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 Angola, with an area of 1,247,000 square kilometres, lies in southern Africa, and is bordered by Namibia, the Democratic Republic of Congo (DRC), Zambia and the Atlantic Ocean (Figure 1a). The Province of Cabinda is a northern exclave separated from the rest of the country by the DRC (Figure 1a).

Terrain comprises a narrow (50–200 km wide) coastal plain, rising to mountainous terrain with extensive inland plateau. Elevation ranges from the highest point at Morro de Moco (2,620 m) in Huambo Province, to sea level (Figure 1b).

The climate of northern Angola is tropical with a hot, rainy season from November to April and a cool, dry season from May to October. Climate is semi-arid in the south and along the coast to Luanda. Average annual rainfall is more than 1000 mm for most of the country, but less than 600 mm in the south-east. The south-west of Namibe Province is desert. Average coastal temperature varies between 16°C and 21°C.

The majority of rivers rise in the central mountains, and a number flow westward toward the Atlantic Ocean. The upper reaches of the Zambezi River are in eastern Angola and the river flows southward toward Zambia. The Cuango River flows

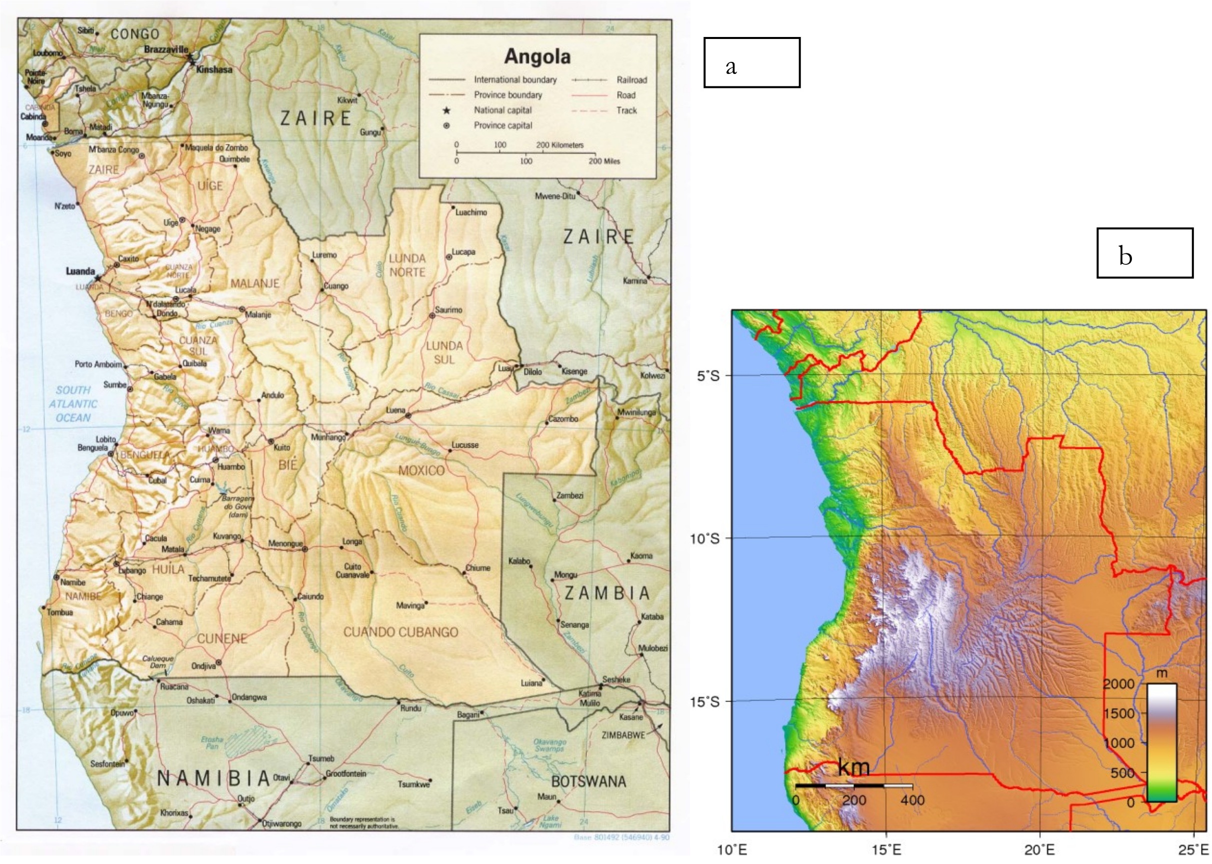

Figure 1a. Map of Angola showing provinces and main towns (courtesy of the University of Texas Libraries, The University of Texas at Austin); **1b.** topography (Wikimedia Commons licence, Sadalmelik).

northwards before turning westwards and forms part of the northern border with the DRC. The Cuito, Cubango, Cunene and Cuando Rivers form parts of the southern borders with Namibia and Zambia. Many of the southern watercourses dry up in the dry season.

Over the last decade, Angola has been rebuilding following the end in 2002 of a civil war which lasted for 27 years. The war saw the loss of some 1.5 million people and displacement of 4 million more (CIA World Factbook, 2013).

Today, Angola has an estimated population of some 18.5 million people (2013), 59% of whom live in urban areas. Subsistence agriculture constitutes the main livelihood and occupies some 85% of the labour force. Nonetheless, arable land covers only 2.7% of the land area. Principal agricultural exports are coffee, sisal, fish products, timber and cotton. Other important crops are bananas, sugar cane, corn and cassava.

Angola has vast mineral reserves including oil, diamonds, gold and copper, and its economy is overwhelmingly based on the mining sector. Angola's main exports are crude oil, refined petroleum and diamonds. Oil has been increasingly exploited during the 2000s since the end of the civil war. Revenues from oil exploitation provide some 85% of GDP and diamonds around 5%. Angola became a member of OPEC in 2006 and by 2008, was Africa's second largest exporter of crude oil.

Environmental problems include soil erosion due to deforestation of tropical rainforest, over-pasturing, localised flooding, river siltation and pollution.

Geology

The geology of Angola can be divided into three main provinces, with ancient (Precambian) basement rocks forming the highlands and sedimentary rocks forming the coastal strip and eastern/southern plateau (Figure 1b). The highlands of central Angola consist of blocks of Archaean (3.4–2.5 billion years old) gneiss and granitic rocks, located in the south-west and north-west, within a more extensive Proterozoic metasedimentary sequence. Proterozoic formations are dominantly clastic metasediments and carbonates with a basal tillite which were metamorphosed some 2.2 billion years ago. Together, the Precambrian rocks crop out in a tract from the south-western to north-western border. Archaean and Proterozoic rocks also form the uplands of the north-eastern and eastern border regions (Schlüter, 2006).

The topographic depression of the Cassanje Graben in north-central Angola is infilled with clastic sediments and volcanic rocks of the Karoo Supergroup (of Late Carboniferous to Jurassic age).

Karoo magmatism (Cretaceous, 100–80 million years old) resulted in the intrusion of a number of kimberlite and carbonatite pipes and dykes with a north-east to south-west alignment across the country. The alignment, some 1200 km long, is controlled by the Lucapa regional fault zone. The kimberlites occur within Archaean basement rocks, mostly located in Lunde Norte Province, but extending further south-west as far as the Namibian border. This period of magmatism also gave rise to intrusion of other alkaline igneous rocks (basalts through to trachytes; Schlüter, 2006).

The kimberlites are diamondiferous and the largest active kimberlite diamond mine is at Catoca (65.7 ha), some 35 km north-north-east of Saurimo (Lunda Norte), close to the DRC border. Diamonds are also mined at Camafuca–Camazamba in Lunde Norte Province 20 km south-east of Lucapa, and also at Camatchia–Camagio, Camatue and Alto Cuilo. Alluvial diamonds (and palaeo-placers) also occur within Lunde Norte Province and eastern Malanje provinces. Locations include Lucapa-Saurimo area, Cuango River (Lunde Norte) and Cuanza and Catumbela Rivers (west-central Angola).

The coastal strip is occupied by sedimentary rocks of Cretaceous to Recent age, which overlie the Proterozoic rocks. The sediments occupy, from north to south, the Congo, Cuanza and Namib sedimentary basins and include mainly Mesozoic and Cenozoic strata. Sediments of the Cuanza Basin have the most complete stratigraphic sequence and include continental, marginal marine and fully marine facies, consistent with marine transgression driven by continental rifting (van Eden, 1978). The sediments comprise Lower Cretaceous continental red sandstones, shales and conglomerates which overlie and are sourced from the Precambrian basement. These are overlain by marginal marine sandstones, siltstones and marls, and lagoonal deposits with evaporite minerals and bituminous shales (Ala and Selley, 1997). In turn, these give way to a thick sequence of cyclical marine/lagoonal dolomitic limestone/evaporite deposits of Aptian age. Within this sequence, the 'Sel Massif' is a 350 m thick evaporite deposit (mainly halite with anhydrite) consistent with formation in a sabkha environment. Occasional bituminous beds are represented. This episode of evaporitic deposition gave way subsequently to normal marine conditions, with deposition of limestones through upper Cretaceous to early Cenozoic times (van Eden, 1978). Coastal evaporites continue to be represented throughout this time, with deep water shales and turbidite sandstones occurring in the central basin further west (Ala and Selley, 1997). Miocene and younger clastic sediments are dominantly sands, shales and marls. The offshore extensions of these Mesozoic-Cenozoic basins host the vast majority of Angola's oil reserves. Proven reserves also occur onshore at Soyo in the extreme north-west.

Palaeogene to Recent continental sediments (<60 million years old) form the vast plains of eastern and southern Angola (Figure 1b). These are mainly yellow, orange and red sands with sandy silts of the Kalahari Group. The deposits can reach up to 600 m thick (UN, 1989). Cenozoic sediments within the upper part of the sequence include deposits of lignite in Moxico Province (Dos Santos, 1972).

Gold and base-metal deposits occur chiefly in association with the Proterozoic and Archaean formations of the uplands (Pinheiro, 2010). Primary gold occurs in Proterozoic metaigneous rocks intruded by granite and in metasediments (greenstone). The largest recognised primary gold deposit occurs at M'Popo, some 35 km south-west of Cassinga. The gold occurs in association with quartz and sulphide minerals, mainly pyrite and chalcopyrite, but with also pyrrhotite, arsenopyrite, bornite and chalcocite. Small amounts of galena and silver are also represented.

Gold is also found in association with alluvial gravels (placers), the largest located at Maiombe, Cabinda Province. The deposits at Maiombe were exploited during the early 20th century but operations ceased around 1950. Alluvial gold deposits also occur at locations in Huambo, Huila, Cuanza Norte and Cunene provinces. Today, no industrial-scale gold extraction remains though artisanal operations continue.

Copper deposits are located within the Proterozoic metasedimentary formations, as well as in Mesozoic sediments and some carbonites. Mining is not well-developed but has recently relaunched at the Mavoio mine in Uíge Province. In the sedimentary basins of western Angola, copper occurs within the basal Cretaceous sequence between Novo Redondo and Benguela (van Eden, 1978). Here, principal minerals are bornite, chalcopyrite and chalcocite.

Carbonatites have enrichments in a number of base-metal and mineral deposits with exploration potential. Besides copper, metals include niobium, tantalum, uranium and rare earth elements, and minerals include fluorite, nepheline and barite. Copper ore is found within carbonatite at Longonjo, south-west of the city of Huambo. This intrusion also has reserves of niobium, tantalum and uranium. Copper also occurs at Catabola and Ucua. At Ucua, the copper is hosted by pegmatite.

The Angolan mining sector also includes iron ore, phosphate, feldspar and bauxite. Iron ore occurs in Malanje, Bié Huambo and Huila provinces and in association with copper at Catabola. Iron ore is commonly developed within Proterozoic banded iron formations. Deposits of phosphate occur at Cacata and Chivovo in Cabinda Province. Granite and marble are also produced for export.

A weathered overburden exists in many areas of the crystalline basement and soils above basement rocks are commonly lateritic.

Groundwater Availability

Over most of Angola, aside from the semi-arid south and south-west, Angola is richly endowed with both surface water and groundwater. Abundance of surface water has resulted in a lack of tradition in groundwater use, with the majority of the development being in the coastal cities, some rural areas and in the semi-arid parts of the country. Groundwater sources include boreholes, wells and spring catchments.

A borehole inventory dating back to the 1970s catalogued some 2000 boreholes nationally, of which the majority were in the south-west, around 40% being in Kunene, 30% in Huile and 15% in Namibe provinces (Figure 1a; RAK, 2013). Around 70% of livestock is also located in these provinces and much of the groundwater supply is for livestock production. More recent groundwater development has occurred in peri-urban areas along the coastal strip. Over 3000 boreholes had been catalogued nationally in the early 2000s (Bee Pee and SRK, 2002).

The sedimentary rocks, particularly those in the coastal belt, represent the best aquifers. Of these, alluvial clayey sandstones have the greatest potential. In the crystalline basement rocks, primary porosity is low and greatest yields are found along fractures, quartz veins, in contact zones between differing rock types and weathered overburden (UN, 1989). Depth to groundwater is in the range 5–30 m below ground level at the coast, 10–30 m in the central highlands (Huambo Province) and more than 200 m in the semi-arid areas of Cunene in the south (RAK, 2013). Some parts of the Kalahari Group sediments in the south are dry (Bee Pee and SRK, 2002). Shallow groundwater in the Kalahari aquifer is likely to be unconfined but confined aquifers likely exist at depth. In neighbouring Namibia, groundwater levels in the Kalahari sediments are dependent on proximity to rivers which recharge the aquifer.

Borehole yields are low to moderate and typically in the range 1–10 L/s (UN, 1989; RAK, 2013). Probability of success in obtaining usable yields decreases southwards. Yields generally less than 5 L/s typify the crystalline Precambrian rocks.

Groundwater Quality

Overview

At the time of writing, availability of data on groundwater quality in Angola is limited. Salinity is a recognised groundwater-quality problem in some coastal areas. Potential problems also include contamination of groundwater with metals and metalloids due to mineralisation and mining; and vulnerability of shallow groundwater to contamination from anthropogenic sources including pit latrines and urban wastes.

Nitrogen species

Shallow groundwater in fractured aquifers including basement and limestones is potentially vulnerable to contamination from surface pollutants and concentrations of nitrogen species such as nitrate may be high. Vulnerability of groundwater in the Kalahari aquifer will depend largely on local permeability of sediments and depth to groundwater, being less vulnerable in places where depth to water increases.

Salinity

Saline groundwater has been reported in the sedimentary aquifers of the coastal strip in association with evaporites in the sediments (Bee Pee and SRK, 2002). Increasing salinity has also been reported in the coastal portion of Namibe Province, likely due to saline intrusion (Bee Pee and SRK, 2002), although problems with saline intrusion appear not to be significant elsewhere.

No data are available on the salinity of groundwater in the Kalahari aquifer, although in neighbouring Namibia, quality of the groundwater is variable and dependent on proximity to rivers as these are the main sources of recharge. Fresh groundwater is located at up to 5–20 km distance from the rivers of northern Namibia as a result of river recharge, but salinity characteristically increases sharply in more distal parts of the aquifer as well as with increasing depth (>50 m below surface; Christelis and Struckmeier, 2011). Salinity of the Namibian groundwater is manifested by high sodium, chloride and sulphate concentrations, likely to be from dissolution of evaporite minerals and evaporation. Similar conditions seem likely for southern Angola.

Fluoride

Granites and gneisses which occur in the Archaean formations of the uplands may be enriched in fluorine-bearing minerals and so the hosted groundwaters may potentially have high fluoride concentrations. The alkaline intrusive rocks of the kimberlite-carbonatite suite also pose a potential risk to groundwater from fluoride. Kimberlites contain phlogopite mica as well as perovskite and apatite. Carbonatites, phonolites and trachytes also have recognised fluorine enrichments due to the presence of micas, amphiboles, fluorite and apatite.

Groundwater vulnerable to fluoride contamination also includes that at the coast affected by saline intrusion and any groundwater in sedimentary aquifers affected by ion exchange. This could include parts of the Kalahari Group in the semi-arid south. Indeed, high concentrations of fluoride have been found in groundwater from some parts of this aquifer in northern Namibia (Christelis and Struckmeier, 2011).

The prevalence of mineralised zones, alkaline igneous rocks and granite-gneisses, together with likely saline intrusion and cation exchange in coastal and Kalahari Group sedimentary aquifers, means that fluoride concentrations in groundwater could be elevated in several areas. Occurrences exceeding the WHO guideline value for fluoride in drinking water (1.5 mg/L) are likely. Testing for fluoride in groundwater development programmes is recommended.

Iron and manganese

In unconfined aquifers such as those of the fractured basement, limestones and shallow Kalahari sands, conditions are likely to be oxic and therefore concentrations of dissolved iron and manganese should be low. Concentrations may be high where groundwater conditions are confined and where reducing conditions can prevail (e.g. deeper parts of the Kalahari sediments, argillaceous deposits of the Cassanje Graben or the Mesozoic coastal aquifers). Problems with iron (and manganese) have been reported in the Kalahari aquifer of neighbouring Namibia (Christelis and Struckmeier, 2011), presumably under confined conditions.

High concentrations of iron and manganese are also possible in aquifers affected by alteration of mineralised veins (metal sulphides) and from mining contamination. These conditions pertain to the Precambrian basement areas (uplands).

Arsenic

There exists a risk of contamination from arsenic in groundwater in the mineralised areas of basement, due to release of arsenic by alteration of metal sulphides and their oxidation products. Groundwater from Mesozoic deposits in the coastal sedimentary basins could also contain high concentrations of arsenic if conditions are reducing. Reducing groundwater in confined aquifers at deeper levels in the Kalahari aquifer and/or in the Cassanje Graben may also have increased concentrations. Shallow, unconfined Kalahari sands and Cenozoic limestones in the coastal aquifers are considered lower-risk. Given the lack of available data on arsenic in Angolan groundwater and the prevalence of diverse aquifers with significant potential for arsenic mobility, testing for the element is strongly advised. Areas of particular focus include the mineralised areas of basement, the Cassanje Graben, sandstones of the Mesozoic coastal sedimentary sequence and deeper Kalahari aquifers.

Iodine

No data could be found from which to assess the iodine concentrations of groundwater in Angola. In line with groundwater chemical data from elsewhere in sub-Saharan Africa, concentrations are likely to be low (of the order of a few micrograms per litre) in the groundwater from Precambrian crystalline basement rocks. Low concentrations are also likely in groundwater elsewhere except where saline conditions prevail through evaporation, dissolution of evaporite minerals or saline intrusion. Higher concentrations can be expected in groundwaters from the coastal sedimentary basins and possibly from the aquifers of the Kalahari Group. Iodine-deficiency disorders have been reported among Angolan populations (Zimmerman et al., 2008).

Other trace elements

The prevalence of metal mineralisation and significance of mining in Angola mean that a number of other trace elements may be present in the groundwater local to the mineralisation at concentrations exceeding limits or guideline values. Elements particularly worthy of scrutiny include copper, lead, nickel, uranium and zinc.

Data sources

Ala, M.A. and Selley, R.C., 1997. The West African coastal basins. In: *Sedimentary Basins of the World*, ed: Selley, R.C. Elsevier. 173-186.

Bee Pee and SRK, 2002. Angola Country Report. Compilation of the hydrogeological map atlas for the SADC region. SADC Water Sector Coordination Unit, 14 pp.

Christelis, G. and Struckmeier, W. (eds.) 2011. Hydrogeological framework, In: *Groundwater in Namibia: an Explanation of the Hydrogeological Map*. Department of Water Affairs, Namibia.

CIA World Factbook 2013. Accessed Jan 2013: https://www.cia.gov/library/publications/the-world-factbook/geos/ao.html.

Dos Santos, P. 1972. Formations Charbonnifères du Système du Kalahari de l'Angola. Bolletim No. 21 dos Serviços de Geologia e Minas de Angola, Luanda, 5-16.

Pinheiro, O. 2010. Mineral Resources of Angola, its importance for the socio-economic and sustainable development of the country. http://www.unece.org/fileadmin/DAM/energy/se/pp/unfc/UNFC_iw_June10_WarsawPl/13_Pinheiro.pdf. Accessed June 2013.

RAK, 2013. Kunene river awareness kit. http://www.kunenerak.org/en/management/references.aspx. Accessed May 2013.

Schlüter, T. 2006. Angola. In: *Geological Atlas of Africa*. Springer, pp 38-41.

UN, 1989. Angola. Ground Water in eastern, central and southern Africa. Natural resources/Water series No. 19. United Nations, pp 14-18.

van Eden, J.G. 1978. Stratiform copper and zinc mineralization in the Cretaceous of Angola. *Economic Geology*, Scientific Communications, 1154-1161.

Zimmerman, M.B., Jooste, P.L. and Pandav, C.S. 2008. Iodine deficiency disorders. Lancet, 372, 1251-1262