwali areas, Raiwind, Kasir, Sangla and Barawalpur (Chilton, 2001). Few fluoride analyses of the drinking water are available to back up the observations but where analysed, concentrations up to 29 mg/l have been reported (Chilton et al., 2001). Concentrations in the range 5–24 mg/l were found in groundwaters from the towns of Raiwind, Kasur and Sargodha (Tariq, 1981). Generally low fluoride concentrations were found in groundwater from northern areas of Pakistan (Districts of Gilgit, Skardu, Diamer and Ghizer; Tabbasum, 1995). Fluoride appears not be a national problem, but is a regional problem of sufficient magnitude to merit consideration in water-testing and supply programmes.

Iron and manganese

Little information is available on the redox characteristics (i.e. whether aerobic or anaerobic) of the groundwaters. At the neutral to alkaline pH observed for Indus Plain groundwaters (Nazir, 1974; Cook, 1987, Mahmood et al., 1997) and expected for most groundwaters in Pakistan, iron and manganese would only be mobile in solution under anaerobic (low-oxygen) conditions. Such conditions may occur in parts of the Indus Plain where surface deposits are fine-grained (clays, silts). High-iron groundwaters have been found in Sargodha, northern Punjab (Iqbal, 2001) for example and concentrations in the range 1.0–1.2 mg/l have been reported in Jhelum (Punjab; Ali and Ahmad, 1994). However, high iron and manganese have not been widely reported. Cook (1987) found generally low concentrations of iron in groundwaters from the alluvial aquifers of the lower Indus (Nawabshah-Mirpurkas areas). Values reported were mostly less than 0.5 mg/l, although occasional highs up to 3.5 mg/l were found. Manganese concentrations were relatively high however, being up to 0.75 mg/l. Hence, manganese may be a problem in some groundwaters from the Indus Plain.

Iron and manganese are usually easy to detect in groundwater through problems with discoloration, staining and metallic taste. However, such problems have not been reported widely in Pakistan.

Arsenic

Of the Provinces of Pakistan, those with aquifers most vulnerable to contamination from arsenic are the recent alluvial and deltaic sediments of the Indus Plain, namely Punjab and Sindh. These sediments have many similarities with the arsenic-affected aquifers of Bangladesh and West Bengal (Quaternary alluvial-deltaic sediments, Himalayan source rocks) but differ in having a more arid climate, greater prevalence of older (Pleistocene) deposits and dominance of unconfined aquifer conditions with greater apparent connectivity between the river systems and the aquifers. Under these conditions, the aquifers are likely to be less reducing than those found in the Bengal Basin, and hence arsenic problems may be less severe. Cook (1987) found that both fresh and saline groundwaters from the lower Indus Plain (Nawabshah-Mirpurkas region) had chemical signatures which were not strongly reducing (anaerobic). Some contained dissolved oxygen for example. In addition, lack of evidence of widespread high iron and manganese concentrations and the common presence of nitrate further suggests that anaerobic conditions have not developed widely in the Indus aquifers. Additional characteristics of high-arsenic groundwaters in Bangladesh are the presence of correspondingly high alkalinity values (typically 500 mg/l or more as HCO_3) and high P concentrations (often >1 mg/l). Few data are available for alkalinity in Pakistan groundwaters, but information given by Cook (1987) indicates concentrations (for both fresh and saline groundwater) from the lower Indus of Sindh mostly in the range 180–250 mg/l. The saline groundwaters of Pakistan are dominated by Cl and HCO_3 (alkalinity) is a less abundant constituent. Even fewer P data are available. Rahim (1998) found concentrations in groundwaters from Rawalpindi up to 0.46 mg/l (as P), although concentrations were typically much less and not indicative of widespread arsenic contamination in that area. Nonetheless, anaerobic conditions suitable for the mobilisation of arsenic may be present in the Quaternary deposits in some areas and awareness of arsenic risk is a necessity.

Few data are so far available for arsenic in the alluvial Indus aquifers. However, following alarm raised in Bangladesh and elsewhere, the Provincial Government of Punjab together with UNICEF began an arsenic testing programme in northern Punjab in 2000. Districts to be tested were selected on the basis of geology and available water-quality information. These included areas affected by coal mining and geothermal springs (Jhelum and

Chakwal Districts), areas draining crystalline rock (Attock and Rawalpindi), areas with high-iron groundwaters (Sargodha) and one district from the main alluvial aquifer (Gujrat). A total of 364 samples were analysed. The majority (90%) of samples had arsenic concentrations less than 10 μg/l, although 6 samples (2%) had concentrations above 50 μg/l (Table 1; Iqbal, 2001). A further phase of well screening has been instigated by the Punjab Government following this initial survey. No confirmed cases of arsenicosis disease have been found in Pakistan, but UNICEF has recently begun an epidemiological investigation in Sargodha, Jhelum and Gujrat Districts. From the available data, the scale of arsenic contamination of Indus groundwaters appears to be relatively small. It is nonetheless still cause for concern and for further arsenic testing.

Although the Indus Plain is the main area of extensive young alluvial deposits in Pakistan, smaller occurrences of Quaternary alluvial valley-fill deposits are also found in the Peshawar Valley, Bannu Basin, Kuchlagh, Quetta, Mastung and Panjgur Valleys. These are partly artesian (WAPDA/EUAD, 1989) and may contain anaerobic groundwaters potentially vulnerable to arsenic contamination. It is also possible that the Quaternary aquifers of the arid Baluchistan Basin of western Pakistan contain groundwater with elevated concentrations of arsenic if groundwater pH values are high (ca. 8.5 or higher). No arsenic data are so far available for groundwaters from these regions.

Sulphide minerals are present in parts of the crystalline basement rocks of northern Pakistan and the pre-Quaternary rocks of the west. Weathering of these minerals may give rise to increased concentrations of groundwater arsenic, although the occurrences are likely to be localised. Muzaffar (1997) has recorded pyrite deposits in Gilgit area as well as around Quetta-Kalat (Baluchistan) in particular.

Table 1. Range of arsenic concentrations found in groundwater samples from northern Punjab (from Iqbal, 2001).

District	No. samples	<10 μg/l (%)	11–20 μg/l (%)	21–50 μg/l (%)	>50 μg/l (%)
Gujrat	38	33 (87)	2 (5)	1 (3)	2 (5)
Jhelum	37	32 (86)	1 (3)	3 (8)	1 (3)
Chakwal	72	63 (88)	9 (12)	0 (0)	0 (0)
Sargodha	59	49 (83)	5 (8)	2 (3)	3 (5)
Attock	74	68 (92)	6 (8)	0 (0)	0 (0)
Rawal-pindi	84	81 (96)	3 (4)	0 (0)	0 (0)
Total	364	326 (90)	26 (7)	4 (1)	6 (2)

Following detection of arsenic in some groundwater sources in Punjab, UNICEF has recently planned a further testing programme, of some 6000 tubewells, in 30 districts distributed across Pakistan. The testing programme was due to start in May 2001.

Iodine

No water-iodine data are available but iodine deficiency disorders (IDDs) including goitre have been reported among some communities, especially in the upland areas of Jammu and Kashmir. IDDs have been tackled to some extent by the distribution of dietary iodine supplements, although the distribution policy has been discontinued recently (Chilton et al., 2001). Iodine deficiency is not likely to be a widespread problem of the other parts of Pakistan where groundwater salinity is high. Indeed, iodine analyses of groundwater from the lower Indus Plain (Sindh) given by Cook (1987) are mostly in the range 10–190 μg/l. These values are much higher than present in groundwaters from other parts of the world where IDDs are endemic (BGS, 2000).

Other trace elements

A number of trace elements are likely to be concentrated in the more saline groundwaters (e.g. boron, selenium, molybdenum). However in these, salinity itself is likely to be the greatest limiting factor on groundwater potability. Increased concentrations of boron may also arise from urban and domestic pollution.

Potentially toxic trace metals such as chromium, cadmium, nickel, and copper are expected to be low in most groundwaters and not problematic for potable supply, except in urban and industrial centres arising from point sources of pollution. Untreated effluent is discharged at various points into a number of rivers, including the Khabul, Ravi and Chenab as well as the Indus. Heavy metals such as lead, chromium and copper have been detected in Karachi's drinking-water supplies (Chilton et al., 2001). Tanneries in industrial areas are likely to be local sources of chromium as well as sulphide, in particular. Mahmood et al. (1998) reported concentrations of lead and cadmium slightly in excess of WHO drinking-water guideline values in groundwater from the Korangi industrial area of Karachi (observed concentrations up to 30 and 3.1 μg/l respectively). Concentrations of chromium, cobalt and nickel were also found to be above background values. Mahmood et al. (1990) also found concentrations of lead up to 9 μg/l in tubewells water from the city of Peshawar, although this is still below the WHO guideline value for drinking water (10 μg/l). Rahim (1998) also found concentrations of lead up to 58 μg/l and chromium up to 103 μg/l in groundwaters from the Islamabad area, although concentrations (90 samples) were more typically less than 8 μg/l and 50 μg/l respectively.

Data sources

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