Groundwater Quality: Malawi

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

Malawi is a landlocked country in southern Africa, situated between Zambia, Mozambique and Tanzania (Figure 1). The country has a total land area of around 118,500 square kilometres. Lake Malawi (formerly Lake Nyasa), some 580 km long, is the largest lake in Africa and forms a significant part of the eastern national border.

The topography is dominated by an elongate plateau on the extreme southern end of the East African Rift Valley. Terrain consists of distinct geographic areas divided into plateau, upland, Rift Valley escarpment and Rift Valley plains. Plateau areas are gently undulating peneplains with broad valleys draining toward the Rift Valley (UN, 1989). 'Dambos', broad areas of grassy swampy ground subject to flooding, occupy many parts of the plateau. The uplands include the Mlanje, Zomba and Dedza mountains (highest point at Sapitwa, Mount Mlanje, 3002 m) and the Viphya and Nyika uplands. The escarpment consists of parallel faults running down to the Rift Valley floor. The lowland plains extend along the shores of Lake Nyasa and the valley of the Shire River, which runs south from Lake Malawi to join the Zambezi River in Mozambique. Elevation in Malawi descends to 37 m at the Mozambique border. The Linthipe,

Figure 1. Map of Malawi and neighbouring countries (courtesy of The General Libraries, The University of Texas at Austin).

Bua, Dwanga and Rukuru Rivers are the main watercourses draining into Lake Malawi. These drain from often large dambos on the plateaux. Elsewhere, most water courses are ephemeral. Lake Chilwa is an endorheic lake (internal drainage basin) which experiences significant evaporation and is saline. Areas marginal to the lake can be swampy during the rainy season (UN, 1989).

Malawi has a sub-tropical climate with a distinct rainy season during November–May. The plateaux have a hot climate with moderate rainfall, while the Rift Valley is comparatively arid. Rainfall is affected strongly by topography and prevailing-wind direction. Average annual rainfall is 1014 mm, but can exceed 1800 mm in the Mlanje and Zomba mountains. Monthly average temperatures are around 10–16ºC in the Nyika uplands and 21–30ºC along the lower Shire valley. Malawi has suffered numerous droughts.

The country is dominantly rural with some 90% of the population living in rural areas and a similar proportion of the workforce employed in agriculture. Around 20% of the land use is arable and an area of 280 square kilometres is irrigated. The main agricultural products are tobacco, tea, cotton and sugar. 97% of power generation is by hydroelectricity.

Geology

Most of the land area of Malawi consists of Precambrian or Lower Palaeozoic crystalline basement rocks, including gneiss and granulite with some granite. Younger Karoo (Jurassic) alkaline granitic and syenitic intrusions of the Chilwa complex also occur in the south-east of the country (Figure 2). These intrusions are harder and more resistant to weathering than the basement rocks and so form the uplands with highest elevations. Mesozoic volcanic rocks occupy a small area in the extreme south of the country.

Sediments of Karoo (mainly Permo-Triassic) age, in places over 3500 m thick, occupy smaller areas in the north and the extreme south (UN, 1989). These deposits are mainly sandstones, marls and conglomerates with some coal seams. They are usually well-indurated with calcite cements. Younger sediments of Cretaceous to Pleistocene age also occur in small areas of the north and south of the country (Figure 2). These include poorly-indurated sandstones, marls, clays and conglomerates with some evaporites.

Quaternary alluvium, colluvium and lacustrine deposits occupy the plains around Lakes Nyasa and Chilwa. Much of the alluvium arises from erosion of rock material from the Rift Valley escarpment slopes. The sediments are partly faulted as tectonism along the Rift Valley is still active. The Quaternary deposits consist of unconsolidated mixed clays, silts, sands and gravels. Along the shore of Lake Nyasa, these reach up to 60 m thick but are up to 150 m thick in the lower Shire valley.

Mineral deposits include unexploited uranium in parts of the north (e.g. Ilomba Hill north of Chitipa). Coal seams also occur in the Karoo sediments.

Superficial deposits of residual soils and colluvium (formed by soil creep) occur extensively over the plateau areas of western Malawi. These are commonly thin deposits, but are quite extensive in the Lilongwe area where borehole records indicate that they can be up to 40 m thick (Geological Survey of Malawi, 1989).

Soil compositions tend to be closely related to underlying geology. Sandy soils occur on many granitic areas of basement and are also well-developed on the edges of the alluvial plain. Many soils are lateritic. Some laterites can be thick (5–20 m; Smith-Carington, 1983). Dambo soils are also widespread in the lower-lying swampy areas. Some dambos contain surface efflorescences of salt (gypsum, epsom salts) as a result of evaporation, for example at Linthembwe dambo (DWIGSP, 1984). Soils are thin or absent on the escarpment slopes.

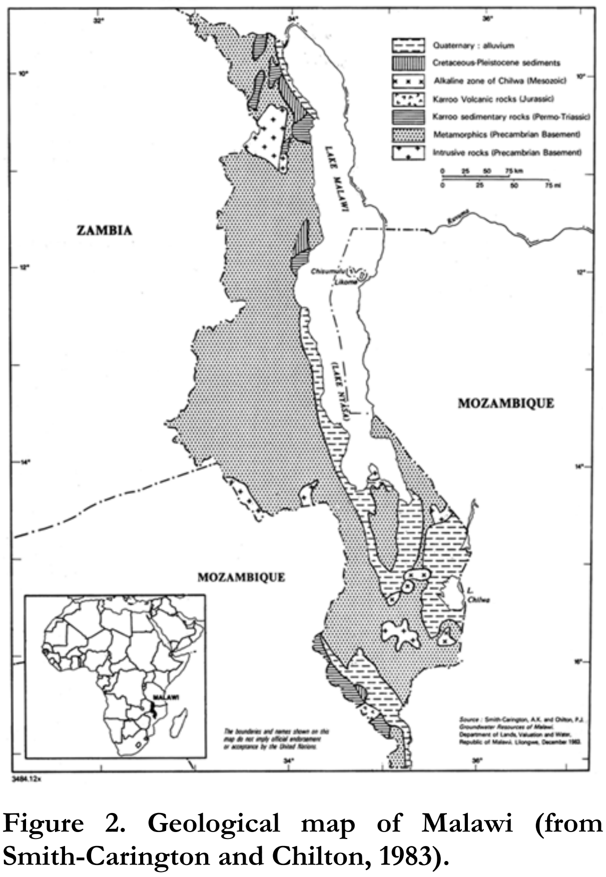

Figure 2. Geological map of Malawi (from Smith-Carington and Chilton, 1983).

Groundwater Availability

The productivity of the crystalline basement rocks as aquifers varies widely according to degree of alteration and distribution of overlying colluvial deposits. Depths of weathering of the basement rocks on the plateau are typically around 10–30 m (Smith-Carington, 1983) but can be thicker in fault zones and thinner close to outcropping inselbergs (Chilton and Smith-Carington, 1984). This weathered layer forms a laterally extensive minor aquifer of considerable value for small-scale rural water supplies. The degree of weathering of the overburden is generally greatest close to the surface and higher permeability is typical in coarse-grained rock types (granites and gneisses; UN, 1989). The frequency of faults and joints also has a major control on rock permeability. Groundwater levels in the basement aquifers are in most cases less than 15 m below surface. Seasonal fluctuations are typically 1–5 m. Yields of 0.25–0.5 l/s can usually be obtained from the basement rocks provided the saturated thickness of the weathered layer is more than 10 m. Such yields are usually adequate for hand-pumped supplies (Chilton and Smith-Carington, 1984).

Mesozoic alkaline intrusions in the south-east uplands are largely fresh and poorly-permeable. As such, they have little aquifer potential.

Since the Karoo sediments are usually well-cemented, they have low porosity (UN, 1989) and therefore their aquifer potential is restricted. Groundwater is usually present only in fractures. In the lower Shire valley, groundwater levels in this aquifer are typically 20–30 m below surface (UN, 1989). The less well-indurated Cretaceous sediments have greater potential as an aquifer.

The Quaternary alluvial deposits can be important areas for groundwater storage and generally form a good resource for water supply. Watercourses draining into Lake Nyasa lose a large part of their flow to infiltration in the alluvial areas upstream of the lake. Sediments below Lake Chilwa are more clayey and hence less permeable. Water levels are generally less than 10 m below surface, with annual fluctuations of around 1–3 m. In areas irrigated by the Shire River, groundwater levels have risen by several metres.

Most rural water supply is provided by groundwater which is abstracted from hand-dug wells, springs and hand-pumped boreholes. In the urban areas, most public supply is derived from surface-water sources. In the alluvial areas, groundwater abstraction is found to be much less than recharge (UN, 1989).

Groundwater Quality

Overview

The chemical quality of groundwater in the aquifers of Malawi has been little documented. From the limited information available, groundwater compositions appear to be spatially variable and highly dependent on aquifer lithology. Most documented groundwater compositions appear to be of near-neutral pH. Chilton and Smith-Carington (1984) gave values of 6.3–6.8 for groundwaters from basement aquifers. MacFarlane and Bowden (1992) gave a range of 6.4–7.0 for springs issuing from dambos, also in basement aquifers and Palamuleni (2002) gave a pH range of 6.4–7.1 for groundwaters from basement aquifers in Blantyre.

One of the main problems affecting the groundwaters appears to be high salinity. This is particularly the case in groundwater from the alluvial deposits of the lower Shire valley. High salinity is less widespread in groundwaters from the weathered basement and overlying colluvium but some areas of saline groundwater occur, the spatial variability presumably reflecting limited permeability and limited groundwater mixing. High sulphate

Table 1. Range of concentrations of selected parameters in groundwaters from Malawi (data from Bath, 1980). Fe_T is total (unfiltered) iron.

Unit	Area	No. samp-les	Na mg/l	NO_3-N mg/l	Fe_T mg/l	F mg/l
15A	Nkhokakota	60	17–720	<0.2–6.1	0.8–82	<0.4–7.6
15B	Nkhokakota	9	0.4–223	<0.5–5.0	1.4–29	<0.1–1.4
5D	Bua	16	nd	0.02–0.63	<0.1–11	0.2–0.5
5E	Bua	65	nd	0.22–6.3	0.2–59	nd
5F	Bua	2	nd	nd	0.6–8.7	nd
1F	Lower Shire	24	16–390	0.09–1.0	<0.2–30	0.2–14
1G	Lower Shire	61	18–3550	0.09–41	<0.1–84	0.6–15
1H	Lower Shire	86	24–3110	0.22–18.5	<0.1–62	0.4–3.0
1K	Lower Shire	22	14–2160	<0.7	<0.2–40*	0.4–13
1L	Lower Shire	8	81–690	<0.07–9.9	<0.2–53*	0.3–15
7	S. Rukuru	71	6–500	0.02–9.3	<0.2–65	<0.1–3.3

*Quality of data uncertain; nd: not determined concentrations have also been reported in some areas of weathered basement.

Fluoride problems appear not to be widespread but high concentrations have been found in some parts of the alluvial aquifers (UN, 1989) as well as sporadically in the basement (Bath, 1980).

Deterioration of water courses through pollution from agricultural runoff, sewage and industrial wastes are concerns for surface-water quality but there is currently little information available to assess their impact on groundwater resources.

Nitrogen species

Most available analyses of nitrate in groundwater have yielded low concentrations. Data summarised by Bath (1980) showed that concentrations at the time of the study were usually much less than the WHO guideline value for nitrate (N) in drinking water of 11.3 mg/l (Table 1). Sporadic high concentrations were apparent in the groundwaters from the lower Shire valley though even here, NO_3-N concentrations were mostly less than 5 mg/l; many were below the detection limit. UN (1989) also quoted values for nitrate (as N) of less than 1 mg/l in groundwater from both the basement and the alluvial aquifers. Such low values imply minimal pollution inputs, although the analyses referred to are relatively old and the extent to which they reflect modern groundwater compositions is unclear. The significance of denitrification (bacterially-mediated removal of nitrate from groundwater under anaerobic conditions) has also not been quantified. Denitrification may be an important process in some of the Quaternary alluvial aquifers but probably has less significance in the basement aquifers where conditions are likely to be more commonly aerobic.

To date, no data are available on the concentrations of other nitrogen species (nitrite, ammonium) in groundwaters from Malawi.

Salinity

High salinity appears to be a feature of some Malawian groundwater and arises as a result of either evaporative concentration or dissolution of evaporate minerals in sedimentary rocks. Evaporative concentration is greatest where the water table is close to the ground surface and where evaporation greatly exceeds recharge.

Particularly high concentrations of sodium and chloride have been reported for groundwaters from the lower Shire valley (Bath, 1980), both as a result of evaporation and dissolution of evaporite minerals. Most boreholes close to the river and with shallow water tables have saline groundwater compositions. Chloride concentrations up to 4000 mg/l and sodium up to 3600 mg/l have been reported (Bath, 1980). Affected boreholes are frequently abandoned in favour of water holes in dry river beds or surface water. Further away from the river, saline groundwaters result from the dissolution of evaporite minerals such as halite (NaCl) and gypsum ($CaSO_4$). In groundwater from alluvial deposits close to the edge of the Karoo sediments (Figure 2), chloride concentrations up to 2100 mg/l and sulphate up to 2400 mg/l were recorded. High salinity is more problematic in these areas as alternative water sources are not readily available. The vertical variation in groundwater salinity in the Shire valley has not been studied in detail but may be significant.

Bath (1980) reported generally low salinity values for groundwaters from weathered basement in the Bua catchment of western Malawi. Total dissolved solids were quoted in the range 200–740 mg/l. Chilton and Smith-Carington (1984) also found mostly low-conductivity groundwaters in basement aquifers from the Livulezi (central) and Dowa West (south-central) areas. Electrical conductances were usually <750 µS/cm but extremes up to 4000 µS/cm (total dissolved solids up to around 2500 mg/l) were found. The saline waters often had high concentrations of sulphate, some in excess of 2000 mg/l, presumably as a result of dissolution of evaporite salts. The salinity and high sulphate concentrations were highly variable spatially.

In the Nkhokakota area on the western shores of Lake Nyasa in central Malawi, Bath (1980) reported electrical conductance values of 180–4600 µS/cm (total dissolved solids up to 2900 mg/l) in weathered basement and colluvium. The groundwaters from this region are mainly of calcium-(magnesium)-bicarbonate type with typically low concentrations of chloride (usually below 60 mg/l). Some of these also had high concentrations of sulphate (up to 2400 mg/l). Those that did tended to have calcium as the dominant cation and were concluded to have been influenced by the dissolution of gypsum in the superficial lakeshore colluvial sediments (Bath, 1980).

In colluvium and weathered basement aquifers of the South Rukuru catchment of north-west Malawi, groundwaters with high salinity have been noted especially around the town of Emcisweni (Bath, 1980). The catchment as a whole has groundwaters with very variable salinity, with electrical conductance values in the range 70–7700 µS/cm and chloride concentrations of 4–2000 mg/l. The saline groundwaters appear to be of calcium-chloride or mixed-ion type with concentrations of sodium up to 500 mg/l, magnesium up to 280 mg/l and sulphate up to 1800 mg/l. Despite this, most groundwaters from the region had low sulphate concentrations (most <15 mg/l). The origin of the salinity in this region is unclear (Bath, 1980).

Fluoride

The East African Rift Valley is well recognised as a high-fluoride province and many countries in the region have significant groundwater fluoride problems. As such, Malawian groundwaters in the Rift zone (eastern alluvial plains) are likely to be most affected. Some groundwaters in the weathered basement in the west may also have high concentrations (greater than 1.5 mg/l, the WHO guideline value for fluoride in drinking water) though climatic factors, i.e. high rainfall compared to high-fluoride basement aquifers elsewhere, suggest that the concentrations in this region should be mostly low. UN (1989) reported fluoride concentrations of less than 1 mg/l in areas of altered basement rocks in Malawi but much higher concentrations, in the range 2–10 mg/l, in groundwater from the alluvial areas.

Bath (1980) reported concentrations of fluoride in the range <0.1–7.6 mg/l in basement aquifers of the Nkhokakota area of central Malawi (Table 1) though only one sample exceeded the WHO guideline value and most were below 1 mg/l. Few analyses were available from the Bua catchment but of those carried out, all were less than 0.5 mg/l. Concentrations in the basement aquifer of South Rukuru were in the range <0.1–3.3 mg/l, though most were below 0.6 mg/l (Bath, 1980). Only two samples exceeded 1.5 mg/l. Similarly, concentrations of around 0.9 mg/l were reported in groundwater from 8 sites in South Lunzu Township, Blantyre (Palamuleni, 2002).

In the lower Shire valley, much higher fluoride concentrations, up to 15 mg/l in some samples, were reported by Bath (1980), though the range was large (Table 1). Hydrothermal sources of fluoride are likely in this active Rift zone.

Iron and manganese

The widespread occurrence of high iron concentrations in Malawian groundwater has been reported by a number of authors (e.g. Bath, 1980; UN, 1989). UN (1989) gave ranges for total iron in groundwater from both weathered basement rocks and alluvial sediments as 1–5 mg/l. Concentrations of iron up to 84 mg/l have been reported by Bath (1980) in the Lower Shire Valley and up to 82 mg/l in the weathered basement aquifers of Nkhokakota area. However, the ranges quoted reflect compositions of unfiltered water samples and therefore represent total iron (including particulate iron) rather than dissolved iron. As such, the concentrations will vary considerably according to the turbidity of the water and the degree of flushing (pumping) of the well before collection. Nonetheless, the total concentrations reported may be indicative of the concentrations in water used for domestic purposes. High concentrations of dissolved iron can occur under acidic or reducing conditions. There is no evidence for the occurrence of strongly acidic groundwaters in Malawi and it is unlikely that groundwater acidity could be responsible for producing the very high iron concentrations observed in some of the groundwaters. However, anaerobic conditions could exist in some aquifers, particularly the alluvial deposits of the lower Shire valley and locally within parts of the basement where overlain by thick deposits of poorly-permeable lateritic soils.

High concentrations of dissolved iron (i.e. from filtered groundwater samples) have been found in groundwater of neutral pH from basement rocks in Timadzi (near Lilongwe) (Bath, 1980). One 60 m deep borehole had a concentration of 7 mg/l iron. It is likely that the groundwater from this borehole was anaerobic, although Bath (1980) speculated that the iron could have been complexed with organic acids in solution.

Some studies have suggested that the high iron concentrations in Malawian groundwater derive from corrosion of metallic pump and pipe parts rather than from the aquifer. These sources are difficult to distinguish. Both are possible but mineral sources within the aquifer are considered more significant. Nonetheless, some improvements in water quality with respect to iron have been reported following replacement of ferrous casing with a PVC alternative (Chilton and Smith-Carington, 1984; Lewis and Chilton, 1989).

The high iron concentrations observed in the groundwaters are not likely to be detrimental to human health but give considerable problems in terms of acceptability because of their adverse effects on water colour and taste. High iron concentrations are one of the main causes of well abandonment in Malawi (Bath, 1980).

Concentrations of manganese have not been reported in Malawian groundwater. Like iron, manganese is mobilised in groundwater under acidic or anaerobic conditions and therefore often accompanies iron (when in dissolved form). Iron cannot be used as an indicator of likely manganese concentration however, as correlations between the two elements are rarely sufficiently good.

Correlations between iron and manganese are less likely if metallic pumps and pipes are responsible for iron contamination of groundwater.

Arsenic

Concentrations of arsenic in Malawian groundwater have not been reported. It is likely that concentrations will be low (less than the national standard for arsenic in drinking water of 50 μg/l adopted by most developing countries and possibly less than the WHO guideline value of 10 μg/l) in most groundwaters from the basement areas and from the Mesozoic (Karoo and Cretaceous) sediments. However, this assumption would need to be tested. Concentrations in groundwater from some of the alluvial deposits may in some cases be higher, especially if anaerobic groundwater conditions exist. However, the predictability of arsenic concentrations in groundwater is notoriously poor, all the more so in aquifers for which hydrogeochemical and hydrogeological information is limited.

Iodine

No data have been found for iodine in groundwater from Malawi. Concentrations are unknown but are likely to be highly variable depending largely on groundwater salinity. Some high concentrations may be expected in the groundwaters of the lower Shire valley though high concentrations in groundwater are not normally linked with health problems. Low iodine concentrations (<5 μg/l) may occur in some low-salinity groundwaters from the basement and could constitute a health problem if insufficient dietary iodine is available to the local populations.

Other trace elements

McFarlane and Bowden (1992) studied the mobilisation of aluminium in seepage waters and springs from dambos in Malawi but found uniformly low dissolved concentrations, all being less than 0.1 mg/l. The WHO acceptability-based guideline value for aluminium in drinking water is 0.2 mg/l. Given the near-neutral pH values of most Malawi groundwaters, the solubility of aluminium minerals is likely to be low.

Little other information is available on trace elements in the groundwater. Lack of information on potentially toxic trace elements such as antimony, cadmium, chromium, lead, nickel and selenium does not necessarily mean that these elements will be uniformly low and hence not problematic. However, there is likewise no evidence to suggest that they will be present in the groundwaters in potentially detrimental concentrations. Water testing would be required to clarify the situation.

Data sources

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