Groundwater Quality: Niger

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

Niger is a land-locked country in West Africa, 1.3 million square kilometres in area, and bordered by seven other African nations (Figure 1). Most of the country lies within the Saharan belt and as such, climate is dominated by hot, dry desert. Savannah conditions exist in the Sahel region of the extreme south-west (around 20% of the land area). Mean annual rainfall varies between 150 mm in the Saharan north-east and 600 mm in the south-west. Average daytime temperatures (Niamey) lie in the range 25–35°C. Most rain falls during June–September. During the dry season, Niger is subject to the dry north-easterly Harmattan winds but moist south-westerlies dominate during the rainy season (UNICEF, 2010). The main population centres are located in the less arid south-west and south.

Terrain consists largely of flat desert plains with dunes but the north-central Aïr Massif, north of Agadez is mountainous (Figure 1). Elevation ranges from Mont Idoukal-n-Taghès (2022 m) in the Aïr Massif to 200 m at the Niger River.

The main river, the Niger River, is the third longest in Africa. Within the desert, water courses are ephemeral. Lake Chad occupies the extreme south-eastern border region with Chad and Nigeria and in

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

recent decades has been receding.

Niger is one of the poorest countries in the world and its economy is largely subsistence-based. The arid landscape means that only 3.5% land coverage is given over to arable agriculture. This is mainly concentrated in the south-west, although relatively high rainfall in the Bagzane Plateau of the Aïr Massif provides for intensive agriculture there too. Main crops produced are cowpeas, cotton, peanuts, millet, sorghum and cassava. The small pastoral farming sector is dominated by cattle, sheep and goats. Industries include uranium mining, cement, brick, textiles, food processing and chemicals. Chief exports are of uranium ore.

Niger is highly prone to drought. Other environmental issues include deforestation, soil erosion and soil salinisation.

Geology

The geology of Niger consists of a crystalline basement of Precambrian igneous and metamorphic rocks, capped by younger sedimentary rocks of Palaeozoic to Quaternary age, together with more minor igneous intrusive and extrusive rocks emplaced since Devonian times.

Outcropping Precambrian basement rocks are mainly restricted to the south-western border region, bounded roughly by the Niger River, and the Aïr Massif, a 200 x 400 kilometre range within the Sahara Desert, north of the town of Agadez. In the south-west, Birimian (Early Proterozoic, 2300–2000 million years old) rocks consist of schists, meta-igneous and granitic rocks accompanied by Late Proterozoic (around 1000 million years) formations. The Aïr Massif consists of Early Proterozoic metamorphic rocks (schist, gneiss) intruded by granitoids. The Proterozoic rocks were deformed and metamorphosed and granitoids emplaced during the Pan-African event some 600 million years ago. Late Proterozoic and younger metasedimentary rocks ('Proche Tenure') were emplaced by overthrusting at Tafadek and Aouzegeur.

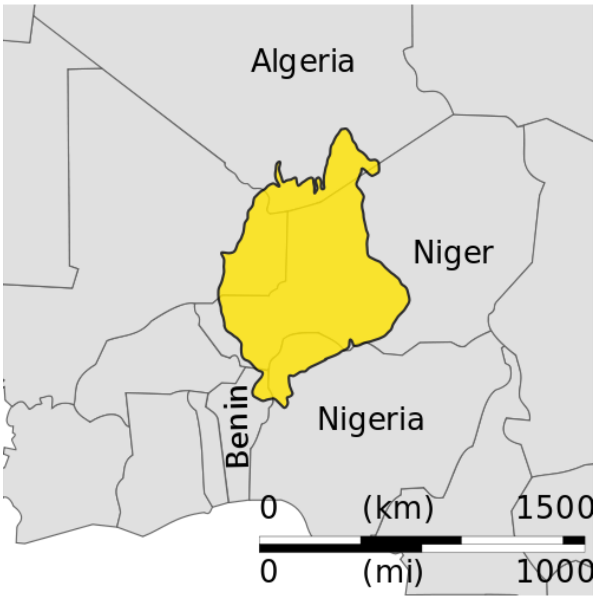

Figure 2. Location of the Iullemmeden Basin, western Niger (attribution: Aymatth2, Wikimedia Commons Licence).

Subsequent (Phanerozoic) sedimentation produced a thick sequence of marine and continental deposits, overlying the basement rocks unconformably. These are deposited in the Iullemmeden, Tamesna, Chad, Djado and Bilma Basins (Ousmane, 2002). The vast Iullemmeden Basin (Moody, 1997), a structural depression situated between the Proterozoic basement rocks of the south-west and the Aïr Massif to the east, covers most of western Niger (areal extent 360,000 square kilometres) and extends beyond into parts of Algeria, Mali, Benin and Nigeria (Figure 2). The basin is infilled with sediments of Cambrian to Pleistocene age, some 1,500 to 2,000 meters thick. The Palaeozoic succession has a thickness ranging from 100 to 1,500 meters and outcrops to the west of the Aïr Massif, in the Tim Mersoï sub-basin. Cambro-Ordovician (oldest) units are composed of coarse clastic marine sediments and Silurian units are dominated by shale. The Devonian is composed of mixed sandstone, shale, siltstone and carbonate, variably of continental and marine origin. The subsequent Carboniferous (Visean-Namurian) sequence is also made up of continental to marine sandstone and shale. This Palaeozoic sequence shows progressive transformation from marine to continental conditions in response to uplift along the axis of the Aïr Massif (Bowden et al., 1981).

Permian to Lower Cretaceous sedimentary horizons in Niger form the 'Continental Intercalaire' (CI), a sequence of mainly continental sandstones, shales and conglomerates with minor evaporite deposits, derived by erosion of the Aïr Massif basement rocks. The sequence outcrops mainly in the Tamesna, Irhazer and Tegama areas. Subsequent Upper Cretaceous to Lower Eocene deposits form the 'Continental Hamadien' (CH). These comprise sandstones, claystones, limestones, marls, evaporites and minor conglomerates. The 'Continental Terminal' (CT) of Mio-Pliocene age (23–2 million years old) consists of claystones, ironstones and lignite deposits up to 450 metres thick in the centre of the Iullemmeden Basin (Graef, 2000). Subsequent weathering of the iron-rich sediments has produced iron-rich residual surface crusts or 'cuirasse' deposits where exposed (Leprun, 1979).

Igneous intrusions of Palaeozoic age (490 to 300 million years) include ring complexes of mixed lithology (gabbro, syenite, peralkaline and alkaline granite, carbonatite, anorthosite). These occur within the Aïr Massif and Mounio Massif (southern Niger), but stretch in a north-south alignment totalling some 1300 kilometres to the Jos Plateau of Nigeria (Bowden and Karche, 1984; Graef, 2000). Within the Aïr Massif, sodic-amphibole-bearing peralkaline granites are common; these are less prevalent in the southern provinces (Bowden and Turner, 1974). Within the Iullemmeden Basin, Cenozoic volcanic plugs of trachyte and phonolite and lavas of basalt also occur.

Unconsolidated Quaternary dune deposits cover a large part of central, east and north-east Niger. Thickness of dune deposits increases northwards (Graef, 2000). Recent alluvium occurs along the Niger River and its tributaries. Soils are lateritic and ferruginous in places.

Natural resources of Niger include uranium, coal, iron ore, phosphate, gold, molybdenum, gypsum, salt and petroleum. Niger has among the largest reserves of sandstone-hosted uranium in the world. The main uranium minerals are pitchblende, coffinite and uraninite (Bowie, 1979; NWT, 2012) although secondary carnotite occurs in places where oxic conditions occur as a result of remobilisation by groundwater. Deposits are present in the Iullemmeden Basin, largely located on the westerly edge of the Aïr Massif (Tim Mersoï sub-basin) around Arlit (Arlette) and in the Gall sub-basin around Agadez (Figure 1). The main deposits are contained within Upper Carboniferous sandstones (Tim Mersoï sub-basin) and within the CI, often in association with organic matter and pyrite. Uranium deposits were discovered at Azelik and Abokorum in the 1950s and at Madaouela, Arlette, Ariège, Artois, Taza, Tamou, Takriza, Imouraren and Akouta in the 1960s. Current mining activity is focussed on Carboniferous formations, including the Visean Guezouman Conglomerate and Namurian Tarat Sandstone. The Imouraren uranium deposit, some 8 kilometres long and 2.5 kilometres wide, occurs within the Jurassic Tchirezrine Sandstone. This has an average ore grade of 0.11% uranium as U_3O_8. The Azelik-Abokorum deposits occur within sandstone lenses at the base of the Lower Cretaceous Irhazer formation. The mineralisation occurs at depths of 10–75m (Bowden et al., 1981). Eroded Palaeozoic igneous ring dyke complexes in the Aïr Massif have been ascribed as the source of uranium in both the Carboniferous and Jurassic sediment formations (Bowden et al., 1981), a mechanism which would explain the spatial distribution of mineralisation close to the Aïr Massif.

Carboniferous sedimentary units also host coal deposits in the Anou Araren area. Gold is found in the Téra area. Phosphate occurs at Tahoua. Extraction of both is artisanal. The CI hosts copper-rich horizons locally.

Groundwater Availability

Niger relies heavily on groundwater because of the limited availability of alternative surface supplies. Only the Niamey, Ader-Doutchi-Maggia, Maradi and Komadougou valley areas have usable supplies of surface water (UNICEF, 2010). In the capital city, Niamey, water for domestic use is supplied from the River Niger as well as from 121 boreholes. Groundwater in Niamey is abstracted from three separate aquifers: basement, alluvium and CT sediments (Ousmane et al., 2006, Hassane, 2010).

Groundwater is also limited due to restricted aquifer recharge but nonetheless is important for both urban and rural use. Some 24,000 wells and boreholes are documented by the Ministère de l'Hydraulique. The sedimentary aquifers are among the most productive aquifers in Niger but water levels within them can be deep. In central parts of the sedimentary basins, water levels can be too deep to access by manual handpumps (UNICEF, 2010). Levels as deep as 800 m have been reported (MHE, 1999) and many in the deep sedimentary basins are fossil groundwaters (not actively recharged). Bromley et al. (1997) observed groundwater levels at 74 m below ground level (below the outcropping CT) in south-west Niger (N'douroua area of Say plateau) although levels rose sharply a few kilometres further east to around 40 m below ground level and within the main CT aquifer of the area. Still, these levels are for the most part below that accessible by manual pumps (ca. 25–30 m; UNICEF, 2010). Levels in the Sokoto Basin, a sub-basin of the Iullemmeden Basin across the border in Nigeria are in the range 15–75 m below surface (BGS, 2003). Many of the deep sedimentary aquifers are artesian (Andrews et al., 1994). Nonetheless, knowledge of water levels is poor in many places (Thomas et al., 2012).

Aquifers with best access to shallow groundwater by manual handpumps include the minor alluvial aquifers (for example Maradi, the Aïr Massif, Teloua, Ader–Doutchi–Maggia and the Komadougou valley) and the basement aquifers of Liptako and the Mounio Massif. Groundwater yields in the crystalline basement rocks are generally low, although dependent on local weathering. Granites are heavily weathered at shallow levels (<10 m) and altered to kaolinite in places (Bromley et al., 1997).

Yields are higher in the Carboniferous sandstones of the Iullemmeden Basin and the Permian to

Cretaceous sediments (CI, CH, CT) as well as in the superficial alluvial deposits, although water levels in the Cretaceous deposits are often too deep to access except by mechanised pumps (UNICEF, 2010). Many of the most permeable deposits exist in the uninhabited parts of Niger (Saharan zone).

Groundwater Quality

Overview

Availability of groundwater chemistry data for the Niger aquifers is limited but evidence indicates that shallow groundwaters, particularly those from alluvial aquifers, are prone to surface pollution. Influences of pollution from urban, domestic and mining sources can be anticipated. Shallow groundwaters in and around Niamey are heavily polluted with both chemical and bacterial pollutants. Abundance of pit latrines and septic tanks and inadequate sanitation in most populated areas give rise to high concentrations of faecal bacteria as well as high salinity (with high concentrations of nitrate, nitrite, chloride and sulphate in evidence; Chippaux et al., 2002; Ousmane et al., 2006; UNICEF, 2010).

Due to the influences of evaporation and presence of evaporite deposits in the sedimentary sequences, many of the groundwaters in these aquifers are saline (UNICEF, 2010). Many of the groundwaters of Niger are also noted to be 'soft' (UNICEF, 2010).

Andrews et al. (1994) documented chemical and isotopic variations in the CI sedimentary aquifer of the Irhazer Plain in the south of the Tim Mersöi sub-Basin. They found groundwaters in mostly reducing (anoxic) condition with largely alkaline pH (6.7–9.7) and compositions ranging from fresh to highly saline. In a downgradient chemical profile, Andrews et al. (1994) documented an evolution from Ca-HCO_3- dominated waters characteristic of modern recharge to Na-HCO_3 compositions due to more prolonged residence time. Some evidence for leakage of saline water from an underlying Permian evaporitic aquifer was demonstrated. Summary data for a number of major ions and trace elements were provided.

Hassane (2010) found largely acidic pH values (3.7–7.1) in groundwaters from the CT aquifer. Values in groundwaters from the crystalline basement aquifer of Niamey were mostly mildly acidic to neutral.

Edmunds et al. (2003) conducted some detailed hydrogeochemical investigations of groundwater in the CI of North Africa (Algeria and Tunisia). While from different locations, the sedimentary units have analogies and some inferences can be drawn with likely conditions in Niger. A number of trace elements were measured in the study and a summary of the most relevant is given below.

Nitrogen species

Chippaux et al. (2002) found high concentrations of nitrate in shallow groundwaters close to the banks of, and in hydraulic connection with, the River Niger in Niamey. Concentrations of faecal pollutants including nitrate increased in shallow wells during the rainy season but diminished with well depth overall. Hassane (2010) found similarly high concentrations in shallow groundwaters from alluvial, CT and crystalline basement aquifers of Niamey.

UNICEF (2010) reported high concentrations of nitrate and nitrite in many parts of Niger although no specific details were given. MHE (1999) reported high concentrations of nitrate in groundwater from the Namurian (Carboniferous) aquifer of Arlit. High concentrations have been reported in some wells and boreholes in Sokoto Basin, a sub-basin of the Iullemmeden Basin in neighbouring Nigeria (Edet et al., 2011).

Salinity

Salinity is evidently variable from available information, though values can be high as a result of influences of evaporation, dissolution of evaporite minerals and surface-borne pollution. Shallow groundwater in the alluvial aquifer of Niamey (Niger River) has mostly low salinity but electrical conductance values up to 3000 μS/cm have been recorded in wells <10 m deep (Hassane, 2010). Such values indicate that the most saline waters are unsuitable for potable use.

Many of the groundwaters from the Mesozoic sedimentary sequences (CI, CH, CT) are also known to be too saline for domestic use. Ranges in electrical conductance documented by Andrews et al. (1994) for the CI of the Irhazer Plain were in the range 400 to 6000 μS/cm. Results for groundwater in the CI of Algeria and Tunisia (Edmunds et al., 2003) also indicate often high salinity in response to groundwater residence time (borehole depth and distance along groundwater flow line) and geochemical reactions. Electrical conductance values upwards of 2000 μS/cm were reported. As in Niger, these in large part relate to the presence of evaporite horizons (including halite and gypsum).

Fluoride

Concentrations of fluoride are likely to be variable, potentially being high in areas of granitic basement in the Aïr Massif and south-west Niger, ring complexes of Aïr and Mounio and Na-HCO_3 dominated waters from the sedimentary aquifers. Occurrences of riebeckite-arfvedsonite and aegirine (peralkaline) granite are reported in the Aïr and Mounio massifs. These rock types are fluorine-enriched (0.04–3 weight % F; Bowden and Turner, 1974) and the groundwaters highly vulnerable to fluoride release (Edmunds and Smedley, 2005).

Andrews et al. (1994) reported fluoride concentrations in the range 0.1–11 mg/L in groundwaters from the CI of the the Irhazer Basin (Tim Mersöi). Around 1/3rd of samples tested had a concentration above the WHO guideline value for fluoride in drinking water (1.5 mg/L). Edmunds et al. (2003) reported comparatively low concentrations of fluoride (0.5–1.0 mg/L) in groundwaters from the CI of Algeria and Tunisia. Nonetheless, many of the aquifers of Niger including the CI are potentially vulnerable to development of high concentrations of fluoride and so testing of wells for potable supply is necessary.

Iron and manganese

Few data exist for distributions of iron and manganese, although Andrews et al. (1994) found concentrations of <0.011–1.32 mg/L and 2.2–25 μg/L respectively in CI groundwaters from Irhazer (Tim Mersöi) Basin. High concentrations correspond with confined, anerobic groundwaters, many of which are artesian. Some of these groundwaters contain iron and manganese at concentrations in excess of drinking-water limits.

Arsenic

No data are known to exist for arsenic in the groundwater although a number of Niger's aquifers are potentially vulnerable to arsenic contamination. Firstly, the Birimian basement rocks in the south-west of the country extend beyond Niger into neighbouring Burkina Faso, Ghana and elsewhere in West Africa. Parts of this basement aquifer are known to contain high-arsenic groundwater and some associated health problems have been recognised (Smedley et al., 1996, 2007). The south-western Birimian complex of Niger is located some 400 kilometres east of villages with documented arsenic-related health problems in Burkina Faso.

The sedimentary formations of the Iullemmeden Basin and sub-basins (Tim Mersöi) could also contain high-arsenic groundwater in some areas. Particularly vulnerable are Carboniferous sediments with high proportions of clay and organic matter (and potentially sulphide minerals) and in which groundwaters are reducing (anaerobic), and potentially artesian. Other vulnerable areas are parts of the CI and CT, again particularly where conditions are anaerobic. Areas of ironstone, lignite and coal-bearing horizons are particularly at risk as these materials tend to be enriched in arsenic. Although the strong affinity for arsenic of these materials means that retention in the solid phase is favoured, release is possible under reducing conditions, and concentrations above the WHO guideline value for arsenic in drinking water are possible. Testing for arsenic in groundwater from the basement and main sedimentary aquifers of Niger is strongly recommended.

Iodine

Andrews et al. (1994) reported iodine concentrations in CI groundwaters of 3–16 μg/L. Edmunds et al. (2003) found iodine concentrations of 20–650 μg/L in the groundwaters of the CI of Algeria and Tunisia. Concentrations in these are usually above what would be considered vulnerable to development of iodine-deficiency disorders and the relative highs are linked to the salinity of many of the groundwaters. Concentrations of iodine in the groundwaters of the crystalline basement are less well-defined and may be lower.

Other trace elements

As Niger has major resources of exploitable uranium, concentrations of uranium in groundwater could potentially be high close to centres of mineralisation and in areas where groundwater levels correspond with depths of mineralisation (10–75 m). Deposits exist dominantly in the Carboniferous sediments of the Iullemmeden Basin and the CI to the west of the Aïr Massif and so testing for uranium in this area in particular is advisable. The current WHO guideline value for uranium in drinking water (30 μg/L) could well be exceeded in some places. Indeed, sampling in the town of Arlit has revealed relatively high alpha activity and uranium concentrations, though whether the concentrations exceeded 30 μg/L is not clear. Radon has also apparently been detected in the Arlit groundwaters (Greenpeace, 2009). Uranium is most mobile under oxic conditions which are likely to pertain in some parts of the Carboniferous to Cenozoic sedimentary aquifers, particularly at shallow levels. Under anaerobic conditions, which are common in the sedimentary basins, uranium should partition preferentially into minerals and so be less mobile. Concentrations in anaerobic groundwaters (devoid of dissolved oxygen and having potentially high concentrations of dissolved iron and manganese for example), are therefore expected to be low. Concentrations of uranium may also be high in aerobic groundwaters in areas of granite and igneous ring complexes (i.e. the Aïr and Mounio massifs and south-west border region), each of which can be relatively enriched in uranium-bearing minerals.

Edmunds et al. (2003) noted a redox control on the distributions of uranium in the CI groundwaters. Concentrations reached 5 µg/L in unconfined conditions but were <0.7 µg/L in confined conditions. In these groundwaters, concentrations were much below the current WHO guideline value for uranium in drinking water (30 µg/L).

Edmunds et al. (2003) also found some noteworthy concentrations of chromium in the CI groundwaters. Concentrations in the range 6–74 µg/L occurred in unconfined (aerobic) groundwaters, although anaerobic groundwater in confined parts of the aquifer had concentrations <1 µg/L. Again, relatively few exceeded the WHO guideline value (50 µg/L). Strontium also reached concentrations up to 19 mg/L in some of the CI groundwaters, likely in response to dissolution of carbonate minerals. However, highest concentrations were present in saline waters which would in any case be unsuitable for potable supply. Concentrations of molybdenum were mostly <10 µg/L, cadmium <1 µg/L and lead <3 µg/L.

Andrews et al. (1994) found boron at concentrations in the range 0.014–6.2 mg/L in the CI groundwaters of Niger. Only one analysed sample had a concentration above the WHO guideline value for boron in drinking water (2.4 mg/L). The relatively high concentration is linked to groundwater salinity and evaporite dissolution.

Data sources

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