Groundwater Quality: Southern 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 describes the groundwater quality of the five southern states of India, namely Maharashtra, Andra Pradesh, Orissa, Karnataka and Tamil Nadu, in which WaterAid has current programmes. These five southern states cover an area of around 900,000 km^2 (around 1500 km north to south) and vary in terrain from upland plateau in the Deccan region to lowland alluvial plains along the eastern coastal area. The highest point, with an altitude of 2636 m, lies in the Nilgiri Hills in Tamil Nadu, although peaks of similar altitude occur in neighbouring Kerala.

Southern India experiences a tropical monsoon climate with monsoons derived from both the south-west (June to September) and north-east (January). Average annual rainfall in Tamil Nadu is 1200 mm, deriving from both monsoons. Average annual rainfall in Andra Pradesh is 940 mm (most deriving from the south-west monsoon; Sastry et al., 1985). Annual rainfall in Maharashtra varies between 500 mm and 1600 mm (Agrawal, 1999). Rainfall is highest (in excess of 3000 mm) and tends to last longer along the western coastal area (Western Ghats). Rainfall along the south-east coast is also higher than the continental interior. Mean annual maximum and minimum temperatures in Tamil Nadu are 37ºC and 20ºC respectively. (Sukhija et al., 1998).

India's economy is strongly dependent on agriculture which includes both modern methods and more traditional rural farming. Around 67% of the national labour force is employed in the agricultural sector. Around 13% of the land area of Maharashtra and around 45% of Andra Pradesh is irrigated for agricultural production.

Geology

The geology of southern India is varied but dominated by crystalline rocks. The Deccan region comprises a thick sequence of volcanic rocks predominantly of basaltic composition, extending from Bellgaum in the south (Karnataka), northwards to just beyond Guna (Madhya Pradesh), but lying mostly in the state of Maharashtra.

Sediments of various ages (Cretaceous to Recent) are present along the south-east coast. The Cuddalore Sandstone (of Miocene age) is a major sedimentary formation which outcrops in a discontinuous linear band running sub-parallel to the coast and extending from Cuddalore at the coast south-westwards towards Madurai in Tamil Nadu. The formation is dominantly sandstone but includes economically important occurrences of lignite. The formation is buried beneath Quaternary deposits between the outcrop and the south-east coast.

The outcropping Quaternary alluvial and deltaic sediments are dominantly unconsolidated sands, gravels, silts and clays but also include limestone. A delta occurs at the mouth of the River Mahanadi in Orissa and smaller deltas occur at the mouths of the Rivers Krishna and Godavari further south. Localised occurrences of unconsolidated Quaternary sediments also occur along the west coast (at Alleppey and Cannanore).

The remainder of the area of southern India is composed of ancient crystalline basement rocks, predominantly of granite and gneiss, but with other less common crystalline rock types (e.g. khondolite, charnockite).

Soils are commonly lateritic, especially in the western area and in parts of Orissa. Volcanic soils of the Deccan region are likely to be relatively fertile.

Groundwater Availability

Flow of groundwater in the crystalline basement of the majority of southern India is dominantly via joints and fractures as primary permeability is low. Groundwater is typically more abundant in the surface weathered horizons.

The sedimentary formations in the eastern coastal part of southern India have higher potential for groundwater storage. Little information is available for the Cretaceous formations of southern India.

The younger Cuddalore Sandstone forms an important aquifer locally and is in parts both unconfined (outcropping at surface) and confined by overlying impermeable sediments (clays, silts, lignite). The unconfined groundwaters are typically aerobic and the confined groundwaters anaerobic.

The Quaternary sediment sequence close to Madras (known as the Madras Aquifer) supplies groundwater for the city. The Formation comprises a 30 m-thick sequence of unconsolidated alluvial sand, silt and gravel and is confined by surface clay (Sherif and Singh, 1999). Hence groundwaters from the aquifer are in part anaerobic.

Groundwater Quality

Overview

Groundwater quality of southern India is strongly dependent on bedrock geology and climate but may also be impacted in parts by pollution, particularly from agricultural and industrial sources. The most important agricultural pollutants are nitrate and pesticides, though it is recognised that fertiliser and pesticide applications are not as intensive as in many western nations (Agrawal, 1999). No data could be found for pesticide occurrences in southern Indian groundwater. Phosphate and potassium fertilisers are also used though the mobility of these beyond the soil zone is much less than that of nitrate. Another impact of pollution is likely to be increased values of total dissolved solids (TDS).

By far the most serious natural groundwater-quality problem known in India derives from high fluoride concentrations which are dissolved from the bedrocks by geochemical processes and have resulted in severe fluorosis in large populations. High iron concentrations have also been reported in some aquifers (Handa, 1984), particularly in confined aquifers which are typically anaerobic. High iron concentrations are not detrimental to health but may deter use of the groundwater due to aesthetic problems and lead to use of alternative less safe sources of water.

Groundwaters from the Quaternary alluvial and deltaic aquifers along the east coast are prone to high salinity as a result of seawater ingress. Smedley (1991) reported concentrations of total dissolved solids in groundwaters from alluvial aquifers in Delang Block, Orissa at up to 4450 mg/l. The high concentrations of dissolved salts in many of these groundwaters, together with high concentrations of iron and manganese have led to abandonment of the groundwater sources.

Some groundwaters from the sedimentary aquifers in the eastern states have been identified by radiocarbon analysis as very old. Groundwater from the deep confined part of the Cuddalore Sandstone (screen depth up to 470 m) has been dated at up to 26,000 years (Sukhija et al., 1998). The quality of such old groundwater is determined by natural water-rock reaction processes with little likelihood of inputs from modern pollution.

Nitrate

The WHO health-based guideline value for nitrate in drinking water is 10 mg/l (as N). Few data are available for concentrations of nitrate in groundwater from southern India. Handa (1975) quoted values between 1.4 mg/l and 17 mg/l (as N) for groundwaters from Andra Pradesh, between 1.4 mg/l and 4.2 mg/l for groundwaters from Tamil Nadu, between 0.14 mg/l and 1.5 mg/l for groundwaters from Karnataka and 0.14 mg/l for groundwaters from Orissa. These values are relatively low, with few exceeding the WHO guideline value. However, in each case the number of samples given was very small and it is hard to assess how representative these are of groundwater compositions across the southern states. Agrawal (1999) named Maharashtra, Karnataka and Tamil Nadu as the southern states worst affected by high nitrate inputs to aquifers, with average values in groundwaters being respectively 10.0 mg/l, 10.6 mg/l and 5.9 mg/l. Groundwaters from Andra Pradesh had an average concentration of 3.0 mg/l. These values indicate some exceedances of the WHO guideline value but not significantly in excess.

Handa (1975) found some very high concentrations of nitrate-N (up to 200 mg/l) in saline groundwaters from Rajastan further north, although these were taken to be high because of natural concentration of solutes by evapotranspiration, rather than related directly to pollution. Concentrations of nitrate in groundwaters in southern India may potentially be elevated above the ranges given by Handa (1975) in the more arid areas inland if the amounts of evapotranspiration are significant (indicated by the presence of saline groundwater).

Table 1. Statistical summary of fluoride concentrations in groundwaters from the southern Indian states (from Handa, 1988)

State	No. of analyses	Mean (mg/l)	Std dev (1σ)
A. Pradesh	1011	1.40	0.81
Karnataka	239	0.73	0.69
Orissa	1157	0.44	0.40
Tamil Nadu	2303	0.84	0.56

Iron and manganese

Few data exist for iron and manganese in most of the abstracted groundwaters from Southern India. However, problems with especially iron are noted in anaerobic groundwaters from the Quaternary alluvial and deltaic aquifers of Orissa. Smedley (1991) recorded iron concentrations up to 37 mg/l in groundwaters from Delang Block. Manganese concentrations were not so extreme but some were found to be above the WHO guideline value of 0.5 mg/l (concentrations reported at up to 0.58 mg/l). The highest concentrations were found in groundwaters from deeper parts of the aquifer (well depths 90–150 m) in response to the development of increasingly anaerobic conditions with greater aquifer depth. Although Smedley (1991) quoted only a small number of water analyses, it is anticipated that iron (and to a lesser extent manganese) is a widespread problem in the anaerobic groundwaters from the alluvial aquifers of Orissa.

Fluoride

High concentrations of fluoride, often significantly above 1.5 mg/l, constitute a severe problem over large parts of India. Long-term use of groundwater for drinking has resulted in the onset of widespread fluorosis symptoms, from mild forms of dental fluorosis to crippling skeletal fluorosis. Teotia et al. (1981) estimated that around 1 million people in India suffer from fluorosis. However, Susheela and Majumder (1992) put the figure much higher at around 25 million in the country as a whole. The worst-affected states in southern India are Andra Pradesh, Tamil Nadu and Karnataka (Table 1). In Andra Pradesh, concentrations of fluoride have been found in some of the groundwaters at up to 20 mg/l (Handa, 1975) and a study by Handa (1988) reported only 36% of groundwater samples from Andra Pradesh with less than 1 mg/l.

Groundwaters from the west coast have typically low concentrations (<0.5 mg/l; Handa, 1975) because of high rainfall and its diluting effect on groundwater.

High fluoride concentrations in the groundwaters correlate positively with alkalinity (bicarbonate concentration), pH and sodium, and are present in groundwaters with low calcium concentrations.

Jacks et al. (1993) found that concentrations of F in groundwaters varied significantly spatially within catchments, with low concentrations on hillslopes and progressively increasing concentrations downgradient into valley bottoms. In the low-lying areas, fluoride concentrations were sufficiently high to allow precipitation of the mineral fluorite (calcium fluoride). It was suggested that groundwater of better quality could be obtained by tubewell installation on hillslopes rather than valley bottoms, although it is recognised that groundwater yields may be compromised by this approach (Jacks et al., 1993).

Teotia et al. (1984) found variations in fluoride concentrations with depth in groundwater from two Indian villages affected by fluorosis. Shallow groundwaters (12-15 m) were observed to have concentrations of around 4 mg/l to 11.5 mg/l, with deeper groundwaters (15-33 m) having mostly less than 1 mg/l. The decreases with depth showed corresponding decreases in alkalinity. The trend is contrary to observations from high-fluoride groundwaters elsewhere which commonly show increasing fluoride concentrations with depth due to increased chemical reaction with increasing groundwater residence time. Nonetheless, the depth relationship is an interesting observation and may be of practical significance in southern India if found to be a representative phenomenon.

Fluoride concentrations in streams have been observed to increase during the dry season as a result of increased proportion of groundwater baseflow to streams during dry periods.

Defluoridation on a village scale is practised in some rural communities in the affected areas. Indeed, one of the best established village-scale treatment methods, the Nalgonda technique, originates from the Nalgonda area of Andra Pradesh.

Arsenic

Although serious problems with arsenic are known to occur in the anaerobic groundwaters from the alluvial and deltaic aquifers of West Bengal, and in a localised area of Madhya Pradesh as a result of mining activity in a sulphide-mineralised area, no occurrences of high arsenic concentrations have been reported from groundwaters in southern India. It is considered that the groundwaters from the crystalline basement (granite, gneiss, Deccan basalts) are unlikely to have widespread high concentrations of arsenic. Groundwaters from similar terrain (granite, charnockite) in northern central Sri Lanka have been found to contain low concentrations of arsenic, less than the WHO guideline value of 10 µg/l (BGS, unpublished data).

Iodine

Few data are available for iodine in southern Indian groundwaters and little information is available concerning iodine-deficiency disorders. However, the study of groundwaters in two Indian villages by Teotia et al. (1984) found concentrations of iodine in shallows groundwaters (12-15 m) of 15-130 µg/l and in deeper groundwaters (15-33 m) of 3.6-70 µg/l. They noted that high concentrations correlated positively with fluoride and that goitre occurrence was lower in the high-fluoride areas. Concentrations of iodine above around 5 µg/l are sufficiently high to be considered non-goitrogenic. The few published iodine data available for Indian groundwaters therefore do not indicate a serious iodine-related health problem.

Other trace elements

Smedley (1991) noted elevated concentrations of boron (up to 0.48 mg/l) in slightly saline groundwaters from the coastal Quaternary aquifers of Orissa (WHO health-based guideline value for boron in drinking water, 0.3 mg/l).

No other references could be found relating to occurrence of other trace elements of potential health concern.

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