THE UNITED REPUBLIC OF TANZANIA

Ministry of Water, Construction Energy, Lands and Environment, Zanzibar

Department of Water Development

THE REPUBLIC OF FINLAND

Ministry for Foreign Affairs

Finnish International Development Agency FINNIDA

ZANZIBAR URBAN WATER SUPPLY DEVELOPMENT PLAN

WATER RESOURCES STUDY

March 1991

DRAFT

WATER RESOURCES STUDY

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1. EXECUTIVE SUMMARY

1.1 Major Conclusions

Drawing of large quantities of groundwater from Zanzibar Islands is justified by the initial hydrogeological calculations. There are enough potential groundwater aquifers to meet the water demand of Zanzibar Town, Chake Chake, Wete and Mkoani up to 2015. Groundwater will be drawn from borehole wells and natural springs. The location of the intakes will be within a radius of about 7 kilometers from town centers. New springs of a substantial importance for town water supplies were discovered during the field studies in Mkoani area.

The aquifers in Unguja are often covered with permeable sandy formations and a number of unprotected local wells are located in the catchment areas. If pollutive waste is released within the catchment areas or if the local wells are polluted, the geological formation is not offering adequate protection against aquifer pollution.

The surface water resources are not feasible alternatives for urban water supplies according to the studies during the planning period. Neither do the hand dug local wells yield enough for installation of machine pumps.

The total artificial discharge in Unguja by 2015 would be about 10 % of the total recharge in the island. In Pemba the respective figure would be less than 5 %. The total recharge to essential groundwater aquifers is about 600 x 10^{6} m3/year and 260 x 10^{6} m3/year in Unguja and Pemba respectively.

Geo-electrical soundings are useful and cheap means for determining the geological formation and for obtaining some indications of the salinity of groundwater. Maximum yield from individual boreholes could be obtained by making the borehole silting through geoelectrical survey.

The ground water reservoirs in Zanzibar are always replaceable. Continuous monitoring of ground water storage will guarantee that no damage will be done to the natural water reservoirs. Even if some over pumping would occur, the natural balance would soon return, if pumping is reduced.

The results of this study should be considered indicative, as the pumping tests, during the planning phase, lasted only from a few hours to three days. In most cases the pumping and observation of water level was done from the same borehole. Observation holes were available only in a few cases.

The condition of the existing water intakes is rather deteriorated and all the boreholes must be rejuvenated in a few years time. The drilling of borehole wells can be done by the proposed urban water supply section of the Department of Water Development. Contractor services can be used for major drilling exercises.

Cable-tool and direct rotary drilling are found to be appropriate drilling technologies in Zanzibar.

1.2 Recommendations

The preparation of the system for ground water management is to be submitted under coordination of an inter-ministerial committee/board, where Department of Water Development, together with the planned Urban Water Supply Authority, will play a leading role. Other relevant parties would be, Department of Irrigation, Commission for Land Use and Environment, Forestry Department, Municipality Council and Private Sector.

In order to control the restoration of the water resources, the pumping of ground water with machine pumps for different use purposes should be licensed. Regulations should be set for use of fertilizers and pesticides in the agricultural production and for handling of wastes and effluent in the catchment areas.

The surroundings of the existing and new water intakes should be protected. For instance trees could be planted in the vicinity of the intakes. Larger scale water shed management program should be initiated in the catchment areas in coordination with the forest conservation program.

Water policy statement supported by Water Act should be formulated. As a provision of this Act the Minister should delegate to appropriate officials in the water administration the task of determining the water conservation areas and handling of related technical issues. An administrative lands and water tribune/court should be established to handle any violations against the water legislation.

Declaration of conservation areas, and all procedures relating to such a declaration should be made in accordance with the procedures in the set out of the Forest Resources Act, which is under review by an interministerial committee and FAO.

The potential water intake areas, identified in this report, should be gazetted for urban water supplies.

Drilling at the lower Mwera valley should be permitted only for urban water supply purpose. The recent proposals to drill for irrigation in this area should be abandoned.

The discharge of ground water from the aquifers, identified for urban water supplies, should be limited to the excess capacity of the aquifers. The natural groundwater storage should not be disturbed permanently.

The coastal areas where the water table is not much above the sea water level should be avoided while locating the new drilling areas

A research & development and drilling unit should be established in connection with the proposed urban water supply section, in order to efficiently run the water resources management, environmental monitoring, further studies, and drilling programme.

All the conclusions and ground water development plans of this report have to be verified by further test drilling, longer (1 - 3 weeks) pumping tests and longer term hydrogrammes. Observation boreholes should be drilled and further testing should be carried out for obtaining actual hydraulic data. Resistivity contour map, storativity map, transmitivity map, potentiometric map, chemical quality map as well as revision of hydrogeological and meteorological maps can be prepared accordingly.

Essential monitoring data should be deposited in a simple database. The database program could automatically produce hydrogrammes from the collected data. After gathering more data and after increasing the discharge from the aquifers, consideration could be given for preparation of a mathematical hydraulic model of the aquifers.

One borehole well drilling unit should be deployed in Pemba nd one in Unguja. The drilled boreholes should be properly designed, based on design criteria given in this report.

No short or long term monitoring data on river flows exist. The Department of Irrigation should undertake a long term river monitoring program in order to asses the feasibility of irrigation development.

The meteorological monitoring stations should be renovated. New equipment should be purchased and monitoring staff trained. Action should be taken by Ministry of Agriculture.

2. BACKGROUND

2.1 Urban Water Supply Development Plan

The preparation of the Zanzibar Urban Water Supply Development Plan took place November 1989 - December 1990.

The work was undertaken as a consultancy project by M/S Plancenter Ltd, in close cooperation with the Department of Water Development (DWD) of the Ministry of Water, Construction, Energy, Lands and Environment, Zanzibar.

The plan covers Zanzibar Town on Unguja Island and the three towns on Pemba Island, Chake Chake, Wete and Mkoani.

The planning period is from 1990 to 2015. The total population coverage will be 232.000 and 590.000 in 1990 and 2015 respectively.

The Water Resources Study is an additional part of the Development Plan. The Development Plan, main report, covers Financial Analysis, Institutional Study, Water Resources Study, Physical Planning and Environmental Impact Assessment.

2.2 Geography

Unguja and Pemba are two islands in the Indian ocean on the East Coast of equatorial Africa. The two islands were formed out of large delta formation of the Ruvu River. They emerged from the ocean during the drift faulting of the coastal areas. Unguja is separated from the mainland of Tanzania by a shallow ocean floor and Pemba by the 700 m deep Pemba Channel.

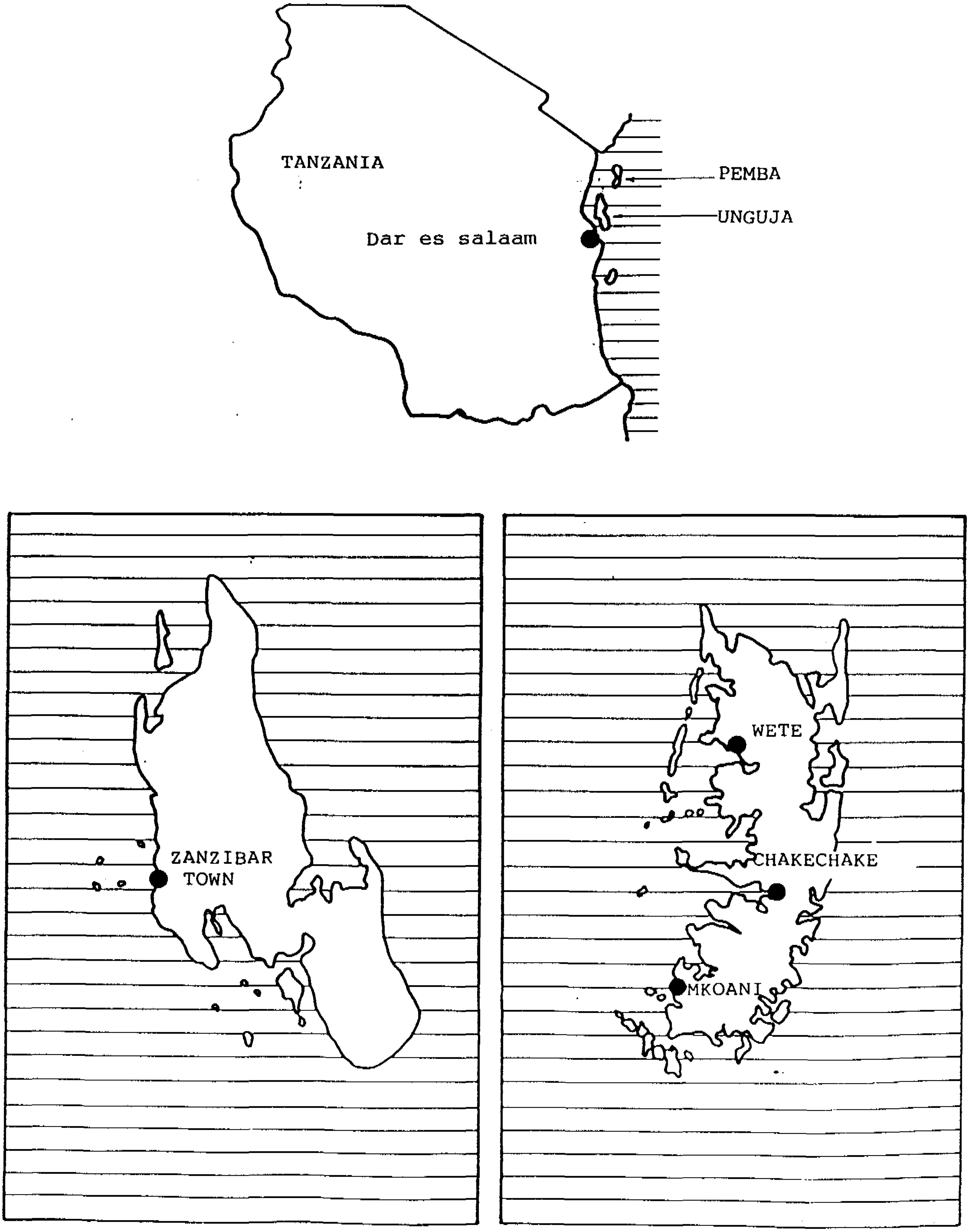
Unguja island is situated between latitude 5 ° 40' and 6 ° 28' south of equator. It is about 35 km off Tanzania mainland. It is the larger of the two islands with an area of 1660 square kilometers and with an 85 km north to south dimension and 35 km east to west. The location of the islands is presented in Figure 1.

Pemba island is situated 40 km to the north-east of Unguja. The area of Pemba is about 980 km2. Pemba is greener and more hilly with more trees and less bush and more intensive land-use.

2.3 Water Intakes

G.M. Stockley states 1951: Zanzibar Township Water Supply is almost world famed for its purity and taste: the springs at Chem Chem have been used for drinking

FIGURE 1. MAP OF ZANZIBAR



UNGUJA

PEMBA

purposes literally for thousands of years - it is said that records are known dating to before the birth of Christ. It is therefore desirous that this unique and old established water supply should continue its reputation undiminished.

At early stages of Urban Water Supply Development of Zanzibar Town in 1920's, Mtoni Spring (Chem Chem) and Bububu Spring were developed for urban water supply sources. Bububu spring is located about 6 km and Mtoni spring about 3 km North from Zanzibar Town. At Pemba, at Wete town, the Gawani spring, about 1 km South - East from the town, was developed in 1944 - 45 for Urban Water Supply. Before 1945 the small Bubujiko Spring at the immediate vicinity of the Wete town was used for town water supply. In Mkoani the Kiguuni spring, a few kilometers North - East from the town, was developed in 1932 and in Chake Chake the Miembeni spring, located in the town area, was developed in early 19th century. Later on borehole wells were drilled for town water supplies and new springs were develop[ed as well.

Since the 1960's drilling activities took place. The total number of boreholes in Unguja and Pemba islands is presently more than 150 nos. The boreholes have been drilled either by the Department of Water Development for urban and rural water supplies or by FAO or Department of Agriculture for irrigation use. Three different drilling methods have been used: core drilling method, cable tool method and direct rotary method.

In 1990 ten boreholes, seven springs and one cave were used as urban water supply intakes in the two islands. About 15000 m3/day and about 4000 m3/day of ground water was pumped to the urban areas in Zanzibar and in Pemba respectively. Location of urban water supply intakes is presented in the Map 1a, b and c.

2.4 Population Growth and Water demand

Water demand in urban areas in Zanzibar is likely to drastically increase during the next few decades due to rapid population growth. Moreover increased quantities of water will be consumed by tourism and industry etc.

Based on estimated areawise population growth percentages, the future projection for urban population will be as follows:

Population Projections

	1998	1990	2000	2015
Zanzibar Town	198991	214430	311310	544710
Chake Chake	35757	37630	48640	71520
Wete Wete	25564	26920	34790	51130
Mkoani	17015	17910	23160	34020

The per capita domestic consumption is planned to be raised from the present theoretical value of 36 l/c/d to 66 l/c/d. Moreover, increased quantities of water will be consumed by the tourism, industrial development and commerce, added by amounts unaccounted for.

The average daily water demand in urban areas is estimated to change from 13.100 m3/day in 1990 to 59.500 m3/day in 2015 and from 2.400 m3/day in 1990 to 12.600 m3/day in 2015 on Unguja and Pemba respectively.

2.5 Previous Ground Water Related Studies

The geology of coastal Tanzania was first studied by German geologists in the beginning of the 19th century. A number of reports on the geology and hydrogeology of Zanzibar have been published since 1928 and they give good background material for further studies and planning of groundwater use.

1) The geology and geophysics of coastal Tanzania, Geophysical paper no. 6. natural environment research council, Institute of geological sciences P.E. Kent & All, 1971.

   The Report gives an excellent presentation, on physical geology of Zanzibar and Pemba, based on geophysical surveys, surface geology and deep borehole data obtained in connection with petroleum research work.

2) Interim report, Hydrogeology, J. Johnson, 1984

   The report outlines the views on hydrogeology of early eighties having an emphasis on irrigation development in Unguja island.

3) Hydrogeological Map of Zanzibar, UNDP/FAO,1987.

The hydrogeological map of Zanzibar summaries very well the information elaborated in the Johnson 1984 report.

4) Mission report to the islands of Zanzibar and Pemba, 26th August - 8th September 1985, Miguel R. Solares, Jan 1986. The report offers a fairly ready made groundwater ordinate which can be modified and applied in the present situation.

3. DESCRIPTION OF NEW STUDIES

The following studies were carried out in connection with the assessment of the water resources in Zanzibar:

Study on existing reports and data

The existing reports were gathered from different institutions and Ministries and from the National Archives for background information prior to starting the field studies.

Survey of existing water intakes including surface geology and environmental aspects

A team of hydrogeologist and technicians visited all the intake sites. The team interviewed the employees at the site and other relevant people who were living in the surroundings of the intakes. Observations on physical condition of the intake, geology and environment were done and the results were noted in questionnaire forms. A separate hydrogeology field visit report was drafted. The location of existing water intakes and potential new intake areas are presented in Map 1a, b and c.

Pumping tests at borehole intakes

The existing borehole intakes were test pumped applying constant rate tests from 3 hours to a few days. Tentative conclusions on aquifer characteristics were drawn and further plans for test drilling and pumping tests were outlined.

Survey of availability and quality of filter sand

Filter sand samples were collected from different places in Unguja and Pemba islands. The samples were analyzed at the University of Dar es Salaam, Geology Department. Recommendations for filter sand collection sites were made.

Geoelectrical soundings survey

The University of Dar es Salaam, Laboratory of Geophysics undertook a field survey of 28 geoelectrical sounding points in Pemba and 28 sounding points in Unguja. In Pemba the points were located in all potential drilling areas. In Unguja four geoelectrical profiles were done across the Bumbwi corridor and one profile across the Kisima Mchanga sub-corridor. The geology and hydrogeology at the sounding sites were interpreted and the information was utilized for writing the hydrogeology report and for making the test drilling plans.

Survey of local wells in catchment areas of potential water intakes

All local wells in Bumbwi-corridor and in Kisima Mchanga sub-corridor were surveyed in Unguja. In Pemba all wells in the planned intake areas were surveyed. The total number of wells found was 108 in Unguja and 53 in Pemba. The water table and electrical conductivity were monitored once a month in each well. A smaller number of wells, i.e. 40 Nos. were selected for more detailed water quality monitoring. Monitoring data was gathered in data sheets which was used as basic material for well monitoring data base. The location of the local wells is presented in Map 2a, b and c.

Monitoring of water levels and electrical conductivity in borehole wells and springs

All the borehole wells were monitored once a month. The over flow of the springs was monitored continuously at regular intervals during the planning period. The water table at Dimani cave was observed regularly. The data will be used for long term hydrogrammes and for developing the hydrogeology data base.

Identification of natural springs in Pemba

The relevant river valleys and natural springs were studied through field visits. The location of the observed springs in Pemba are marked in Map 2a, b and c. Data was collected in data sheets. Two new natural springs with substantial potential for town water supply were discovered in the vicinity of Mkoani.

Survey of rivers and surface water resources

Rivers of Unguja were observed during the hydrogeology field visits. Regular monitoring was arranged in a few relevant sites. The rivers in Pemba were studied by field visits and estimates of water discharge were made. Location of rivers, visited during the field survey, are presented in map 3a,b and c and in figure 12. A few sites were selected for a continuous river monitoring. It is recommended that Department of agriculture would continue this exercise.

Evaluation of Meteorological Stations. Collection of Meteorological data

All the Meteorological stations were visited. The condition of the measuring instruments was observed and available data was collected. The Department of agriculture has a program for renewing the meteorological instruments and for improvement of the quality of the monitoring.

Drilling Technology Study

The drilling machines tools and accessories, available in Zanzibar and Pemba, were checked. The drillers were interviewed and conclusions were drawn for defining most appropriate drilling technologies in Zanzibar. The condition of existing boreholes was assessed and criteria for borehole design was established.

4. CLIMATE AND METEOROLOGICAL DATA

4.1 General

There are sixteen and fourteen meteorological observation stations in Unguja and Pemba respectively. The location of these stations is presented in figure 2.

The rainfall in the islands is strongly seasonal related to change of monsoon and movement of the tropical convergence zone. The season of heavy rains (Masika) comes during March- May. The relatively cool and dry season (Kusi) takes place during June - September. A lesser rain season (Vuli) is during October and December. The north-east monsoon (Kaskazi) is during January and February and the weather is dry and hot. (Unguja and Pemba have an average weather temperature of 27 °C in January and 24 °C in July. The average annual temperature is 26 °C).

The Johnson,1984, report summarizes climatical and meteorological data from the two islands until the year 1984. Some new data has been gathered since 1984. Summaries on the old and the recently obtained precipitation data were made.

4.2 Precipitation

In Unguja and in Pemba the average annual rainfall varies between 1000 - 2250 mm. Mean monthly and annual rainfall based on data obtained from the meteorological stations of Unguja and Pemba Airports is presented in Figure 3. Mean annual distribution of rainfall is presented in Figure 2.

The average annual rainfall is about 1700 mm per year in Unguja. In Pemba the respective figure is slightly higher. As for planning purposes, total annual rainfall of 1500 mm is applied in Unguja and 1600 mm in Pemba.

The total average precipitation contributing to ground and surface water development is roughly 2490×10^{6} m3/year in Unguja and 1570×10^{6} m3/year in Pemba.

4.3 Temperature

The mean monthly minimum and maximum temperatures in Unguja and Pemba are presented in figure 4. The mean annual maximum and minimum temperature in both of the islands is about 30 C ann 22 C respectively.

4.4 Other Meteorological Information

The mean monthly class pan evaporation at Unguja

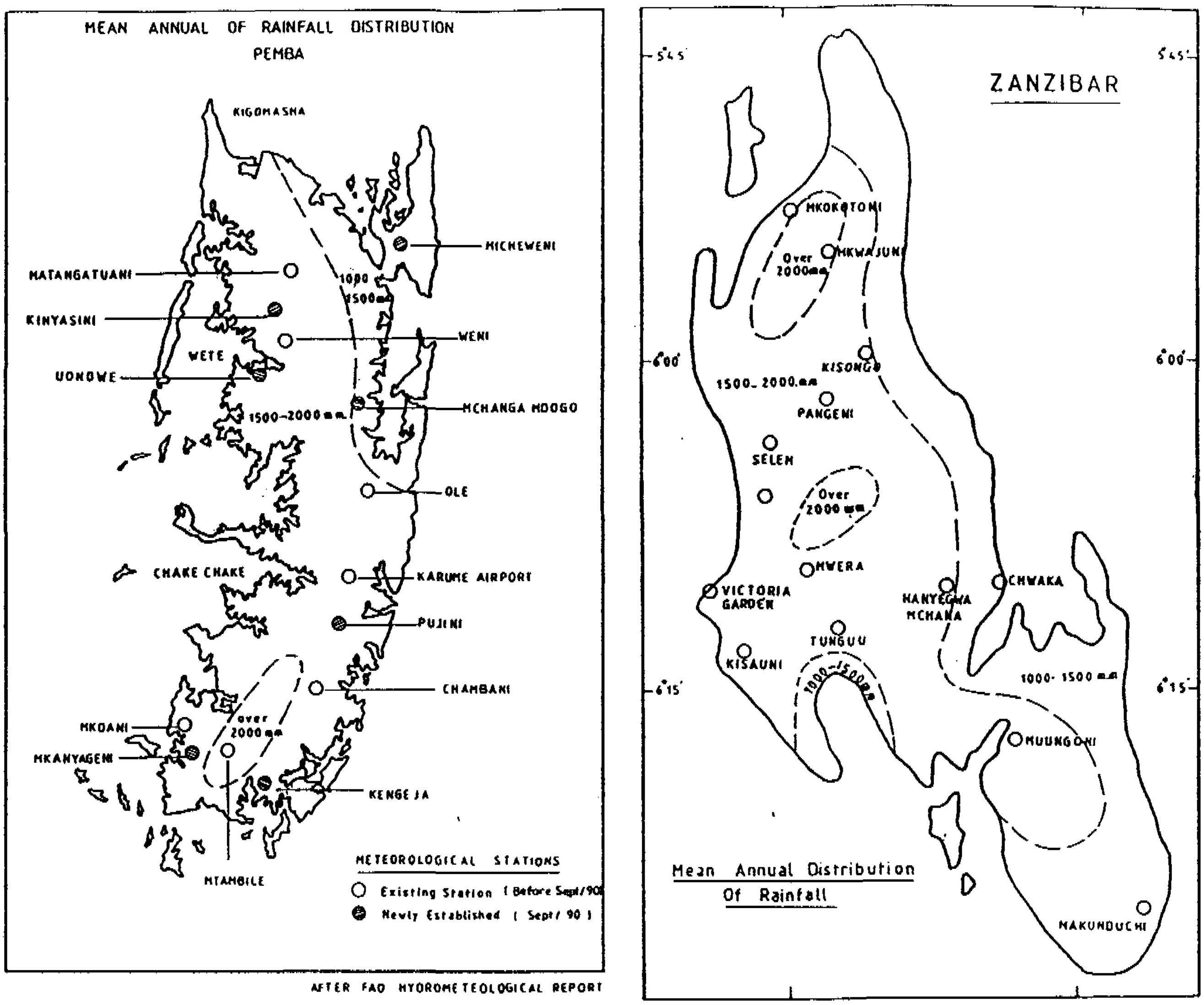


Figure 2 Mean annual rainfall distribution and location of Meteorological stations

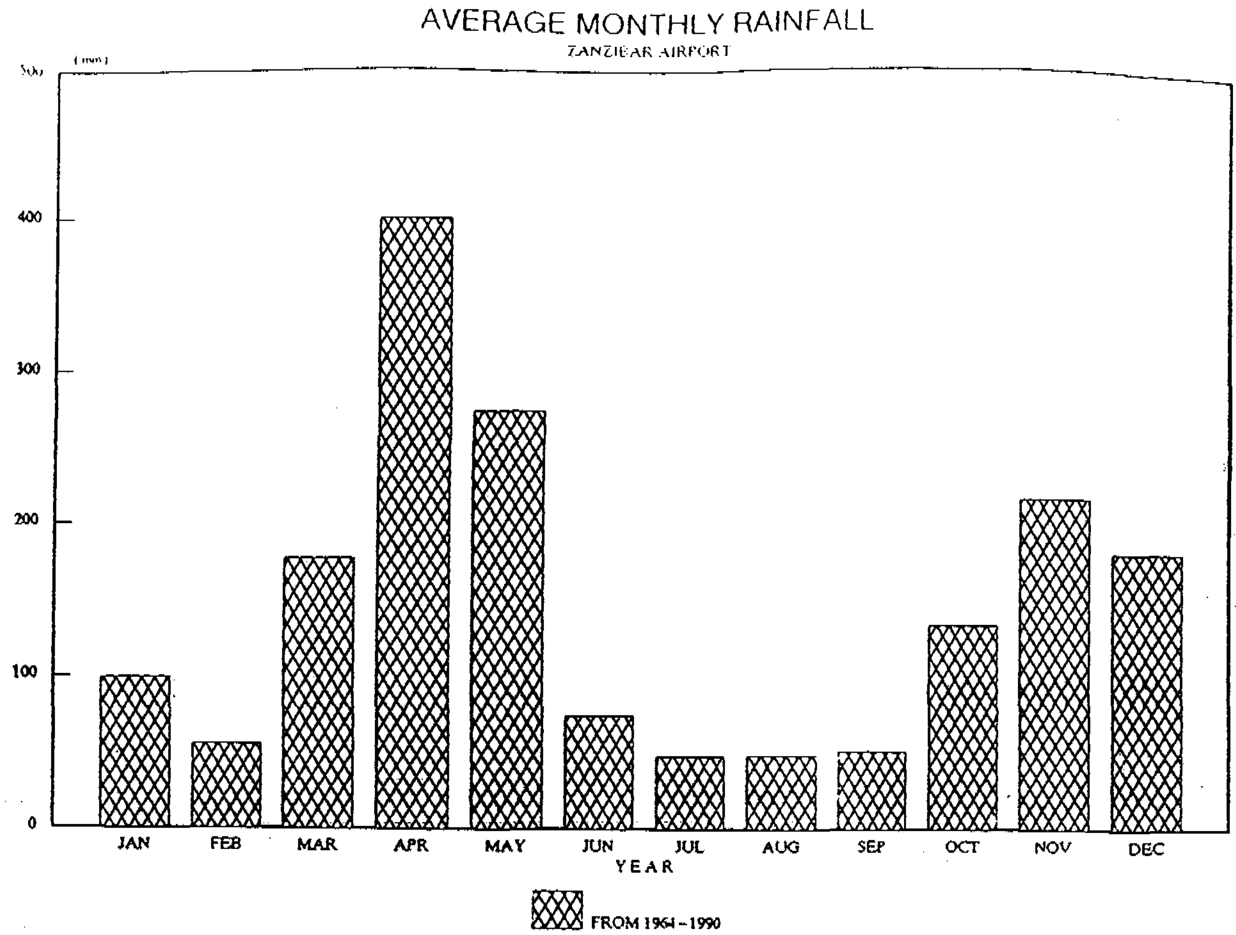


Figure 3a Mean Monthly Rainfall Unguja Airport
Average Annual Rainfall 1722 mm

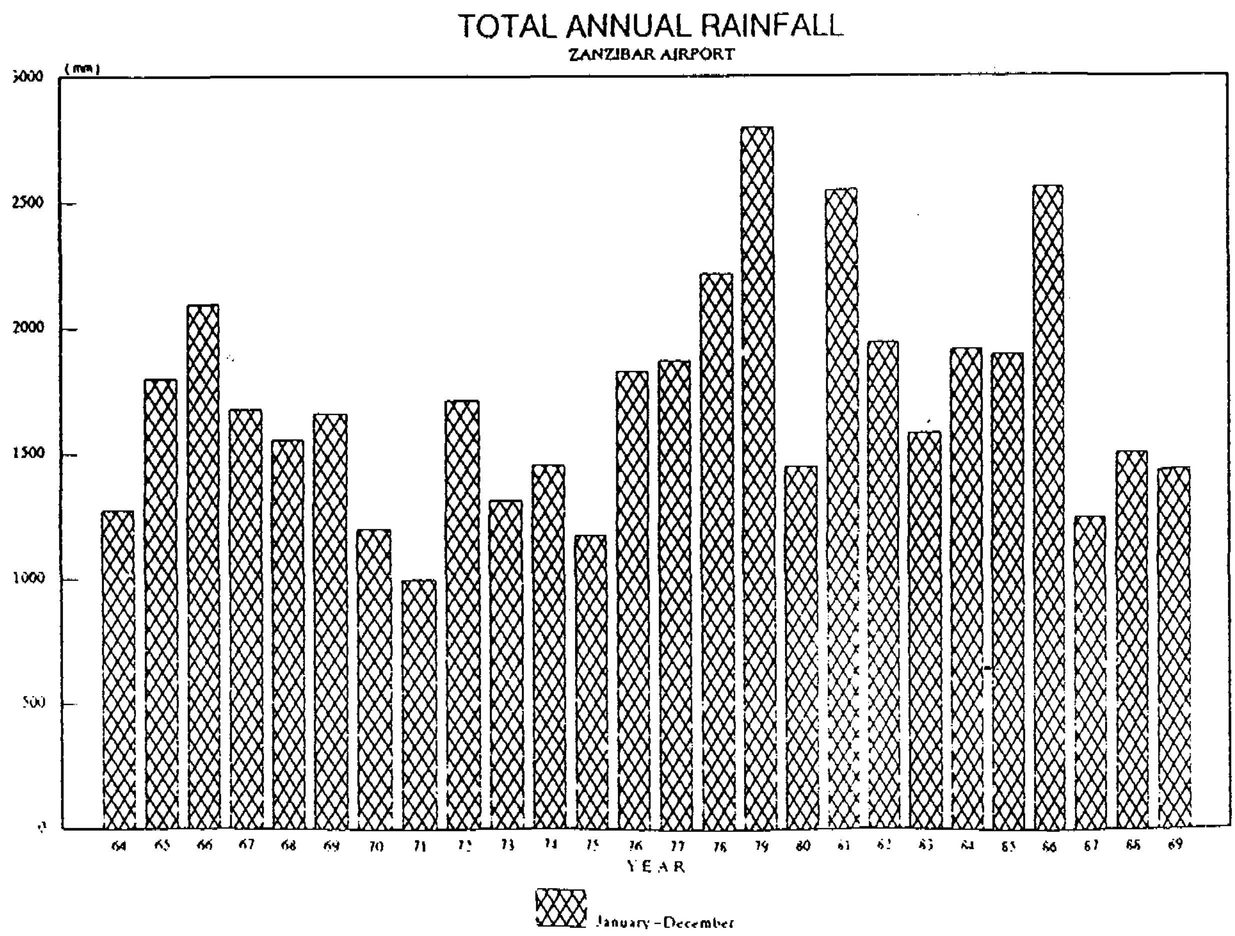


Figure 3b Total Annual Rainfall Unguja Airport
Average Annual Rainfall 1722 mm

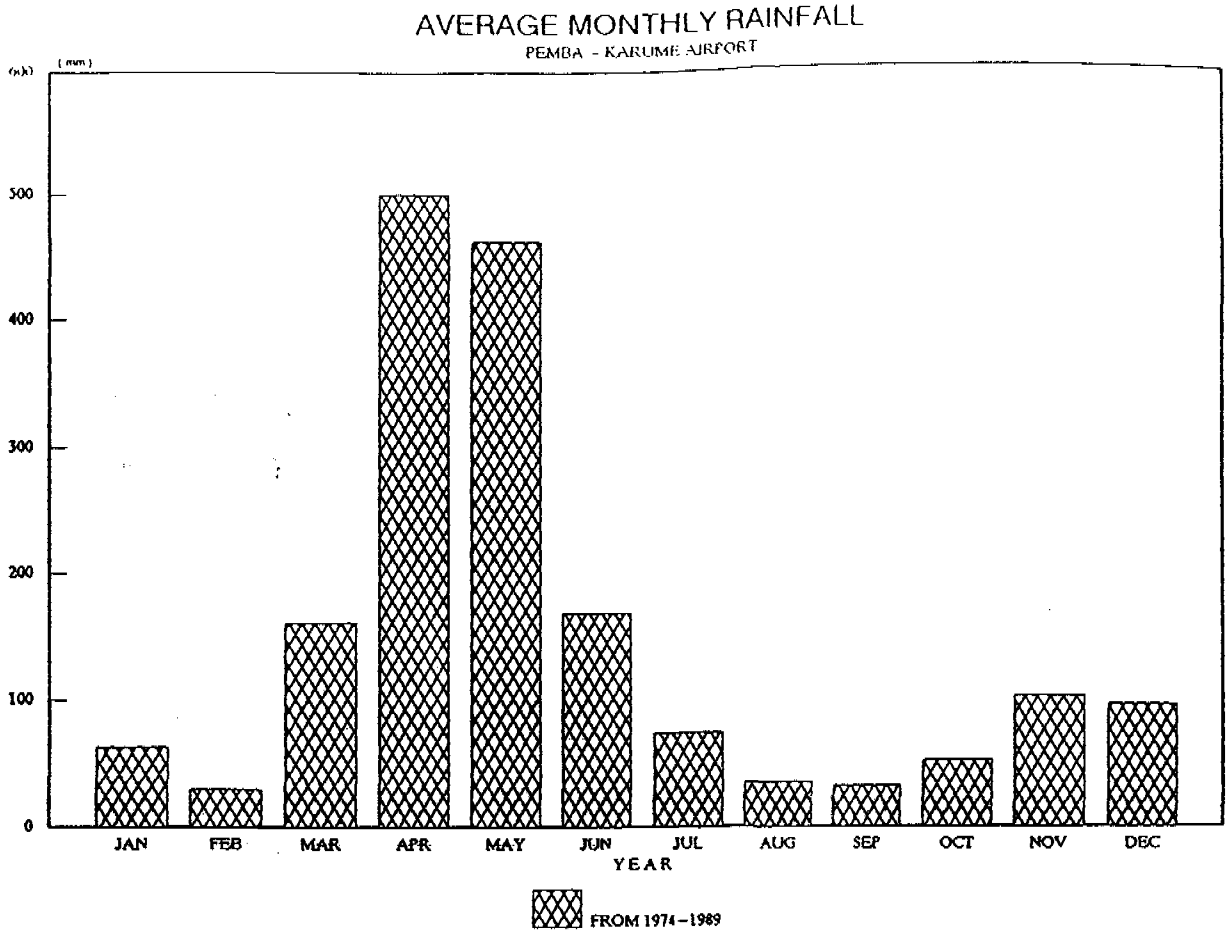


Figure 3c Mean Monthly Rainfall Pemba Airport
Average Annual Rainfall 1720 mm

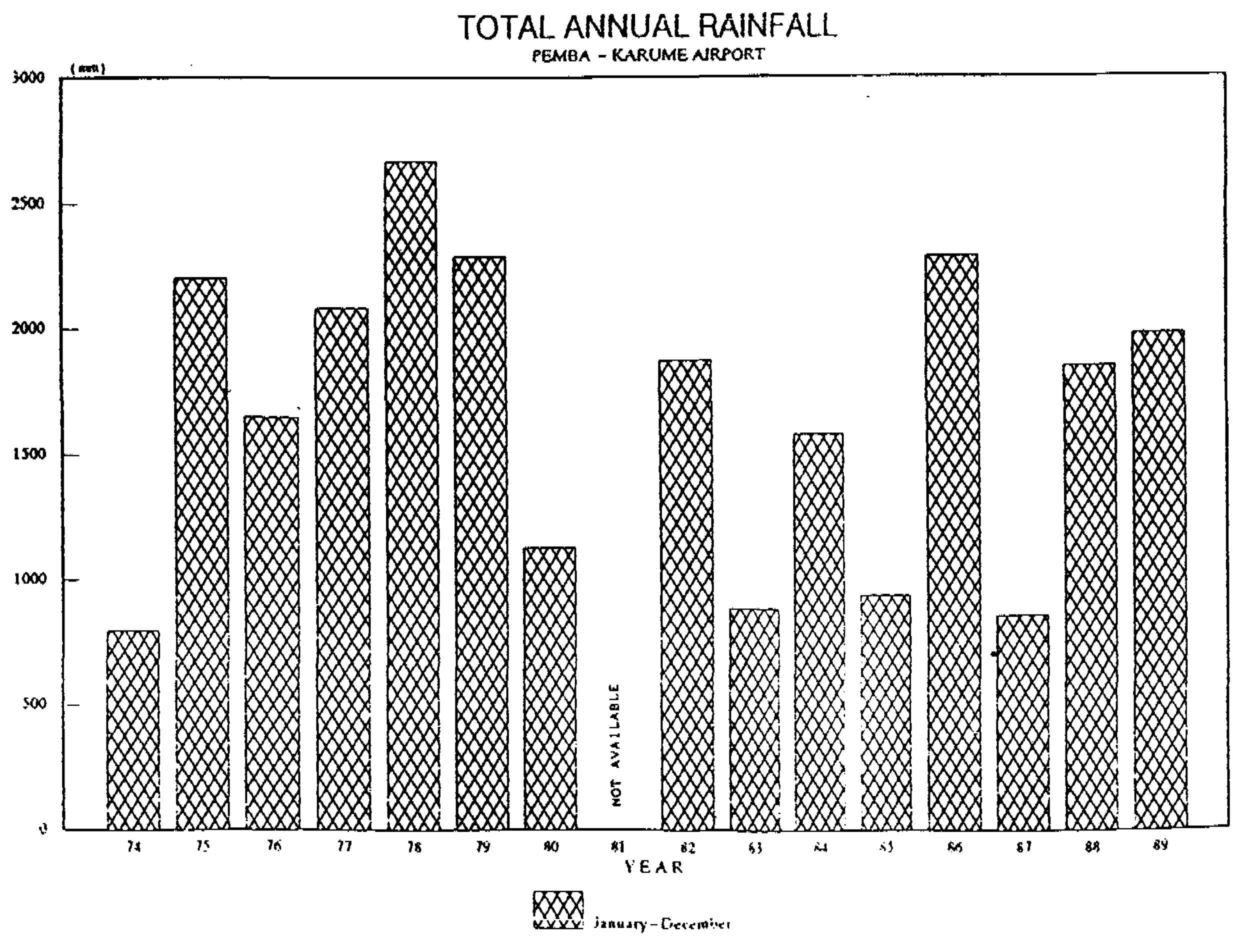
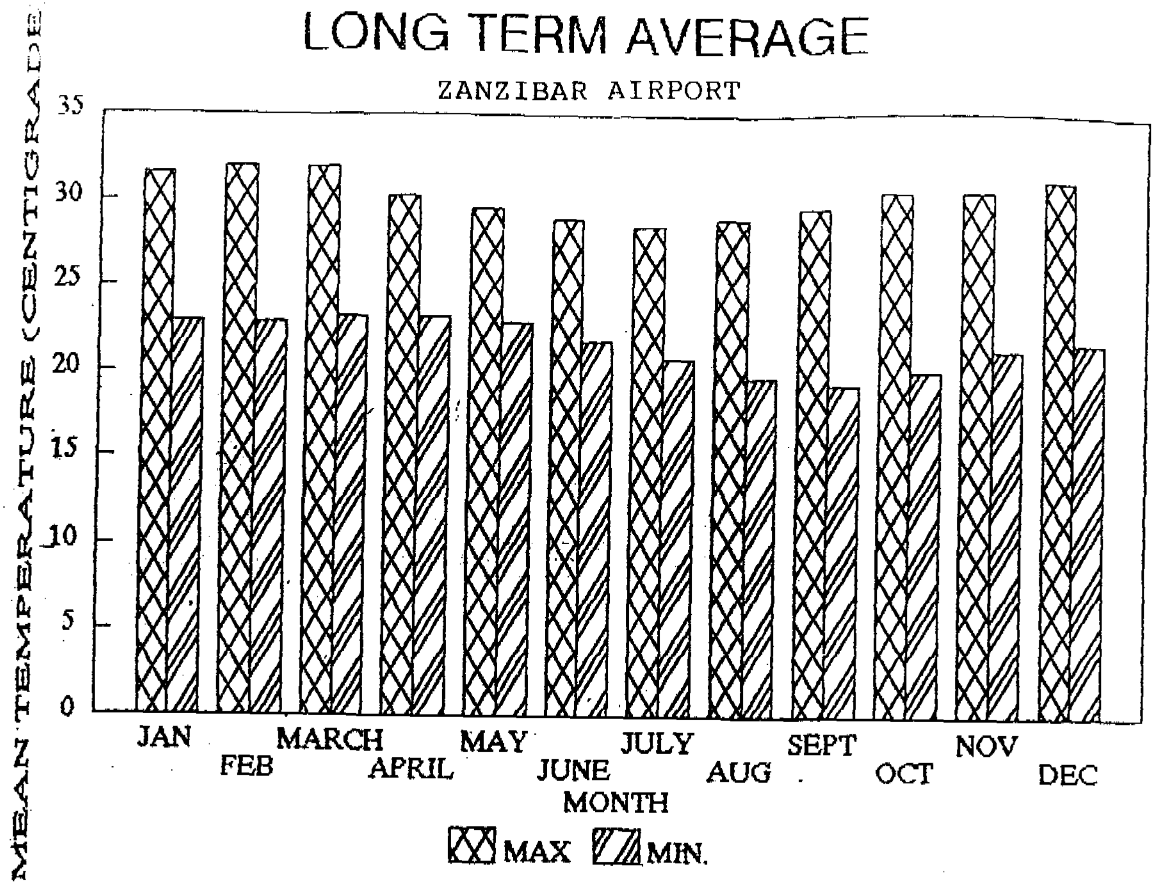
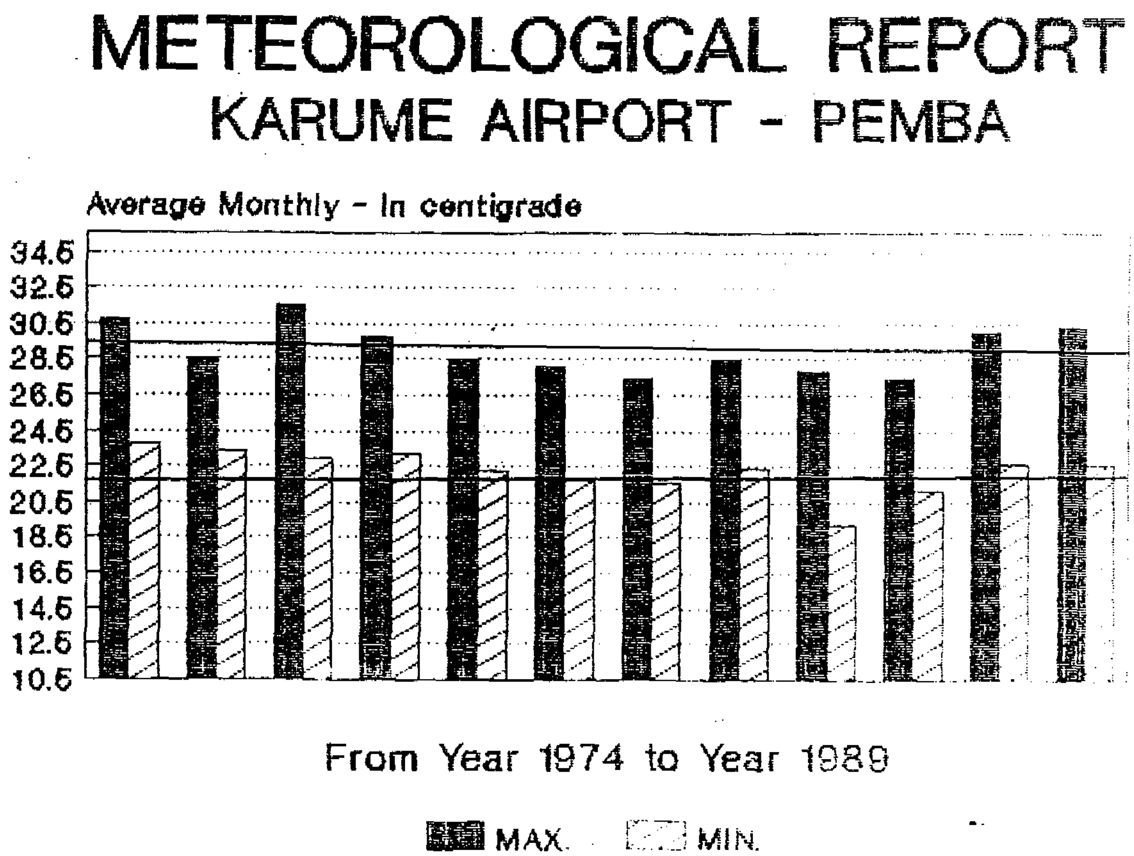


Figure 3d Total Annual Rainfall Pemba Airport
Average Annual Rainfall 1720 mm





No data for year 1981

Figure 4

Mean Daily Maximum and Minimum Temperatures in Unguja and Pemba

Airport is presented in figure 5. The total annual evaporation is about 1650 mm, equal with the total rainfall. Respective data from Pemba was not available.

The mean monthly relative humidity at Unguja Airport at 6 hrs and 15 hrs is presented in figure 6. The maximum and minimum varies from 55% to 95%. The lower humidity values correlate with the dry seasons. No respective data from Pemba was obtained.

Average monthly wind speed in knots at 15 hrs at Unguja Airport is presented in figure 7. The higher wind speeds correlate with the dry seasons.

Number of raindays per month is presented in figure 8. A clear correlation with the rainy seasons can be observed. There seems to be five or more rainy days per month every month.

Daily radiation in langlays is presented in figure 9. There is a correlation with the rainy season.

Cloud cover in oktas is presented in figure 10. There is correlation with the rainy seasons.

Mean sunshine hours per day are presented in figure 11. There is a correlation with the rainy seasons.

4.5 Assessment on the Status of the Meteorological Monitoring

The meteorological stations are divided into the following three categories:

a. Meteorological Stations
   - Kisauni (Airport)
   - Victoria Garden
   - Mahonda
   - Karume Airport

Meteorological stations are dealing with all meteorological data collection.

b. Agrometeorological Stations
   - Kizimbani
   - Weni

Agrometeorological station are dealing with meteorology and they are equipped with special instruments for measuring the soil temperatures.

c. Rainfall Stations

   Mkokotoni, Mkawagini, Kosongoni, Pangeni, Selem, Mwera, Tunguu, Hanjegwa Mehana, Chawaka, Mungoni

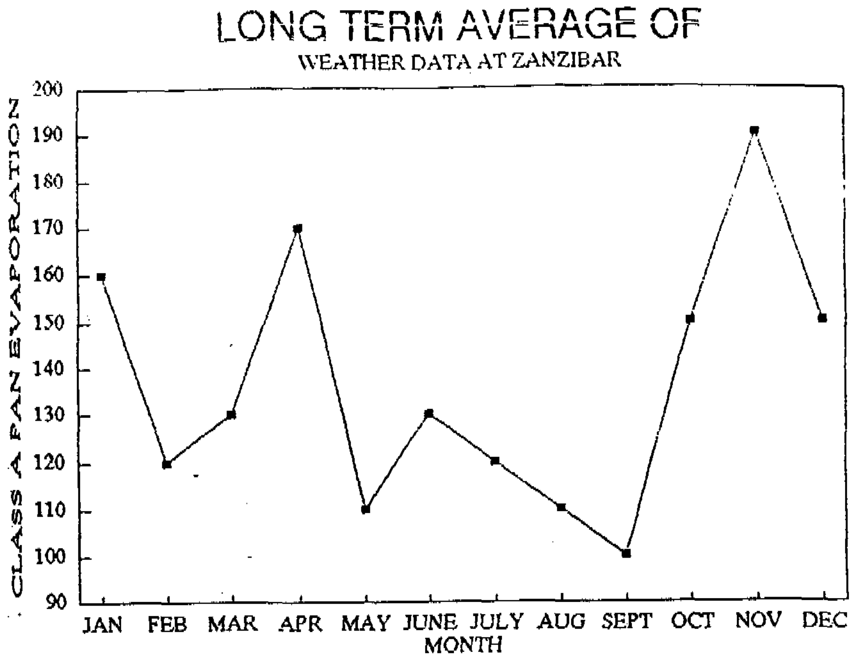


Figure 5

Mean Monthly Class Pan Evaporation

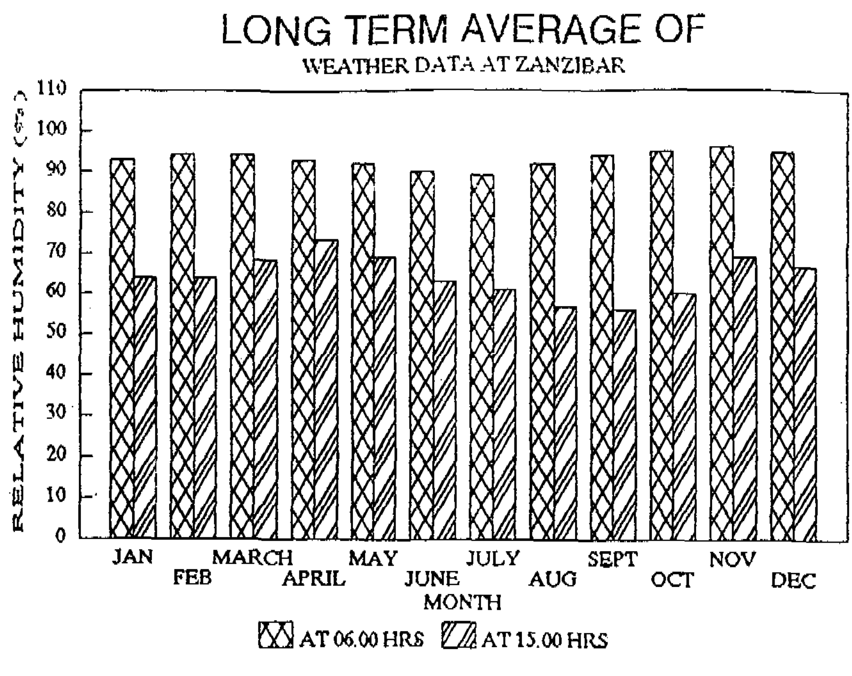


Figure 6

The Average Monthly Relative Humidity at Unguja Airport

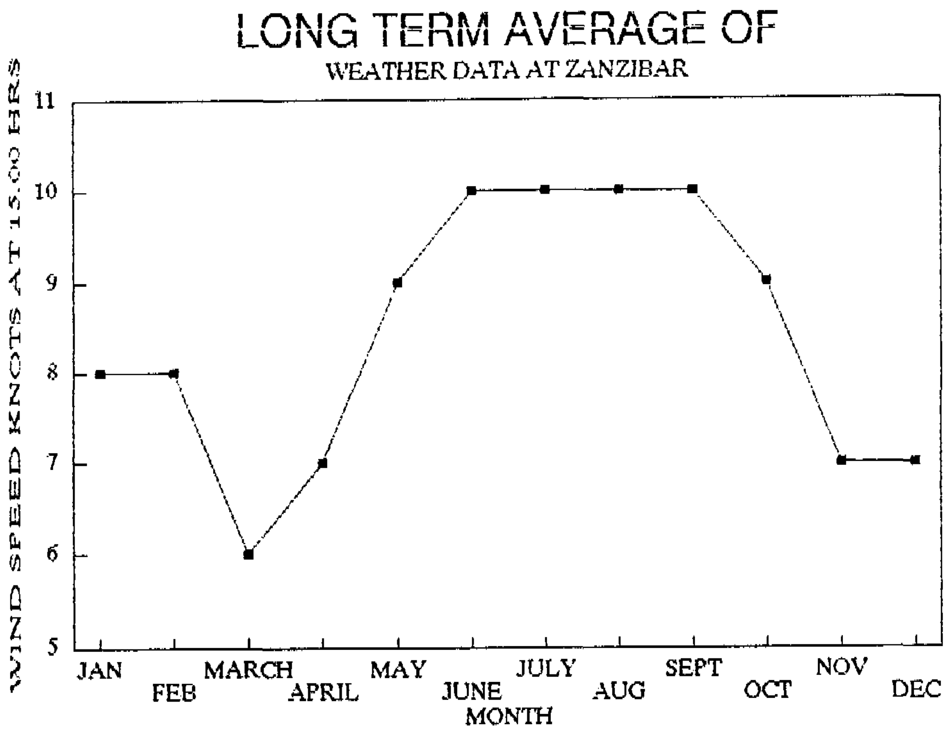


Figure 7 Average Monthly Wind Speed

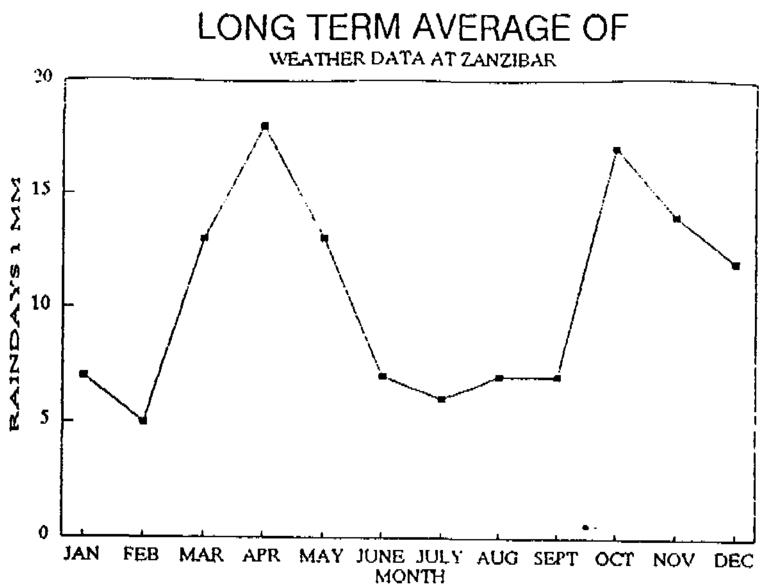


Figure 8

Raindays Per Month, Zanzibar Airport

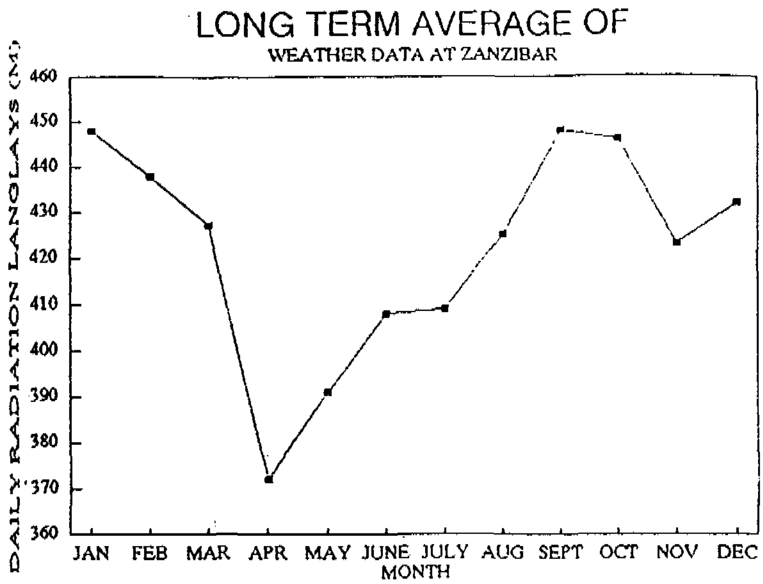


Figure 9

Daily Radiation, Zanzibar Airport

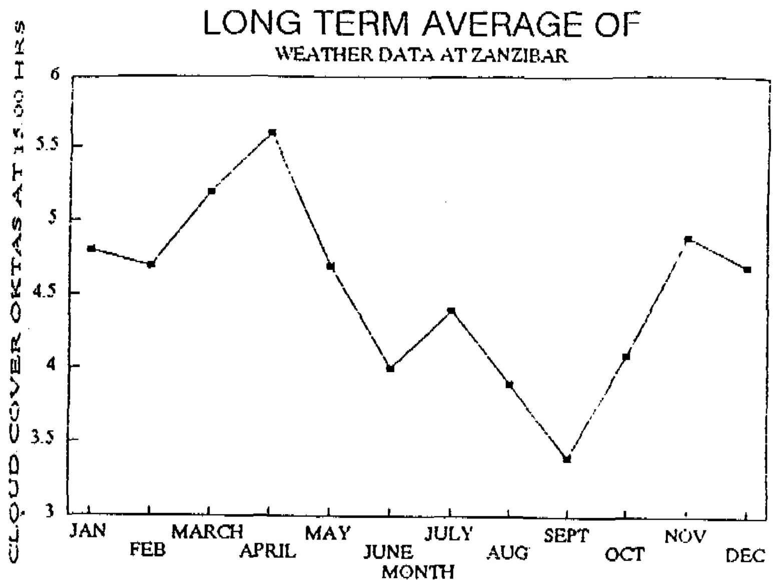


Figure 10

Cloud Coverage, Zanzibar Airport

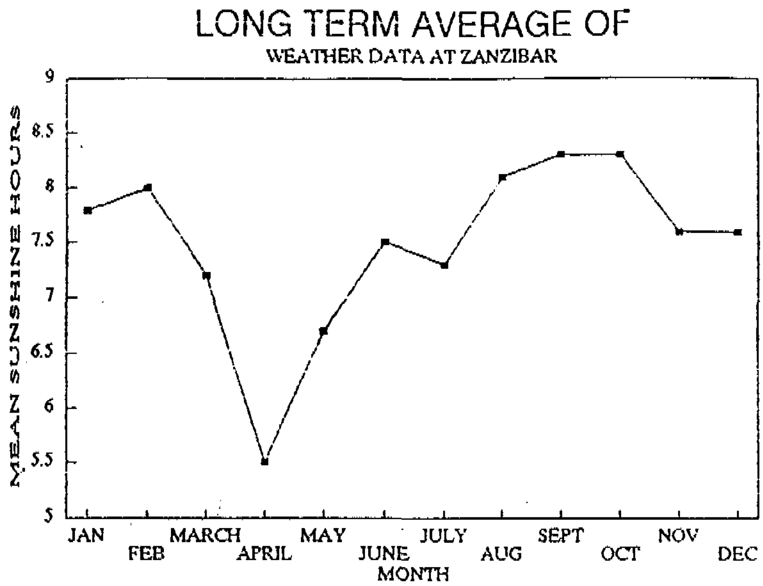


Figure 11

Mean Sunshine Hours Per Day, Zanzibar Airport

Summaries of data obtained from each meteorological station are kept in files in the project office.

4.6 Recommendations

In some of the stations the area is too crowded with vegetation and buildings and the site should be changed. For instance Mtambile station.

In almost all the stations the instrumentation should be updated and the non-operational or poor condition instruments should be replaced.

The staff with basic training should be provided with further training. The staff with no training should be provided with the necessary basic training.

The compounds of the stations should be properly fenced.

The implementation of the recommendations with recard of meteorological monitoring should be undertaken by the Ministry of Agriculture.

5. SURFACE WATER RESOURCES

5.1 Streams, Unguja

There are no perennial rivers, flowing from Unguja inland to the sea. Rivers which have perennial sections or which do not get dry every year are:

1. Mwera - Mwera valley
2. Zinwe Zingwe - Donge
3. Mwanakombo - Mahonda
4. Tinga Tinga - Kipange

The location of the above rivers is presented in Figure 12.

The Mwera river is located near Zanzibar town and it disappears in sandy formation around Fuoni area. The quantities of stream flow were beyond the possibilities of the Project to monitor. The estimated dry season flow of Mwera River in 1990 at the Mwera bridge was 15000 m3/day. The water table was monitored at Mwera river and its branch Kianga river at the Mwera bridge and at the Kianga bridge. It appears that the rivers have a few hours peak flow after the rainstorms.

The surface water resources do not play any

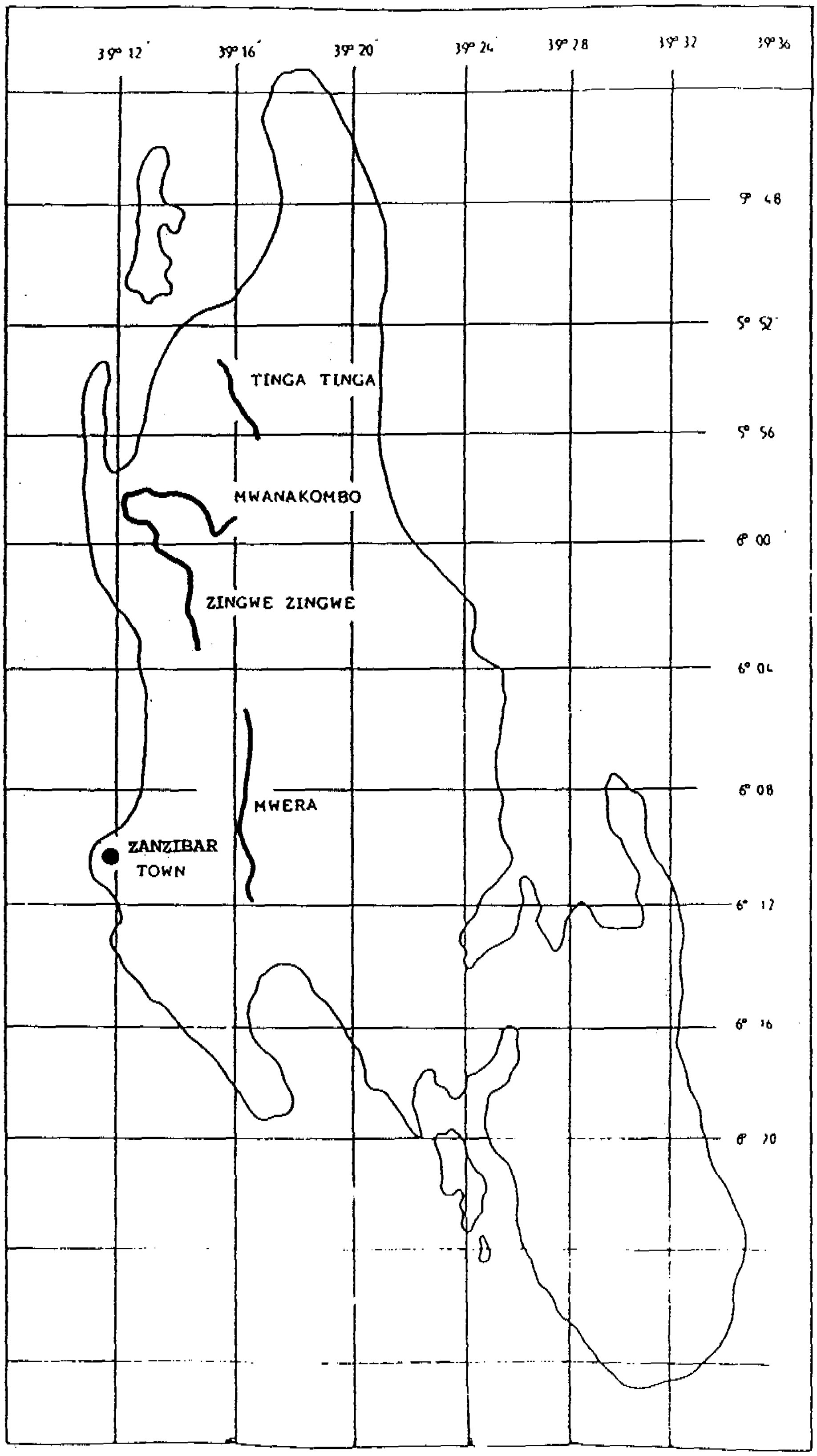


Figure 12 Location of Rivers, Unguja

significant role as urban water supply sources. At the lower Mwera valley the rice irrigation should continue to utilize surface water resources. The plans for drilling new irrigation boreholes should be held until the Mwera river water is fully utilized and the impacts to the aquifer, caused by long term urban water supply pumping programmes. A proposal to gazette lower Mwera areas for urban water supplies was first made by Mr. Johnson 1984.

The Mwera river is seen as a feasible surface water source to be developed for irrigation use.

5.2 Streams, Pemba

The streams in Pemba are more numerous and more often perennial than in Unguja. The small rivers form small insignificant deltas in the sea. The river mouths are usually occupied by thick mangrove vegetation. The downstream valley bottoms are always flat floodplain and topographically on a relatively low level.

The rivers are fed by small springs, emerging from lime/sandstone formations at the lower valley banks. The small springs usually originate small rivulets, which later on join together forming the river. The small streams meander along the plains at the valley bottoms with relatively low flow velocity due to small topographical gradients. Suspended sediments accumulate into the plain areas of the valley bottoms.

There were no means for regular monitoring of the actual water flow rates, however water tables were monitored in the four biggest streams in Pemba. The monitoring sites were as follows:

River	Monitoring site
1. Mangwena River	Mangwena bridge
2. Weni River	Kizimbani and Weni bridges
3. Machengwe River	Machengwe bridge
4. Kwapweza River	Umangani bridge

The location of the visited rivers and monitoring sites are presented in Map 3a,b and c.

During the peak discharges the rivers go over their banks but the valleys are not usually water logged more than 24 hours. At the higher elevations the topographical gradients increase and the flow gradients of the storm waters increase substantially. The upstream parts of the rivers reach their peak flow rates soon after the actual storms and dry up in a few hours time. During the dry season the river flow reduces substantially.

Although there was no actual flow rate reading, it is assumed that about 25 - 30% of the precipitation returns directly to sea by rivers and streams. This discharge rate is in accordance with global average river discharge rates.

The use of river water for urban water supplies is not recommendable due to water quality constraints and because there is reasonably good availability of ground water.

It is suggested that the Department of Irrigation would organize long term monitoring of the perennial rivers, as it will be their interest to use this resource for rice irrigation.

5.3 Lakes and ponds, Pemba

A number of water logged ponds have developed in the flat lying areas of the Eastern parts of the island. Eroded silts and mud have developed water tight basins on the topsoil. The ponds are recharged by rainwater and discharged by evaporation. These ponds are often polluted with diseases like bilharzia and they really have no significance as drinking water supply sources.

6. GROUNDWATER RESOURCES

6.1 Monitoring of Local Wells

A total number of 161 local wells were selected for monitoring in the catchment areas of the existing and proposed water intakes. 108 and 53 wells were monitored in Unguja and Pemba respectively. The location of the wells is presented in Map 2a,b,c. The monitoring was carried out monthly and the following parameters were recorded:

1. Unchanging parameters as per the local well monitoring sheets Annex 1.

2. Changing parameters

   well depth
   Static water level
   Conductivity
   Temperature
   Other water quality parameters
   ph - value

A database program was prepared for depositing the monitoring data and for drawing hydrogrammes. A description of the database is presented in Annex 2. The data sheets of each well with about one years monitoring data were deposited in the database.

The monitoring results show that the fluctuation of water table in the miocene formations varies from 4 to 7 meters. The respective fluctuation in the quartednary corridors is less than 2.5m. This is in accordance with the results obtained by Mr. Johnson 1984.

6.2 Monitoring of Borehole Wells and Springs

Fourteen and thirteen borehole wells were monitored in Unguja and Pemba respectively. The location of the boreholes is presented in Map 1a,b and c. The following parameters were recorded:

1. Unchanging parameters as per the borehole completion forms Annex 3

2. Changing parameters

   well depth
   Static water level
   Conductivity

Temperature
Other water quality parameters

A database program was prepared for depositing the monitoring data and for drawing the hydrogrammes. About one year borehole wells monitoring data are presented in Annex 4.

In many cases the monitoring was carried out while the boreholes were pumped continuously. These results can not be used for any short term conclusions. They will serve as data for long term hydrogrammes, which will indicate the development of aquifers related to the increased discharge.

6.3 Geophysical Survey

The University of Dar es Salaam, laboratory of geophysics, undertook a geo- electrical survey in Unguja and Pemba. The Slumberger array was used in all the soundings. The total number of sounding points was 56, i.e. 28 in both islands. The survey sites were located in the vicinity of the present intakes or in the proposed potential intake areas. The selection of potential intake areas was based on aerial photograph survey and hydrogeological information. The location of the sounding points is presented in the Map 4a, b, c and d. Detailed interpretation of soundings are presented in Annex 5. Geo - electrical cut section profiles of the sounding lines are presented in Annex 6. The results of the survey were utilized while making the assumptions of the geology and while determining the discharge forecasts. The interpreted apparent resistivity values correlate with the hydrogeology as follows:

1. < 10 Ohmm => water is saline or the layer is impermeable due to high clay content

2. 10 - 30 Ohmm => the formation is clayey or silty, permeability value is low, not a high yielding aquifer

3. 30 - 200 Ohmm or more, => the aquifer is good with good quality water. With young sediments the value is usually less than 100 Ohmm.

4. > 500 Ohmm => dry formation

An approximate correlation with geological formation and apparent resistivity values is presented in Figure 13.

It was found that the geoelectrical sounding results

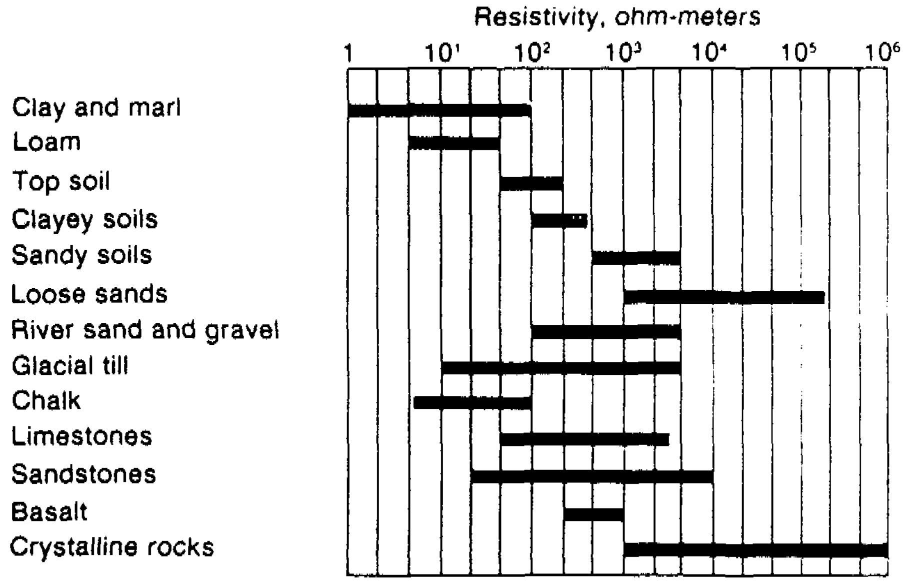


Figure 13 Approximate Correlation with Geological Formation and Apparent Resistivity

gave new information on the formations. The clay lenses, sand beds and lime/sand stones have rather local variations. The geophysical cross sections of the survey sites differ significantly. The studying of potential new sites would benefit of geoelectrical survey. It would be economical to locate the optimum drilling sites trough geoelectrical soundings in each drilling area. The cost of one sounding point is shs 6000.

6.4 Regional Geology

6.4.1 Sediment Deposition

The geology of Unguja and Pemba islands is related to the regional geology of Northern Part of coastal Tanzania. The islands are part of a large sedimentary basin which developed on the western side of the pre Bajocian Tanga Fault, North from the present location of Rufiji river. The coastal sediments developed during a period of over 250 million years and reached an estimated thickness of about nine kilometers. The formation developed as a function of erosion, river flow volume and gradient, vertical movement, uplift of the hinterland, sea bottom tilting down to the East, sea level transgression and regression periods and fault development periods. A graphical presentation on vertical movement as a function of time, after Kent & all 1971, is shown in Figure 14. A summary on geological periods referred here is given in the Geocronological table 1.

According to Kent & all the first sediment deposition cycle constituted of gradual deposition of post-Basement complex rocks up to Jurassic times and of deposition of Upper Jurassic rocks and shallow water limestones or non - marine clastic sediments since middle Jurassic age. The second cycle started in Albian age and continued through Upper Cretaceous. Deposition of very thick Tertiary beds continued after Cretaceous transgression and later underwent regression and transgression phases. The volume of sedimentary basin of Tanzania greatly increased in the transgression of lower and Middle Miocene. It is evident that the oscillating regressions and transgressions resulted to a long term regression, which brought the sea level down (or the land raised, or both and) as much as about 180 m from the highest estimated levels.

It has been estimated that the sea level has risen during the last century about one centimeter and in some scientific discussions the estimated sea water level rise will be something between 70 and 150 cm during the next century. If this is true, there would

Table 1

GEOCRONOLOGICAL TABLE

Eon	Era	Period		Epoch	Time (Millions of years)
Phanerozoic	Cenozoic	Quaternary		Holocene	0.01
				Pleistocene	1.6
		Tertiary	Neogene	Pliocene	5.3
				Miocene	23.7
			Palaeogene	Oligocene	36.6
				Eocene	57.8
				Paleocene	66.4
	Mesozoic	Cretaceous		late Cretaceous	97.5
				early Cretaceous	144
		Jurassic		late Jurassic	163
				middle Jurassic	187
				early Jurassic	208
		Triassic			245
	Palaeozoic	Permian			286
		Carboni-ferous		Pennsylvanian	320
				Mississippian	360
		Devonian			408
		Silurian			438
		Ordovician			505
		Cambrian			570
Proterozoic	Precambrian				
Archaean					4,600

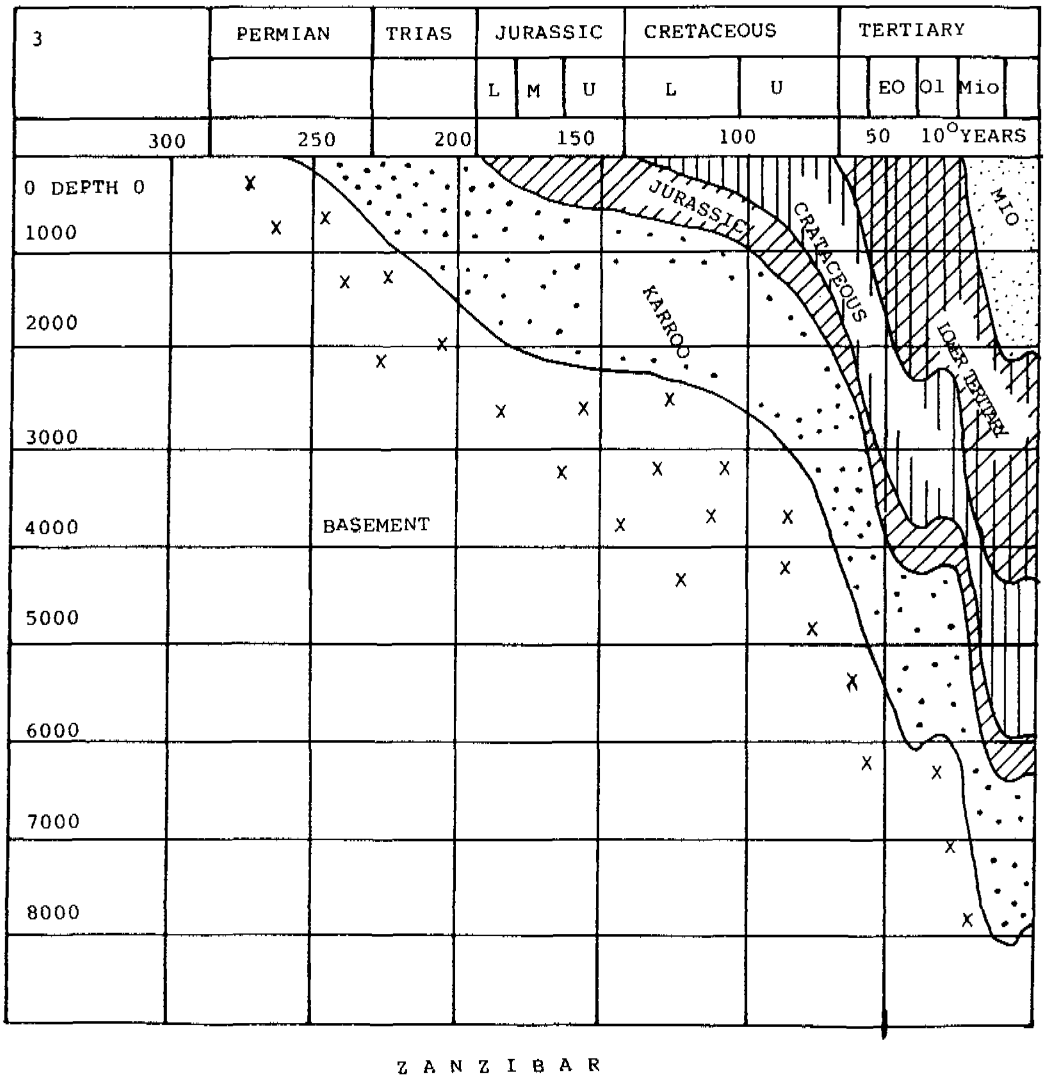


Figure 14 Vertical movement as a function of time, after kent & all 1971

deeper than the final borehole depth, 4200 m. In the Pemba deep borehole No 5 (4 shallow boreholes were drilled for detailed silting of the deep borehole) the drilling was stopped at 3800 m without hitting the hard rock basement. Geophysical airomagnetic survey indicates the depth to the crystalline bedrock to be as much as 6000 - 9000 m in Zanzibar area. Based on information from Kent & all 1971, a correlation graph in Zanzibar and Pemba deep boreholes is presented in Figure 15.

It is evident from the correlation in Zanzibar and Pemba deep boreholes that the base of Miocene in Pemba is about 2000 m higher up than in Unguja. Pemba is separated from mainland by about 700 m deep Pemba channel while Unguja is linked with the mainland by a shallow ocean floor. The geophysical gravity and offshore reflection seismic contour maps of Pemba (Kent & All 1971) seem to have no continuity towards Unguja island. Also the surface geology of the to islands is different and consequently the hydrogeological environment is different.

The regional airomagnetic intensity contour map, as per Kent & All 1971, Figure 16, indicates a steep slope of crystalline basement on the western side of Tanga area, i.e. the Tanga fault of prior Jurassic age. Due to the fault zone rift depression, the sedimentary column westward from Tanga is considerably thicker than elsewhere on the coast.

According to information from Kent & all the fault formations developed since the Upper Karroo age. The first collapse of arches took place under tension forces during Upper Carroo and a further collapse during the Middle Jurassic age. During Upper Jurassic and Lower Cretaceous ages tilting down to East and sea level regression took place causing faulted sagging between major faults and hinging about the west most fault zones. During Upper Cretaceous and paleocene age further tilting developed new hinge fault zones and depositional steep zones. Renewed faulting and sea level transgression and uplift of the hinterland and tilting down to East contributed to the formation of off- shore horsts during lower miocene, to form the Pliocene lagoon surrounded by an island barrier.

During and after Jurassic times the Ruvu delta experienced changes of major magnitude while the North -South direction rift faulting tore the edge of the continent. A fault zone passes between Pemba and the mainland and continues along the eastern side of unguja along the coastal belt of islands and shoreline. Major fault trends around Unguja and Pemba are shown in Figure 17. Structural cross sections over the coastal line and the islands are presented in

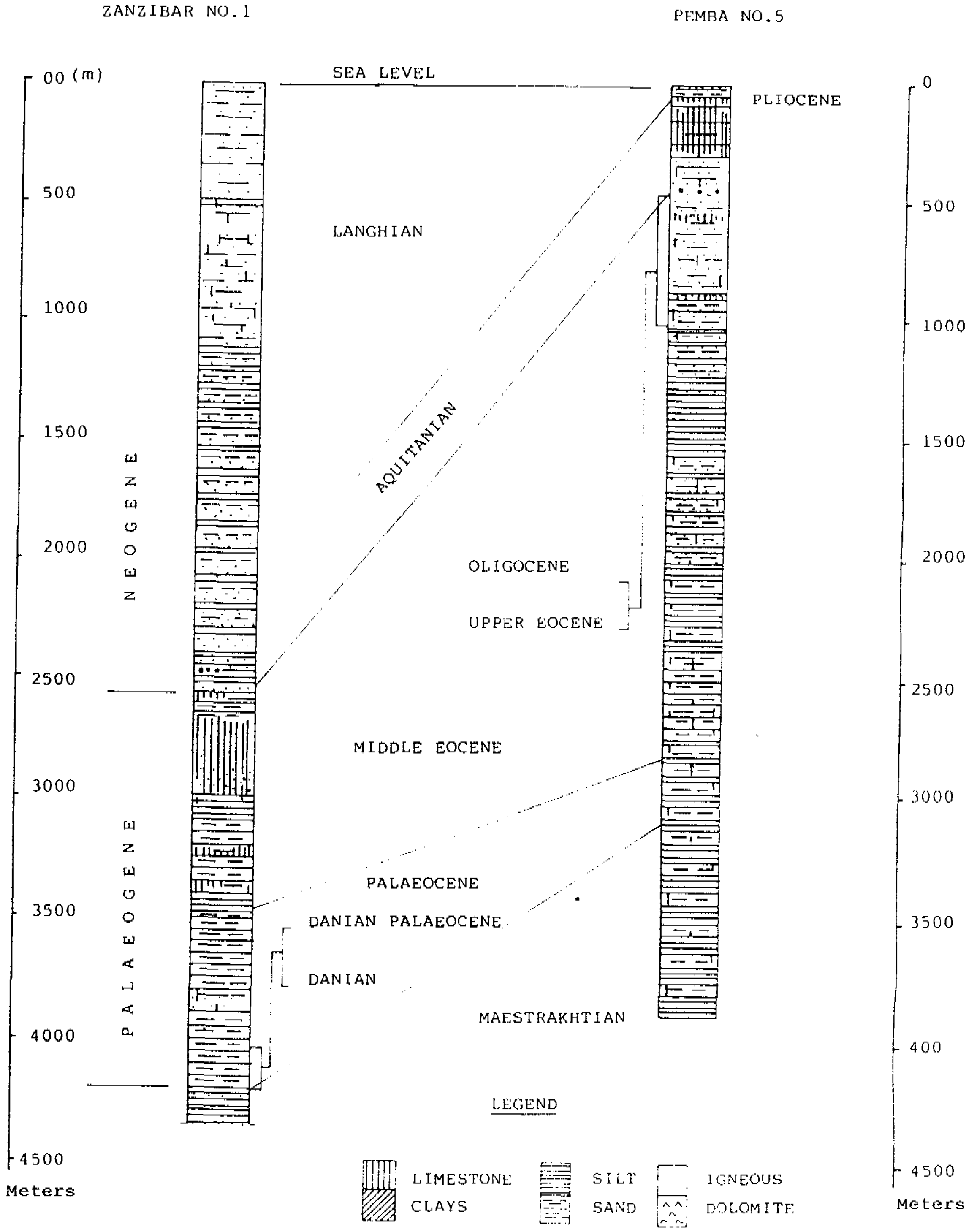


Figure 15

Correlation in Zanzibar and Pemba Deep Boreholes

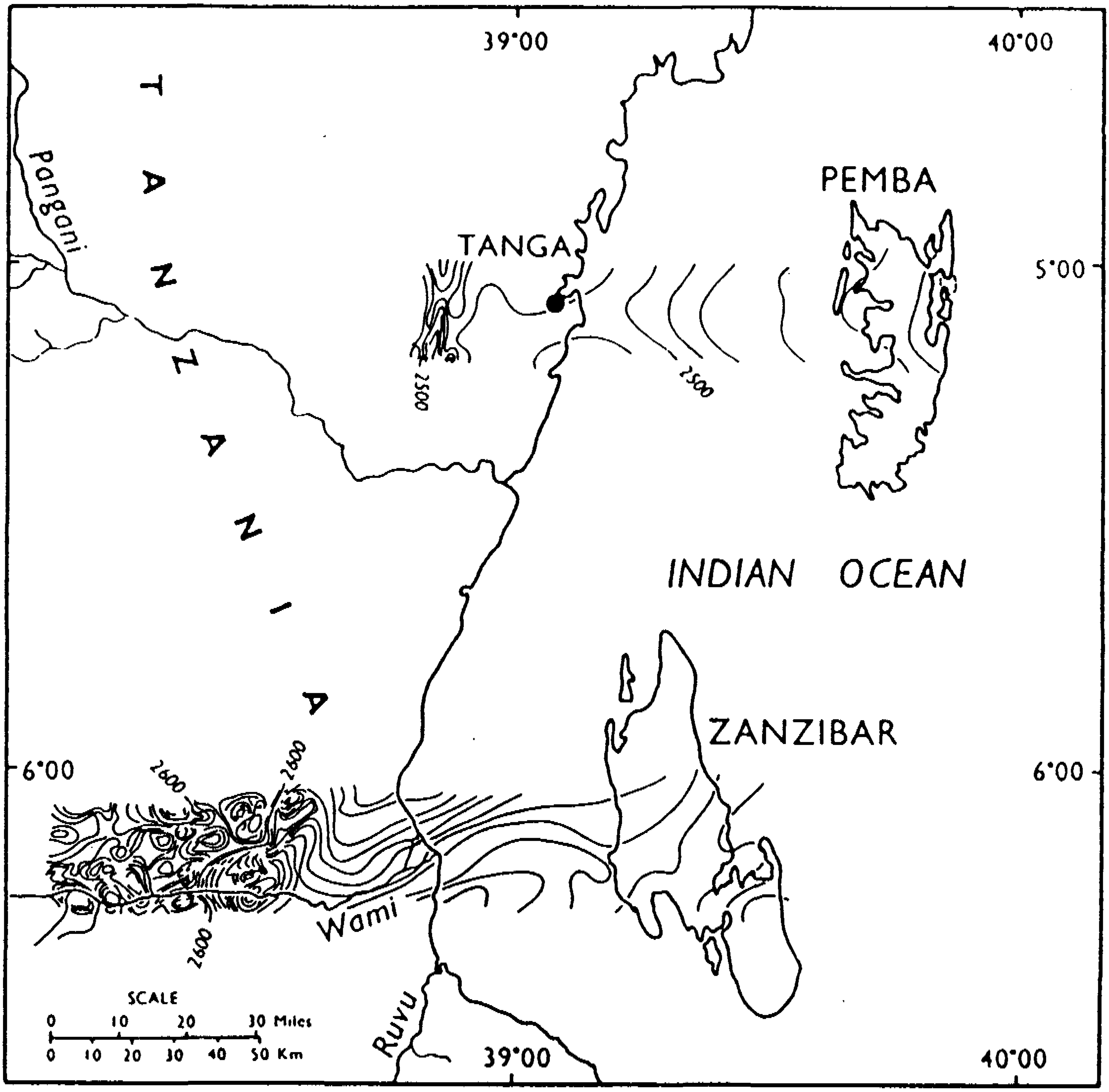


Figure 16

Regional Airomagnetic Intensity Contour Map
Total Magnetic Intensity in Gammas, After
Kent & All 1971

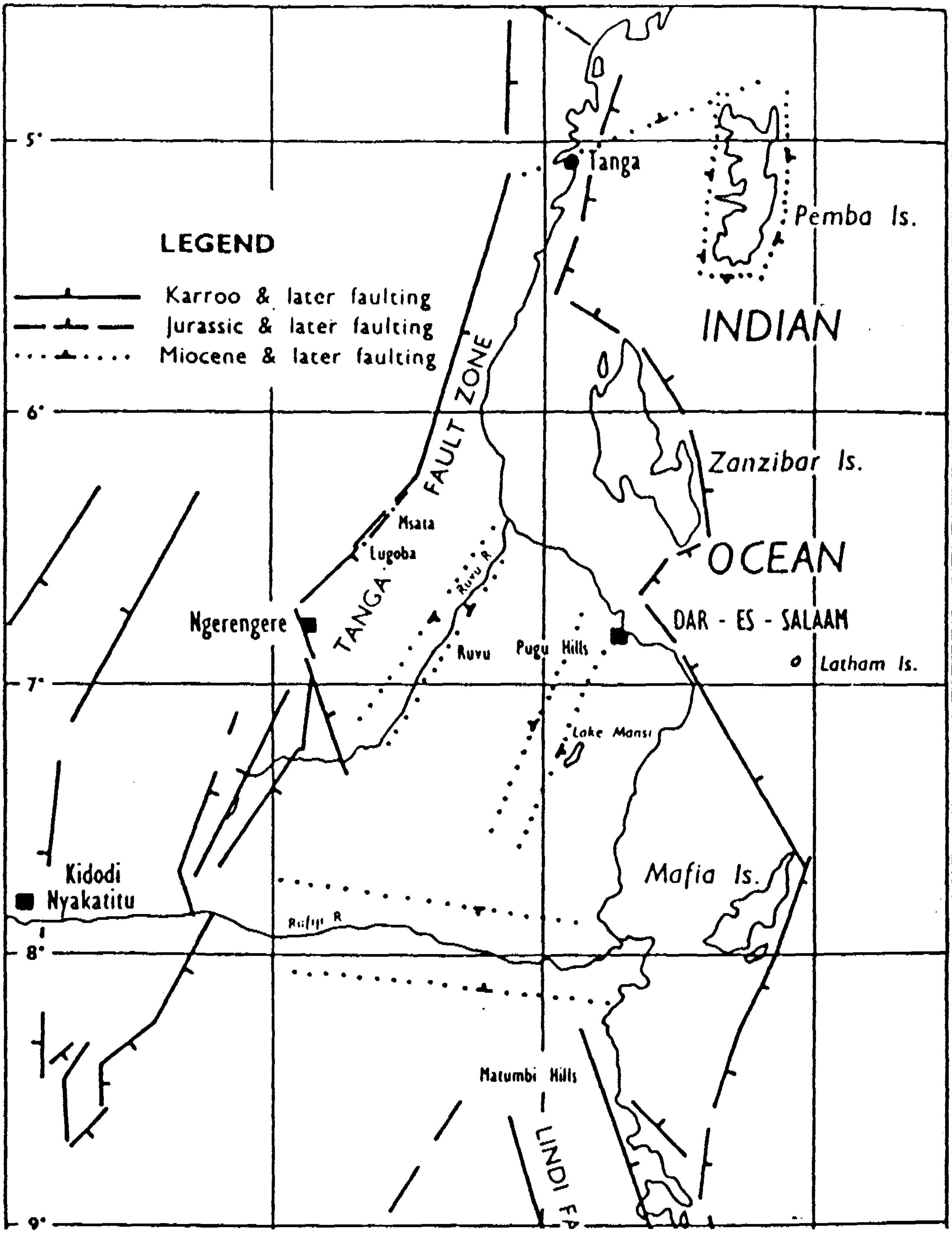


Figure 17 Major Fault Trends Around Unguja and Pemba, After Kent & All 1971

Figure 18.

According to Kent & all 1971, the geophysical definition of deep structures shows that in the islands the known fold and fault structures have developed progressively throughout Tertiary times. The Unguja, Pemba and Mafia Islands were emerging from the sea as a cluster of islands, while other blocks sagged and formed a shallow underwater platform in front of the eastern coast of the continent.

While Pemba remained as a simple structural block, Unguja experienced a further major fault development during pliocene and is now split in four blocks by two faults, which were, during the course of time, filled with ferruginous, calcareous, siliceous and gypsiferrous cements and covered with a thin Quaternary coral rag. The faults are crossing each others slightly to the South from the center point of the island. The four blocks have settled at different altitudional levels. The block structure of Unguja is presented in Figure 19.

6.5 Geology of Unguja

6.5.1 Introduction

In Unguja the underwater corridor zones were an appropriate growing base for corals. Coralline limestone filled the shoestring channels, as an approximately 15 m thick layer, during the Quaternary age i.e since about 1.6 million years ago. Also the plain areas in the surroundings of Unguja were covered by a few meters thick layer of coral, forming large coral rag areas. Simultaneously the seawater level commenced to depreviate allowing waves to further modify the island to a wave cut platform with residual hills and sea cliffs. The corridor zones remained in between the karstic miocene coral formations and were further fillet with quaternary sand and soil materials and at the uppermost parts with recent sediments. A typical corridor profile consists of 15 m thick top layer of red and brown soils upon a 15 m layer of coralline limestone followed by sand and soft sandstone until the bluish, grey or greenish miocene sediment is met at about 40 m depth. Johnson 1984 calls the uneroded miocene formation as bedrock.

The depth of the bedrock, interpreted from geoelectrical soundings, varies between 30 - 150 m. Cut section profiles in different locations are presented in Annex 6.

The three major corridors in Unguja are the Bumbwi- ,Kisima Changa- and Bambi - Upenja corridors, and they can be observed from the topography and surface

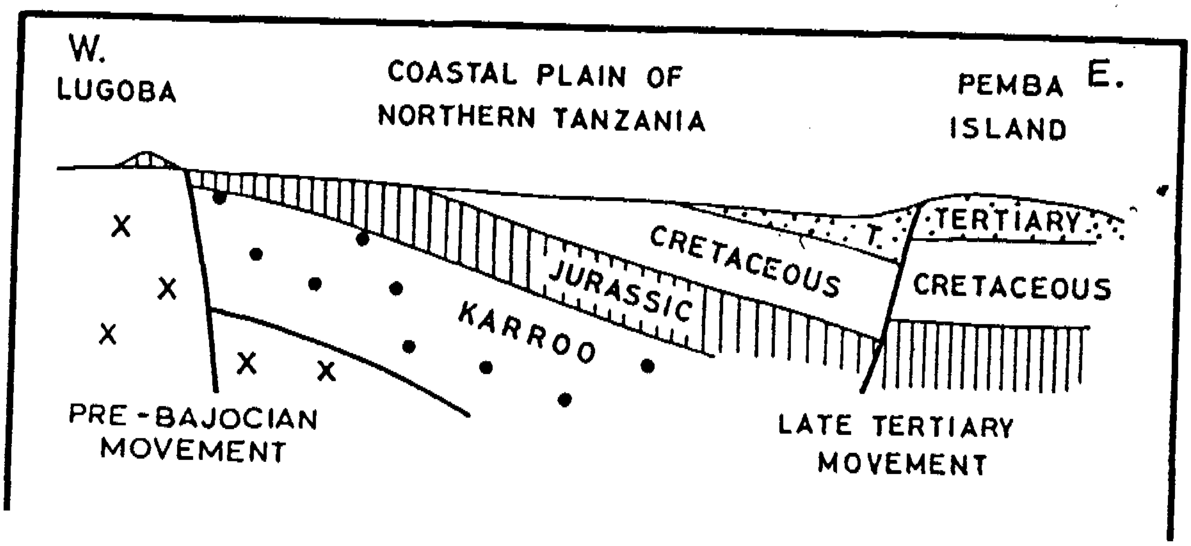


Figure 18 Structural Cross Section Over Coastal Line and Pemba Island

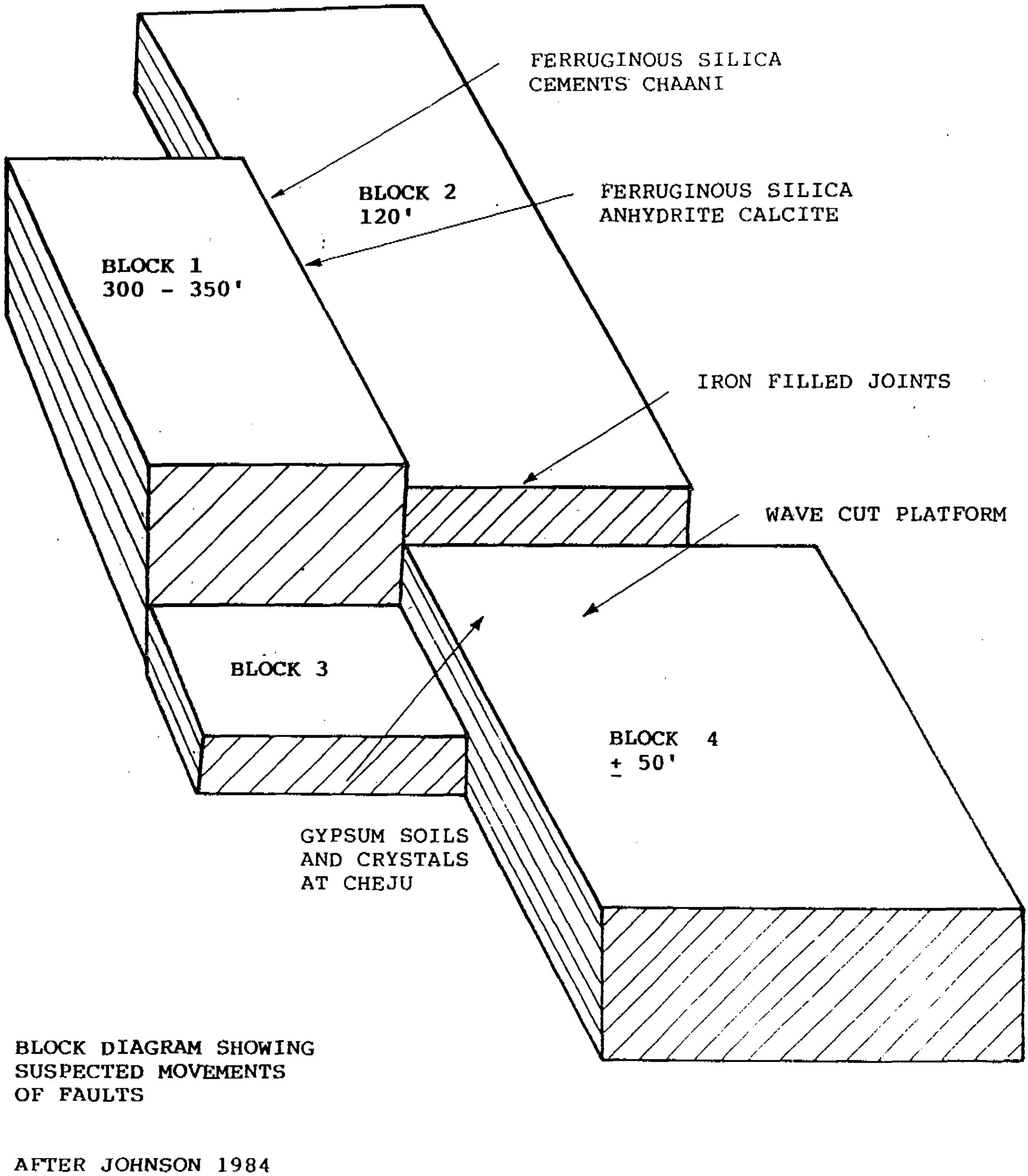


Figure 19 The Block Structure of Unguja

geology of the island, Figure 20. They follow the miocene coastal line paleography and cross the Unguja island in N - S direction terminating to eroded bays in the Northern and Southern ends.

The water quality studies in the island indicate that during the geological history of the island the land raised from western side of the island first, but according to Johnson 1984, the eastern side of the island seems to have recently started to rise and is continuingly rising. The pressure conditions and land movements developed an anticlinal axis in E- W direction to cross the island around the Bumbwi area.

6.5.2 Topography

The topography of Unguja is dominated by fault structures and residual hills together with the wide corridor valleys. The topography reaches its highest point,over 100 m at the Masingini-ridge. The three ridges Masingini, Donge and Upenja are located on sides of Bumbwi and Bambi-Upenja corridors approximately in North-South direction. The southern and South Eastern area of Unguja is a flat lying Quaternary coral rag of low altitude. The essential topographical features are presented in Figure 20.

6.5.3 Geology

The above described geological development produced the following rock and soil types, today found in the island and the overall location of which are presented in Figure 21, and in the hydrogeological map of Zanzibar:

Miocene

M1 Limestone, crystalline,sandy, reef and detrital facies, karstic.

M2 Sands and sand stones, uneroded, interstratified.

M3 Clays , shales, marl, silty, sometimes sandy.

Quaternary

Q1 Soils, laterites, colluvials

Q2 Coral rag

Q3 Reworked shoestring sands out of M2 sands

6.6 Hydrogeology, Unguja

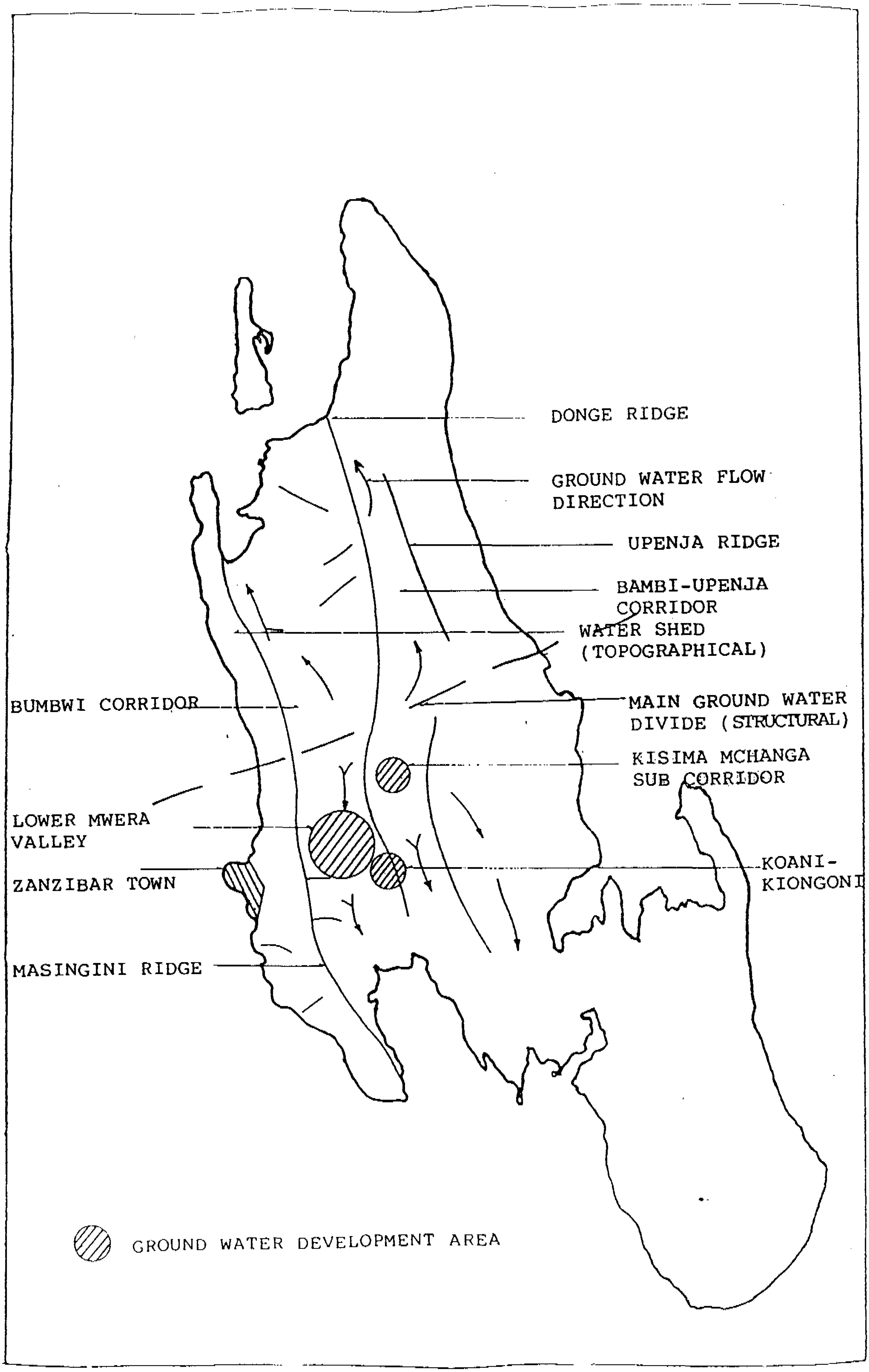


Figure 20 Essential Topographical Features and Groundwater Flow Patterns in Unguja

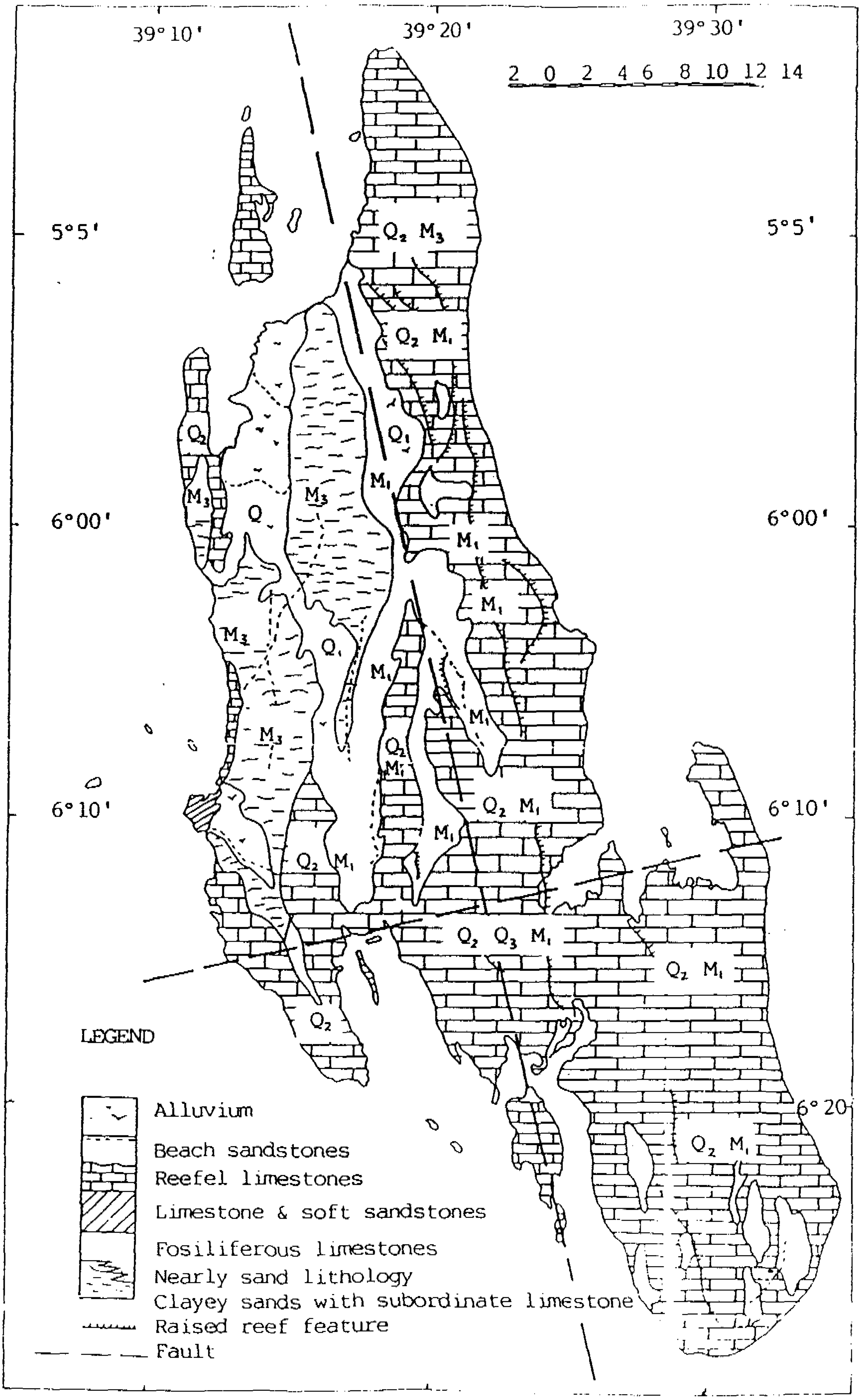


Figure 21 Geological Map of Unguja

6.6.1 General

The geological environment for groundwater occurrence in Unguja is as follows:

1. Systematic joints in limestones, Major importance in Unguja
2. Solution channels in limestone
3. Openings in fractured lime and sand stones, fault zones
4. Intergrain pores in sandstone and shale
5. Intergrain pores in unconsolidated gravel and sand

Almost all the formations posses some aquifer potential. As for drawing large quantities of water for Urban water supplies the corridor zones are offering a feasible alternative.

The formation of the corridor zones is suggested to be as follows.

During a slow sea level transgression coral growth took place on the miocene deltaic clays of the shoestring channels. The slow changes of seawater level facilitated growth of about 15 m thick coralline limestones. Sea level depression ceased the coral growth and soil formations developed over the limestone bed forming the phreatic zone above the water saturated aquifer. A long term regression, evidently due to land rise exposed the formations, which now serve as a storage for major quantities of groundwater.

According to Johnson 1984, the aquifers in Unguja are found to be unconfined and interactive all over the island. Some confined aquifers also exist. The springs on the Western side of the island and the Machui spring in the lower Mwera valley in Bumbwi Corridor are evidently in karstic formation.

The aquifers are confined by miocene deltaic clay at the bottom at the depth varying from 20 to over 100m in the corridor zones and possibly by clays on the top.

6.6.2 Erosion and Drainage

There are no major rivers contributing to the drainage of Unguja. The sheetflow, developed by rainstorms, infiltrates in the sandy topsoil in the flat lying areas. Some drainage channels have developed along the downward slopes of the miocene limestone ridges, draining directly to the sea on the Western side of the island and forming minor rivers to the corridor valleys. During and after the storms the rivers of the western coast are filled with storm water, which drains away in a few hours time. After a dry period of a few days the river flow becomes very low and finally dries up.

The precipitation in the hinterland gets fairly totally infiltrated or evaporated and little of the water does drain as surface flow. The infiltration takes place fairly fast in many areas. Some perched water aquifers seem to have started to develop in the intensively irrigated areas. This fenomenom should be subjected under more detailed monitoring. A detailed study on the occurrence of perched waters could be useful as more substantial development of perched water may reduce the groundwater infiltration rates from the most important catchment areas.

6.6.3 Groundwater Flow

The determination of the groundwater flow patterns, velocities and gradients were estimated in order to assess the safeness of the water quality from a known watershed area. The pollution risks are evident if the pollution sources, flow patterns and water intakes coincide. Using the water table information from the hydrogeological map, average assumed porosity values for the geological formations and hydraulic conductivity values derived from the hydrogeological map, the groundwater flow velocity would be 2 - 5 m/d and 2 - 7 m/d in the corridor zones and the surrounding miocene respectively. The groundwater flow patterns are presented in Figure 20. The groundwater flow patterns coincide with the open local wells and borehole wells. It is possible that the local wells cause bacteriological pollution to the borehole wells.

The water table fluctuations, recorded in the local wells, in the miocene formations are of the range 5 - 7 m. These records have been used as basic data while doing the hydrogeological map. The magnitude of the water table changes may relate to the perched water aquifers rather than groundwater recharged aquifers. So the potentiometric (piezometric) contours of the hydrogeological map may have some inaccuracies, particularly in the areas of high topography. Some more details may be received during the test drilling programs in future.

6.6.4 Seawater Intrusion Risks

There are no long term hydrogrammes on the groundwater behavior under the present discharge conditions. Neither are the discharge rates alarming in any respect.

As for danger of seawater intrusion, the most critical pumping sites are the Kaburi Kikombe and Chunga C9 boreholes. Kaburi Kikombe clearly has some indications of seawater influence in terms of relatively high conductivity value. The pumping rate from this borehole should be kept low, and there should be no major rejuvenation of this borehole any more. The area should be gradually abandoned from use of high quantities of groundwater.

The pumping rate from Chunga 8 borehole was lifted from 70 m3/day to 130 m3/day in June 1990. There was no evidence of any salinity increase by February 1991. However the monitoring has to continue intensively, especially after taking the c8 in use and after drilling and utilizing the borehole field on the southern side of Welezo.

Although there is some proof (Johnson 1984) that the Ghyben - Hertzberg principle (1:40 height/depth relationship of freshwater lens) holds in the western hydrogeological province (see 6.6.4), there is no proof of applicability of the same principle in the other provinces. The water table contours do not much exceed the sea level and the freshwater lens may be disturbed if water discharge is not controlled.

6.6.5 Hydraulic Model

Johnson 1984, divides the Unguja in three hydrogeological provinces:

1. the eastern limestone/sandstone/corridor limestone province
2. the western sedimentary/ corridor limestone province
3. the non-corridor coastal rag or q2 province

The hydraulic model for the Eastern and the western provinces of Unguja is described by Johnson 1984. A slightly modified model is as follows:

A sustained but slow flow regime from the larger elevated Miocene areas of side slopes, supporting the higher flow and discharge regimes of the corridor Q2 limestone aquifers.
A sustained slow recharge from the miocene from the bottom of the corridor zones.

6.6.6 Hydraulic Parameters, Unguja

The objective of the pumping test program could be described as follows:

1. to study the hydrostatic pressure drop in the aquifers during pumping

2. To study the influence of decreased pressures in the thickness of the aquifers
3. Based on the obtained information to make recommendations for a groundwater exploitation program.

From the test pumping results different kinds of hydraulic parameters were calculated. The hydraulic parameter transmitivity (T) indicates how much water can move through the formation and the parameter storativity (S) indicates how much water can be removed from the formation through pumping or draining. Specific capacity (Sp) of the well characterizes the yield per draw down relationship.

After determining the S and T values rather far reaching predictions of the behavior of the aquifer can be made, including:

1. Drawdown of the aquifer at various distances from the pumped well.

2. Drawdown in the well at any time after starting the pumping

3. Drawdown in the aquifer at various pumping rates.

4. Well efficiency

5. Interaction with different wells in the same wellfield

The theory of test pumping requires that all measurements are made from an observation hole and not from the pumped hole. Observation holes were available only in the following locations:

1. Bumbwi Sudi BH2
2. Bumbwi Sudi BH27
3. Kaburi Kikombe
4. Mwembe Mchomeke
5. Changaweni, Mkoani

The observation hole Mwembe Mchomeke was drilled during the Planning Phase.

The S values cannot be calculated but only for the above mentioned sites. T values can be calculated from results obtained from the pumped wells.

It is assumed that 90% of the well yield is obtained with 67% of maximum drawdown. So the recommended yield/drawdown values are actually slightly lower than theoretical maximum values. This reduces pumping costs and produces a safety factor against seasonal groundwater level fluctuations.

Graphical presentations of the test pumping results are given in Annex 7.

A summary on calculated and graphically determined aquifer parameters and respective predictions is presented in Annex 8.

The definitions of the parameters are as follows:

1.	Date of pumping test	Self explanatory
2.	Static water level	Undisturbed water rest level from casing top/sea level
3.	Yield during pumping	Pumped water quantity/time
4.	Drawdown	Depression of water table due to pumping
5.	Equilibrium	The aquifer recharges equally to discharge
6.	Impervious boundary	The depression cone meets impervious geological formation
7.	Specific capacity	Quantity of discharge per unit drawdown
8.	Transmitivity	Explained above
9.	Storage coefficient	Explained above
10.	Displacement of	Upwards displacement means residual drawdown/recharge to aquifer or variation (T/t') in Storage coefficient value. Downwards displacement means incomplete recovery due to limited extend of aquifer
11.	Theoretical maximum	The yield to be obtained by yield maximum drawdown value i.e. at the borehole bottom
12.	Projected yield with 12m drawdown	Self explanatory

13.	Radius of influence	Radius of the depression cone
14.	Well efficiency	Percentage of theoretical drawdown against actual
15.	Type of aquifer	Self explanatory
16.	Recommendation	Self explanatory

The coefficient of transmissivity has been calculated;

1. from the pumping rate and the slope of the time drawdown graph

$$T = \frac{0.183\ Q}{\Delta s}$$

2. from the pumping rate and the slope of the distance drawdown graph

$$T = \frac{0.366\ Q}{\Delta s}$$

3. from the recovery results

$$T = \frac{0.183\ Q}{\Delta S}$$

where, T = coefficient of transmissivity, in m2/day

Q = pumping rate, in m3/day

S = change in drawdown during one log cycle, in m

ΔS = change in drawdown during one log cycle, in m

The coefficient of storage has been calculated;

1. from the pumping rate and the time-drawdown graph (Kaburi Kikombe II)

$$S = \frac{2.25\ Tt_o}{r^2}$$

where, S = storage coefficient

T = coefficient of transmissivity, in m2/day

t_o = intercept of straight line at zero drawdown, in days

r = distance between the pumped well and the observation well, in m

2. from the pumping rate and the distance-drawdown graph

$$S = \frac{2.25\ Tt}{r_o^2}$$

where, S = storage coefficient

T = coefficient of transmissivity, in m2/day

t = time since pump started, in days

r_o = intercept of extended straight line at zero drawdown, in m.

The hydrogeological map shows storativity of 30% in the whole bumbvi corridor area. Such a high storativity was only found in Chunga area. In Bumbwi Sudi area much lower storativity was observed. It was assumed that equilibrium, that was reached during the pumping execersises, was caused by recycling.

6.6.7 Groundwater Potential

<u>General</u>

Groundwater potential calculations were already completed by Johnson 1984. The calculations were revised and supplemented with new information in connection with the testpumping and hydrogeology programme.

The total available recharge to essential aquifers in Unguja would be 600 x 10^6 m3/year. The maximum total discharged quantity after 25 years from now is estimated to be less than 160.000 m3/day. The total discharged quantity would be about 10 % of the total ground water resources available.

In the groundwater potential calculations it was assumed that the high sturativity values are applicaple in the whole corridor area. If the storativity is lower the draw down values of the planned well fields will be accordingly higher, and the rise of water table due to recharge is higher. The optimum location of the well fields is the areas of maximum storativity. The proposed well field areas are an the assumed high storativity sites. the optimum location has to be later on verified by test drillings.

Artificial discharge

The artificial discharge of groundwater for urban and rural water supplies and for irrigation is estimated to be as follows:

Water Demand in 2015, (m3/day)

Urban	60.000 - 90.000
Rural	6.000
Irrigation	40.000 - 50.000
Total	106.000 - 146.000

A plan for utilization of groundwater resources is presented in annex 10.

Availability of Groundwater, Zanzibar Town

The observed rise of water table during the two rainy seasons in the corridor area is from 3 to 3.5m. Some additional water level rise takes place in the interim periods as there seems to be at least 5 rainy days every month. A total of three meters recharge is assumed in the calculations.According to the hydrogeological map, the area of 30% storativity on the southern side of the Bumbwi water divide is about 20 -28 km2. Consequently if the recharged quantity of water is utilized, 70.000 m3 per day may be pumped from the lower Mwera Valley.

The location of the existing water intakes is presented in Map 1a. Detailed descriptions of the water intakes including hydrogeological, water quality and environmental aspects together with conclusions and recommendations are given in Annex 9.

Altogether 8.000 - 10.000 m3/day could be developed from Bububu Spring and Mtoni spring, which are located just near Zanzibar Town center, and therefore, would be very economical sources. Mtoni spring, however, has got some problems with water quality, which have to be solved at first.

The Bumbwi - Corridor, crossing the Unguja island in North-South direction and passing a few kilometers East from the Zanzibar town, offers a feasible ground water development areas for drawing water to the town, to an approximate daily quantity of 70.000 m3/day.

Further potential source could be Kisima Mchanga sub-corridor (20.000 m3/day), which lies at a distance of about 15 - 25 km away from Zanzibar Town. This distance can be considered a rather uneconomical pumping distance. Another potential source is Koani - Kiongoni area, at a distance of 6 - 8 km, which could yield up to 10.000 - 20.000 m3/day.

The feasibility of different alternatives is to be studied in more detail during 1991 - 1994, through test drilling and test pumping programs. The overall locations of the proposed ground water development areas are presented in Figure 20 and in Map 1a.Approximate locations of potential test boreholes sites and well field areas given in Map 1a.

There are very little or no contradicting interests on use of ground water form the concerned areas. The areas are therefore to be gazetted as areas restricted for ground water exploitation and development for Zanzibar Town. Possible contingencies of available water resources may be allocated for rural and irrigation use, to be decided by the proposed water resources cordination board in due course of time.

The water quality in the corridor areas (except Mtoni Spring has to be further tested) is very good for domestic purposes. There is a theoretical chance for sea water intrusion from the southern end of the Bumbwi Corridor as the potentiometric gradient decreases to only +2 m above the mean annual sea water level. However, the recently obtained test pumping results show that large quantities of ground water can be pumped from this area without changing too much the water table conditions.

6.6.8 Borehole Fields

The annual recharge and use of storage without affecting the storage permanently would allow pumping from individual boreholes with a drowdown rate of about 6 m in the high storativity areas. The annual recharge to the pumping area would be about 2.5 - 3.0

m and the depth of 3.0 - 3.5 m from the storage would be compensated by the areas where the drowdown remains smaller and by the interaction of aquifers. To make the well fields efficient and to use their maximum capacity the individual wells should be located so that the depression cones overlap at about one meters depth of draw down. The distance of boreholes from each others in the proposed borehole field areas is thus estimated to be 400 -700 m. The proposed borehole field areas are presented in the Map 1a.

6.7 Geology of Pemba

6.7.1 Introduction

Pemba is separated from the mainland by a 600 - 750 m deep fault channel, Pemba channel. The size of the island is 68 x 19 km2. The broken west coast of the island is rising steeply to a 23 - 24 m high shelf. The topography of the island is dominated by a series of steps rising from the West to East up to a height of about 75 - 90 m at the center of the island.. The axis of the island is approximately in North - South direction. At the Eastern side of the axis the landscape slopes rather smoothly to a 5-6m high reefal rag above the modern reefal flat.

The drainage patterns of the island are somewhat of angular shape on the western side of the island. The topography clearly differs from that of Unguja and steep sloped, eroded valleys are dominating large areas of the surface of the island. The bottoms of the valleys are not much higher than the sea level and are often silty and swampy. The valleys correlate with fault directions and form lineaments in East - West direction. There are abundantly exposures of rocks on the western coast of the island.

The eastern side of the island is not so broken with creeks and inlets but is a 5 - 6 m high terrace of raised reefal limestones. The exposed parts of the limestone are wave cut platforms.

The Pemba island is surrounded by a modern reefal flat of 200 to 500 m width.

6.7.2 Geology

According to Kent & all 1971 the island is a fairly simple structural block with the following exposed stratigraphic column:

<u>Pleistocene</u>

Recent alluvium and modern reefs

Raised reef limestones

Miocene (?)

Wete Beds (fluviative/estuarine)

Lower and Middle Miocene

Chake Chake Beds (marine clays, sands)

A sketch geological map is presented in Figure 22.

Stockley nominated the oldest Miocene formations on the western side of Zanzibar as Chake Chake Beds. According to Kent & all, the thickness of the Chake Chake beds is about 230m. Most of the Pemba Miocene formations originate from Middle Miocene. Lower miocene is found only in Chake Cake area. The miocene marine cays, lime and sandstones and sands are rich in faunas.

Over the Chake Chake beds lie the unfossileferrous Wete Beds. They are products of ancestral Ruvu River delta. They consist of lenticular clays crossbedded with sands. From several exposures, geoelectrical soundings and from several spring outbreaks it can be concluded that in less than 30m dept the wete beds are underlain by sand/limestone layers.

At Miembeni area the wete beds consists of sandy and clayey crosbeddings and in Vitongoji area, the Vitongoji beds consist of sandy clays and plastic clay layers. At miembeni limestones are met at the depth of 17m while in Vitongoji the clayey formation continues only about 6 m and then turns to limestone with some clayey interbeddings.

The coastal strip in the East consists of raised reefal Azanian limestones of Pleistocene age.

6.8 Hydrogeology, Pemba

6.8.1 General

The hydrogeological situation in Pemba is a typical one of a small island, where a freshwater lens lays on the saline seawater. Rough estimates show that the thickness and recharge of the freshwater aquifer are adequate with regard of present water demand and for the projected groundwater demand during the next 25 years.

There are three different axis of hydrogeological interest, passing through the island in North - South direction.

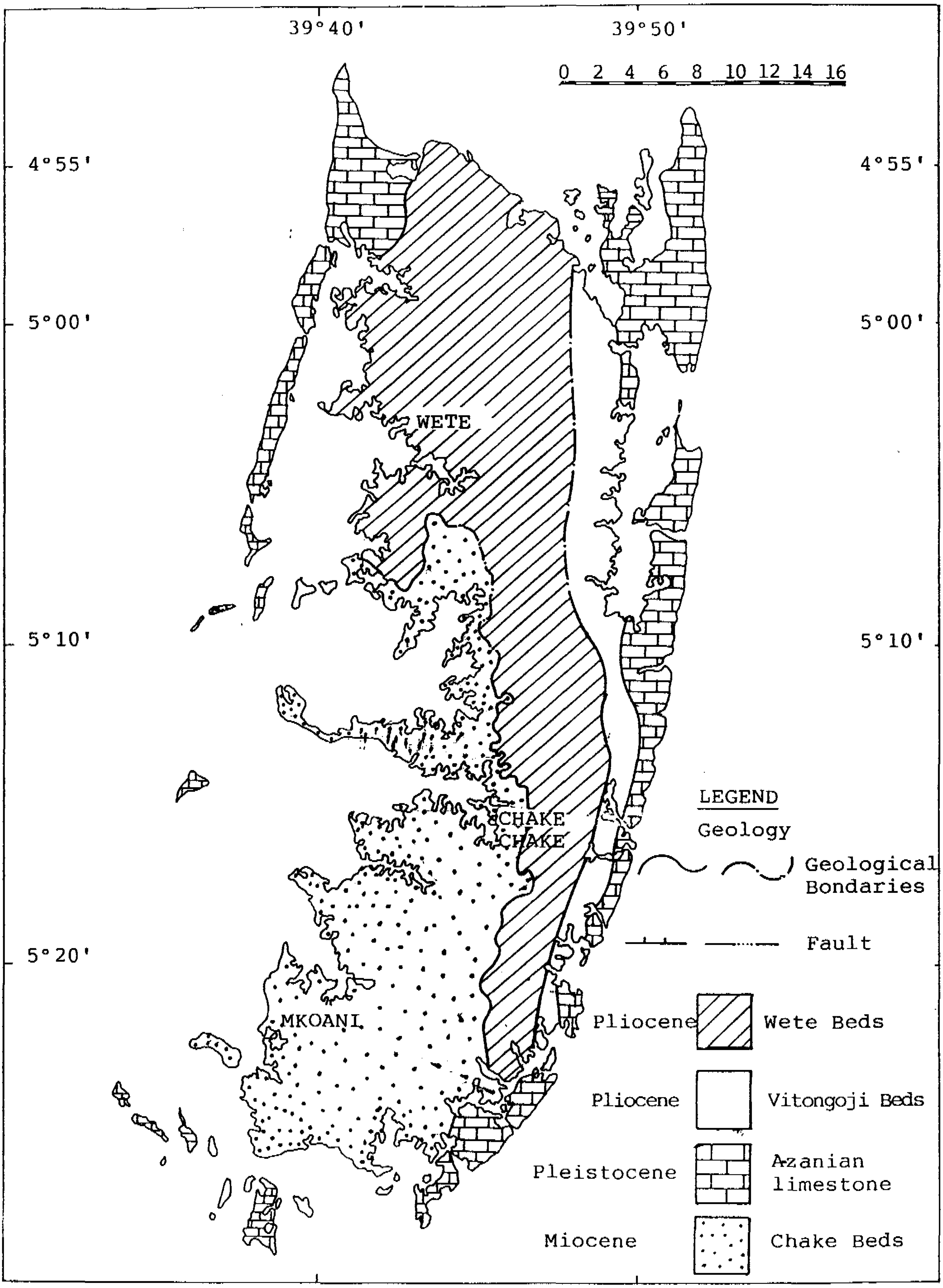


Figure 22 A Sketch Geological Map of Pemba

1. Anticlinal axis
2. Topographical high axis
3. Main water divide

Approximate locations of these axis are presented in Figure 23.

It seems that the anticlinal axis has no major importance as for the hydrogeology, while the topographical conditions and the water divide affect the groundwater conditions in the island.

6.8.2 Erosion and Drainage

The central area of the island is somewhat flat plateau. At the Western side of the highlands the land developes gradually to steep sloping valleys ending to the ocean creeks. On the Eastern side the topography slopes gently along flat lying areas. At the upper areas the valley bottoms of the small upland valleys are not silty and swampy but eroded materials are transported by the rivers as suspension.

Evidently the top formation at the Eastern side possesses a better capacity to absorb storm water than the top soil at the Western side of the island. During storms excess recipitation drains from the Sandy plateau. So called sheetwash water channelizes into rills or rivulets and continue along the small valley inlets to the major valleys. The infiltration of water is enough to prevent formation of any major rivers and later on the silty downstream valleys absorb a great deal of the drainage water.

Transport of eroded material in the flat lying areas in the valleys usually takes place as a suspended load. The valley bottoms are deposits of fine materials, transported by river as a suspension from highlands and steeper sloped areas above. The main part of suspension takes place on the steep banks and not on the fairly horizontally lying areas. As for bedload erosion the Pemba geology appears to be fairly resistive. In bedload erosion the rolling particles are carried along the streams.

Moreover an undefinable quantity of dissolved erosion material goes along with the storm water flow.

6.8.3 Hydraulic Model

An overall hydraulic model for Pemba is presented in the hydrogeological map. A slightly more elaborate, modified version is as follows:

Recharge from rainfall infiltration.

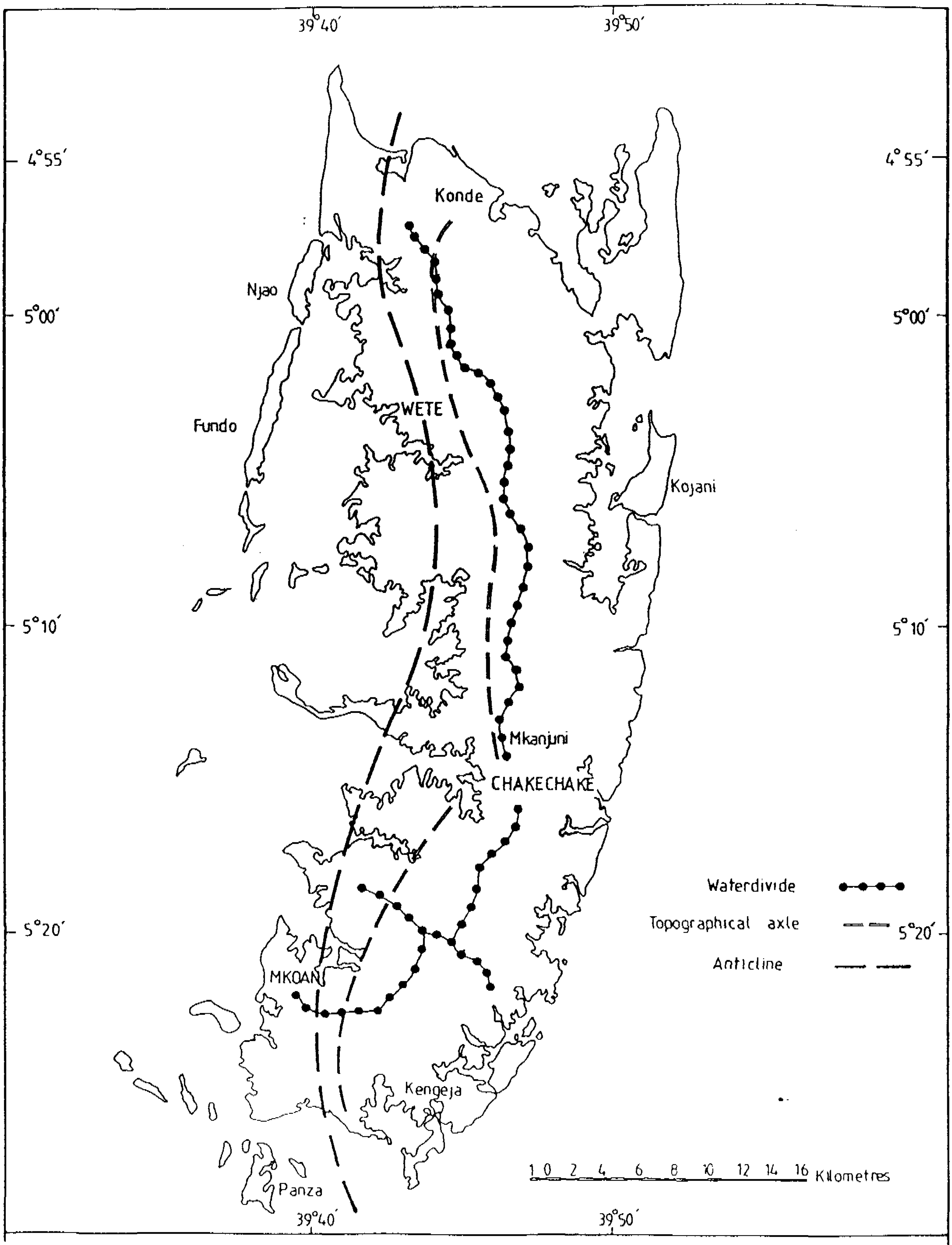


Figure 23 Approximate location of Water Divide, Anticline and Topographical Axis, Pemba

Rather large high elevated flat lying areas in the water divide or central and eastern parts of the island, with sandy top formation feeding the under lying low flow regime. Eastward flow mainly along the gently sloping silty sand and lime- and sandstone layers. Higher flow and discharge regimes in the reefal limestones of the western coast. Frontal discharge to the sea.

Originating from the same infiltration areas, equally or more low flow component regime in silty sands and lime and sandstones to the western side of the water divide area. To some extend restricted or confined by the mudstone and clay layers on the Eastern side and horizontally sloping top area of the anticlinal axis. Significant discharge to sea through East - West direction disturbed valleys and fault related creeks and inlets which often penetrate several kilometers inland.

6.8.4 Pumping Tests

The Pemba urban water sources were test pumped in July - August 1990. The period coincides with the early dry season. The results given here are based on constant rate tests. Step tests were tried, but it was soon discovered that the results were unreliable. The aquifer parameters were explained in Chapter 6.6.5. There were no observation boreholes available, but one in Changaweni, Mkoani. Distance drawdown curves, permeability and storativity calculations were not possible elsewhere.

The S values cannot be calculated but only for the above mentioned site. T values can be calculated from results obtained from the pumped wells.

Graphical presentations of the test pumping results are given in Annex 7.

A summary on calculated and graphically determined aquifer parameters and respective predictions is presented in Annex 8.

6.8.5 Groundwater Potential

<u>Artificial Discharge</u>

Groundwater potential calculations in Pemba can be done only in a rather vague basis. However indicative figures are obtained by defining the groundwater reservoir as a function of freshwater recharge, transmitivity of the formations, evaporation, above ground drainage and artificial discharge.

An average annual rainfall of 1600 mm may be applied for planning purposes. Estimating a typical evaporation loss of 50 %, above ground flow of 50 %, (i.e. 25 % recharge) the total recharge to essential aquifers (60 % of total recharge) would be 260 x 10^6 m3/year.

The total artificial discharge by 2015 would be projected as follows:

	2015
Urban Water Supplies	12600 - 18900
Rural Water Supplies	5200
Irrigation	-
Total	**17800 - 24100**

The total artificial discharge in 2015 would be less than 5 % of total recharge.

The locations of existing water sources and potential new ones are given in Map 1b and c. A plan for utilization of groundwater resources is presented in annex 10.

Availability of groundwater, Chake Chake Town

The Kwapweza spring would offer a source to supply up to 50 %, i.e. over 50 m3/h, of today's water demand for Chake Chake area. Three to four test/production boreholes should be drilled at Kwapweza and Mzingeni area to determine the available additional ground water potential. Based on very tentative estimates a total of about 10.000 m3/day of ground water could be developed from the Kwapweza valley.

According to geoelectrical sounding results, high yielding boreholes - over 50 - 100 m3/hour - can be drilled in the Kiziwamaji area, about 4 km north-east of Kwapweza.

The valley of Jamvini C7 - borehole is a continuation of the Kwapweza valley and offers the first alternative well field location and can yield 3000 - 6000 m3/day.

The Changaraweni borehole valley could yield about 4000 m3/day. This area requires careful monitoring and detailed study as there is a chance for sea water intrusion. The water contains iron compounds and has to be treated. Changaraweni should not be considered as a priority area in the future well field plans.

Availability of groundwater, Wete Town

The nearest potential groundwater development area is the Weni river valley on the eastern side of the Wete town. The geoelectrical soundings along the valley show a presence of a flat lying sandstone formation at an approximate depth of 20 - 50 m. The sandstone is overlaid by silts. The geoelectrical sounding profile is presented in Annex 6. This sandstone is evidently recharging from the upper lying areas and may posses groundwater with artesian pressure, which remains to be studied by test drilling.

Based on the quantity of precipitation, catchment area and aquifer type assumptions, together with geophysical survey it is concluded that boreholes with a yield of about 500 - 1000 m3/day could be drilled in the Weni valley. Taking into account the estimated recharge, the total groundwater production capacity of the valley could be about 5000 m3/day. Possible interaction with other aquifer areas could increase the estimated groundwater potential. Thus about 5 - 10 boreholes can be drilled in a properly planned field. It is suggested that the depression cones of the boreholes would overlap in the water level depression area of 1 m. This suggestion is in accordance with the proposal of Bumbwi Sudi well field design proposal of Johnson 1984.

The Gawani spring was test pumped on 20th and 21st July 1990. The time coincides with the early dry season period. The details of the pumping and of the analysis of the results are given in the Water Resources Study report. The discharge rate was 53 m3/h. Total obtained drawdown was 3.7 m. The transmitivity of the aquifer formation was estimated to be approximately 200 m3/d. To sustain the water table above sea level, and to avoid sea water intrusion, a maximum long term discharge should not exceed 40 m3/h, i.e. 1000 m3/d from the Gawani spring valley.

The Bungumi spring was test pumped on 21st July 1990. The pumping rate of 75 m/day was producing a total drawdown of 2.5 m. The estimated aquifer transmitivity was as good as about 500 m3/day.

Based on rough estimates from the test pumping results, geoelectrical soundings and geological data it may be concluded that the Bungumi valley could yield about 6000 m3/day from a properly designed borehole field. There would not be any major concern on possible sea water intrusion, however the water quality has to be regularly monitored in this respect, if discharge from the area is increased.

A constant rate pumping test was performed at Masipa borehole on 23rd July 1990, with a discharge rate of 58 m3/h. Drawdown reached the level of 6.8 m during 270 minutes of pumping. No recharge boundaries were observed. The aquifer seems to be unconfined. The aquifer transmitivity was about 200 m3/day, enough for a production borehole.

The Masipa area is a suitable groundwater development area and may yield about 1000 m3/km2. If more boreholes are drilled in this area, the groundwater potential calculations done have to be verified using actual hydraulic data from more than one borehole.

Availability of groundwater, Mkoani Town

The water supply for Mkoani Town has to be collected from several different points. Makombeni Valley nearby the town has some potential for groundwater development.

There is an artesian borehole just near to the sea on the beach near the harbor, near the Makombeni valley. The aquifer with small artesian pressure is at the depth of 10 - 20 m. The aquifer layer could be followed, and penetrated by several shallow boreholes. The artesian overflow could be collected along a collection pipeline and pumped to the town.

The overflow in the existing borehole is rather small and the artesian yield might hardly be enough for pumping the water to the town. The yield could be increased by pumping from the boreholes but keeping the potentiometric level well above the sea level. Depending on the continuity of the aquifer it is estimated that up to 300 m3/day could be developed from N'gombeni valley.

The borehole nearby Uweleni Waterworks could be rejuvenated. The estimated maximum yield from this site could be about 150 m3/day. Special attention should be paid to the borehole design due to silt problems in this area.

The Changaweni pumping station should be maintained and further developed. According to test pumping results, about 300 m3/day can be developed from Changaweni. Special attention should be paid to the borehole design due to silt problems in this area.

The main part of the Mkoani future Water supply, over 1000 m3/day, may be developed from newly discovered

Meli nne spring. The natural spring area is located on the northern side of the main road. If the area proves not to be suitable for such a quantity , an additional supply can be developed from the valley in Mtambile.

At a distance of about 8 km from town the Sisimizini spring was found during the spring identification program. The spring overflow was about 1100 m3/day. This spring could be considered as an alternative to Mtambile intakes. Final decision should be done after test drilling in Mtambile. Another potential spring, although very far away, with a tested yield of 900 m3/day with 70 cm drawdown is located at Mgelema area.

6.8.6 Borehole Fields

The annual recharge and use of storage without affecting the storage permanently would allow pumping from individual boreholes with a drowdown rate of about 6 - 10 m in the miocene formations. This figure has to be verified after actual storativity figures are calculated. Depending on the storativity capacities in different borehole field areas, the annual recharge is estimated to lift the water level about 4 - 8 m. The depth up to 6 m from the storage would be compensated by the areas where the drowdown remains smaller and by the interaction of aquifers. To make the well fields efficient and to use their maximum capacity, the individual wells should be located so that the depression cones overlap at about twoe meters depth of draw down. The distance of boreholes from each others in the proposed borehole field areas is thus estimated to be 300 - 400 m. The proposed borehole field areas are presented in the Map 1b and c.

7. BOREHOLE WELLS

7.1 Drilling Technology

According to Johnson "Groundwater and wells, 1989" the drilling should follow the following basic criteria:

i. Use of materials that will provide an efficient well with long service life

ii. Use of techniques in drilling and well construction that take maximum advantage of the hydrogeologic conditions.

iii. Apply the principles of hydraulics in practical way to the analysis of wells and aquifer performance.

Cable - tool and direct rotary drilling are found apropriate drilling technologies in Zanzibar. There are a few drillers who are familiar with these technologies from the previous drilling programmes.

7.2 Borehole Well Data

All the boreholes in the catchment areas and near surroundings were registered. The number of boreholes registered was 14 and 13 in Unguja and Pemba respectively. Data from all relevant boreholes were collected and gathered in a database. Borehole data sheets are presented in Annex 3 and 4. The monitoring of the boreholes is presented in chapter 6.2.

7.3 Condition of the Existing boreholes

There is a total of thirteen boreholes in the vicinity of Zanzibar town. The oldest boreholes were drilled in the 1960's and the latest in the end of 1980's. At the moment five wells are under pumping, yielding a total amount of 11000 m3/day. This figure is an estimate according to the capacities of the pumps and should be reviewed by continuous flow measurements. In addition to these wells there are three boreholes in fairly good condition, unfortunately without pumps. The remaining five holes can be used only for water level monitoring.

The condition of boreholes is presented in Table 2. It can be concluded that the condition of boreholes is rather fair than good. High corrosion of well casing and screens, infilling, reduced yield and silt pumping are common problems.

A number of boreholes have been abandoned due to the following reasons:

- the collapse of the well casing or screens
- the caving of the boreholes during drilling
- the boreholes sites were not ascertained, and therefore they never produced water
- poor quality of water due to poor gravel pack, etc.
- too much siltation in the boreholes (no equipment for cleaning)
- jammed pumps inside the borehole (no equipment to fish them out)

Losing or abandoning an already drilled well is quite an expensive exercise and measures should be taken to avoid such incidence during the implementation phase of this program.

7.4 Design of the existing boreholes

Well casing and Borehole Diameter

In the existing wells the well casing diameter has been from 8 to 12 inches. Generally the diameter at the piped section has been, for core-method 12 in., for cable tool method 16 in. and for direct rotary 14 in.

Casing Material

Usually the well casing material has been iron, jointed by threads or by welding. Only a few number of wells have been piped with PVC well casings.

Well Depth

The existing boreholes can be regarded as rather shallow ones. Drilling depth has been varying from 30 to 90 meter and the average depth has been 53 meter.

Well Screens

Most commonly used type has been hand-made torch-cut screen. Disadvantages of these screens have been the limited percentage of open area (4 - 6 %) and the variable slot size (1 - 6 mm). The cutting surface has been highly exposed to corrosion. Due to the limited open area the screen length has been 40 - 60 % of the borehole depth.

Small amount of wells have been completed with bridge-slotted or continuous-slotted screens. The open area for bridge-slot is up to 30 %. The material of bridge-slotted screens is galvanized iron and that of continuous slotted galvanized or stainless steel.

Filter Pack

The characteristics of filter pack have been varying very much. Often the purpose of filter pack has been only to fill the annular space between the well casing/screen and the hole. The used grain size has been from sieved beach sand to limestone chipping (from 3 - 6 mm to chipping). Depending to the drilling method the filter pack thickness has been 40 - 50 mm.

Recommended borehole design

The new boreholes should be drilled according to the design criteria of Annex 11.

8. FILTER SANDS STUDY

A study on availability of filter pack material was carried out and it was discovered that reasonably good filter sand material is available at the western coast of Unguja Island.

Eighteen filter sand samples were collected from different locations in Unguja and Pemba. Sample sites are presented in the Figure 24. The samples were analyzed in the University of dar es Salaam geology laboratory, the results are presented in Annex 12. A detailed description of each sample is presented in Annex 14. According to the study results the following sites are suitable for sieving borehole filter sand:

1. NO1 KIZINGO
2. NO2A PEMBA RIVER SITE B
3. NO3 MARUHUBI
4. NO7 JKU.KAMA
5. NO8 INN-BY-THE SEA
6. NO9 MAZIZINI BEACH

SCHEMATIC PLAN FOR FILTERSAND SAMPLING

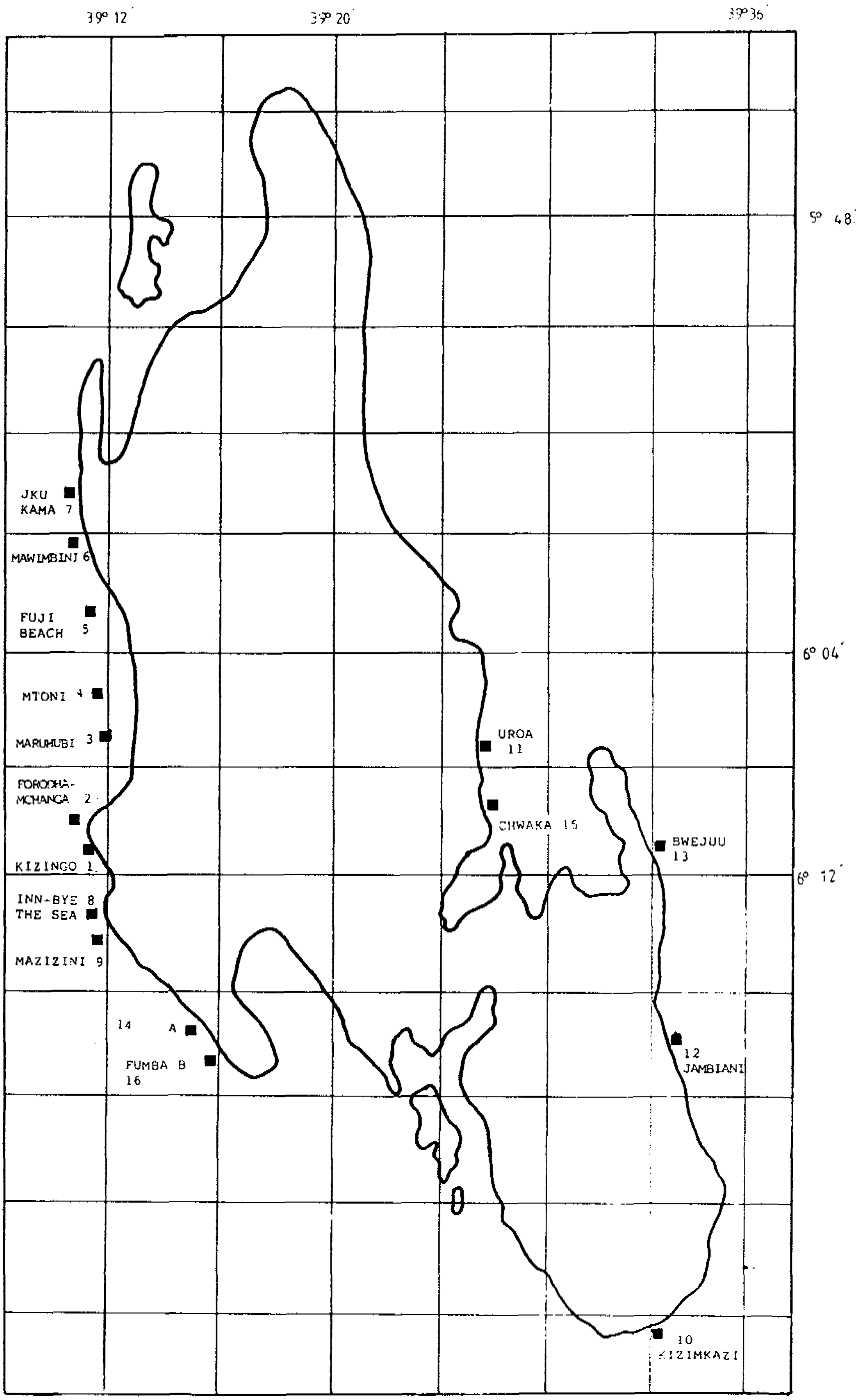


Figure 24 Filter Sand Sample Collection Sites

9. COSTS AND ECONOMIC ASPECTS

9.1 Salary Costs

It is assumed that salaries of the staff in a parastatal organization will develop as follows:

	Total Shs/Month
Professional staff member with university education Shs 20.000 per month	
Three persons	60.000
Survey technicians Shs 12.000 per month	
12 persons	144.000
Professional drillers Shs 12.000 per month	
4 persons	48.000
Assistant drillers Shs 9000 per month	
4 persons	36.000
Mechanics Shs 9000 per month	
2 persons	18.000
Laborers Shs 6000 per month	
8 persons	48.000
Grand total, salary costs per month	354.000
Drilling operations in two shifts will add to the costs about Shs 180.000	180.000

9.2 Survey Costs, Geophysics

The services of university of Dar es Salaam are available for making geo-electrical soundings in connection with the hydrogeological survey work. The cost of one survey point is Shs 6000 + accommodation and food and travel costs of the survey team. The team completes 3 - 4 sounding points a day. The estimated total cost per one point will be Shs 9000. This figure does not include the salaries of the permanently employed survey technicians. This part of the costs is covered in the salary costs.

The total need for geoelectrical survey points, is estimated to be 60 Nos per annum. The total annual cost would thus be Shs 540.000, and

the average monthly cost would be Shs 45.000

9.3 Laboratory Costs

Laboratory costs for water quality and environmental monitoring will be as follows:

	Total Shs/Month
Costs of chemicals, electricity etc. per one water sample Shs 2000,	
50 samples a month	100.000
Capital costs of laboratory equipment, repayment period 5 years, Shs 1800 per sample,	
50 samples per month	90.000
Grand total laboratory costs	190.000

9.4 Drilling Costs

Drilling costs for the existing drilling team of the Department of water Development will be as follows:

Costs of one production borehole

	Shs
PVC - casing, plain, 40m	220.000

PVC - screen, 10 m	82.500
Diesel, 80 l/day, 40 l/shift, 13 days 120 Shs/l	124.800
Spareparts for the rig and vehicles	55.000
Drill bits cables etc. material	55.000
Other costs, filter sand etc.	30.000
(Salaries, already covered in salary costs)	(181.500)
Total direct costs	567.300 (+181.500)
If the unit will produce 20 boreholes a year and the drilling equipment will be compensated in 5 years time, the capital cost per one borehole will be	850.000
If the production speed will be 20 boreholes a year the monthly drilling costs will be	2.362.000 (+302.500)

The total costs per month of the research and development without drilling cost	589.000

The total cost per month of the research and development with drilling costs	3.311.000

10. WATER RESOURCE MANAGEMENT

10.1 General

The planned increased pumping of ground water for urban water supplies (113.000 - 159.000 m3/day) will evidently be accompanied by increased use of water resources for irrigation (50.000 m3/day) and for piped rural schemes (1500 m3/day). The water discharge in some cases tends to concentrate in rather limited aquifer areas in the islands. This would, no doubt, at some stage, lead to a situation where the optimum use of the natural resource, water, needs to be established, on the basis of use priorities and availability of the resource. Therefore the recent efforts of Government of Zanzibar, to formulate a general water policy and legislation including groundwater management ordinates, are seen as most positive development and they should be strongly supported.

Interministerial control over safe yields, based on scientific survey and monitoring, would be required to protect the aquifers from depression of water tables and from seawater intrusions in the coastal areas. The watersheds should be protected from environmental deterioration.

The proposed groundwater exploitation activity can start only after there is an authorization to it from a relevant national authority. Otherwise the drilling may be considered to have no legal justification.

All pumping records and future pumping plans from all programs and private users should be gathered by the Water Department and deposited in a simple data base developed for this purpose. Preparation of a simple data base was initiated during the planning period.

Supply of drilling materials during the course of the Urban Water Supply Program should be conditional with the availability of hydrograms and monitoring data. No facility to draw large quantities of ground water without proper monitoring, should be provided.

There is no river management for the time being. It is estimated that with proper management and maintenance the river flow could be increased in many cases with about 20 %. River management would be useful if river water is used for instance for irrigation purposes.

10.2 Institutional Procedures

The table 3 outlines the institutional procedure, required to control and manage the water resources.

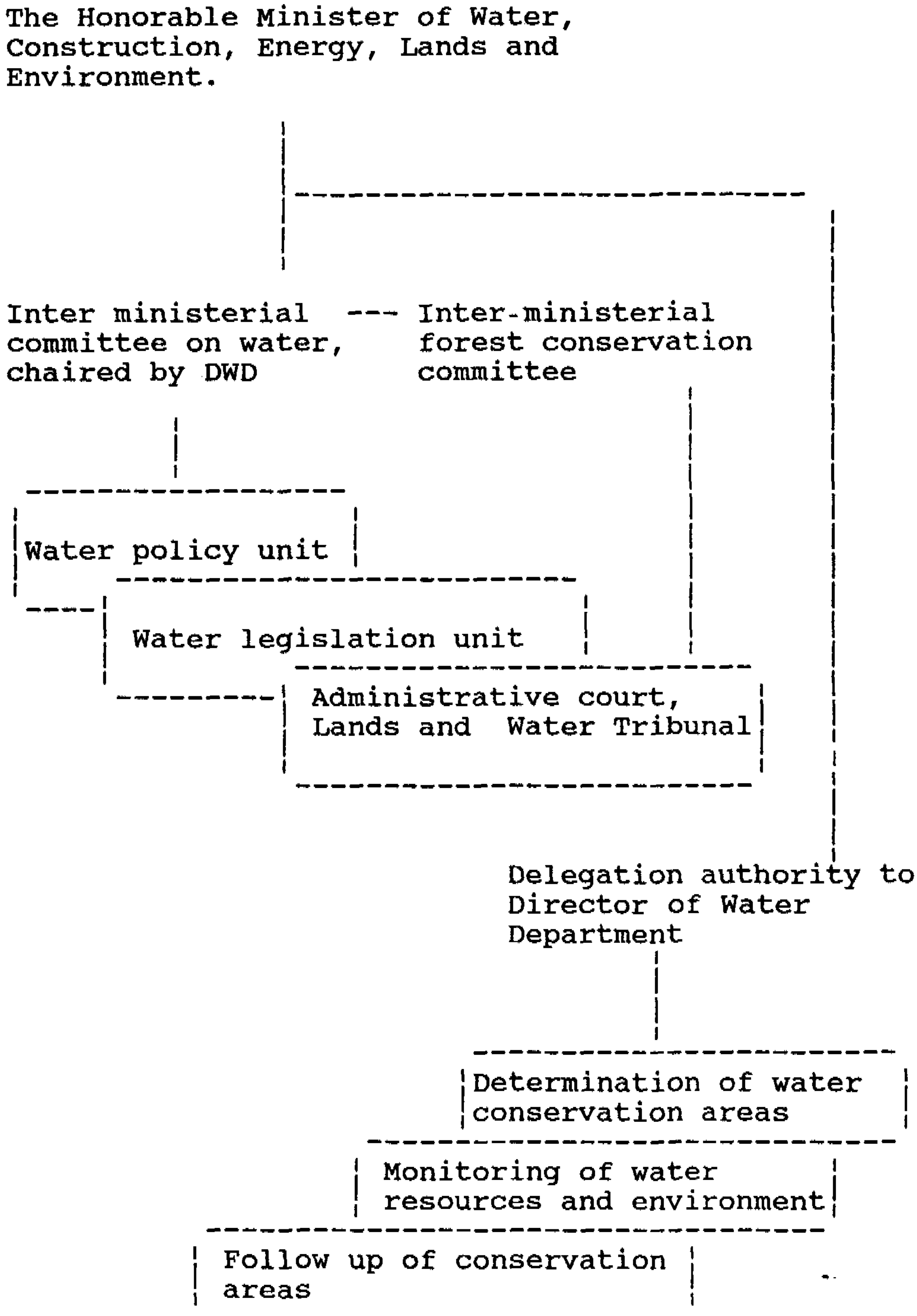


Table 3. Some institutional procedures related to groundwater management.

During the planning phase separate reports were prepared on the water resources and environmental and water quality issues. However these components are very much interlinked and the same survey teams and personnel worked with all the programs. It will be institutionally and organizationally clear that the hydrogeologist of the Water Department will have overall responsibility for these components.

In the Department of Water Development there is a plan to establish a unit for research and development and drilling activities. An outline of the organizatorial status of this unit is given in the organization chart of Figure 25.

10.3 Water Legislation

10.3.1 General

Issues of water and lands legislation were discussed with the Water Ministry and DWD-staff and with a FAO consultant who was in the process of revising the Forest and Lands conservation degree. It would be necessary to engage a short term consultant, one to two months, to draft the water policy statement and water act. The following procedure, considerations and resolutions were the outcome of the discussions.

10.3.2 Procedure for Preparing the Act (provisions in the act not necessary)

a. Inter-ministerial committee appointed and discusses issues;
b. Working Group prepares Water Policy;
c. Water Policy is turned into a Water Act -

    a. water management planning;
    b. conservation areas;
    c. Authority for the Director of Water to deal with the conservation issues;
    d. The resolution of disputes that arise in the sector.

10.3.3 Some Considerations About Substantive Provisions for the Water Act.

a. Basic provisions of Water law relating to conservation should include provisions relating to the preparation of water management plans every so many years (7 perhaps) - provisions from the new draft Forestry Act may be helpful in this regard as there are extensive provisions setting up a planning procedure there.

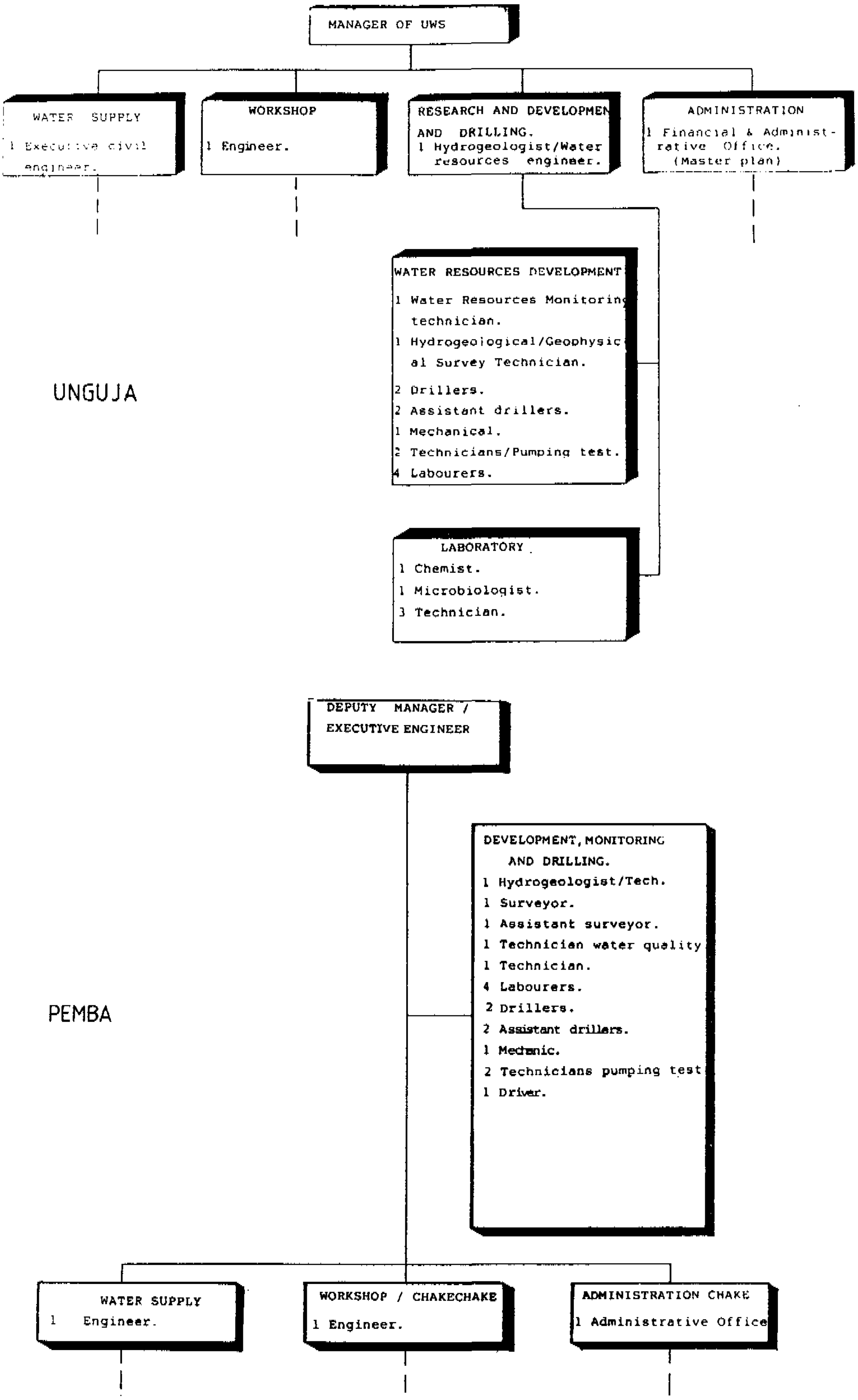


Figure 25 Organizational Status of Research and Development and Drilling

b. Conservation Area Provisions which should be "incorporated by reference" form the provisions from the soil and water conservation act developed for Forestry will adequately provide a set of procedural provisions which will meet the needs for any of the water conservation issues that might arise;

c. This should include a provision that allows the "Minister" to delegate the authority to the Director of Water to oversee the technical aspects of water conservation (as proposed to the issues that would arise under the definition of forestry conservation) when it is part of the Conservation Area procedures.

d. So there is no need for overlapping provisions from different laws. The provisions of one which sets up a satisfactory procedure for conservation will be applicable to other technical areas without the necessity of creating competing provisions. The important issue is to ensure that the appropriate technical persons are available to make the decisions and produce the plans that are necessary.

10.3.4 Resolution of Disputes that Arise from Licensing and Other Procedures:

a. There is to be created an informal administrative court that will deal with "land" issues to be known as the Lands Tribunal. It will be made up of a President and two persons probably to be called "assessors" who will be selected on a District basis because of their technical knowledge.

b. This court could also be given jurisdiction over the water issues (possibly renamed Land and Water Tribunal) and would be adequate to satisfy the needs of the administrative issues that might come up in dealing with drilling, water use or any other issues concerning ground water. -

c. Note: The Land Tribunal will be the body given jurisdiction for disputes that are unresolved by the judicial mechanism of the Farmers' Associations in the Irrigated Sector - thus showing it relevance for other water related issues.

11. RECOMMENDED STUDIES AND ACTIVITIES

11.1 Coordination of Activities

The water conservation, lands and forest conservation and environmental conservation have common goals. There is a need for careful interministerial coordination of activities to avoid vaste of resources by duplicating some activities.

As proposed in chapter 10.2, the water resources and environmental development programs would be run as one program in future. There would be need to also Prepare and implement an action plan of joint activities with other sectors of urban and rural water supply.

11.2 Water Resources Development

- Establishing a coordinating system for ground water utilization by RGoZ according to the guidelines of chapter 10.
- Orientation at interministerial level
- Arranging of training courses
- On-the-job training
- Developing a data collection and storing system:
  - ground water level monitoring
  - preparation of long term hydrogrammes
  - preparation of mathematical hydraulic model
  - water quality monitoring
  - meteorological information
  - Carrying out drilling and monitoring activities:
  - drilling
  - geoelectrical soundings
  - quality control

- Preparing revised maps and plans:
  - resistivity contour map
  - storativity map
  - transmitivity map
  - potentiometric map
  - chemical quality map
- Material supplies

11.3 Protection of Water Sources

- Preparation of plans for site selection
- Preparation of plans for intake protection zones

11.4 Environmental Monitoring

Environmental issues are dealt with in detail in aseparate Environmental impact assesment report.

- Monitoring ground water quality
- Monitoring scheme water quality
- Monitoring waste water quality
- Monitoring sea water quality
- Follow-up on the development of industry and possible pollution
- Studying the use of pesticides
- Monitoring other environmental aspects
- Studies to be carried out in the early stage of the project:
  - EIA (Environmental Impact Assessment) during rainy season
  - basic studies on the spread of fecal pollution
  - basic study on the quality of waste water
  - basic study on pesticide pollution

11.5 Water Quality and Environmental Awareness

- Training, education and orientation to be carried out:
  - orientation of authorities
  - intersectoral seminars
  - water quality and environmental issues to be included in all training programs of other sub-projects
  - training of laboratory personnel