

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

Ethiopia, with a total area of some 1,127,000 square kilometres, is a landlocked country in East Africa, situated to the west of Somalia and north of Kenya. The terrain consists largely of high mountains and plateaux with elevations above 1500 m, divided from south-west to north-east by the East African Rift Valley, a major structural feature some 40–60 km wide and in places 1000 m below the flanking plateau areas. The Rift extends across Ethiopia via Lakes Rudolf and Chamo in the south-west, Awasa, Nazret, Mile and Lake Afrera in the north (Figure 1). The Awash River flows along much of the northern section. The southern part of the Rift, extending between Lake Chamo and the Awash River is known as the Lakes District and is a zone with numerous lakes, largely elongated parallel to the Rift axis. Some of these are freshwater lakes while some are alkaline and saline. The floor of the Rift rises from the south-west to a maximum altitude of more than 1800 m north of Lake Zwai, beyond which it descends into the low-lying Afar section of the Rift, which is in large part below sea level. Elevation in Ethiopia varies from the highest point at Ras Dshen Terara (4620 m) to the lowest in the Danakil Depression (-125 m; northern section of the Afar Depression). The Ogaden region of eastern Ethiopia (bordering Somalia) is also a flat-lying plain, with an elevation of around 600 m (Figure 1).

Ethiopia has a tropical monsoon climate with a wide climatic variation induced by varying topography. Annual rainfall varies from less than 100 mm along the borders with Somalia and Djibouti to more than 2000 mm in the highlands of the south-west. The national average rainfall is 744 mm per year (FAO, 1995). The country has a dry season from October to February (being drier and more prolonged in the north) and a wet season from April to September. However, the rains generally fall in two distinct periods, the first peaking in April and the second in September. Temporal variations in rainfall mean that parts of Ethiopia are highly prone to drought.

Most of the population of Ethiopia is concentrated in the highland areas. Land-use is dominantly agricultural, with more than 50% used as arable and pasture land and around 25% forested. Some 80% of the population is employed in the agricultural sector, most being subsistence farmers. An estimated 1,900 square kilometres of land is irrigated. Much of this is in the Awash valley of the central Rift, where large sugar estates and fruit and cotton farms are situated. Both the Ogaden and Awash regions are important for cattle rearing.

Geology

The geology of Ethiopia comprises a mixture of ancient crystalline basement rocks, volcanic rocks associated with the East African Rift system and sediments of various ages. Ancient (Precambrian) rocks outcrop in four main regions: Tigray in the north, along the Sudanese border (Gojam, Wollega, Illubabor and Kefa regions), in Sidamo and Bale regions in the south and Harerghe region in the east (Tefera et al., 1996). These rocks are usually highly metamorphosed and include some granites. Some have zones of associated sulphide minerals bearing gold, copper and other metals. The best-known is the Adola gold field in Sidamo region, where gold mining has been conducted for several decades (Tefera et al., 1996). Gold and platinum deposits are also recognised in Wollega, and Kefa regions.

The highlands flanking the Rift Valley and the Rift itself are dominantly composed of volcanic rocks (lavas and ashes, mainly of Tertiary and younger age), associated with the evolution of the Rift system. In the southern part of the Rift, the Lakes District, the volcanic rocks are dominantly acidic (silica-rich), including much ash and pumice. In the Afar section of the Rift and much of the flanking plateau areas, the rocks are dominantly basaltic (iron- and magnesium-rich). The volcanic rocks in these areas are often interbedded with sediments. During the period of rifting and volcanism, down-faulting in the north produced the low-lying Afar Depression (Tefera et al., 1996).



Figure 1. Location map of Ethiopia (from University of Texas Map Library).

The lowlands of south-eastern Ethiopia (east of Goba, Figure 1) as well as parts of the north are composed of sedimentary rocks of various ages. Many occupy low-lying depressions (e.g. the Danakil Depression) which are the result of the many tectonic movements associated with rifting. The sediments are largely mixed deposits of sandstone, limestone and silt, but contain frequent occurrences of evaporite minerals, including halite (rock salt), gypsum (a calcium-sulphate mineral) and potassium- and magnesium-salts. Major reserves of rock salt, possibly on an economic scale, exist for example in the Danakil Depression.

In addition, young (Quaternary) unconsolidated alluvial and lake sediments also occur within the Rift zone as well as in low-lying parts of the south-west, along Sudanese border.

Groundwater Availability

Groundwater is an important source of water and is the dominant source for domestic supply in many areas, especially the dry areas where surface waters are scarce and seasonal (e.g. Somali region in the east). Much of the remaining water supply is from rivers, although these often only supply water for parts of the year.

Many parts of Ethiopia have limited supplies of groundwater because of the poor permeability of the crystalline rocks and variable water-table depths. Success with obtaining groundwater in these areas depends upon locating water-bearing fractures. The

permeability of the ancient (Precambrian) rocks is generally poor and wells normally give poor yields as a result (UN, 1989).

The permeability of volcanic rocks within and flanking the Rift is generally more variable, although is often good. Increased water yields often occur along joints and fractures, in interbedded sediment horizons and in areas with porous (vesicular) lava and ash flows.

The sedimentary rocks of eastern, central and northern Ethiopia also have variable groundwater potential. The sandstones are normally permeable and porous and have good groundwater yields, although water levels are in places deep and hence difficult to access (e.g. 280 m below surface in the Jessoma Sandstone; UN, 1989). The limestones are often well-fractured and have increased yields as a result. Permeability is however, hindered by the occurrence of interbedded silty or clay horizons with poor permeability. In eastern Ethiopia, limited groundwater resources also relate strongly to low rainfall (Figure 2).

The best aquifers with the largest exploitable resources of groundwater occur in the young (Quaternary) lake and alluvial sediments. Unconsolidated alluvial sediments occur in the main floodplains of the Rivers Wabi, Shebali, Genale-Dawa, Omo, Baro, Angereb, Tekeze, Gash and Barka (UN, 1989). Lake sediments also occur within the Rift and are exploited for drinking water and

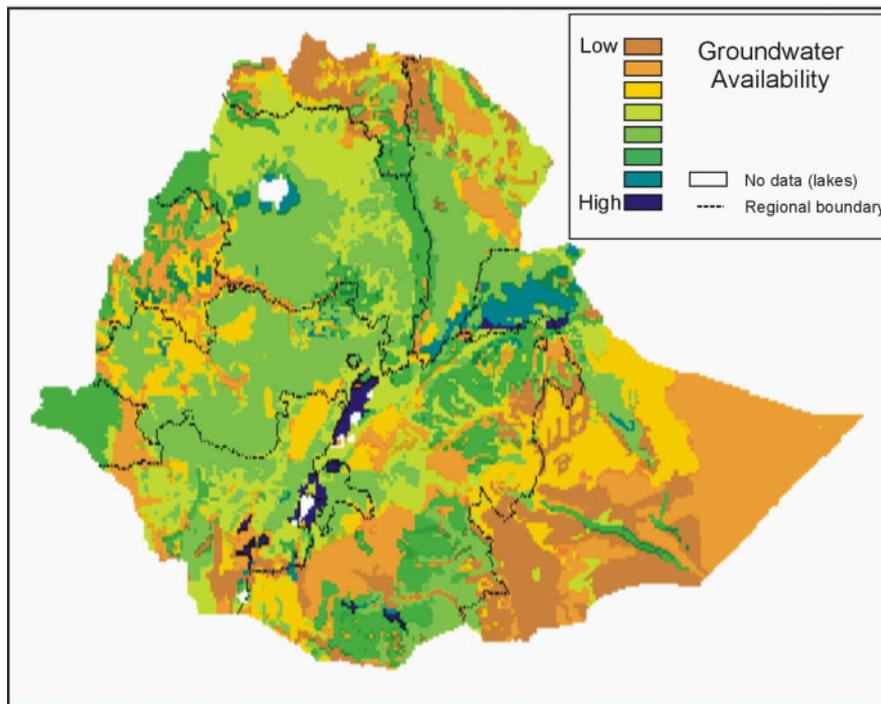


Figure 2. Map showing the estimated distribution of groundwater availability in Ethiopia (from MacDonald et al., 2001).

irrigation. The water table in these unconsolidated sediments is also typically shallower than in other rock formations (typically around 15 m below surface; UN, 1989). Figure 2 shows the likely high abundance of groundwater in the Rift relative to the neighbouring areas.

Communities use groundwater from a combination of springs, dug wells and tubewells. In the highlands, springs predominate. In the hard-rock areas, groundwater abstraction sources are mainly for domestic use as a result of small yields. Groundwater use for irrigation is mainly limited to the more permeable areas of alluvial sediment.

In areas using traditional dug wells where water is scarce, such as the low-lying plains of eastern Ethiopia, clusters of wells are sometimes used to increase the access to water. Tubewell drilling programmes have been instigated over the last few decades, but groundwater provision is often unsuccessful because of poor groundwater yields, adverse drilling conditions or poor water quality. UN (1989) estimated that more than 20% of tubewells drilled in Ethiopia had been abandoned as a result of a combination of these reasons. Tubewell depths vary considerably across the country. Many in the Rift and highlands are in the range 50–100 m. Depths in the sediments of eastern Ethiopia (Ogaden) are often in excess of 200 m because of deep water tables.

Groundwater Quality

Overview

Few data exist for the general state of groundwater quality across Ethiopia. From those available, the quality is shown to be highly variable, ranging from fresh waters in many of the springs issuing from the crystalline basement rocks (e.g. the Ansokia Highlands; Aberra, 1990) to more saline waters in parts of the Rift and the sedimentary formations of the plains.

Most of the accessible published information is for water quality within the Rift. From this, it is evident that groundwater in the Rift zone is influenced by geothermal waters with abnormally high concentrations of fluoride and/or total dissolved salts. Fluoride is therefore a recognised major problem, especially for the communities living within the Rift. Observed increased salinity in many groundwaters from sediments in the south, south-east and north-eastern parts of the country arises from the dissolution of evaporite minerals (the products of evaporation) in certain horizons of the sediments.

Total dissolved salts

As noted above, high salinity in the Ethiopian groundwaters is apparent in some parts of the Rift as a result of the influence of saline geothermal waters. This appears to be especially the case in the

Afar section of the Rift. Influxes of saline lake water to groundwaters may also increase the salinity in parts of the Rift locally. In the Afar section, sodium and chloride are likely to be the dominant dissolved constituents, with total dissolved solids often in excess of 2000 mg/l. In the southern parts of the Rift, sodium and bicarbonate (high alkalinity) are the dominant dissolved constituents.

High concentrations of dissolved salts in the groundwaters from the sedimentary formations are also common, as a result of reaction of the often abundant evaporite minerals. In these, high salinity may be manifested by high concentrations of sodium, chloride and/or sulphate in particular. Groundwaters from the Ogaden region are noted to be dominated by sodium and sulphate with total dissolved solids concentrations in excess of 1500 mg/l (EIGS, 1993). In groundwaters from the Wabe Shabele catchment of south-eastern Ethiopia, dominant dissolved constituents are reported to be sodium and chloride, with total dissolved solids in excess of 3000 mg/l (EIGS, 1993).

While not directly detrimental to health, high concentrations of sodium and chloride ('salt') in groundwater used for drinking may be unacceptable to the users. Some of the saline groundwaters occur in areas of Ethiopia which are sparsely populated (e.g. the Ogaden region).

Lowest concentrations of dissolved solids (<500 mg/l) are reported for groundwaters from the ancient crystalline basement rocks of the north-central and south-west highlands and on the south side of the Rift.

Fluoride

Fluoride has long been a recognised water-related health concern in Ethiopia, as in other parts of the East African Rift (see *Tanzania* and *Uganda* Fact Sheets). Concentrations of fluoride greater than the WHO guideline value of 1.5 mg/l have been found in groundwaters from several parts of Ethiopia (Kloos and Haimanot, 1999), but are recognised to be highest in the Rift zone. Concentrations often greater than 10 mg/l are found in waters from the Rift. Moderately high (unacceptable) concentrations have also been found in groundwaters from volcanic rocks in the highlands. Concentrations in groundwaters from the ancient basement rocks are typically low (e.g. Mekele area; Chernet and Eshete, 1982).

As a result of the long-term use of high-fluoride drinking water, both dental and skeletal fluorosis are known to occur in populations from the Rift Valley. The worst cases of skeletal fluorosis are recorded at Wonji and attempts to defluoridate the water are

ongoing. Dental fluorosis is also recognised in some highland communities (Kloos and Haimanot, 1999) where the water is abstracted from volcanic rocks.

In the Ethiopian Rift, as elsewhere along the East African Rift system, hot springs and alkaline (and saline) lakes are noted to have particularly high fluoride concentrations. Gizaw (1996) studied waters in the Lakes District of the southern Rift. He reported fluoride concentrations up to 60 mg/l in hot springs and groundwaters from deep geothermal wells (temperatures in excess of 40°C), and fluoride in excess of 200 mg/l in some of Ethiopia's alkaline, saline lakes (Lakes Chitu, Shalla and Abayata). The high concentrations of fluoride and dissolved salts in the lakes are mainly caused by evaporation. Gizaw (1996) noted by contrast, that hot springs from the Afar Depression in the north were of sodium-chloride composition and had low fluoride concentrations. From this, it is likely that groundwaters affected by geothermal water in the Afar region will have relatively low fluoride concentrations. However, salinity is likely to be high.

Unusually low fluoride concentrations have been reported in groundwaters from wells and springs in the Rift Valley town of Arba Minch and the nearby escarpments in southern Ethiopia. This is apparently due to inputs of low-fluoride runoff from the highlands or from nearby rivers or lakes (Kloos and Haimanot, 1999).

Ashley and Burley (1994) carried out a study of fluoride concentrations in waters around two sugar estates in the Rift, close to the River Awash. The two estates, Wonji/Shoa and Metahara, are located some 100 km south-east and east of Addis Ababa respectively. The bedrock geology of the areas is young rift-related volcanic material but two distinct basins of unconsolidated sediment, some 60 m or more thick, overlie the volcanic rocks and provide much of the groundwater for each estate. Samples of groundwater and some surface waters were studied to determine the causes of high fluoride concentrations and to find low-fluoride alternatives for the estate workers.

The authors reported fluoride concentrations in one hot spring (47°C) as 17.6 mg/l and other wells in the two areas appeared to show some relationship between groundwater temperature and fluoride concentration: several wells with temperatures of 35°C or more had relatively high fluoride concentrations, in the range 3.5–20 mg/l. High alkalinity (HCO₃ greater than around 500 mg/l) and high sodium (linked with low calcium) were also, as elsewhere, linked with the increased fluoride in the groundwaters. The authors reported two determinations of fluoride in the Awash River itself

as 1.3 and 0.9 mg/l and made a recommendation that this water, after treatment, should be used for future potable supplies on the estates (Ashley and Burley, 1994).

The results reported by Ashley and Burley (1994) suggested that the problematic fluoride concentrations were derived from hot springs and by weathering of the volcanic bedrocks. Concentrations appeared to decrease slightly as the groundwaters flowed from the volcanic bedrocks into the sediments and began reacting with calcium-bearing minerals in the sediments (presence of calcium in the groundwaters favours formation of the mineral fluorite, CaF_2 , which results in removal of dissolved fluoride). Nonetheless, despite improvements in the quality of groundwaters from the sediments relative to those from the basin margins, concentrations of all samples analysed were greater than the WHO guideline value for fluoride in drinking water of 1.5 mg/l (range in the groundwaters 2.1–26 mg/l; 33 samples) and were therefore unacceptable for use without treatment or blending. The depths of wells in each area and the relationships between fluoride concentration and well depth are not known. A separate study of fluoride distributions in groundwaters from the Rift and highlands areas revealed significantly higher fluoride concentrations in tubewells than in hand-dug wells (Kloos and Haimanot, 1999 and references therein) and demonstrate the likely variability within a given fluoride-problem area.

The links between high fluoride and both high alkalinity (HCO_3^-) and increased temperature are quite strong in the Ethiopian groundwaters. These parameters can therefore be used as potential indicators of groundwater-fluoride problems in areas of exploration for new groundwater sources.

As noted above, several studies have suggested that the fluoride content of the rivers is relatively low compared to groundwater compositions. However, concentrations in some cases exceed 1 mg/l. In addition, temporal variations in fluoride concentrations are likely as a result of seasonal variations in rainfall and baseflow (groundwater) inputs to the rivers. Consideration of the seasonal fluctuations in water quality should therefore be made if river water is to be used for potable supply.

Iron and manganese

Few data are available for iron or manganese in the Ethiopian groundwaters. Basic hydrogeochemical data in published reports suggest that the groundwaters in most of the country are not likely to contain high concentrations, since these are usually expected in anaerobic or highly acidic

groundwaters, neither of which have been reported in the available literature.

Nitrate

Few data could be found for nitrate and other pollution indicators. However, UN (1989) reported that nitrate concentrations are high in groundwater from several urban areas (especially around Dire Dawa and Addis Ababa) as a result largely of leaking effluent from septic tanks. Nitrate concentrations are likely to be worst in urban areas where the water tables are reasonably close to the ground surface (i.e. within a few metres). Nitrate concentrations may also be increased in some of the saline groundwaters affected by evaporation.

Springs sampled in the north-central Highlands (Ansokia Highlands) had average $\text{NO}_3\text{-N}$ values of 7 mg/l, i.e. below the WHO guideline value of 11.3 mg/l (Aberra, 1990). Coliform counts in the springs were generally low, but with counts increasing slightly in the springs issuing at lower altitudes (Ansokia foothills, Aberra, 1990).

Arsenic

No data are known to exist for arsenic in Ethiopian groundwaters. The geology of most of the country suggests that concentrations in groundwater are not likely to be high. Possible exceptions occur where sulphide minerals occur in association with gold, platinum or copper ores. These are likely to be restricted to the areas of ancient (Precambrian) crystalline rocks listed above. Although other regions in the world have been shown to have seriously contaminated groundwaters close to the occurrences of such mineral veins, the scale of contamination is typically local and is likely to be so in Ethiopia too.

Arsenic may also be present in some groundwaters within the southern Rift where sodium-bicarbonate geothermal waters exert an influence on groundwater quality, although no data are available to substantiate this.

Iodine

Iodine-deficiency disorders (IDDs), including goitre, have been recognised in several regions of Ethiopia. Goitre prevalence rates have been reported to vary regionally from less than 1% to more than 70%. Studies carried out by Cherinet and Kelbessa (2000) in Shoa, Jimma, Arsi and Gomo-Gofa regions found the highest goitre prevalence in Gomo-Gofa region, with some villages having in excess of 90% prevalence. Concentrations of iodide in the drinking waters were not especially low (8–

24 µg/l) but iodine contents of local food crops were reported to be generally low and the authors linked goitre prevalence to additional factors such as the presence of *E. coli* and other coliforms in the drinking water. Although the Cherinet and Kelbessa (2000) study concluded that the observed goitre incidence may not have been caused by iodine deficiency, the latter is nonetheless a recognised problem in Ethiopia.

By contrast, other parts of the country with saline groundwaters may have high concentrations of iodine, although this is not thought to be of health concern.

Other trace elements

To the best of our knowledge, no data so far exist for other trace elements in the Ethiopian groundwaters. The geological formations present for the most part do not signal obvious problems with other trace inorganic constituents, although occasional exceedances of some trace elements (e.g. lead, nickel, chromium) above WHO guideline values may occur to some extent. Areas of sulphide mineral veins (e.g. those in association with gold, platinum and copper ores) may yield groundwaters with higher concentrations of some trace metals but no data are so far available for these areas to test whether a potential problem exists.

Areas of the Rift affected by geothermal waters, as well as saline groundwaters from the evaporite-bearing sediments of eastern and northern Ethiopia may have increased concentrations of boron, although no data are available. The WHO guideline value for boron in drinking water is 0.5 mg/l. This may be exceeded in some of the saline waters.

Data sources

Aberra, T. 1990. The hydrogeology and water resources of the Ansokia Highlands springs. Memoires of the 22nd Congress of IAH, Vol. XXII, Lausanne, 1990.

Ashley, R.P. and Burley, M.J. 1994. Controls on the occurrence of fluoride in groundwater in the Rift Valley of Ethiopia. In: *Groundwater Quality*, eds: Nash, H. and McCall, G.J.H. Chapman & Hall, London.

Cherinet, A. and Kelbessa, U. 2000. Determinants of iodine deficiency in school children in different regions of Ethiopia. *East African Medical Journal*, 77, 133-137.

Chernet, T. and Eshete, G. 1982. Hydrogeology of the Mekele area. Memoire No. 2, Ethiopian Institute of Geological Surveys, Addis Ababa.

EIGS, 1993. Hydrogeological map of Ethiopia. 1:2,000,000 scale. Ethiopian Institute of Geological Surveys, Addis Ababa.

FAO, 1995. <http://www.fao.org/waicent/faoinfo/agricult/agl/aglw/aquastat/ethiopi.htm>.

Gizaw, B. 1996. The origin of high bicarbonate and fluoride concentrations in waters of the Main Ethiopian Rift Valley, East African Rift System. *Journal of African Earth Sciences*, 22, 391-402.

MacDonald, A.M., Calow, R.C., Nicol, A., Hope, B. and Robins, N.S. 2001. Ethiopia: water security and drought. BGS Technical Report WC/01/02.

Tefera, M., Chernet, T. and Haro, W. 1996. Explanation of the geological map of Ethiopia, scale 1:2,000,000. 2nd edition. Ethiopian Institute of Geological Surveys, Addis Ababa.

UN (1989). Ethiopia. In: *Groundwater in Eastern, Central and Southern Africa*. Natural Resources/Water Series No. 19, United Nations, New York, pp 84-95.

British Geological Survey

2001

© NERC 2001