

Department of Technical Co-operation for Development
and Economic Commission for Africa

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**GROUND WATER
IN
NORTH AND WEST 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 data 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

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- 1/ United Nations publication, Sales No. 60.II.B.3
 - 2/ United Nations publication, Sales No. E.71.II.A.18.
 - 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.

fourth, entitled Ground Water in the Pacific Region, 6/ for the fifth, entitled, Ground Water in Continental Asia, 7/ and for the present volume, the sixth in the series, which is to be followed by a seventh on ground water in central, eastern and southern Africa and an eighth on ground water in Europe. This 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 among its nationals university graduates or engineers specializing in hydrogeology or ground water.

It is to be hoped that this volume, which deals with a number of arid countries, in particular the "Sahelian" countries affected by long periods of severe drought since 1973, 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 from Africa and other countries who have collaborated in the preparation of this work, in particular the Department of Water and Energy of Mali, the Office of Water Research and Planning of the Department of Water of the Kingdom of Morocco, the Mataria Desert Research Institute (Arab Republic of Egypt), the National Service for the Installation of Water Points of the Republic of Guinea, and the Office of Geological and Mining Research (Orleans, France), as well as A.M. Abdoul, N.B. Ayibotele, I. Barry, R.M. Blamdandi, A. Cavaco, P. Chaperot, Checkh Becaye Gaye, N.C. D'Almeida, E. De Boer, A. Diallo, M.A. Diallo, S.M. Dossou, J. Dubus, M. Faloci, D. Fernandopulle, R. Friedmen, J.A. Hanidu, M. Haupt, W. Iskander, M.T. Jones, L. Kossakowski, J.C. Lachaud, J. Margat, T. Mba Mpondo, L. Moullard, E. Njié, Saad Ali Sabet, O.M. Salem, M. Simonot, W.G. Strupczewski, D.Z. Sua, P.S. Zahiri, E.H. Zander and H. Zebidi.

The simplified hydrogeological map of Africa appended to this volume was kindly supplied by Mr. J. Marget. 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.

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

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

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 dollars.

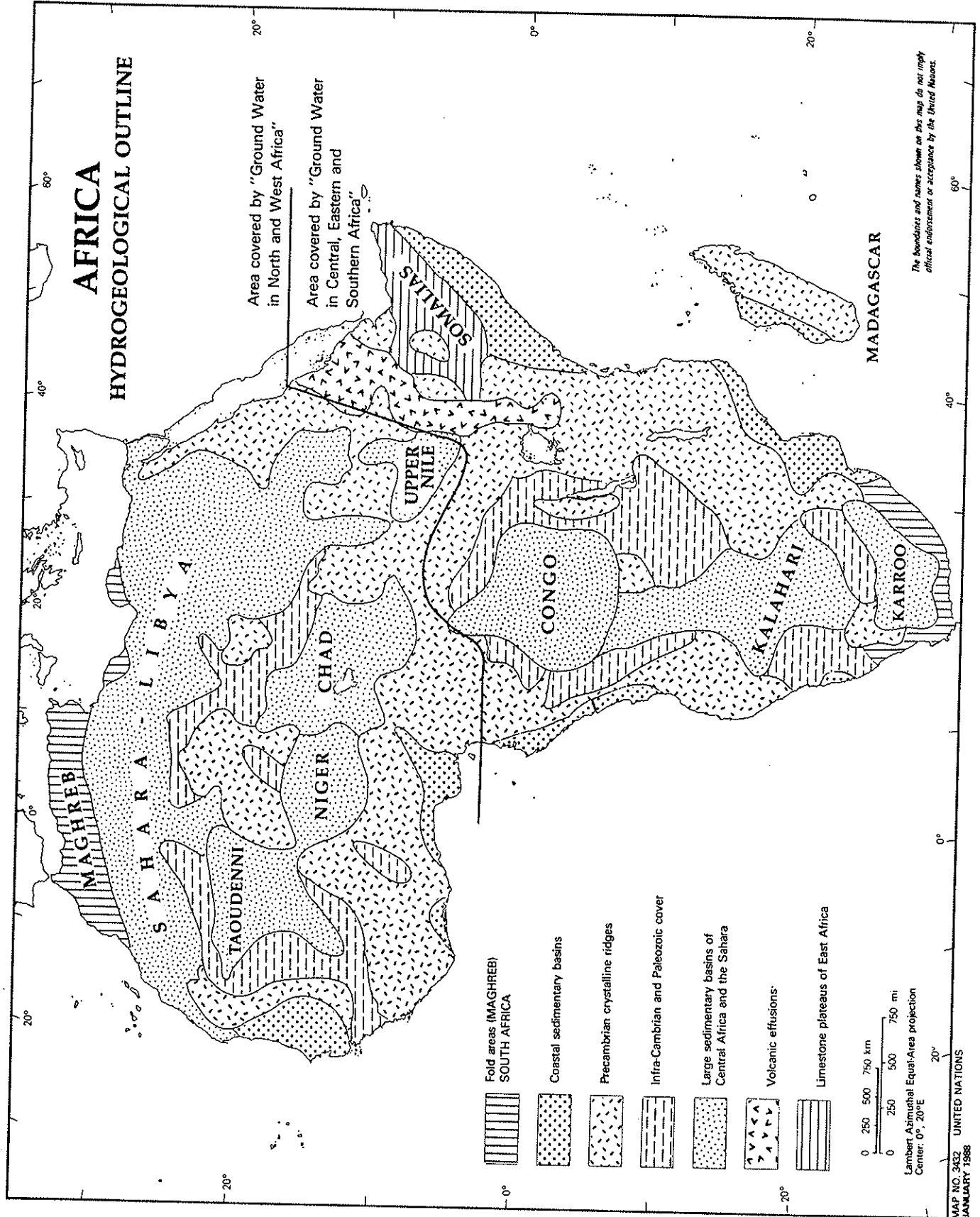
Details and percentages in tables do not necessarily add to totals because of rounding. Some of the data series are not homogeneous; they have been taken from various reviews and publications; the differences or divergencies may be due to typing errors.

The designations employed and the presentation of the material 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.

AFRICA

HYDROGEOLOGICAL OUTLINE



The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations.

PART ONE

OVERVIEW

This volume deals with ground water from the standpoint of the physical conditions of the accumulation 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 north of the Equator, except for Ethiopia and Somalia which belong geographically to East Africa, to be covered in a second volume on all the countries of central-equatorial and southern Africa, including Madagascar and the neighbouring island countries and territories.

I. LARGE AQUIFER SYSTEMS

This vast territory of 17.2 million km² with 300 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) To the north-west, the mountains and plateaus of the Atlas and the Rif and the Mediterranean and Atlantic coasts in the north and west. This is the "Maghreb" of Morocco, Algeria and Tunisia, north of the Sahara. From the geological standpoint these are mainly sedimentary formations strongly affected by Alpine orogeny. The region has contrasting landscapes: it has different climates ranging from the Mediterranean or subhumid type to the semi-arid or even arid type: Moroccan plains north of the Atlas, Algerian high plateaus; here the ground water is intensely exploited to an average extent of 80 or 90 per cent of the renewable resources or even higher in some places, especially in the semi-arid and arid areas.

ii) In the north-east, the Mediterranean fringe constitutes a kind of extension of the Atlas but much more modest in its relief, extent and altitude. The mountains receive quantities of rain which can recharge the neighbouring aquifers, but the renewable resources are small and generally overexploited.

iii) To the south of these areas lies the Saharan region and the deserts which form its eastern extension - the Libyan and Nubian deserts; this is an enormous, generally flat, monotonous territory where the rainfall is infrequent, irregular and very meagre, except over some mountainous areas. It is made up of sedimentary basins mainly of continental origin but with some lagoonal and marine basins in which the beds generally lie in regular horizontal or subhorizontal strata. Two sandstone formations constitute large aquifers of the fossil and Mesozoic types: the "intercalated continental" in Algeria and Libya and the "Nubian sandstones" in Libya-Egypt-Sudan. To the west (western Algeria and Mauritania), the formations are of hard Paleozoic rocks with low permeability in which the ground-water resources are much smaller, except locally.

- iv) The crystalline Precambrian basement rock underlying these sedimentary basins emerges in great masses at the west-east axis of the Sahara: Tiris-Adrar, Yetti-Karet (Mauritania-Algeria). The Hoggar mountains which rise to almost 3,000 m in volcanic peaks (Algeria) flanked in the south by the ranges of Adrar des Iforas (Mali) and Air (Niger), Tibesti (Chad), Ouaddai (Chad), Darfour (Sudan) and the majority of the territory to the east of the Nile as far as the Red Sea. As far as ground water is concerned, this is a mainly barren region, with the exception of a number of alluvial deposits at the foot of the mountains. When present - a fairly rare occurrence - the ground water is far from abundant and in many cases heavily mineralized.
- v) To the south of this ancient backbone the general situation of the aquifers is fairly similar to the one found in the north; here too there are enormous sedimentary basins subject to a desert climate, with hard and unproductive Paleozoic strata in the west (Tagant, Mauritania), except for a number of limestone layers, and with sandstone strata in the east: intercalated continental (Azaouad in Mali), the Air sandstone in Niger and the Nubian sandstone further east, which contain fossil aquifers.
- vi) The Chad basin, occupied in its centre by the eponymous lake which is shallow and has declined in size over the last decade, is formed by a complex of sediments of various ages, mainly recent, Quaternary and Cenozoic, in which the ground-water resources are considerable: in places artesian, but with relatively low unit yields per well, for the clay strata are frequent and extensive.
- vii) The basement-rock areas of West Africa which cover the majority of the territory of Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin, Burkina Faso and Cameroon, as well as large areas of Mali and Nigeria. The rocks are exposed to Sudano-Sahelian climatic conditions and are water-bearing in their altered and fractured parts. At its northern edge the crystalline shield of western Africa is flanked by a sandstone rim of Precambrian or Paleozoic age which constitutes a major aquifer in Mali and Burkina Faso. The unit yields obtainable from the wells or boreholes are not large except in a few cases (Bobo Dioulasso sandstone) but they are usually sufficient for village and livestock needs. The sedimentary basins in the central part of Niger, along the axis of which run the River Niger and its main tributary the Benoue, which has its source in Cameroon, are made up mainly of gray argillaceous Cretaceous formations containing artesian aquifers.
- viii) The coastal sedimentary basins are very different in extent, the largest being the Senegalese-Mauritanian basin which runs southwards into Guinea-Bissau. Then come the bevel-shaped coastal basin of Nigeria which narrows towards the east (Cameroon) and towards the west (Benin, Togo, Ghana), and the very narrow but economically important coastal basins along the shoreline of Guinea, Sierra Leone, Liberia, Côte d'Ivoire and Ghana. These basins contain recent, Quaternary and Cenozoic sediments with very productive sandstone and limestone layers. They are intensely exploited - sometimes overexploited.

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

The territory is subject to very varied climatic conditions in which latitude plays an essential role. From the anticyclone of the Azores, a high-pressure centre, the trade winds blow towards the Equator and are deflected westwards by the rotation of the earth. In January a cool dry wind - the Harmattan - blows from the Sahara towards the west coast of Africa from Mauritania to the Niger delta. At this period the whole of Africa south of the equator is subject to a low-pressure system (below 700 mm). In July, in contrast, a high-pressure system prevails over southern Africa and a cyclonic depression is centred over the plateaus of Iran. As a result, the winds tend to blow towards the east and a monsoon from the southwest brings heavy rains to the western coast.

As a general rule the winds blow from the sea to the land, bringing rain; but there are notable exceptions: the Harmattan and in mid-year some local winds from the Maghreb which blow towards the Mediterranean, and some regular winds which blow towards the north-east of Africa in the direction of the Arabian Peninsula. The mountains halt the wet winds.

In January, the regions to the south of the 20th parallel N (from Nouakchott to Port Sudan) have average temperatures below 20°C. In July, the whole of the continent north of the equator (except for the coastal zones) has temperatures above 30°C, sometimes 32°C.

The temperature ranges are very small in the equatorial regions (10°C) but increase in step with distance from the equator; they are from 20°C to 30°C in the Sahara.

The rainfall is irregular with wide variations from season to season and year to year.

In the extreme north of the continent the Maghreb and certain coastal parts of Libya and Egypt and, in the extreme south, the Cape region have rainfall of the Mediterranean type (winter rains).

The very wet equatorial regions to the south of 10° latitude N have two rainy seasons when the sun is high above the horizon, generally from March to June and from September to November. From the 10th to the 15th parallel N the tropical regions have only one rainy season, from May to October. Lastly, the subtropical desert region, i.e. the whole of the north of the continent with the exception of the Mediterranean zone, receives only occasional and irregular showers.

The annual rainfall is two to six metres along the coast of West Africa from Conakry to Abidjan and from the Niger delta to Libreville in Gabon; one to two metres in some mountainous regions of the Maghreb and south of the line from Dakar to Mogadishu; 500 to 1,000 mm in the High Atlas, in the coastal regions of Algeria and Tunisia and in a strip 300 to 500 km wide to the north of the line mentioned above; less than one metre to the

north of the line from Nouakchott to Port Sudan, with the exception of the Maghreb, the majority of this region receiving less than 20 mm.

Climatic zones

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

- Mediterranean zone with dry summers (hot season) northern Maghreb.
- Steppe zone with the following subdivisions:

Pre-Saharan regions south of the Maghreb with drier summers. This climate is sometimes described as "semi-arid Mediterranean". The rainfall is less abundant and the temperature range broader than in the Mediterranean zone.

Regions to the south of the Sahara with semi-arid tropical climate of the Senegalese or Sahelian type. They receive more abundant rainfall in the hot season from June to September.

- Wet savannah zone or zone of tropical Sudanese climate. 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 with Saharan climate (Sahara).

- Equatorial forest zone with very wet climate and two rainy seasons or continual rain. It includes, over a width of 300 km, the region of the Gulf of Guinea from Freetown to Accra and from Lagos to Douala, southern Cameroon and 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 Canaries current, flowing north to south from Tangiers to approximately the 20th parallel N, is cold; the Guinea current, flowing west to east from Dakar to the equator, is warm.

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 rainfall and its distribution and which expresses a characteristic ratio between potential evapotranspiration and the amount of rainfall.

The surface aquifers (lakes) undergo large variations in level owing to the imbalance in some years between the headings "evaporation" and "recharge". This is particularly true of Lake Chad. It is also true of the unconfined ground-water aquifers when the piezometric surface is shallow in comparison with the soil. Evaporation produces - and can be

measured by - concentrations of salts in the aquifers. The question of the depth to which evaporation takes place is disputed. However, all authors agree that this effect operates for several metres (five metres on average and as deep as eight to ten metres). 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, in the Sahara 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.

The following table compares some potential evapotranspiration values with the rainfall at a number of climatological stations in Africa.

	Annual rainfall (cm)	Potential evapotrans- piration (cm)	Quotient (percen- tages)
<u>Arid and hyper-arid zone</u>			
<u>(rainfall below 250 mm):</u>			
In Salah (Sahara)	0.5	140	0.3
Biskra (southern Algeria)	18	133	
Moudjeria (Mauritania)	17	187	3
<u>Coastal regions</u>			
Nouadhibou (Mauritania)	4	116	4
Tarfaya (Morocco)	11	85	13
<u>Zone with rainfall between</u>			
<u>250 and 1,000 mm:</u>			
Kayaes (Mali)	74	187	30
Algiers: wet Mediterranean climate	76	92	83

Thus in some regions a large or even overwhelming part of the rainfall is almost immediately lost through evaporation. The heading "evapotranspiration" in the water balances is often the largest. Some authors offer the following figures for the various regions of Africa: evapotranspiration, 40 to 98 per cent; infiltration, 2 to 40 per cent; runoff, 2 to 12 per cent.

In regions with rainfall between 250 mm and one metre (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 temperate 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 data in the Sahelian 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 upper layers of the soil.

- A system of very heavy, brief and frequent showers 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" when the main consequence is a drop in the level of water in the wells, which can even dry up completely. Lastly, a drop of 50 per cent in the amount of total annual rainfall as a result of less frequent showers can mean so 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 (see Part Two).

Extensive sand formations

In Africa sand dunes cover large areas north of the 14th parallel. Little is known about their role as aquifers in the Sahara. But it is known that the sands themselves, despite their great permeability, cannot provide a large reservoir in many cases since they quickly lose, through runoff or evaporation, the rainwater which they absorb.

Country	Location	Geology	Flow rate per installation
Mauritania	Plain of Kaffa	Sand dunes	5 to 10
	Plain of Assaba	Sand dunes	5 to 10
Senegal	Malika	Sand with clay	26
Cape Verde	Tiaroye	Sand dunes	50

Alluvial fill, deltas, chott deposits, Quaternary formations of the Chad basin and coastal sedimentary basins

Country	Location	Geology	Flow rate per installation (m ³ /h) <u>a/</u>	Drawdown (m)
<u>Fluvial alluviums.</u> These aquifers are among the most important and serve large populations.				
Algeria	Wadi Biskra	Sands-gravels	-	-
Morocco	Doukkala	Sands-gravels	10 to 1,000 m ³ /day	-
	Tafilalet	Gravelly alluviums	-	-
	Sous	Gravelly alluviums	Up to 360	1
Mauritania	Wadi Seguelil	Gravelly alluviums	10	-
Egypt	Nile	Coarse Pliocene-Pleistocene gravels	1000	3
<u>Coastal or continental alluviums</u>				
Côte d'Ivoire	Treichville lagoon	Coarse sands	210	-
Guinea	River Nunez	Alluviums	20 to 50 (subartesian boreholes: 7)	-
Togo	Coastal zones	Argillaceous sands	3 to 5	-
Cameroon	Flats	Fill formations	10 to 80	-
<u>Coastal sedimentary basins</u>				
Cote d'Ivoire	Abidjan	Paleocretaceous sands and limestones	18	80
Benin-Togo	Coastal region	Cretaceous sands	1 to 35 m ³ /h/m; (average: 8 to 15)	-
Togo	Afagnagan	Cretaceous sands	18	10
Libya	Syrte	Miocene limestones and sands	25	42
Morocco	Agadir	Pliocene limestones and sandstones	5 to 20 m ³ /h/m	-
	Plains of Doukkala and Berrechid	-	10 to 100	-
Senegal	Basin (total)	Maestrichtian sandstone	15 to 120 (artesian)	-
Tunisia	Zarzis-Djerba	Upper Miocene	50 (artesian)	-

a/ In the column "Flow rate per installation", the underlined values indicate a specific yield.

Terminal continental sandstones and conglomerates (Late or Post-Cretaceous)

Terminal continental

Burkina Faso	Bobo Dioulasso	-	90
Mali	Gondo	-	50 to 100 (up to 300/day)
Mauritania	Trarza	Sandy intercalations	1 to 4
	Bennichab	Sandy intercalations	30
	Nouakchott	Sandy intercalations	15
Senegal	Casamance	Argillaceous sand-sandstone	6 m ³ /h/m
Togo	Lomé-Agouévé	Variegated sandstone	5 to 40 m ³ /h/m

Intercalated continental, Nubian sandstone and other continental Precretaceous or Cretaceous continental sandstone

Algeria	Charadaia	Intercalated continental argillaceous sandstone	variable
Cameroon	Bénoué-Garoua	Cretaceous sandstone	10 to 20, up to 50
Nigeria	Sokoto	Consolidated Eocene sands	heavy flows (variable)
Egypt	Casis de Kharga	-	3,000 to 4,000 per day (artesian)

Limestone tableland of the hammadas of northern Africa (Pliocene-Pleistocene)

The hammadas cover vast areas south of the Atlas; their surface is generally made up of a subhorizontal plate of hard Pliocene-Villafranchian lacustrine limestones with varying degrees of sandiness, often overlying softer sand-clay formations. The scant rainfall which infiltrates in the hammadas quickly circulates through a karstic system, flows towards peripheral or central depressions and is rapidly lost through evaporation. The few wells found in the hammadas are fed from dune or alluvial formations. Water-drilling operations have generally not produced positive results.

Karstified limestone aquifers of the Jurassic, Cretaceous (North African Cenomanian-Turonian plate) and Eocene periods

Country	Location	Geology	Flow rate per installation (m ³ /h)	Drawdown (m)
Algeria-Morocco	High plateaus	Jurassic limestones	150 (artesian)	
Morocco	-	Liassic limestones	Up to 500 (artesian)	
	Doukkala	Upper-Jurassic marly limestones	10 to 100	
	Bahira	Dolomitic limestones	150 to 200	
	Sous	Cenomanian-Turonian limestones	Up to 1,200	
		Cretaceous sandy-marly limestones	1 to 10	
Mauritania	Trarza	Eocene limestones	0.1 to 1	
Senegal	Pout-Ndiass	Paleocene limestones	Up to 4	
Tunisia	Djebel Zaghouan	Liassic limestones	2,000 (in 6 springs)	

These few examples show that the karstified limestones of North-West Africa can yield rates of flow often in excess of 50 m³ per hour, sometimes as high as 100 and even several hundred in certain cases.

Tectonized zones of northern Africa with complex structures of marl-sandstone, marl-limestone, flysch, etc., of the Jurassic and Cretaceous periods.

The ground-water resources are very local; they are found mainly in fractured zones with thin limestone or sandstone seams alternating with schists, marl-limestones, clays, etc. The available yields are very variable.

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

The dolomitic-limestone sedimentary formation (of Upper Precambrian and Cambrian age) is often very thick and constitutes a major ground-water reservoir:

Dolomitic limestones of Tin Hrassan (Burkina Faso) in arid zones. Transmissivity: $5 \times 10^{-4} \text{ m}^2/\text{s}$. Flow: $4 \text{ m}^3/\text{h}$, with a drawdown of 10 m. Storage coefficient: 1.8×10^{-3} ;

Fissured dolomitic limestones of Atar (Mauritania). Flow: $70 \text{ m}^3/\text{h}$, with a drawdown of 4 m. Such a flow is exceptional for an arid area; it is produced by a river bed infiltrated by flood waters;

Precambrian and Cambrian limestones of the Anti Atlas (Morocco). A number of overflow springs have flows of 20 to $40 \text{ m}^3/\text{h}$ and up to $250 \text{ m}^3/\text{h}$;

Mention must also be made of the dolomites of Tiara (Burkina Faso) and Gondo with its karstic sink-holes (Mali), for which no figures are available.

Precambrian and Paleozoic hard sandstones, schist-sandstones and quartzites

Country	Location	Geology	Flow rate per installation (m ³ /h)
Mauritania	Hodh	Cambrian pelitic sandstones	Up to 0.2 to 0.5
		Brazer sandstone	2 (maximum)
	Ayoun el Atrous	Precambrian sandstones	0.2 to 0.3
Togo	Bombouaka	Sandstone	0.3 to 7
	Dapango	Sandstone	3 to 7 (maximum)
Togo-Benin	-	Atakora quartzites	2 to 3, up to 7

Schists (mainly Precambrian and Paleozoic) and clays

When they are not totally impermeable these formations do contain some meagre water resources, mainly in fracture zones. Some examples of available yields per installation are given below:

Country	Location	Geology	Flow rate per installation (m ³ /h)
Ghana	-	Volta schists	Very low
Guinea	-	Black Gothlandian slates	Very low in fractures and seams
Burkina Faso	Banfora	Schist-sandstone	12 (exceptional)
Mali	Nara	Cambrian schists	Very low
	Azaoud-Timbuktu	Metamorphized Pre-Cambrian schists	0.5
Mauritania	Atar	Schists under alluvium	20
Togo	Sansanne-Mango	Schists	<u>0.3 to 1 per day</u>
	Buen	Marly-sandy schists	<u>0.5 to 10 per day</u>

Examples of available yields per well and borehole in crystalline zones

Country	Location	Geology	Flow rate per installation (m ³ /h)	Drawdown (m)
Cote d'Ivoire	Yamoussoukro	Fractured granites	6	-
	Daloa	Granitogneiss	2 to 4 (up to 12)	12
Benin	Parakou	Fractured granites in tectonic depressions	7 to 8	-
Benin-Togo	-	Birimian schists, quartz seams	3 to 7 (exceptional)	-
Ghana	-	Granites and granodiorites with quartz seams	5 to 20 m ³ /day	-
Burkina Faso	Various	Mica schists	less than 1 m ³ /day	-
	Various	Granitogneiss	1 to 4	10 to 20
Mauritania	Fort Detrick	Mica schists and gneiss with pegmatitic seams	20 m ³ /day	-
	South-east	Diorites	0.5	-
Chad	Ouaddai	Granitic sands	2	-
Togo	Elavagnon	Mica schists and graniteogneiss	2 to 5	6 to 20
	Kande	Chlorite schists quartz seams	7 to 12	9 to 15
	Dapango	Alkaline granite-gneiss	1 to 5 m ³ /day	-
	Palime	Granites and granodiorites with amphibolites and quartz	5 to 20 m ³ /day	-

In summary, a flow rate of 5 m³/h is a good one for granites and granitogneiss; a rate of 1 m³/h is considerable for mica schists and metamorphic schists. Better yields are obtained in the quartz zones.

Crystalline and metamorphic rocks (basement formations, granites and gneiss)

Since they have virtually no porosity, the crystalline rocks are impermeable except in faulty, fractured or altered zones. The best yields are usually obtained when a relatively thick altered stratum overlies a fault zone.

The nature and structure of the altered stratum vary according to the parent rock. This stratum can be almost entirely argillaceous and therefore barren.

Volcanic rocks

Lavas, especially basalts, dolerites and certain basal rocks which sometimes give high yields can be put in a separate category; a few examples are given below:

Fissured dolerites in arid zones - Ayoun el Atrous (Mauritania): less than 0,1 m³/h; non-fractured: 0,2 to 0,3 m³/h;

Basal rocks of Akjoujt (Mauritania): 30 to 45 m³/h, with a drawdown of 13 m;

Basal rocks of Conakry (Guinea): 13 to 72 m³/h (very rainy tropical climate), with a drawdown of 20 to 50 m;

Green rocks of Kongolikan (Burkina Faso), fractured: 3 m³/h.

Conclusion

There is almost nowhere in Africa where ground water is not found at one depth or another. The highest flows 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 arid zones the ground water is usually of calcium/magnesium bicarbonate facies at the higher 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. This is particularly the case in pre-Saharan North Africa for the sabkhas (continental depressions).

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 North Africa.

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 thermo-mineral springs abound in the African continent in the fracture zones. They constitute a major potential resource which has been explored and exploited in only a few places.

IV. EXPLOITATION OF THE GROUND WATER

In Africa as in the rest of the ancient world ancient, densely populated civilizations with advanced social organization and a sophisticated way of life were associated with the big rivers. These rivers furnished abundant water, rich soil, and fish and game in their valleys and deltas, as well as means of transport and places of refuge.

Away from the big rivers the surface-water resources are scanty especially in the dry season. In tropical Africa they are limited to water-holes. In the northern Africa the ancient inhabitants, the Berbers, usually established themselves in the mountainous regions near the sources of permanent rivers. It was the Arabs, the occupiers of the plains and Saharan oases, who developed the use of ground water through the construction of wells and infiltration galleries, employing the original techniques of Central Asia and the Middle East. Various methods of dewatering were also imported from those regions.

However, until recent times and with the exception of Arabized Africa, ground water was drawn off only from shallow holes dug in alluvial beds devoid of surface water in the dry season. These crude wells are in general use in the pre-Saharan regions. 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.

Traditional wells and drains

The digging of wells and construction of traditional drains - underground galleries linking aligned wells - was practised mainly in arid countries under Arab or Turkish influence in northern Africa, including the oases of the Sahara, Libya and Nubia and some of the Southern fringes of these deserts.

The wells were excavated with simple digging tools in soft earth of good consistency. Sometimes the walls or vaults were reinforced in places with timbering or brickwork, either dry-stone or with lime mortar. Some of these wells, especially in arid piedmont areas, attain considerable depths, sometimes 100 metres and more.

The well systems described in the Bible and very numerous in Iran, where they are called kanats, are widespread in northern Africa where the total length of the galleries amounts to several thousand kilometres. In Egypt and the Sahara they are called foggaras; in Morocco, rhattaras. This system makes it possible to obtain the ground water from the soil without

using dewatering methods. The galleries are first built as trenches which climb underground until they intersect over a certain length the saturated formations to be drained. The length of the galleries is limited by the maximum depth of the "head well", which depends on the techniques used and the nature of the terrain.

These drains can only be built in formations of suitable consistency where the digging is easy: lacustrine formations, soft sandstone, tuff, consolidated alluvium, etc. The aquifer must also be relatively shallow and lie under land which slopes sufficiently for the galleries to discharge in the open air; but the slope must not be too steep, for the head wells must be of a reasonable depth. These foggaras are found in the beds of certain wadis and their environs: middle or adjacent beds on the flanks of gently sloping valleys and at the foot of dejection cones spreading from piedmonts. Some drains penetrate rock formations and reach aquifers whose flow is blocked downstream by natural obstacles.

The construction, cleaning and maintenance of these drains - arduous and dangerous work - is now very difficult. Many of the installations are deteriorating and collapsing for lack of maintenance. In small aquifers with irregular recharge the drains can cause a permanent discharge - often unused - which quickly leads to total depletion: this is particularly the case in the plain of Haouz (Marrakesh) and the plain of Sous (Morocco).

The traditional means of raising the water from the wells vary according to region, raw materials, depths and uses. For shallow irrigation wells (norias) bucket wheels operated by animal traction are widely used. For greater depths a simpler procedure is often employed; it involves a treadmill worked by an animal (cow or camel) which hauls up a leather water-bucket by means of a system of ropes and pulleys. This method raises hardly more than a few cubic metres a day.

The deepest wells are drawn by hand, for they are used only to supply the population and livestock. Beam wells are a traditional feature of the landscape in the Nile Valley. They are also found in Sudan and in all the sub-Saharan countries from Chad to Mauritania.

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 twentieth century and from the progress made in the same period by British and Swedish manufacturers of drilling equipment for the exploitation of ground water. In French Africa drilling for water also underwent a great expansion, especially from the time

when oil exploration activities were started in the Sahara, i.e. from the 1950s.

The ground water was first exploited by borehole in the arid zones of northern Africa: Algeria, Morocco, Tunisia, Egypt and northern Nigeria where there are vast stocks of ground water. This ground water sometimes has natural outlets in topographically low-lying areas such as the chotts, where it is subject to direct evaporation; in other cases these depressions offer favourable conditions for the drilling of artesian wells. Artesian wells have been dug in chotts in Tunisia from the end of the 19th century using big augers operated by groups of workers. Mention must also be made of the many artesian bore-holes drilled in the 1940s and 1950s in the New Valley, i.e. in the depressions of El Kharga and El Dakhla in Egypt's Western Desert.

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 first carried out in northern Africa; they 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.

In most cases the boreholes are not 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, which is now manufactured in Africa, in particular in Mali.

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 operations are usually costly.

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 bodies 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 in the region, 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 and Sahelian zones north and south of the Sahara.

Thus, for a Sahelian country in which about 20 wells a year were dug in 1965/66 the number of wells drilled had increased to four or five hundred in 1985.

Ground water is intensively used to supply urban and industrial areas, especially in arid regions and coastal zones. This is particularly true of Tangiers, Fez, Meknes, Marrakesh, Agadir, Constantine, Tripoli, Benghazi, Port Sudan, Ibadan, Cotonou, Lomé, Bobo Dioulasso, Abidjan, Bissau, Banjul, Dakar and Nouakchott.

The exploitation of ground water in Africa is intended mainly to meet the water needs of the towns, villages and pastoral areas and 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 countries of North Africa - from Morocco to Egypt - the areas irrigated by ground water are still very small. However, small market-garden centres have been spontaneously created around the hand pumps installed in villages and this kind of small-scale operation is tending to increase (Mali).

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 tending to be 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 always 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 a 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 the desert zones where there is little or no recharge from rainfall and the coastal zones subject to deep intrusion of sea water in the direction of the wells. In contrast, the rainy tropical areas 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 do not always 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 appropriate technologies for the construction and restoration of wells and for the movement of the water; 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; 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 North Africa are managed to best effect, i.e. without wastage or long-term threat to the existence of these resources in terms of both quantity and quality. This comment applies equally to the intensely exploited coastal zones, especially at Nouakchott, Dakar and Lomé.

Nor are the objectives of the International Drinking Water Supply and Sanitation Decade about to be achieved for the villages of the countries of Western and Central Africa south of the Sahara. 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. The organizations of the United Nations system - as can be seen from the list of projects in the annex - will have contributed to this vast undertaking in a very considerable and in many cases decisive manner.

MAURITANIA

Area: 1,240,000 km²

Population: 1.8 million (United Nations estimate, 1983)

I. BACKGROUND

Mauritania has an Atlantic coastline of 500 km and forms a bridge between two African subregions: the Maghreb in the north and West Africa. The country straddles these two subregions in terms of its climate, geography and population, which includes two Moorish groups - of Arab type - Berbers and blacks. It has served as a transit route for herds, mainly of camels and goats, caravans and warriors between the "Saharan ports" - the oasis markets at the edge of the Sahara south of the Maghreb - and the Senegal valley in the south, which forms the southern frontier between Mauritania and Senegal. Ground water is a vital resource, for the country has no permanent surface water apart from the river. The Saharan peoples have lived traditionally from their animals and the water supplies which they bear when the grazing land is adequate and the water points not too far apart. However, in periods of drought, such as the one which has afflicted Mauritania for some years, the traditional water points and grazing land are not sufficient; this has brought about a profound change in the lifestyle of the nomads. Furthermore, increasing urbanization, education of children, improvement of health and social conditions and the development of agriculture and industry demand increasing amounts of water, and a permanent supply can be guaranteed only through the exploitation of ground-water aquifers which are protected from the effects of current climatic conditions.

Mauritania has few mountains and is a country of vast tablelands: the Reguibat peneplain in the north, the Atlantic coastal plain in the west, and the Taoudénit basin in the east. The average altitude is 200 to 400 m with a high point of 915 m (Kediet Idjil). Four-fifths of the country lies north of the 17th parallel N, which roughly corresponds to the 200 mm isohyet, and it therefore has a climate of the Saharan type with low and irregular rainfall and large interannual ranges; in some years hardly any rain falls.

In the rest of the country, south of the 17th parallel N, the rainfall is more regular and heavier, with an annual average of 600 mm at Selibabi. The rainy season is from June to October in these regions, where the population tends to be sedentary. The population density is also quite heavy in the Atlantic plain where the Saharan influence is tempered by the trade winds and the proximity of the ocean.

As a result of these morphological and climatic conditions, no permanent watercourse rises in Mauritania, except for the Gorgol, a temporary tributary of the Senegal (right bank). In periods of heavy rainfall this right bank is also fed by considerable runoff from the Mauritanian regions of Guidimaka and Aftout, which are drained by a very dense hydrographic network. Outside these regions the hydrographic network is weak and dispersed; it has no flow to the ocean and is partly blocked by sand.

II. GEOLOGY

Geologists usually distinguish six main structural units (see general geological chart below).

- In the west, the Mesozoic and Cenozoic sedimentary coastal basin, which consists of sand-clay and limestone formations resting on the crystalline and metamorphic basement rock. The thickness increases from east to west, reaching 1,000 m at the coast;

- In the centre, the Paleozoic edge of the Taoudénit basin (Cambrian-Siluran), which includes the plateaus of Assaba, Tagant, Adrar, Khatt and Hank, topped with limestone and sandstone and bounded in the west by high cliffs;

- At the foot and to the west of these cliffs lies an "epimetamorphic" unit (Precambrian-Cambrian), which is part of the Arc des Mauritanides. It consists mainly of metamorphic schists carried down during the period of Hercynian orogeny;

- In the north, the Reguibat ridge - Pre-cambrian granitogneiss basement rock injected with green rocks;

- At the northern borders and in the north-west of the country (Zemmour-Noir-Yetti) outcrops the southern limit of the Tindouf syncline (Cambrian-Ordovician and Devonian) which consists mainly of limestone and sandstone;

- Lastly, in the east, the Mesozoic-Cenozoic Taoudénit sedimentary basin, which is one of the largest and least known basins in the world, for it is almost entirely covered with sand dunes. The formations increase in thickness towards the east, and the basin's centre is in Mali.

III. GROUND-WATER RESOURCES

Intense hydrogeological research has been carried out in Mauritania since 1950. The extent of this research can be seen from the list of works cited at the end of this article, in particular in the area of cartography.

Mauritania's ground-water resources have been more or less extensively prospected, depending on the region. They are found in very different kinds of deposits, as can be seen from the table below.

The coastal basin has several continuous aquifers lying one above the other, including the familiar Trarza aquifer which is bounded in the east by a dry segment and in the west by a saline segment, and the so-called Maestrichtian deep confined aquifer, about which little is known.

The Paleozoic sandstones and limestones of the Tindouf syncline and the Taoudénit basin also contain aquifers which are probably continuous, but little is known about them: the pelitic aquifer of Hodh, the Atar limestones, the Oujeft sandstones, and the (assumed) aquifers of the Cambrian-Ordovician sandstones of Zemmour-Noir and the Aoun sandstones. Mention must also be made of a Taoudenit aquifer which is probably continuous but little known except at the southern edge (aquifers of Dahr de Néma and the Quartemachet trench).

The metamorphic and crystalline rocks of the Arc des Mauritanides and the Reguibat ridge contain local aquifers in the alteration, fracturation and fissuration fringes.

Lastly, several aquifers are found in the Quaternary formations; they are mostly small and scattered throughout the territory.

IV. GROUND-WATER STUDY AND EXPLOITATION

Most ground-water activities are the responsibility of the Ministry of Water and Energy and in particular of the Water Department, which has the following services:

Water resources

- Water points inventory and control office;
- Hydrogeological office: hydrogeological studies and control of drilling and test pumping;
- Geophysical office,

Water infrastructure

- Pastoral water-supply office: this office controls the nine well-construction teams based at Rosso, Ayoun, Néma, Kiffa, Aleg, Tidjikja, Kaédi, Selibabi and Atar;
- Drilling office: this office carries out drilling operations and is responsible for the installation, operation and maintenance of pumping stations.

Urban water supply

This service is responsible for water supply and sanitation in settlements of more than 2,000 to 2,500 inhabitants; this does not include the large towns where the networks are built and managed by the National Water and Electricity Corporation (SONELEC).

Equipment

This service has its main base at Ayoun and has approximately 70 vehicles, some compressors and INCERSOLL TH 100 drilling rigs.

Mauritania has several private well construction and drilling companies:

- SAFOR: this Mauritanian company has 10 mechanical well-digging rigs and units equipped with two Salzgitter RB30 rigs (combined rotary/down-the-hole hammer on a Mercedes truck and one heavier Salzgitter RB 225, also a combined rig.

- SOMAFOR: This Mauritanian drilling company has one combined INGERSOLL TH 100 rig (a second is planned),

Mention must also be made of the SODESE-ENGINEERING study company which is particularly concerned with surveys of water use in rural areas.

There is a very large programme of water drilling and well construction and repair for 1985 and subsequent years. It is financed by several bodies including:

- The West African Economic Community (CEAO);
- The European Development Fund of the European Economic Community (EDF/EEC);
- UNDP and associated bodies (the United Nations Sahelian Office in particular;
- The African Development Bank;
- The Arab Fund for Economic and Social Development;
- The World Bank;
- The Government of Saudi Arabia;
- USAID.

The programme envisaged the installation of 76 new wells and the repair of 180 existing wells.

The country's water points total about 10,000 to 12,000 (?), distributed as follows:

- More than 1,000 boreholes;
- About 3,000 modern wells;
- Several hundred waterholes;
- Five to ten thousand traditional water points (?), most of which are temporary excavations in alluviums.

The capital Nouakchott is supplied with water from a group of 18 boreholes at Idini, almost 70 km to the east, which draw water from a fossil aquifer in sands and sandstones of the continental terminal formation.

The problem of water - and especially of ground water - is in the forefront of Mauritania's priorities owing to the persistent drought which has exhausted the shallow aquifers which are the people's traditional source of water, and as a result of the sedentarization of the nomads and the development of urban and peri-urban communities. The considerable efforts made and the assistance furnished must be co-ordinated by rational planning designed to draw maximum profit from the investments and save water resources. To this end it is necessary to update and computerize the inventory of water points.

determine the needs and place them in order of priority, and improve ground-water research techniques and well-drilling technology, with a view to rapid implementation and adaptation to local natural and social conditions at minimum cost,

It is also necessary to determine the most suitable drawoff methods, in order to keep costs low and reduce the work of maintenance, repair and replacement; these operations must involve the Government's technical services and the local people, who should be largely responsible for implementation.

This is the goal of a United Nations project financed by UNDP which started up in 1986.

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