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Department of Technical Co-operation for Development

Natural Resources/Water Series No. 19

GROUND WATER IN EASTERN, CENTRAL AND SOUTHERN AFRICA

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NOTE

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such a symbol indicates a reference to a United Nations document.

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FOREWORD

The Economic and Social Council, by resolution 675 (XXV) of 2 May 1958, requested the Secretary-General to take appropriate measures for the establishment, within the Secretariat, of a centre to promote co-ordinated efforts for the development of water resources. It also singled out ground-water problems as one of the priority subjects in the development of a programme of studies. Large-scale Ground-water Development, published in 1960 1/, was the first study prepared in this field by the Water Resources Development Centre (now the Water Resources Branch of the Division of Natural Resources and Energy, Department of Technical Co-operation for Development).

The Advisory Committee on the Application of Science and Technology to Development, in its World Plan of Action 2/, gave priority to ground-water exploration and development. In fact, in the course of the First and Second United Nations Development Decades, more than 100 projects assisted by the United Nations Development Programme (UNDP) and other United Nations technical co-operation programmes were entirely or partially devoted to ground-water prospecting, assessment or pilot development. (A list of ground-water projects in the Eastern Mediterranean and Western Asia sponsored by UNDP is contained in the annex to the present report.)

While such operational activities were developing, the need for a comprehensive review of the results of the projects and for a dissemination of relevant information became more evident. As a result, the Economic and Social Council, by resolution 1761 B (LIV) of 18 May 1973, requested the Secretary-General to take the necessary measures, within the budgetary limitations, to improve and strengthen the existing United Nations services for the analysis, evaluation and dissemination of world-wide date on natural resources, including water resources.

With respect to ground water, a first comprehensive review of the African continent was published in 1972 and 1973 under the title Ground Water in Africa 3/ as a synthesis of material available in the records and files of the United Nations. The material of the second volume in this series, Ground Water in the Western Hemisphere 4/, was drawn from country papers which were prepared by hydrogeologists and by ground-water engineers, specialists of the countries concerned. This was also done for the third volume entitled Ground Water in the Eastern Mediterranean and Western Asia 5/, for the fourth, entitled Ground Water in the Pacific Region 6/ for the fifth, entitled Ground Water in Continental Asia 7/, for the sixth, entitled Ground Water in North and West Africa 8/, and for the present volume, the seventh in the series, which is to be followed by an eighth on ground water in Europe. This

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2/ United Nations publication, Sales No. E.71.II.A.180.

3/ United Nations publication, Sales No. E.71.II.A.16.

4/ United Nations publication, Sales No. E.76.II.A.5.

5/ United Nations publication, Sales No. E.82.II.A.8. ✓

6/ United Nations publication, Sales No. E.83.II.A.12. ✓

7/ United Nations publication, Sales No. E.86.II.A.2. ✓

8/ United Nations publication, Sales No. E.87.II.A.8. ✓

will complete the presentation of (a) a necessarily brief but full overview of the world's ground-water resources, (b) the state of knowledge about them and their potential, and (c) information about their exploitation and the problems involved.

The present work indicates the progress made since the publication of the first volume on ground water in Africa. A point to note is the large number of African specialists who have taken part in the drafting of the text. There is now hardly a single African country which does not have university graduates or engineers specializing in hydrogeology or ground water.

It is to be hoped that this volume, which deals with several arid countries, in particular the countries of Eastern and Southern Africa affected by long periods of severe drought since 1983, will contribute to the development of ground water which is so vital in this part of the world.

The United Nations wishes to thank for their valuable assistance the governmental organizations and the consultants and experts on Africa and other countries who have collaborated in the preparation of this work, in particular the Ministry of Mineral Resources and Water Affairs of the Republic of Botswana, the Department of Geology of the Republic of Burundi, the Ministry of Mines and Energy of the People's Republic of Congo, the Agricultural Engineering Service of the Republic of Djibouti, the Hydrogeology Department of the Ethiopian Institute of Geological Surveys, the Inter-African Committee for Hydraulic Studies at Ouagadougou, the Department of Land Valuation and Water of the Republic of Malawi, the Central Water Authority of Mauritius, the Public Utilities Corporation of the Republic of Seychelles, the National Water Well Association (USA), the Executive Secretariat of the National Action Committee for Water and Sanitation of the Republic of Zaire, the Ministry of Agriculture and Water Development of the Republic of Zambia, and the Office of Geological and Mining Research (BRGM-Orléans, France), as well as S. Bonfa, J.L.T. De Sommerville, D. Ferro, J.J. Imangue, S. Jacobi, J.H. Johnson, E.P. Kabunduh, F. Kolman, D. Labodo, C.L. Lekkerkerker, S. Makhoalibe, J.S. Makundi, J. Margat, A. Navarro, T. Nkanira, J. Nowacki, R. Pozzi, J.H. Rakotondrainibe, N.S. Robbins, G. Rogbeer, E.M. Siamachoka, L. Stieltjes, C. Uramutse and P. Wurzel.

The colour map of the ground-water resources of Africa, which will be found in the jacket, was kindly supplied by Mr. J. Margat, chief of the water mission of BRGM Orléans, France. He is warmly thanked for that. The Division of Natural Resources of the United Nations Economic Commission for Africa (ECA, Addis Ababa) helped with the collection of information on some countries for this publication, for which ECA is jointly responsible with the United Nations Secretariat in New York.

Explanatory notes

The following symbols have been used in the tables throughout the report:

A dash (-) indicates that data are not available or are not separately reported.

A blank indicates that the item is not applicable.

A full stop (.) is used to indicate decimals.

A slash (/) indicates a crop year or financial year, e.g. 1976/77.

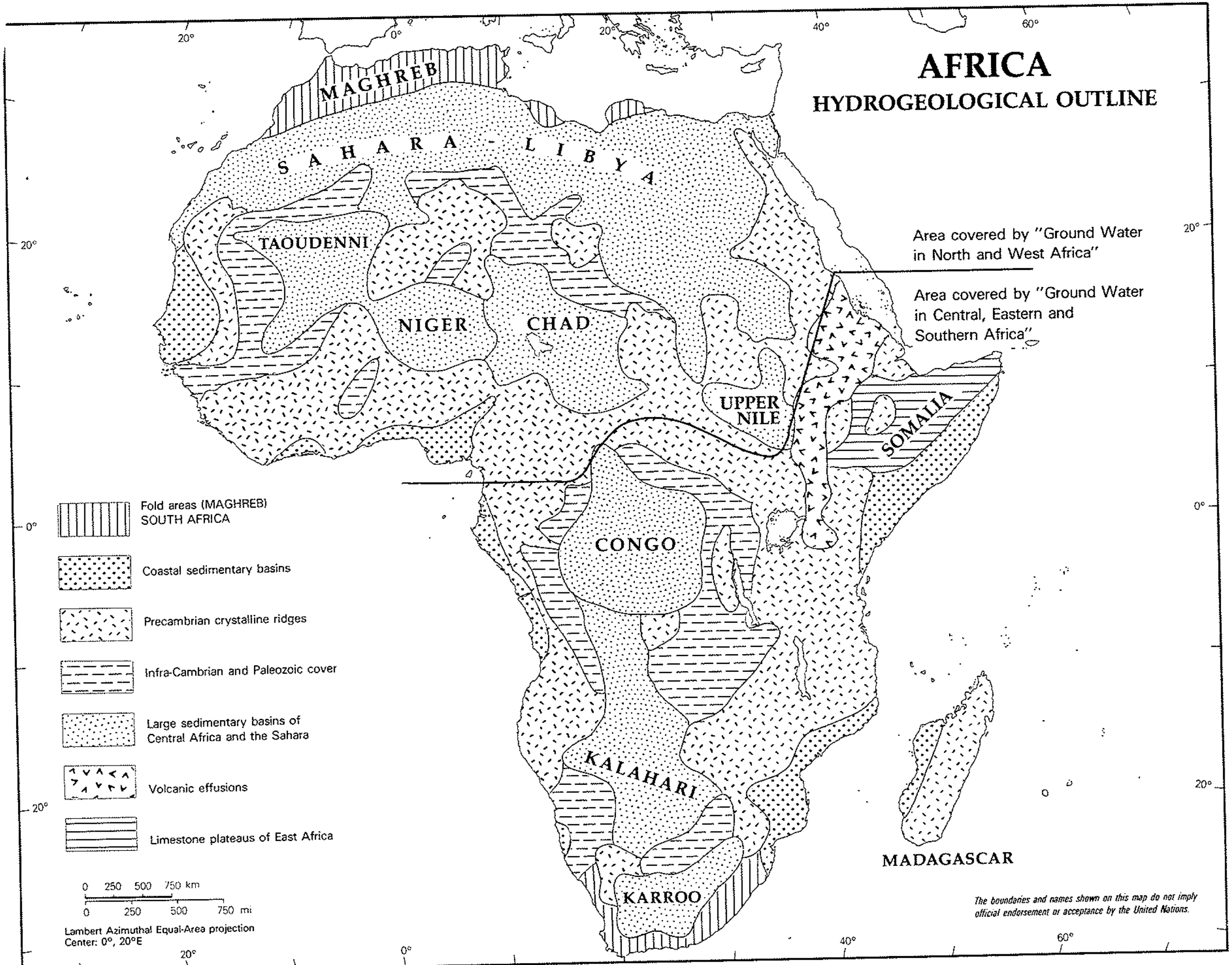
Use of a hyphen (-) between dates representing years, e.g. 1975-1978, signifies the full period involved, including the beginning and end years.

Reference to "dollars" ($) indicates United States dollar.

Details and percentages in tables do not necessarily add to totals because of rounding. Some of the data series are not homogeneous; they have been taken from various reviews and publications; the differences or divergences may be due to typing errors.

The designations employed and the presentation of the materials in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The term "country" as used in the text of this report also refers, as appropriate, to territories or areas.



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PART ONE - OVERVIEW

This volume deals with ground water in Eastern, Central and Southern Africa from the standpoint of the deposits of this natural resource, the state of knowledge about its potential, its exploitation and the uses to which it is put. It deals with all the African countries located entirely or partly in the southern hemisphere, with the addition of the Republic of Djibouti and Equatorial Guinea. The other African countries, i.e. those situated in North and West Africa are dealt with in a sister publication.

I. LARGE AQUIFER SYSTEMS

This vast territory of more than 13 million km^2 with 230 million inhabitants can be subdivided on the basis of geological, morphological and climatic considerations into a number of large aquifer systems in which the ground-water resources can be reasonably well distinguished from the standpoint of their accumulation, their fossil or renewable state and their accessibility.

(i) The Precambrian crystalline basement rock which forms the continental mass outcrops - or suboutcrops - in a band 100 to 300 km wide, inland from the Atlantic coast in Equatorial Guinea, Gabon, Congo, Zaire, Angola, Namibia and South Africa. The outcrops are much larger towards the east, for the crystalline formations are in places raised above the big Rift Valleys - major tectonic depressions, the floors of which are covered by a series of big lakes. Masses of outcropping or suboutcropping crystalline formations are found in almost all the countries considered here. In some countries such as Rwanda, Burundi, Tanzania, Kenya, Zimbabwe and Madagascar, they cover most of the land area.

(ii) The sedimentary formations which overlie the depressed crystalline basement in the axial part of the continent. This includes the basins of the Zaire, the Okavango, and the Kalahari. The Karroo basin is a fossil basin raised in a vast plateau. Mention must be made, at the edge of the basement rock, of the "stromatolithic" calcarodolomitic Lower Cambrian formations which are very extensive in Congo, Gabon, Zaire and in Angola, Namibia, Tanzania and Zambia.

The essentially Continental formations of the Karroo (Carboniferous and Triassic) consist of fairly coarse sandstones which are good aquifers. The sand and sandstone formations of the Kalahari (Neogene-Pleistocene), likewise continental, can also provide good aquifers.

(iii) The vast basalt effusions resulting from the tectonic movements which have affected the African continent at various periods since the end of the Triassic, especially in Ethiopia and in the Rift Valley zone, Kenya, Tanzania and Rwanda, and in South Africa, Botswana and Madagascar. These volcanic formations provide springs in accidented areas (Ethiopia). When they form vast tablelands, as in Kenya, they provide large aquifers exploited by borehole but the water layer can be fairly shallow.

(iv) The sedimentary coastal basins, which differ very greatly in size: the Gabon basin, the narrow basin which covers the whole of the west coast from Angola to the Cape, the vast basin of variable width of Somalia-Kenya Tanzania-Mozambique, and the basin of the west coast of Madagascar. These basins consist of Recent, Quaternary and Cenozoic sediments, in which the sandstone-sand and limestone strata form large aquifers, artesian in some cases.

II. CLIMATIC CONDITIONS: EFFECTS ON THE RECHARGE OF THE AQUIFERS

This vast territory is subject to very varied climatic conditions in which latitude plays an essential role. From the anticyclones of the South Atlantic and the southern Indian Ocean, which are high-pressure centres, the trade winds blow towards the Equator and are deflected westwards by the rotation of the earth. As a general rule, the winds blow from the oceans to the land, bringing rain as the high ground checks the wet winds. Some depressed areas such as the Rift Valleys receive little rainfall. Eastern, Central and Southern Africa has maximum average temperatures of over 20 °C, with 30 °C in the Ogaden and 35 °C in the Kalahari, and average minimum temperatures generally below 20 °C; these minimum temperatures decline from the equatorial zone to the Cape. The world's highest average temperatures have been recorded in southern Somalia.

The temperature ranges are very small in the equatorial regions (1 °C) but increase in step with distance from the equator: they reach 02 °C to 30 °C in the Kalahari.

The Sahara

The precipitation is irregular in the Sahara, with large seasonal variations from year to year.

The extreme south of the continent, the Cape region, has a rainfall pattern of the Mediterranean type (winter rains).

The very wet equatorial regions have two rainy seasons at the solar zenith - i.e. when the sun is high above the horizon - usually from March to June and from September to November. From 10 to 15 degrees of latitude the tropical regions have only one rainy season - from May to October. Lastly, the subtropical desert zone, in particular the Kalahari-Namib and Somalia, receives only occasional and irregular showers.

The annual rainfall is 2 to 6 m in Gabon, in the loop of the River Zaire, to the west of the Great Lakes, and on the east coast of Madagascar; it is 1 to 2 m on the Ethiopian plateau, to the north of a line between Mossamedes and Dar Es Salaam, on the east coast of Southern Africa, and over most of Madagascar; it is 500 to 1,000 mm to the south of the Mossamedes-Dar Es Salaam line, with less than 500 mm in Somalia, in some parts of Uganda, Kenya and Tanzania, and in the Kalahari and the south-west part of Madagascar.

Climatic zones

The climatic zones, characterized by very different vegetation types, are as follows:

- Mediterranean zone with dry summers (hot season): Cape region.

- Steppe zone with a semi-arid tropical climate, i.e. with rainy summers (cool season). The precipitation is less abundant and the temperature ranges are larger than in the Mediterranean zone: this includes the whole of Eastern Africa with the exception of the coastal areas and the highest plateaus, and the central part of South Africa. The dry savannah zone (tall grasses) forms the transition between the steppe - with short grasses - and the wet savannah.

- Wet savannah zone or zone of wet tropical climate. Here the wet season grows longer the closer to the equator, but in some places the uninterrupted dry season can last from four to five months. The belt of wet savannah is 500 km wide on average.

- Desert zone (Kalahari-Namib and Somalia).

- Equatorial forest zone with very wet climate and two rainy seasons, or continual rain: it includes the Congo basin as far as the Rift Valleys.

- Coastal fringe zone, a narrow coastal strip in which the climate is heavily influenced by the sometimes very powerful coastal currents.

The current of Benguela flowing south-north from Cap to the equator, is a cold current. The warm currents are those flowing north to south from the Mozambique channel towards the Cape, and the monsoon current flowing south to north from Mozambique to Somalia, with surges of cold water in the area of Cape Ghardafui.

Aridity and evaporation

The climatic zones can also be classified according to the index of humidity or aridity (Thornthwaite), which takes into account both the temperature and the rainfall and its distribution and which expresses a characteristic ratio between potential evapotranspiration and the amount of rainfall.

Some evapotranspiration values are given below and compared with the rainfall values at a number of African weather stations:

Weather station	Annual precipitation (cm)	Potential evapotranspiration (cm)	Quotient %
Arid coastal regions			
Walvis Bay (Namibia)	1	78	17
Area of rainfall between 250 and 1,000 mm			
Lug Ferrandi (Somalia)	36	206	17
Garissa (Kenya)	31	187	17
Luanda (Angola)	33	134	25
Dodoma (Tanzania)	59	111	50
Catuane (Mozambique)	67	130	50

Thus, in some regions a large or very large proportion of the rainfall is lost almost immediately through evaporation. The heading "evapotranspiration" often has the highest values in the water tables. Some authors put forward the following figures for the various regions of Africa: evapotranspiration - 40 to 98 %; infiltration - 2 to 40 %; runoff - 2 to 12 %.

The surface water (lakes) is subject to wide variations in level owing to the imbalance in some years between the headings "evaporation" and "recharge". This is particularly true of Lake Victoria. It is also true of unconfined ground water when the water table is close to the surface (delta of the Okavango in Botswana). Evaporation determines - and can be measured by - the concentration of salts in the ground water. The question of the depth to which evaporation takes place is disputed. All authors agree that this effect operates for several metres (5 m on average and as deep as 8 to 10 m). Some authors speak of much greater depths.

Conclusion

The amount of rainfall available to recharge the ground-water aquifers depends on three main climatic factors: the annual rainfall, its distribution in time or the "heaviness of the precipitation", and the value of the potential evapotranspiration, which is essentially a function of latitude, altitude and temperature.

In some cases each of these three factors singly can have a decisive influence.

In all the regions in which the rainfall exceeds roughly 1 to 1.2 metres a year, neither the heaviness of the rain nor the evapotranspiration value should be taken into account, for a large part of the rainfall is almost always available for infiltration, in some places after runoff. In this case the decisive factor is the amount of the rainfall.

In the case of rainfall below 250 mm, it is the heaviness of the precipitation which is important. It is interesting to note that in conditions of increasing aridity - decline in rainfall accompanied by an increase in the evaporation potential - the heaviness of the showers increases to the point where most of the annual precipitation sometimes falls in a few hours. Accordingly, some daily figures can produce a surplus - which can persist over several days - of rainfall over potential evapotranspiration; this gives the water time to infiltrate and thus recharge local aquifers in particular cases.

In regions with rainfall between 250 mm and 1 m (steppe and dry savannah) the potential evapotranspiration is the decisive factor, for the rainfall is spread out better in time. During the rainy season, which can vary widely from one year to the next, the potential evapotranspiration can still have a large value. However, a very variable remainder is almost always available for runoff and infiltration. In contrast, during the dry season which can last from three to six months, some regions of Africa have climatic conditions of the semi-arid or arid type while receiving more annual rainfall than some countries in the wet temperature zone of Europe. During the dry season, the evaporation effect can be considerable in surface and shallow aquifers.

Some recent studies on the treatment of rainfall date in the savannah countries tend to show that the rainfall falls into two distinct categories:

- A "monsoon" system with moderate rainfall fairly well distributed in time and little variation from year to year. To some extent this rainfall can help to maintain the vegetation but most of the water evaporates after having soaked the supper layers of the soil.

- A system of very heavy, brief and frequent shows which produces large amounts of surface runoff and deep infiltration. This type of rainfall is essential for the renewal of surface and ground-water resources. It is the decline in the heaviness or frequency of these showers which causes "drought" and one of its main consequences: a drop in the level of water in the wells, which can even dry up completely. Lastly, a drop of 50 % in the amount of total annual rainfall as a result of less frequent showers can mean no surface runoff or recharging of the aquifers.

III. PRODUCTIVITY OF THE AQUIFERS

The values given below are by way of example. Additional data will be found in the country papers.

Coefficients: S = storage
K = permeability
T = transmissivity

1. "Porous" aquifers

Alluvial fill, deltas, Quaternary formations of the Congo basin, sedimentary coastal basins

Country	Location	Geology	Flow rate per installation (m^3/h) a/	Drawdown (m)	S %	K (m/d)	T (m^2/d)
		Fluvial alluviums					
These aquifers are among the most important and serve large populations.							
Congo (both Republics)	Congo (river)	Sands-gravels	(1 to 100 100 m^3/h/m)	-	-	-	-
Madagascar	Tananarive	Alluviums with clays	(15 to 40)	-	-	-	-
Zimbabwe	Sabi (river)	Non-argillaceous alluviums	60	-	-	-	-

a/ In the column "Flow rate per installation", the values in brackets indicate a specific discharge.

Country	Location	Geology	Flow rate per installation (m^3/h) a/	Drawdown (m)	S %	K (m/d)	T (m^2/d)
			Extensive alluvial fill				
Burundi	Graben	Fill formation	10 to 60	-	-	-	-
Congo	Basin apart from river	Fill formation	(1 $m^3/h/m$)	-	-	-	-
			Coastal sedimentary basins				
Madagascar	-	Cretaceous sandstones	60	-	-	-	-
			Kalahari sands				
Angola	-	Argillaceous-calcareous sandstones	2.5 to 4.5	-	-	-	-
Malawi	-	Non-argillaceous sands	1 to 5	-	-	-	-
	-	Argillaceous sands	0.5 to 3	-	-	-	-
Zimbabwe	-	Sands	Up to 70	-	-	-	-
Zambia	Barotseland	-	4 to 8 maximum	-	-	-	-
			Karroo sandstones and other Precretaceous or Cretaceous continental sandstones				
Madagascar		Isalo argillaceous sandstones	15 to 40	-	-	-	-
Namibia	Botswana frontier	Ecca sandstones (Karroo)	(40 to 4,000 per day, artesian)	-	8 to 15	-	-
Zimbabwe	-	Upper Karroo sandstone	3 to 6 (up to 50)	-	-	-	-
Swaziland	-	-	-	-	-	-	-

Country	Location	Geology	Flow rate per installation (m^3/h) a/	Drawdown (m)	S %	K (m/d)	T (m^2/d)
Zambia	-	Lower Karroo sandstone	Low	-	-	-	-
		Sandstone of Grit escarpment	7 to 10 (up to 60)	-	-	-	-
		Beaufort formations	20	-	3 to 10	-	-
Zimbabwe	-	Cretaceous conglomerates	2 to 7	-	-	-	-

2. Fractured aquifers

Karstified limestone strata

Country	Location	Geology	Flow rate per installation (m^3/h) a/	Drawdown (m)	S %	K (m/d)	T (m^2/d)
Madagascar	West coast	Eocene limestones	40 to 300, artesian (160 to 200 $m^3/h/m$ pumped)	-	-	-	-

Dolomitic-limestone massifs and plateaus of the Upper Precambrian and Cambrian

The dolomitic-limestone sedimentary system (Upper Precambrian and Cambrian) is often very thick and constitutes one of the most important ground-water reservoirs in Africa. This is borne out by the few examples given below:

Dolomites of the middle Katanga (Zambia): 4 to 10 m^3/h (40 m^3/h in the Mazabuka fault). The town of Lusaka draws 2,000 m^3/d from 10-inch boreholes;

Dolomites of Lubumbashi (People's Republic of Congo): specific yield - up to 100 $m^3/h/m$;

Dolomitic limestones of the Transvaal - Far West Rand (South Africa). Useful porosity: in the order of 10 % at 60 m, 2 to 3 % at 100 m, and 1 to 2 % at 150 m. The Suurbekom pumping stations supply 30,000 m^3/d to Johannesburg. A yield 30 times greater is available. The main purpose of the pumping in this region is to exhaust the limestone stratum which overlies the gold-bearing conglomerates, with a view to their exploitation. Over 15 years, 10^9 m^3 have been pumped.

3. Compact-rock aquifers

Formations with little or no porosity, except locally in suitable altered or fissured zones

Precambrian and Primary hard sandstones, schist-sandstones and quartzites

Example: Angola (southern)

Lower-Cambrian quartzites and conglomerates: Yield, 0.5 to 3 m^3/h.

Schists (mainly Lower-Cambrian, Paleozoic and Karroo) and clays

When they are not totally impermeable, these formations contain very few water resources, mainly in the fracture zones.

Example: Zambia - phyllades, biotitic schists, Katanga schists, yield per well from 1 to (exceptionally) 4 m^3/h.

Examples of available yields per well and borehole in crystalline formations

Country	Location	Geology	Flow rate per installation (m^3/h)
Angola	South	Metamorphic rocks	0.6 (fractured)
	Catuiti	Tectonized and alterated granites	3 to 30 (up to 80)
Congo	-	Granitogneiss in alterations and fractures	(1 to 10 $m^3/h/m$)
Madagascar	Various	Altered gneiss	0.4 to 1.2
Malawi	Various	Gneiss with graphited biotite	2 to 5
Mozambique	Various	Rhyolites	Springs: 0.1 to 0.5 (wells 1 m^3/d)
	Various	Granites paragneiss orthogneiss	4 to 8
	Porto Amelia, Villa Perry	Granites paragneiss orthogneiss	12 to 20 (up to 25)
Namibia	Namaqualand	Gneiss and quartzites	1 to 20 (artesian)
Uganda	Karamoja	Acid gneiss	5 to 50
Zambia	Kaloma Choma	Quartz veins	8 to 12

In fact, a flow rate of 5 m^3/h is a good yield for the granites and granitogneiss; a flow of 1 m^3/h is considerable for the micaschists and metamorphic schists. Better yields are obtained in the quartz zones.

4. Volcanic rocks

The lavas, especially the basalts, the dolerites and certain basic rocks which sometimes afford large yields can be classified in a separate category; some examples are given below:

Jurassic basalts (Zimbabwe) - artesian waters: 8 m^3/h;

Bulawayo lavas, tufas, etc. (Zimbabwe) metamorphized into green rocks: 8 to 15 m^3/h (exceptionally 70); certain lavas have a low yield of under 1 m^3/h;

Basalts (Mozambique): 3 to 4 and up to 25 m^3/h, with drawdown of 5 m;

Stormberg basalts (Swaziland): 1 to 2.5 m^3/h;

Karroo doleritic dykes (Swaziland): 1 to 4 m^3/h;

Akjoujt basic rocks (Mauritania): 30 to 45 m^3/h, with drawdown of 13 m;

Altered basic rocks (southern Angola): 7 to 12 m^3/h.

The volcanic rocks, and especially the basalts, also give large yields, in particular from big springs, in other countries (Ethiopia).

Conclusion

There is almost nowhere in Africa where ground water is not found at one depth or another. The biggest yields are provided by clay-free alluviums, continental or marine Cretaceous sandstones and karstic limestones.

Most of the ground water is acceptable for human consumption and therefore for livestock as well. In very general terms it can be said that, with respect to its quality, which depends on the geology, climate and geographical situation:

- In arid zones the ground water is usually of calcium/magnesium bicarbonate facies at the upstream level, i.e. near the regions where the surface runoff infiltrates. It then acquires a higher sulphate content and finally increased amounts of chlorine and sodium at the end of the course in the regions where the evaporation effect is high and operates directly on shallow aquifers;

- Some geological formations, especially of Permian-Triassic or Cretaceous age and lagoonal origin, contain mineral salts which pass in solution into the ground water. This is particularly the case in Mozambique;

- In the coastal sedimentary basins, often made up of permeable formations, pumping causes sea-water intrusion which tends to contaminate the fresh-water aquifers;

- In the Precambrian basement rock in tropical rain country the water is usually not very mineralized or aggressive.

Mineral-water and thermomineral springs abound in the African continent in the fractured zones. There is a large potential for geothermal energy in the Rift Valleys which is currently being exploited, especially in Kenya.

IV. EXPLOITATION OF THE GROUND WATER

Up to recent times in this part of the world, ground water was drawn off from crude wells - shallow holes dug in the alluvial beds of water courses devoid of surface water in the dry season. These wells are in general use in arid regions such as northern Uganda.

They are rarely more than a metre deep and provide temporary water points still frequented by nomads; they usually last only a short time, for flood water in any amount destroys them.

Wells drilled and dug by modern methods

In the deserts, the discovery of ground water by deep drilling is essential for oil exploration works, especially for the mixing of drilling mud and the raising of oil by injecting water under pressure. The general geological studies and the geophysical studies carried out for this purpose have led to the identification of deep confined aquifers which have then been exploited by means of artesian boreholes. Thus, even before the proclamation of their independence the African territories under British administration benefitted from the experience acquired in oil exploration in the Middle East during the second quarter of the 20th century and from the progress made in the same period by British and Swedish manufacturers of drilling equipment for the exploitation of ground water.

Ground water was first exploited by borehole in the arid zones of Southern Africa.

Many small boreholes have also been drilled in all the countries of the semi-arid or arid zone in order to supply from shallow aquifers the administrative or economic urban and rural centres and modern agricultural enterprises. These works were then extended to the wetter areas and as far as the equator, for the wet tropical countries also need ground water to supply their towns and villages.

The number of water-drilling rigs in Africa has increased rapidly over the past decade, especially in the arid countries. These rigs are used by a number of African and foreign companies and by State services such as departments of water development, or equipment, etc.

The boreholes are not usually equipped with motorized pumps. In rural areas many types of hand-operated or animal-traction pumps have been tried out. Some of these pumps are particularly simple and tough, for example the India Mark II developed with the help of UNICEF, and the Volanta of Netherlands'conception, which is now manufactured in Africa.

In addition to drilled wells, there are many wells dug by hand on the initiative of the administration in areas where they could not be constructed by the methods traditionally used by the local people (shovels and picks). In areas of hard rock, particularly Paleozoic schists and sandstones, compressed air tools and explosives are used to excavate the wells. These methods are usually costly and are going out of use.

In many African countries in the wet tropical zone the formations usually contain very loose clay seams which make it impossible to dig wells by hand, for the walls collapse even before the digger reaches the water-bearing strata underlying the clays. In such cases an appropriate lining must be used; this is always tricky and sometimes expensive or difficult, which means that the wells must be drilled.

The construction of wells is also very difficult in areas of sand-clay sediments where the installation of a prefabricated reinforced-concrete lining is always essential.

The installation of motorized pumps is justified only when the water requirement is large, and account must be taken of economic and social factors, the chemical quality of the water and the height of the lift. The communities or services concerned must also have the technical and financial means to maintain and repair the installations.

During the last 15 years the digging and drilling of wells has undergone spectacular development, partly as a result of the International Drinking Water Supply and Sanitation Decade and partly because of the periods of exceptional drought (1973-1975 and 1983-1985) which affected the arid subtropical zones.

Ground water is extensively used to supply urban and industrial areas, especially in arid regions and coastal zones. This is particularly true of Djibouti, Berbera, Mogadishu, Mombasa, Zanzibar, Gaberones, Pretoria, Windhoek, Lusaka and several towns in Zaire.

The exploitation of ground water in Africa is intended mainly to meet the water needs of the towns, villages and pastoral areas and also those of industrial and mining enterprises. In contrast, irrigation with ground water is limited either by its cost and the expenditure of convertible currency involved in the purchase of pumps, motors and fuel, or by the exhaustion of the aquifers in arid regions. Apart from the zones of semi-arid and Mediterranean climate in Southern Africa, the areas irrigated by ground water are still very small. However, the creation of small market-garden centres is envisaged in the vicinity of the motorized or hand pumps installed in the villages, with a view to diversifying the people's diet.

V. CONCLUSION

The sharp increase in the use of ground water in Africa goes hand in hand with the continent's rapid entry into the modern world. This use is important for all sectors of the economy but was first concentrated in the towns, the mining centres and some priority farming regions. It is now being extended to the small centres in the most isolated tropical and desert regions. A considerable effort to this end is being made both by Governments and by international and bilateral technical co-operation bodies. This sharp increase in the use of ground water is almost one of the fundamental conditions for economic and social development, for it is an essential factor in the life or survival of many existing centres of population and the fundamental condition for the establishment of new centres.

However, the development of ground water is beset with many difficulties. Firstly, the areas with the best aquifers from the standpoint of the capacity of the rocks to absorb, hold and discharge large quantities of water are often arid or even desert zones with little or no recharge from rainfall and coastal zones subject to deep intrusion of sea water in the direction of the wells. In contrast, some rainy tropical zones have rocks which are poorly suited to the absorption and storage of water supplied by rainfall and surface runoff.

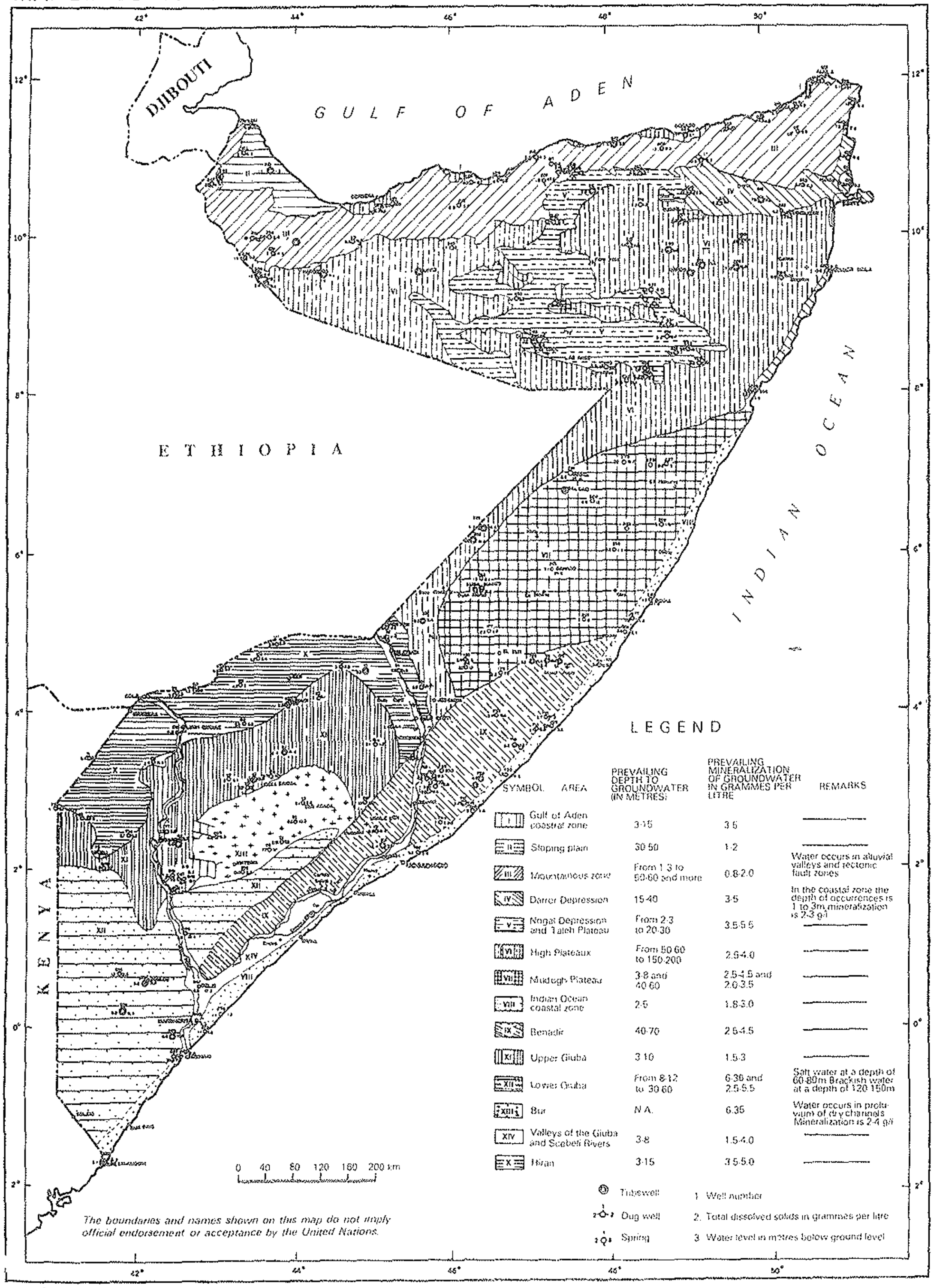
Furthermore, ground-water prospecting and the drilling and digging of wells are usually difficult and expensive operations owing to the weakness of the infrastructures, the unfavourable natural conditions, the remoteness of the zones to be reached and the wide dispersal of the villages, as well as the lack of equipment, qualified personnel, project-uptake facilities, and investment and maintenance funds.

Lastly, and this is not the least problem, African villagers and herdsmen do not everywhere have the motivation, the basic technical capacity and the material resources required for the satisfactory operation, maintenance and repair of the manual pumps supplied to them. Substantial progress has nevertheless been made in recent years in several fields: training of technical personnel at various levels, including management and decision-making; rational planning of drilling operations; introduction of relatively cheap and effective methods of prospecting (particularly remote-sensing and geophysical techniques); computerization of data and inventories; manufacture of equipment - especially hand pumps - in Africa itself (Tanzania); grassroots animation and education of villagers and creation of African water-drilling enterprises.

However, much remains to be done to ensure that the ground-water resources of arid Africa are managed to best effect, i.e. without wastage or medium and long-term threat to the quantity and quality of these resources. This comment applies equally to the intensively exploited coastal zone, especially at Mogadishu and in southern Madagascar.

Nor are the objectives of the International Drinking Water Supply and Sanitation Decade about to be achieved for the villages. However, it can be hoped that towards the end of the century the necessary infrastructures - wells and boreholes - and the corresponding elementary superstructures will be in place in all the villages and that the maintenance of the pumps, if not their replacement when they are worn out, will be undertaken mainly by the villagers themselves.

MAP 24. SOMALIA — HYDROGEOLOGICAL SKETCH



3484.16x

SOMALIA

Area: 638,000 km^2
Population: 5.3 million

I. BACKGROUND

Somalia has the longest coastline in Africa: in the north on the Gulf of Aden and in the east on the Indian Ocean. Along the Gulf of Aden in the north there is a mountainous zone with rugged relief; the hydrographic network is deeply incised and the torrential flows which occur here are still causing considerable erosion. The land slopes down towards the south and the watercourses which flow southwards peter out in the sands of the desert.

The rest of the country consists of a plateau with dominant limestones and sandstones. In the south the plateau is crossed in the direction of the Indian Ocean by two large rivers which rise in Ethiopia - the Juba and the Shebeli. At the end of its course the Shebeli runs parallel to the coast and disappears in a kind of interior sand delta.

In the Baidoa region between the two rivers there is a granitic mass which dominates the plain with its inselbergs. The most densely populated regions are Hargeisa in the north, the coastal zone on the Gulf of Aden in the south, the coastal plain of the Shebeli with the capital Mogadishu, and the Baidoa area.

Climate

Somalia has four seasons: two main seasons associated with the "Gu" and "Dayr" monsoons, separated by two secondary short seasons - "Gilal" and "Hagai".

Gilal - From mid-December to mid-March with dominant north-east monsoons;

Gu - From March to May; this is the spring transitional period;

Hagai - From June to the end of September, with dominant south-east monsoons;

Dayr - From October to December; the autumn transitional period.

The climate is of the arid type, especially at the coasts, with annual rainfall of less than 250 mm in the north up to the 5th parallel, with 400 mm in the south and 700 mm in the south-west. The average annual rainfall at Mogadishu is 520 mm. At some points in the country the average annual temperatures are among the highest in the world.

Surface water

The Juba River crosses the country over a distance of 875 km. At Bardera the mean annual flow is 100-125 m^3/s, with a maximum of 1,100 m^3/s.

The Shebeli River is 750 km long in Somalia and at Beled Weyne near the Ethiopian frontier its mean annual flow is 65 m^3/s. Downstream at Afgoi/Audegdle it is about 500 m^3/s. The flow is not known further downstream.

The drainage basins are small in the north. Brief and violent floods occur after rain.

II. GEOLOGY

There are two large geological units: in the north, the formations of the crystalline basement with igneous and metamorphic rocks; in the centre and south, Tertiary and Quaternary sedimentary formations, except for the Bur mountains where altered crystalline formations outcrop.

Petroleum research has indicated fault zones underlying the sedimentary formations. Two large faults run parallel to the coast and step down the sedimentary formations in successive levels from the Ethiopian plateau to the Indian Ocean.

The oldest rocks are the Bur granite and gneiss of Precambrian age. The granitic and metamorphic rocks in the north, i.e. the Borama Darbuk and Abdel Cader Heis series, are younger. They are covered with metamorphic granitogneiss with pelitic and psammitic formations (Inda Ad series). The sedimentary formation is transgressive on the crystalline formation.

The oldest formations (Lower Jurassic) are those of Adigrat and Bihendul which have alternating strata of sandstone and limestone. The formations which outcrop in the south have been encountered by deep drilling in the centre and south. The Upper Jurassic includes the Iscio Baidoa formation which has calcareous limestone and conglomerates in southern Somalia and the Bur mountains. The Anole formations outcrop between the Juba and the Shebeli (marls and limestones); the Vegit formation (limestone) and the Garba Harre formation (dolomite, sandstone) and the Cretaceous formations have been identified in outcrops through the logging of deep boreholes. At the base of the Cretaceous formation lies the Marehan formation (sandstone with clay strata in places) which outcrops in the south near the frontier with Kenya.

The Middle Cretaceous consists mainly of gypsums and limestones (the Main gypsum formation and the Garba Harre and Mustail formations) which outcrop in the Shebeli valley towards the Ethiopian frontier and between the Shebeli and the Juba. The Upper Cretaceous is covered by the Belet Uen and Fer formations consisting of gypsum, marls and dolomites.

Paleocene deposits are found in the centre of the country (Auradu formation). These are fractured karstic limestones with marl and dolomitic strata.

The very thick Taleh formation covers a large area in the centre of the country (Haud and Sol Haud plateaus; Nugal valley), and in the north. This formation consists of dolomites and gypsums, with the gypsums predominating.

The Karkar formation overlies the Taleh and is 200 m thick. It outcrops in the north. It includes limestones, marls and dolomites. Gypsum is also present.

The Eocene series are topped by the Daban formation which consists of sandstones and marls and outcrops south of Berbera and in the north.

The Upper Nummulitic and the Neogene include sedimentary formations of various origins (marine, lagoonal and continental) formed of soft limestones, conglomerates and sandstones (Daban, Scusciuban, Hafun and Duber). The Miocene is typical of the continental deposits covering the centre of the country. The Miocene-Pliocene outcrops in the Bosaso region and along the coast. It includes soft sandstones and conglomerates. The Pliocene is volcanic (Aden formation) with basalts and tufas in the northern region.

AQUIFERS

STRATIGRAPHY

Geological period	Series	Thickness (m)	Lithology	Geographical location
Pleistocene - Recent	Surface formations	0-5	Breccia conglomerate Limestone crust Laterite, gypsum crust	Whole country
	Alluviums	Up to 100	Alternation of sand and clays	Shebeli and Juba valleys and temporary watercourses
Pliocene - Recent	Sand dunes	Up to 120	Fine-grained eolian sands, crumbly sandstones, reef deposits	Coastal zone of Indian Ocean and Gulf of Aden
	Proluvium and littoral deposits	120-150	Accumulations of gravels and pebbles, coarse sands, coral and reef limestones	North-west coastal plain - narrow strip along Gulf of Aden
	Proluvium diluvium	180-220	Gypsum clays, sand, gravel, fat clays	Northern provinces, Haud plateau
	Proluvium alluviums	100-120	Clays, sands, gravel lenses	Southern provinces, lower course of Juba
Pleistocene-Pliocene	Aden volcanic series	20-70	Basalts and tufas	Northern provinces - mountainous zone of north-east

Geological period	Series	Thickness (m)	Lithology	Geographical location
Miocene-Pliocene	Upper Daban series	100-125	Sandstones and conglomerates	Northern provinces, Gulf, south of Bosaso
Miocene	Mudugh Merca	40-500	Limestone, marl, sandstone, gypsums	Southern provinces, Mudugh plateau and coast
Miocene-Oligocene	Hafun and Dubar	40-560	Conglomerate, coral and foraminiferous limestones, sandy clays	Indian Ocean coast north of Hordio and Gulf of Aden coast (Dubar)
	Scusciuban series	150-200	Marls, gypsum strata, clays and limestones	Darror depression
Miocene-Paleocene	Traps	60-80	Basalts and tufa	Interfluve, north Shebeli, Juba
Oligocene	Middle Daban	800-2,000	Sands, limestones, lenses of conglomerate with pebbles	South of Berbera, north-west region
	Hafun marine facies	200-220	Constructional limestone, sandstones, limestones, clays	Indian Ocean coast between Hordis and Eil

Geological period	Series	Thickness (m)	Lithology	Geographical location
Eocene	Lower Daban	245	Sandstones, lenses of gypsum and conglomerate, silicified wood	South of Berbera, north-west region
	Kartar	80-230	Limestones, marls, dolomites, clays	Mountainous zone, north-east (Mijurtinia)
	Taleh	350	Anhydrite, gypsum with beds of dolomites and marls	Mountainous zone in the east, haud and Sol Haud plateaus, Nogal valley
	Auradu	200-400	Massive limestone, dolomitic limestone, marls, sandstones	Mountainous zone in east, Haud plateau
Paleocene	Jesumma	100-200	Sandstone with intersected stratification, compact clays	East of the Shebeli and south of Hargeisa
Paleocene-Cretaceous	Non-differentiated	200-1,700	Massive limestones and sandstons, irregular sandstones, gravels	Western part of mountainous zone, Haud plateau
Upper Cretaceous	Fer Fer	55-90	Gypsum, anhydrite, interstratified dolomite	East of the Shebeli near Ethiopian frontier
	Belet-Uen	220	Limestone, marls, gypsiferous clay	North-east of the Shebeli

Geological period	Series	Thickness (m)	Lithology	Geographical location
Lower Cretaceous	Mustahil	120-180	Sandstones with gypsum	West of the Shebeli
	"Main gypsum" Garba Harre Mao	350-450	Gypsum, anhydrite, clay limestone	West of the Shebeli and between the Juba and the Ethiopian frontier
Undifferentiated Cretaceous	Marehan	300	Sandstones with clay strata	Near the Kenya frontier
Upper Jurassic	Garba Harre Busul	400	Marly or clastic limestone, marls, clay, limestone	North of Shebeli-Juba interfluve
	Uegit	350	Coral limestone, calcarenite	"
	Anole	300-450	Marly or clastic limestone, marls, clay, limestone	Northern part of Shebeli-Juba interfluve
	Iscia Baidoa	250-870	Quartz, limestone, marls	Western and northern edges of Bur massif
Undifferentiated Upper and Middle Jurassic	Bihendula	830-950	Limestone with sandstone intercalations, sandstones, marls, gypsum, conglomerates	Mountainous zone (centre)
Lower Jurassic	Adigral	40-1,000	Coarse quartzitic sandstones	Mountainous zone in centre and west
	Unnamed	80	Limestone and sandstone at the base	North-east of Bur

Geological period	Series	Thickness (m)	Lithology	Geographical location
Ancient Paleozoic	Post-Indo	over 1,000	Granite, pegmatite, aplite, quartz, porphyrite	Mountainous zone between latitudes 47° N and 49° N
	Halveto	200-300	Pelites, limestone strata	
	Seinat	800	Tufa, sandstone, interstratified conglomerate, schists	
	Hadit	2,500	Irregular sandstones, conglomerates	
	Magno	2,000	Sandstones	
Upper Paleozoic	Aran	3,000	Sandstones, conglomerates called interstratified limestones	
Lower Proterozoic (crystalline basement)	Acid igneous rocks	over 1,000	Granite, gneiss, pegmatite, aplite	Mountainous zone of west
	Basic igneous rocks	over 1,000	Gabbro, ultrabasic rocks, syenites	"
	Abdel Cades Heis	over 1,000	Andesite, tufa, pelites, schists, gneiss	Mountainous zone of west, north-west of Erigavo
	Borama Darburuk	over 1,000	Metamorphic limestone, pelites, schists, gneiss	Mountainous zone of west

Geological period	Series	Thickness (m)	Lithology	Geographical location
Undifferentiated Precambrian	Bur igneous rocks	over 1,000	Granite, gneiss, diorite	
	Bur Acaba	over 1,000	Gneiss, schists, amphibolites, quartzite	Bur zone west of Mogadishu

Lastly, mention must be made of an extensive Eocene-Quaternary formation consisting of sandy deposits with clays and saline soil.

III. HYDROGEOLOGY

The Water Development Agency (WDA) has central responsibility for ground-water affairs. The large towns have their own services; the country enjoys international and bilateral aid in ground-water development (especially from the Federal Republic of Germany, the United States and Italy). Studies and data collection were undertaken in 1950-1960. Several United Nations projects were subsequently implemented. The drilling operations were not always successful; in some cases the chemical composition of the water made it unfit for use.

The following are the main aquifers:

- Pleistocene-Pliocene volcanic rocks (Aden);
- Miocene-Oligocene conglomerate sandstones (Hafun);
- Oligocene tufas and basalts (Traps);
- Eocene dolomitic limestones (Karkar);
- Eocene massive karstic limestones (Auradu);
- Eocene sandstone (Jesoma-Nubian);
- Eocene limestones (Belet-Uen);
- Cretaceous sandstones (Marehan);
- Jurassic sediments without gypsum.

The Taleh Cretaceous formations and the Jesoma-Nubian sandstones are of very little interest owing either to the smallness of the accessible yield or to the poor quality of the water. The Auradu formation is an excellent aquifer in its fractured zones. The volcanic "Traps" in the centre of the country (Shebeli valley) are an excellent aquifer.

The ground-water potential of each of these main regions of the country can be summed up as follows:

Mountainous zone in the north

Good yields can be expected in the accessible areas at the foot of the slopes consisting of consolidated sediments; here the aquifers are unconfined but lie at great depth. The yields ought to be fairly high, in particular in the tectonized limestone or dolomitic zones, the gently sloping plain and the alluvial zones.

However, the potential is poor in the areas of crystalline rock and in the coastal plain, but there may be some potential close to areas of heavy runoff.

Northern sub-basin of the Ogaden and sub-basin of the Darror depression

An excellent yield can be expected from:

- Recharge zones which contain the unconfined aquifers of the upper alluviums of Tug Der in the Burao and Erigavo sectors and in the areas around the Darror depression;

- Jesoma sandstones near Bulo Burti and Belet-Uen and in the sector which may be recharged from the Shebeli.

The exploitation of the consolidated subartesian aquifers for irrigation purposes is considered unlikely. These formations have very poor transmissivity, and this means large drawdowns for small yields. The prospects are better with respect to supplying the people and their livestock, but the boreholes must be installed very efficiently if the desired output is to be obtained with an acceptable drawdown.

Baidoa basin

The potential of the recharge zones may be good, with strata about 3 m thick lying close to the surface and offering acceptable specific yields, i.e. drawdowns in the order of 1.5 m for yields of 12 to 15 l/s. These conditions are promising, for the aquifer can be reached by hand-dug wells.

Although the rest of the basin has a good potential with respect to supplying the people and their livestock, the possibilities of irrigation are limited by the depth to the water table and the large drawdowns in the artesian part of the basin. Further west, the shallow-lying water is saline; heavy pumping would place this saline water in communication with the deeper sweet water and impair its quality.

Alluviums

Generally speaking, the alluvial aquifers have not really been studied and, with the exception of the Shebeli valley, they have not been exploited. On$25athe basis of the lithology of the basin lying above the alluviums, the recharge potential, some data collected from old documents and discussion with drillers and geologists, it can be argued that the potential will be:

Excellent in:

- Uadi Giohel (but there is no proof of this; it is only an opinion);

- Upper Tug Der: this is confirmed by data on Brava and indirectly by the results in the Hargeisa region.

Good in:

- The Erigavo-Gardo area: again there are no figures to confirm this, but if the general observations are confirmed, this zone could have a good potential in places;

- The lower valley of the Tug Der-Nugal, for which very few data are available. However, the observations of the upstream potential and of downstream springs of drinkable water suggest that the potential of the upper valley extends downstream;

- The upper Galka'yo, where there is less contamination from surface gypsums. This appears to be the oldest alluvial system in the region.

Poor in:

- Lower Galka'yo, although the middle Galka'yo might furnish water suitable for irrigation but with a high sulphate content;

- Dusa Mareb;

- The alluviums of the Juba River.

Chemical quality of the water

These data are taken from an unpublished GTZ report written by C. Faillace in 1986. They refer to the central and southern parts of the country.

Zone	Depth (m)	Water quality	Comments
North of Baidoa	100-150	Good for all uses	Water resources still to be evaluated
South-west of Baidoa	100-150	Good to average	Additional boreholes can be drilled to supply villages and livestock
Waajid	60-80	(Believed good)	Villages and livestock
Damassa	120-200	Promising	Three or four test holes needed
Tabda-Hosingo	120-180	Good to acceptable	Additional pastoral boreholes to be drilled depending on availability of grazing land
Lach Dera (alluvium)	Shallow	Good	Study programme recommended
River Juba (alluvium)	Shallow	Good to acceptable	Favourable zone for shallow wells or boreholes for village water-supply programme
Shebeli River	Shallow	Good to acceptable	Favourable zone for shallow wells or boreholes for village water-supply programme and sites to be chosen close to river banks and swampy areas
Bur area	Shallow	Good to marginal	Suitable for shallow wells and galleries
Coastal sand dunes	Shallow	Good to acceptable	Additional studies needed to determine potential of sweet-water lense

Unresearched areas where studies should be made

Zone	Aquifer depth (m)	Water quality	Comments
North-east of Bur-Acaba	100-150	Estimated good	Reconnaissance hole needed
Bandar-Jalalqsi fault	80-100	Unknown	Geophysical exploration and drilling recommended
Juba fossil bed	30-50	Unknown	Exploration by shallow borehole recommended
North-east of Chisimayo		Acceptable to marginal	Exploration of deep aquifer for pastoral purposes desirable

IV. EXPLOITATION OF THE GROUND WATER

In Somalia the Water Development Agency (WDA) is responsible for most operations concerning the development of ground water, including construction of installations and their maintenance. The WDA has several departments, sections and offices in the field and employs more than 500 persons: hydrogeological engineers, administrators and drillers. Some of these persons have been sent abroad for higher studies. The WDA has 20 drilling rigs: 7 Ingersoll-Rand, 5 Failing, 3 Speedstar, 3 Bomag and 2 Soviet rigs. There are 30 foremen drillers and an equal number of assistant drillers with poor technical qualifications. Somalia has only a small number of private drilling firms. The projects financed by foreign aid usually employ foreign subcontractors.

The other bodies concerned, although to a lesser degree, with ground-water exploitation in Somalia are: the National Range Agency, the Livestock Development Agency, the Banana Board, and the water boards of Mogadishu, Chisimayo and Hargeisa.

V. USE OF THE GROUND WATER

The ground water is used mainly to supply urban and rural dwellers and also for industrial installations such as the Mogadishu oil refineries. It is also used to water livestock, of which there are large numbers: 5 million camels, 4 million cattle, nearly 10 million sheep, and 15 million goats. In the rainy season the herds are watered from surface water - either watercourses or natural or artificial ponds. In the dry season they are watered from the two main rivers, wells and boreholes, and swamps.

It was estimated in 1982 that 60 % of urban dwellers and 20 % of rural dwellers had water of acceptable quality in sufficient quantities.

Needs

In the north-west the availability of water is the main condition of development. Rain water must be collected before it runs off carrying with it arable topsoil It is difficult to envisage the construction of dams, owing to their high cost, the intense evaporation, the presence of salts and the lack of hydrological data. The construction of underflow dams would reduce both the amount of evaporation and the maintenance costs.

In the rest of the country the water resources are generally sufficient to meet the needs. The studies needed for the exploitation of the aquifers are still to be carried out.

VI. CONCLUSION

The best conditions for development of ground water are found in the alluvial valleys descending from the northern mountains towards the Ogaden, in the Uadi Giohel area, near Burao (upper Tug Der region), in the Bur area, in the lower Shebeli valley, and along the faults in the coastal zone.

When the potential resources are compared with the population's needs (taking into account the distribution of the population and industries), it does not seem that Somalia should be a country short of water, but the resources need to be explored and exploited. Most of the main towns, with the exception of Galka'yo, and Dusa Mareb, have in vicinity ground-water resources in suitable quantities and of suitable quality which can be exploited at a reasonable cost.

Mention has already been made of the existence of promising aquifers in areas where the land is suitable for irrigation.

Elsewhere, i.e. in grazing areas, water for the animals can be found in the sand formations, in springs rising in the beds of the watercourses and in boreholes. However, most of the installations consist of shallow hand-dug wells in which the water level is subject to wide seasonal fluctuations of 1 to 2 m. In these conditions 70 to 80 % of the country's livestock has no water in periods of drought. Sixty-five per cent of the wells are only 4 m deep and contain less than 50 cm of water. Most of the other 35 % are in the Shebeli alluviums where water supply is not a problem.

VII. REFERENCES

Geology

Piccoli, G., Rassegne bibliografica geologica della Somalia. Quaderni di Geologia della Somalia, No. 2. Mogadishu, Faculty of Geology, 1978.

Water demand

Gribb, Feasibility study for Mogadishu water supply expansion. Nairobi, 1976.

Howards, H., Hargeisa water supply investigation. Westminster-Nairobi, 1960.

HTS, Inter-rivenue agriculture study. Herts, England, 1977.

__________, Livestock sector review and project identification. Herts, England, 1976.

Surface water

FAO, Ctr Kreger, Lockwood, Meredien, 1968.

HTS, Project "Water resource control and management of the Shebeli River, Somalia". UNDP/FAO, 1969.

MMP, Genale-Bulo Marera project. Cambridge, MMP, 1978.

Ground water

Faculty of Geology, Ground-water survey - Farjano project, 1986.

Faillance, Surface and underground water resources of the Shebeli Valley. Mogadishu, 1964.

FAO, A conceptual review of Somalia's ground-water resources, 1978.

Hunt, Report on the geological work carried out in connection with proposed subsurface dam, Hargeisa, 1954.

Hydrotechnic Co., Ground-water investigation for Mogadishu. New York, Hydrotechnic Co., 1963.

__________, Feasibility report on Mogadishu water supply system. New York, 1963.

Pozzi, Lineamenti Idrogeologici della Somalia. Mogadishu, Faculty of Geology, 1978.

Pozzi and Benvenuti, G., Studio geologico applicato e geofisico per dighe subalvee del distretto del Nugal. Padua, Memoria della Societa, 1979.

Parsons, Hydrogeological studies - Mogadishu water supply. Los Angeles, Parsons Co., 1970.

Mention must also be made of the technical and terminal reports of the following UNDP projects executed by the United Nations:

(*) - Mining and ground-water research - Phase I (1970)
- Mining and ground-water research - Phase II (1971)
- Mining and ground-water research - Phase III (1975)
- Ground-water research and exploration (1977)

(*) With hydrogeological reconnaissance map which has subsequently been published.