UNITED REPUBLIC OF TANZANIA

Area: 937,062 km²
Population: 20.4 million (United Nations estimate, 1983)

I. BACKGROUND - SURFACE WATER

Most of the territory of the United Republic of Tanzania is situated in mainland Eastern Africa south of the equator; the country also includes the islands of Zanzibar and Pemba.

The coastal plain on the Indian ocean is 15-60 km wide; in the west it yields to the gently undulating plateau which covers most of the country at an altitude of 800-1,200 m; this plateau is broken by a few isolated peaks and chains. The highest ground is found in the area of Mt. Kilimanjaro, a volcanic cone which rises to 5,963 m at Kibo, the highest point in Africa. Mention must also be made of Mt. Meru (4,566 m). The Usambara, Uluguru and Mbeya mountains are over 3,000 m high.

The south-west and north-east of the country are cut by the Rift Valley, a major tectonic depression 20-30 km wide dominated by escarpments 100-300 m high; the floor of the Rift contains a number of lakes, including Lake Tanganyika which is over 1,500 m deep.

Over most of Tanzania the climate is tropical, with annual rainfall ranging from 500 to 1,000 mm. The high relief, the Rift Valley and the proximity of the Indian Ocean exercise a local influence on the average figures and can lift them to over 2,000 mm in the mountains and the coastal zone and lower them to 300-400 mm in the depressions.

The temperature is moderate to high, generally between 25 °C and 32 °C; it is 12-15 °C in the mountainous areas in winter. Sixty per cent of the country can be said to have a climate of the semi-arid type; the rainy season lasts three to four months, and the potential evaporation is generally higher than the precipitation, reaching 2,000 mm in the centre of the country, as against 600-700 mm of annual rainfall. In the coastal zone, in contrast, the potential evaporation and the rainfall are roughly in balance.

The country has five hydrographic networks:

(i) The "Indian Ocean" network, which covers 414,600 km^2. The Rufiji River has a maximum flow of 12,000 m^3/s. The other major rivers of this network are the Pangani in the north, the Ruvu in the centre, and the Ruvuma in the south, forming the frontier with Mozambique;

(ii) The endorheic basins of Lake Eyasi and the Bahi depression with Lakes Manyara and Natron cover 153,800 km^2 in the great Rift Valley in north-eastern Tanzania;

(iii) The drainage basin of Lake Rukwa covers 77,340 km^2 in the south of the Rift Valley;

(iv) The upper basin of the Nile in Tanzania (Lakes Victoria and Kagera) covers 88,270 km^2 in the north;

(v) The interior basin (Lake Tanganyika and the Malagarasi River).

With the exception of the major rivers mentioned above (to which should be added a few other smaller rivers and some springs at altitude), most of the watercourses in the centre and north of the country are temporary.

II. GEOLOGY

Tanzania has four large geological systems:

(i) The Precambrian crystalline basement which covers three-quarters of the country. It is divided into four units, according to structure: P1, P2, P3 and P4.

P1: These are the oldest rocks, with the following subgroups:

a) "Dodomian" - consisting mainly of cratonal granites, migmatites and gneiss;

b) "Nyanzian" - also cratonal with metamorphic rocks, granites, and ribonned ferrous hard rocks;

c) "Kavirondian" - mainly conglomerates, argillaceous sandstones and hardened fine sandstones.

P1 dates to 3,000-2,000 million years ago. It occupies most of the centre and north of the country.

P2: This subgroup includes mineralized zones of crystalline granites and metasedimentary rocks ("Karagwean-Ankolean") near the north-west frontier with Burundi.

P3: This subgroup dates to 1,000-700 million years ago and is called "Bukobian". It includes sedimentary formations (sandstones, dolomites, argillaceous sandstones) and volcanic rocks of basaltic type; it occupies the north-west of the country between Lakes Victoria and Tanganyika.

P4: This subgroup includes the Ubendian (P4a), which is the oldest, and the Usangarian-Mozambiquan (P4b). The Ubendian runs north-west in the far south-west of the country. The Usangarian-Mozambiquan dates to 600 million years ago and runs north-east in the eastern part of the Tanzanian plateau, crossing into Kenya in the North-east and Malawi/Mozambique in the south. It consists of gneiss, schists, migmatites, amphibolites, charnockites and crystalline dolomitic limestones describes in geological publications as the "basement complex".

(ii) The Karroo system of Mesozoic age contains continental sedimentary rocks: sandstones, clays, coal seams, and conglomerates of Devonian to Lower Jurassic age which can be up to 2,000 m thick and cover 10 % of the country in the south and east.

(iii) The post-Karroo system, also of Mesozoic age: the Upper Jurassic and Lower Cretaceous formations consist mainly of marine limestone and fluvial sediments. This system is found mainly in the east of the country (5 % of the territory).

(iv) Cenozoic and Quaternary volcanic and sedimentary rocks cover 7 % of the country, with the volcanic rocks dominating in the north-east/south-west: basalts, phonolites, trachytes and various pyroclastics.

The sediments include lacustral deposits, alluviums and continental deposits of the Rift Valleys, beds and flood plains of the major watercourses and of the coastal zone.

III. GROUND WATER

The Tanzanian Government has made great efforts to develop ground water for various purposes. The Ministry of Water has two departments whose main responsibilities lie in the area of ground water:

- Project Preparation Department (PPD); geophysics and hydrogeology section;

- Drilling section of the Construction Department.

There is also a number of regional water development organizations which operate in conjunction with bilateral or multilateral aid bodies.

Co-ordination is the responsibility of the Water Master Planning Co-ordination Unit (WMPCU).

Each of Tanzania's 20 regions has been furnished with a hydrogeology office responsible for the collection, evaluation and synthesis of ground-water data, which have been largely incorporated in the regional water master plans.

About a quarter of the country's population depends on ground water for its supplies. This proportion will increase in the near future, for the use of surface water is not advisable because it contains pathogenic agents and is increasingly polluted.

Wells have been dug since the eleventh century - the time when the first Arabs established themselves in Eastern Africa. Some stone-lined wells dug during German colonial rule in the 19th century are still in use. The first water borehole was drilled in 1931. Three thousand boreholes with depths of 30-150 m have been drilled since then.

Since 1953 various scientific methods have been used in the installation of boreholes, mainly geophysical prospecting, magnetometry and resistivity measurements.

At present (1987) Tanzania has about 30 national ground-water experts, including hydrogeologists, geophysicists and hydrochemists. Most of them have taken an active part in the preparation of the regional water master plans which so far cover 17 of the 20 regions, and they have acquired detailed professional experience in the following areas:

- Hydrogeological cartography; interpretation of aerial photographs and remote-sensing images;

- Magnetic, seismic and electrical geophysical prospecting, and well logging;

- hydrogeochemical studies;

- Test pumping and hydrological interpretation of the results.

These study methods are used both in the surface formations to depths of 10-15 m and in the deeper formations down to 150 m, with a view to the installation respectively of dug wells equipped with hand pumps and boreholes.

Dug wells. Favourable areas are determined by geological reconnaissance. The best results have been obtained close to river valleys or other zones or unconsolidated deposits identified on aerial photographs and topographical and geological maps. Hand-auger drilling is then carried out. If water is found, a brief evaluation is made of the available yield, together with chemical and bacteriological analyses.

The DHV company (Netherlands) has drafted very useful general guidelines for the studies and for the construction of shallow wells on the basis of its work in the Shinaganga and Morogoro regions. At present (1987) there are about 5,000 shallow wells equipped with hand pumps installed since 1974, but mainly in only five regions: Shinyanga, Morogoro, Mtwara, Lindi and Tanga. Most of these wells are less than 15 m deep. They are considered to be positive when they supply 5-10 m^3/day by pumping or hand bailing.

Drilled wells. Installation requires special skills, especially with respect to the interpretation of data before and during drilling. It is first necessary to identify the areas and types of formation which may prove productive by interpretation of aerial photographs, study of maps, an field reconnaissance. In the areas of crystalline basement rock studies are made of the granite and pegmatite sectors and the fissured and fractured zones. Geophysical prospecting is then used to identify the laterites and the fracture zones.

The master-plan studies in the five regions of Tabora, Shinyanga, Mwanza, Kagera and Mara have identified in the Precambrian formations of the Dodomian and Nyanzian subgroups many positive sites which have yielded 6-15 m^3/h from boreholes 70-90 m deep, with drawdowns of 20-30 m in non-fractured altered rocks.

In the sedimentary areas of Tanzania aquifer zones containing sweet water can be distinguished from zones of impermeable clays or saline water on the basis of electrical geophysical prospecting. The following table presents data taken from the master plans for Mtwara and Lindi relating to the coastal zone.

Table 1

Formation resistivity (Ohm - m)	Sedimentary formation	Estimated ground-water resources
Under 5	**Impermeable clay deposits with electrical conductivity of 3,000 with very saline water (EC: 6,000 s/cm)**	**Very small**
5 - 10	Impermeable clay deposits or permeable formations with saline water (EC: 3,000 s/cm)	Small
10 - 30	Semi-permeable silt or limestone formations (EC: 1,000-3,000 s/cm)	Average
30 - 80	Permeable sandstones with coarse grains and limestone cement containing sweet water (EC: 500-1,500 s/cm)	Good
80	Sandstones containing sweet water (EC: 1,000 s/cm)	Very good or average

Once the boreholes have been drilled, logging is sometimes and test pumping and hydrochemical analyses always carried out. The purpose of the logging is to identify the zones where strainers have to be installed, but the lack of equipment and of qualified personnel to interpret the measurements prevents the widespread use of this technique.

The test pumping is usually carried out by airlift with a constant yield and variable drawdown. Precise estimates of the transmissivity and storage coefficients are not usually made. The test pumping merely gives an idea of the possible output of the well and the capacity of the pump. The test pumping is continued for a maximum of 24 hours.

The physical and chemical analyses determine the electrical conductivity the pH value, the hardness and alkalinity, and the amounts of sodium, potassium, sulphate, chloride, nitrate, iron and fluoride.

The results are used to determine whether the water is suitable for the envisaged use. These analyses also facilitate a regional classification of the aquifers by recharge and ground-water flow. Mathematical modelling has not yet been used.

Table II

General data collected from water boreholes, for various formations

Geological formation	Number of boreholes	Depth (m)	Specific yield (l/s/m)	Main aquifers	Comments on water quality
	In 25 to 75 % of cases				
Precambrian Pla and Plb (most of the regions of Tabora, Mwanza, Iringa, Shinyanga, Dodoma and Singida)	1,500	90–120	0.015–0.15	Altered crystalline rocks	Sweet to slightly brackish water, with high fluorine content in some cases
Pl a	50	90–120	0.25–5	Fractured granitic rocks	-
P2 and P3	200	70–90	0.01–0.25	Fissured zones of sandstones, argillaceous schists and granites	Sweet
P4 (in many places in regions of Handeni, Masasi, Lindi, Ngerengere, Kiteno and Ufipa)	200	70–100	0.01–0.15	Altered zones and joints of crystalline rocks	Slightly brackish or saline
P4 (Mombo, Kilosa, Korogwe)	25	70–100	0.25–1.00	Fractured crystalline rocks	Sweet
Karroo at Tanga	20	30–60	0.15–0.5	Clastic formations	Sweet
Post-Karroo at Tanga, Chalinze, Kidugalo	50	40–70	0.01–0.15	Clastic formations	Occasionally brackish
Mbeya Tertiary volcanic rocks	20	90–120	0.10–0.15	Lavas and pyroclastics	Sweet
Tertiary volcanic rocks of lower Moshi, Sanga, Arumeru	50	90–120	1.5–6	Lavas and pyroclastics	Sweet with high fluorine content in some cases
Tertiary lacustral sediments of Wembere, Manyara, Rukwa, Bahi, Manouga	10	90–150	0.005–0.02	Contact zones of strata	Slightly brackish to saline, high fluorine content
Tertiary continental deposits of Kilimatinde and Itigi	30	80–110	0.10–0.30	Sands, gravels	Slightly brackish to saline
Neogene coastal deposits of Tanga, Kibaha, Mitawanya, Dar Es Salaam	100	50–65	0.005–5.0	Clastic rocks	Slightly brackish to saline
Neogene colluviums-alluviums of the valleys of Usangu, Kilombero, Dakawa, Kitangiri, Rufiji	30	50–65	0.25–3.0	Sedimentary clastic rocks	Sweet

IV. PROTECTION AND USE OF GROUND WATER

As a rule, the development of ground water depends on the distribution of the resource over the territory, the level of demand and the possible uses. The option is for shallow wells when they can be dug by hand. Yields of half to 1 m^3/h are considered satisfactory. These wells are equipped with hand pumps. They are dug by pick and shovel, with diameters of 1-2 m and depths of 2-3 m below the level of the water. Prefabricated strainers and linings are then installed. Finally the well is covered with a protective concrete slab and the pump is installed.

In the case of shallow aquifers in light ground, holes are also drilled by hand auger, usually 6-inch diameter down to 6-10 m, penetrating the aquifer to a sufficient depth. Perforated PVC tubing and a filter block are then installed, followed by the hand pump. This method is simpler and cheaper than the first one described above, but it can be used only in high-yield aquifers, and this means that more time must be spent on the preparatory studies.

Mechanical drilling is used when larger yields are required. Boreholes with modest test yields (3-4 m^3/h) are usually equipped with hand pumps.

Motorized pumping stations can provide yields of over 4 m^3/h and even as high as 600 m^3/h. They are used to supply rural and urban dwellers and for livestock and irrigation. Various types of drilling rig are used: cable, rotary and compressed air down-the-hole hammer. Before 1975, water drilling operations were carried out almost exclusively by private companies. Most of them are now carried out by the State with its 20 rigs, some of which are not in a satisfactory condition owing to the lack of spare parts.

The holes are drilled as deep as possible in order to penetrate as far as possible into the aquifer. In most of the crystalline formations the borehole is left unlined. The borehole is lined and a filter block installed only in soft formations. Many boreholes are equipped with diesel, electric or wind pumps. Owing to the high cost of fuel, diesel pumps are tending to be replaced by wind pumps if there is sufficient wind, or by hand pumps.

Table III

Use of ground water in Tanzania

Overview (1986)

Shallow dug wells equipped with hand pumps	Rural population served	1,800,000
Boreholes equipped with hand or motorized pumps	Population served	
	rural	2,500,000
	urban	600,000
	Total	4,900,000

(Out of a total population of 22 million)

V. CONCLUSION

Tanzania has set a time-limit of 20 years (1971-1991) for supplying all its people with drinking water of acceptable quality within 400 m of their dwellings. This will help to reduce the risk of water-borne diseases and release for productive work the time at present wasted in fetching water on foot from sometimes considerable distances.

Ground water is developed with this goal in view after study of the conditions of the deposit and its chemical composition and once the permanence of the supply is established.

Since the development of surface water requires the import of equipment and spare parts for which the country lacks the foreign exchange, the policy is to construct wells which can be easily maintained by villagers and to manufacture hand pumps in the country itself.

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ZANZIBAR AND PEMBA

The islands of Zanzibar and Pemba form part of the ancient Rufiji/Ruvu delta of Miocene age. Following subsequent tectonic movements only the islands of Zanzibar, Pemba, Mafia and Latham remain unsubmerged.

The sedimentary series consisting mainly of marls, clays and argillaceous sands is 2,560 m thick. Zanzibar is in hydraulic communication with the mainland, but Pemba is separated from it by a fault. However, the aquifers in question are too deep to be exploited.

Zanzibar's geology includes Miocene and Quaternary strata. Erosion occurred from west and east, thus giving the islands their elongated north-south shape. The following levels are recognized:

Q3 (the oldest)	Sorted fluviatile sands, with shark or fish teeth and concentrations of heavy minerals
Q2	Coral reef limestone (maximum thickness 35 m)
Q1	Argillaceous sands and fertile red soils

Pemba is formed exclusively of Miocene formations, without the coral limestones of Zanzibar. The "Miocene 2" includes the "Chake beds" and the "Weti beds", while the "Vitongages beds" of the east coast are attributed to the Pliocene. The Miocene rocks are lithologically and hydrogeologically similar to those of Zanzibar although finer-grained and more argillaceous. In its topography, Pemba is a rocky chain flanked in the east by a raised coastal coral shelf (Q2), with a submerged and indented coastline in the west, so that the tides penetrate far in land. The valleys of the eastern drainage basin are flat-floored and filled with erosion products, silts, clays and sometimes sorted pebbles. The coast is flat and fertile but often swampy. The island's main water resources are found here.

The geology and topography of both islands are reflected in the clove and spice plantations. Cloves do not grow in poor soils (Q2) or in the water-saturated "corridor" zones of Zanzibar and the eastern coastal zone of Pemba. The Miocene rocks are clearly indicated by these plantations, while the grazing land, rice fields and sugar cane plantations are found in the saturated zones; scrub, bushes and woodland indicate the Q2 coral formations. The coconut palm plantations indicate the path of the disastrous hurricane of 1872, after which the devastated clove plantations were replaced by coconut palms.

The climate has two regular rainy seasons: the Masika rains which come from the south from March to May; and the Vuli rains from the north-east in November-December. The rainfall in the wet season is usually scattered, local, torrential and short-lived. Northern Zanzibar receives about 1,800 mm of rain a year; the south 1,500 mm. Pemba has heavier rainfall: 2,500 mm in the south and 1,500 mm in the north-east. Measurement of water levels in the wells shows that the Masika rains are the more important with respect to recharge of ground water, for during these periods the increase in the level is double the increase during the Vuli rains.

Infiltration is rapid during the abundant rains, and the water levels increase immediately. Surface runoff is short-lived and never lasts longer than the storm. Few of Zanzibar's watercourses reach the ocean, for they peter out in the Q2 coastal coral limestones. For example, the Mwere River disappears in a karstic cavity and does not reappear downstream. Other streams flow underground and sometimes emerge as springs. The best example of this is the Zingwe which flows towards Kiwani bay in northern Mahonda. All the geological formations of both islands are water-bearing to various degrees. Quantitative assessment can be made of the permeability and porosity coefficients of each water-bearing stratum, and the recharge and discharge flows can be evaluated. There is widespread unconfined aquifer, with artesian conditions in places. Perched aquifers also occur, causing errors in the interpretation of the variations of the water level. The M3 Miocene aquifer is the least productive, although the water resources of the laterites, limestone lenses and sands are very useful. The movement of water in the aquifer indicates a poor storage capacity: 8 % at most. It is common for the wells or boreholes crossing the Q2 channels to penetrate limestone pockets and give high yields: for example, the Mbiji well on Zanzibar. The M2 Miocene is not a separate aquifer and it is exploited jointly with the M3. The M5 Miocene reef limestones certainly constitute an important aquifer but it has not yet been tested. It contains many cavities and has an estimated storage capacity of 15 %. The most important aquifer is found in the "corridor" zones of Zanzibar: 2 to 4 km wide and 50 m thick on average. At Kibokua some boreholes do not reach the Miocene at a depth of over 120 m (i.e. 70 m below sea level). These "corridor" zones include the Q1, Q2 and Q3 strata, of which only the last two have underground flows.

The main permeable zone corresponds to the altered upper part (about 10 m) of Q2. Depending on the altitude of the stratum in relation to the water level, it may be either saturated or unsaturated and thus behave as an aquifer or not.

Although the top of Q2 is relatively flat, the aquifer slopes steeply down to sea level from its altitude of 40 m at Bumwiet Upenja. The roof of Q2 is 10-15 m below the level of the aquifer at Bumbwi. At Kibokwa in the Bambi-Upenja corridor and at Kisima Mchanga they are at roughly the same level.

The transmissivity is high when the summit zone of Q2 is present and hydraulically active. In this case (Bumbwi, Kobokwa and along the central "corridor" zones of Zanzibar) yields have been as high as 225 l/s. Prolonged test pumping has indicated that the storage coefficient can be as high as 27 %, a level which can probably be reached in other "corridor" zones. Transmissivity of 500 to 100 m^2/day has been measured for the Q3 aquifers (Q2 being absent) at Kisima, Mchanga and in the plain at Cheju, where the sands are fairly unstable but can be controlled by strainers.

Little or nothing is known about the M1 Miocene limestone on Zanzibar, but transmissivity values of 500 and 1,000 m^2/day have been recorded for the Cheju and Matemwe wells respectively.

The Zanzibar Q2 and M1 limestone aquifers are not found on Pemba, where the main aquifer is the M3 Miocene. Boreholes on Pemba have penetrated the "Weti beds" and extract water from limestones and sandstones. The aquifer is very crumbly and the soft sands are a constant problem. No test-pumping results are available for Pemba, but a borehole (Bumbwi No. 1) has been drilled on Zanzibar in similar conditions and equipped with lining and a filter block over the whole depth of the altered zone. It has yielded 8 l/s for a maximum drawdown. As is usually the case on Pemba, it has been impossible to keep out the fine sands and silts. There is an additional problem on Pemba due to the abundance of bicarbonates in the water which cause encrustation of the boreholes.

The two islands have similar hydrogeological systems: the isopiestic curves are roughly the same and the recharge is provided by infiltration of rain water, surface flows and springs flowing towards the Zanzibar corridors and the narrow valleys on

Pemba. Discharge to the sea occurs on Zanzibar along the corridors and low valleys and on Pemba along a fairly large front in the east of the island. The coastal basins discharge through seaside springs or through fissures and channels in the Q2 coastal fringe. It has been established that the recharge is effected mainly from infiltration of surface runoff. During dry periods ground-water flows are determined by the topographical and geological conditions.

For the ground-water aquifer, the storage coefficients determined by pumping and long-term observation are as follows: Q2 - 25 %; M1 - 15 %; M3 - 7 %. The maximum annual recovery when these aquifers are not affected by the proximity of topographical systems or the coastline or by sizable surface flows, are, 1, 2.2 and 8 m respectively. On the basis of these data, the recharge can be estimated at 320 million m^3 on Zanzibar, i.e. 30 % of the rainfall (cautiously estimated at 1,500 mm on average), which is normal for an ocean island. Of this total, the accessible resources on Zanzibar are 102 million m^3 for the western corridor (Bumbwi) and 170 million M^3 for the eastern corridor (Bambwi Upenja).

Similar estimates can be offered for Pemba. The aquifers have poor transmissivity and can therefore be exploited only by means of small local projects. On Pemba only the upper few metres of the aquifer will ever be exploited, so that the drawdown does not fall below sea level.

An important complex of Q1-Q2 rocks is found in eastern Zanzibar: they are porous, fissured and cavitied in places, and the aquifer is either a discontinuous lense or a perched aquifer with unequal recharge owing to the local topography and local amounts of runoff. The village wells in this region draw water from small aquifers perched above a saline aquifer. Severe seasonal conditions can depress the level of the shallow aquifer.

Most of the water of both islands is suitable for all uses (domestic, irrigation and industrial), having a dry residue between 50 and 600 mg/l, or exceptionally up to 1,200 mg/l in the deepest parts of the Bambi-Upenja corridor at Kibokwa. These concentrations are due to deltaic water or ancient deposits. Other high values are due to deposits of anhydrites and to invasion of shallow sea water along the coast caused by 1-5 m tides.

In the south-west of Zanzibar the aquifer is situated at two levels, and sea water has invaded the lower level as far as a line from Fuoni to Mtoni. This area includes the town of Zanzibar and the Fuoni municipal wells. At some point in the future Zanzibar's tapping zone will have to be shifted further north in the Bumbwi corridor.