Groundwater Quality: Sierra Leone

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 Republic of Sierra Leone is located in West Africa and bordered by Liberia to the south, Guinea to the north and east and the Atlantic Ocean to the west (Figure 1). With an area of 71,740 square kilometres, terrain consists of a coastal plain, inland plains rising eastwards to mountain plateau. The highest point is Mount Bintumani (1948 m) on the eastern border.

Sierra Leone lies in the equatorial rainforest belt and has a humid tropical climate. Average rainfall is 2530 mm/year (varying from 5000 mm/year in the Freetown Peninsula to 1800 mm/year in the north-east). A distinct rainy season occurs from May to October and a dry season from November to April. During the dry season, cool harmattan winds blow from the Sahara desert. Average daily temperature lies around 26°C.

Five major rivers: the Jong (Pampana), Rokel, Sewa, Little Scarcies and Moa flow westerly cross-country and a further two (Great Scarcies and Moro) form the northern and southern national borders respectively. The rivers spill into the Atlantic Ocean via large estuaries. Uplands, central and eastern parts are largely forested; the north is dominated by savannah vegetation. Freshwater swamps occupy low-lying valleys and mangrove swamps occupy parts of the coast. Arable land covers around 7% of the land area.

Sierra Leone has a population around 5 million

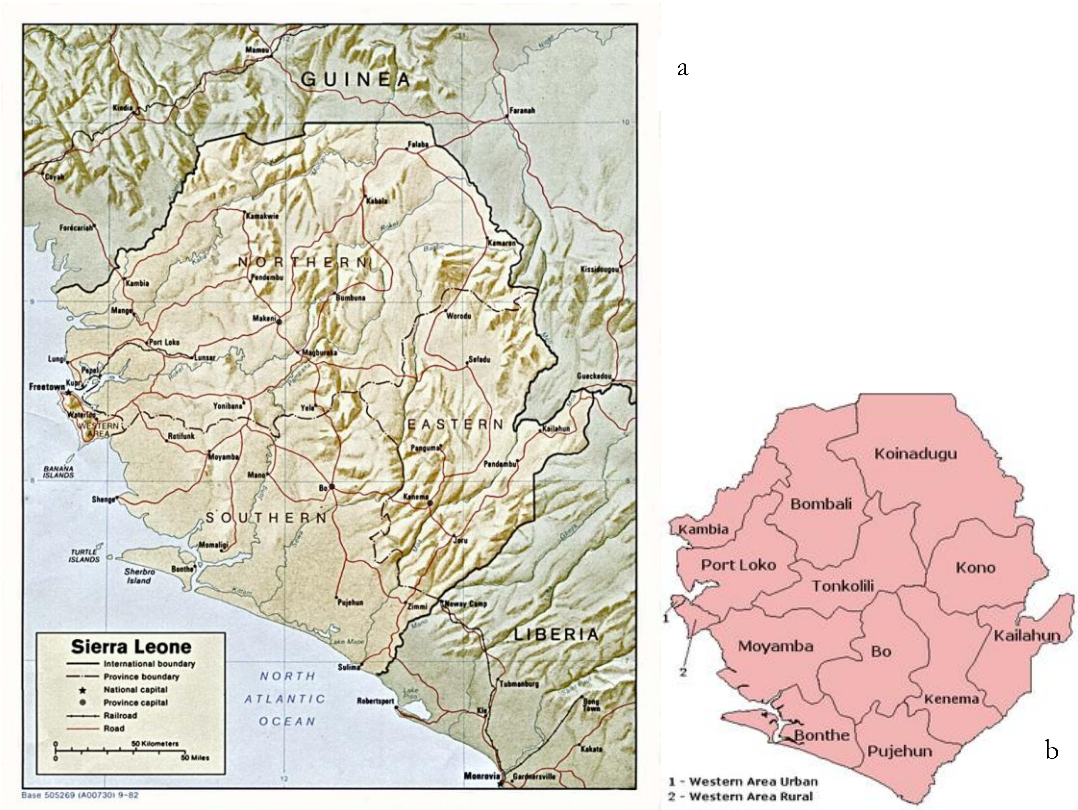

Figure 1a. Relief map of Sierra Leone (courtesy of the University of Texas Libraries, The University of Texas at Austin); **b**. District map (copied under Creative Commons Attribution licence).

people, 70% of whom live in rural areas. The capital, Freetown, (Figure 1a), has developed around the largest natural harbour in the world. The main areas of population are concentrated in the Freetown Peninsula and Kono, Kenema and Bo districts (Figure 1b). The northern part of the country is more sparsely populated.

Sierra Leone suffered a decade of civil war following its outbreak in 1991, fuelled largely by the diamond industry. The war saw huge loss of life, internal and external population displacement and collapse in infrastructure and the economy. Economic recovery has been slow in the post-war decade and poverty and unemployment remain high.

Subsistence agriculture is the dominant occupation, employing around 60% of the workforce. Main crops include rice, cassava and sweet potato. Coffee and cocoa are grown for export. Dominant exports derive from mining: Sierra Leone is one of the world's most important diamond producers, and both industrial and artisanal operations exist. Titanium (rutile) and aluminium (bauxite) are also major export industries, and iron ore and gold are also produced. Pre-conflict, the mining sector contributed to around 20% of GDP but the sector suffered near collapse in the conflict years, during which an industry in diamond smuggling proliferated. Post-conflict, the contribution of the mining sector to public funds remained weak due to the bypassing of official export channels but today the situation has been partially restored. By 2007, the mining sector provided some 4.5% of GDP (OECD/African Development Bank, 2009) with some further gains subsequently, largely due to iron-ore extraction. Two large mines (one bauxite, one rutile) which were forced to close in 1995 have reopened. Haematite mining restarted production in 2011. Mining and quarrying currently employ around 14% of the labour force. Artisanal mining chiefly concerns diamonds and gold and around 8% of the labour force is involved in artisanal diamond operations. Other industrial development is minor. Shipping is focussed on the major international port at Freetown. Artisanal fishing is important along the coast.

Environmental problems are dominated by deforestation, soil erosion and impacts of mining, although poor land and water management are cited as additional problems.

Geology

Geology consists dominantly of Precambrian (Archaean and Proterozoic) basement rocks that compose the westerly edge of the West African craton. Precambrian formations occupy three quarters of the land area. Archaean rocks dominate and include mainly granite and gneiss with greenstone and some metabasic intrusive rocks (amphibolites). These rocks were formed and metamorphosed during two periods of earth movement, some 3200–3000 million years and 2700 million years ago. Granite and acid-gneiss dominate throughout the districts of Pujehun, Kenema, Bo, Kono, eastern Tonkolili, Bombali and Koinadugu. The Archaean Kasila Group is a formation of schist and gneiss which stretches in a north-westerly tract from Pujehun district to Kambia. Archaean greenstone belts include amphibolites, quartzites and ironstones and are most prominent in the Sula Mountains and Kangari Hills in the central part of the country, as well as the Nimini and Gori Hills in the east.

Proterozoic rocks are less significant, but include clastic sedimentary and volcanic rock types within the Rokel River Group which extends in a north-west to south-east tract from the Guinea border across the inland plains to Bo district. This group was deformed by earth movements around 550 million years ago.

A minor outcrop of Ordovician rocks in north-western Sierra Leone, the Saiony Scarp Group, constitutes part of the Grès Horizontaux of Guinea and consists of sandstones, grits and shales with dolerite sills.

In addition, a coastal strip around 50 kilometres wide comprises marine and estuarine sediments (sand, gravel and mudstone) of Palaeogene to Recent age.

Mesozoic dolerite intrusions occur as north-east–south-west-trending dykes across the basement complex as well as in sills within the Rokel River Group. Kimberlite dykes of Jurassic age have similar orientation and occur in the east of the country. The Mesozoic Freetown Igneous Complex is a layered gabbro which crops out on Freetown Peninsula.

As noted above, diamonds, rutile, bauxite, gold and iron ore constitute Sierra Leone's principal mineral resources. Diamonds occur within kimberlite dykes and pipes intruded into the greenstone belt as well as in granite-gneiss in the eastern part of the country. Diamond extraction centres around the mining towns of Tongo (Kenema district) and Koidu (Kono district). Alluvial diamonds occur in the drainage channels that cross these areas (in Kono, Kenema, Bo and Pujehun districts) but are particularly prevalent in the deposits of the River Sewa (Figure 1).

Gold is mainly associated with the greenstone formations. Principal locations of gold mineralisation are the Sula Mountains including

Lake Sonfon, Maranda and Yirisen; the Kangari Hills, especially Baomahun, Makong and Makele; the Nimini Hills (Kono district); Kamakwie-Laminaia (Bombali district) and the Gori Hills (Kailahun district). Alluvial gold occurs in the river valleys that cross these areas. Commercial mining of alluvial gold occurs at Kateh (Bobali district). The Lake Sonfon area has gold and sulphide minerals associated with steeply-dipping quartz and pegmatite veins. Sulphide minerals include pyrite and chalcopyrite. At Kalmaro, mineralised quartz veins have been traced for around 800 metres. At Baomahun, the vein structure is some 1500 metres long.

Bauxite deposits are mined between Moyamba and Mano (Freetown Peninsula), at Krim-Kpaka (Pujehun district) and in the north at Kamakwie and Mukumre. Haematite deposits, likely the products of extreme weathering, are extracted at the Marampa open-cast mine near Lunsar (Port Loko district). Other mineralisation includes cassiterite (tin ore), molybdenite (molybdenum ore), columbite-tantalite (niobium-tantalum ore) and chromite (chromium ore). Rutile occurs principally in south and west Sierra Leone, including along the southern coast. Chromite occurs in the Sula Mountains and in a south-westerly-orientated tract from Tongo through Kenema and Pujehun districts. Platinum has been found in gravels over several outcrops of anorthosite gabbro of the Freetown Peninsula.

Soils and weathered bedrock are heavily lateritised. Laterite is particularly well-developed over the greenstone belts (Davies et al., 1989) and dolerite intrusions. Bauxite, formed as part of the lateritisation process, occurs above parts of the Archaen Kasila Group and is mined at Moyamba. Gold also occurs in laterite above greenstone bedrock.

Groundwater Availability

Groundwater resources are plentiful though water supply infrastructure is patchy and limited. Infrastructure and governance suffered huge setbacks during the civil war years and in the mid 1990s, access to safe water in the rural areas dipped to just 15%. The situation showed some improvement post-war and by 2006, some 84% of the urban and 32% of the rural population had access to an improved water supply (Westhof, 2006). Access to improved supplies is particularly restricted in Freetown because of infrastructure difficulties and population pressures (Blinker, 2006).

Supply in both urban and rural areas is dominantly from surface water. Groundwater supplies a minor proportion of the rural population with some recent boreholes installed in large cities. Freetown's supply is provided by surface water from the Guma Dam, supplemented by groundwater from boreholes. Some protected boreholes exist but groundwater sources are commonly unprotected shallow wells. Throughout Sierra Leone, access to sanitation is limited (Jimmy et al., 2013).

As the geology of Sierra Leone is dominated by Precambrian crystalline rocks, primary porosity is low and flow is dominantly via fractures and joints, except where water levels are sufficiently shallow for storage to occur within the weathered overburden layer. Porosity is higher in the 50 kilometre-wide coastal belt of unconsolidated sedimentary rocks which offer the greatest potential for groundwater storage.

In a study of the feasibility of manual drilling for water supply, Unicef (2010) identified only 421 groundwater points in a swathe of land running north-south including parts of the districts of Pujehun, Bo, Tonkolili, Moyamba and Bombali, and covering about a quarter of the country. Water levels in investigated water points were mostly <10 m deep and boreholes usually less than 30 m deep. The observations are consistent with the presence of groundwater in shallow fractures and the weathered overburden layer. The study indicated that greatest potential for manual drilling existed in the western coastal sedimentary belt, but that eastern Sierra Leone had significant potential for shallow hand drilling because of shallow water levels and strongly weathered bedrock.

Groundwater Quality

Overview

Availability of data on groundwater quality is limited because of an apparent lack of systematic monitoring (Blinker, 2006). Assessment of the status of national groundwater quality is therefore difficult and much of the following account highlights potential rather than actual problems, based on available data for regional geology and mineralisation, landuse and climate.

Limited access to safe water and sanitation means that incidence of waterborne diseases is high (UN, 2007; Jimmy et al., 2013) and shallow groundwater is particularly vulnerable to contamination from domestic and urban pollution (e.g. latrines, septic tanks, waste tips). The prevalence of mining activity is also likely to have had an impact on groundwater quality. Other industry is comparatively minor, and impacts on groundwater quality likely to be more localised.

Engineers Without Borders (2012) reported the presence of faecal coliforms in shallow spring water from the village of Baoma on the outskirts of Freetown. Similar observations were made for groundwater in Kulanda town, Bo. Jimmy et al. (2013) analysed water samples from 36 wells. The depths of wells ranged between 2 and 34 m although 56% were less than 5 m deep, and most were unlined. Of the analysed samples, 60% had detectable faecal coliforms though none contained detectable *E. coli*. Most had low values of total dissolved solids (maximum 639 mg/L), pH was largely acidic (5.1–6.6) and waters were soft. The water quality shows the effect of interaction of shallow groundwater with carbonate-poor crystalline basement rocks in a high-rainfall region and demonstrates the vulnerability to surface-borne pollution.

Assessing combined data from a number of Sierra Leonian authorities, Ndomahina and Kabia (2004) also reported largely acidic groundwaters (range 5.1–7.4), the most acidic being reported from Moyamba district and the least from Kambia.

Nitrogen species

Concentrations of nitrate in groundwater from Kulanda town ranged between 0.5 and 28 mg/L as NO_3[1], none exceeding the WHO guideline value of 50 mg/L (Jimmy et al., 2013). Concentrations of nitrite were mostly low but higher where concentrations of nitrate were higher (maximum observation 1.1 mg/L as NO_2). These concentrations are consistent with oxidising conditions in shallow groundwaters and some show the influence of urban/domestic pollution. Engineers Without Borders (2012) similarly detected nitrate but found that concentrations were below the WHO guideline value for drinking water. Ndomahina and Kabia (2004) reported concentrations of NO_3 in the range 0.8–23 mg/L. Again these were below the WHO guideline value, although 35% of groundwater samples from Kono district were reported to be relatively high.

Concentrations of dissolved ammonium would be expected to be mostly low but, like nitrite, could be higher locally in proximity to sources of urban pollution (e.g. latrines).

The apparent paucity of protected groundwater sources and the prevalence of shallow groundwater levels mean that testing for nitrogen species, and nitrate in particular, would be advisable.

Salinity

High rainfall and recharge, together with predominance of crystalline basement rocks mean that groundwater salinity is expected to be generally mostly low. The usually low concentrations of total dissolved solids of samples detailed in the Jimmy et al. (2013) study support this conclusion. Ndomahina and Kabia (2004) also reported that dissolved solids concentrations for the majority of groundwater analyses obtained for their study were less than 250 mg/L.

High concentrations of dissolved solids can result from point sources of pollution. No data are available on groundwater quality in the sedimentary aquifer of the coastal belt, although potential for saline intrusion exists here, depending on abstraction rates.

Fluoride

Groundwater interacting with granitic and gneissose rocks, which are typically enriched in fluorine-bearing minerals (biotite, apatite, amphibole), has the potential to accumulate dissolved fluoride. This reaction is however, offset by high recharge rates and short residence times in shallow aquifers, which limit such dissolution reactions. The resulting concentrations of fluoride are therefore difficult to predict and may be variable. Results for the 36 shallow groundwater samples from granite-gneiss basement in Kulanda town, Bo, showed concentrations in the range 0.10–1.4 mg/L (Jimmy et al., 2013). These are all below the WHO guideline value of 1.5 mg/L but in some cases are close: 8 of the analysed samples (22%) had concentrations of 1 mg/L or more. Ndomahina and Kabia (2004) also reported fluoride concentrations up to 1.05 mg/L, although the locations of the highest concentrations were undefined.

The concentration ranges observed give no undue cause for concern, but the proximity of some to the WHO guideline value mean that testing for fluoride in groundwater would be advisable. This is particularly the case for groundwaters from granite-gneiss basement rocks. Kimberlites could also be sources of fluoride as they contain amphibole and mica, although these are of more limited lateral extent.

Concentrations of fluoride in groundwaters from the greenstone formations and sedimentary rocks from the coastal belt are expected to be comparatively low.

[1]Values quoted as NO_3-N in error in the reference

Iron and manganese

At the time of writing, few data could be found for dissolved iron and manganese. Prevalence of shallow groundwaters and likely overall oxidising conditions in these conditions would normally render Fe and Mn oxide minerals poorly-soluble, and dissolved concentrations low. However, higher concentrations could be present in acidic groundwaters (e.g pH<6) which evidently pertain in some areas of the crystalline basement (Jimmy et al., 2013) and may be particularly prevalent in areas of sulphide mineralisation and metal mining. In the shallow groundwaters from open wells in Kulanda town, the Jimmy et al. (2013) study showed that concentrations of iron and manganese were mostly low, only one sample exceeding the WHO guideline value (in this case, for Mn). Ndomahina and Kabia (2004) also reported mostly low concentrations, but with manganese values up to 1.7 mg/L. Some exceedances for manganese in drinking water clearly exist.

Arsenic

Using evidence from analogous lithologies in other areas of West Africa (Ghana, Burkina Faso), areas of greenstone with gold-sulphide mineralisation are potentially vulnerable to contamination of groundwater with As at concentrations greater than the WHO guideline value of 10 μg/L. Areas close to gold-mining activity (alluvial and basement-hosted) are particularly at risk. Testing for arsenic in groundwaters from the greenstone belts, and especially in proximity to mined sites, is strongly recommended.

Granite-gneiss basement and sedimentary rocks from the coastal plain are likely to be less at risk unless the presence of reducing conditions can be demonstrated. Investigation of concentrations of iron and manganese can be of some assistance in ascertaining whether this is the case.

Iodine

No data are known to exist for iodine in Sierra Leone groundwaters. Although the country has a large area of coastline and maritime rainfall is known to contain iodine, this is to be offset by the predominance of Precambrian basement rocks which are usually iodine-poor. Accumulation of iodine in groundwater from local aquifers is therefore unlikely and iodine content would likely be dominantly rainfall-derived. High concentrations of groundwater iodine are not expected. If food sources are dominantly of local origin, dietary iodine deficiency is possible, especially in areas of crystalline basement. No WHO guidelines exist for iodine concentrations in drinking water.

Other trace elements

As mining is such an important industry in Sierra Leone, the mobility of other trace metals associated with sulphide mineralisation and oxidation must be considered and testing for elements such as copper, zinc, aluminium, nickel, lead, cadmium and antimony is advised.

Occurrence of chromite in economic proportions in central and southern Sierra Leone also suggests a potential for contamination of shallow groundwater with chromium. The element is mobile in its oxic (hexavalent chromium) state, although mobility is limited in acidic conditions by adsorption. Conditions in the shallow basement and greenstone aquifers are expected to be mostly oxic but also often acidic, as suggested by the Jimmy et al. (2013) survey. Concentrations of chromium above the WHO guideline value of 50 μg/L are therefore not expected on a regional scale. Testing of groundwater in areas close to chromite mineralisation would help to clarify the concentrations.

Uranium concentrations in groundwater are often observed to be relatively high in the areas of granitic basement. However, assuming short residence times, high recharge rates and largely acidic conditions, concentrations above the WHO guideline value for uranium (30 μg/L) are considered unlikely. Reconnaissance testing should be carried out to establish whether exceedances occur.

If as practised elsewhere in West Africa, artisanal gold mining involves extraction with mercury, some localised mercury contamination is possible. Mercury has in the past been detected close to some artisanal gold-mining operations in Ghana (Akiwumi, 1997), although the impact should be local and occurrence predictable by artisanal mining locations. Background concentrations of mercury would be expected to be low or undetectable.

Data sources

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