Groundwater Quality: Madagascar

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

Madagascar is a large island, some 1600 km in length (north to south) and 587,000 square kilometres in area. The island lies around 300 km off Mozambique (south-east Africa) in the Indian Ocean. Topography consists of a central mountainous region with an average altitude of 2000 m, which covers around two thirds of the island. The highest point is Maromokotro (2876 m). The uplands are surrounded by a number of narrow coastal plains.

Madagascar has a variable climate, ranging from tropical along the coast, to temperate in the inland plateau areas, to arid in the south. Average annual rainfall is 1700 mm, but with large regional variations from 3000 mm in the east to less than 400 mm in the extreme south (Sourdat, 1977; UN, 1989). The rainy season, influenced by the north-west monsoon, occurs during November to April, and the dry season, influenced by the south-east trade winds, occurs from May to October. The average annual temperature is 17.8ºC, but is hottest in the western coastal area. The high plateau areas have a tropical mountain climate with average temperatures in the range 16–20ºC (UN, 1989).

Land use is dominated by pasture and woodland (each covering around 40% of the land area). The dominant arable crops are coffee, vanilla, sugar cane, cocoa, rice and cassava.

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

Geology

The geology of Madagascar is composed substantially of ancient (Precambrian) crystalline basement rocks ('socle'), largely of granite, gneiss and schist, which form the high plateau regions. Younger rocks are present in sedimentary basins which form the coastal lowlands and alluvium occurs in intermontane valleys in the plateaux. These often have intercalations of volcanic rocks, largely of basaltic composition.

There are four main coastal sedimentary basins in Madagascar, each with mixed sequences of sands and clays and with abundant carbonate material (marls, limestones) as well as volcanic formations. Most are of Mesozoic and younger age. Quaternary sediments at the topmost parts of the sediment sequences are dominantly beach sands and dunes with alluvium and some coastal mangrove swamps.

In the west, an elongate tract of sediments extends virtually the length of the island. The sediments are largely continental and of Karroo age (Upper Carboniferous to Jurassic), with overlying younger deposits. The Karroo sediments are mainly sandstones, clays, some conglomerates and metamorphosed sediments.

In the extreme north, the Diégo-Suarez Basin (also known as Antsiranana Basin) consists of mixed sediments of Permian to Quaternary age, with an additional outcrop of basaltic volcanic rocks (Massif d'Ambre). The eastern coastal strip of the island comprises a sedimentary basin of Cretaceous to Quaternary age, with abundant sandstone and some volcanic deposits. In the flat-lying area of the far south, sediments consist of Tertiary clays and sandstones, with a number of young (Quaternary) dune formations.

Mineral deposits in the crystalline basement rocks include graphite, coal and some uranium deposits. Copper deposits are also present in some basement areas, notably the south-western part of Madagascar (Besairie, 1952). Exploration for gold is also ongoing in some areas of basement.

The crystalline basement rocks are generally covered by a layer of weathered material ('overburden'), typically 10–40 m thick (Grillot, 1992). Overlying soils in these areas are often hard and lateritic. Peat is also developed in some upland areas over the weathered basement (Grillot and Dussarrat, 1992).

Groundwater Availability

Groundwater is a major source of public supply for Madagascar, and in some drier areas (e.g. the south) it is the only source of available water. Surface water is used as a complementary supply in some areas, notably the towns of Fianarantsoa and Antsirabe in central Madagascar (Figure 1). Groundwater abstraction is from a large number of different formations, but usually the sedimentary aquifers. Of the sediments present, the limestone strata form the best aquifers. These are in places karstic due to solution of carbonates along fissures. The largest towns supplied with groundwater are Majunga and Toliary, which each use groundwater from an Eocene (Tertiary) limestone aquifer (UN, 1989). Groundwater in deeper horizons of the sedimentary basins often occurs under artesian pressure (Besairie, 1959).

Groundwater availability in the basement areas is generally more sparse, except where fractures are developed in the crystalline bedrock, principally at shallow levels, and where the weathered overburden is best-developed. In the southern part of the basement complex, UNICEF has installed 150 tubewells with handpumps in an area north and west of Antanimora (east of Ampanihy, Figure 1). The World Bank is also financing the construction of an additional 500 tubewells in this area.

Groundwater Quality

Overview

Groundwater quality varies considerably across the island and with depth, especially in the distinct sediment formations of the coastal basins. Groundwater is generally soft (low Ca, Mg concentrations) in the silicate rock types (sands, silts and crystalline basement) and may be aggressive with relatively low pH values (<7, typically 6; Besairie, 1959). Where carbonate rock types occur, groundwater is generally harder with near-neutral pH values (7 or more). Groundwater is typically fresh (low salinity) in the crystalline rocks and in areas away from the coast. However, deeper groundwater from the basement complex is affected by high salinity in some areas. Some older formations within the sedimentary basins (e.g. Triassic sediments where they occur) may also have increased salinity, although few data exist from which to assess them (Besairie, 1959). Salinity is a particular problem in some of the coastal aquifers where affected by saline intrusion and by infiltration of salt water from near-coastal rivers.

Shallow groundwater has a relatively low temperature (<30ºC), reflecting ambient air and ground conditions. However, higher temperatures (often in excess of 40ºC) have been recorded in groundwater from some deeper sediments in the coastal basins, reflecting deeper circulation and longer residence times of groundwater in the aquifers. Groundwater upwelling along deep fracture zones in the crystalline basement or at the contact zones between basement and sediments also has increased temperatures in places. These are also typically more mineralised than the shallow groundwaters (Besairie, 1959). Thermal springs have been reported in a number of places across the island, including Ranomafana (southern margin of the Diego-Suarez Basin, near Ambilobe), Itasy and Antirabe (south-central Madagascar) and Doany area (north-east) (Besairie, 1959; Serge, undated).

Little information is available with which to assess the pollution status of Madagascar's groundwaters, but surface water is noted to be polluted in places with raw sewage and other organic wastes (CIA, 2000). Some shallow groundwater samples have high nitrate concentrations, though concentrations are likely to be low in deeper aquifers, especially where they occur under artesian conditions.

Many of the groundwaters have high alkalinity values. High-iron groundwaters are also present in some areas, especially in Cretaceous and young alluvial aquifers (UN, 1989).

Nitrogen species

Few data exist for nitrogen compounds in water from Madagascar. However, a limited number of nitrate analyses were given by Besairie (1959). These are relatively high (above the current WHO guideline value of 11.3 mg N/l) in some shallow groundwaters, most likely as a result of pollution. Groundwater from Pliocene to Recent sands from the extreme south of the island also had high concentrations, up to 35 mg/l (as N; Besairie, 1959). This may also be partly pollution-derived, but evaporation is an additional factor that may have increased the concentrations of nitrate and other solutes in groundwater from the arid areas of the south.

No data are available for groundwater from deeper groundwaters. However, these are likely to have generally low concentrations because i) they are less vulnerable to surface-derived pollution, ii) they are more likely to be older groundwaters and may predate pollutant inputs, and iii) many deep groundwaters are likely to be anaerobic and to have undergone nitrate reduction. Anaerobic conditions may be indicated by the presence of high concentrations of dissolved iron and by the occurrence of artesian conditions.

Although nitrate concentrations are likely to be low in the anaerobic groundwaters occurring at depth in the sedimentary basins, concentrations of ammonium (NH_4) may be increased. This does not pose a health risk but may make the water less acceptable on grounds of adverse taste or smell.

Salinity

Malagasy groundwaters have very variable salinity as a result of variations in rainfall, rock types, groundwater ages and saline intrusion influences in the coastal areas. In the high plateau areas, shallow groundwater from crystalline basement rocks and their weathered overburden commonly has a low degree of mineralisation (low concentrations of dissolved solids) where rainfall is high and water infiltration to the aquifers rapid. Grillot (1989) gave conductivity values of less than 35 µS/cm (i.e. very low) for springs from shallow weathered rocks in the high plateau of north-central Madagascar. Deeper fluids in parts of the crystalline basement appear to be saline (sodium-chloride-rich) brines. Upwelling of these to shallower levels may increase the salinity of shallow water in some areas. Around 30% of the UNICEF boreholes completed in the basement rocks of Antanimora area had prohibitively high salinity for potable purposes and a number were abandoned after completion. Salinity appears to increase with depth but in the Antanimora area has been found to vary significantly over small distances (UNICEF/World Bank, 2001). The distribution of saline groundwaters in the region suggests that a preferable borehole site selection would be at shallowest depths and close to alluvial channels where groundwater recharge is greatest.

Groundwater is relatively fresh in most aquifers from the sedimentary basins, with electrical conductance of typically <1000 µS/cm and with calcium and bicarbonate as the dominant dissolved ions. However, the sediments from the coastal aquifers are vulnerable to saline intrusion and those from the arid, low-lying southern basin have particularly high salinity (UN, 1989). Salinity increases are marked by increasing concentrations of solutes such as sodium, chloride and sulphate. Besairie (1959) found chloride concentrations up to 21,000 mg/l (i.e. equivalent to the salinity of seawater) in superficial dune sands from the southern basin. Concentrations of chloride up to 3210 mg/l were found in the underlying karstic Quaternary carbonates and high salinities were also reported in Neogene and older sediments from the basin. Groundwater from the fissured basement underlying the sediments had chloride concentrations up to 1840 mg/l (Besairie, 1959). Increased salinity (chloride up to 970 mg/l) has also been reported in groundwater from alluvial sediments in the northern Diégo-Suarez Basin.

Although little studied, deep older aquifers in the sedimentary basins (Triassic, Jurassic and Cretaceous age) are typically saline, with sodium and chloride as the dominant ions (Besairie, 1959).

Fluoride

Fluoride concentrations are unknown in the Malagasy groundwaters. Concentrations are likely to be very low in groundwater from the humid plateau areas of large parts of Madagascar, especially the spring waters of low salinity. Circumstantial evidence from dental practitioners suggests that concentrations are generally low as Madagascar has a relatively high rate of dental caries despite having a relatively low sugar intake (The Sugar Bureau, 1999).

Fluoride concentrations may be higher in the more saline waters from the coastal aquifers and from deeper basement, although these may not be used significantly for water supply. Increased concentrations may also be expected in the groundwater from aquifers in the more arid south and south-west of Madagascar. Whether these exceed the WHO guideline for fluoride in drinking water (1.5 mg/l) is uncertain and could only be determined by water testing. Exceedances are possible in some sources. However, there are no known records of dental fluorosis in the country.

Iron and manganese

Although few data exist, high iron concentrations have been reported for groundwater from a number of aquifers in Madagascar, particularly in parts of the coastal sedimentary basins. Superficial sand aquifers typically have low concentrations as the groundwater conditions are aerobic. However higher concentrations have been found in groundwater from young alluvial sediments and from Cretaceous and other older aquifers, particularly those under artesian conditions. Besairie (1959) found iron at a concentration of 12 mg/l in groundwater from a 40 m deep artesian borehole in the Marovoay area of northern Madagascar. Here, under ambient anaerobic conditions, the concentration of dissolved manganese was correspondingly high (0.13 mg/l). Few other data exist for manganese in the groundwaters.

If iron is present in groundwater in sufficiently high quantity (greater than around 1 mg/l), the groundwater may be considered unfit for use by the local communities if an alternative low-iron source is available nearby. While high iron concentrations may promote acceptability problems, they are not known to pose a health problem. Some of the high-iron sources may exceed the WHO health-based guideline value for manganese in drinking water of 0.5 mg/l.

Arsenic

No data are so far available for arsenic in the groundwater. Most are expected to have low concentrations, below drinking-water guideline values. However, the recognised occurrence of high-iron groundwaters in some of the sediments (especially Cretaceous and recent alluvial sediments) means that arsenic concentrations may potentially be elevated in some of these abstraction sources. Testing for arsenic should be a priority in wells from these high-iron areas to assess the degree of risk posed.

Iodine

Given the maritime location of Madagascar, it is likely that iodine concentrations of the groundwaters will be sufficiently high to prevent the significant development of water-related iodine-deficiency disorders (IDDs; see Iodine Fact Sheet). Relatively high concentrations of iodine (tens to hundreds of µg/l) may be expected in some of the more saline waters found at depth in the basement rocks and in coastal areas affected by saline intrusion. Nonetheless, such concentrations are not considered to pose a health risk. WHO has no health-based guideline value for iodine in drinking water.

Other trace elements

There is little other information on inorganic groundwater quality. Kokusai Kogyo and Sanyu (1996) reported concentrations of chromium up to 0.13 mg/l in groundwater from the Malaimbandy area of south-west Madagascar (Sakény River basin). This is in excess of the WHO guideline value for chromium of 0.05 mg/l, but would need to be checked to verify the quality of the data quoted.

Occurrence of uranium mineral deposits in some areas of the crystalline basement (mobilised at depth by hypersaline brines) leads to the prospect that uranium concentrations may be high in some groundwaters from the basement areas (e.g. Tsarasaotra area, north central Madagascar; Besairie, 1952). Since the WHO guideline value for uranium in drinking water is very low (2 µg/l), it is possible that a number of sources will have concentrations close to or in excess of this value. Reconnaissance analysis of uranium in a selection of Malagasy groundwaters is recommended.

Data sources

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