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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

UNITED NATIONS
New York, 1989

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.

ST/TCD/6

UNITED NATIONS PUBLICATION

Sales No. E.88.II.A.5

03950

ISBN 92-1-104223-2

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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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1/ United Nations publication, Sales No. E.60.II.B.3.

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.

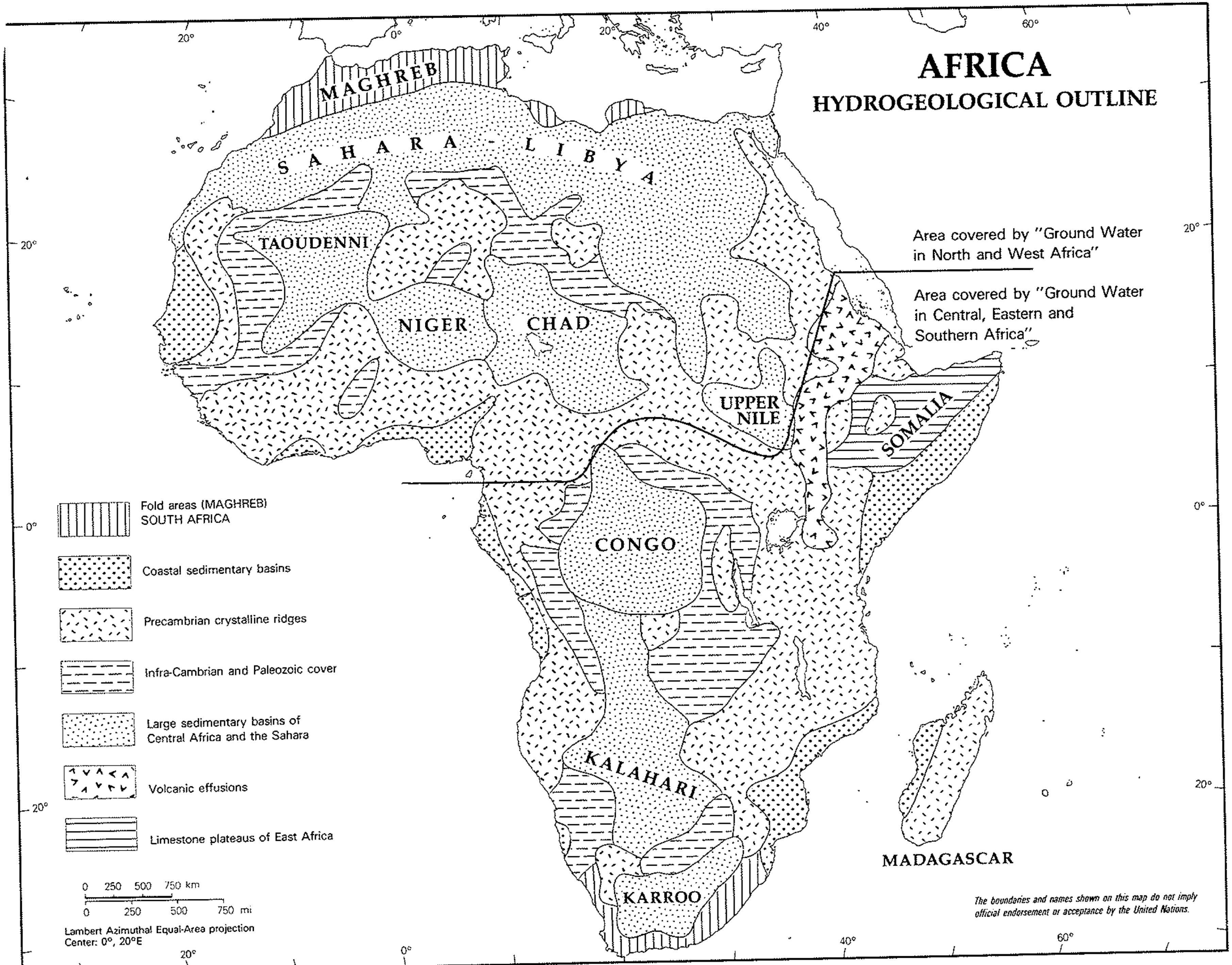
Use of a hyphen (-) between dates representing years, e.g. 1975-1978, signifies the full period involved, including the beginning and end years.

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.



MAP NO.3432 Rev.1 UNITED NATIONS
MARCH 1989

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.

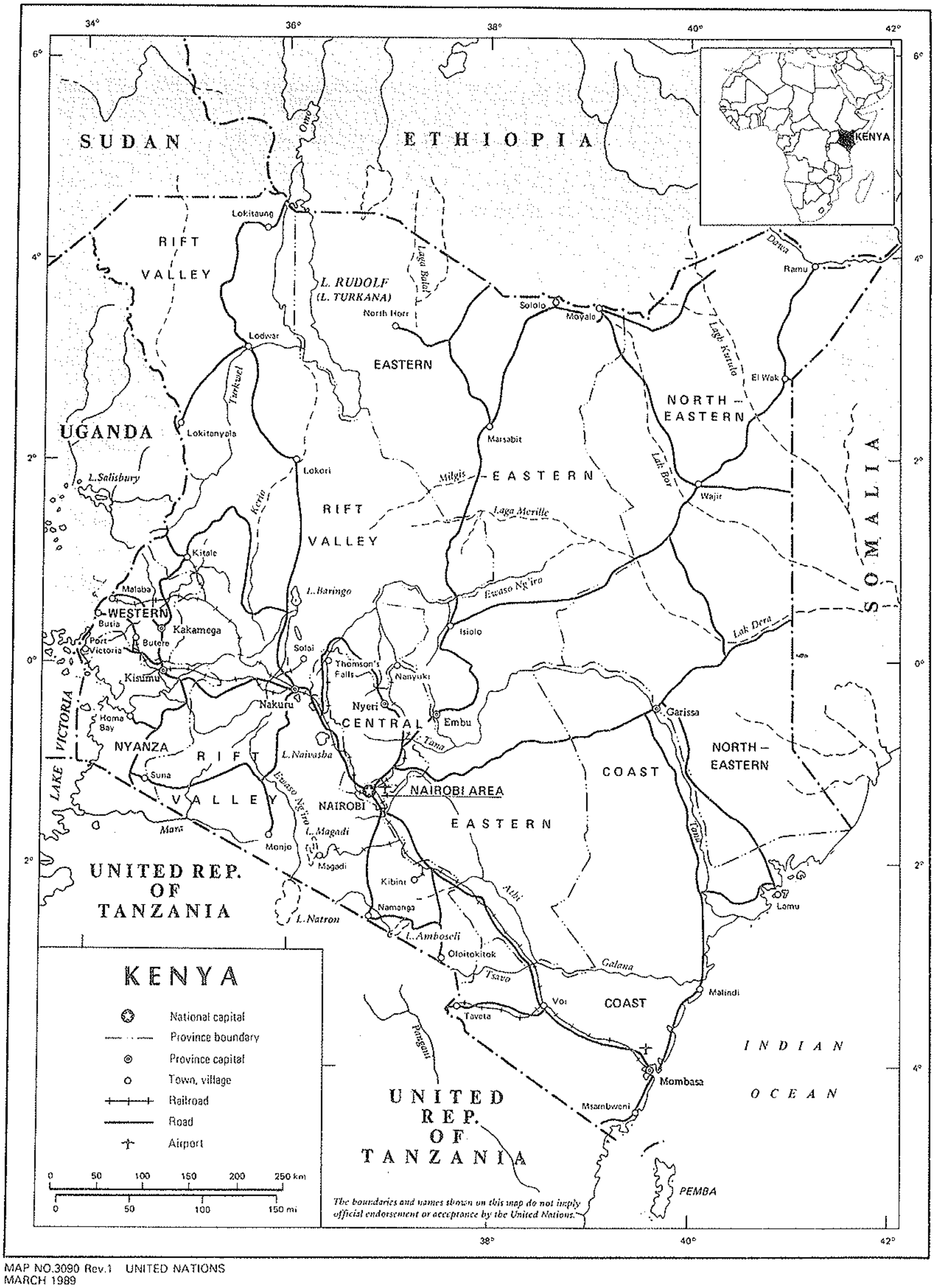
Furthermore, ground-water prospecting and the drilling and digging of wells are usually difficult and expensive operations owing to the weakness of the infrastructures, the unfavourable natural conditions, the remoteness of the zones to be reached and the wide dispersal of the villages, as well as the 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 12. KENYA — GENERAL MAP



MAP NO.3090 Rev.1 UNITED NATIONS
MARCH 1989

KENYA

Area: 582,700 km^2
Population: 19 million

I. BACKGROUND

Kenya has 500 km of coastline on the Indian Ocean between Ethiopia and Tanzania; it also has access to Lake Victoria, Africa's largest lake. The country is crossed at its centre by the equator. The altitude increases from east to west. The western half of the country is over 1,000 m and the region north-west of Nairobi at 2,000 m above sea level. The highest point is Mt. Kenya (5,200 m).

Rainfall averages 250 mm in the arid regions and over 2.5 m in the mountains. The 700 mm isohyet marks the eastern limit of the wet region, which has an abundance of watercourses and springs. The eastern half of the country has a climate of the semi-arid or arid type, desert in places. The same is true to some extent of the north-west of the country.

In contrast, the south-west third of the country is well watered and has a pleasant climate and good-quality soils. The majority of the population is concentrated in this region, and the population growth rate is one of the highest in the world (3.5 to 4 %).

Surface water

The country's hydrographic network is dominated by the Rift Valley which bisects the plateaus region from north to south. The floor of the Rift Valley is occupied by lakes in the centres of endorheic basins. West of the Rift Valley, the surface water flows towards Lake Victoria and into the Nile Basin: to the east it flows south-east to the Indian Ocean.

The country has five large systems of drainage basins, with many small lakes in the intervening areas.

The Athi drains most of the south-east of the country from the slopes of the Aberdare mountains and the eastern side of the Rift Valley and flows into the Indian Ocean. Some other watercourses reach the coast and others peter out before the coast.

The Tana drains the western slopes of the Aberdare, the southern slopes of Mt. Kenya and the Nyambeni mountains, flowing towards the Indian Ocean.

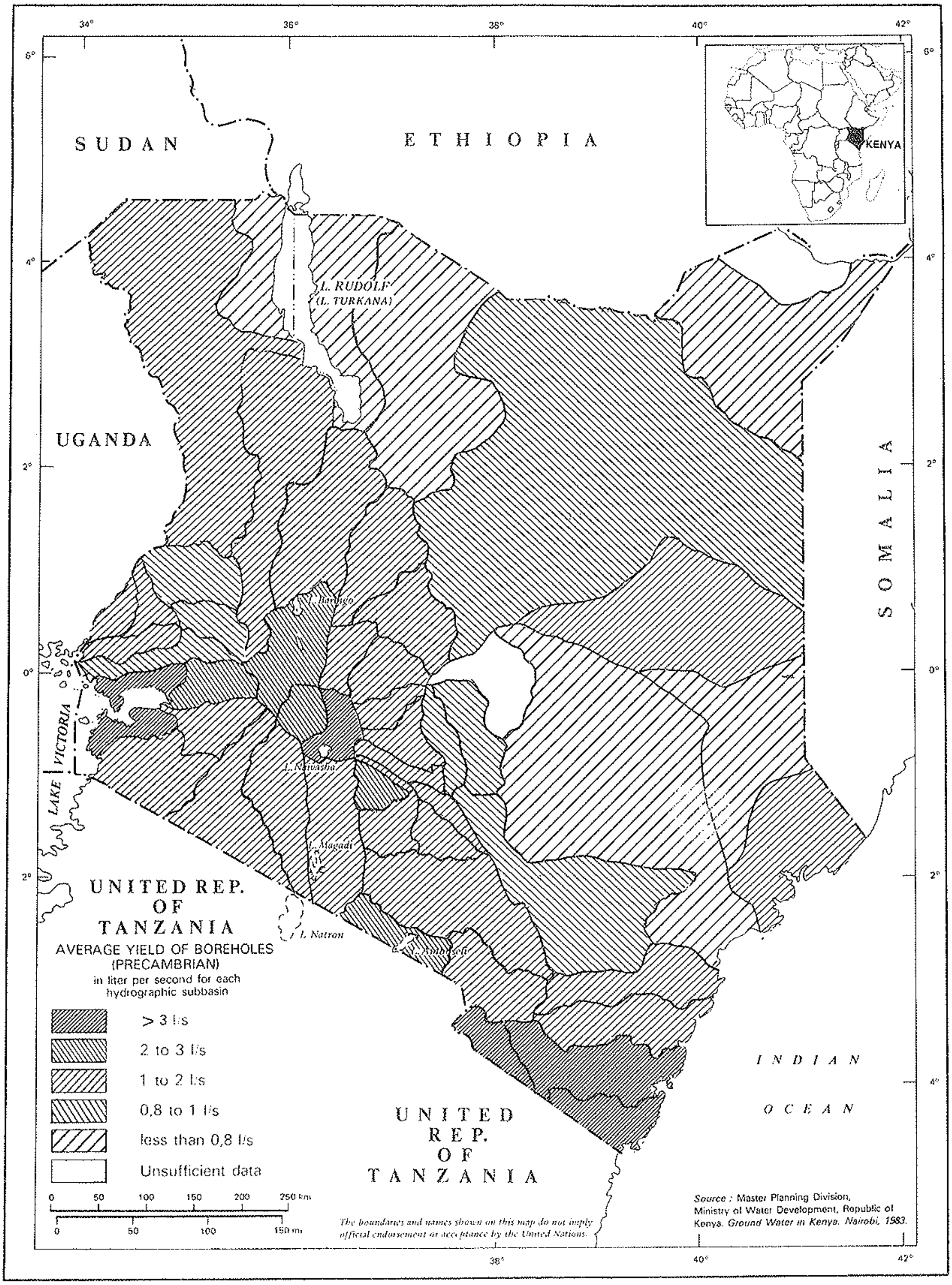
The waters of the Ewaso Ng'iro region come from the northern slopes of the Aberdare and Mt. Kenya and from the high plateaus and lower mountains in the north and north-east. With the exception of the Ewaso Ng'iro itself the flows, which are of the torrential type, occur immediately after rain.

These large basins are in turn subdivided into 52 main basins and sub-basins.

II. GEOLOGY

The whole of the centre and west of the country is part of the Precambrian crystalline basement: "Archean" schists, quartzites and cipolins, conglomerates, schists, feldspathic sandstones, volcanic rocks and quartzites of the Middle and Upper Precambrian.

MAP 13. KENYA — AVERAGE YIELD OF TUBEWELLS



3484.9x

Karroo sandstone sediments of carboniferous-triassic age outcrop parallel to the coast in a strip 80 km wide.

Jurassic formations outcrop in the coastal zones, in north-eastern Mandera and at Wajer, near the frontier with Somalia.

Cretaceous (limestones) and Tertiary (argillaceous limestones) formations of marine origin also cover vast expanses in the east. The Great Rift Valley, which was formed in the Tertiary period, is covered with continental sediments.

Volcanic eruptions in the Miocene period produced effusions of phonolitic and rhyolitic basaltic lavas. These volcanic formations cover more than a quarter of the country north and east of Nairobi.

III. GROUND WATER

State of knowledge

The main studies which have been made are listed in the reference section. The reports provide excellent information about some of the areas studied. The report prepared by the World Health Organization in 1973 gives a good summary of the state of knowledge at the time of its drafting. However, there are detailed studies for on a small part of the country. Moreover, in most cases these studies consist only of reconnaissance work; the quantitative aspects of ground-water flows are only rarely taken into account; the recharge zones are not delimited, and the effect of pumping on the artesian aquifers is not specified. The reasons for this are clear: priority had to be given to the extraction of ground water to meet the country's needs. Almost all the available funds were spent on drilling operations, and little money or time was given to the study of the effects of the operation of the installations.

The importance of ground water in Kenya is evident when there are no other available water resources. Kenya has some 4,500 water boreholes drilled in the past 50 years.

Between 1923 et 1934, about 190 boreholes equipped with casing strings and strainers were drilled, and a further 133 during the Second World War. Since 1970 an average of 100 boreholes have been installed every year.

Water-drilling operations are monitored by the Ministry of Water Development (MWD). The MWD collects data on boreholes drilled by private individuals and companies by means of the mandatory prior authorization required by law.

The MWD is itself responsible for most of the water-drilling operations in Kenya. Its stock of equipment included in 1983: 6 rotary rigs, 7 cable rigs, 1 combined rotary-percussion rig and 3 light rigs. It also subcontracts to companies which have a total of about 15 drilling rigs.

The data on the oldest boreholes are incomplete and the location of several old holes is not known. However, substantial and reliable data are available for recent years, especially with respect to the results of multiple test pumping and the corresponding recovery curves.

Aquifers

Kenya has unconfined, artesian and semi-artesian aquifers.

The table below presents some data on the aquifers. These data were obtained by computer processing of the inventory of boreholes. The following remarks may be made in this connection:

- Depth of the installations. These are boreholes traversing volcanic rocks down to very great depths: 125 m as against 92 m for the crystalline rocks of the Precambrian basement and 78 m for sedimentary rocks;

- Water level (after stabilization in the borehole). This is an important datum, for the depth of the water below ground level, at rest and under pumping, has a direct effect on the cost of pumping. A map has been produced which indicates the water depth by basin. It shows that the greatest depths are found in the north of the country and in the Rift Valley where they exceed 55 m. The shallowest holes (under 20 m) are located in the west and south-east and in the Upper Tana basin;

- Artesian head. The average value for all the boreholes in the sedimentary rocks is only 6 m; for 25 % of the installations it is only 1 m. In the crystalline basement rocks and volcanic rocks it is 20 and 40 m respectively;

- Abandoned boreholes. Some boreholes were abandoned on completion either because the yield was thought insufficient (or nil) or because the water proved unsuitable for the uses for which it was intended. Other holes were abandoned shortly after commissioning, mainly because the yields steadily declined. On the basis of the available data the proportion of boreholes abandoned is estimated at:

  9 % for volcanic rocks
  24 % for the crystalline basement
  22 % for sedimentary rocks

Yield of boreholes
(See table below)

The average yield for the whole country is 6 m^3/h, with large differences from basin to basin. The basins with the highest yields are in the regions of Lake Victoria and Lake Naivasha and in the far south-east of the country.

The basins with the lowest yields are in the vicinity of Lake Turkana in the north-east and around the middle and lower courses of the Tana.

The type of water-bearing geological formation has an important influence on the yield, with on average:

4.4 m^3/h for the crystalline basement
7.6 m^3/h for volcanic rocks
7.7 m^3/h for sedimentary rocks

BASIC DATA ON BOREHOLES - AVERAGE VALUES

Drainage basin identification number		Main geological formation	Total number of boreholes	Average depth (m)	Water level (m)	Initial output (m^3/h)
1	A	Crist. basement	12	63	14	7.1
	B	"	82	70	18	3.1
	C	Volcanic rocks	88	71	15	3.5
	D	Crist. basement	11	86	8	6.5
	E	"	9	95	17	7.1
	F	Volcanic rocks	16	133	23	3.5
	G	"	82	123	38	9.5
	H	"	63	96	18	11.7
	J	"	26	160	46	4.4
	K	"	22	111	23	6.8
	L	"	24	158	71	5.4
2	A	None	5	41	8	0.5
	B	Basement	31	44	16	3.7
	C	None	17	80	28	4.2
	D	Volcanic rocks	13	130	53	4.6
	E	"	226	151	67	7.9
	F	"	163	149	85	7.4
	G	"	234	113	62	11.8
	H	"	62	182	110	5.1
	K	"	20	163	80	5.4
3	A	Volcanic rocks	443	127	50	6.1
	B	"	932	132	47	8.2
	C	Basement	40	145	47	9.4
	D	"	22	109	26	6.2
	E	"	101	103	24	6.2
	F	"	239	107	36	5.4
	G	"	12	119	59	4.7
	H	Sedimentary rocks	24	93	41	4.6
	J	Volcanic rocks	5	55	28	17.0
	K	Sedimentary rocks	21	81	21	13.0
	L	"	121	51	19	4.1
	M	"	126	99	24	12.8
	N	Volcanic rocks	22	106	42	9.4

Drainage basin identification number		Main geological formation	Total number of boreholes	Average depth (m)	Water level (m)	Initial output (m^3/h)
4	A	Volcanic rocks	30	122	53	5.8
	B	"	60	90	14	6.1
	C	"	99	120	42	6.5
	D	Basement	13	109	26	3.3
	E	"	23	105	50	3.0
	F	Volcanic rocks	2	21	11	2.0
	G	Basement	22	115	62	2.0
	H	"	40	91	31	3.4
	J	Sedimentary rocks	21	147	118	3.0
	K	Basement	18	71	36	8.4
5	A	Volcanic rocks	93	121	50	4.7
	B	"	107	106	40	6.2
	C	"	41	149	46	5.0
	D	None	89	104	36	4.7
	E	Basement	162	96	58	3.1
	F	Sedimentary rocks	54	128	104	5.5
	GH	Basement	25	114	60	1.4
	J	"	16	84	17	2.5

The specific yield can be as high as 18 $m^3/h.m$. The highest values are obtained in the central and eastern parts of the country, while the lowest values are very irregularly distributed (no data are in fact available for many of the basins; average values have not therefore been given).

The boreholes in the basement formations have the lowest specific discharges and those in the sediments have the highest.

Quality of the ground water

Systematic water analyses are made, including quantitative analysis of the main ions, for most of the boreholes currently being drilled, but this was not always the case in the past. The computerized inventory of boreholes distinguishes three categories: good, poor and unfit for drinking.

In the eastern half of the country, one borehole in seven yields undrinkable water, while in the western half the proportion is only 1 in 170. This difference is due to the rainfall, where there is little rainfall, the recharge and flow of ground water are also low, and this cause increased salinity.

The small scale map opposite shows the facies and mineral content of the water. In the areas with high rainfall, i.e. in the centre of the country and the coastal zone, the water is mainly bicarbonate with a dry residue below 1,500 mg/l; this water can be classified as "good". In the areas with little rainfall in the north and east, chlorides predominate and the salinity is much higher. This part of the country contains most of the water points classified as "unfit".

The presence of ground water with an exceptionally high fluoride content has long been knows in Kenya. It is clear that this phenomenon is directly related to volcanic activity, but no detailed study has yet been made, although this is a particularly important factor owing to its effects on the health of the people concerned.

IV. EXPLOITATION OF THE GROUND WATER

About a quarter of the boreholes are located in the Nairobi area and account for a third of the total volume of water pumped for the whole country.

The amounts of water drawnoff are not usually measured. The only datum is the test yield established on the completion of the installation, and this is the figure which appears in the inventory. If a borehole utilization coefficient of 15 % is applied, the average drawoff from the boreholes can be estimated as 15 % of the initial test yield. It has been verified that this rate is close to the actual rate in Kenya, as in other countries, for various water uses. The table which follows presents, on this basis, an evaluation of the current rate of extraction of ground water.

Drainage basin	Number of boreholes	Average initial yield (m^3/h)	Total initial yield (m^3/h)	Estimated drawoff (millions of m^3/year)*
1	403	6.4	2,579	3.4
2	672	8.4	5,645	7.4
3	2,015	7.4	14,911	19.7
4	296	5.3	1,569	2.1
5	512	4.5	2,304	3.0
	3,898	-	27,008	35.6

* Estimated drawoff calculated from the total initial yield multiplied by a utilization factor of 15 % and converted into millions of cubic metres per year.

The following example will illustrate the exploitable potential. It may reasonably be estimated that 5 to 10 % of the rainfall goes to recharge ground water in all the regions of the world; for greater safety, a rate of 1 % is used for Kenya.

In the table below the potential calculated in this way is compared with the draw off, which could be increased by a factor of 88 over the 36 million cubic metres a year currently drawn off from a total potential stock of 3 billion m^3 a year.

No. of drainage basin	Annual rainfall (millions m^3)	Annual drawoff (millions m^3) Potential	Present	Non-present potential quotient
1	59,000	590	3.4	174
2	64,800	648	7.4	86
3	41,800	418	19.7	21
4	71,800	718	2.1	342
5	74,100	741	3.0	247
Kenya	311,500	3,115	35.6	88

A potential drawoff of 3 billion m^3 a year does not in fact represent a limit but merely expresses an average rate of recharge of the aquifers equal to 1 % of the rainfall. This very general and simplified estimate does not take into account the effects of the exhaustion of certain overexploited aquifers, the interaction between closely spaced pumping points, or chemically unacceptable water quality - factors which must be considered even in an outline programme for the development of ground-water aquifers.

V. CONCLUSION

The potential values given above must be treated with great caution. Defective installation, for example, may lead to overexploitation or harmful interaction between boreholes, and thus to increased water costs. If the ground water is to be exploited efficiently and economically, with high-yield boreholes, the holes must be drilled with great care, using the necessary techniques such as geophysical prospecting and test pumping and interpretation of the results.

The installation of linings and strainers in the boreholes must receive careful attention in both planning and execution.

The limitations of estimates based on a rainfall infiltration rate of 1 % must also be borne in mind; in many basins some of the ground water drains towards the surface and emerges as springs and resurgences in the beds of watercourses. This water cannot therefore be counted as new ground-water resources to be developed by borehole. In contrast, in the most arid zones the aquifers are recharged in very few places, mainly where the sudden and brief torrential flows converge following rainfall. The best conditions for the exploitation of ground water are found in the vicinity of small towns and villages in areas of medium altitude where the ground water can be exploited for domestic purposes and also to provide additional irrigation for crops which need it.

The most recent studies and prospecting work, particularly in western Kenya, have demonstrated that ground water is accessible close to the surface over vast areas; this must be taken into account for the implementation of large village water-supply programmes on an economic basis and with the appropriate technology, i.e. with wells drilled or dug to a maximum depth of 20 m and equipped with hand-operated pumps. It mays thus be expected that in the future greater use will be made of shallow-lying ground-water resources to supply rural dwellers.

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