Groundwater Quality: Mali

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

Mali is located in the Sahel region of West Africa, to the south-west of Algeria and north of Burkina Faso and Niger (Figure 1). It has a large area of some 1.24 million square kilometres. The terrain is dominated by flat or rolling sand-capped plains in the north and savannah in the south, although rugged hills occur in the north-east. Elevation varies from the highest point at Hombori Tondo (1,155 m) to the lowest on the Senegal River (23 m).

Mali experiences a sub-tropical to arid climate with a mild rainy season during June–November, a cool dry season during November–February and a hot, dry season during February–June. Mean annual rainfall is around 440 mm, varying from around 1500 mm in the south to less than 50 mm in the north. The mean annual temperature exceeds 25°C.

The main water courses are the Niger River which flows mainly north-eastwards across central and southern Mali (Figure 1) and the Senegal River which flows westwards to Senegal via the town of Kayes (Figure 1). Northern Mali is a dry plateau area with little surface drainage.

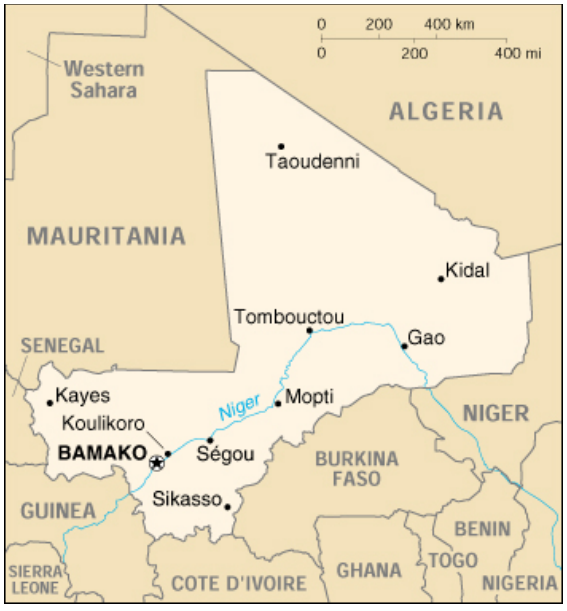

Figure 1. Relief map of Mali (from the CIA World Factbook).

The Niger River is the longest river in West Africa and enters Mali from Guinea, at which point the total annual flow is around 40 km^3. The river flows across the inner delta and is joined at Mopti by the Bani River before flowing downstream towards Niger (Figure 1). The inner delta (between Ségou and Timbuktu) is a flat-lying area of tributaries, swamps and small lakes and becomes a major wetland of around 30,000 km^2 during the rainy season. Significant losses of water occur in the area as a result of seepage to the sub-surface and evaporation.

As a result of the arid climate, some 65% of the land area of Mali is occupied by desert or semi-desert. Agriculture comprises only around 27% of the land area, most of this being pastureland. Agricultural and other economic activities are mainly restricted to the irrigated areas close to the River Niger. Farming and fishing occupy about 80% of the labour force and 10% of the population is nomadic (CIA, 2001). The main crops produced are cotton, millet, rice and corn. Industrial activity is dominated by production of local consumer goods and food processing, but also includes mining, tanneries and minor chemicals industries.

The area is particularly prone to drought, desertification and soil erosion. Irrigation in some areas has led to an additional problem of soil salinisation, which further restricts agricultural development. The problem has been exacerbated in the recent past by a gradual change from cotton to rice production and consequent increased irrigation needs (Valenza et al., 2000).

Geology

The main geological units of Mali are Birimian (Precambrian) crystalline basement, Lower Cambrian to Palaeozoic indurated sandstones and metamorphosed clays ('pelites') Permian dolorite intrusions, mixed continental sediments of the

'Continental Intercalaire' Formation (of Mesozoic age), Upper Cretaceous to Eocene marine sediments, the Pliocene 'Continental Terminal' sedimentary Formation and superficial deposits largely of Quaternary age (UN, 1988).

The crystalline basement occurs principally in southern Mali but also crops out in the Kayes region and the middle of the Adrar des Iforas. Rock types include metasedimentary and metaigneous units, with some granite. Intrusions of crystalline Permian dolorite crop out in parts of south-west and central Mali.

Lower Cambrian and Palaeozoic sediments have accumulated in vast sedimentary basins, which cover more than two thirds of the Mali land area. Lower Cambrian sediments outcrop along the southern margin of the major Taoudenit Basin, which covers most of central and northern Mali. The Lower Cambrian sediments exceed 1000 m in thickness in many places and are composed mainly of sandstone, but with some argillaceoous and carbonate horizons, especially in the upper parts (UN, 1988). Palaeozoic sandstones, schists and limestones crop out in the northern part of the Taoudenit Basin.

The Taoudenit Basin is infilled in its central part by the vast 'Continental Intercalaire' Formation of mid-Jurassic to mid-Eocene age. This covers an area of around 125,000 km^2 and varies in thickness from 20 m on the basin margins to 400 m in the area of the Nara Trench, between Nara and Tombouctou (Fontes et al., 1991). The formation comprises clays, fine to coarse unconsolidated sandstones and basal conglomerates. Continental Intercalaire deposits also occur in eastern Mali on the east edge of the Adrar des Iforas plateau and in the Tullemeden Basin on the south-east Mali border.

The Continental Intercalaire is overlain by Upper Cretaceous to Eocene marine sediments on the eastern edge of the Adrar des Iforas plateau and the Tullemeden Basin. The sediments compose mostly limestone and marl with some fine sands.

The Neogene 'Continental Terminal' Formation is more than 1000 m thick in south-east Mali (Tullemeden Basin) but generally a few tens of metres thick elsewhere. It crops out in a large area of the central Taoudenit Basin, and in the Gondo Basin on the southern border. The sediments are mostly poorly consolidated sands and clays with some lateritised horizons. Pyrite and lignite are common in the sequence (UN, 1988).

Superficial Quaternary deposits include fine-grained alluvium, mostly in the Niger Basin, sand dunes in northern Mali, lacustrine sediments in the Taoudenit Basin and northern Mali (UN, 1988; Fontes et al., 1991). Sabkha (evaporite salt) deposits are also found in parts of the Taoudenit Basin.

Soils are commonly lateritic, ferruginous and often thick. These are particularly well-developed on the areas of crystalline Birimian basement and on the sandstone plateaux (UN, 1988). Sea et al. (1990) reported iron-rich lateritic soils in excess of 35 m thick from Misseni area.

Sulphide mineral veins (containing mostly iron and copper sulphides) are prevalent in the Birimian (Precambrian) basement rocks in some areas. In Misseni area, they are found in association with metamorphosed volcanic rocks (Sea et al., 1990). The sulphide mineralisation is often associated with gold, which is exploited in some areas, notably the Galam Bambouk gold area on the Mali/Senegal border, near to Guinea. Economic reserves of phosphate are also exploited in some areas.

Groundwater Availability

Groundwater is heavily used for public supply. Around 55% of the population of the capital city of Bamako uses water from aquifer resources. Groundwater occurs in greatest abundance in the sedimentary aquifers, particularly in the Continental Intercalaire and the Contine tal Terminal, but is more limited in the crystalline and indurated sedimentary rock types. Unfortunately, the poorer aquifers are more prevalent in the south of the country where the major proportion of the population is concentrated. Hence, the sedimentary aquifers are of limited viability for public supply despite their greater permeability and storage capacity.

In the crystalline basement rocks, aquifer permeability is irregularly distributed but is mostly low. Groundwater occurs in fractures and is more abundant where weathered overlying layers (overburden) are thickest. Water-level variations in the crystalline basement are large and the average depth of wells is 60 m (UN, 1988).

In the indurated Lower Cambrian and Palaeozoic formations, groundwater availability depends on local lithology and degree of fracturing. Sandstones with overlying laterite soils form the best aquifers, and these are the main supply aquifers of Mali. However, permeability is limited, especially where the rocks are crossed by massive (crystalline) doloritic intrusions. Groundwater is mainly concentrated in the top 20–60 m and water levels are typically 10–25 m below surface (UN, 1988). These formations are poor aquifers in the Gourma Basin of south-central Mali and wells constructed in this area have had a low rate of success.

The Continental Intercalaire is the greatest water-bearing formation in Mali, though as a result of its location in the northern Sahel and Saharan areas, it is largely only exploited in the west and on the southern edge of the Adrar des Iforas. Producing wells in the formation can be extremely deep, up to or in excess of 150 m (UN, 1988). Groundwater levels may also be up to 100 m deep (Fontes et al., 1991).

The Continental Terminal is the second largest aquifer in Mali. It is particularly well-developed in the inner delta, where it is in hydraulic contact with overlying Quaternary alluvial deposits. Good yields are obtained when water levels are shallow (<20 m), as occur close to the Niger River. Yields diminish away from the river (UN, 1988). Well depths are typically 20–60 m deep in the inner delta area, depending on distance from the river.

Recent irrigation has modified groundwater levels in the major river valleys. During the 1940s, natural groundwater levels in the valleys were typically 30–50 m deep (Miézan and Dingkuhn, 2001). Today they are reported to be closer to 1 m below surface and this has contributed to significant soil salinisation in the irrigated plains.

Groundwater is generally limited in the superficial Quaternary alluvium as a result of fine sediment grainsize. Small-scale supplies of water may be obtained from surface sand dune deposits.

Groundwater Quality

Overview

Few data are available from which to assess the inorganic quality of Mali groundwater. Information available suggests that groundwater is for the most part fresh and of good quality. However, increased salinity has been observed sporadically in several of the aquifers.

Salinisation of soils and shallow groundwater is also seen as a problem in the river valleys. The salinisation largely results from recent irrigation practices and has led to high total dissolved salt contents and high alkalinity in the irrigated riverine areas of Mali.

Reports suggest that poor sanitation in urban areas may lead to pollution of shallow groundwater sources with nitrate and other pollutants.

Nitrogen species

Few data were available for nitrate or other nitrogen compounds. Concentrations of nitrate (and ammonium) are likely to be low in most rural groundwaters. However, nitrogen-based fertilisers are used in the agricultural areas of Mali (Diara, 1998) and may contribute some nitrate in particular to shallow groundwaters.

Fontes et al. (1991) found concentrations of NO_3-N in the range <0.1–7.3 mg/l in groundwaters from the Continental Intercalaire of the Taoudenit Basin. This confirms the expected low concentrations as all are below the WHO guideline value for nitrate (N) in drinking water of 11.3 mg/l. However, many of the groundwaters from the formation are believed to be present under anaerobic conditions. Hence, some nitrate loss resulting from denitrification may have occurred in this aquifer.

Concentrations of nitrate may be higher in urban areas where domestic pollution is most concentrated. Although poor sanitation in urban areas poses a greater threat to surface waters through direct discharge, groundwater at shallow depths is also at increased risk.

Salinity and hardness

The limited information available suggests that groundwater from crystalline basement aquifers and from the Lower Cambrian and Palaeozoic formations is generally fresh and soft, though often aggressive (pH of groundwater in the basement aquifers is commonly acidic: around 5.5–7.7; UN, 1988). Cambrian schists mostly also contain acidic and fresh water, though dissolved salt contents up to 17000 mg/l have been recorded (UN, 1988).

Groundwater in the Continental Intercalaire is typically fresh and of good quality, although salinity is variable. In the Taoudenit Basin of central Mali, Fontes et al. (1991) reported electrical conductivity values between 50 µS/cm and 13,100 µS/cm (chloride concentration up to 3300 mg/l) in groundwater from wells up to 100 m deep.

Groundwater in the Cretaceous to Lower Eocene sediments is also of variable salinity, being brackish in some areas. In the Continental Terminal, groundwater salinity is low close to the course of the Niger River, but increases away from the river (the recharge area) towards the margins of the Taoudenit Basin. Salinity also apparently increases with depth in the Continental Terminal (UN, 1988).

As noted above, salinisation of soils and shallow groundwater is a particular problem in the river valley areas of Mali. Problems have been especially noted for the Niger River and the Fala of Molodo (west of the Niger River; Valenza et al., 2000). Much of this is related to recent irrigation, but increased salinity in these areas is also due to the presence of ancient saline soils (solonchaks, which

contain halite, NaCl and trona, $NaHCO_3$. $Na_2CO_3.2H_2O$). These form a wide sabkha plain in the Fala of Molodo, which is the former course of the Niger River (Valenza et al., 2000). Rising water tables resulting from irrigation have allowed these salts to be redissolved in shallow groundwater and to increase the salinity further.

Miézan and Dingkuhn (2001) observed increased sodium and chloride concentrations in groundwater samples from close to the water table in the river valleys of Mali. They also reported sodium adsorption ratios (SARs) in groundwater of 10–50 and often high pH values (8.5 to 10). The salinisation and alkalinisation of the soils and shallow groundwaters can be severely detrimental to plant nutrient availability as well as to water potability.

In the area around Molodo (west of the Niger River), Valenza et al. (2000) found groundwater with electrical conductivity values in the range 300–1500 μS/cm, whilst values in groundwater east of the Niger were around 300 μS/cm and irrigation water had a very low conductivity of around 30 μS/cm. The most saline waters sampled had a dominance of either sodium-bicarbonate or sodium-sulphate ions. Although the highest values observed in this area are potable, they are liable to taste salty and may be unacceptable to users.

In urban centres, concentrations of major elements, especially sodium, chloride and sulphate, may be increased as a result of urban (domestic and industrial) pollution.

Fluoride

Few data are available for fluoride in the groundwater. Fontes et al. (1991) gave fluoride concentrations for groundwater from the Continental Intercalaire of the Taoudenit Basin. These were generally low, giving a range of <0.2 to 1.7 mg/l. Only one sample exceeded the WHO guideline value for fluoride in drinking water of 1.5 mg/l. Most had concentrations of the order of 0.3–0.7 mg/l (19 samples).

Fluoride concentrations in the other aquifers are also expected to be low but may increase in parts of the crystalline basement rocks, especially where granite occurs. Concentrations may also be higher in the more saline groundwaters from the other sedimentary formations. Sufficient variability in fluoride concentrations is expected for it to merit testing for in Mali groundwaters.

Iron and manganese

Concentrations of iron and manganese should be low in most groundwaters, except where particularly acidic, as in some of the crystalline basement rocks and indurated Palaeozoic sediments. Concentrations may also increase where aquifers become anaerobic, as for example found in areas of the Continental Intercalaire. In the Taoudenit Basin, dissolved iron concentrations were found by Fontes et al. (1991) to range between <0.01–3.5 mg/l and manganese between <0.002–3.8 mg/l. The highest concentrations were taken to be due to anaerobic conditions. The low nitrate concentrations in many samples from the area also suggest the presence of anaerobic conditions in parts of this aquifer.

Arsenic

No arsenic data are available for Mali groundwater. Concentrations should be mostly low, but may increase in the anaerobic groundwaters from the Continental Intercalaire of the Taoudenit Basin. Concentrations may also be higher locally in the areas of sulphide mineralisation, particularly where gold-mining activity is prevalent as this leads to preferential oxidation of arsenic-rich sulphide minerals and to their release into the environment.

Lateritic soils from some mineralised areas of Mali (e.g. Misseni) have been noted to contain accumulations of arsenic in the shallow layers (upper 2 metres or so), which often contain 'iron pans' (layers of indurated iron-rich laterite) (Sea et al., 1990). Here the arsenic most likely derives from the strong weathering (oxidation) of primary sulphide mineral veins in the bedrock and the accumulation in the surface layers is related to the relative abundance of iron oxides, which are known to have a strong affinity for arsenic. In such mineralised areas, arsenic is likely to be much more abundant than in other areas of bedrock and if mobilised, may cause localised groundwater-quality problems. However, as iron oxides are capable of binding arsenic strongly, the arsenic is likely to be retained in the solid minerals. Hence, the shallow soils and overburden are considered unlikely to be major sources of dissolved arsenic.

Iodine

Much of the iodine present in water is derived from the oceans as a result of maritime rainfall or marine aerosols. Iodine may also be concentrated in organic matter in the soil. Little iodine is derived from rock weathering. Hence, in a country such as Mali, which is remote from the sea and with a paucity of organic-rich soils, iodine concentrations in groundwater are expected to be generally low. If the

overall diet of Mali inhabitants contains insufficient iodine, there may be an increased vulnerability to development of iodine-deficiency disorders (IDDs) such as goitre. Where drinking-water iodine concentrations are less than around 5 μg/l, this may signal a potential problem with IDD development. Where shallow groundwaters are saline as a result of evaporation and soil salinisation, iodine concentrations may be higher. However, potability of these groundwaters is anyway limited as a result of the increased salinity.

In groundwater from the Continental Intercalaire of the Taoudenit Basin, Fontes et al. (1991) found iodine concentrations in the range 1–440 μg/l (average 69 μg/l, 20 samples). This is a very large range but the lowest concentrations observed could indicate a problem with the development of IDDs.

Other trace elements

Little other information is available on trace-element contents of the groundwaters. Concentrations of detrimental trace elements are likely to be low in most groundwaters, especially in rural areas and areas away from mining or other industrial activity. Concentrations of elements such as lead, copper, nickel, chromium and zinc may be locally high in areas affected by effluent from mining. Urban pollution may also be responsible for increased concentrations of some trace metals locally. Concentrations of chromium may be increased in water sources close to tanneries and a number of trace elements may be increased close to chemicals factories, depending on the chemicals being processed. Diara (1998) reported the occurrence of pollution from mercury and lead in urban water supplies from Bamako, but gave no data to substantiate the observation. If such metals are found in high concentrations, they are likely to be localised to a small number of wells rather than of widespread occurrence in the urban areas.

Fontes et al. (1991) found concentrations of uranium in the range <0.05–106 μg/l (average 10.4 μg/l, 21 samples) in groundwater from the Continental Intercalaire of the Taoudenit Basin. A number of these are significantly above the WHO guideline value of 2 μg/l for uranium in drinking water. The health consequences of long-term exposure to uranium at such concentrations are poorly understood, but the concentrations found are potential cause for concern and suggest that testing for uranium should be included in groundwater analysis programmes in the sedimentary aquifers of Mali.

Data sources

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