Hydrogeology of Ethiopia

From Earthwise

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Ethiopia is one of the oldest countries in the world, having existed within similar borders to today for over 2000 years. For most of its long history its governmental system was an independent monarchy, which was overthrown in 1974. The communist military Derg government that followed was itself overthrown in 1991, since when a shaky democracy has seen several contested elections. The African Union is headquartered in Addis Ababa, Ethiopia's capital.

Ethiopia's economy grew rapidly between 2005 and 2010. Agriculture is a major contributor to export income and most of the population is engaged in agriculture. Most agricultural production is by small-scale farmers, but the cash-crop sector accounts for a large proportion of agricultural exports, with the most important being coffee: Ethiopia is the largest coffee exporter globally. The country also has large mineral resources, with gold a major export commodity, but they have not seen much development to date; nor has the investigation of oil potential.

Groundwater provides more than 90% of the water used for domestic and industrial supply in Ethiopia, but a very small proportion of water used for irrigation, which mostly comes from surface water. Ethiopia has vast surface water resources in lakes and rivers, which supply most of the country's electricity through hydropower. Further expansion of hydropower capacity is planned, including the 'Grand Ethiopian Renaissance Dam', which is intended to become the largest hydroelectric power plant in Africa. However, the country has also suffered recurring devastating droughts, with severe impacts including famine, increased poverty and civil unrest.

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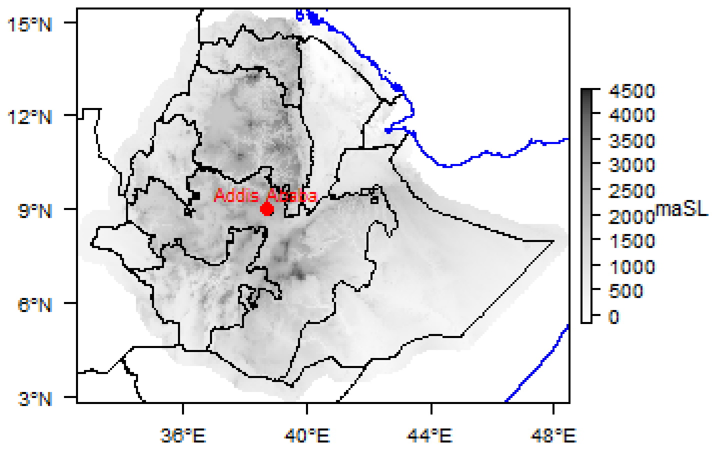
Terms and conditions

Geographical Setting



Ethiopia. Map developed from USGS GTOPOPO30; GADM global administrative areas; and UN Revision of World Urbanization Prospects. For more information on the map development and datasets see the geography resource page

General

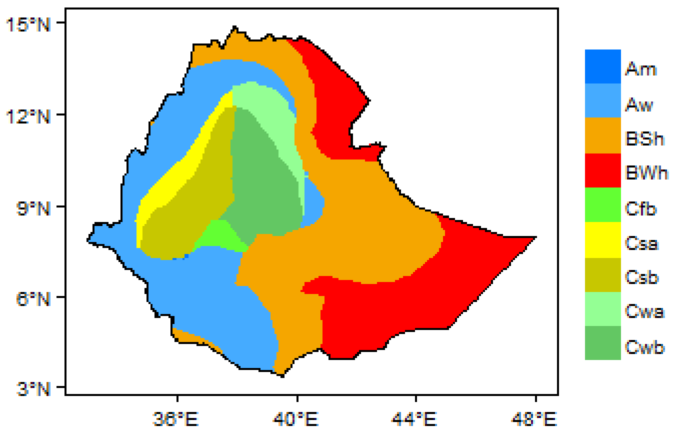
Ethiopia's landscape includes a large highland area of mountains and dissected plateaus, divided by the Rift Valley, which runs generally southwest to northeast and is surrounded by lowlands, steppes, or semi-desert. This large diversity of terrain has led to wide variations in climate, soils and natural vegetation.

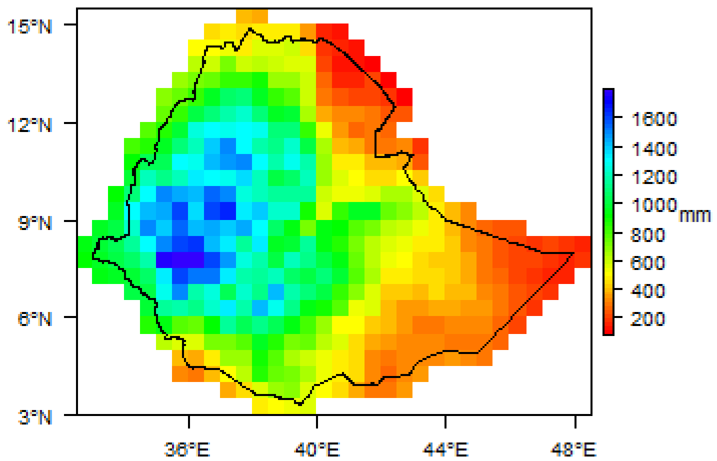
Capital city	Addis Ababa
Region	Eastern Africa
Border countries	Eritrea, Sudan, South Sudan, Kenya, Somalia, Djibouti
Total surface area*	1,104,300 km^2 (110,430,000 ha)
Total population (2015)*	99,391,000
Rural population (2015)*	80,125,000 (81%)
Urban population (2015)*	19,266,000 (19%)
UN Human Development Index (HDI) [highest = 1] (2014)	0.4418

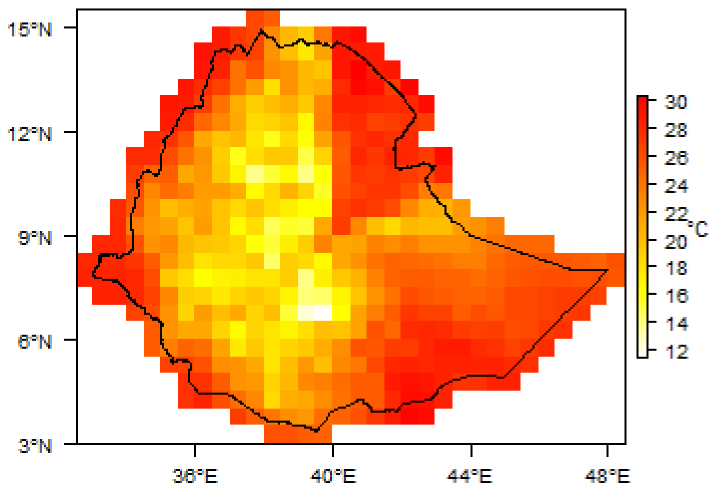
* Source: FAO Aquastat

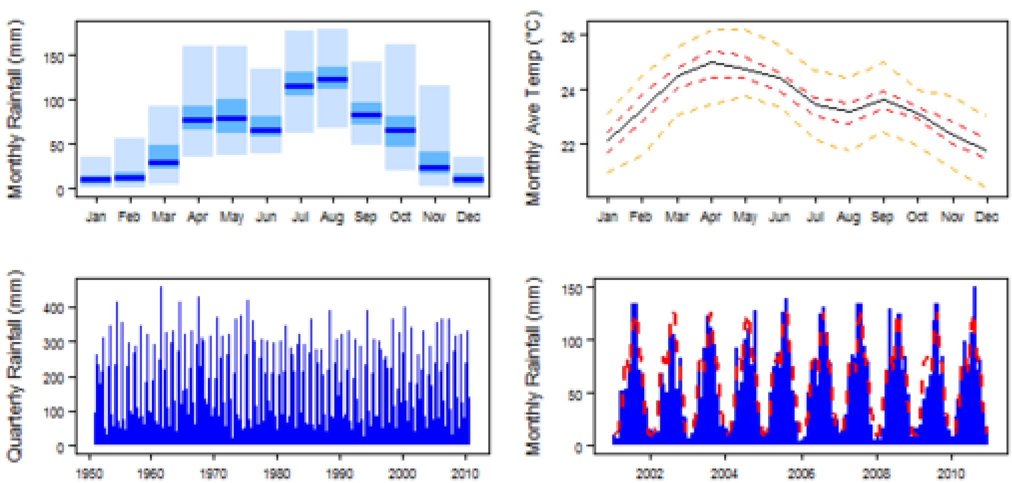
Climate

The highlands in the central-west of the country are temperate, with high annual rainfall, or tropical savannah, with distinct dry and wet seasons. In the lowland areas in the east, the climate is arid steppe or arid desert, and is significantly hotter and drier.







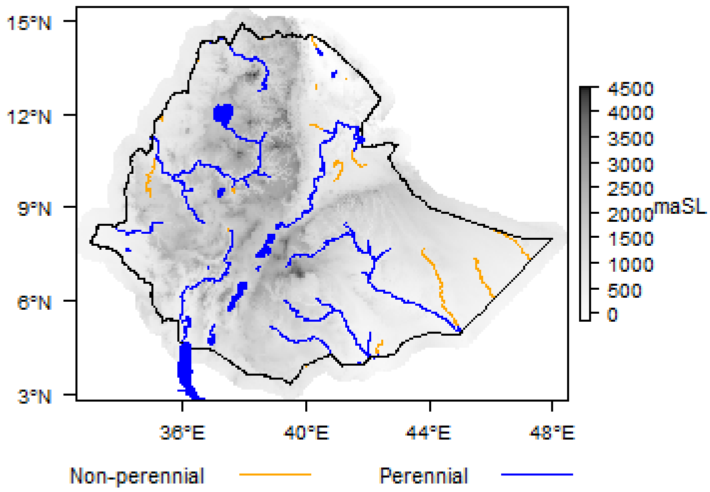


More information on average rainfall and temperature for each of the climate zones in Ethiopia can be seen at the Ethiopia climate page.

These maps and graphs were developed from the CRU TS 3.21 dataset produced by the Climatic Research Unit at the University of East Anglia, UK. For more information see the climate resource page.

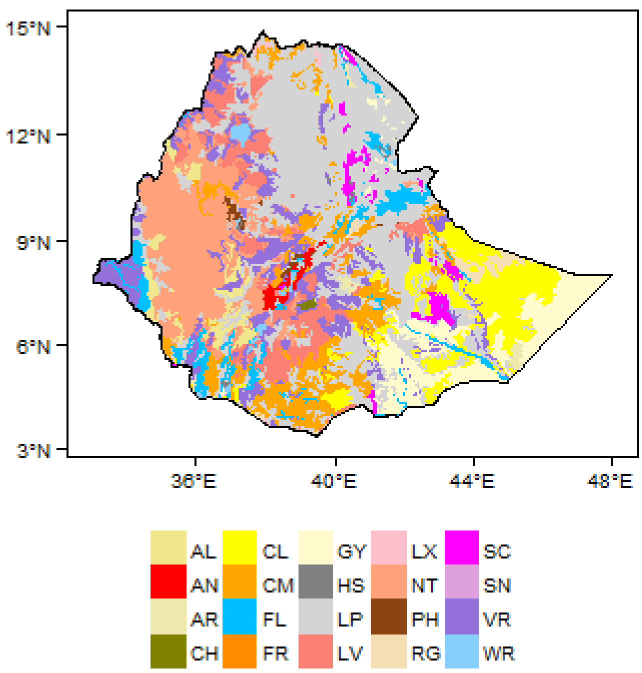
Surface water

The highlands of Ethiopia are the source of major perennial rivers, and Ethiopia also has a number of large lakes. Lake Tana, in the north, is the source of the Blue Nile, and there are a number of other major rivers. However, apart from these major surface water features, there are hardly any perennial surface water flows in areas below 1,500 m.
The Hydrology Directorate of the Ethiopian Ministry of Water Irrigation and Energy is the responsible body for installation and maintainence of river gauges. They also manage and disseminate the resulting river discharge data. Most hydrological records started in the 1960s following the initiation of the Blue Nile Basin Master Plan study by the USBR (United States Bureau of Reclamation). There are currently 489 operational river gauging stations in Ethiopia.



Major surface water features of Ethiopia. Map developed from World Wildlife Fund HydroSHEDS; Digital Chart of the World drainage; and FAO Inland Water Bodies. For more information on the map development and datasets see the [surface water resource page]

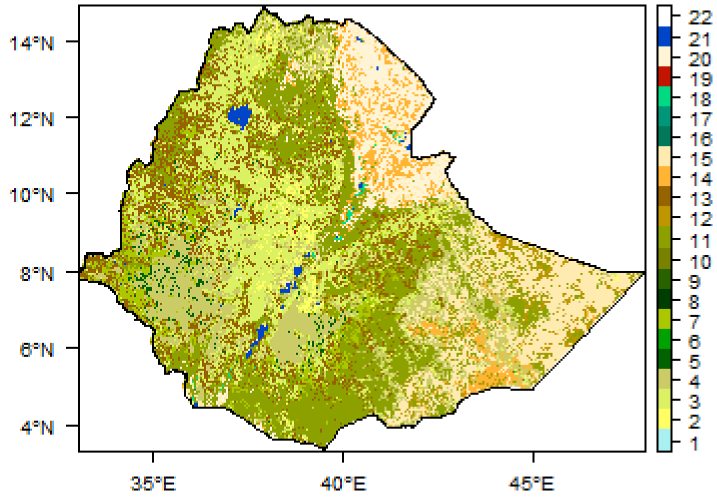
Soil



Soil Map of Ethiopia, from the European Commission Joint Research Centre: European Soil Portal. For more information on the map see the [soil resource page]

Land cover

Ethiopia is an ecologically diverse country, including deserts along the eastern border; tropical forests in the south; and extensive mountains in the north and southwest.



Land cover map of Ethiopia, from the European Space Agency GlobCover 2.3, 2009. For more information on the map see the land cover resource page

Water statistics

	2001	2005	2012	2014	2015	2016
Rural population with access to safe drinking water (%)					48.6	
Urban population with access to safe drinking water (%)					93.1	
Population affected by water related disease	No data	No data	No data	No data	No data	No data
Total internal renewable water resources (cubic metres/inhabitant/year)				1,227		
Total exploitable water resources (Million cubic metres/year)	53,000					
Freshwater withdrawal as % of total renewable water resources						
Total renewable groundwater (Million cubic metres/year)					20,000	
Exploitable: Regular renewable groundwater (Million cubic metres/year)		2,600				
Groundwater produced internally (Million cubic metres/year)				20,000		
Fresh groundwater withdrawal (primary and secondary) (Million cubic metres/year)	No data	No data	No data	No data	No data	No data
Groundwater: entering the country (total) (Million cubic metres/year)						

Groundwater: leaving the country to other countries (total) (Million cubic metres/year)	No data	No data	No data	No data	No data	No data
Industrial water withdrawal (all water sources) (Million cubic metres/year)		51.1				
Municipal water withdrawal (all water sources) (Million cubic metres/year)		810				
Agricultural water withdrawal (all water sources) (Million cubic metres/year)						9,687
Irrigation water withdrawal (all water sources) (Million cubic metres/year)						9,000
Irrigation water requirement (all water sources) (Million cubic metres/year)	1,475					
Area of permanent crops (ha)				1,140,000		
Cultivated land (arable and permanent crops) (ha)				16259		
Total area of country cultivated (%)				14.72		
Area equipped for irrigation by groundwater (ha)	2,611					
Area equipped for irrigation by mixed surface water and groundwater (ha)	No data	No data	No data	No data	No data	No data

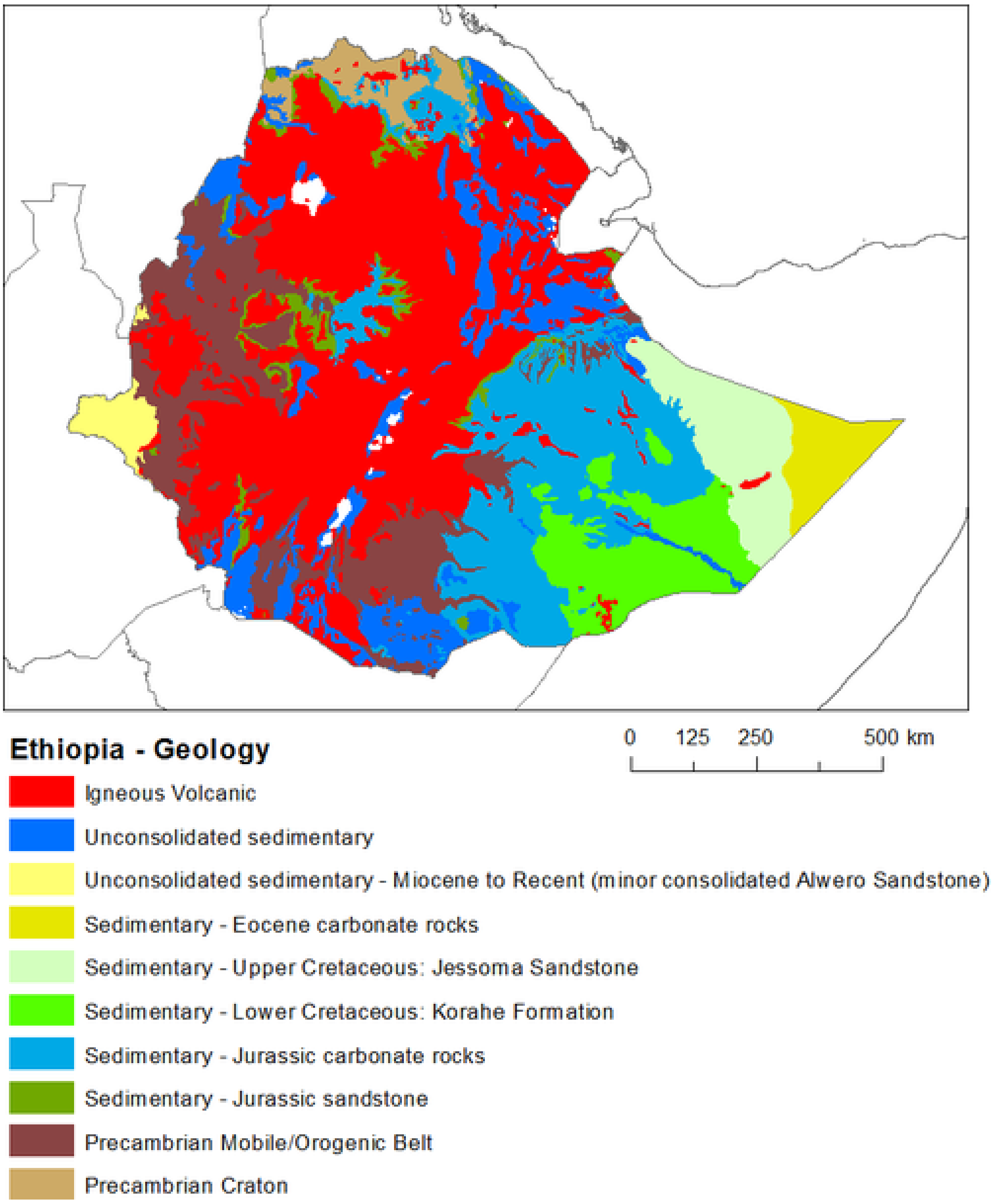
Source and more statistics at: FAO Aquastat.

Geology

The following section provides a summary of the geology of Ethiopia. More detailed information can be found in the key references listed below: many of these are available through the Africa Groundwater Literature Archive.

The geology map on this page shows a simplified version of the geology of Ethiopia at a national scale (see the geology resource page for more details).

Download a GIS shapefile of the Ethiopia geology and hydrogeology map.



Geology of Ethiopia at 1:5 million scale. Developed from USGS map (Persits et al. 2002). For more information on the map development and datasets see the geology resource page. Download a GIS shapefile of the Ethiopia geology and hydrogeology map.

Geological Environments

Key Formations	Period	Lithology	Thickness and important structural features
		Igneous - volcanic	
Rift volcanics	Quaternary	Rift related, unwelded and welded pyroclastics and basalts. Composed of ash, pumice, ignimbrites and pyroclastics.	Thickness reaches 500 metres; multiple sets of faults, fractures and volcanic landforms, isolated volcanoes and cones, calderas and craters

Quaternary plateau basalts	Quaternary	Scoraceous basalts, mostly vesicular and scoraceous. Have a limited lateral extent.	Associated with central eruptions from volcanic centres on the plateau; mainly associated with shields.
Shield volcanics	Miocene (Tertiary)	Basalts intercalated with minor acid volcanic rocks (eg rhyolites) and trachytes. The basal diameters of the shields range from 50 to 100 km. They radiate from a peak, and dip at an angle of 5°.	500 metres; broad based (up to 100 km) shields dotting the Ethiopian plateau
Aiba, Alaji and Termaber formations (Upper Basalts)	Oligo-Miocene (Tertiary)	Basalts with intercalations of rhyolites and ignimbrites towards the top part. Can be associated with shield volcanics. Mostly massive basalt, but columnar jointed layers are common. Layers of acidic rocks, rhyolites and tuffs are also common. Paleosol layers may be visible between the contact of this unit with the the underlying Ashangie Formation.	Thickness 1000 metres. Typically forms flat topped, uniform plateau areas, with cliffs at plateau edges.
Ashangie Formation (Lower Basalts)	Oligocene (Tertiary)	Deeply weathered, brecciated basalts	500 metres, forms rugged terrain
Sedimentary - Miocene (Tertiary) to Recent			
Alwero Formation (largely consolidated) and associated unconsolidated sediments	Miocene (Tertiary) to Recent	1. Holocene alluvial sediments Alluvial sediments composed of diatomites, red beds, fluvial materials and paleosols. These were probably developed during the Holocene climate fluctuations. Up to 400 metres thick. 2. Quaternary alluvio-lacustrine sediments Quaternary to recent alluvial sediments, lacustrine sediments, river terraces, volcanoclastics, colluvial and talus slopes, fluviatile and deltaic sediments, elluvials and soils. These localised deposits are present in central Ethiopia, southern and north western Ethiopia. Up to 500 metres thick. 3. Pliocene (Tertiary) Alwero Formation Sandstones	1 km?. The Basin forms part of the Blue Nile rift in South Sudan and extends toward the west
Sedimentary - Eocene			
Auradu and Taleh formations - carbonate and evaporite rocks	Eocene (Tertiary)	Interbedded limestone, evaporite (anhydrite, gypsum) and shale	500 metres; karst features observed
Sedimentary - Upper Cretaceous			

Jessoma Sandstone	Upper Cretaceous	Detrital, poorly cemented sandstone	500 metres; poor surface drainage and plain forming-extends south up to Mogadishu in Somalia
		Sedimentary - Lower Cretaceous	
Korahe Formation	Lower Cretaceous	Marine deposits; interbedded gypsum, shale, anhydrite, dolomite, limestone and sandstone	Not known
		Sedimentary - Jurassic	
Gabredarre, Hamanile, Urandab and Antalo formations - limestones	Jurassic	Dominantly limestone (75%) with some shale, marl and gypsum intercalations The **Gabredarre Formation** includes oolitic limestones, marls and some gypsum. It is horizontally bedded and characterised by karst features, including solitary caves such as the famous Sofomar caves. The limestones of the Sofomar caves region have the highest degree of karstification of Ethiopia's carbonate rocks. The Gabredarre Formation has limestone cliffs that are moderately jointed and have intercalations of sand, marl and gypsum beds. The Gabredarre Formation grades down to the underlying Urandab Formation, which is the equivalent of the Antalo Limestone. The **Hamanile Formation** consists of organogenic and oolitic limestones with shale and sandstone. The limestones are well jointed. The Haminile limestone plateau occurs on the Dolo to Negele Borena road around Bidre and consists of a marly, fractured, thinly (~1m) bedded limestone. Around Negele Borena the Hamanile limestone formation can be classified into at least five sub-units characterized by variable lithologies and intercalations. The succession is thinnest in the area of Negele town. The maximum thickness is about 700 m in the area of Filtu.	1000 metres
Adigrat Sandstone	Jurassic	Highly cemented sandstone. The top part has been altered by heating from Cenozoic volcanism.	700 metres
		Precambrian Mobile/Orogenic belt	

Precambrian: Medium-High grade Mozambique belt in south and west Ethiopia	Proterozoic	Paleoproterozoic metasediments and gneiss and pre- and syn-tectonic granites. Generally high grade metamorphic rocks are interbedded with low grade metamorphic rocks	This part of the basement in Ethiopia, unlike the basement in much of central Africa, has undergone multiple episodes of deformation and orogenesis.
Precambrian: Low grade Arabian Nubian Shield in Northern Ethiopia	Proterozoic	A transition zone between low grade volcano sedimentary succession and mafic ultramafic complexes of the Arabian Nubian Shield. The key lithologies are metavolcano sedimentary rocks and post-tectonic granite intrusive igneous rocks.	

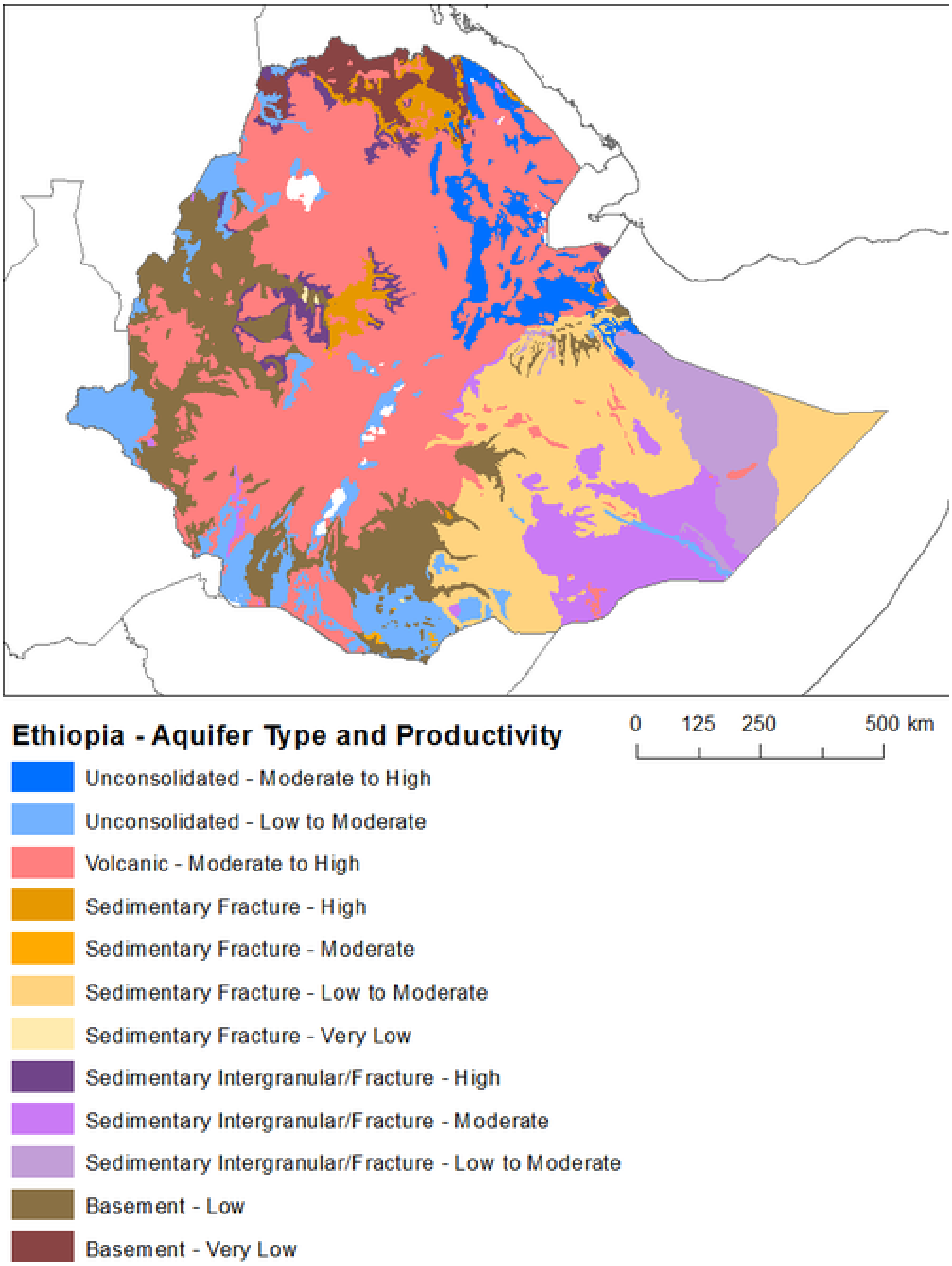
Hydrogeology

The most important aquifers in Ethiopia are formed by **unconsolidated Quaternary sediments**; **Tertiary-Quaternary volcanic rocks**; and **Mesozoic consolidated sedimentary rocks**. Basement aquifers are also important locally. A summary of these aquifers and their physical and chemical characteristics is in the tables below. More detailed information is available in the references listed below each table: many of these are available through the Africa Groundwater Literature Archive.

The hydrogeology map on this page shows a simplified version of the type and productivity of the main aquifers at a national scale (see the hydrogeology Map resource page for more details).

Download a GIS shapefile of the Ethiopia geology and hydrogeology map.

Other hydrogeological maps from different sources have been produced and are available in different formats. Some can be viewed on the WHYMAP website.



Hydrogeology of Ethiopia at 1:5million scale. For more information on how the map was developed see the hydrogeology map resource page. Download a GIS shapefile of the Ethiopia geology and hydrogeology map.

Unconsolidated

Named Aquifers	Aquifer Productivity	General Description	Water quality

Alluvial sediments	Afar Region - High Productivity. Northern Ethiopia - Low Productivity.	Afar Region: alluvial deposits in floodplains have moderate to high permeability, with measured transmissivity from 1-500 m^2/day and yields of up to 20 l/s. These aquifers can be unconfined and confined; they vary in thickness from 0 - 400 metres; water table depth is typically in the range 1 to 60 metres; typical borehole depth is 100 m; salinity is very variable. In the Holocene alluvial aquifer borehole yields of 0.1 to 1 l/s have been recorded. Water levels are usually less than 5 m below ground surface. Northern Ethiopia: alluvial sediments overlying basement rocks can store appreciable volumes of water and are characterised by high permeability and high water infiltration capacity. They are typically shallow and have limited lateral extent, and form perched aquifers. Springs and hand-dug wells are common, with recorded yields ranging between 0.05 l/s and 0.17 l/s.	Variable salinity
Alluvio-lacustrine sediments	Variable productivity, but can be highly productive in places	These sediments have highly variable permeability. Fine sand deposits have the highest permeability, with some boreholes providing more than 10 l/s with minimal drawdown. Transmissivities range up to 700 m^2/day and specific yields are of the order of 3.2 l/s/m. In several places higher transmissivities have been noted. For example, a 150 m deep borehole in alluvio-lacustrine deposits at the foot of the southern plateau has a transmissivity of 3012 m^2/day. These aquifers can be both unconfined and confined; they vary in thickness from 0 to 400 metres; water table depth is typically in the range 1 to 60 metres; and the typical borehole depth is 100 m. Fine-grained sands interbedded with massive volcanic tuffs and fine ash are known to have low productivity in many places (e.g. in the central Ethiopian Rift). In the eastern part of the country the total thickness of these sediments can reach about 300 m. In most of the outcrops, they consist of conglomerates, sandstone and mudstone, which are gypsiferous and locally bear saline groundwater.	Variable salinity

Quaternary Alluvial Aquifers within Lake Tana basin	Moderate to High Productivity	These occur dominantly in the eastern part of the basin following the lower Rib and lower margin of Gumera and Fogera plain (East of Lake Tana). They also cover a significant area of the north part of the basin at the lower part of the Megech and Western shore of Lake Tana. However, the distribution of alluvial sediments is limited compared to the volcanic aquifers. The deposits vary in thickness from 1 to 400m. The aquifers can be unconfined or confined. Water table depth is typically in the range 1 to 60 metres, and typical borehole depth is 100 m. The productivity of this aquifer is controlled by the intergranular permeability of the unconsolidated gravels, sand and clay. They are typically high productivity aquifers, with boreholes up to 60 m depth recorded as yielding more than 6 l/s. The previous investigation aided with drilling on the lake floor shows the occurrence of indicates stiff clay up to 80 m depth.	Variable salinity
Wadi bed aquifers	Moderate to High Productivity	Although localised, these intergranular aquifers have significant groundwater potential in water scarce arid and desert settings. Wadi bed length exceeds 30 000 km across Ethiopia, and total groundwater storage in these aquifers could be as much as 3 billion cubic metres. The most important wadi aquifers, which support the livelihoods of millions of people living a pastoral lifestyle, include those in Borena, Lower Omo, Ogaden, the Western Lowlands bordering Sudan, and in the Afar depression. The most productive wadi bed aquifers are those dominated by sandy and gravelly sediments with a low proportion of clay. One of the highest yielding recorded boreholes abstracting from a wadi bed aquifer is the El-Gof borehole, which taps an intergranular sand and gravel aquifer, overlain by lacustrine sediments, and has a yield of 5 l/s. Other boreholes have recorded discharges of 0.5 l/s to 8 l/s. An important source of groundwater in areas with little surface water	Variable salinity
Talus slope, landslide bodies, alluvial terraces	Moderate Productivity	These deposits form small outcrops 0.5 to 2 km^2 in area. Permeability is enhanced in areas where the material is loosely packed. Groundwater from mountain areas flows towards the talus slope and landslide deposits, from where springs commonly emerge. Typical spring yields are 1 to 2 l/s. These aquifers with readily available groundwater discharges support several villages in areas of relatively gentle slopes and good soil development. Recharged from groundwater flowing from higher elevation.	Variable salinity

Key references for Quaternary unconsolidated aquifers of Ethiopia are Alemneh (1989); Chernet (1993) and Hadwen et al. (1973) (for more details see Key Hydrogeology References).

Igneous - Volcanic

Named Aquifers	Aquifer Productivity	General Description	Water quality
Rift volcanics	Moderate Productivity	Borehole yields generally from 1 to 5 l/s. In some conditions the aquifer is confined, leading to artesian conditions. Both direct rainfall and indirect (eg from river beds) recharge is common.	High fluoride and salinity, often exceeding WHO limits.
Quaternary plateau basalts	High Productivity	The most extensive occurrence is in the Lake Tana Basin, where these form a highly productive, fractured aquifer, with borehole yields reaching 20 l/s (there are other records of borehole yields of between 5 and 100 l/s), and groundwater discharge to rivers and springs. Elsewhere in Ethiopia the Quaternary volcanics are highly productive but have dual fracture-intergranular porosity. Direct and indirect recharge occurs.	Good water quality: generally bicarbonate type, low salinity, low fluoride.
Shield volcanics		This aquifer can be up to 500 m thick. Groundwater discharge occurs through springs, which are common at the foot of the shield areas. The intercalation of volcanic ash with basalt forms a dual porosity and permeability groundwater system: groundwater storage is focussed in ash layers, while groundwater flow is focussed through fractures in the basalt layers. Shield areas dominated by acid volcanic rocks show lower groundwater potential (e.g. in the Bale Massif). The aquifer is typically unconfined to semi confined. The depth to water ranges from 5 to 60 m, and borehole depths are typically 60 to 150 metres. Recharge occurs through fractures in highland areas.	Good water quality: generally bicarbonate type, low salinity, low fluoride.
Upper basalt aquifer (Aiba, Alaji and Termaber formations)	High Productivity	This aquifer forms the most productive of the volcanic aquifers in Ethiopia. It is typically unconfined to semi-confined and often artesian. Groundwater discharge occurs to wetlands and to springs on cliffs. The aquifer thickness ranges from 50 to 1000 m. The depth to water table varies from 0 to 250 metres. Borehole depths are typically from 100 to 150 m. Borehole yields are generally up to 20 l/s. The Aiba Formation has dual porosity, with groundwater occurring in joints, fractures and scoriaceous layers. Deep boreholes show the presence of narrow but extensive fracture zones with high permeability and low storage. Transmissivity varies between 0.5 and 1400 m^2/day. Borehole yields range from 5 to 150 l/s. Pumping test analysis and well logs from the Termaber Formation show that it is dominated by fracture flow. Recharge occurs vertically through the soil zone and fractures in the rocks.	Good water quality: generally bicarbonate type, low salinity, low fluoride.

Lower basalt aquifer (Ashangie Formation)	Low to High Productivity	These rocks are characterised by rugged topography with dissected and irregular morphology. The rocks are deformed, and in their northern section dip at up to 40°. They are thinly bedded, and in several areas are brecciated. Field evidence shows that the brecciated parts are characterized by lower permeability. The rocks are typically deeply weathered, when they are reddish in colour, but generally have low permeability. Both primary (vesicle) porosity and secondary (fracture) porosity have been modified and reduced by secondary mineralisation (e.g. by calcite, zeolite and silica). In more detail, the Ashangie Formation can be divided into three zones: 1) an upper layer, with gentle topographic slopes. Mostly scoriaceous, with several thin beds of clay soils. Recharge occurs vertically through this layer to the underlying layers. Springs are rare, and most groundwater discharge occurs as diffuse seepage on slopes, often contributing to landslides. 2) a thinner middle, more resistant layer, which often forms cliffs. When exposed at the ground surface by erosion, this can form locally extensive plateau areas, such as around the Upper Tekeze plains, Lalibela and the Belesa plain. Typically has higher groundwater productivity. 3) a lower layer, also with gentle slope. Mostly scoriaceous, with several thin beds of clay soils. Often contains cross-cutting dykes which are conduits for groundwater convergence and discharge. The aquifer thickness varies up to 500 m. The rugged topography means that the aquifer is not laterally extensive. Depressions in the rugged terrain are areas of groundwater discharge. The aquifer is usually unconfined to semi-confined. Typical borehole yields are between 0.5 and 20 l/s. Transmissivity ranges between 0.5 and 85 m^2/day. The water table depth is typically between 100 and 200 m, and borehole depths are typically 150 to 200 m. The contact between this unit and the upper basalt above is characterised by spring discharge.	Good water quality: generally bicarbonate type, low salinity, low fluoride.

Key references for volcanic aquifers of Ethiopia are Kebede (2013) and Ayenew et al. (for more details see Key Hydrogeology References).

Mesozoic Consolidated Sedimentary Aquifers with Fracture and Intergranular Flow

Notable hydrogeologic and geologic features of Mesozoic sedimentary rocks of Ethiopia are:

- Uplifting and formation of tabular plateaus;

- deep incision by river gorges;

- absence of or limited karstification in carbonate rocks;

- absence of regional folding and flexures at the margins of the units; and

- extensive cover by younger volcanic rocks.

These features contrast with typical sedimentary basins elsewhere in Northern and Eastern Africa. In contrast to the sedimentary basin aquifers of northern and Sahel Africa, structural traps (such as synclines formed by compressional deformation) are uncommon, leaving little room for large volume groundwater storage.

Named Aquifers	Aquifer Productivity	General Description	Water quality
Hamanile, Gabredarre and Antalo formations (Jurassic limestones)	High Productivity	The **Gabredarre Formation** is characterised by karst features, including caves. The limestones of the Sofomar caves region have the highest degree of karstification of Ethiopia's carbonate rocks. The aquifer has moderate permeability and productivity. The **Hamanile Formation** limestones are well jointed with moderate to high permeability. Evidence from boreholes in highland and midlands areas, where the aquifer crops out, shows that groundwater levels can be very deep: for example, more than 200 m below ground level between Filtu and Negele. Where the water table is shallower, the Hamanile limestones form relatively productive aquifers. In general, these aquifers are typically 500 to 1000 m thick, and are unconfined to semi-confined. The water table is usually 200 to 400 m deep; typical borehole depth is 300 m. In high rainfall highlands, recharge could reach 200 mm/yr. In arid regions it varies between 10 mm/yr and 50 mm/yr.	Good quality water generally. However, high concentrations of dissolved salts, including sodium, chloride and/or sulphate, occur due to reaction with abundant minerals in evaporite beds, and salinity can reach 3 mg/l.
Adigrat Formation (Jurassic sandstone)	Moderate Productivity	The highly cemented **Adigrat Formation** has low primary porosity, and the top part has been altered by heating by Cenozoic volcanism. Fracturing has created secondary porosity and permeability. The emergence of springs at the contact of the Adigrat sandstone and the overlying volcanic rocks is indicative of the low permeability of the Adigrat Formation. This aquifer is typically 200 to 1000 m thick and is unconfined to semi-confined. The water table is usually 200 to 400 m deep; typical borehole depth is 300 m. In highlands areas with high rainfall, recharge could reach 200 mm/yr. In arid regions it varies between 10 mm/yr and 50 mm/yr.	Very good quality water

Key references for Mesozoic sedimentary aquifers of Ethiopia are BSEE (1973), Chernet (1993), Hadwen et al. (1973), Haile et al (1996) and Kebede (2013) (for more details see Key Hydrogeology References).

Precambrian Basement

Named Aquifers	Aquifer Productivity	General Description	Water quality

Precambrian basement aquifers of Southern Ethiopia and Northern Ethiopia; Crystalline Basement aquifers of Western Ethiopia	Very Low to Low Productivity.	**Basement aquifers in general** The productivity of basement aquifers in Ethiopia largely depends of the development of regolith (weathered rock) amd the density of fractures. In turn, these are partly controlled by the type or grade of metamorphic rock that forms the basement. Less important controls on groundwater occurrence are the sustainability of recharge; and topography. Groundwater in the basement aquifers occurs in shallow regolith (weathered rock) basins. Borehole yields from the most productive boreholes in basement aquifers are generally less than 0.1 l/s. Spring discharges in the basement complex are of the order of 1 l/s. Generally, basement aquifers in western and south-central parts of Ethiopia are productive, and the lowest productivity basement aquifers are located in northern Ethiopia and the Borena lowlands (near the southern border). The basement aquifers are unconfined. Aquifer (regolith) thickness varies from 0 to 60 m (thinner in northern Ethiopia and thicker in western Ethiopia - see below). The deepest known borehole struck water at 100 m. The water table is typically 2 to 60 m deep. Boreholes tend to be 60 to 120 m deep. Regional details **Northern Ethiopia**: the basement rocks of Northern Ethiopia have low groundwater potential. Groundwater occurs generally in fractures in the upper few metres of the unweathered rocks; in very thin regolith layers; and in patches of overlying alluvial sediments in river valleys (see the Unconsolidated section for further information). **Southern Ethiopia**: groundwater in the basement rocks is stored in, and transmitted through, both regolith layers and fractures. There is variable fracturing and regolith development. Borehole yields range from 0.13 to 0.33 l/s. **Western Ethiopia**: the crystalline basement aquifers of Western Ethiopia have better groundwater storage than in other areas. This higher groundwater potential is related to high rainfall that supports high recharge; to a relatively thick regolith which favours groundwater storage; and to rugged undulating topography which favours accumulation of weathering products in depressions and flat plains allowing groundwater storage and circulation. The average borehole yield is 5 l/s (Bako & Abakoran). The hydraulic conductivity of this aquifer varies from 0.12 m/day to 2.3 m/day. Recharge varies from 10 to 250 mm/yr depending on rainfall regime	Good quality

The key reference for basement aquifers of Ethiopia is Kebede (2013) (for more details see Key Hydrogeology References).

Recharge

Recharge over Ethiopia is extremely variable. It varies from nearly 0 to 300 mm/yr. Nearly 60% of aquifers receive indirect recharge from floods, mountain runoff, as well as fast recharge from high rainfall events. Diffuse recharge is limited to the plateau region which accounts for around 30% of the country.

The geological uplift in the Cenozoic which led to erosion and dissection of the aquifers into smaller size units, has resulted in generally low storage compared to large sedimentary basins elsewhere in Africa. The storage to recharge ratio is around 28 years (Kebede, 2013).

Groundwater Quality

Groundwater quality is highly variable across Ethiopia, from fresh waters in many of the springs flowing from basement aquifers, to more saline waters in volcanic aquifers in parts of the Rift Valley and sedimentary aquifers of the plains.

The key natural groundwater quality issues are:

Fluoride.

Fluoride has long been a recognised health concern in Ethiopia. Concentrations of fluoride in groundwater that are higher than the WHO guideline value of 1.5 mg/l have been found across Ethiopia, but are concentrated in the Rift Valley, linked to the volcanic geology. Groundwater fluoride values of greater than 10 mg/l have been found in some areas (Smedley 2001). 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. However, more research is needed on the links between geology, hydrogeology, fluoride concentrations and fluorosis in order to target interventions.

Salinity.

High values of total dissolved salts in volcanic aquifers in the Rift Valley are linked to the influence of geothermal waters. Increased salinity in many groundwaters in sedimentary aquifers in the south, southeast and northeast of the country, is linked to the dissolution of evaporite minerals.

Key references for more information on groundwater quality in Ethiopia are:

British Geological Survey/WaterAid. 2001. Groundwater Quality: Ethiopia. Leaflet.

Groundwater Status

Groundwater quantity

Annual renewable groundwater resources are estimated at around 36,000 million cubic metres (36 billion cubic metres) , with estimates of total groundwater storage varying from 1,000 to 10,000 billion m^3.

Groundwater quality

An estimated 30% of groundwater storage is not available for direct use because of high salinity and/or high fluoride.

Groundwater-Surface Water Interaction

- There are a number of groundwater dependent surface waters, including wetlands and lakes. - Wetlands are increasingly threatened by deepening, widening and propagating gullies as well as by infestation by invasive weeds

Groundwater Dependent Ecosystems

There is low recognition at government level of the fact that wetlands are groundwater dependent.

Groundwater use and management

Groundwater use

Some 80% of the total national water supply comes from groundwater.

Kebede (2013) gives national estimates of groundwater abstraction volumes. Groundwater provides most of the water for domestic supply (90%) and industrial use (95%).

To date only a very small proportion of irrigation demand (<1%) comes from groundwater, including small well irrigation by smallholder farmers, but some larger commercial irrigation schemes are pioneering the use of groundwater. Groundwater use for livestock watering is unknown. More hydrogeological research may help increase the use of groundwater for irrigation, for example in proving the existence of a large enough resource that can be sustainably abstracted.

Groundwater sources in Ethiopia consist of:

- Boreholes
- Hand dug wells
- Improved cold springs
- River bed excavations/pits
- Haffirs
- Traditional Ella wells (very large diameter wells)
- Bircados

Groundwater management

There are currently no regional or national groundwater level or quality monitoring programmes, and relatively little formal registration of boreholes and other water abstraction points.

The key groundwater institutions, and their roles, are:

- Ministry of Water Irrigation and Energy- Regulatory, policy, financing, planning, maintenance of information base
- Geological Survey of Ethiopia- Exploration and Mapping
- Ministry of Forestry and Environment: Reviewing possible impacts of national investments on groundwater quality and quantity; Selected strategic environmental assessments – linked to

groundwater management plans

- Agricultural Transformation Agency- Shallow groundwater mapping and management policy
- Regional Water Bureaus- Regulatory, policy, financing and planning
- Water Works Enterprises- Study, Design, Supervision and Development
- Regional Ministry of Forestry and Environment: Licensing and Impact assessment of investment on groundwater
- River Basin Organizations: Allocation and supplies
- Water User Associations: Local regulation and allocation; formal and informal
- Drillers' Association
- Technical and vocational Schools (TVETs): training human power in groundwater development , low skill

There is a limited legal framework for groundwater management, but the regulations are not systematically implemented. No regulatory provision exists to protect vulnerable areas. The report "Groundwater Management framework document (MWR, 2010)" includes the following regulatory provisions:

- No person shall be engaged in the drilling or rehabilitating of water wells without a permit duly issued by the Ministry or his designee.
- Any person who wants to have water well drilled shall first acquire a permit to do so from the Ministry or his designee before entering a contract for this purpose with a water well drilling or rehabilitating contractor. Applications made to have a water well drilling or rehabilitating contractor. Applications made to have water well drilled must be accompanied with the design and specifications of such well.
- All water well drillers and rehabilitators shall, before entering in to a contract to drill water well, first ensure that the Ministry or his designee has approved that such well be drilled.
- All persons who want to have a water well drilled or rehabilitated shall, before entering in to a contract to have such water well drilled or rehabilitated, first ensure that the driller or rehabilitator has a permit to undertake the drilling or rehabilitating or water wells.
- A well driller or rehabilitator shall, within three months of completing a well drilling or rehabilitation, submit to the Ministry or his designee a technical report – that includes information about the drilling, construction and rehabilitation process, the geological and electrical log, yield tests, laboratory tests, problems encountered during drilling, construction and rehabilitation, pump installed.

Informal local water user organisations exist for most small-scale traditional water schemes, including groundwater, that operate on more than an individual/household level, and typically do not have legal recognition or support. For formal and most modern schemes, there is usually a formal statutory water user association or irrigation cooperative.

Transboundary aquifers

The major transboundary aquifers in Ethiopia are:

- The unconsolidated sedimentary aquifers of Gambella (Upper Blue Nile) and Alwero Sandstone: Ethiopia and South Sudan
- The Bulal Basalt aquifer: Ethiopia and Kenya

- The Hanle Graben aquifer: Djibouti and Ethiopia
- The Sedimentary Basin of Ogaden: Ethiopia and Somalia

No management system exists specifically pertaining to transboundary aquifers. Conflict over water sources in general is common among pastoralists in the border region of Ethiopia and Kenya.

Groundwater Projects

Information on particular groundwater projects in Ethiopia, including links to project results and outputs, can be found on the Ethiopia groundwater projects page.

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Many of the references below, and others relating to the hydrogeology of Ethiopia, can be accessed through the African Groundwater Literature Archive.

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