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British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Groundwater Quality: Nigeria

WaterAid

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

Nigeria is situated in West Africa, bordered by Benin in the west, Cameroon in the east and the Gulf of Guinea in the south (Figure 1). It has a land area of some 911,000 square kilometres. The terrain is very variable, with mountains in the south-east, hills and plateaux including the Jos Plateau in the centre, lowlands in the south and plains in the north. The highest point is Chappal Waddi (2419 m) in eastern Nigeria and the lowest is sea level.

Nigeria's climate varies from equatorial in the south to tropical in the centre and arid in the north. Annual rainfall varies from over 4000 mm in the south to less than 250 mm in the north, the national average being 1180 mm. Rainfall is seasonal with a wet season occurring between July to September in the north, extending to between April and November in the delta area. Recent years have seen decreasing rainfall totals in northern Nigeria (Carter and Alhassan, 1998) and drought is a frequent problem in that region. The mean annual temperature in northern Nigeria is around 25ºC (Alagbe, 2002).

Vegetation largely follows the climatic variation, with densely vegetated mangrove swamps in the

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

south, tropical rainforest in the centre, through to savannah in the north and Sahel savannah in the extreme north-east.

With a population of around 130 million people, Nigeria is the most populous country in Africa. It is composed of 36 states and the capital city is Abuja (Figure 1).

The main river is the Niger which flows from the north-west of the country southward to the delta. The river has been dammed at Kainji (Figure 1). The principal tributary of the Niger is the Benue River which runs south-westwards and joins the Niger at Lokoja (Figure 1). Other important rivers are the Cross River in the south-east and Imo River in the south. Lake Chad, the largest freshwater lake in Africa, lies to the north-east of the Nigerian border and its drainage basin occupies 20% of the nation's land area. Other bodies of surface water in the arid north-east include a number of small lakes and playas, some of which are saline.

The Nigerian economy is largely petroleum-based. Nigeria is the largest producer of oil in Africa and an important producer worldwide. Oil production began in the 1950s and today amounts to some 20% of GDP. Coal is also an important natural resource which has been exploited since the early twentieth century. Tin is mined locally in the Jos Plateau. Much of the rest of the economy is based on subsistence farming, although this has in recent years failed to keep up with population growth. Agriculture employs some 70% of the workforce. Around 30% of the land is arable, and around 4% of the cultivated land is irrigated. Principal crops include cocoa, palm oil, peanuts, corn, rice, sorghum and millet. Principal livestock are sheep, goats and pigs.

Geology

Ancient Precambrian basement rocks (deformed during a period of earth movement known as the Pan African orogeny, ca. 550 million years ago) occupy about half the land area of Nigeria, outcropping in the west (Lokoja–Abeokuta–Babana), south-east (plateau bordering Cameroon) and north-central (Bauchi–Kano–Anka–Kontagora) areas (FMMP, 1974). The basement rocks include mostly metasediments (gneisses, schists, migmatites and calc-silicates) along with amphibolites and rarer metamorphosed tuffs and volcanic rocks. Banded iron formations, rich in magnetite and haematite, also exist in the basement. One of the most prominent of these outcrops south-east of Kabba in southern Nigeria. Precambrian granitic intrusions ('Older Granites', 450–650 million years old) are also common in the basement areas (Wright, 1985). So-called 'Younger Granites' and associated minor intrusions of Jurassic age (190–145 million years old) form a large part of the Jos Plateau of central Nigeria. These are often associated with tin (cassiterite) mineralisation. Tertiary volcanic rocks (basalts and rhyolites) also occur sporadically above basement rocks on the Jos Plateau and the eastern plateau areas.

Mesozoic and younger sediments cover the remaining parts of Nigeria and these are located in a number of sedimentary basins, comprising the Benue (central), Sokoto (north-west border), Chad (north-east), Bida (central, along the Niger valley), Benin–Dahomey (south-west) and Anambra (south) Basins and the Niger delta (south coastal).

The Benue Basin is a large elongate rifted basin running along the approximate line of the Benue River. The basin is infilled with around 5000 m of Cretaceous sediment overlying crystalline basement rocks. Sediment thickness increases southwards in response to basin subsidence (UN, 1988). The Bida Basin is a shallow unfaulted extension of the basin, aligned north-west to south-east passing through Bida to Auna and occupied by the Niger River.

Oldest Cretaceous sediments (Albian to Cenomanian) of the Benue Basin include marine black shales, often carbonaceous and pyrite-rich, in the lower part of the basin (south). In the upper part of the basin, coarser grained sediments dominate. These are fluvial-deltaic sandstones with occasional shale intercalations and conglomerate horizons (Wright, 1985). Later Cretaceous sediments (Turonian to Maastrichtian) are mixed shales, sandstones and limestones with occasional ironstones and coal deposits. Some strata contain gypsum (calcium sulphate) locally. In the south-west of the basin, Maastrichtian deposits include Coal Measures, reaching up to 900 m in thickness. Coal deposits are best developed around Enugu. Sulphide ore minerals including galena, sphalerite and chalcopyrite also occur in the Benue Basin. These are principally along fold axes running NE-SW, from Abakaliki in the south to near Gombe in the north.

Conglomerates and pebbly sandstones with clay lenses predominate the Cretaceous sequence in the Bida Basin. Ironstones are also present and are best developed in the Agbaja Plateau near Lokoja. Although not exploited at present, these are of potential economic interest for iron ore. The sediments reach up to 1000 m thick in some parts of the basin.

Tertiary (Eocene) marine clays dominate in the Sokoto Basin in the north-west. Tertiary and Quaternary (Chad Formation) clay-rich sands and sandstones, some 700 m thick, dominate the sequence of the Chad Basin in the north-east.

The Niger delta in southern Nigeria has been prograding outwards to the Atlantic Ocean since late Cretaceous times and is infilled with Tertiary and Quaternary sediments which decrease in age progressively southwards. The deposits comprise from north-east to south-west, the Imo Shale, a unit of Palaeocene to Eocene (Lower Tertiary) blue-grey shales with thin sandstones and limestones; the Eocene to Oligocene Ameki Formation, comprising clays, sandstones and limestones; Oligocene to Miocene clays, sands and grits with occasional lignite (carbonaceous deposits) of the Ogwashi-Asaba Formation; and the Miocene to Pliocene Benin Formation composed of coastal-plain sands and pebbly sands with clay lenses and lignite. The sediments were deposited in a variety of environments from marine, through deltaic, estuarine and coastal swamp to lagoonal and fluvial. In all, the sediment pile reaches a thickness of around 12,000 m (Beka and Oti, 1995). The delta contains significant reserves of oil and gas in some 250 oil and gas fields. Oil fields predominantly occur in the Warri to Port Harcourt areas. The gas fields are mainly offshore, but to date have been largely unexploited.

Soils vary in thickness, reaching up to around 10 m in thickness in some areas. Laterites are developed locally. Organic-rich and acid-sulphate soils have developed over clay-rich sediments (Chad Formation) in the Manga grasslands of north-eastern Nigeria, bordering Niger (Carter and Alhassan, 1998). Dunes are also common in the arid areas of the north.

Groundwater Availability

Groundwater constitutes an important source of water for domestic supply and agriculture in Nigeria. The sedimentary basins generally form the best aquifers. The Sokoto Basin in the north-west is part of the vast Iullemenden Basin of Mali, Niger and Algeria. The depth of the water table in unconfined parts is typically 15–75 m. Artesian conditions occur in confined aquifers at 75–100 m depth at the eastern edge of the basin but with piezometric levels going down to around 50 m below surface further west (UN, 1988). Significant groundwater ages (in excess of 3000 years) have been found for some confined groundwaters from the Sokoto Basin (Geyh and Wirth, 1980).

Artesian conditions also exist in the Chad Basin. Here, three main aquifers have been identified: an upper aquifer at 30–100 m depth, a middle aquifer (eastern part of the basin) some 40–100 m thick occurring from 230 m depth near Maiduguri and a lower aquifer consisting of 100 m of medium to coarse sands and clays occurs at a depth of 425–530 m. The upper and middle aquifers are exploited intensively in the Maiduguri area (UN, 1988). Over-exploitation of the aquifers in the Chad Basin has led to a recent decline in groundwater levels and has necessitated drilling to greater depths in order to tap the lower aquifer. Isotopic evidence suggests that groundwaters from the middle and lower aquifers are old (20,000 years or more) and are not being actively replenished by modern recharge (Edmunds et al., 1998; 1999).

Comparatively little groundwater exploitation has been carried out in the Benue Basin further south. Here, the sediments are more often fine-grained and give relatively low yields. Most of the aquifers in the basin are unconfined, but confined conditions occur locally in the Yola-Numan area (UN, 1988).

The Cretaceous sandstones of the Bida Basin also contain significant groundwater resources. Artesian conditions occur in parts of the aquifer near Pategi (UN, 1988) and numerous springs also occur.

In the Anambra Basin south-east of Lokoja, coarse Cretaceous sandstones form a good aquifer which is largely unconfined in its northern part but becomes artesian further south (UN, 1988). Groundwater levels are typically 60–150 m deep.

Good aquifers are also present in the Tertiary and Quaternary sediments of the southern coastal areas, the best being the Tertiary 'Illaro Formation' composed of sands with occasional beds of clay and shale. An unconfined shallow aquifer also exists at less than 30 m in much of the near-coastal area (UN, 1988).

Compared to the sedimentary aquifers, groundwater storage in the crystalline basement is small. The failure rate of new boreholes in the basement has in some cases been as high as 80% (Edet et al., 1998). Groundwater availability is largely limited to fracture zones and areas of deep weathering. In places, the weathered overburden layer overlying crystalline basement can be thick. Alagbe (2002) reported overburden thicknesses up to 50 m in the River Kan Gimi Basin of north central Nigeria. In large areas of the basement complex, the principal source of groundwater is from dug wells.

Groundwater Quality

Overview

A number of groundwater quality investigations have been carried out in Nigeria, though these are usually on local scales and consider a limited number of chemical constituents. This account attempts to summarise the salient features from them.

The country's shallow aquifers are potentially vulnerable to pollution from agricultural (fertilisers), domestic (waste dumps, latrines) and industrial sources, except where surface layers are of poor permeability and afford some protection of the underlying aquifers. Sangodoyin (1993) found poor bacteriological quality of groundwater close to sites of waste disposal in Abeokuta area, highlighting the potential for impacts from other pollutants. Sangodoyin and Agbawhe (1992) found high concentrations of total dissolved solids, with particular impacts on calcium, chloride and nitrate, in shallow groundwaters affected by leachates from abattoir sites in the Ibadan area. Increased concentrations were notable up to 250 m from the sites of contamination. Oil spillages are also known to have some impact on the environment in the vicinity of oil boreholes and pipelines (Eze, 2002; Akujieze et al., 2003) although their effect on groundwater quality in Nigeria is difficult to quantify. Aremu et al. (2002) linked high concentrations of iron, lead and nickel in dug-well waters from the Warri area to contamination from petroleum chemicals.

Natural water-quality problems have also been noted. While the groundwater in the alluvial aquifers is usually fresh, in some cases high salinity related to dissolution of evaporate minerals is a recognised problem. Under confined (i.e. anaerobic) conditions, high concentrations of iron and manganese are also common. Acceptability problems related to the presence of hydrogen sulphide may also occur in some areas (e.g. parts of the Benue Basin).

Recent overabstraction of groundwater from parts of the coastal sedimentary aquifers has led to problems with saline intrusion. This has been noted particularly around Lagos, and in Ondo, Bendel and Rivers States (UN, 1988). Overabstraction of groundwater for irrigation in the arid northern areas also has the potential to cause salinisation of shallow groundwaters (Carter and Alhassan, 1998) through the long-term effects of evapotranspiration. However, there is little evidence that this has happened to date.

Problems with acid mine drainage have also been reported in some mineralised areas, particularly the Coal Measures of Anambra State.

Asubiojo et al. (1997) carried out a survey of tap water and groundwater quality taken from various sources in southern Nigeria. A summary of the findings from groundwater analyses for a total of 250 samples is given in Table 1. The locations, source aquifers and well details (depth etc) for the samples are unknown but the data illustrate the ranges of a number of trace elements in Nigerian groundwaters that are assumed to be typically used for potable supply. The data indicate that most elements investigated are present at concentrations below the respective WHO health-based guideline values. The exceptions are barium (Ba), lead (Pb), nickel (Ni) and selenium (Se). The percentages of samples exceeding the guideline values are also unknown. Seasonal variations were noted in the Nigerian waters sampled, affecting barium, lead, manganese and molybdenum in particular (Asubiojo et al., 1997). Whether the elements found in excess are likely to be problematic on a regional scale is also unknown but their presence in some analysed samples highlights the need for selected trace-element testing.

Table 1. Summary of selected trace-element data for groundwaters from southern Nigeria (from Asubiojo et al., 1997). All values in µg/l, n=250 (150 boreholes, 100 dug wells).

Element	Min	Max	Mean	WHO GV
Al	22	270	94	200*
As	0.40	6.9	1.9	10
Ba	9.48	**1150**	420	700
Br	41	210	95	
Cd	0.06	1.1	0.27	3
Cs	0.09	3.7	0.61	
Cr	0.18	9.1	1.1	50
Co	0.09	6.1	0.60	
Cu	0.23	54	9.3	2000
Pb	0.61	**14**	2.8	10
Mn	1.4	290	55	500
Mo	0.90	30	4.1	70
Ni	0.80	**37**	5.2	20
Rb	1.8	530	68	
Se	2.3	**22**	7.1	10
Sn	0.23	1.5	0.59	
Sr	23	150	76	
V	0.27	2.8	1.2	
Zn	8.6	1700	100	3000*

GV: guideline value; *aesthetic, rather than health-based, value. WHO exceedances are highlighted.

Nitrogen species

Concentrations of nitrate and ammonium related to pollution inputs may be high in some shallow groundwaters, particularly from dug wells and dugouts, if pollution sources exist nearby. Malomo et al. (1990) reported concentrations of nitrate-N up to 124 mg/l and nitrite-N up to 1.2 mg/l in shallow groundwaters from dug wells in weathered basement rocks of south-west Nigeria. These extremes were unusual, though concentrations over 10 mg/l and 0.06 mg/l respectively were common. Similarly, data for shallow groundwaters from sedimentary aquifers in the Chad Basin indicate nitrate-N concentrations up to 102 mg/l (Table 2). However, not all shallow groundwaters from dug wells are contaminated. Alegbe (2002) found concentrations of nitrate-N in groundwater from dug wells in the Kan Gimi catchment of north central Nigeria to be 1.2 mg/l or less. This is far below the WHO guideline value for nitrate-N in drinking water of 11.3 mg/l. Groundwater from some deeper boreholes in unconfined aquifers may also have elevated nitrate concentrations.

By contrast, concentrations of nitrate are likely to be low in the confined aquifers, where conditions are anaerobic. In groundwaters from the poorly permeable clay-rich aquifers of the Oju area of the Benue Basin for example (Davies and MacDonald, 1999), groundwaters usually have concentrations of nitrate less than 3 mg/l (range <0.2–23 mg/l, median 0.5 mg/l; BGS unpublished data). Concentrations of ammonium were also usually <0.01 mg/l. Occasional high values (up to 1 mg/l) observed are still below the WHO guideline value for ammonium in drinking water. Ammonium concentrations may be high in some of the confined anaerobic groundwaters from the sedimentary basins, though few data are currently available to verify this.

Salinity

Groundwaters in most Nigerian aquifers are likely to be fresh with low concentrations of total dissolved solids. As noted above, exceptions have been reported in some coastal aquifers where the groundwaters are heavily abstracted and have resulted in saline intrusion. Edet and Okereke (2001) found groundwaters with total dissolved solids concentrations up to 1250 mg/l in the coastal part of the Niger delta. Ajayi (1998) also found concentrations of total dissolved solids in the range 1300–1500 mg/l for groundwaters from Ondo State. In the most saline samples, sodium and chloride were found to be the dominant ions.

Some groundwaters in the sedimentary basins also have high salinity, though fresh waters appear to be more common. Akujieze et al. (2003) characterised the principal hydrochemical features of the sedimentary aquifers. They reported the occurrence of saline waters with high concentrations of sulphate and/or chloride in parts of the Benue Basin in particular. In the shallow aquifers of the Oju area of the Benue Basin, the groundwaters are usually fresh but with some more saline (sodium-calcium-sulphate-rich) compositions (BGS data, unpublished). Concentrations of sodium up to 1950 mg/l and sulphate up to 5300 mg/l have been found in some poor-yielding boreholes (BGS, unpublished data, summarised by Davies and MacDonald, 1999). These are unacceptable for potable use. The source of the salinity in these groundwaters is likely to be from dissolution of evaporate minerals such as gypsum in the sediments. Some of the shallow wells from the Oju area showed some seasonal variation in groundwater salinity caused by dilution of groundwater during wet periods by infiltrating rainfall. Deeper groundwaters showed little temporal variation however.

Increased groundwater salinity may also be possible in shallow aquifers from arid northern Nigeria as a result of evapotranspiration, especially in areas with saline playa lakes. Data from Edmunds et al. (1999) suggest that high groundwater salinity is not a general feature of the region however. In a survey of groundwater from 340 wells in the shallow aquifer of the Geidam–Gashua area of the Chad Basin, they found fresh groundwaters with an average chloride concentration of 16 mg/l, although some sporadic occurrences above 100 mg/l were noted. Deeper aquifers from the Chad Basin also contain groundwater which is largely of low salinity. Chloride concentrations in groundwater from the middle aquifer near Maiduguri reached up to 110 mg/l (Table 2), but averaged 45 mg/l, and were often <10 mg/l (Edmunds et al., 1998).

In areas of crystalline basement, groundwaters are mostly expected to be fresh with low concentrations of total dissolved solids. Alagbe (2002) found groundwaters from shallow (<15 m) dug wells in the Kan Gimi Basin of north central Nigeria to be slightly acidic (pH 4.5–6.8) and of very low salinity, with total dissolved solids being <230 mg/l. Raji and Alagbe (2000) also found fresh groundwaters (with total dissolved solids up to 830 mg/l) in the crystalline basement aquifers of the Asa catchment, western Nigeria. These had near-neutral pH values.

Fluoride

The WHO guideline value for fluoride in drinking water is 1.5 mg/l. Problems with fluoride occurrence in groundwater above this value tend to be found in crystalline rock terrains (metamorphic rocks, some volcanic rocks and granite) and occasionally in sedimentary basins. They are also more likely to be found in arid regions than regions with high rates of groundwater recharge (*Fluoride Fact Sheet*). Granitic rocks and sedimentary basins in the arid northern parts of the country are therefore potentially most vulnerable to development of high groundwater-fluoride concentrations.

Table 2. Statistical summary of selected chemical data for groundwaters from the Maiduguri area, Chad Basin (summarised by Edmunds et al., 1998, 1999). WHO guideline values are also given.

Aquifer	Ca	Na	Cl	SO_4	NO_3-N	Fe	F	Mn	I	B	Cr	Ni	Mo	Pb	U
	mg/l							µg/l							
WHO					11.3	0.2*	1.5	500		500	50	20	70	10	2
Upper	2.2	7.1	0.5	<0.5	<0.4	<0.02	<0.1	<3	1	3.1	<0.3	<0.5	<0.1	<0.5	<0.1
	68	764	68	330	102	1.5	5.6	770	160	170	85	51	86	18	150
Middle	2.7	13	1.0	<0.5	<0.4	<0.02	0.2	4	6	8.9	<0.3	<0.5	0.2	<0.5	<0.1
	69	258	110	480	1.8	20	2.1	3000	670	920	2.5	5.8	26	0.5	9.1
Lower	1.4	45	7.5	<0.5	<0.3	0.11	1.9	8	13	86	<0.3	<0.5	3.5	<0.5	<0.1
	4.1	134	30	11	<0.3	2.1	2.4	210	110	920	<0.3	0.2	30	<0.5	<0.1

*Aesthetic grounds

As noted above, granitic rocks occur extensively in Nigeria. These typically contain significant concentrations of fluoride-bearing minerals such as mica, hornblende and apatite which on weathering may release fluoride to groundwater. The Younger Granites have peralkaline compositions with many similarities to the acid igneous rocks of the East African Rift. This is a well-known high-fluoride province with significant groundwater fluoride problems.

Only a few fluoride data are currently available for Nigerian groundwaters. As early as 1954, Wilson noted the occurrence of dental fluorosis in school children and adults from Adamowa, Bauchi and Bornu States in the north-east of the country. However, from a limited number of samples tested, there was little evidence of high groundwater fluoride concentrations. Six water samples from wells in Maiduguri town (Chad Formation aquifer) had fluoride concentrations ranging from 0.1 to 1.2 mg/l. Ten drinking-water samples from the granitic plateau area were also found to have low concentrations (of 0.4 mg/l or less), although these may have been taken from streams and are likely to have lower concentrations than groundwaters which have been in contact with bedrock aquifers for longer periods.

Other investigations in the Chad Basin have found fluoride in excess of the WHO guideline value. Studies summarised by Edmunds et al. (1998, 1999) found concentrations up to 5.6 mg/l in groundwaters from the aquifers in the Maiduguri area (Table 2).

In groundwaters from sediments of the Oju region of the Benue Basin, fluoride concentrations mostly less than 0.4 mg/l have been found (BGS, unpublished data). Of the samples analysed (20 in total), none exceeded the WHO guideline value for fluoride in drinking water (1.5 mg/l), the maximum observed being 1.4 mg/l. Very low concentrations (0.2 mg/l or less) were also found in selected groundwaters from the sedimentary aquifers of south-eastern Nigeria (Okagbue, 1988; Akujieze et al., 2003). Concentrations of 0.2 mg/l or less were also found in groundwaters from the eastern Niger delta (Amajor and Ofoegbu, 1988).

In summary, a few high-fluoride groundwater sources exist in Nigeria and high concentrations can be anticipated in the granitic areas in particular. However, data available to date suggest that most aquifers have low or acceptable concentrations. Insufficient fluoride can also be detrimental to health because of the links between low dietary fluoride intakes and dental caries. Testing for fluoride as a precaution would be advisable, especially in areas of granitic bedrock and in the arid sedimentary basins of the north.

Iron and manganese

Groundwaters in the confined aquifers of the sedimentary basins are particularly vulnerable to the build-up of dissolved iron and manganese under anaerobic conditions. A number of accounts have noted the occurrence of high iron and manganese concentrations in confined groundwaters. Concentrations of total iron up to 2 mg/l were reported in groundwaters from sedimentary aquifers of Akwa Ibom State, south-east Nigeria (Akujieze et al., 2003). Okagbue (1988) found concentrations of total iron up to 1.1 mg/l in groundwaters from the south-east sedimentary aquifers. Amadi et al. (1989) found total iron concentrations up to 6.2 mg/l in groundwaters from the Niger delta. Iron concentrations up to 20 mg/l and manganese up to 3 mg/l have also been found in the Chad Basin (Table 2). In the Oju area of the Benue Basin, concentrations of iron and manganese have been found in the range 0.03–8.4 mg/l and 0.004–5.6 mg/l respectively (BGS, unpublished data). The maxima observed for both elements in these aquifers are well over the WHO guideline values for drinking water, although that for iron is on aesthetic rather than health grounds and iron is not considered detrimental to health.

High concentrations of iron and manganese may also be expected in groundwater from areas of crystalline basement if acidic conditions occur. As groundwater abstracted from the crystalline basement is often derived from dug wells, high iron concentrations in these may also be due to the presence of particulate iron, especially if the groundwaters are highly turbid. Alagbe (2002) found some high-iron groundwaters in basement rocks of north central Nigeria, although all were found to be below the WHO guideline value. Malamo et al. (1990) found concentrations of iron up to 5 mg/l and manganese up to 1.3 mg/l in dug-well waters from south-west Nigeria.

High concentrations can also be present in groundwaters close to areas of sulphide mineralisation if the mineralised zone has been subjected to weathering (oxidation). Minewaters from the Enugu coal mine, Anambra State, are a particular example, being acidic (pH 2.5–4.1) with concentrations of iron up to 56 mg/l and manganese up to 8.3 mg/l (Akujieze et al., 2003).

Arsenic

The WHO guideline value for arsenic in drinking water is currently 10 μg/l although the Nigerian national standard is 50 μg/l. Few data are so far available for arsenic in groundwater from Nigeria. However, a large body of information is now available on the likely aquifer conditions that give rise to arsenic problems in groundwater (Smedley and Kinniburgh, 2002) and some evaluation of arsenic risk in the various Nigerian aquifers is therefore possible. The Niger delta in particular has some similarities with the well-known high-arsenic aquifers of the Bengal delta (Bangladesh and West Bengal). Many of the Niger delta groundwaters are anaerobic with some high concentrations of iron and manganese. Organic matter is also known to be abundant in the aquifer sediments to generate anaerobic conditions necessary for arsenic mobilisation. Hence, the Niger delta is likely to contain some groundwaters with arsenic concentrations above acceptable limits. The Niger delta sediments are generally older than the equivalents in the Bengal delta. This may have some bearing on the mobility of arsenic and may mean that differences emerge between the severity of contamination in Nigeria compared to Bangladesh.

Other aquifers from the sedimentary basins with anaerobic groundwaters (shown for example by high iron and manganese concentrations and low nitrate) may also have arsenic present at concentrations above the WHO guideline value. BGS data (unpublished) for selected groundwaters from the Oju area of eastern Nigeria (Benue Basin) revealed arsenic concentrations to be mostly <20 μg/l although one saline sample with high concentrations of iron (1.8 mg/l) and manganese (2.7 mg/l) had an arsenic concentration of 40 μg/l. High iron concentrations should not be taken as an indication that the arsenic concentration will be high in a given well as correlations between iron and arsenic are often poor. However, the presence of high iron concentrations in groundwaters in sedimentary aquifers can be taken as a broad indication that conditions are anaerobic and that arsenic may therefore be an additional constituent to test for.

Areas of basement and parts of the Benue Basin with an abundance of sulphide ore minerals are also vulnerable to contamination from arsenic, as are sedimentary aquifers with an abundance of sulphide minerals (Coal Measures, lignite deposits). Acid-sulphate soils identified in northern Nigeria may also be sites of localised arsenic mobilisation, though contamination of underlying aquifers is unlikely since recharge via clay-rich deposits underlying the soils is limited (Carter and Alhassan, 1998) and adsorption of arsenic is likely to restrict its transport.

Data given by Asubiojo et al. (1997) for groundwaters from southern Nigeria (various aquifers) have concentrations of arsenic all below 7 μg/l (Table 1).

Iodine

The only data found for iodine in Nigerian groundwaters is from BGS datasets (unpublished). Groundwater from the Oju area of the Benue Basin has concentrations of iodine which are often quite low. From 150 groundwater samples taken from boreholes, wells and shallow dugouts, iodine concentrations ranged from 1 μg/l to 420 μg/l with a median of 4 μg/l. The highest values were found in the more saline samples. The minimum values observed can be considered insufficient for health without supplementary forms of dietary iodine (*Iodine Fact Sheet*). Indeed, the Benue Basin has a relatively high prevalence of goitre, which is related to iodine deficiency, compared to other areas of Nigeria (Davies and MacDonald, 1999). The iodine concentrations in other parts of the country are unknown, but are likely to be low in fresh groundwaters away from the coastal areas.

Concentrations of iodine in groundwaters from the Chad Basin are occasionally low in the shallow aquifer (Table 2) though reach high values, in excess of 100 μg/l, in groundwaters from all three aquifers in the region.

Other trace elements

Available data for other trace elements are very limited. As noted above, Asubiojo et al. (1997) found some exceedances of barium, nickel, lead and selenium above WHO health-based guideline values in their survey of groundwaters from southern Nigeria. With the possible exception of selenium, which Asubiojo et al. (1997) took to be related to agricultural pollution, these elements are likely to derive from natural water-rock reaction processes in the aquifers. Barium probably derives from weathering of feldspars or carbonate minerals. Nickel and lead may be from dissolution of iron or manganese oxides or from weathering of pyrite (iron sulphide). Nkono and Asubiojo (1998) also reported exceedances for mercury above the WHO guideline value of 1 μg/l in some groundwaters from south-east Nigeria.

Groundwaters from the Chad Basin in north-eastern Nigeria usually have low concentrations of other investigated trace elements (BGS, unpublished data). Some high concentrations of barium, boron, chromium, nickel, molybdenum, lead and uranium are noted (Table 2), though these are usually in only a small number of samples.

The peralkaline Younger Granites of Nigeria contain occasional uraniferous minerals. Although no uranium data are available for groundwater from the granitic provinces, concentrations above 2 μg/l, the WHO provisional guideline value for uranium in drinking water, are likely in some groundwaters near to mineral uranium sources. Although the health effects of drinking water with such low uranium concentrations are so far unknown, investigation of the uranium concentrations in groundwaters on a reconnaissance scale in the granitic areas would be advisable.

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