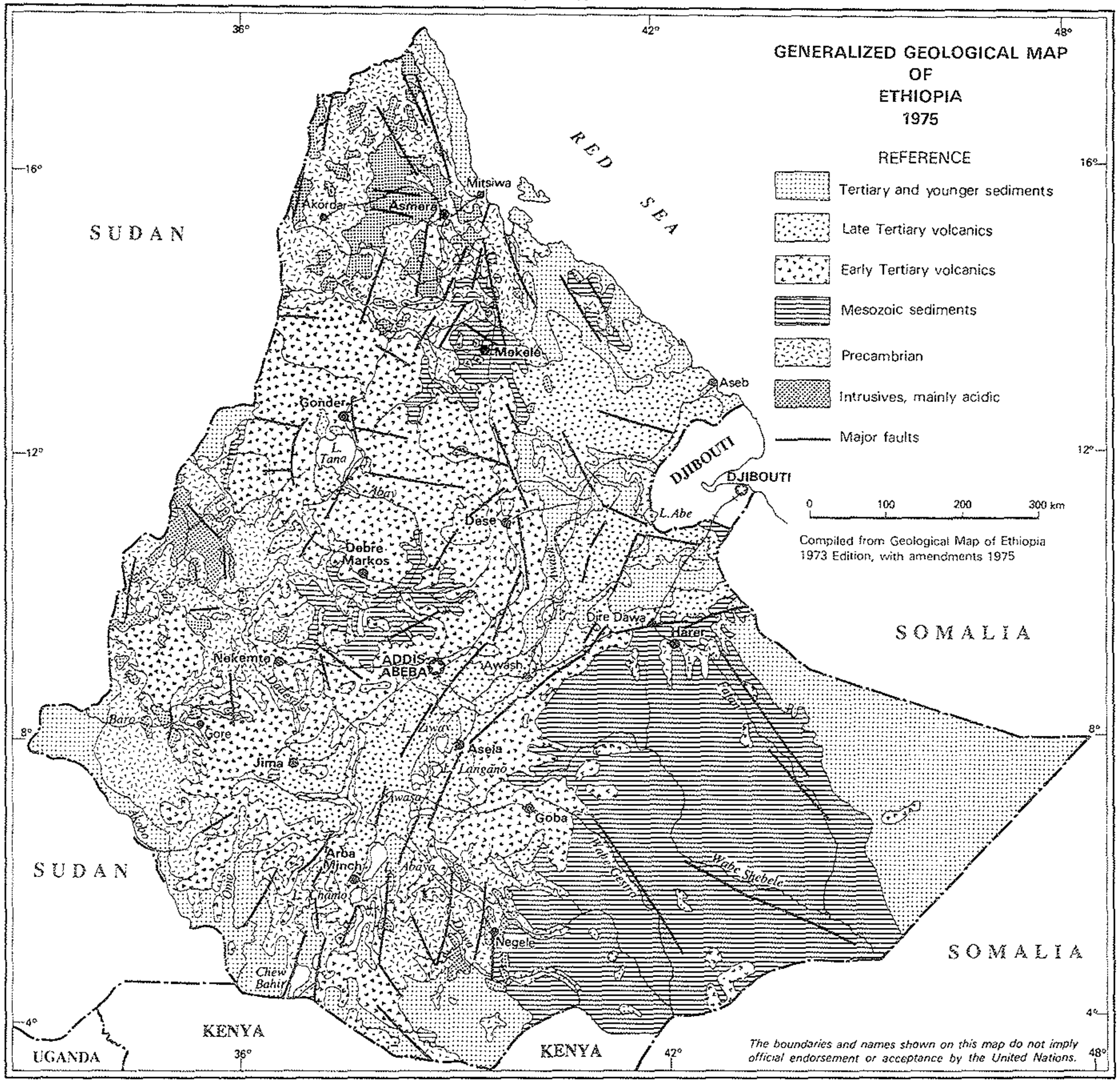
MAP 10. ETHIOPIA – GENERALIZED GEOLOGICAL MAP



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Source: Geological Survey of Ethiopia

ETHIOPIA

Area: 1,230,000 km^2
Population: 33.7 million

I. BACKGROUND

Ethiopia is a vast mountainous country in Eastern Africa with 1,000 km of coastline on the Red Sea from Ras Kasa in the north to the Republic of Djibouti in the south; it has a very contrasted relief with altitude ranging from 116 m below sea level to 4,620 m above sea level at the summit of Ras Dejen. The big Rift Valley, a subsided tectonic depression which is part of the East African Rift System, crosses the country from south-west to north-east, dividing it into two regions: the high plateaus of the north-west with their associated lower plateaus; and the high plateaus of the south-east, also with their lower associated plateaus. The eastern part of the high plateaus of the north-west ends at the escarpment of the Rift Valley, and it declines westward towards the Sudanese plain. It includes the following geographic units:

- The north-central massif, with accidented relief, deeply scored by the tributaries of the Tekeze and the Abbay gorges;
- Ras Dejen, the country's highest peak;
- The Tigre plateau;
- The Shewan plateau;
- The south-west plateau;
- The low area along the Sudanese frontier.

The northern and north-western parts of the high plateaus of the south-east end at the escarpment Rift Valley, and they decline eastwards and southwards towards the Gulf of Aden and the Indian Ocean. They include the Arusi-Bale massifs, the Harer plateau, and the Shebeli and Genale plains.

The Ethiopian Rift is a chimney-shaped depression tapering towards the south-east. It includes:

- The Southern Rift System or lakes region and the Afar Rift System;
- The Danakil depression, the floor of which is 116 m below sea level, is located in the northern part of the Afar Rift System.

The coastal plains are narrow. The coastline is slight indented. The Danakil or Afar "Alps", which consist of mountain ranges running parallel to the Red Sea, are situated between the northern Afar Rift System and the coastal plains.

Climate

Ethiopia has wide climatic variations due to its geographical position, its mountainous relief, and the big differences in altitude mentioned above.

Some watercourses are seasonal owing to the very irregular distribution of the rainfall over time, which produces equally irregular flows. The rivers are not navigable owing to the rapids and falls which mark their courses. Only the Baro River is navigable as far as Gambela in the rainy season. In contrast, many watercourses have a considerable hydroelectric potential.

The country has 14 hydrographic basins with an annual flow of 105 billion cubic metres, of which 101.5 billion flow out of the country: 78.7 billion to Sudan (77.5 %), 16.1 billion to Kenya (15.9 %), 6.5 billion to Somalia (6.2 %), and the remaining 0.2 % to the Red Sea.

River Basins

No.	Name	Area (thousand of km^2)	Annual flow (billions of m^3)	Flow towards
1.	Red Sea	44.0	0.2	Red Sea
2.	Danakil	69.1	Unknown	Endorheic basin
3.	Awash	113.7	2.5	Endorheic basin
4.	Gulf of Aden	2.0	Unknown	Gulf of Aden
5.	Ogaden	71.9	Unknown	Endorheic basin
6.	Wabe Shebeli	205.4	2.5	Indian Ocean
7.	Genole Dawa	168.1	4.0	Indian Ocean
8.	Central lakes	54.9	1.1	Endorheic basin
9.	Ghibe-Omo	77.2	16.1	Lake Turkana
10.	Baro-Akobo	75.7	13.4	Nile
11.	Abbay	198.5	53.0	Nile
12.	Atbara-Tekeze	88.4	10.4	Nile
13.	Mereb-Gash	23.7	0.6	Sudanese plains
14.	Barka	41.0	1.3	Sudanese plains
	Total	1,233.6	105.1	

Ethiopia has many lakes of all sizes, from tiny crater-lakes to big fresh-water lakes with areas up to 3,500 km^2. Most of the lakes are situated in the southern part of the Rift Valley.

The water of Lakes Ziway and Tana is of good quality and suitable for domestic use and irrigation. The water of Lakes Langano, Abayata and Chew Bahir, however, is too saline for these uses. Many lakes are suitable for fish-farming and leisure activities.

No.	Name	Area (km^2)	Maximum depth (m)	Altitude (m)
1.	Abaya	1,160	13	1,268
2.	Abyata	205	14	1,573
3.	Ashenge	20	25	2,409
4.	Awassa	129	10	1,708
5.	Chamo	551	10	1,235
6.	Chew Bahir*	-	-	520
7.	Hayk	35	23	2,030
8.	Langano	230	46	1,585
9.	Shala	409	250	1,567
10.	Tana	3,600	9	1,840
11.	Ziway	434	4	1,846

* The water level of this lake is very variable: depending on the time of year, it is either a shallow lake or a dry bed with saline crusts.

II. GEOLOGY

Ethiopia has a large variety of rocks ranging from the Precambrian to the Quaternary. The crystalline rocks of the Precambrian basement have undergone several orogenies and periods of metamorphism and they have been eroded to various degrees into peneplains.

The oldest basement formations include gneiss and other intensely metamorphized rocks. The Middle and Upper Precambrian include initially sedimentary or volcanic rocks which have been subject to less intense metamorphism. The Precambrian formations outcrop in the eastern part of the Harer, southern Sidamo and Gemu Gofa, western and south-western Kefa, Ilubabor, Welega and Gojam, central and northern Tigre and Eritrea, where the youngest rocks have been eliminated by erosion.

An upthrust occurred at the end of the Precambrian; it was followed by a long period of erosion in the Paleozoic. At that time, argillaceous sandstones, tillites and silts were deposited in the erosion valleys and depressions of the basement rock in the Harer, the Abbay gorges and Tigre. The outcrops of these formations are relatively small in area.

Subsidence phenomena occurred in the Mesozoic period, inducing marine transgression from the south-east towards the north and west.

The Adigrat sandstones resting in discontinuity on the crystalline basement and the Paleozoic sediments were deposited in shallow water during this transgression. This quartzy sandstone is generally yellow to pink in colour; the granulometry is fine to medium, non-calcareous, well sorted and with intersected stratification; it contains intercalations of silt and clay in places; its thickness varies from a few metres to 800 metres.

As the depth of the sea water increased, evaporites, fine sandstones and argillaceous schists were deposited. In the north-west plateau these formations constitute the Antalo group which includes the Antalo limestone, the Agula argillaceous schists and the Amba Arodem formations. The first of these formations consists mainly of limestone, but the other two include marls, argillaceous schists, silts, gypsum, sandstone and limestone.

The Amba Arodem formation was probably deposited during the regression of the sea. On the south-east plateau and its associated plains it is distributed between the series of:

- Hamanlis (limestone and dolomite);
- Uarandab (marly schists and gypsiferous limestone);
- Main gypsum (gypsum with layers of dolomite, marl, argillaceous schist and rock salt);
- Mustachil (dolomites and dolomitic limestone);
- Ferfer gypsum (alternate layers of dolomite, limestone, argillaceous schist and sandstones);
- Belet-Uen (limestone, argillaceous schist, sandstone).

The total thickness of these series varies from place to place and can be over 2,000 m in the south-east of the country.

Sedimentation continued in the east of the country during the Cenozoic period, producing fine-grained Jossoma sandstone with banks of interstratified argillaceous schists, the Aurada series (limestone blocks with concretions of cherts and effusions of submarine basalts), the Taleh series (gypsum blocks and chert limestone), and the Kercher series (chalky limestone, argillaceous schist and gypsum). This latter formation outcrops in a small zone along the frontier with Somalia.

The Danakil depression contains the Red Sea series, consisting of conglomerates, sandstones, fine gypsiferous sandstones and saline formations 1,200 m thick composed of halite, gypsum, potash and magnesian salts. Along the Red Sea the rocks consist mainly of marine sediments of the Dogali, Desset and Danishule formations, and in the low valley of the Omo are found the fluvial and eolian deposits of the Murs and Nkalaboni formations which are of Cenozoic age.

The plateaus are mostly covered with the volcanic rocks of the Trap series which erupted through the fractures during the Lower and Middle Cenozoic periods. They are subdivided into two groups:

- Ashange: basaltic strata with layers of pyroclastic rocks;

- Shield: mainly basalts; this group constitutes the country's main massifs.

The Magdala and Afar groups appeared during the Middle and Upper Cenozoic periods. The Magdala group consists mainly of acid rocks with tufas, ignimbrites, rhyolites and trachytes and it appears mainly in the southern and central parts of the Rift Valley and the adjacent plateau. Basalt predominates in the Afar group; it outcrops in the floor of the Afar Rift. These two groups were intensely faulted during the constitution of the Rift Valleys.

The other volcanic rocks include siliceous domes consisting of acid rocks and forming dome-shaped hills and mountains in the Rift Valley and small scattered eruptive features and effusions of basic and acid lavas. Quaternary lacustral and alluvial sediments are widespread in the flood plains, the floor of the Rift Valley, the coastal plains and the piedmonts.

The Post-Precambrian in deposits show no major folding. The slope of the strata is generally gentle, except in the vicinity of faults. The main structural episode, which occurred long after the Precambrian orogenic movements, was the formation of the Rift Valley in the Paleozoic period, with internal fracturation in the floor of the valley, along the cliff wall of the Rift, and in the neighbouring region of Lake Tana. The main direction of the faults are NNE, NNW and ESE, corresponding respectively to the Southern Rift, Red Sea Rift and Aden Rift systems.

III. GROUND WATER

In 1907, in the reign of Menelik II, the Ministry of Public Works was requested to develop the country's water resources. In 1950, the services responsible for this work were reorganized and a start was made on the study and development of surface-water and ground-water resources using modern methods and techniques. From 1950 to 1987, the institutional framework for water activities underwent many changes.

In 1981, the National Water Resources Commission was created by Proclamation Order 217, which entrusted to it the development of ground-water and atmospheric-water resources. This Commission has four separate subsidiary organizations:

- Water Resources Development Authority;

- Water Supply and Sewerage Authority;

- Ethiopian Water Works Construction Authority;

- Ethiopian Meteorological Service Agency.

In addition to the Commission, there are the following three bodies which deal with specific aspects of the development of water resources:

- The Ministry of Mines and Energy, which carries out hydrogeological and geothermic studies and research;

- The Ministry of Agriculture, which is responsible for water and soil conservation, fisheries, and livestock water points;

- The Ministry of Transport and Communications, responsible for ports and navigation;
- The Ethiopian Electric Light and Power Authority, responsible for the generation and distribution of hydroelectric power;
- The Addis Ababa Water and Sewerage Authority, responsible for water supplies and sanitation in the capital.

Ground-water resources: potential

In 1970, a hydrology section was established in the Ethiopian Institute of Geological Survey (EIGS) in order to study and map water resources. At present (1985) it has 12 geologists responsible for data collection and cartography. Under the authority of the National Water Resources Commission, aquifers have been identified by drilling only in the areas where their exploitation is necessary in the immediate future. Remote-sensing and geophysical prospecting play a major role in ground-water research in Ethiopia.

The conditions of deposit and formation of ground water are very diverse and detailed studies of the aquifers have not yet been made. This paper will accordingly confine itself to general considerations.

Precambrian crystalline rocks

Most of the boreholes drilled in solid and compact rocks have furnished only low or insignificant yields. Owing to the arid climate and the lack of alteration in these rocks, their water-bearing potential is generally very poor over most of the country with the exception of the south-west.

Paleozoic rocks cover only small areas in the centre and north of the country and their importance as aquifers is very local. In the Ogaden the thick sandstone strata have favourable hydrogeological characteristics. In theory they could be considered good aquifers, but their economic exploitation is extremely unlikely, for they are overlain by thick Mesozoic and Cenozoic formations.

The Mesozoic and Cenozoic sediments have varied hydrogeological characteristics. The Adigrat sandstone has high permeability and porosity. The ground water can be saline in the zones where it is in hydraulic contact with the overlying saline aquifers. In the south-east of the country the formation is too deep for economical drilling. The limestone strata of the Antato group are permeable in the stratification joints and openings caused by fractures and/or karstification. The sandstone strata are porous and permeable. These two geologic units - Antato sandstones and limestones - are among the main aquifers in the centre-north of the country.

The limestones of the Hamunlei series are intensely karstified and they yield sweet and drinkable water on the Harer plateaus. They also yield saline water is some wells in the Ogaden. The Uarandab and Gabredare formations contain mostly saline water owing to the alternation of layers of gypsum and layers of clays and gypsiferous marls. Fresh water has been found in the Gabredare limestone strata in the flood plains where the aquifers are regularly recharged by flood waters. The Main gypsum and Ferfer gypsum strata contain saline water. The Mustahil formation intercalated between the two gypsum groups may contain salt water owing to hydraulic contact between the overlying and underlying strata. Fairly sweet water has been found in the deep boreholes drilled south of the town of Gabridar.

The Jessoma sandstones, which extend over 130,000 km^2, are unconsolidated and very permeable. They have hardly any impermeable strata, so that infiltration water penetrates to great depths. The water table lies at a depth of 280 m below the surface and the water is slightly saline. The aquifer has a generally poor yield. Drilling is difficult in this series owing to crumbling of the walls and loss of drilling fluid.

The Belet-Uen formation, the Auradu series and the Taleh and Karkar series have a very small recharge from infiltration of surface flows, and it is probable that exploitation by borehole would deplete the water resources. Most of the existing boreholes give small yields of rather saline water.

The volcanic rocks have very diverse hydrogeological characteristics. On the plateaus, the Trap series has good water-bearing properties. The available discharges and the depth to the water table depend on the density of the fractures and joints and on the presence of impermeable strata which check the circulation of the water. In the Rift Valley, the basalts, ignimbrites and other volcanic rocks are intensely fractured with interconnected faults and joints. The exploitation potential depends on the presence of impermeable strata, the possibility of recharge of the aquifer, and the nature and concentration of the chemicals in the water. The water can be saline and contain high concentrations of fluorides of magmatic origin.

The Quaternary lacustral and fluvial deposits are the largest exploitable sources of ground water in Ethiopia. They include the alluviums of the flood plains, talus cones, valley fills and lacustral deposits.

The alluvial deposits include sands, silts and clays, with considerable vertical variation in granulometry. Owing to their seasonal or permanent recharge and their high transmissivity, the sandy strata of the flood plains have a considerable potential for exploitation of ground water for domestic purposes or for irrigation.

This potential has been proved to be an effective resource by the fairly deep wells installed in different parts of the country. Ethiopia's major flood plains lie along the courses of the rivers Wabi, Shebeli, Genale-Dawa, Omo, Baro, Angereb, Tekeze, Gash and Barka and their tributaries. Open or elongated alluvial cones ("bajada") are found along the Rift Valleys; some of them are very big. For example, the Dire Dawa-Ise plain has an area of over 13,000 km^2. In some cases it is a question of valley fills: for example, in the valleys of Woldia-Alamata and Chefa Kombolcha.

At their top these alluvial cones have a better potential than at their downstream terminations where the alluviums are much finer and where the possibly saline water is recharged by seasonal flood water descending from the high plateaus.

Water quality

The presence of gypsum and rock salt in most of the sedimentary formations of Mesozoic, Tertiary and Quaternary age is responsible for the poor quality of the ground water in the south, south-east and north-east regions of the country.

Saline deposits formed in the regularly flooded plains or in dejection cones have made the water of the alluvial aquifers brackish in some parts of the low plains and the Rift Valley. In some cases water from saline aquifers has contaminated the sweet water of other aquifers when contact has been established, for example by boreholes in which the saline strata have not been isolated.

High concentrations of fluorides have been found in the boreholes and springs of the Rift Valley. As these concentrations are above the limits for drinking water established by the World health Organization, many wells have had to be abandoned. The minerals in the water of the Rift Valley can also be of magmatic origin.

Industrial effluents and non-watertight septic tanks contaminate the ground water in urban areas, as can be seen from the high concentrations of nitrates in the vicinity of several towns such as Dire Dawa and Addis Ababa.

The average depth of the water table and the average unit yield of the installation in the main lithological units are as follows:

No.	Aquifer	Water table (depth in metres)	Average yield (l/s)
1.	Crystalline basement rock	(moderate)	0.5
2.	Adigrat sandstone	(moderate)	3
3.	Antalo limestone	45	3
4.	Hamanlei series	120	2.5
5.	Jessoma sandstone	250	0.5
6.	Tilah series	160	2
7.	Trap series	65	3
8.	Mekdela group	105	2.5
9.	Afar group	80	2
10.	Alluviums and colluviums	15	10

The averages given above are based on data collected from existing wells. In fact, the depths and yields for a single lithological unit can vary from one zone to another, depending on the physiographic conditions, the recharge of the aquifers and the geological structure.

IV. EXPLOITATION OF THE GROUND WATER

The main body responsible for ground-water exploitation is the Ethiopian Water Works Construction Authority (EWWCA) which reports to the National Water Resources Commission and has eight regional offices and one central office. The regional offices are responsible for the development of surface and ground water for domestic use. The Water Well Drilling Agency is responsible for the installation of boreholes to supply the towns, for industrial and other uses, on behalf of various organizations.

EWWCA has about 40 drilling rigs, of which 22 are cable, 5 rotary and 13 down-the-hole hammer. Some 250 boreholes with an average depth of 100 m can be drilled per year. The ground water is exploited not only by boreholes but also by means of shallow hand-dug wells and underground dams.

In the areas affected by drought, the assistance organizations have supplied a number of additional drilling rigs. Private companies play little part in drilling for water.

More than 20 % of the boreholes have been abandoned owing to adverse factors such as: poor water quality, low discharge, low or non-existent output, and technical drilling problems. It is thought that this fairly high failure rate could be considerably reduced if a central system was established for the collection and computerization of data and if adequate hydrogeological studies were made prior to drilling.

Personnel and training

Ethiopia has insufficient qualified ground-water personnel. In order to overcome this handicap, the National Water Resources Commission organizes in its training centre training and further-training courses for technicians and drillers. Geologists and hydrogeologists are also trained abroad in universities and institutes. A water technology institute has been established at Arba Minch. The first personnel to be trained were drillers, water point builders and maintenance technicians. Other activities will follow for the water sector in general and for research.

Use of the ground water

Ground water is exploited in Ethiopia mainly by means of wells dug by hand in the alluviums and in the hard fractured and altered rocks. This type of well is installed for local communes or families for domestic purposes and for livestock. In the low plains where permanent surface water is rare, herdsmen dig groups of wells at hydrogeologically favourable sites. In the south-east of the country where there are few such sites, up to 100 hand-dug wells can be found at a single location, and up to 30 elsewhere. In the low plains in the south the hand-dug wells are helicoidal in shape and wider at the bottom, i.e. the wells are not dug on a vertical axis, and they also have narrow platforms at various depths to enable the drawers of water to pass the buckets from hand to hand to the surface. Elsewhere the walls of the wells are more-or-less vertical; the water is drawn off by buckets on ropes.

It is estimated that Ethiopia has about 50,000 traditional wells, of which 90 % have no lining. Some of them last only a very short time, for they can be seasonally flooded or washed away. A large part of the population and their livestock obtain their supplies from these hand-dug wells.

Governmental bodies and foreign assistance organizations give the rural people encouragement, advice and material aid in installing better-built wells. They also organize training courses to enable villagers and herdsmen to ensure the proper use and maintenance of the wells and pumps.

There are about a dozen different types of hand pump in use in Ethiopia. The NWRC, in co-operation with the University of Addis Ababa, is carrying out research with a view to the construction of simple and easily maintained pumps, as well as wind-driven pumps for use in rural areas. In addition to the shallow wells, there are about a thousand deep boreholes equipped with various types of pump which are exploited to supply rural centres or serve as watering points along the routes travelled by the herds. Ground water is in fact the main source of supply for domestic and industrial purposes in 67 urban centres with a total of 1.4 million inhabitants. Elsewhere it is used as a supplementary source when surface water is the main source. Although there is some prospect of using ground water for irrigation in Ethiopia, such use is at present confined to only a few small areas.

Operation and maintenance

The traditional and private wells are maintained by the communities or private individuals to whom they belong. The operation and maintenance of the other installations has been the responsibility up to now of governmental bodies, but as such installations have increased considerably in number, it has become impossible for the State to carry out this work with teams attached to a central body.

This is why the NWRC has launched a programme to train agents to encourage and organize institutionally and technically the participation of village communities - by establishing "water committees". These committees chose persons to be responsible for the pumps who will receive training at the regional level so that they will be able to keep the pumps in good working order, as well as carrying out current maintenance and minor repairs. Technicians from the central body will make regular visits to the installations in order to identify cases where work is required which is beyond the capacity of the rural communities.

The governmental body bears full responsibility for the operation and maintenance of the systems of ground-water production and distribution in the urban and village communities where users pay for their water. This has been possible so far, but the situation is becoming difficult owing to the constant increase in the number of installations. The current problems include a shortage of spare parts for the pumps and motors, a shortage of means of transport and maintenance materials and equipment, and a shortage of qualified personnel.

V. CONCLUSION

The availability of ground water in Ethiopia in the formations of hard rock varies greatly from one location to another, depending on the possibility of recharge, the density of the fracturation, the permeability, the presence of internal obstacles to the movement of the ground water, the concentration and nature of the chemicals in the water, the depth of the aquifer's water table, the physiography, and the difficulties encountered in drilling. Similar types of lithological units can offer different prospects with respect to their ground-water potential, depending on the factors listed above. The fluvial and lacustral deposits are the country's most reliable aquifers, especially in areas in which they can be recharged by perennial flows or flood waters. It often happens that small deposits of poor-quality ground water are exploited in regions where there is no alternative.

Owing to the depth and the small yield of the boreholes in hard rocks, they are exploited only for domestic purposes. In contrast, the alluvial deposits of the flood plains and alluvial cones have sufficient potential for them to be exploited for irrigation, especially when they are located in areas affected by drought. Construction, operation and maintenance costs vary with the hydrogeological conditions.

Shallow aquifers have traditionally been exploited to meet the needs of the rural population and their livestock. During the past 30 years modern methods have been used to study and rationally exploit the shallow aquifers. The country has acquired different types of drilling equipment and improved pumps. Services have been organized for the exploration, mapping and exploitation of ground water, and personnel training centres have been established. A system for the centralized collection and storage of ground-water data and information still needs to be organized. Very little reliable data and information about the hydrogeological characteristics of the various lithological systems is yet available; this is the reason for the lack of summary reports and hydrogeological maps, documents which are essential for the rational planning and exploitation of the resources.

VI. REFERENCES

(EIGS Archives)

1. Hydrogeological maps (Scale 1:250,000) and accompanying texts:

   - Bilate-Gidabo-Galana river basins and lakes region of the Rift: maps and accompanying texts prepared but not finalized.

     Reconnaissance work was being carried out in 1986 in other sectors:

     - Allideghe-Galeaba (east of country);
     - Asosa-Kurmuk (west of country);
     - Southern part of Rift Valley.

   - Harer: Map and accompanying text prepared but not printed;
   - Mekele: Map and accompanying text printed;
   - Nazret: Upper basin of the Awash: id.;
   - Lakes region: Report printed;
   - South Afar and adjacent areas: Map and accompanying text prepared but not finalized.

2. There are also some technical reports and publications, including:

   Hadwen, P., Mesfin Aytenffisu and Girma Mengesha: "Ground water in the Ogaden", note No. 113, EIGS, 1979.

   Mesfin Aytenffisu: "Hydrogeology of Northeastern Part of Hararyhe", ITC, Netherlands, 1981.