Groundwater Quality: Northern India

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

This report gives a summary of the information currently available on groundwater quality in northern India, incorporating 23 of the 28 Indian states, but excluding the five southern states of Maharashtra, Andra Pradesh, Orissa, Karnataka and Tamil Nadu. These (essentially peninsular India) have been described in the 'Southern India' leaflet (BGS, 2000). The northern states cover an area of around 2.24 million km^2 stretching from the Arabian Sea coast in the west, through Rajasthan, Madhya Pradesh, Haryana and Punjab to Jammu & Kashmir in the northern Himalayan region, to the eastern states bordering Nepal, Bhutan, Bangladesh, China and Burma (Figure 1).

The terrain ranges from the extremes of the

Figure 1. Relief map of India (courtesy of The General Libraries, The University of Texas at Austin).

Himalayan highlands (up to 8598 m above OD at Kanchenjunga, Sikkim), to the flat-lying Ganges alluvial and deltaic plain which extends down to sea level. The low-lying wetlands of the Rann of Kutch also occupy a large part of south-west Gujarat. Lower hill ranges occupy the central region, including the Aravalli Hills of Rajasthan (up to 1722 m).

The climate is largely temperate in the northern regions of India and contrasts with the tropical monsoon climate further south. Average annual rainfall is highly variable reflecting regional topography. Average annual rainfall is around 570 mm in Haryana state, 660 mm in Rajasthan, and 900 mm in Punjab, most falling in June–September (Kamra et al., 2002; Umar and Absar, 2003; Dhillon and Dhillon, 2003). Rainfall exceeds 1000 mm/year in Jammu & Kashmir and 3000 mm in the north-eastern states. The Himalayan uplands have permanent snow. Temperature extremes range between around 7ºC and 42ºC in Haryana and Rajasthan but with much lower temperatures occurring in the Himalayan region.

The Great Indian Desert (Thar Desert) occupies much of the west, including terrain in the states of Gujarat and Rajasthan. Large parts of northern India are prone to drought though flash floods also affect the alluvial plains.

The largest river system is that of the Ganges which flows south-eastwards from the Himalayan highlands across the vast Gangetic Plain towards its delta in West Bengal and neighbouring Bangladesh. Major tributaries include the Yamuna, Ghaghara and Son Rivers. In addition, the Brahmaputra River runs south-westward from Arunachal Pradesh via Assam and into Bangladesh. The smaller Hugli River runs south to the Bay of Bengal in West Bengal and the Narmada River runs south-westwards across Madhya Pradesh to the Gulf of Cambay. In addition, the Rajasthan Canal runs south-westwards across the Thar Desert (Figure 1).

Traditional farming is the dominant basis of the Indian economy though industry and support services are of increasing importance. Agriculture employs some 60% of the national workforce (1999 estimate), the main crops produced being rice, wheat, oilseed and cotton. Some 23% of the workforce are employed in services and 17% in industry. Dominant industries are textiles, chemicals, food processing and steel production.

Geology

Quaternary alluvial deposits form a major component of the surface geology on non-peninsular India, covering about half the land area. Alluvium occupies major parts of Gujarat and Rajasthan, most of Uttar Pradesh, Haryana, Punjab and West Bengal, as well as northern Bihar and northern Assam.

Tertiary sediments are much more restricted in area, occupying most of the smaller eastern states of Tripura, Manipur, Arunachal Pradesh, Nagaland, Mizoram and southern Assam. Tertiary sediments also occur in parts of the extreme north (Kashmir and Himachal Pradesh).

Deccan Plateau volcanic rocks (Jurassic age) crop out in western Madhya Pradesh but are much less abundant than further south in peninsular India. Gondwanan (Permo-Carboniferous and Mesozoic) and Vindhyan (Proterozoic) sedimentary rocks occupy most of Jammu & Kashmir, Himachal Pradesh and eastern Madhya Pradesh. The Vindyan rocks chiefly comprise metamorphosed limestones and sandstones. Gondwana sediments are mainly fluviatile sands and clays with some coal deposits. In northern India, coal occurs in the sediments of the Rajmahal Hills and the Damodar & Sone river valley (West Bengal). The Damodar Valley area includes the Jharia, Raniganj, Bokaro and Karanpura Coalfields.

The oldest rocks are Precambrian metamorphic basement rocks which occur in the Aravalli Range of southern Rajasthan, as well as southern Bihar and most of Meghalaya. They also underlie the younger rocks elsewhere. The basement rocks comprise largely gneisses and granites but also include metasediments (shales, limestones and quartzites).

The Himalayan region in the extreme north is geologically highly complex with rocks of diverse ages (Precambrian to Quaternary) and lithologies. The rocks of the region have been highly fractured and contorted as a result of compressive stresses associated with the Himalayan orogenic events.

Soils largely reflect underlying geology and climate. In the north-west arid region, they are commonly alkaline and calcareous, some being saline (Dhillon and Dhillon, 2003).

Groundwater Availability

The best-yielding aquifers of northern India are the Quaternary alluvial deposits of the Gangetic plain. These constitute a major source of water supply. Good groundwater yields are also found in many of the Tertiary sediments. Groundwater storage in crystalline basement rocks is restricted to the fractures and groundwater yields are determined by fracture density. This can be significant in some areas: groundwater yields of around 10–50 m^3/day were reported from dug wells in fractured basement rocks of the Gambhir River Basin of Rajasthan for example (Umar and Absar, 2003).

In the arid regions of northern India, groundwater is often the only source of available drinking water. Overexploitation of aquifers in some areas has resulted in falling water levels. Singh and Singh (2002) reported decreases in groundwater levels of 1–2 m/year in some boreholes. At the same time as a result of irrigation, some canal levels have been rising at a rate of 1 m/year. Experiments in some areas are being conducted to assess the feasibility of aquifer storage and recovery to alleviate the water shortage problem.

Groundwater Quality

Overview

Groundwater quality is highly dependent on the nature of the aquifers and on the ambient climatic conditions. Groundwaters of calcium bicarbonate type with near-neutral pH values typify the wetter regions of the north and north-east of the region where alluvial sediments constitute the most important aquifers. Both alluvial sediments and crystalline aquifers in the arid regions of Rajasthan often contain sodium-bicarbonate or sodium-chloride type groundwaters, reflecting increased salinity where rates of evapotranspiration are high and recharge low. Salinity is a notable problem in the most arid areas, exacerbated by salinization related to irrigation. In many arid areas, evaporite salts are observed as surface encrustations (Umar and Absar, 2003). Soil and groundwater salinization as a result of irrigation has been documented in Haryana, Rajasthan and Punjab states in particular (Kamra et al., 2002; Khan, 2001). Salinity can also be a problem in some of the low-lying coastal areas as a result of saline intrusion.

Pollutant inputs related to farming, domestic wastes (including latrines) and industry have had an impact on water quality throughout many parts of northern India. Discussion of pollution impacts from organic compounds and pathogenic organisms is beyond the scope of this report, but of the inorganic constituents, nitrate is an important manifestation of such pollutant inputs. High concentrations of nitrate have been found in some groundwaters.

In addition, fluoride and arsenic have become increasingly recognised as problem elements in a number of groundwater sources, though they rarely occur together in high concentrations under the hydrogeological conditions pertaining in the region. An estimated 62 million people nationwide are believed to suffer from problems with fluorosis (dental or skeletal) as a result of long-term exposure to high-fluoride drinking water (Susheela, 1999). These are principally in the arid and semi-arid regions though some have recently, somewhat surprisingly, also been identified in the wetter state of Assam (Chakraborti et al., 2000). An estimated 5 million people are likely to be drinking water with concentrations of arsenic greater than the national standard of 50 μg/l, principally in West Bengal (PHED/UNICEF, 1999). The numbers diagnosed with arsenicosis problems have been estimated at around 200,000 (Das et al., 1996). A large amount of survey, patient identification and mitigation work has been going on in recent years in West Bengal to alleviate the arsenic problems.

Nitrogen species

Nitrate in groundwater may be produced by inputs from surface pollutants (e.g. fertilisers, domestic wastes). Concentrations may also be increased by evaporation under hot, arid conditions. Concentrations of nitrate in the range 0.5–29 mg/l (as NO_3-N) were reported by Umar and Absar (2003) for groundwater from alluvial sediments of the Gambhir River Basin of Rajasthan. Half of the 28 groundwater samples investigated had concentrations at or greater than the WHO guideline value of 11.3 mg/l for nitrate-N in drinking water. No other nitrogen species were reported. High concentrations of nitrate (up to 44 mg/l as NO_3-N) were also reported by Handa (1975) for groundwaters from Rajasthan. These concentrations were much higher than for groundwater from other regions sampled in that study. The high concentrations were accompanied by high salinity and may reflect evaporative concentration processes rather than pollutant inputs. Low or undetectable concentrations of nitrate are expected in the anaerobic groundwaters of the alluvial and deltaic aquifers of West Bengal, Assam and Bihar.

Few reports have included chemical analyses of nitrite or ammonium and so assessments of the regional distribution of these compounds in the groundwaters of the region is difficult. High concentrations of ammonium (>1 mg/l as NH_4-N) are a feature of the anaerobic groundwater conditions of West Bengal, but these are believed to be a natural phenomenon related to breakdown of organic matter in the aquifers rather than to pollution.

Salinity

Arid regions of north-central India (notably Rajasthan, Haryana) commonly have groundwaters with high salinity values, affecting their acceptability for drinking and irrigation purposes. Kamra et al. (2002) reported variable electrical conductance values, in the range 100–3000 µS/cm (equivalent to a total-dissolved-solids concentration of around 100–1800 mg/l), for groundwater from Haryana state in areas affected by irrigation-induced salinization. Umar and Absar (2003) reported concentrations of total dissolved solids in groundwater from the Gambhir River Basin of Rajasthan as mostly greater than 500 mg/l (29 samples), with 10% of samples having more than 1000 mg/l (up to 1300 mg/l). Chloride concentrations were in the range 40–335 mg/l and sulphate in the range 53–256 mg/l. The high salinity reflects naturally high rates of evapotranspiration as well as salinity changes resulting from long-term irrigation. Uptake of surface evaporite salts contributes to the salinization process. Khan (2001) also found electrical conductance values of 1000–2000 µS/cm in groundwater from the Bandi River area of Rajasthan, though this was considered by the authors to be linked to industrial pollutants recharged to the aquifer via the river.

In the wetter regions of north and eastern India, salinity of groundwater is much lower, except in coastal regions (e.g. 24 North and South Parganas, West Bengal) where it is affected by saline intrusion. Adyalkar et al. (1981) for instance described groundwaters of dominantly sodium-chloride type (electrical conductance values up to 4500 µS/cm) from alluvial aquifers in 24 South Parganas of West Bengal.

Fluoride

Fluoride has long been recognised as one of the most significant natural groundwater-quality problems affecting arid and semi-arid regions of India. Indeed, one of the most sustainable forms of appropriate-technology water treatment developed for the removal of fluoride, the Nalgonda technique, was pioneered and is still in use in the Nalgonda region of Andra Pradesh (Nawlakhe and Bulusu, 1989).

High fluoride concentrations in groundwater have been reported in many states, the worst-affected northern states being Andra Pradesh, Rajasthan, Haryana and Gujarat. Many exceed the WHO guideline value of 1.5 mg/l. Rao et al. (1974) found fluoride concentrations up to 20 mg/l in groundwater from Andra Pradesh. Handa reported concentrations up to 2.8 mg/l in Gujarat, up to 7 mg/l in Rajasthan and up to 3 mg/l in Andra Pradesh. Meenakshi et al. (2004) found fluoride concentrations in the range 0.3–6.9 mg/l in groundwater from Jind district, Haryana and reported that more than 80% of water samples analysed had unacceptably high fluoride concentrations for drinking purposes. Many of the fluoride occurrences are linked to crystalline basement rocks including granites, although some sedimentary aquifers also appear affected.

High fluoride concentrations have also been found in groundwater from Karbi Anglong and Nagaon districts of Assam (Chakraborti et al., 2000). These occur under wetter conditions than those in the central region. Das et al. (2003) also reported high concentrations (in the range 0.35–6.88 mg/l, 235 samples) in groundwaters from the city of Guwahati, Assam. The aquifers are alluvial clay and sand associated with the Brahmaputra River, overlying Precambrian crystalline basement, including granite. Results indicated that 10.7% of samples had concentrations more than the WHO guideline value for fluoride in drinking water of 1.5 mg/l. By contrast, 46% of samples had less than 0.6 mg/l fluoride and hence can be considered deficient in fluoride. Concentrations showed an apparent increase with borehole depth (depth range <10–70 m). The source of the fluoride was concluded to be groundwater circulating in the deeper granitic basement.

Handa (1975) reported low concentrations for limited numbers of groundwater samples from Delhi (0.4 mg/l), Bihar (up to 0.38 mg/l), Uttar Pradesh (up to 0.19 mg/l) and Assam (up to 0.4 mg/l). Handa (1988) also reported generally low concentrations for groundwater from Assam, Punjab, West Bengal, Himachal Pradesh and Jammu & Kashmir where climatic conditions are generally wetter. These observations indicate the large variability in fluoride concentrations of groundwater across the continent and largely reflect the local geological conditions and climate (see *Fluoride leaflet;* BGS, 2000).

Iron and manganese

Surprisingly little information is available on the concentrations of iron and manganese in northern Indian groundwater. High concentrations are expected in anaerobic groundwater conditions and under strongly acidic conditions. Anaerobic conditions are known to be a feature of the confined and semi-confined alluvial and deltaic aquifers of West Bengal and concentrations of iron and manganese commonly exceed 1 mg/l in these groundwaters (PHED, 1991; CGWB, 1999). Das et al. (2003) also reported high concentrations of iron (range 0.01–4.23 mg/l) in groundwater from Guwahati City, Assam in similar alluvial deposits. High concentrations of iron and manganese may be expected in other parts of the alluvial plain where anaerobic conditions exist.

Although iron in drinking water is not considered a health hazard at the concentrations usually observed, it may give rise to acceptability problems through adverse taste and colour. High concentrations of manganese are believed to have detrimental health effects and may be problematic if present at concentrations significantly above the WHO guideline value of 0.5 mg/l.

There are few reports of the occurrence of iron and manganese in groundwaters from the older aquifers of the region.

Arsenic

Problems with arsenic in groundwater are severe and most prevalent in the state of West Bengal. Arsenic-related diseases were first identified there during the 1980s, although they have only been appreciated internationally since the mid 1990s (e.g. Das et al., 1996). Concentrations of <10–3200 μg/l have been reported (CGWB, 1999). Arsenic occurs predominantly in groundwater from the youngest, Holocene, alluvial deposits. These aquifers have variable thicknesses but where high arsenic concentrations occur they tend to be in boreholes with depth ranges of around 10–80 m (CGWB, 1999). Groundwater from older (deeper) Pleistocene deposits appears to have low arsenic concentrations. Groundwaters from the laterite upland of western Bangladesh and the older Barind and Ilambazar Formations also tend to have low arsenic concentrations (PHED, 1991). Several studies have also reported generally low concentrations (<50 μg/l) in groundwater from dug wells, presumably because these are relatively oxic compared to groundwater from drilled boreholes.

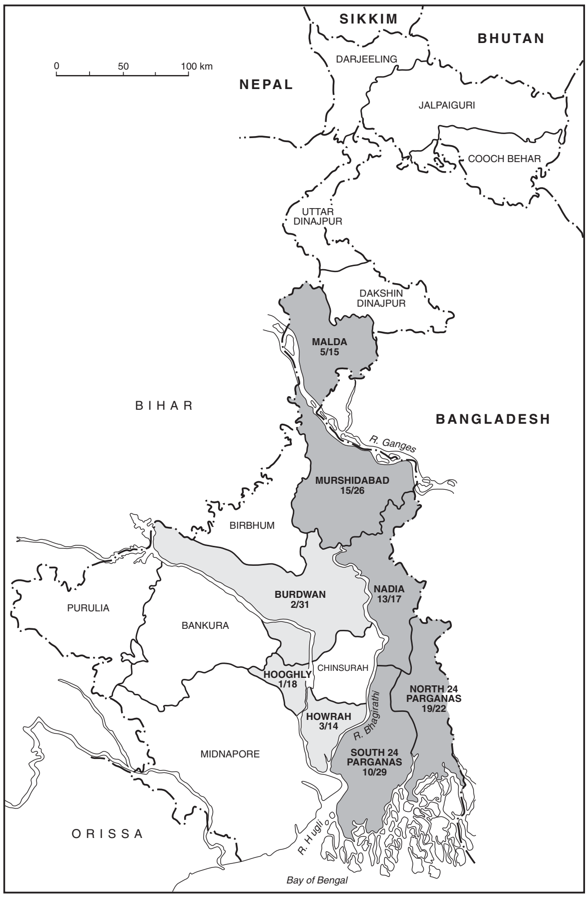

Figure 2. Map of West Bengal showing districts affected by high groundwater arsenic concentrations. Numbers refer to number of blocks with concentrations >50 μg/l relative to the total number of blocks. Darker shading shows worst-affected areas (1999 data).

Up to eight districts in West Bengal have recognised high-arsenic groundwater, the worst-affected being Malda, Murshidabad, Nadia, 24 North Parganas and 24 South Paraganas (Figure 2). These lie to the east of the Bhagirathi–Hugli river system, along the border with Bangladesh. More than 100,000 arsenic analyses are said to have been carried out on groundwater samples from West Bengal, though maps of point-source data showing the spatial distribution of arsenic are lacking. Arsenic concentrations are highly variable from well to well even within the same village, as is typical of high-arsenic groundwaters elsewhere. Prediction of arsenic concentrations at the village scale is therefore difficult or impossible.

More recent reports have also documented arsenic problems in Quaternary aquifers in Bihar, Tripura, and eastern Uttar Pradesh (Mahalanobis, 2004). Arsenic-related health problems in the village of Semria Ojha Patti in Bihar prompted a recent groundwater survey. Of 206 boreholes tested, 57% exceeded the national standard for arsenic in drinking water of 50 μg/l; 20% exceeded 300 μg/l (Chakraborti et al., 2003). This showed a severe problem in the village but to date, the documentation for arsenic occurrence more widely in Bihar, as well as in Tripura and Uttar Pradesh, is poor and the scale of the problem in these states is therefore unclear.

Kamra et al. (2002) reported high concentrations of arsenic (along with lead, cadmium and nickel) in groundwater from the alluvial plains of Haryana state, although the quality of the chemical analyses from the study is uncertain and further investigation would be warranted to verify the concentrations reported.

High arsenic concentrations have also been found in groundwater from some areas of crystalline basement rocks in northern India. Acharyya (2002) found locally high concentrations in groundwater from weathered granitic rocks from the Dongargarh rift belt of Chhattisgarh. Arsenicosis problems linked to high groundwater-arsenic concentrations have also been found in crystalline rocks in a gold-mining area (likely associated with sulphide mineral deposits) in Rajnandgaon District, Madyha Pradesh. Concentrations of <10–880 µg/l were reported by Chakraborti et al. (1999). In contrast to the situation in West Bengal, these occurrences are relatively localised.

Iodine

Few analyses are available for iodine in groundwater in northern India. Concentrations are likely to reflect climatic conditions, with higher concentrations likely in more saline groundwaters from arid areas. In the wetter alluvial plains of north-eastern India, iodine-deficient groundwaters (typically containing just a few µg/l) may occur and may give an inadequate iodine intake to populations without supplementary iodine from food sources.

Selenium

High concentrations of selenium have been reported in some arid areas of north-western India though this is not thought to be widespread. Selenium is toxic to humans and the WHO guideline value for selenium in drinking water is 10 µg/l. Some 1000 ha of seleniferous soils have been described in north-eastern Punjab (Dhillon and Dhillon, 2003). High concentrations of groundwater selenium are commonly associated with high salinity and with waterlogging and soil salinization related to irrigation practices. Dhillon and Dhillon (2003) reported selenium concentrations of 0.25–69.5 µg/l in groundwater from alluvial aquifers in Punjab, 11% of samples being above the WHO guideline value. Some 4% also exceeded the USEPA maximum permissible concentration for irrigation water of 20 µg/l. Concentrations were found to be higher in the shallow boreholes (24–36 m) compared to deeper boreholes (up to 76 m). This is most likely related to evaporation processes, although if conditions become increasingly reducing with depth, this may also have an effect as selenium is typically most soluble under oxic conditions. The groundwaters from the seleniferous region were alkaline (pH 7.8–8.8) with sodium and bicarbonate as the dominant ions.

Other trace elements

The concentrations of uranium in groundwater of Indian aquifers are largely unknown. The current WHO guideline value for uranium in drinking water is 2 µg/l though this is likely to increase to 9 µg/l in the revised (3rd edition, 2004) guidelines. High concentrations of uranium (12–114 µg/l) were reported for groundwater in Bathinda district of Punjab state (Singh et al., 1995), with concentrations up to 20 µg/l in Amritsar. Singh et al. (1994) also found concentrations up to 21 µg/l in Himachal Pradesh. It is possible that uranium concentrations close to or above the new WHO guideline value occur elsewhere in the shallow groundwaters from the Quaternary alluvial aquifers, although data are so far lacking to substantiate this. High uranium concentrations have been found in groundwater from geologically similar aquifers in neighbouring Bangladesh (BGS and DPHE, 2001), especially from dug wells where concentrations up to 42 µg/l were found.

There have also been a number of reports of the presence of dissolved radon in groundwater from northern India. Radon is a radioactive gas known to be a carcinogen. Despite its known health effects, no WHO guideline value exists for radon in drinking water because of the difficulties in defining a regionally-applicable value given the relative importance of inhalation compared to ingestion from drinking water. Radon concentrations in groundwater also change significantly on abstraction, aeration, storage and boiling. Radon is a radioactive decay product of uranium and high radon concentrations are frequently found in groundwater and air in buildings associated with uraniferous rocks. These include granites and some limestones. The concentrations of radon in groundwater can vary typically between around 3 and tens of thousands of Bq/l. Virk et al. (2001) found concentrations of radon in groundwater from tubewells in Bathinda and Gurdaspur districts of Punjab, India in the range 3.0–8.8 Bq/l. These are not unusually high though they are higher than values reported in the same study for surface waters. The concentrations were found to be slightly higher in Gurdapur where the geology comprises Siwalik Himalyan sediments compared to the alluvial Punjab plains of Batala. Although likely to be derived from uranium decay in the rocks, no association with dissolved uranium was observed in the water samples. This probably reflects the differing transport behaviour of the two elements in water, one (radon) being a dissolved gas and the other (uranium) a redox-sensitive solute. Relatively high concentrations of radon (25–92 Bq/l) were reported by Choubey et al. (2003) for groundwater from Quaternary alluvial gravels associated with uranium-rich sediments in the Doon Valley of the Outer Himalaya. Although probably not a health hazard at the observed concentrations, high concentrations of radon may be an indicator of possible high concentrations of uranium in groundwater, though for reasons outlined above, the correlations may be weak.

Few data exist for the concentrations of other potentially detrimental trace elements such as lead, nickel, cadmium and chromium. Lack of information on such potentially toxic trace elements does not necessarily mean that these elements will be uniformly low and hence not problematic. However, there is likewise no evidence to suggest that they will be present in the groundwaters in potentially detrimental concentrations. Water testing would be required to clarify the situation.

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