Groundwater Quality: Liberia

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

The West African Republic of Liberia is bordered by Sierra Leone in the west, Guinea in the north, Cote d'Ivoire in the east and the Atlantic Ocean in the south. The country is richly endowed with mineral, water and forestry resources but years of civil war, finally ending in 2003, severely impacted the country's economy, industry and infrastructure. The process of rebuilding continues although the economy and security situations remain fragile.

Liberia is a largely low-lying country with flat to rolling coastal plains, rising through rolling plateau of about 100–150 m elevation in the interior, to the uplands closer to the Guinean border. The highest point, Mount Wuteve (1380 m), lies in the Wologizi Range (Figure 1). Coastal plains are occupied by lagoons and mangrove swamps, the largest area of coastal wetland occurs at Lake Piso.

Rivers flow mainly south-westward from the upland areas, although the River Cavalla flows south and forms a large part of the eastern national border (Figure 1). Coastal plains are prone to alluvial flooding during the rainy season.

Liberia is near-equatorial and experiences a humid

Figure 1. Topographic map of Liberia (attribution: Mysid, based on UN, NOAA; Wikimedia Commons).

tropical climate with an average annual rainfall around 2500 mm along the northern border, increasing to more than 4000 mm at the coast. Most of the country has one rainy season (the West African Monsoon), from May to November, during which prevailing winds bring moist air from the Atlantic Ocean. Monthly rainfall in the coastal areas can exceed 1000 mm during this period. During the dry season, wind reversals bring dry 'Harmattan' winds from the Sahara Desert. Temperatures vary relatively little, being in the range 24–27°C in the dry season and 24–25°C in the rainy season.

The country lies within the West African rainforest belt and much of the land is forested, although the country has suffered heavy deforestation by logging companies in recent years. Only 3% of the land area is defined as arable, with permanent crops amounting to a further 2%. This is mostly concentrated in the coastal plain. Nonetheless, agriculture constitutes some 77% of annual GDP and occupies around 70% of the labour force. Principal agricultural exports are rubber, coffee, cocoa, palm oil, sugar cane and timber. Local food crops are dominantly rice and cassava. Principal industries are processing of rubber and palm oil, timber and diamonds.

Important environmental issues in Liberia besides deforestation include soil erosion and pollution of coastal waters, particularly from oil and sewage.

Geology

Liberia lies within the West African Shield and almost the whole land area is composed of crystalline basement rocks (granite, gneiss, schist), of Precambrian age. Archaean rocks (greater than 2700 million years old) occupy the western part of the country, west of the River Cess (Figure 1) and Proterozoic rocks (more than 2000 million years old) occupy the area to the east. The basement rocks have everywhere been folded and faulted intensely. Several shear zones are developed across the country, largely with north-east–south-west orientation. The most prominent is the Dube Shear Zone, close to the eastern border with Cote D'Ivoire. A weathered overburden layer exists, but thickness varies and data on its development are relatively sparse.

Younger sedimentary rocks crop out along the coastal zone between Monrovia and Buchanan, extending some 20 km inland. Sedimentary units occupy two small basins (White, 1969; NU, 1971), consisting of deposits of Palaeozoic through to Recent age, thought to be up to 1000 m thick in places. The basins contain shallow and patchy unconsolidated sediments of sand, sandy clay and peat up to 20 m thick, overlying mixed units of sandstone, shale and conglomerate of Cretaceous age and/or lithified sandstone of probable Palaeozoic age (White, 1969). Sandstone dominates the sedimentary sequences. The sediments are underlain by crystalline basement. Basaltic intrusions (sills and dykes) crop out in some areas of Liberia. These dominantly strike north-westwards (parallel to the coast) and vary in age. The most prevalent band of intrusions occurs around 80 km north-east of the coast. These are of Palaeozoic age. A belt of intrusions of Jurassic age occurs close to the coast. These can be seen cross-cutting the indurated sedimentary rocks in the coastal basins. The capital city, Monrovia, itself stands on such an intrusion ('Monrovia Diabase'; White, 1969).

Lateritic soils (heavily leached, rich in residual iron, aluminium and silica) cover 75% of the land area. These are of poor to medium fertility Poor sandy soils also occupy the coastal plain. Where forested, soils can be thick and rich in humus but this is rapidly denuded following deforestation (von Gnielinski, 1972).

The main geological resources of Liberia are iron ore, gold and diamonds. The country is endowed with plentiful resources of iron ore, consisting mainly of magnetite and haematite, along with quartz in 'banded iron formations'. The ore is mined principally at Mount Nimba, 360 km east-north-east of Monrovia. Iron ore is also present in the Mano Valley (Sierra Leone border), the Bong Range (100 km north-east of Monrovia), the Bomi Hills (60 km north of Monrovia) and Bea Mountain (100 km north-west of Monrovia). The reserve at Mount Nimba is a 300 m thick, 800 m long deposit of haematite (Berge et al., 1977) which accounts for about 1% of world iron ore production. The Bomi deposit ceased iron ore production in 1977 but, along with the Mano deposit, is scheduled to restart in 2012–2013. Bea Mountain has not been exploited. Bomi also has a localised occurrence of associated economic-grade phosphate. A phosphate deposit is also present along with a more minor iron ore at Bambuta, 70 km north-north-east of Monrovia.

Gold is mined predominantly from alluvial deposits (Hadden, 2006). A number of mines have opened in recent years in eastern Liberia and several small-scale artisanal workings occur across the country. Mining operations by a Liberian-owned gold company first began in 1881, but placer mining was restricted until the middle of the 20th century when a gold rush in the 1940s, centred around Grand Cape Mount County, saw increased production. In Grand Cape Mount, gold mineralisation occurs particularly at Largor. Gold mineralisation is also prevalent in the Proterozoic rocks of eastern Liberia and shear zones (e.g, Dube Shear) are particularly prospective for gold. The most significant gold placer deposit in Liberia is that at Bukon Jedeh, some 60 km east of Greenville in Maryland. The deposit has an areal extent of some 150 km^2 (Boadi, 1991). Mining operations began there recently and gold exploration programs are also underway elsewhere in Maryland as well as River Gee and Grand Kru counties. In Grand Kru, exploration activities are especially focussed around Jolodah mine within the Dube Shear Zone.

Within the prospective areas, gold occurs in mineralised zones of bedrock, in lateritic soils and in alluvial deposits. Laterite-hosted gold dominates at Bukon Jedeh and appears to be the in-situ weathering product of primary bedrock ores. Alluvial gold occurs through weathering of laterite and redistribution within local drainage networks (Boadi, 1991).

The placer gold is associated with disseminated sulphides and arsenides. In both Bukon Jedeh and Largor, sulphides include pyrite, pyrrhotite and chalcopyrite with minor occurrences of arsenopyrite and niccolite (Boadi, 1991; Evans, 2001). Textural analysis of soils has shown that weathering was initiated by breakdown of primary sulphides and arsenides. Alluvial placer deposits also contain some galena (lead ore), sphalerite (zinc ore) and chromite (chromium ore). Galena Creek, 10 km south-west of Tawalata, owes its name to the findings of ore fragments in the stream gravels.

Diamonds were first discovered at the beginning of the 20th century when stones were recovered from alluvial deposits being panned for gold. The most important diamond occurrences have been found in Lofa and Nimba counties. Discoveries also gave rise to diamond rushes in the 1950s. The occurrences derive from weathering of primary kimberlite dykes. Known kimberlite occurrences are rare and where present are highly weathered and do not crop out. However, the widespread occurrence of diamondiferous alluvial deposits suggests that kimberlite may be more widespread than formally identified (White, 1970).

Groundwater Availability

Liberia has plentiful rainfall and abundant water resources, although data on groundwater sources, availability and yields are relatively scarce (Republic of Liberia, 2008). Groundwater storage is greatest in permeable sedimentary units, alluvium and weathered overburden overlying the crystalline basement rocks, particularly in areas of granite. Republic of Liberia (2008) produced a map of manual drilling potential in Liberia based on rock permeability, hardness and depth to water. Areas of greatest drilling potential were identified as the coastal (sedimentary) areas and areas of granite along the eastern border region of Nimba county, in Sinoe, and Lofa in northern Liberia (Figure 1).

Available information suggests that groundwater is generally available in sufficient quantity for rural supplies which are chiefly accessed by shallow dug wells and spring catchment systems and less commonly by boreholes. Republic of Liberia (2008) catalogued 3500 shallow dug wells and 360 boreholes for which data exist. These were chiefly from Nimba, Bong, Lofa, Montserrado, Bomi and Grand Cape Mount counties. A more recent survey has identified 7500 water points across the country (World Bank, 2012); further occurrences of dug wells are likely in other counties, but information on these areas is lacking. Depth to water in some of the shallow wells can be as shallow as <1 m (Republic of Liberia, 2008); total depth of dug wells is dominantly <25 m.

Large urban centres are more commonly supplied by either surface water or from boreholes which can be up to 100 m deep. Since the 1940s, Monrovia has been supplied by borehole groundwater from the thick local sedimentary deposits. Since the civil war, more hand-dug wells have also developed in Monrovia (Gehrels et al., 1995). The cities of Buchanan, Kakata, Zwedru, Harper and Greenville are also supplied by groundwater largely from boreholes (Republic of Liberia, 2008). Other urban centres are supplied by small-scale abstractions from shallow wells (largely <10 m) in crystalline basement and overburden; NU, 1971).

For Liberia as a whole, improvements in water supplies in recent decades mean that some 40% of the population is estimated to have access to potable water (Hadden, 2006). However, water-supply infrastructure and capacity have been affected badly by the years of civil war.

Groundwater Quality

Overview

As with data on groundwater availability, data on quality are scarce. Evidence suggests that, as many of the rural and peri-urban sources are shallow, they are vulnerable to surface contamination. Rural sanitation appears strictly limited, with existing sewerage systems commonly damaged during the civil war and consequently non-operational. Sewerage systems, where present, are dominated by pit latrines or on-site septic tanks. Some domestic sewage has apparently been disposed of in surface watercourses (Republic of Liberia, 2008). Mining, logging and agriculture also pose potential threats to shallow groundwater quality.

In a limited survey of groundwater from shallow wells in Monrovia, Gehrels et al. (1995) concluded that inorganic chemical quality was generally good, with near-neutral pH (6–7.8) and low salinity (average concentration of total dissolved solids around 50 mg/L). The largest problem observed was bacterial contamination from coliform and other pathogenic organisms.

Urban supplies from deep boreholes in Monrovia appear to have been subject to saline intrusion as a result of overabstraction (Republic of Liberia, 2008), although developments in water-supply infrastructure may mean that this problem is historical.

Given the paucity of data for inorganic constituents in Liberian groundwater, reconnaissance testing of supplies is strongly recommended.

Nitrogen species

Contamination of shallow groundwaters from urban and domestic wastes will inevitably lead to a vulnerability of shallow groundwater to contamination from nitrate and potentially also ammonium. There is currently a lack of evidence for high concentrations of nitrogen species: the Gehrels et al. (1995) survey of groundwater from shallow wells in Monrovia found concentrations of nitrate-N to be mostly <10 mg/L (i.e. less than the WHO guideline value) although the scale of testing was small. Any anaerobic groundwaters in the deeper groundwaters from the sedimentary basins are likely to have low nitrate concentrations, although these may in turn have elevated concentrations of ammonium.

Salinity

As hinted by the overview of water quality, groundwater is in most areas likely to be of sufficiently low salinity for potable use, although saline intrusion may impact groundwater in deep, heavily used boreholes close to the coast. Salinity can also increase to some extent where affected by surface pollution (e.g. from sewage, mining) and so may increase in wells closest to pollution sources. Otherwise, high rainfall, likely short residence times of shallow groundwaters and the dominance of ancient crystalline basement suggest that salinity should not be a widespread problem.

Fluoride

No data are known to be available on fluoride in Liberian groundwater. As for salinity, high rainfall, likely high recharge and short residence times in shallow aquifers are also likely to yield groundwater with low fluoride concentrations (less than the WHO guideline value for fluoride in drinking water). Increased concentrations may be present in groundwater from some sources within granite (Nimba, Lofa and Sinue counties) although the limited information available on granite mineralogy and chemistry in Liberia does not indicate the presence of unusually high concentrations of fluorine in the solid phase. However, testing of water supplies is needed to confirm the concentration ranges present, particularly in areas of granitic basement.

Iron and manganese

Concentrations of iron and manganese in groundwater are controlled in large part by pH and redox conditions. As information on both is limited, so is knowledge of the occurrence of iron and manganese in the groundwaters. Groundwater from deep boreholes in the sedimentary basins may well be anaerobic in places and could therefore generate high iron and manganese concentrations. Areas with developments of iron ore can also be areas with relatively high concentrations in groundwater. This does not necessarily follow though if local groundwaters are of neutral pH and oxic. Elsewhere, in shallow groundwaters developed on basement rocks and weathered overburden, concentrations are likely to be mostly low. High concentrations of iron and manganese will be most likely sporadic and localised and based on local groundwater flow paths and geology. Gehrels et al. (1995) found concentrations mostly <200 μg/L in shallow groundwater from Monrovia, in line with their neutral and oxic character.

Arsenic

The iron ore deposits of Liberia have many similarities with iron ore occurrences in the Iron Quadrangle of Minas Gerais State in Brazil, which constitutes one of the main iron-ore producing regions in the world. Some areas of the Iron Quadrangle contain gold-arsenic bearing ore deposits which have been associated with release of arsenic to water sources, contamination of local drinking water supplies and resultant health impacts. The deposits of Liberia have less documentary evidence of arsenic-bearing sulphide minerals associated with the iron ore (haemetite) sequences, but as iron oxides are known to have strong affinities with arsenic, the occurrence of arsenic in groundwater in localised areas around the iron-ore zones cannot be ruled out. Testing of water supplies in these areas is recommended.

Areas of recognised gold mineralisation, whether bedrock-hosted, laterite-hosted or alluvial, are also closely associated with sulphide minerals and their weathering products and are therefore potentially vulnerable to mobilisation of arsenic in groundwater. Reconnaissance testing for arsenic in groundwater in areas of gold mineralisation (particularly Grand Cape Mount, River Gee and Maryland counties) is recommended. The basement rocks of eastern Liberia (Birimian) have some analogies with those occurring in Ghana and Burkina Faso, both of which have recognised occurrences of arsenic-rich groundwater, albeit in localised association with the zones of sulphide mineralisation.

In other areas, the barren crystalline basement rocks, their overburden, basaltic intrusions and the sandstones in sedimentary basins are less likely to contain high concentrations of arsenic. Groundwater in deep boreholes from the sedimentary basins may be possible exemptions if conditions are anaerobic. Reconnaissance testing for arsenic in these areas is also recommended.

Iodine

Concentrations of iodine in groundwater will likely coincide with salinity and are expected to be highest in more saline waters closest to the coast. High concentrations may be present in areas of saline intrusion for example. The dominance of crystalline basement rocks and their weathered overburden, together with indurated sandstones in the coastal basins are inconsistent with high concentrations of iodine in groundwater in other areas of Liberia. To the best of our knowledge, no data are currently available to confirm these conclusions.

Other trace elements

No data are available for other trace elements in the Liberian groundwaters. From the sporadic occurrences of ore minerals of lead, copper, zinc, nickel and chromium, it can be inferred that sporadic high concentrations of trace metals may occur. Of these trace elements, lead is potentially the most problematic as the WHO guideline value for this element is the more stringent than for the other elements. Significant exceedances for chromium, copper, zinc and nickel are considered less likely.

Data sources

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