# CONCLUSIONS AND RECOMMENDATION

# CONCLUSIONS AND RECOMMENDATION

This Project is situated in the central southern part of the Republic of Tanzania, and is the Kihansi Hydroelectric Power Development Project to be constructed on the Kihansi River, a tributary of the Rufiji River, the largest river in the country, which empties into the Indian Ocean. With regard to this hydroelectric power development project, the JICA Study Team has carried out a prefeasibility study of the Upper Kihansi Project located on the upstream part, and a feasibility study of the Lower Kihansi Project located on the downstream part. As a result of these studies, it is concluded that the two projects are amply feasible from engineering, economic, and environmental points of view. An outline of the conclusions are given below.

## Conclusions

1) Power demand in the Republic of Tanzania, reflecting stagnation of the economy up to 1985, had shown an annual growth rate of 5.9 percent, but as a result of the economy turning around favorably with an economic plan receiving aid from the World Bank in 1986-1988, the growth rate rose sharply to 10.3 percent. Hereafter, from 1990 to 2005, the annual growth rate in power demand is estimated as 6.2 percent. Accordingly, the peak demand of 285 MW in 1990 is anticipated to become 707 MW in 2005, and when the capacities of thermal power plants to be discarded during that time are taken into account, new facilities of more than 520 MW will be required.

2) Coal and natural gas have been confirmed as energy resources in the Republic of Tanzania, but these will require great expense for development and transportation. On the other hand, the hydroelectric potential of the country is estimated at 38 million kilowatts with the portion already

developed being not even 1 percent, and hydro power is recognized as being an important energy resource in the future.

3) The development scheme for the Kihansi River proposed in the Master Plan was reviewed, and appropriate selections were made of timings of development, development scale and layouts. For the sequence of development, the conclusion was drawn that development should be in two stages, commissioning of the Lower Kihansi Project as Phase I, and commissioning of the Upper Kihansi Project as Phase II. With regard to the starts of operation of the two projects, it was concluded as a result of load forecasting that it is appropriate for start-up of the Lower Kihansi Project to be in 1996, and that of the Upper Kihansi Project in 1999.

4) For the construction costs of the two projects, estimating was done assuming that design and construction methods, and materials and products according to the technological levels that could be expected as of June 1989 were applied, with the geological conditions and regional conditions of the project sites, construction scales, etc. taken into consideration in the construction unit prices, and with import duties and interest during construction included.

The construction costs, including both local and foreign currency requirements, are US$261 million for the Upper Kihansi Project and US$206 million for the Lower Kihansi Project, for a total of US$467 million.

5) The economical natures of the two projects are that, even independently, they are economically superior compared with an alternative thermal facility and, particularly, the unit construction cost per kilowatt-hour of the Lower Kihansi Project is 0.37 US$ to comprise the cheapest power source in the Republic of Tanzania.

The expenses and revenues of the two projects were calculated and the economic internal rate of return (EIRR) on discounting to present worth was 39.3 percent. This value far exceeds the marginal rate of return set by international financing institutions, indicating that this Project is feasible from the standpoint of the national economy.

6) For the dam of the Upper Kihansi Project, a rockfill dam is adopted taking into consideration of topography, geology, construction materials, construction costs, etc., while for the Lower Kihansi Project, a concrete gravity dam is adopted. It is possible for both sites to be provided with economical semi-underground powerhouses and, especially, since Lower Kihansi Power Station has a high head, Pelton type turbines are adopted and design of the waterway is simplified. Both projects involve no problems that will cause hindrances to realization of construction and are technically feasible.

7) The Slash-and-burn farmland to be submerged in the reservoir area as a result of this Project is a few and no habitant exists, while there are no items at all requiring compensation such as roads, public buildings, etc.

8) The water quality of the Kihansi River has strong acidity due to the influences of the topsoils and slash-and-burn farming, while because of oligotrophication and the swift flow where rock is exposed at the river bed, there are almost no aquatic organisms such as fishes to be seen. As for the areas planned for water impoundment, since they consist of slash-and-burn farmland or land lying fallow and are cleared away, the existence of large wild animals has not been confirmed. However, it will be necessary to be careful about outbreaks of harmful plants and insects in the reservoir areas or dewatered areas, and a reasonable amount

of environmental protection funds, including monitoring device, are calculated in the construction cost.

9) It is assessed that the effects on the natural and social environments of the surroundings will be small, and it is expected that this power development project will contribute greatly to the regional society, at the same time making possible stable supply of electric power.

## Recommendation

Hydroelectric power development project on the Kihansi River is judged to be technically and economically feasible and the commissioning programs in the power system in accordance with the electric power development program in the Republic of Tanzania are planned for the Lower Kihansi Project in the year 1996 and for the Upper Kihansi Project in the year 1999. Consequently, the necessary preparations for the development are recommended to be executed under the development scheme.

For realization of this Project, the following items are necessary to be performed;

1) The feasibility study should be performed on the Upper Kihansi Project.

2) The necessary preparatory works for the construction such as the definite design, the preparation of tender document and so on should be implemented on the Lower Kihansi Project.

3) The additional investigations and tests described in Chapter 14 "Future Investigation Works" of the Final Report should be executed for the definite design on the Lower Kihansi Project and the results should be thoroughly reflected in the definite design.

# Chapter 1 INTRODUCTION

## Chapter 1

## INTRODUCTION

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# Chapter 1 INTRODUCTION

## 1.1 Antecedents

Tanzania suspended the 4th 5-Year Economic Development Plan (1981 - 1985) and is restructuring its economy by formulating National Economic Saving Program (NESP) and Structural Adjustment Program in 1986 as well as Economic Recover Program (ERP) in 1986.

According to a long term power demand forecast prepared by Tanzania Electric Supply Company Limited (TANESCO), the demand of electricity will increase by some 5% from 1992, when a symptom of economic recovery by ERR executed from 1987 will appear.

Tanzania is endowed with energy resources for power generation such as coal, natural gas, hydroelectric potentials. Among these resources, TANESCO basically puts emphasis on development of hydroelectric energy. In order to meet demand of electricity in mid 1990's, hydroelectric power development on Kihansi River is recommended as a most appropriate project in "Master Plan" prepared by Norconsult (Norway) and "Power Development Plan 1985 - 2010" prepared by ACRES (Canada).

Kihansi hydroelectric power development scheme is located on the middle part of Kihansi River, a tributary of Rufiji River, approximately 450 km south-west of Dar Es Salaam.

The project consists of Upper Kihansi scheme (with a reservoir which can regulate totally the annual inflow), Lower Kihansi scheme (with a regulating reservoir downstream Upper Kihansi), and Transmission Line scheme (interconnecting Lower Kihansi - Upper Kihansi - Iringa

Substation). Total installed capacity of the project will be 200 MW.

In October 1987, Government of Tanzania requested Japan to implement feasibility study on Kihansi Hydroelectric Power Development Project, contemplating the completion of Lower Kihansi Project by 1995 and Upper Kihansi Project by 1997, so as to meet the increasing electric power demand of the country.

And that Tanzania requested again the immediate implementation of the Project during discussion with JICA mission for Project Selection Confirmation dispatched in November 1987.

Responding to this request, JICA dispatched Scope of Work mission in October 1988 to carry out field investigation and discussion with TANESCO and confirmed that feasibility study should be implemented. Thus Scope of Work was concluded between TANESCO and JICA on October 20, 1988.

## 1.2 Scope of Work and Field Reconnaissance

### 1.2.1 Purpose of the Study

Main purpose of the study is to prepare feasibility report of Kihansi Hydroelectric Power Development Project by formulating technically, economically and financially optimum development plan through implementing field reconnaissance and home office work.

Another purpose is to transfer technology to the counterpart engineers through implementation of the study.

### 1.2.2 Area and Level of the Study

Study area is limited to those areas relevant to the Project (catchment area, dam site, intake, headrace tunnel, surge tank, penstock, powerhouse, tailrace, switchyard, transmission line route, transportation route, quarry site, etc.) along Kihansi River of the Rufiji System.

Lower Kihansi is to be studied at feasibility study level, while Upper Kihansi pre-feasibility level.

### 1.2.3 Outline of the Study

The study has been carried out in the following 3 stages, according to the contents of the study.

1 Preliminary Study
2 Detailed Field Investigation
3 Feasibility Design Study

(1) Preliminary Study

- To collect and review the existent data and reports relevant to the project.

- To carry out field reconnaissance in the Project area.

- To carry out comparative study of development plans based on the existent data, and to select optimum scale of development.

- To formulate implementation plan and technical specifications for detailed field investigation.

(2) Detailed Field Investigation

- To carry out field works based on the study implementation plan formulated in the Preliminary Study. Field works consist of aerial photograph mapping and drilling works including permeability test.

- To analyze hydrological and meteorological aspects by collecting existent data as well as by observing discharge and wash-load.

- To analyze aspects on electric power market, environment, compensation by collecting existing data and forecasting effect caused by the Project.

(3) Feasibility Design Study

- To establish development plan and confirm the appropriateness from technical, economical and financial point of view, based on result of preliminary study and detailed field investigation, as well as the most recent study results including environmental data.

## 1.3 Existent Report

The following six reports/data are available for study of this Project.

(1) Rufiji Basin Hydropower Master Plan
1984 Norconsult/NORAD

(2) Power Sector Development Plan 1985 to 2010
1985 TANESCO/Acres Int.

(3) Power Sector in Tanzania, 1986
1986 TANESCO

(4) National Accounts of Tanzania 1976 - 1986
1987 Bureau of Statistics, Ministry of Finance

(5) TANESCO Statistical Data
1988 TANESCO

(6) TANESCO Power Tariff Effective 1979 to 1988
1988 TANESCO

## 1.4 Field Reconnaissance and List of Engineers

### 1.4.1 Field Reconnaissance

The study team conducted their activities in Tanzania since commencement of the study in February 1989.

(1) Field Reconnaissance (First Time)
Period: 15/Feb./'89 ~ 31/Mar./'89

(2) Field Reconnaissance (Second Time)
First Progress Report
Period: 1/Jun./'89 ~ 30/Jun./'89
29/Aug./'89 (Survey work)

(3) Second Progress Report
Period: 1/Aug./'89 ~ 15/Aug./'89

(4) Third Reconnaissance
Period: 1/Aug./'89 ~ 29/Sep./'89 (Environment)
~ 30/Nov./'89 (Geology)

(5) Third Progress Report
Period: 1/Dec./'89 ~ 15/Dec./'89

(6) Interim Report
Period: 19/Feb./'90 ~ 5/Mar./'90

(7) Draft Final Report
Period: 2/Sep./'90 ~ 16/Sep./'90

### 1.4.2 Field Investigation Works

The following field study, investigation works and laboratory test were carried out by the JICA Study Team and TANESCO:

(1) Topography

| | | | |
|---|---|---|---|
| Establishment of aerophotographic marks and benchmarks | | 19 | points |
| Levelling | | 60 | km |
| Aero photography | 1 : 30,000 | 110 | $km^2$ |
| " | 1 : 7,000 | 22 | $km^2$ |
| Mapping | 1 : 5,000 | 16.5 | $km^2$ |
| " | 1 : 1,000 | 1.5 | $km^2$ |

(2) Geological Investigation Work

| | | |
|---|---|---|
| Drilling (including permeability test) | 8 holes | 230 m |
| " (material test) | 2 holes | 40 m |
| Seismic Prospecting | 2 lines | 105 m |
| Test Pitting | 4 pits | 6.8 m |
| Laboratory Test | | 27 samples |

(3) Other studies

| | |
|---|---|
| Installation of runoff gauging station | one (1) set |
| Runoff measurement | weekly (1 year)<br>monthly (continuing) |
| Water quality | anytime (continuing) |

### 1.4.3 List of Engineers

TANESCO

| | |
|---|---|
| Mr. S. L. Mosha | Managing Director |
| Mr. S. J. Kimaryo | Dy. Managing Director (Technical Service) |
| Mr. J. K. Tesha | Director (Projects & Transmission) |
| Mr. B. E. A. T. Luhanga | Director (Corporate Services) |
| Mr. K. K. Iranga | Director (Distribution & Customer Services) |
| Mr. S. L. Mhaville | Director (Production) |
| Mr. M. S. Masanja | Company Secretary |
| Mr. K. R. Abdulla | Manager (Projects) |
| Mr. F. X. Saidi | Manager (Study & Design) |
| Mr. A. A. Kapasi | Manager (Transmission) |
| Mr. M. M. Fazal | Manager (Distribution) |
| Mr. D. E. P. Ngula | Chief Hydrologist |
| Mr. A. F. Abdullah | Chief Design Engineer |
| Mr. J. M. Lukumai | Chief Project Engineer |
| Mr. A. P. Mbwatila | Chief System Planning Engineer |
| Mr. G. Nyamko | Chief Generation Engineer |
| Mr. G. N. M. Nyamboha | Senior Civil Engineer |
| Dr. H. R. Mursal | Senior Civil Engineer |
| Mr. G. F. Mosha | Civil Engineer |

| | |
|---|---|
| Mr. Lebbi Changullah | Planning Engineer |
| Mr. Mwinuka | Senior Surveyor |
| Mr. Magoti | Civil Technician |
| Mr. H. E. Kileo | Regional Manager (Iringa) |
| Mr. H. E. Maruwa | Regional Manager (Morogoro) |
| Miss Kiangi | Area Manager (Ifakara) |

JICA

| | |
|---|---|
| Mr. Y. Ebi | Team Leader |
| Mr. S. Ariga | Hydrologist |
| Mr. K. Iino | Planning Engineer |
| Mr. M. Seino | Planning Engineer |
| Mr. T. Ushijima | Chief Design Engineer |
| Mr. J. Hori | Civil Design Engineer |
| Mr. M. Shiomi | Civil Design Engineer |
| Mr. K. Niimi | Geologist |
| Mr. H. Ishii | Geologist |
| Mr. M. Shigeta | Geologist |
| Mr. M. Nakai | Surveyor |
| Mr. K. Tamari | Surveyor |
| Mr. K. Hayakawa | Surveyor |
| Mr. H. Sugiyama | Hydrologist |
| Mr. H. Fujimaki | Environmental Engineer |
| Mr. M. Noda | Electrical Engineer (Power) |
| Mr. T. Hagiwara | Electrical Engineer (System) |
| Mr. T. Nanba | Economist |
| Mr. M. Tanaka | Economist |

# Chapter 2 GENERAL STATE OF THE REPUBLIC OF TANZANIA

Chapter 2

# GENERAL STATE OF THE REPUBLIC OF TANZANIA

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# Chapter 2 GENERAL STATE OF THE REPUBLIC OF TANZANIA

## 2.1 Geography

Tanzania is situated at the eastern part of the African Continent from 1°44′ south latitude and 29°40′ to 40°27′ east longitude. It is bounded on the north by Kenya and Uganda, on the west by Rwanda, Burundi and Zaire, and on the south by Mozambique, Malawi and Zambia, while it faces the Indian Ocean on the east. The total area of the national territory is 945,050 $km^2$, which territory is made up of the Lake Tanganyika and Lake Victoria Basin Region in the northwest, the Kilimanjaro Region in the northeast, and the Indian Ocean Coastal Region centered at Dar Es Salaam.

The project area is in the Rufiji River Basin which comprises the center of the Indian Ocean Coastal Region and is located on the Kihansi River which is a major tributary of the Rufiji River. This Kihansi River rises from a hill area to the south of Iringa, runs south down the southeast slope of the Uzungwa Mountainland and drops abruptly down to the marshlands of the Kilombero River fan so that the upstream part is a slow stream with a meandering river channel while the downstream part is a swift stream consisting of a series of waterfalls.

## 2.2 Climate

The climate of Tanzania is that of a tropical savannah, but is greatly varied depending upon landform and elevation. Temperatures differ according to rainy season and dry season, but in general, are in a range of 34°C to 15°C, while the seasonal variation in temperature in the Indian

Ocean Coastal Region is less than 10°C and very small. On the other hand, in the project area, the difference in elevation between the upstream and downstream parts has a great influence, and temperature differences of more than 20°C occur at times.

The annual rainfall of entire Tanzania is from 400 mm to 2,000 mm, varying greatly depending on the location, but in any event, there is a difference of rainy season and dry season, with the rainy season starting in November and continuing into May. The rainfall characteristics are influenced by the movements of intertropical convergence zones and landforms so that the annual rainfall of the project area has a spread between 1,000 mm and 1,800 mm depending on the place, with the characteristic being of more rain in the southeastern part of the basin and increasingly less going toward the northwest. Even during the rainy season, wind directions, wind forces, humidities, etc. differ, while also, from December to February, the monthly rainfalls are small from 150 mm to 200 mm.

## 2.3 Population

The total population of Tanzania is estimated to have been 22,650,000 as of 1988, the population increase in recent years being 3.4 percent annually. The population density is 23.8 per square kilometer.

In this area, people who had mainly been engaged in slash-and-burn agriculture have formed villages at the right-bank side limited to upstream on the Kihansi River since the left-bank side has been designated as a forest reservation, and the downstream part is a continuation of cliffs of the Uzungwa Mountainland. The population has shown almost no increase since 1971 and is about 3,400 even when the two villages of Uhahiwa and Ukami are added together.

## 2.4 Economy

### 2.4.1 General Economic Trends

The GNP of Tanzania in 1986 was 146,168 million shillings, the per capita GNP having been at the level of $126. Although various industries such as oil refining, cement manufacturing, and fertilizer manufacturing have developed in recent years, industry is centered on agriculture, and the ratio of agriculture in the GDP of 1986 was 39.4 Percent.

Conversely, the ratio of manufacturing in that year had declined by 6.5 percentage points in comparison with the previous year, the causes of this having been shortages in imported raw materials and parts due to the tight situation in foreign currency reserves and the frequent occurrences of power outages and water supply shutdowns which had had great effects.

The favorable and unfavorable conditions of the Tanzanian economy, similarly to other developing nations dependent on export of primary products, are greatly affected by the international balance of trade. The worsening of the balance of foreign trade since 1981 was directly caused by the slump in agricultural production, and the Tanzanian Government has since been aiming for the rehabilitation of agriculture through policies for improvement in the agricultural structure and increases in aid from foreign aid agencies. As a result of these policies, the trend of decline in agricultural production was reversed in 1986 with cotton, for example, increased 108 percent over the previous year.

More than half of the development budget comprising 22.3 percent of the annual budget for the fiscal year 1987 -

1988 which started in July 1987 (total amount 77,320 million shillings) was planned to be made up with grants and loans from abroad, with moreover, 27.1 percent of the development budget allocated to the agricultural sector.

The Economy Recovery Program (ERP) covering a period of three years initiated from that year to overcome the economic crisis ended in June 1989, and the growth in GDP for 1988 was 4.1 percent, a tolerable figure compared with the worst period of the first half of the 1980s.

### 2.4.2 Trends by Industry

(1) Agriculture

Agriculture accounts for approximately 75 percent of total exports and is the most important industry of Tanzania. Particularly, coffee is the most important product for earning foreign currency, and in 1986 and 1987, it made up 49.2 percent and 31.3 percent, respectively, of total exports.

The growth rate of the agricultural sector in recent years has been about 0.6 percent, and the Tanzanian Government, in order to break out of the economic difficulties, intends to raise the growth rate to 5 percent in the early 1990s, and is aggressively promoting agricultural restructuring policies. The major products other than coffee are cotton, sisal, tobacco, tea, and cashew nuts.

(2) Manufacturing

The manufacturing industry of Tanzania is constituted of the following:

a) Basic raw materials industries such as steel, cement, glass, paper pulp production

b) Import substitute consumer goods production

c) Agricultural products processing

Production capacities were increased in many industries in the 1970s. For instance, production capacities of textiles and cement were doubled in the period from 1976 to 1980, but as a result of rapid industrialization, demand was unable to keep up as the 1980s were entered and the situation has been that operating rates have declined.

The proportions of GDP made up by the manufacturing sector in 1985 and 1986 dropped 3.3 percent and 6.5 percent, respectively, compared with the previous years.

(3) Mining

Tanzania has many mineral products with diamonds making up the greatest amount of production and ranking fourth as an export item after coffee, tea, and cotton. The Tanzanian Government announced a reorganization in the development system for diamond, gold, etc. in July 1987, making it possible for developers to retain 70 percent of sales, for a policy of increasing the incentive for development.

(4) Tourism

Tanzania has great tourism resources such as Kilimanjaro, with the potential to exceed coffee, cotton, etc. in foreign currency earnings. Because of such matters as inexpertness in hotel management, tourists from foreign countries decreased from 84,000 people in 1980 to 58,000 in 1985, with revenues dropping from 18 million dollars to 10 million, but as management of 16 hotels was consigned to foreign hotel chains in 1986 the occupancy rate rose from 40 percent in 1985 to 60 percent in 1986 and improvement is being made.

(5) Fisheries

Tanzania has 58,000 $km^2$ of water area including rivers and streams, and coastal waters, while in the Indian Ocean there is a sea area of 64,000 $km^2$ having fisheries potential.

The present situation in catch is that only about 40,000 tons are being made against a potential of 10,000 tons in marine products while at Lake Tanganyika, the catch has been only about 60,000 tons against an annual potential of 300,000 tons. It is said that Lake Victoria also has a potential of 200,000 tons annually.

The greatest reason for the poor showing in the fisheries industry is thought to be the shortages in fishing nets, motors, etc. due to foreign currency restrictions.

## 2.5 Energy Resources

### 2.5.1 Coal

Reserves of coal are estimated to exceed one billion tons.

It is said that the quality of this coal is that of extremely low sulfur content, but the ash content is very high, and it is suspected that the reason for the high fuel cost at colliery of the Kiluwa Thermal Power Development Project (100 MW) listed in the long-range electric power development plans is the effect of ash content. At present, coal field development on a scale of 500,000 tons annually is being carried out by the Mining Development Corporation (STAMICO).

### 2.5.2 Natural Gas

Since the discovery of the Songosongo Gas Field offshore in the Indian Ocean, there has been active exploration going on for natural gas. The greater part of the natural gas is planned for use at fertilizer plants and in manufacturing, with 61 bcf corresponding to 8.4 percent considered possible to be used for electric power. A large gas field has been additionally discovered offshore in the Indian Ocean 40 km south of Dar Es Salaam and investigations have just been started.

Reserves of both and feasibilities of development will probably become definite in the 1990s, but they are presently unconfirmed.

### 2.5.3 Water Power

The hydroelectric potential of Tanzania is estimated to be 38 million kW with an annual effective energy production of approximately 190 billion kWh. Development already carried out consists of 3 sites, 46.5 MW, on the Pangani River and 2 sites, 284 MW, on the Great Ruaha River, for a total of 330.5 MW and annual energy production of 1,653 GWh. This is less than 1 percent of the hydroelectric potential, and so water power is an important energy resource of the future for this country.

## 2.6 Transportation and Telecommunication

Transportation network in Tanzania is composed of road for an extension of 82,000 km; railroad for an extension of 3,610 km; Ports of Dar Es Salaam, Tanga, and Mutowara all facing to the Indian Ocean; Ship transportation in Lakes Tanganyika and Victoria; and airway network of 60 local airports in addition to international airports in Dar Es Salaam and Kilimanjaro.

However, situation of transportation network is immature because the Government has been adopting an economic policy based on self-sufficiency. Thus only 4% of the road in the country is paved. Therefore, an extension of 18,000 km for the first and second class national road can be deemed as trunkroad for transportation.

Number of vehicles in Tanzania was 5,000 in 1976, but it increased to 300,000 including official cars.

Situation of telecommunication has also been immature. As of the end of 1988, number of telephones is 130,000.

Number of circuit is 81,214, 24% of which are operated manually. There are 91,000 applications for new telephones. Current number of telex subscription is 1,400, still there are 2,400 potential subscribers.

## 2.7 Environment

### 2.7.1 Natural Environment

Nature preservation is an important problem culturally and economically in Tanzania, and 11 percent of the territorial area has been designated for national parks and is strictly protected. Also, 16 percent of the land has been designated as game refuges and hunting reserves, while in addition, there are 134,000 $km^2$ of preserved forests. These restrictions or designations were established for the purposes of proper utilization of natural resources and protection of existing rights, and there are various restrictions placed on agricultural cultivation, hunting and forest clearance, land use, etc.

### 2.7.2 Social Environment

The total population of Tanzania was about 22.5 million with the annual average population growth rate 3.4 percent, but the average life expectancy is only 52 years. The infant mortality rate is approximately 10 times that of developed nations, and it may be comprehended from the fact average life expectancy is short that the sanitary, medical, and nutritional conditions of the nation are not good.

Formation of villages has progressed with the village settlement policy based on the socialism which started out in 1971, but there has been hardly any increase in recent years, and there is a trend for the population to become concentrated in cities.

Tanzania is divided into 19 regions, and Swahili is the language in common.

# Chapter 3 GENERAL STATE OF THE PROJECT AREA AND SURROUNDINGS

Chapter 3

# GENERAL STATE OF THE PROJECT AREA AND SURROUNDINGS

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# Chapter 3 GENERAL STATE OF THE PROJECT AREA AND SURROUNDINGS

## 3.1 Outline of Landform and Meteorology

The Rufiji River Basin in which this project area is situated has a catchment area of 177,000 $km^2$ and is one of the largest rivers in Tanzania. The Kihansi River on which the Project is located is a tributary of the Kilombero River of the Rufiji River System, and the catchment area of the dam site is only 590 $km^2$, but the annual inflow is approximately 500 million tons, and the Kihansi is a river with a stable discharge duration.

Upstream parts of the Kihansi River comprise a hill area, and the river channel down to EL. 1,500 m is gently-sloped and meanders, but the gradient below EL. 1,400 m abruptly changes for the river to become a swift stream, and although the distance down to the Kilombero Plain of elevation 300 m is only 5 km, the head is as much as 1,000 m. This steeply-sloped river channel exists because the river travels straight down the Uzungwa Mountainland. Due to the influence of this mountainland, annual average runoffs differ greatly between the upstream part (2.5 $m^3/s/100\ km^2$) and the downstream part (3.5 $m^3/s/100\ km^2$).

Almost all of Tanzania including the project area has a tropical savannah climate, with a clear distinction between rainy season and dry season, and although there is a spread between 1,000 mm and 1,800 mm in rainfall in this region depending on the location, it is as a whole a rainy area of Tanzania.

The Upper Kihansi dam and powerhouse are located 80 km south of the city of Iringa in the central south part of Tanzania. Lower Kihansi Dam is located at a point 3 km farther south, and the Lower Kihansi powerhouse 4 km still farther to the south. The waterway route for this crosses the Uzungwa Mountainland so that the powerhouse is located at the foot of the Uzungwa Scarp, at EL. 300 m. Further downstream is the Kilombero Marshland, and the Tazara Railway and a provincial road run between the foot of the scarp and the Marshland. The Lower Kihansi powerhouse is located approximately 20 km west of Chita Station of this Tazara Railway.

### 3.2 Natural and Social Environments

People engaged in slash-and-burn agriculture on the mountain slopes other than forest reservations on the right-bank side of the Kihansi River have built villages there and are making a livelihood on a self-sufficiency basis. The principal agricultural products are staple foods such as beans, maize, and sweet potato, and with plentiful rain, cultivation is possible throughout the year. On the other hand, there are hardly any people living downstream of the Lower Kihansi dam site because of the rugged topography.

This region is located in the Usagar Orogenic Belt bordering the southeast part of the Tanzanian Plate and the constituent basement rocks may be divided into gneisses and granites. Of these, gneisses are widely distributed, and dolerite dykes are predominant in this basin. There are distributions of river deposits at some places along the Kihansi River, but hardly any are seen in the downstream area. At parts of high elevation rainforest soils and lateritic soils overlie the basement rock.

Comparatively thick weathered layers cover the part upstream of the Lower Kihansi dam site, but there are few faults, with only two having been confirmed in the vicinity of the Upper Kihansi dam site.

Landslide topographies have not been found according to site reconnaissances and aerial photo interpretations, but at the steep slopes on the upstream side of the Lower Kihansi powerhouse site there are numerous scars of small scale seen.

The downstream part of the Kihansi River, as described previously, consists of a continuous series of waterfalls as the river runs down a stretch of steeply-sloped topography, among which Kihansi Falls is a waterfall of grand scale with a drop of 200 m, but because of the complex topography, it cannot be approached, and thus cannot be made into a tourist attraction.

Water quality investigations have been made at this river, and as a result, it has been confirmed that the water is acidic (pH 5.0 - 6.0). Accordingly, there are hardly any fishes found to inhabit the upstream part and only amphibian frogs and crustacean crabs have been caught.

Meanwhile, the existence of rare species of land animals and birds has not yet been reported. There are no cultural assets of importance archaeologically or historically at the project site and its surroundings, while neither are there water utilization facilities and public facilities to be objects of compensation.

# Chapter 4 CURRENT STATUS OF TANZANIAN ELECTRIC UTILITY

Chapter 4

# CURRENT STATUS OF TANZANIAN ELECTRIC UTILITY

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# Chapter 4 CURRENT STATUS OF TANZANIAN ELECTRIC UTILITY

## 4.1 Electric Utility Industry of Tanzania

The electric utility service of Tanzania is provided by the Tanzania Electric Supply Company, Limited (TANESCO), a corporation fully subsidized by the Government of Tanzania. The head office of TANESCO is located in Dar Es Salaam, and the Company operates power generation, transmission and distribution service in Tanzania, and also supply power to Zanzibar. The organization chart of TANESCO is given in Fig. 4-1.

## 4.2 Power Supply Facilities

### 4.2.1 Power Transmission and Substation Facilities

The power system of Tanzania consists of a nation-wide Grid System and a number of independent systems. The interconnection of systems are in progress, and most of the major cities of the nation have been incorporated into the Grid System when the interconnection was extended to the north-western part of the country in 1988. In the areas where the Grid System is not accessible, the electric power is supplied by isolated power system of each area. It is difficult to incorporate economically such isolated power systems into the Grid System, since they are at far distance from the Grid System and their sizes are small. In the ACRES Report, it is stipulated that the following small supply areas can be economically interconnected to the Grid System.

a) Interconnection from Mbeya to Tukuyu

b) Interconnection from Dodoma, through Chamwino, to Mpwapa

c) Branching an existing transmission line at Makambako and connecting Makambako to Njombe.

The total generating capacity of TANESCO was 471 MW as of the end of 1988. Approximately 91%, or 430 MW of generating facilities, belong to the Grid System.

The Grid System, as shown in Fig. 4-2, mainly consists of 220 kV and 132 kV transmission lines, and 66 kV and 33 kV lines are used in some areas. The main distribution systems supply power with 33 kV and 11 kV distribution lines. The transmission lines and facilities of substations of the Grid System are given in Table 4-1 and Table 4-2.

The 220 kV transmission lines form the backbone of the Grid System, and these lines connect Kidatu and Mtera Power Stations, the major power sources, to Dar Es Salaam to the east, Mbeya to the southwest, and Mwanza on the region of Victoria Lake to the north. The total length of 220 kV lines is 1,598 km, and all of them are single circuit lines.

132 kV lines run from Dar Es Salaam, pass the load centers on the eastern coast, and reach Arusha. Other 132 kV lines in the inland areas connect Shiyanga to Tabora, and Mwanza to Musoma. The total length of 132 kV lines is 1,345 km, and all of them are single circuit lines.

Fig. 4-1 Organization of TANESCO

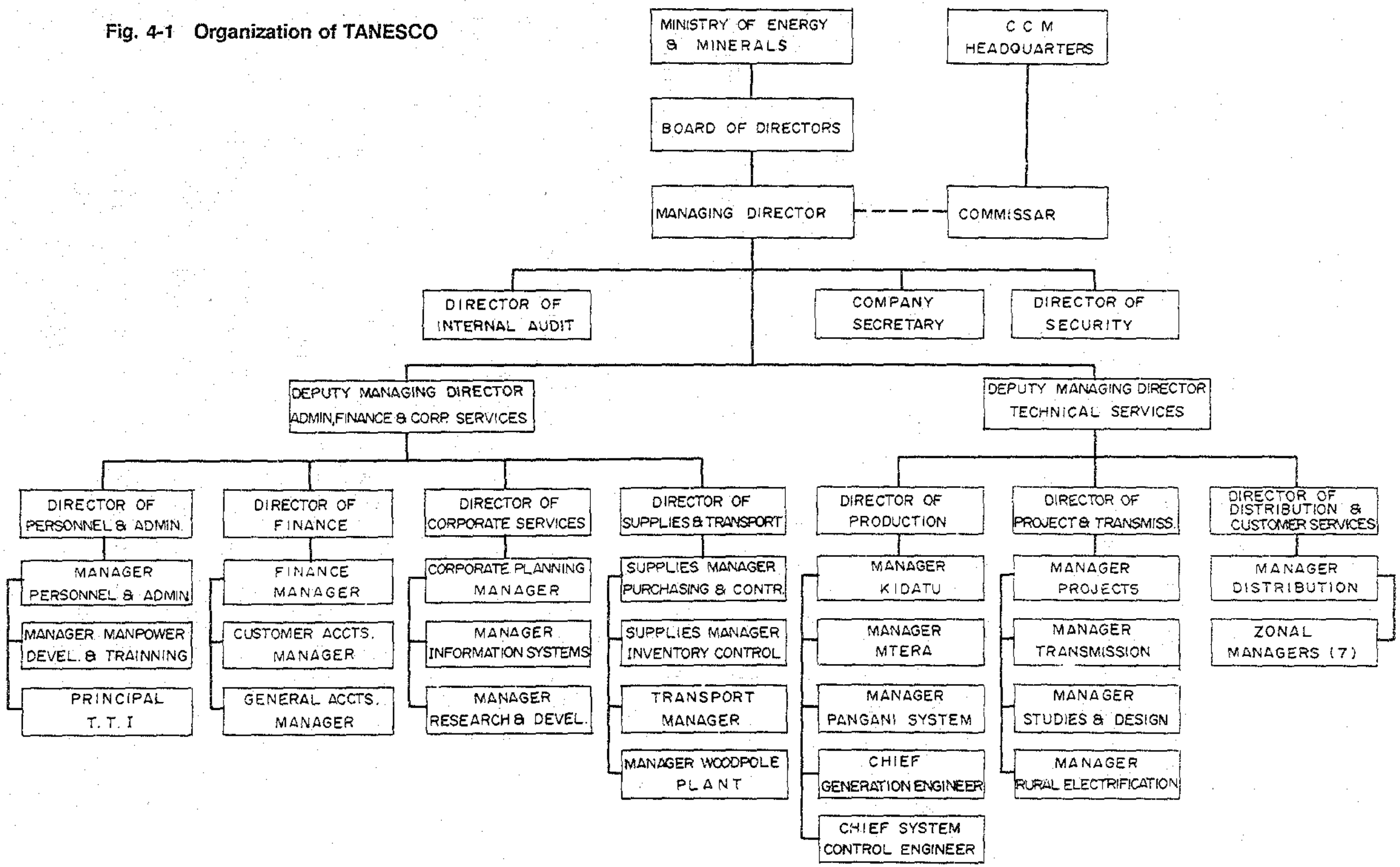
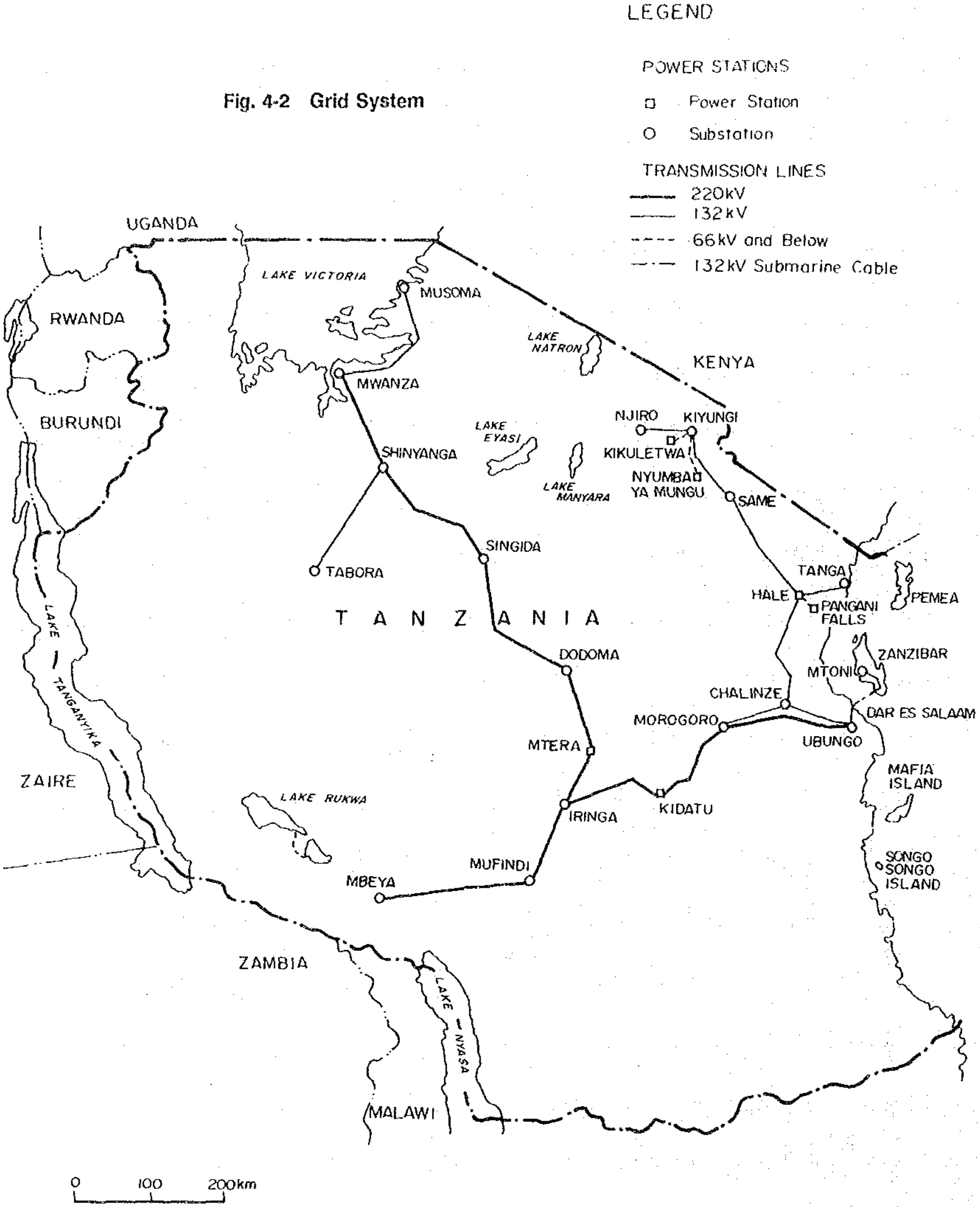


**Fig. 4-2 Grid System**




Note: Information is as of mid 1989

Table 4-1 Characteristics of Transmission Lines

| Transmission line | Voltage (kV) | Circuit (No.) | Distance (km) | Conductor | |
|---|---|---|---|---|---|
| | | | | Type | Code name |
| Kidatu-Morogoro | 220 | 1 | 128 | ACSR | Bluejay |
| Morogoro-Ubungo | 220 | 1 | 172 | ACSR | Bluejay |
| Kidatu-Iringa | 220 | 1 | 160 | ACSR | Bison |
| Iringa-Mufindi | 220 | 1 | 130 | ACSR | Bison |
| Mufindi-Mbeya | 220 | 1 | 220 | ACSR | Bison |
| Iringa-Mtera | 220 | 1 | 100 | ACSR | Bison |
| Mtera-Dodoma | 220 | 1 | 138 | ACSR | Bison |
| Dodoma-Singida | 220 | 1 | 211 | ACSR | Bison |
| Singida-Shinyanga | 220 | 1 | 200 | ACSR | Bison |
| Shinyanga-Mwanza | 220 | 1 | 139 | ACSR | Bison |
| Ubungo-Ilala | 132 | 1 | 11 | ACSR | Wolf |
| Ubungo-Chalinze | 132 | 1 | 97 | ACSR | Wolf |
| Chalinze-Morogoro | 132 | 1 | 82 | ACSR | Wolf |
| Chalinze-Hale | 132 | 1 | 175 | ACSR | Wolf |
| Hale-Same | 132 | 1 | 170 | ACSR | Wolf |
| Same-Kiyungi | 132 | 1 | 100 | ACSR | Wolf |
| Kiyungi-Arusha | 132 | 1 | 118 | ACSR | Wolf |
| Hale-Tanga | 132 | 1 | 60 | ACSR | Wolf |
| Ubungo-Ras Kiromoni | 132 | 1 | 20 | ACSR | Wolf |
| Ras Kiromoni-Ras Fumba | 132 | 1 | 38 | Submarine Cable | |
| Ras Fumba-Mtoni | 132 | 1 | 21 | ACSR | Wolf |
| Mwanza-Musoma | 132 | 1 | 250 | ACSR | Wolf |
| Shinyanga-Tabora | 132 | 1 | 203 | ACSR | Wolf |

Source: ELECTRICAL PARAMETERS FOR 220kV AND 132kV GRID, TANESCO

## Table 4-2 Facilities of Substations of the Grid System

| Substation | Transformer | | | | Reactor | | | Capacitor | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Voltage (kV) | Type | Capacity (MVA) | Unit (No.) | Voltage (kV) | Capacity (MVA) | Unit (No.) | Voltage (kV) | Capacity (MVA) | Unit (No.) |
| 220kV | | | | | | | | | | |
| Ubungo | 220/132/33 | Auto | 150 | 2 | | | | | | |
| | 132/33/11 | Three winding | 50 | 2 | 33 | 10 | 1 | | | |
| Morogoro | 220/132/33 | Auto | 90 | 1 | | | | | | |
| Kidatu | 220/33 | Three winding | 22.5 | 2 | | | | | | |
| Iringa | 220/33 | Three winding | 22.5 | 2 | 33 | 10 | 2 | | | |
| Mufindi | 220/33/11 | Three winding | 35 | 2 | 11 | 30 | 1 | | | |
| Mbeya | 220/33 | Three winding | 30 | 2 | | | | | | |
| Dodoma | 220/33 | Three winding | 20 | 2 | 220 | 20 | 1 | | | |
| | | | | | 33 | 10 | 1 | | | |
| Singida | 220/33 | Three winding | 20 | 2 | 220 | 20 | 1 | | | |
| | | | | | 33 | 10 | 1 | | | |
| Shinyanga | 220/132/33 | Auto | 60 | 2 | 33 | 10 | 2 | | | |
| Mwanza | 220/132/33 | Auto | 60 | 2 | 33 | 10 | 1 | | | |
| 132kV | | | | | | | | | | |
| Ilala | 132/33/11 | Three winding | 45 | 2 | | | | | | |
| Mtoni | 132/33 | Three winding | 20 | 2 | | | | | | |
| Chalinze | 132/33 | Three winding | 5 | 1 | | | | | | |
| Hale | 132/33 | Two winding | 15 | 2 | | | | | | |
| Tanga | 132/33 | Two winding | 10 | 2 | | | | | | |
| Same | 132/33 | Three winding | 6.66 | 1 | | | | | | |
| Kiyungi | 132/66/11 | Three winding | 20 | 1 | | | | | | |
| | 66/33 | Three winding | 5 | 2 | | | | | | |
| Njiro (Arusha) | 132/33 | Three winding | 20 | 2 | | | | | | |
| Musoma | 132/33 | Two winding | 15 | 2 | | | | | | |
| Tabora | 132/33 | Two winding | 15 | 2 | | | | | | |

Sourse: ELECTRICAL PARAMETERS FOR 220kV AND 132kV GRID, TANESCO

### 4.2.2 Generating Facilities

The generating facilities connected to the Grid System are given in Table 4-3. The major power source for the Grid System is hydroelectric, which accounts for approximately 79% of the total generating capacity of 418 MW, or 329 MW. The hydroelectric power stations which have a dam for annual regulation are limited to those on Pangani river system and Great Ruaha river system, and the operation of the Grid System are mainly implemented by the power stations of these two river systems. In particular, the two hydroelectric power stations on Kidatu and Mtera on the Great Ruaha river system have a combined rated capacity corresponding to 86% of the total hydroelectric power, and supply the majority of power consumed in the Republic of Tanzania. Nyumba ya Mungu Power Station on Pangani river system was rehabilitated in July, 1989.

In isolated power systems, diesel power stations are mainly used, but some small hydroelectric power stations and coal fired thermal stations are also operated.

## 4.3 Features of Existing Power Systems

The power systems are controlled by Ubungo Load Dispatching Center which is located at an outskirts of Dar Es Salaam. the power of the system is mainly supplied by hydroelectric power stations, and thermal power stations are used as reserve power sources.

While the major power sources, such as Kidatu and Mtera Power Stations, are located in the central part of Tanzania, the load centers are concentrated to the eastern and northern areas. This makes heavy load flowing from Kidatu and Mtera to Arusha, located at the end of the Grid

System, and voltage drop in 132 kV power system between Ubungo and Arusha is a matter of concern. The 220 kV lines running from Kidatu to southwest and northwest areas are lightly loaded, and no voltage problem is encountered.

All transmission lines are single circuit lines, and there are few loops. This makes it possible to introduce a wide blackout in case a line is lost by lightning strokes or other failures.

Table 4-3 Generating Facilities of the grid System (January 1989)

| Power station | Installed Capacity (MW) | Units (No.) | Total Installed (MW) | Rated Capacity (MW) | Type | Commissioning year |
|---|---|---|---|---|---|---|
| (Hydro) | | | | | | |
| Kikuletwa | 0.6 | 1 | | | | 1950 |
| | 0.4 | 1 | | | | 1937 |
| | 0.16 | 1 | 1.16 | 1.16 | | 1935 |
| Nyumba Ya Mungu | 4.0 | 2 | 8.00 | 8.00 | | 1969 |
| Hale | 10.5 | 2 | 21.00 | 21.00 | | 1964 |
| Pangani Falls | 2.5 | 3 | | | | 1934 |
| | 5.0 | 2 | 17.50 | 12.50 | | 1934 |
| Kidatu | 51.0 | 4 | 204.00 | 204.00 | | 1975/1980 |
| Mtera | 40.0 | 2 | 80.00 | 80.00 | | 1988 |
| Tosamaganga (Iringa) | | | 1.22 | 1.22 | | 1951 |
| Mbalizi (Mbeys) | | | 0.34 | 0.34 | | 1958 |
| Total hydro | | | 333.22 | 328.22 | | |
| (Thermal) | | | | | | |
| Arusha | | | 3.70 | 2.50 | Diesel | 1956 |
| Zuzu (Dodoma) | | | 2.58 | 2.58 | Diesel | |
| Iyunga (Mbeya) | | | 15.38 | 13.50 | Diesel | 1982 |
| Musoma | | | 7.35 | 7.35 | Diesel | 1979/1985 |
| Nyakato (Mwanza) | | | 13.50 | 12.00 | Diesel | 1978 |
| Ubungo (D.S.M) | | | 40.50 | 30.50 | Diesel | 1963 |
| Ubungo (D.S.M) | | | 14.77 | 12.5 | Gas turbine | 1973 |
| Shinyanga | | | 2.44 | 2.33 | Diesel | 1978 |
| Singida (new) | | | 1.28 | 1.28 | Diesel | 1965/1983 |
| Tabora | | | 5.08 | 4.98 | Diesel | 1983 |
| Total thermal | | | 106.58 | 89.52 | | |
| Total grid system | | | 439.80 | 417.74 | | |

Source: Review of 1985 Power Sector Development Plan, TANESCO/ACRES, 1989

## 4.4 Power Supply and Demand

### 4.4.1 Electric Power Demand

The energy consumption data in each area in the Grid System, for the years 1987 and 1988, are presented in Table 4-4. The total energy consumption in the Grid System was 1,123 GWh in 1988. This energy consumption is expected to grow further in 1989, as the load centers in the northern area is to be connected to the Grid System.

In the Grid System, the energy consumption in Dar Es Salaam has the largest share of approximately 51%. When the loads connected to the 132 kV lines reaching Arusha are added, approximately 86% of the total power consumption is concentrated to this eastern area.

Speaking of the maximum power demand in the Grid System in 1988, the demand of Dar Es Salaam was 100 MW, which was equivalent to the half amount of the peak generation of the Grid System.

### 4.4.2 Energy Consumption by Categories of Customers

The data of energy consumption of each category of customers, for the period from 1980 to 1984, are given in Table 4-5. The proportion of energy consumption of each category of customers in 1984 is given below, and it can be seen that the industrial loads account for roughly half of the total consumption.

| | |
|---|---|
| Domestic | 26.2% |
| Commercial | 19.8% |
| Light Industrial | 4.6% |
| Industrial | 47.1% |

| | |
|---|---|
| Public Lighting | 0.5% |
| Sales to Zanzibar | 1.8% |

## Table 4-4 Electricity Consumption of the Grid System

Energy Consumption

(GWh)

| Region | 1987 | 1988 |
|---|---|---|
| Arusha | 73.74 | 77.68 |
| Moshi | 78.19 | 86.11 |
| Tanga | 103.98 | 103.90 |
| Dar es Salaam | 559.55 | 576.57 |
| Zanzibar | 45.16 | 42.95 |
| Morogoro | 50.78 | 78.31 |
| Iringa/Mufindi | 66.88 | 74.11 |
| Dodoma/Singida/Shinyanga | 27.73 | 37.56 |
| Mbeya | - | 46.09 |
| Total | 1,006.01 | 1,123.28 |

Peak Load

(MW)

| Region | 1987 | 1988 |
|---|---|---|
| Arusha | 16.8 | 16.6 |
| Moshi | 12.9 | 13.5 |
| Tanga | 18.0 | 23.7 |
| Dar es Salaam | 92.8 | 100.2 |
| Zanzibar | 9.7 | 11.0 |
| Morogoro region | 12.6 | 13.2 |
| Iringa | 3.1 | 3.2 |
| Dodoma | 5.0 | 5.2 |
| Singida | 1.8 | 1.2 |
| Mufindi | 19.0 | 26.4 |
| Mbeya | 11.0 | 12.0 |

Source: TANESCO

Table 4-5 Sales of Electricity Split into Different Categories of Consumers (GWh)

| Category | 1980 | 1981 | 1982 | 1983 | 1984 |
|---|---|---|---|---|---|
| Domestic | 156.9 | 168.4 | 178.5 | 174.7 | 186.7 |
| Commercial | 155.7 | 151.9 | 139.7 | 129.8 | 141.0 |
| Light Industrial | 31.2 | 30.5 | 32.1 | 26.8 | 32.7 |
| Industrial | 387.9 | 395.0 | 353.7 | 328.7 | 336.4 |
| Public Lighting | 6.2 | 5.9 | 4.5 | 3.8 | 3.8 |
| Sales to Zanzibar | - | 38.7 | 28.7 | 29.4 | 13.0 |
| Total | 737.9 | 790.4 | 737.2 | 692.8 | 713.6 |

Source: TANESCO ANNUAL REPORT, 1984

#### 4.4.3 Power Generation

The energy generation and peak power generation of the Grid System for the period from 1980 to 1988 are illustrated in Table 4-6. The energy generation in the Grid System in 1988 accounted for 92% of the nation's total generation of 1,382 GWh, or 1,266 GWh, and the peak power generation of the system was 219 MW. The average growth of energy generation was 5.9% per annum for the period from 1980 to 1985, but the average growth rate increased to 10.3% for the period from 1986 to 1988 as the result of good economic condition owing to the Economic Recovery Programme (ERP). The average load factor was fairly high, being 64% for the period from 1984 to 1988.

The energy generation of each power station in the Grid System in 1988 is given in Table 4-7 and Fig. 4-3. The hydroelectric power accounts for 97% of the total generation. In particular, the Kidatu and Mtera of Great Ruaha river system supply approximately 87% of the total.

#### 4.4.4 Load Curve

Daily load curves in April of 1989 is presented in Fig. 4-4. The load factor calculated from the curve is fairly high, being approximately 75% on weekdays and 71% on holidays. In a weekday, the load starts to increase around 6 a.m., and reaches a peak at around 11 o'clock when the industrial loads become maximum. Then the load gradually decreases, and then rises again from around 17 o'clock when lighting loads pick up, and reaches the maximum value at around 20 o'clock. On holidays, there is no increase of load during daytime, but starts to increase at around 17 o'clock as on weekdays, and reaches the maximum value at around 21 o'clock. The trend of monthly peak load from 1986 to 1988 is illustrated in Fig. 4-5. The seasonal variation of the peak load is small, and peak load tends to increase in the latter part of a year, and increases every year.

## Table 4-6 Energy Generation of the Grid System

| Year | Units Generated (GWh) | Peak Generation (MW) | Annual Load Factor (%) |
|---|---|---|---|
| 1980 | 686.5 | 117.6 | 66.5 |
| 1981 | 715.3 | 124.0 | 65.9 |
| 1982 | 720.2 | 122.8 | 67.0 |
| 1983 | 740.1 | 127.8 | 66.1 |
| 1984 | 773.7 | 139.2 | 63.3 |
| 1985 | 914.9 | 176.4 | 59.2 |
| 1986 | 1,041.1 | 183.1 | 64.9 |
| 1987 | 1,168.6 | 200.3 | 66.6 |
| 1988 | 1,265.9 | 219.0 | 65.8 |
| 1980 - 1985 Growth Rate | 5.9 | | |
| 1986 - 1988 Growth Rate | 10.3 | | |
| 1984 - 1988 Average | | | 64.0 |

Source: POWER SECTOR IN TANZANIA 1986, TANESCO

## Table 4-7 Energy Generation by Power Stations

<Thermal>

| | Ubungo (D.E.S.) | Shinyanga | Nyakato (Mwanza) | Mwanza South | Zuzu (Dodoma) | Town P.S (Dodoma) | Iyunga (Mbeya) | Singida | Arusha | Thermal Total (MWh) |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 242 | 54 | | | 6 | 1 | 50 | 1 | 554 | 908 |
| February | 142 | 8 | | | 23 | 1 | 90 | 4 | 667 | 936 |
| March | 19 | 8 | | | 12 | 3 | 105 | 2 | 783 | 931 |
| April | 1 | 74 | | | 176 | 45 | 180 | 58 | 397 | 932 |
| May | | 332 | | | 57 | 7 | 104 | 332 | 470 | 1,302 |
| June | | 432 | | | 16 | 3 | 371 | 146 | 728 | 1,696 |
| July | 210 | 220 | | | 50 | 6 | 1,324 | 41 | 679 | 2,529 |
| August | 265 | 54 | | | 176 | 13 | 425 | 88 | 715 | 1,736 |
| September | 48 | 18 | | | 43 | 10 | 13 | 27 | 653 | 812 |
| October | 79 | 141 | | | 50 | | 28 | 19 | 496 | 813 |
| November | 217 | 27 | | 18 | 16 | 3 | 124 | 17 | 552 | 975 |
| December | 68 | 56 | 17 | 41 | 7 | 11 | 21 | 5 | 435 | 660 |
| Total | 1,290 | 1,424 | 17 | 59 | 632 | 104 | 2,835 | 739 | 7,128 | 14,229 |

<Hydro>

| | Kidatu | Mtera | Hale | Pangani Falls | Nyumba ya Mungu | Kikuletwa | Tosamaganga | Hydro Total | Total |
|---|---|---|---|---|---|---|---|---|---|
| January | 88,758 | | 5,926 | 4,921 | 2,398 | 360 | | 102,364 | 103,272 |
| February | 85,610 | | 5,038 | 4,439 | 2,089 | 305 | | 97,481 | 98,417 |
| March | 96,172 | | 5,139 | 4,385 | 2,188 | 350 | 223 | 108,458 | 109,389 |
| April | 80,698 | | 8,593 | 4,630 | 2,543 | 369 | 179 | 97,012 | 97,944 |
| May | 78,354 | 9,483 | 6,273 | 4,588 | 2,460 | 379 | 238 | 101,776 | 103,077 |
| June | 59,093 | 24,634 | 5,617 | 4,235 | 2,468 | 169 | 223 | 96,439 | 98,135 |
| July | 65,705 | 25,688 | 5,081 | 4,277 | 2,248 | 124 | 151 | 103,274 | 105,803 |
| August | 71,986 | 23,389 | 5,434 | 4,234 | 3,066 | 122 | 80 | 108,310 | 110,046 |
| September | 68,041 | 23,970 | 6,622 | 4,524 | 3,003 | 114 | | 106,273 | 107,086 |
| October | 69,710 | 25,286 | 5,977 | 4,443 | 3,079 | 122 | 244 | 108,861 | 109,674 |
| November | 72,062 | 23,450 | 5,637 | 4,410 | 2,926 | 121 | 194 | 108,799 | 109,774 |
| December | 70,762 | 29,366 | 5,096 | 4,112 | 2,924 | 114 | 294 | 112,669 | 113,329 |
| Total | 906,951 | 185,266 | 70,432 | 53,198 | 31,394 | 2,649 | 1,825 | 1,251,715 | 1,265,945 |

Note: Mtera was commissioned in May 1988

Fig. 4-3 Energy Supply of the Grid System (1988)


Note: Mtera was commissioned in May 1988

Fig. 4-4 Hourly Load Curve

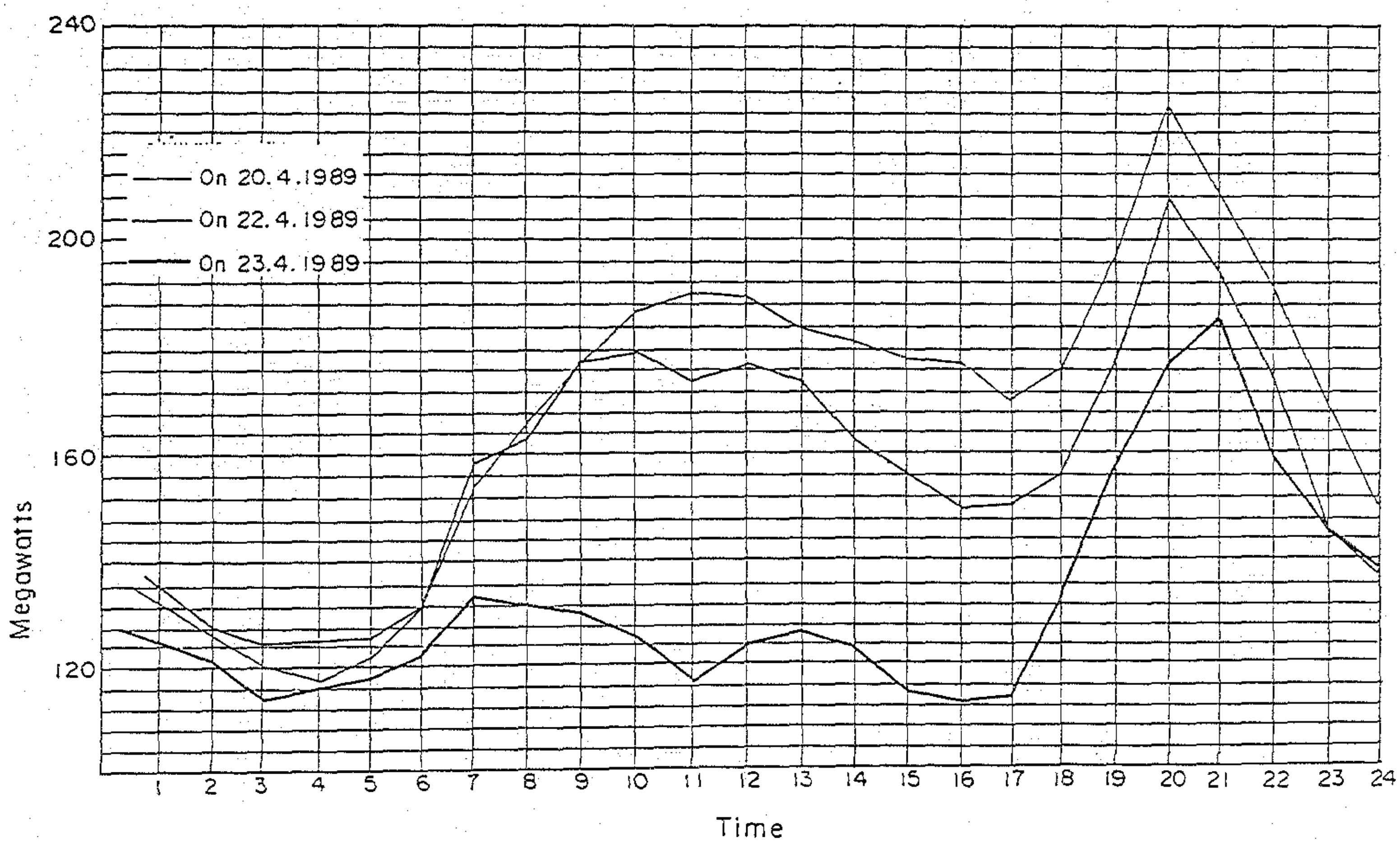
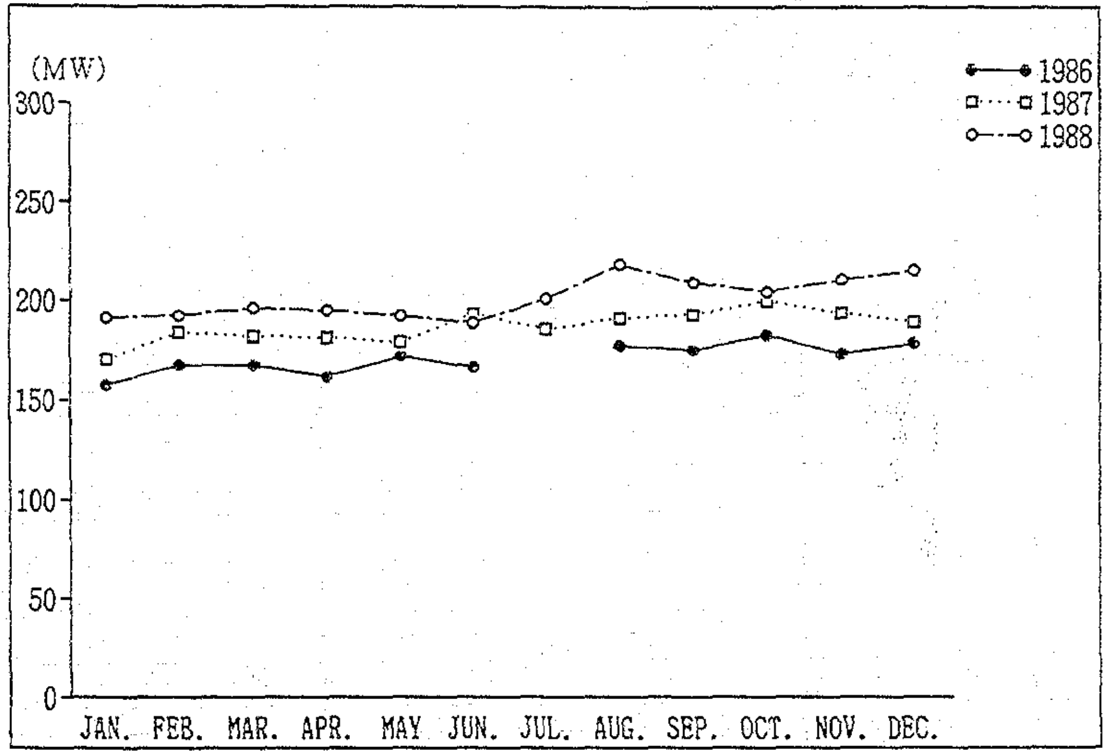


Fig. 4-5 Monthly Maximum Load of the Grid System



# Chapter 5 POWER DEMAND FORECAST AND ELECTRIC POWER DEVELOPMENT PLAN

Chapter 5

# POWER DEMAND FORECAST AND ELECTRIC POWER DEVELOPMENT PLAN

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# Chapter 5 POWER DEMAND FORECAST AND ELECTRIC POWER DEVELOPMENT PLAN

## 5.1 Economic Status

The past trend of the real gross domestic products (GDP) of Tanzania is given in Table 5-1. As we can see from the past GDP data, the economy of Tanzania steadily grew until 1979. After this, the growth stagnated, and little increase in GDP was observed. This was because the economy of Tanzania was gravely affected by the oil price escalation, similarly to other nations of the world.

The conditions of the economy of Tanzania was improved by the Economic Recovery Programme (ERP) that was started in 1986 by an agreement with the World Bank and completed in June 1989. According to the economic review for 1988/89 and the development plan for 1989/90 reported to the House , the productions increased in the past 3 years except in the mining sector. The GDP growth increased from 3.6% in 1986 to 4.1% in 1988. The average annual growth for the period from 1986 to 1988 was 3.9%. It is expected that the growth rate of 4.5% which is the target of ERP will be reached in 1990.

The GDP of each sector is given in Table 5-2. The production in agricultural sector, which accounts for a majority of GDP, was good, owing to ERP and favorable weather conditions. The production in the industrial sector was not so good because sufficient raw materials and parts could not be procured due to foreign currency shortage. Tanzania spent 109 million dollars, which was a quarter of foreign currency income, for import of oil in 1988. For this reason, the electric utility sector of Tanzania is trying to use as little oil as possible, and the Grid System is supplied mainly by hydroelectric power.

The population growth rate of Tanzania was 2.8% per annum according to the census of 1988.

Table 5-1 Energy Generation and Gross Domestic Product

| Year | Energy generation (GWh) | (%) 1) | GDP at 1980 price (MTShs) | (%) | Price of petroleum 2) (US$/Barrel) |
|---|---|---|---|---|---|
| 1970 | 393.02 | – | 26,022 | – | 1.30 |
| 1971 | 425.50 | 8.3 | 27,110 | 4.2 | 1.65 |
| 1972 | 471.88 | 10.9 | 28,933 | 6.7 | 1.90 |
| 1973 | 515.11 | 9.2 | 29,817 | 3.1 | 2.70 |
| 1974 | 535.96 | 4.0 | 30,562 | 2.5 | 9.76 |
| 1975 | 557.62 | 4.0 | 32,301 | 5.7 | 10.72 |
| 1976 | 590.95 | 6.0 | 38,994 | 20.7 | 11.51 |
| 1977 | 619.02 | 4.7 | 40,092 | 2.8 | 12.40 |
| 1978 | 682.41 | 10.2 | 41,258 | 2.9 | 12.70 |
| 1979 | 757.36 | 11.0 | 41,768 | 1.2 | 17.26 |
| 1980 | 792.10 | 4.6 | 42,118 | 0.8 | 28.67 |
| 1981 | 823.78 | 4.0 | 41,654 | -1.1 | 32.50 |
| 1982 | 829.96 | 0.8 | 42,192 | 1.3 | 33.47 |
| 1983 | 857.88 | 3.4 | 42,008 | -0.4 | 29.31 |
| 1984 | 922.71 | 7.6 | 43,049 | 2.5 | 28.47 |
| 1985 | 1,017.42 | 10.3 | 42,952 | -0.2 | |
| 1975 -1985 Average growth rate | | 6.2 | | 2.9 | |

Note: 1) Rate of growth (Over preceding year)
2) Saudi Arabia (Ras Tanura)
Source: International Financial Statistics, IMF
Power Sector Development Plan, ACRES/TANESCO

Table 5-2 Gross Domestic Product by Kind of Economic Activity at Current Prices (Million Tshs)

| | | 1986 | (%) | 1987 | (%) |
|---|---|---|---|---|---|
| 1. | Agriculture, Forestry, Fishing and Hunting | 84,153 | 57.8 | 120,941 | 59.1 |
| 2. | Mining and Quarring | 474 | 0.3 | 563 | 0.3 |
| 3. | Manufacturing | 7,417 | 5.1 | 9,044 | 4.4 |
| 4. | Electricity and Water | 2,096 | 1.4 | 2,259 | 1.1 |
| 5. | Construction | 3,257 | 2.2 | 3,658 | 1.8 |
| 6. | Whole sale and retail trade hotels and restaurants | 18,851 | 12.9 | 27,453 | 13.4 |
| 7. | Transport and Communication | 9,863 | 6.8 | 16,794 | 8.2 |
| 8. | Finance, Insurance, Real Estate and Business services | 8,127 | 5.6 | 11,062 | 5.4 |
| 9. | Public Administration and other services | 11,340 | 7.8 | 12,771 | 6.2 |
| 10. | Total Industries | 145,578 | 100.0 | 204,545 | 100.0 |
| 11. | Imputed bank services charge | -2,544 | | -6,444 | |
| 12. | GDP at factor cost | 143,034 | | 198,101 | |

Source: TANESCO

## 5.2 Analysis of Power Demand

The trend growth rate of real GDP and electric energy generation are illustrated in Fig. 5-1. The average annual growth rate of electric energy generation for the 10 years from 1975 to 1985 is 6.2%. Although real GDP grew little from 1979 to 1988, the electric energy generation grew steadily. When we analyze the relation between GDP growth rate and electric energy generation growth rate for the period from 1976 to 1985, we obtain the following equation.

$$y = 0.61x + 5.61 \qquad <1>$$

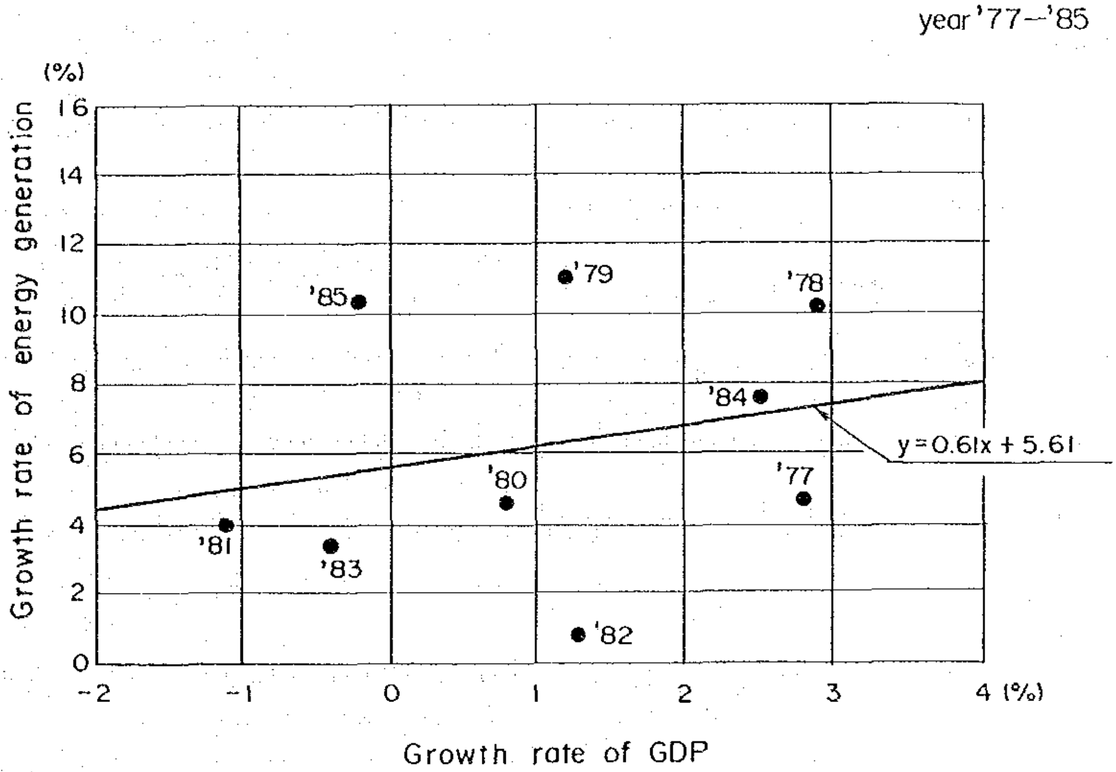
Where:

$y$ = Energy Generation Growth Rate (%)
$x$ = GDP Growth Rate (%)

According to Equation <1>, the electric energy generation grew at a rate which is 0.6 times the GDP growth rate. While the contribution of the agricultural sector is large in GDP, the contribution of the industrial sector is large in energy generation, and this makes the elasticity of energy generation to GDP relatively small. On the other hand, we can observe that electric energy generation grew at a rate of 5.6 even during the period when the GDP growth rate was zero. This was because the electric power is mainly consumed in domestic and commercial sectors in Tanzania, and since the rate of electrification is still low, the electric power consumption grew even during the period the aggregate national production was reduced.

As the electrification rate of Tanzania is still low, it is expected that the electric energy demand will grow only if the supply capacity is expanded. The Tanzanian Government is promoting electrification of rural areas in dealing with the shortage of local fuel resources caused by the deforestation, and this policy will also increase the electric power demand.

**Fig. 5-1 Growth Rate of GDP and Energy Generation**



## 5.3 Power Demand Projection

As discussed in the previous section, the average electric energy generation in the period from 1975 to 1985 was 6.2%. When we substitute the GDP growth rate in Equation <1> with the value of 4.5%, which is the target of ERP, the electric energy generation growth rate of 8.4% is obtained. It is not practical to assume that such a high growth rate of electric energy generation will continue for a long time. The part of energy consumption which is not proportional to GDP will gradually decrease as electrification rate is increased and the elasticity of energy generation to GDP will increase in future as industrialization progress.

The growth rate of generation in the Grid System has been fairly high in recent years, reflecting the strong economic activities. The average growth rate for the period from 1986 to 1988 was 10.3% as given in Table 4-6. We do not expect that such a high growth rate will be maintained for a long time, but the growth rate in near future will exceed 6.2%. So we assumed that the electric energy demand growth rate up to 1990 will be 8.4%, which is a value consistent to the current composition of electrical loads.

The relation between per capita GDP (1980 prices) and per capita energy generation from 1979 to 1985 of some countries of equatorial area in Asia and Africa are given in Fig. 5-2.

When we analyze the relation between per capita GDP and per capita energy generation in Fig. 5-2, we obtain the following equation.

$$y = 5.99 \times 10^{-4} X^2 + 6.73 \times 10^{-3} X + 35.1 \qquad \langle 2 \rangle$$

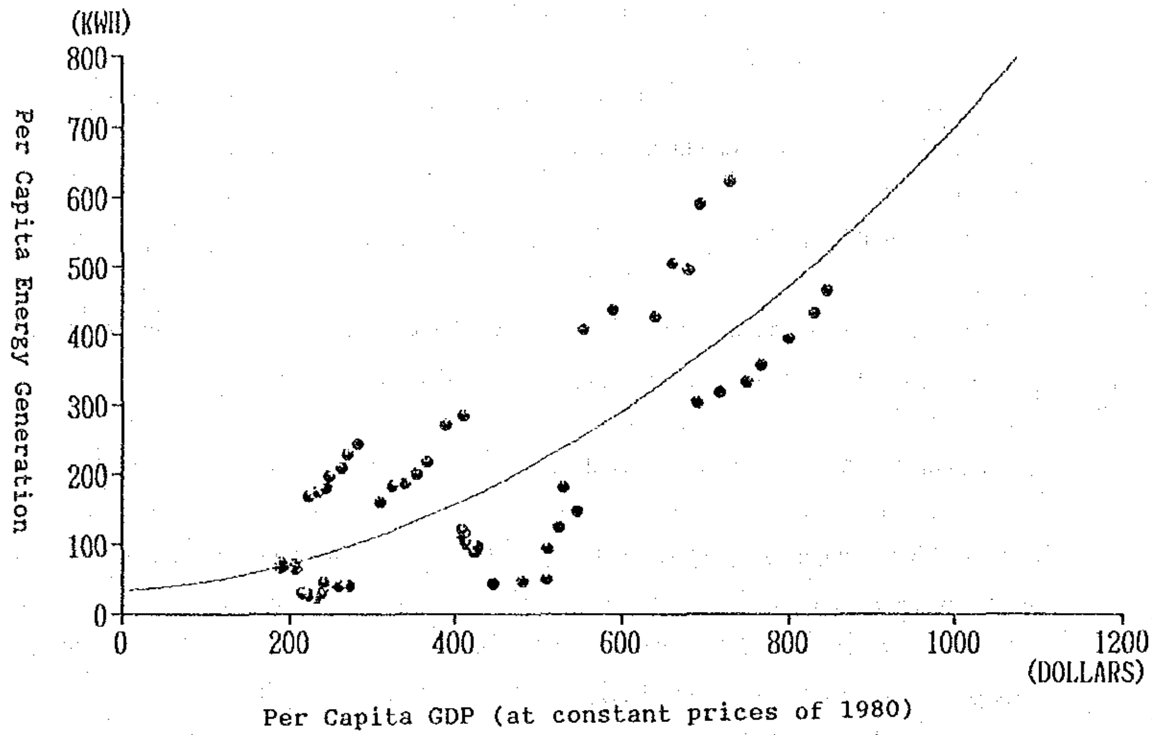
Where:

y = Per Capita Energy Generation (kWh)
x = Per Capita GDP (dollars)

The per capita GDP of Tanzania is 241 dollars (1980 prices) in 1985. If we assume that the growth rate of GDP is 4.5% and the growth rate of population is 2.8%, the growth rate of per capita GDP becomes about 1.7%. When we apply this growth rate from 1985 to 2005, the per capita GDP of Tanzania is estimated as 340 dollars in 2005. We get the per capita energy generation 72 kWh in 1985 and 107 kWh in 2005 by substituting the per capita GDP in equation <2> with the value of 241 and 340. The average growth rate of per capita energy generation during 20 years is calculated as 2.0%. The average growth rate of energy generation is estimated as 4.9% by multiplying the growth rate of per capita energy generation and population. As the per capita energy generation of Tanzania is smaller than the value of the equation <2>. The growth rate of energy generation will probably exceed 4.9%.

As the average energy generation growth rate between 1975 and 1985 was 6.2% and the average energy generation growth rate in the ACRES Report is also projected to be 6.2% from 1990 to 2005, by studying the energy consumption of each category, we assumed that the electric energy demand growth rate will be 6.2% for the period from 1990 to 2005. As the growth rate of energy generation changes with high sensitivity to the economic status and load composition, this projection should be reviewed and revised every year.

Fig. 5-2 Per Capita Energy Generation and GDP




Note : Based on the data of Thailand, Indonesia, India, Pakistan, Tanzania, Rwanda, Kenya, Malawi and Egypt from 1979 to 1985

Source: National Accounts Statistics: Analysys of Main Aggregates 1985, UN
Energy Statistics Yearbook, UN
International Financial Statistics 1989, IMF

The rated capacity of the existing hydroelectric power stations is given in Table 5-3 and the rehabilitation plan of the existing thermal stations is given in Table 5-5. According to the ACRES Report, the rated capacity of the hydroelectric power stations is 330 MW and firm energy is 1,480 GWh/yr in 1990. The rated capacity of thermal station is 90 MW which is given by adding 6 MW of Arusha, Shinyanga and Singida to the total value of 84 MW in the Table 5-5 and the energy generation is 426 GWh by assuming the plant factor as 0.54. The hydroelectric power stations development program of the ACRES Report is presented in Table 5-4. The balance of energy generation and peak supply capacity based on the power demand projection of the former section and the power development plan of the ACRES Report are presented in Table 5-6, Fig. 5-3 and Fig. 5-4. The ratio of energy consumption and energy generation was assumed to be 0.844 and the load factor of the Grid System was assumed to be 64% which was the average value for the period from 1984 to 1988.

By looking at the energy balance calculated as above, the energy supply of the Grid System is not sufficient to meet the demand one year before the commissioning year of Lower Kihansi Power Station and in five years before the commissioning of Rumakali Power Station.

Although it is expected that the hydroelectric power stations will supply energy over their firm energy values, it will be required to rehabilitate the thermal power stations which are planned to be retired in the commissioning year of Upper Kihansi Power Station or to develop new thermal power stations.

In terms of the peak supply capacity, the capacity of the power stations can not meet the whole peak demand one year before the commissioning of Masigira Power Station and two years before the commissioning of Rumakali Power Station, when 15% reserve capacity is assumed. Therefore, the rehabilitation of the existing thermal stations or the development of new thermal power stations will also be requested from the view point of the peak supply capacity.

The above analysis indicates that the power development program lags behind the required power supply. Although TANESCO plans to operate the interconnected system with only hydroelectric power, the development of large hydroelectric resources requires large amounts of time and funds, so construction and replacement of thermal power stations under systematic planning will be required.

Table 5-3 Existing System Hydroelectric Generating Capability

(April 1989)

| Power Station | Installed Capacity (MW) | Average Annual Energy (GWh/yr) |
|---|---|---|
| (Pangani River) | | |
| Nyumba Ya Mungu | 8.0 | 48 |
| Hale | 21.0 | 143 |
| Pangani Falls | 17.5 | 150 |
| Subtotal | 46.5 | 341 |
| (Great Ruaha River) | | |
| Mtera | 80.0 | 303 |
| Kidatu | 204.0 | 1,009 |
| Subtotal | 284.0 | 1,312 |
| Total | 330.5 | 1,653 |

Note: The 1:30-yr firm capability of the grid system is about 169 MW continuous (1,480 GWh/ry)

Source: Review of 1985 Power Sector Development Plan, TANESCO/ACRES, 1989

Table 5-4 Development Plan of Hydroelectric Projects

| Year [1] | Project | Installed Capacity (MW) | Energy Firm (GWh/yr) | Energy Average (GWh/yr) |
|---|---|---|---|---|
| 1995 | Pangani Falls Redevelopment | 60.0 [2] | 305 | 380 |
| 1996 | Lower Kihansi | 153.0 [3] | 551 | |
| 1999 | Upper Kihansi | 47.0 [3] | 335 | 1,164 [4] |
| 2002 | Masigira | 80.0 | 482 | 505 |
| 2005 | Rumakali | 204.0 | 1,270 | 1,225 |
| 2009 | Ruhudji Stage 1 | 250.0 | 1,261 | 1,540 |
| 2012 | Mpanga | 160.0 | 416 | 840 |

Note:
1) First full year of operation
2) Existing Pangani Falls Station is to be retired
3) Based on JICA plan
4) Total of Upper and Lower Kihansi

Source: Review of 1985 Power Sector Development Plan, TANESCO/ACRES, 1989

Table 5-5 Rehabilitation Plan of Diesel Units of the Grid System

| Power station | Rated Capacity (MW) | Units (No.) | Rehabilitated Capability (MW) |
|---|---|---|---|
| (Units that have been rehabilitated at April 1989) | | | |
| Mwanza Nyakato | 4.0 | 2 | 8.0 |
| Tabora Kiloleni | 1.5 | 1 | |
| | 2.6 | 1 | 4.1 |
| Musoma | 0.75 | 4 | 3.0 |
| Subtotal | | | 15.1 |
| (Units remaining to be erected at April 1989) | | | |
| Mbeya Iyunga | 2.5 | 1 | 2.5 |
| Dodoma Zuzu | 2.6 | 1 | |
| | 1.5 | 1 | 4.1 |
| Tabora Kiloleni | 2.6 | 2 | 5.2 |
| Subtotal | | | 11.8 |
| (Units remaining to be rehabilitated at April 1989) | | | |
| Mbeya Iyunga | 2.5 | 3 | |
| | 3.0 | 2 | 13.5 |
| Dodoma Zuzu | 2.6 | 1 | 2.6 |
| Mwanza Nyakato | 4.0 | 1 | 4.0 |
| Musoma | 0.75 | 4 | 3.0 |
| Ubungo | 2.5 | 3 | |
| | 7.0 | 2 | 21.5 |
| Ubungo G.T. | 12.5 | 1 | 12.5 |
| Subtotal | | | 57.1 |
| Total | | | 84.0 |

Source: Review of 1985 Power Sector Development Plan, TANESCO/ACRES, 1989

## Table 5-6 Power Demand Forecast

| Year | Energy Generation (GWh) | Peak Demand (MW) | System Firm Energy Capasity (GWh) | System Capacity (MW) | Installed Capacity (MW) | Remarks |
|---|---|---|---|---|---|---|
| 1990 | 1599 | 285 | 1906 | 420 | | |
| 1991 | 1707 | 304 | 1906 | 420 | | Interconnect Tukuyu |
| 1992 | 1813 | 323 | 2028 | 440 | 20.0 | Bridging Thermal (C.F.; 0.7) |
| 1993 | 1925 | 343 | 2028 | 440 | | |
| 1994 | 2045 | 365 | 2028 | 440 | | |
| 1995 | 2171 | 387 | 2223 | 483 | 42.5 | Pangani Redevelopment |
| 1996 | 2306 | 411 | 2223 | 483 | | |
| 1997 | 2449 | 437 | 2774 | 636 | 153.0 | Lower Kihansi |
| 1998 | 2601 | 464 | 2774 | 636 | | |
| 1999 | 2762 | 493 | 2739 | 604 | 47.0 | Upper Kihansi |
| | | | | | -78.3 | Retire Existing Thermal |
| 2000 | 2933 | 523 | 2739 | 604 | | |
| 2001 | 3115 | 556 | 2739 | 604 | | |
| 2002 | 3309 | 590 | 3221 | 684 | 80.0 | Masigira |
| 2003 | 3514 | 627 | 3221 | 684 | | |
| 2004 | 3731 | 666 | 3221 | 684 | | |
| 2005 | 3963 | 707 | 4435 | 877 | 204.0 | Rumakali |
| | | | | | -11.8 | Retire Existing Thermal |

Note:1) Growth Rate of Energy Generation is estimated at 8.4 % for 1990 and 6.2 % for 1991 -2005.
2) Grid Sales/Generation ratio is estimated at 0.844
3) Grid Load Factor is estimated at 64.0 %
4) C.F.; Capacity Factor

Fig. 5-3 Installed Capacity

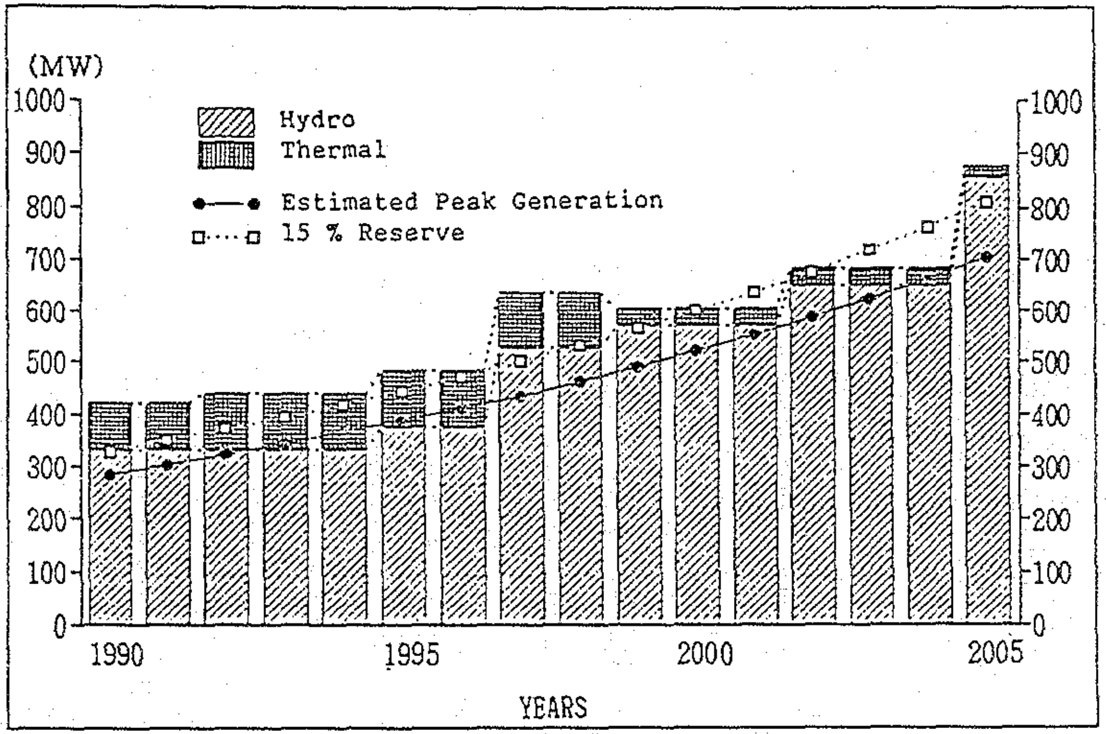
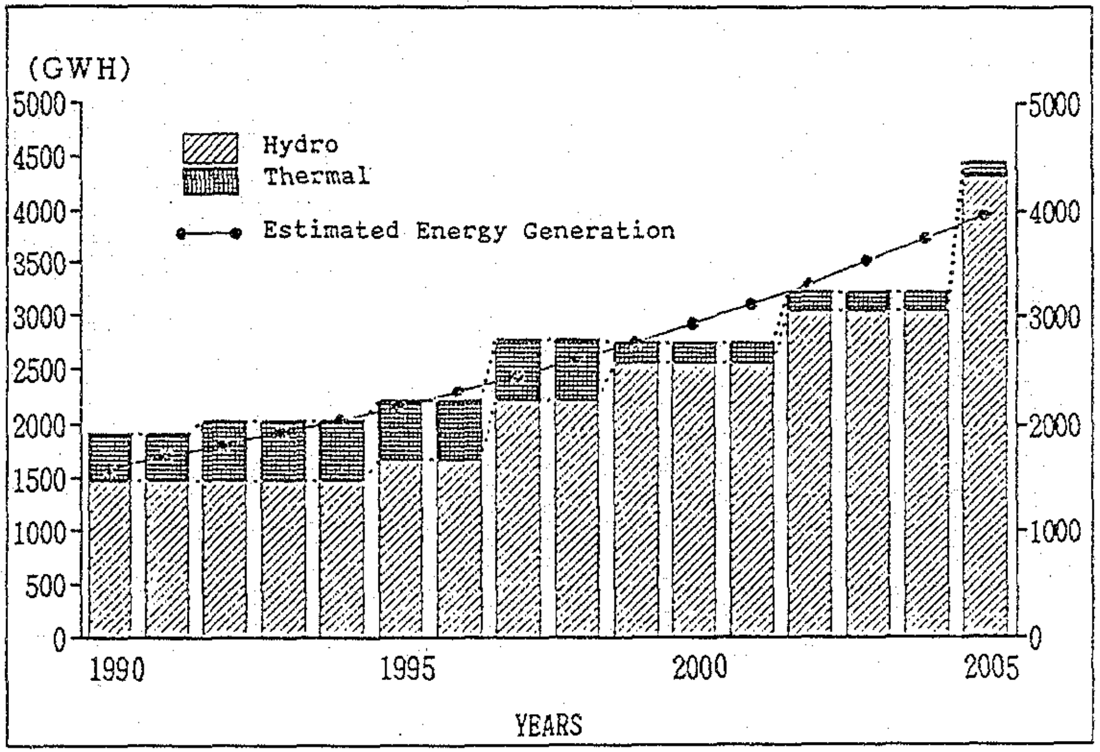


Fig. 5-4 Firm Energy



# Chapter 6 HYDROLOGY AND METEOROLOGY

Chapter 6

# HYDROLOGY AND METEOROLOGY

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# Chapter 6 HYDROLOGY AND METEOROLOGY

## 6.1 General

### 6.1.1 Topography

The Kihansi River is a tributary of the Kilombero River which belongs to the Rufiji Basin and originates at the southern part of the Iringa Region. The source of the Kihansi River shows a hilly shape and is covered with grass, a part of which is cultivated.

Although the river channel at the upper reach forms a meander and the amplitude of the meanders is very short, the river at the lower reach is composed of many falls and rapids. Fig. 6-1 shows the Kihansi Basin and its stream pattern and Fig. 6-2 shows the profile of the Kihansi River.

Most of the basin is situated above EL. 1,500 m and the river slope is about 1/50 to 1/130 there. Below EL. 1,400 m, however, the slope becomes to be steeper of 1/30 and especially between the lower dam site and the lower powerhouse site, the elevation differs by 800 m, while the horizontal distance is only 4 km. Fig. 6-3 shows the watershed relief condition. One grid of this Fig. 6-3 is 1 km square and the figure in a grid indicates the degree of relief, e.g. 1 means that the difference of elevation varies 0 to 100 m and 2 means that the difference varies 100 to 200 m. According to this figure, north-western part of the basin, that is the upper reach, is very gentle, but along the south-eastern border the topography changes to become steep. This border corresponds to the Uzungwa Scarp running in the NE-SW direction. The stream pattern divides into two roughly; one is the main Kihansi River like a tree branch and the other is the Ruaha River, the largest tributary of the Kihansi, which flows parallel to the escarpment. These two river basins

Fig. 6-1 Kihansi Basin and Its Stream Pattern

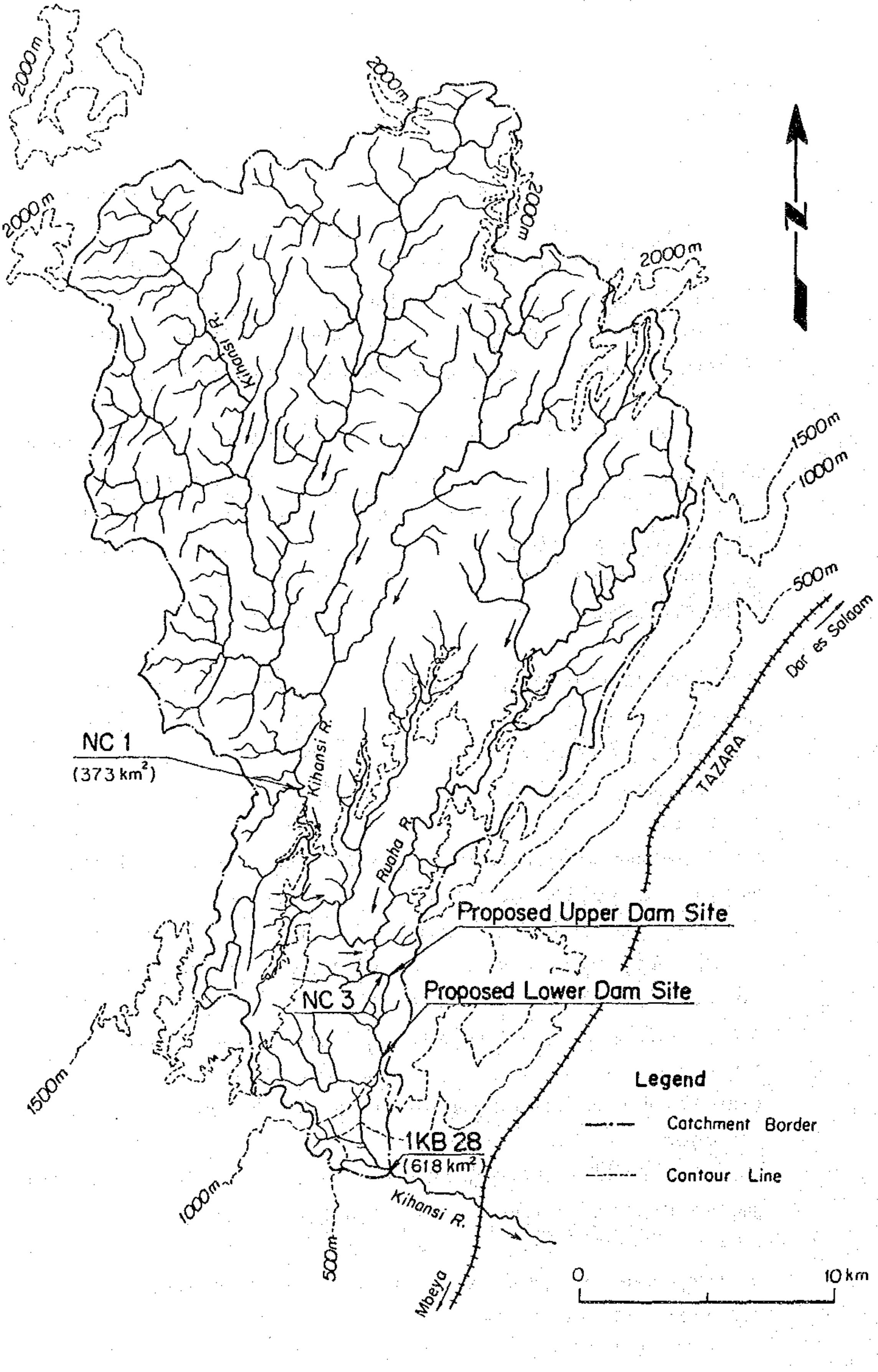


Fig. 6-2 Profile of Kihansi River

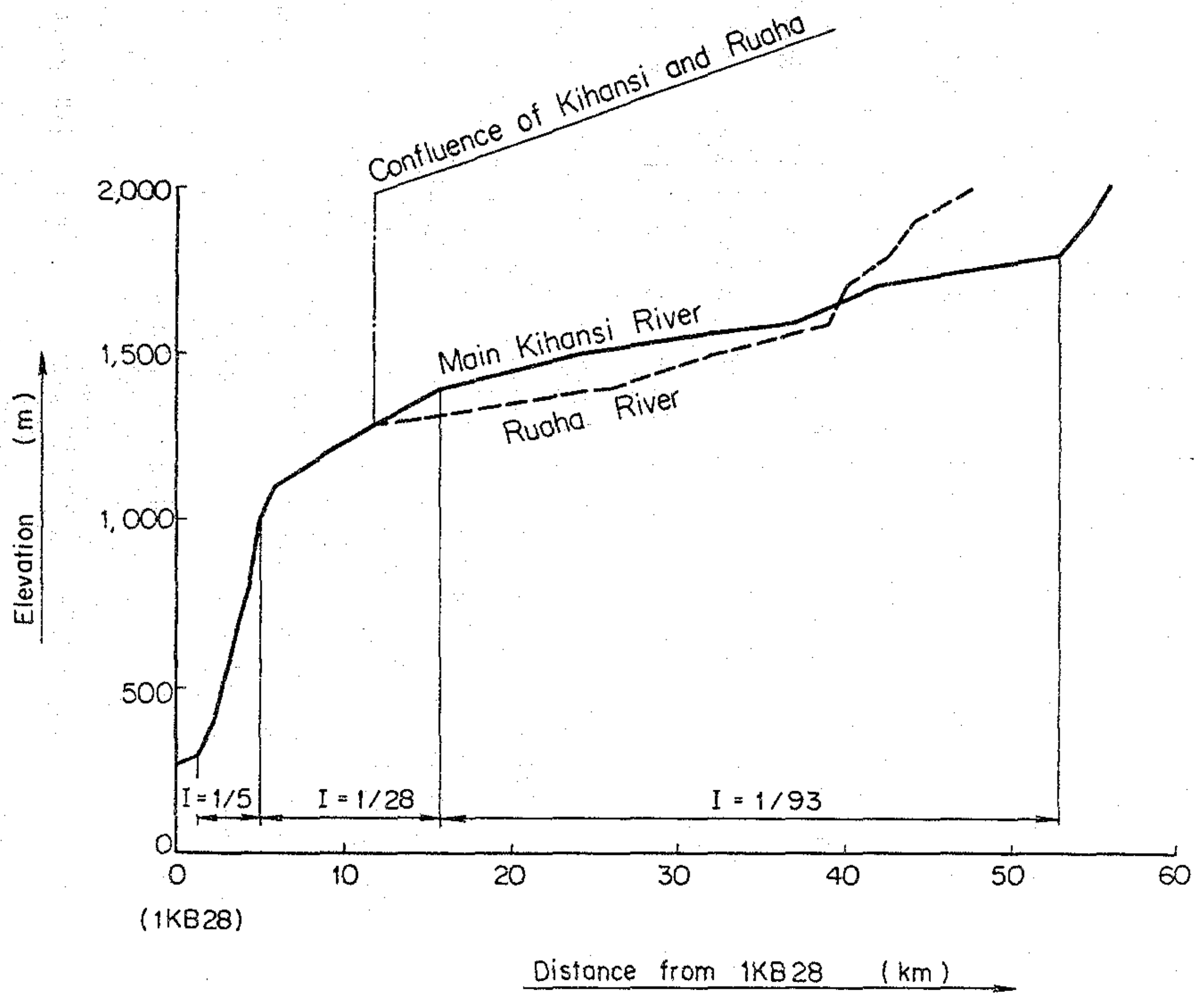
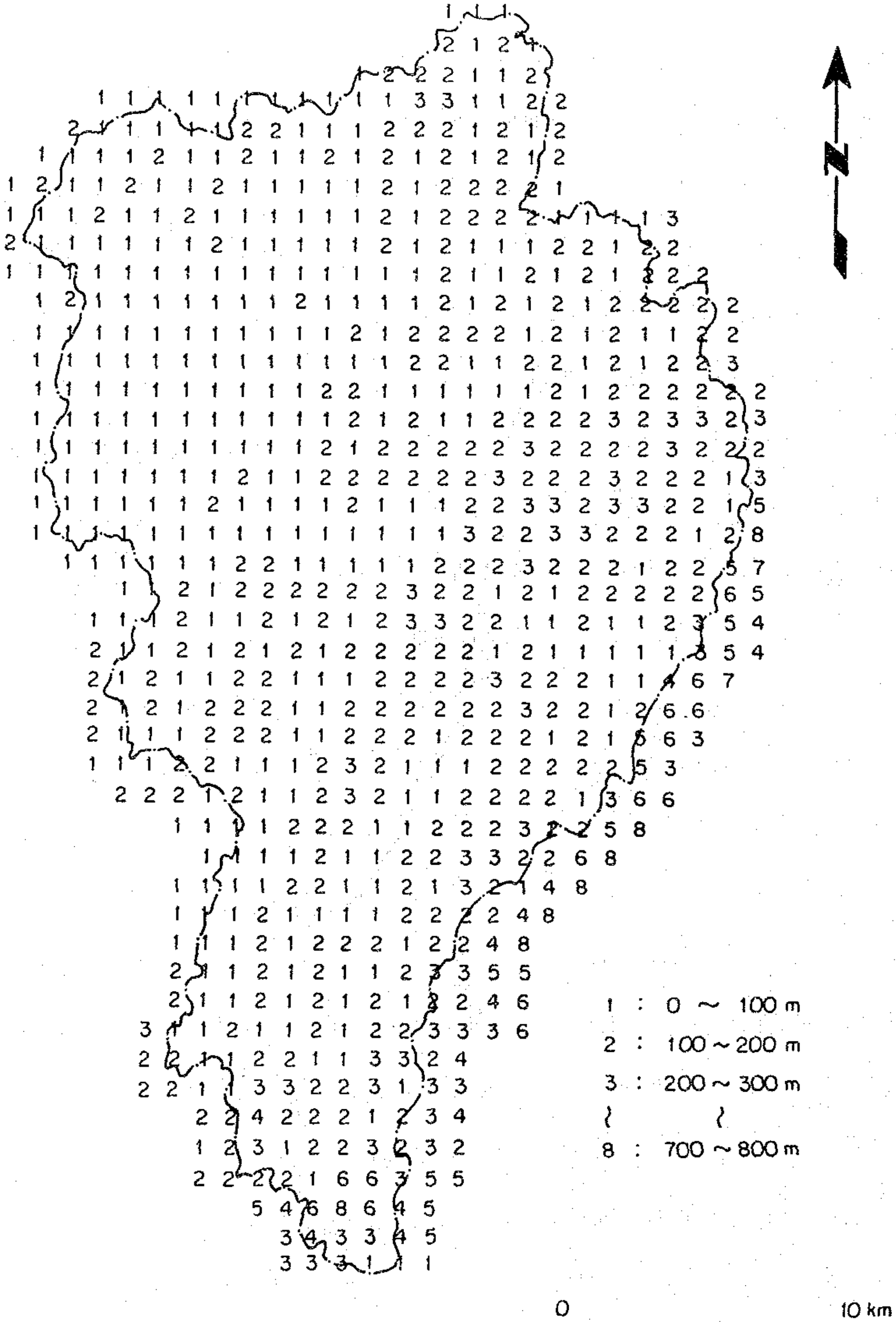


Fig. 6-3 Watershed Relief in the Kihansi Basin

( Each Grid is 1 km Square )



differ in many respects besides the stream pattern as shown below.

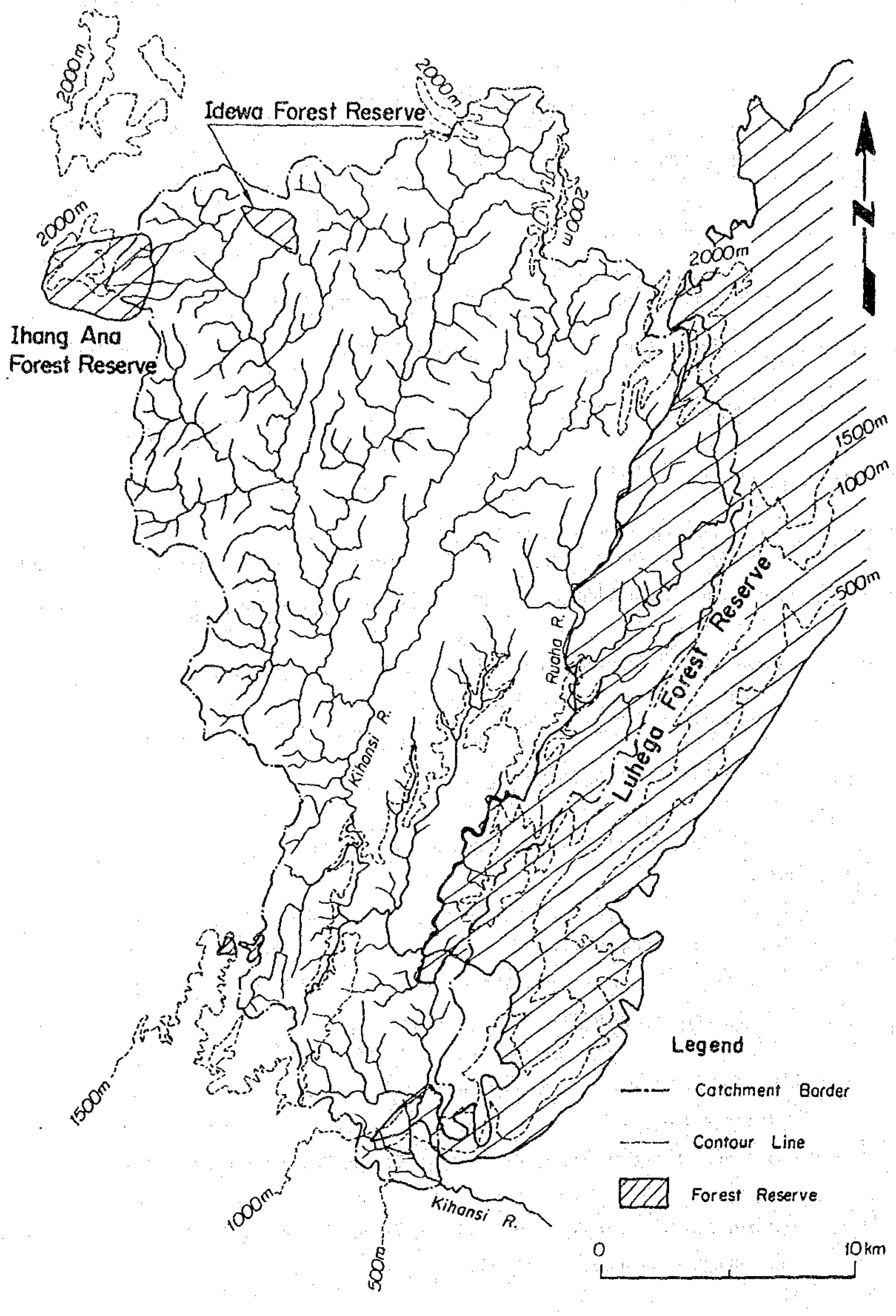
| | Main Kihansi | Ruaha |
|---|---|---|
| Vegetation (Fig. 6-4) | Grass and cultivated land | Forest (Reserved forest) |
| Valley (Fig. 6-3) | Gentle | Steep |
| Catchment Area/ River Length | 12 km | 5 km |
| Mean annual specific runoff | 2.5 $m^3/s/100\ km^2$ | 3.5 $m^3/s/100\ km^2$ |

In this Table, the difference of mean annual specific runoff results from the difference of rainfall distribution and is related to the low flow analysis. On the other hand, other factors influence the rainfall-runoff relation directly and it is necessary to consider such topographic and climatic characteristics to estimate the flood discharge.

### 6.1.2 Climate

Most of Tanzania including the Kihansi Project area belongs to the tropical savanna climate (or semi-arid tropical climate) and has two distinct seasons, that is, rainy and dry seasons. The rainy season begins in November and continues until May. The meteorological phenomena, such as rainfall, wind movement and humidity, are mainly influenced by ITCZ (Intertropical Convergence Zone). The cause of the rainfall is limited to the convergent shower due to the activity of ITCZ and other factors such as a cyclone and a front hardly occur from

Fig. 6-4 Land Use of the Kihansi Basin



the histrocial records. The monthly position of ITCZ over the African continent is shown in Fig. 6-5.

Although annual rainfall in whole Tanzania varies from 400 mm to 2,000 mm, most of rainfall concentrates the rainy season in spite of the amount. The Kihansi Basin is located in the much rainfall area and mean annual rainfall is estimated to be 1,500 mm. The characteristics of rainfall are described in 6.1.3.

Since temperature mainly depends on the land elevation, the project area divides into two areas; one is a higher land whose height is approximately 1,500 m, and the other is around the Lower Kihansi powerhouse site whose height is approximately 300 m.

Mean maximum temperature at Iringa, which is 100 km north of the project site and considered to represent the climatic condition of the higher part, is 26.2°C and mean minimum one is 14.3°C. The seasonal variation of both maximum and minimum temperature is very small within 5°C as shown in Table 6-1 (1). Since no climatic data representing the lower part is collected, the data at Morogoro, which is 300 km northeast of the project area and 580 m high above sea level, are adopted as a reference (Table 6-1 (2)). Mean maximum temperature at Morogoro is 30.0°C and mean minimum one is 18.6°C. The seasonal variation of temperature is also very small within 6°C similarly to Iringa.

### 6.1.3 Rainfall

Annual rainfall amount in the Kihansi Basin varies from 1,000 mm to 1,800 mm according to the typical isohyetal map (Fig. 6-6). The rainfall distribution indicates that the south-eastern part of the area along the escarpment

Fig. 6-5 (1) Mean Surface Flow Patterns and Locations of Discontinuities in the Flow for January ~ June

( ASECNA , 1973 )

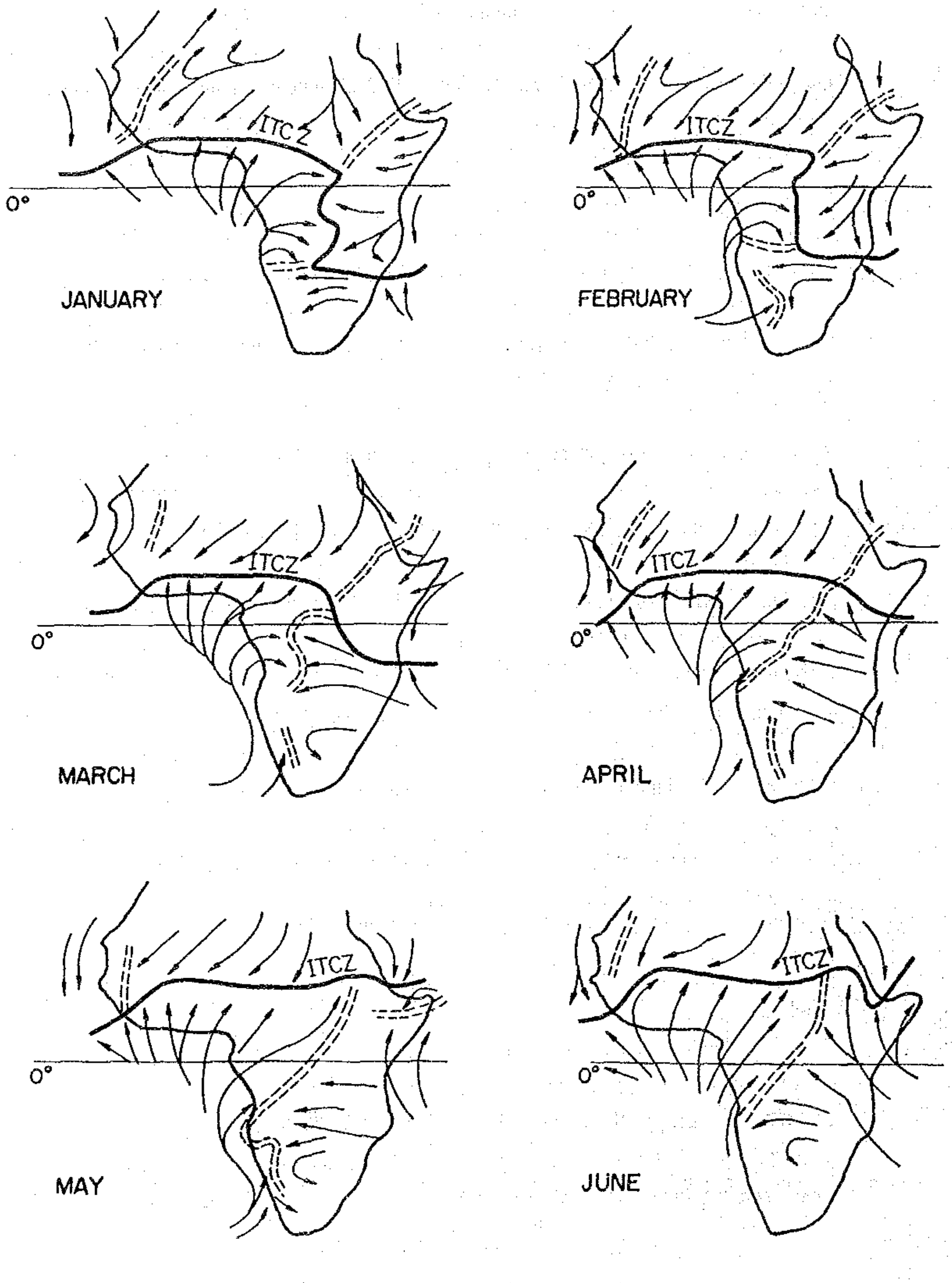
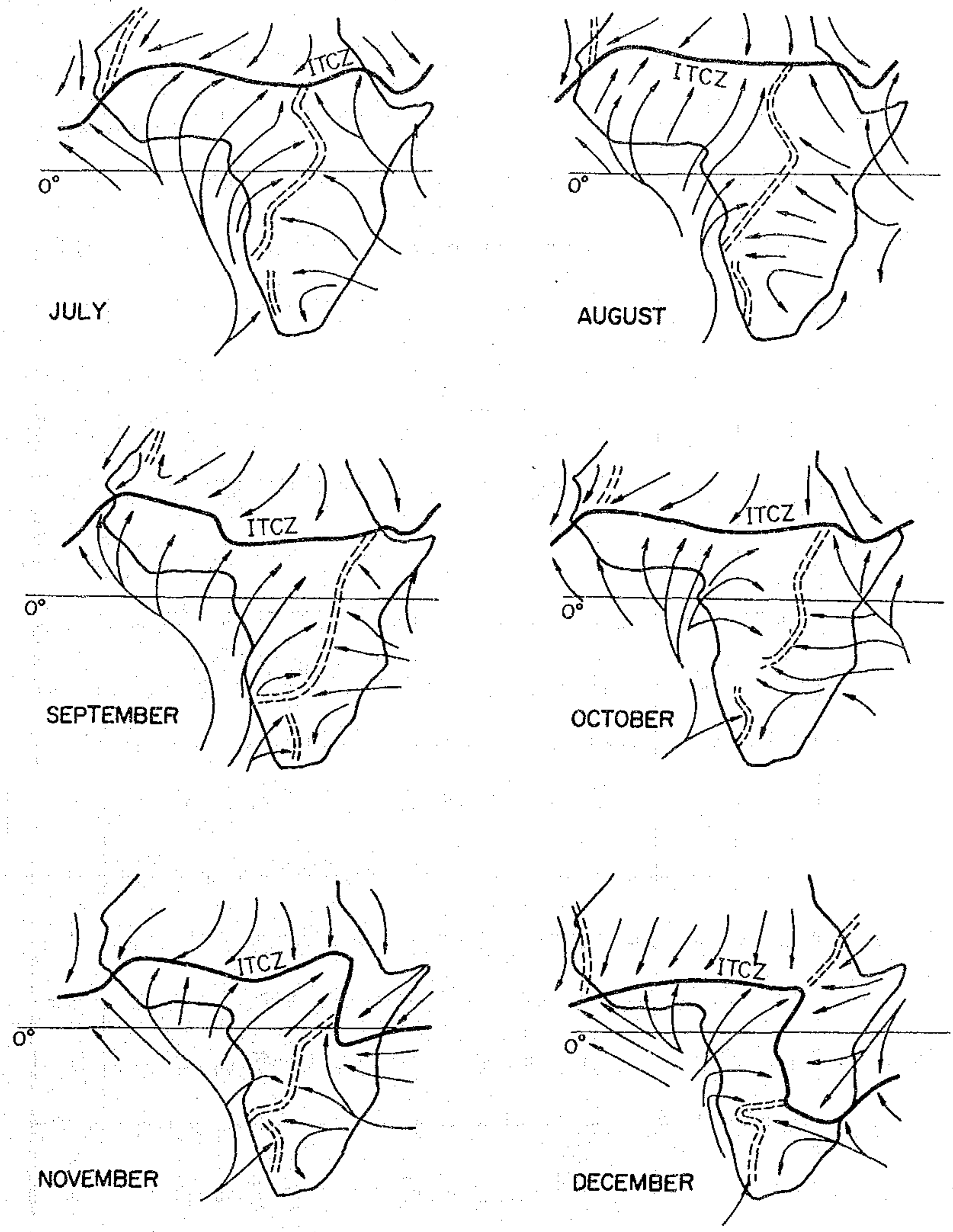


Fig. 6-5 (2) Mean Surface Flow Patterns and Locations of Discontinuities in the Flow for July ~ December

( ASECNA, 1973 )



### Table 6-1 (1) Meteorological Data at Iringa

Latitude 07° 40'S Longitude 35° 45'E Altitude 1,428 m

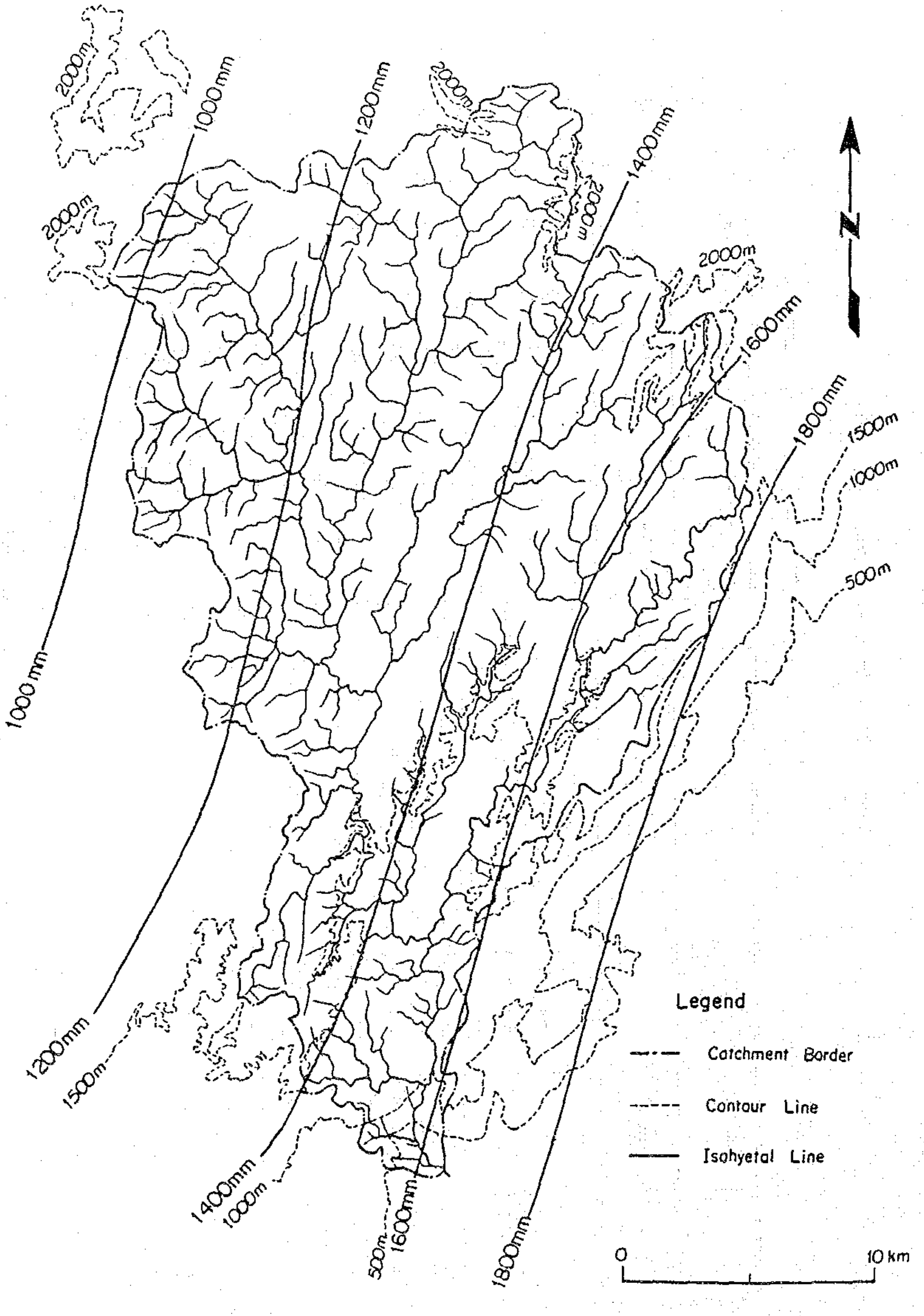
| Month | Temperature (°C) (1960~80) | | Relative Humidity (%) | | Rainfall (mm) (1960~80) | | Mean Number of Days of | | Monthly Evaporation (mm) (1973~80) |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | 6:00 | 12:00 | Mean | Max. 24 hour fall | Rain (> 1 mm) | Thunder | |
| Jan. | 25.8 | 15.7 | 79 | 61 | 138 | 88.5 | 13 | 10 | 146 |
| Feb. | 25.8 | 15.5 | 81 | 62 | 115 | 45.7 | 12 | 9 | 138 |
| Mar. | 25.9 | 15.3 | 79 | 63 | 130 | 55.1 | 14 | 11 | 128 |
| Apr. | 25.8 | 15.2 | 76 | 60 | 63 | 67.3 | 9 | 5 | 123 |
| May | 25.5 | 14.1 | 68 | 50 | 10 | 25.1 | 3 | 1 | 142 |
| Jun. | 24.9 | 12.4 | 62 | 42 | 1 | 10.6 | 0 | 0 | 160 |
| Jul. | 24.3 | 12.0 | 63 | 42 | 0 | 0.6 | 0 | 0 | 171 |
| Aug. | 25.0 | 12.1 | 60 | 41 | 1 | 9.4 | 0 | 0 | 190 |
| Sep. | 26.7 | 13.6 | 55 | 37 | 1 | 3.8 | 0 | 0 | 212 |
| Oct. | 28.4 | 14.3 | 53 | 37 | 4 | 22.8 | 0 | 1 | 244 |
| Nov. | 28.8 | 15.6 | 57 | 42 | 27 | 58.4 | 3 | 4 | 223 |
| Dec. | 27.0 | 16.1 | 72 | 55 | 159 | 102.4 | 12 | 11 | 177 |
| Year | 26.2 | 14.3 | 67 | 49 | 649 | 102.4 | 66 | 62 | 2,054 |

Table 6-1 (2) Meteorological Data at Morogoro

Latitude 06° 51'S Longitude 37° 40'E Altitude 579 m

| Month | Temperature (°C) (1946~60) | | Relative Humidity (%) | | Rainfall (mm) (1960~80) | | Mean Number of Days of | | Monthly Evaporation (mm) (1973~80) |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | 6:00 | 12:00 | Mean | Max. 24 hour fall | Rain (> 1 mm) | Thunder | |
| Jan. | 31.5 | 21.0 | 83 | 55 | 96 | 70.4 | 6 | 12 | |
| Feb. | 31.7 | 20.8 | 84 | 57 | 99 | 110.9 | 5 | 11 | |
| Mar. | 31.5 | 20.8 | 86 | 60 | 162 | 93.0 | 9 | 14 | |
| Apr. | 29.6 | 20.4 | 91 | 69 | 217 | 64.5 | 16 | 8 | |
| May | 28.2 | 18.8 | 91 | 68 | 92 | 59.0 | 9 | 1 | |
| Jun. | 27.3 | 15.9 | 87 | 59 | 27 | 33.5 | 3 | 0 | |
| Jul. | 27.2 | 15.0 | 87 | 54 | 14 | 38.1 | 3 | 0 | |
| Aug. | 28.3 | 15.8 | 83 | 49 | 11 | 34.5 | 2 | 0 | |
| Sep. | 29.8 | 16.6 | 80 | 47 | 18 | 62.0 | 2 | 0 | |
| Oct. | 31.2 | 18.0 | 77 | 45 | 28 | 72.1 | 3 | 1 | |
| Nov. | 31.8 | 19.5 | 77 | 49 | 60 | 87.9 | 6 | 4 | |
| Dec. | 32.0 | 21.1 | 79 | 53 | 81 | 80.5 | 8 | 9 | |
| Year | 30.0 | 18.6 | 84 | 55 | 905 | 110.9 | 72 | 60 | |

Fig. 6-6 Typical Isohyetal Map on Annual Rainfall



has the most amount of 1,800 mm and the rainfall decreases by degrees toward northwest. Monthly rainfall data at the rainfall observatories nearby the project area are shown in Fig. 6-7.

From December to February, monthly rainfall of each observatory amounts about 150 to 200 mm in common. In this period, ITCZ is located in the southern part of Tanzania, and so the NE wind direction predominates (see Fig. 6-5). In this case, the orographic influence is not very remarkable because the escarpment almost parallels the wind flow. Moreover, between the ocean which is the source of moist and the project area, there are so many high lands that the moist air in the lower part of the air stream which is the key factor of orographic rain is cut by the front barrier until it reaches the project area. Therefore, during this period, the rainfall has non-orographic characteristics rather than orographic ones. On the other hand, from March to April, ITCZ crosses Tanzania and wind direction changes to E or SE so that the rainfall distribution indicates the orographic feature around the project area. In this period, the moist air stream flows directly from the ocean to the escarpment which faces to the wind normally, and moreover, the Kilombero Valley spreading in the southeastern side of the escarpment is also thought to be a moisture source as a local hydrologic cycle.

The moist air ascends along the escarpment and then the rapid ascending current occurs and results in heavy rain. On the contrary, the highland of the Kihansi Basin becomes a shadow area and the rainfall decreases gradually toward northwest.

Rainfall is usually accompanied with thunderstorm whose duration continues within only one hour at a certain point and the rainfall area is very limited in general.

Fig. 6-7 (1) Seasonal Characteristics of Rainfall

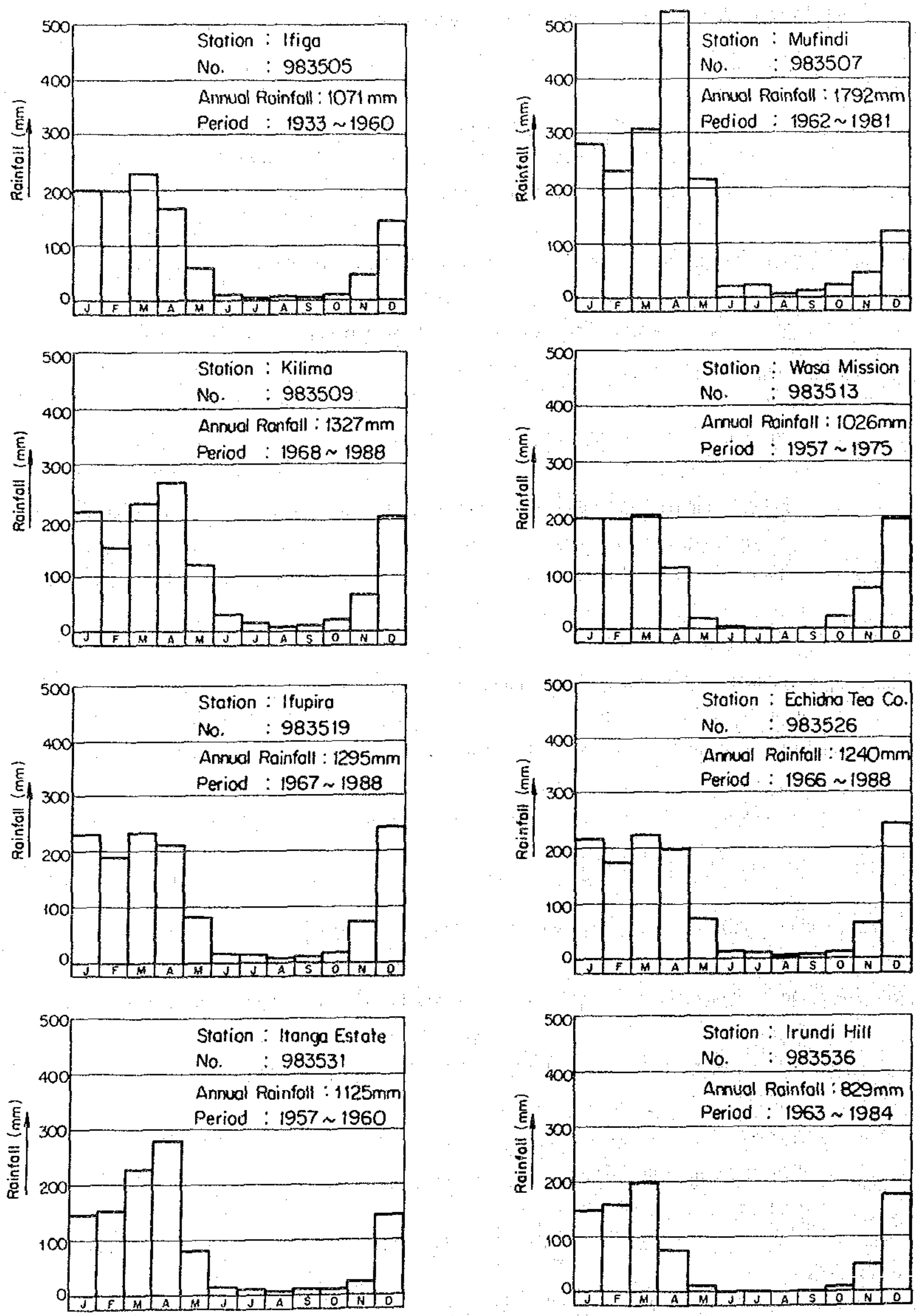
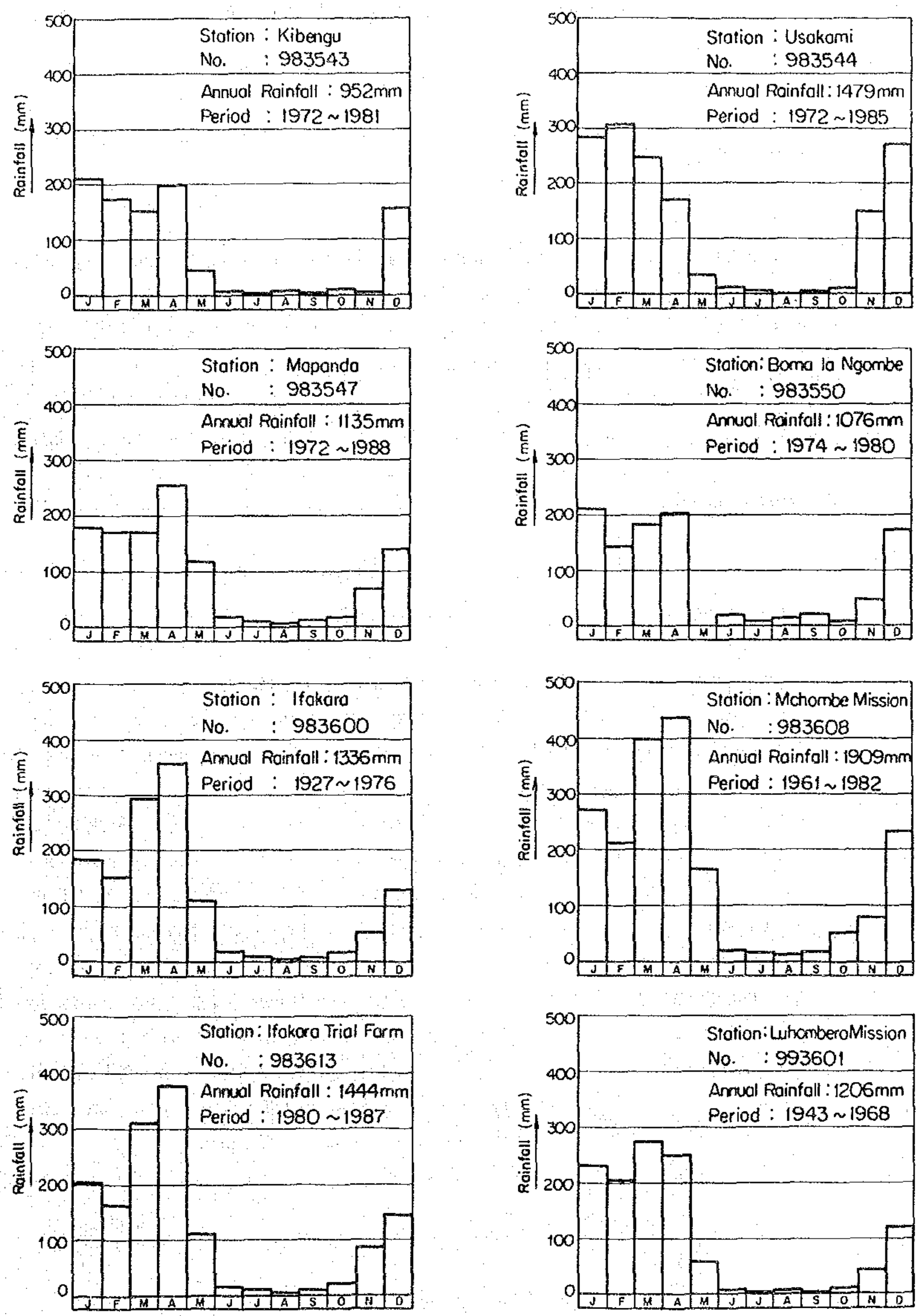


Fig. 6-7 (2) Seasonal Characteristics of Rainfall



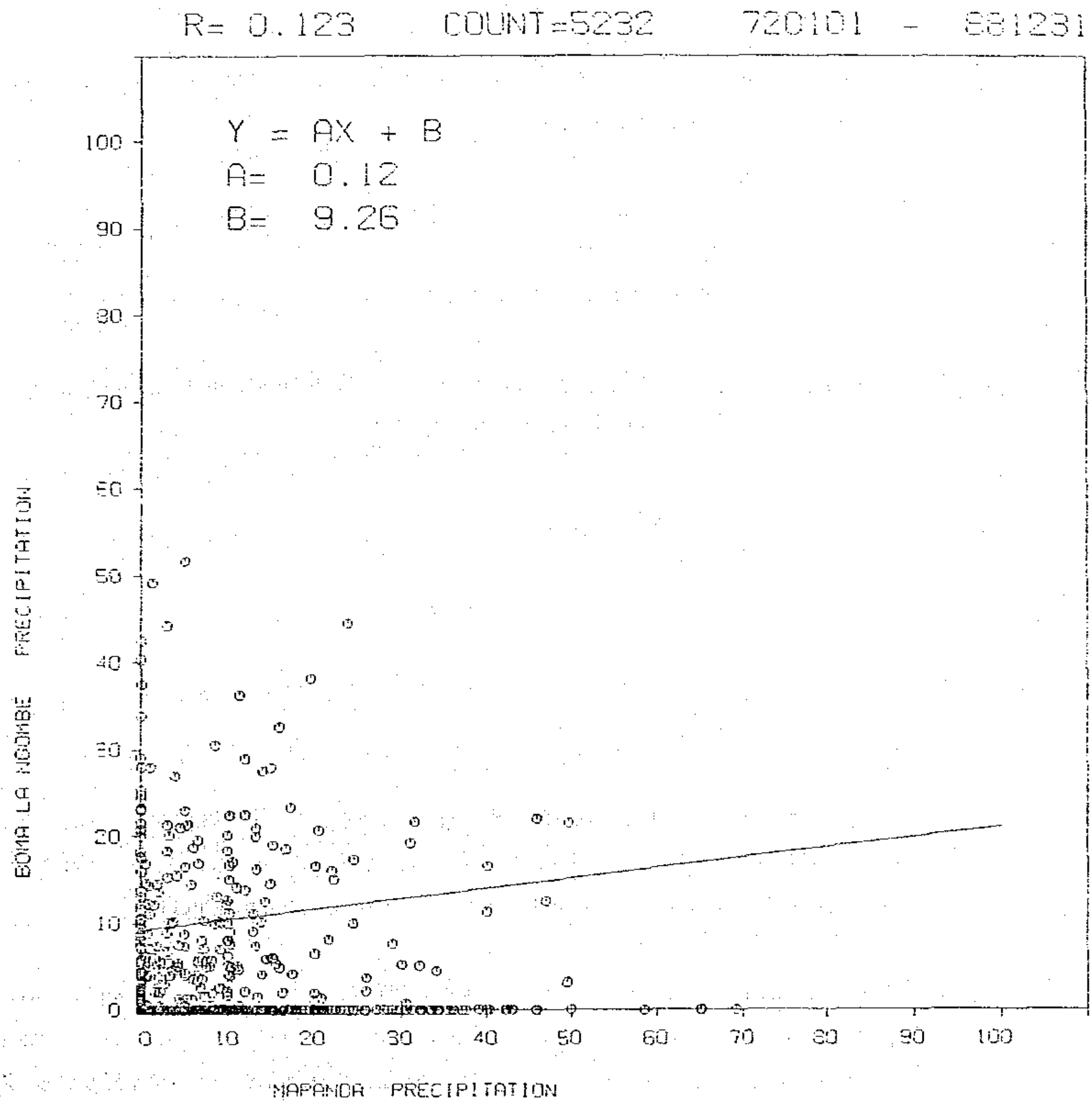
There is no constant pattern of rainfall and this indicates that the correlation of daily rainfall data between close two observatories is very bad (see Fig. 6-8).

### 6.1.4 Evaporation and Transpiration

Evaporation is observed by means of a pan at Iringa since 1973 and this measurement is thought to represent the potential evapotranspiration in the Kihansi Basin as well as the evaporation from the planned Upper Kihansi reservoir. Mean annual evaporation at Iringa is 2,054 mm. The potential evapotranspiration is defined as the water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation.

Under an ideal condition, the potential evapotranspiration is said to approach the evaporation from a free-water surface very closely. According to "Studies of Potential Evaporation in Tanzania" written by T. Woodhead in 1968, the potential evaporation at Iringa is estimated to be 1,919 mm a year by the Penman formula. Since the Penman formula treats only climatic condition and neglects the other factors such as a kind of vegetation on the ground, precipitation variation and soil moisture, the actual evapotranspiration should be grasped in order to estimate the net evaporation loss from the reservoir. In this report, the main objective as to evapotranspiration is to compare the evaporation from the original land without the reservoir and one from the reservoir surface after the dam completion. Therefore, according to the following procedure, the net evapotranspiration loss is to be calculated.

**Fig. 6-8** **Correlation of Daily Rainfall between Mapanda and Boma la Ngombe**



i) The average rainfall of Mapanda and Mchombe is adopted as an areal precipitation over the Upper Kihansi reservoir.

ii) The potential evaporation at Iringa calculated by T. Woodhead above-mentioned is assumed to be a potential evapotranspiration.

iii) The minor value between i) average precipitation and ii) a potential evapotranspiration is selected as an actual evapotranspiration.

iv) This actual evapotranspiration is adjusted on the monthly basis by the following modification factor to meet a water balance between rainfall and runoff.

$$\text{Modification} = \frac{\text{(Mean annual precipitation)} - \text{(Mean annual runoff)}}{\text{(Actual evapotranspiration per year)}}$$

$$= \frac{1,522 - 912}{1,034}$$

$$= 0.59$$

v) The observed evaporation by a class A pan at Iringa multiplied by 0.7 is to be adopted as a free-water evaporation from the Upper Kihansi reservoir.

vi) Net evaporation loss is obtained after iv) an adjusted actual evapotranspiration minus v) a free-water evaporation. The result shown in Table 6-2 indicates that the net evaporation loss of 828 mm per year is expected to occur newly over the reservoir area after the Upper Kihansi reservoir is completed.

**Table 6-2 Net Evaporation Loss from the Upper Kihansi Reservoir**

| Month | i) Precipitation (mm) | ii) Potencial Evapo-transpiration (mm) | iii) Actual Evapo-transpiration (mm) | iv) Adjusted Actual Evapotranspiration (mm) | v) Free-water Evaporation (mm) | vi) Net Evaporation Loss (mm) |
|---|---|---|---|---|---|---|
| Jan. | 225 | 149 | 149 | 88 | 102 | - 14 |
| Feb. | 189 | 131 | 131 | 77 | 97 | - 20 |
| Mar. | 282 | 149 | 149 | 88 | 90 | - 2 |
| Apr. | 346 | 145 | 145 | 86 | 86 | 0 |
| May | 140 | 149 | 140 | 83 | 99 | - 16 |
| Jun. | 19 | 143 | 19 | 11 | 112 | -101 |
| Jul. | 12 | 150 | 12 | 7 | 120 | -113 |
| Aug. | 8 | 168 | 8 | 5 | 133 | -128 |
| Sep. | 11 | 184 | 11 | 6 | 148 | -142 |
| Oct. | 32 | 199 | 32 | 19 | 171 | -152 |
| Nov. | 72 | 186 | 72 | 42 | 156 | -114 |
| Dec. | 186 | 166 | 166 | 98 | 124 | - 26 |
| Year | 1,522 | 1,919 | 1,034 | 610 | 1,438 | -828 |

This value multiplied the reservoir area becomes the total loss of runoff discharge.

### 6.1.5 Runoff

There are three runoff gauging stations within the Kihansi Basin; they are 1KB28, NC3 and NC1. 1KB28 has the longest observation period of the three stations and was established in 1974. NC1 was installed in 1982 and NC3 in 1985. The detailed description of these stations is to be discussed in 6.2, Hydrometeorological Network.

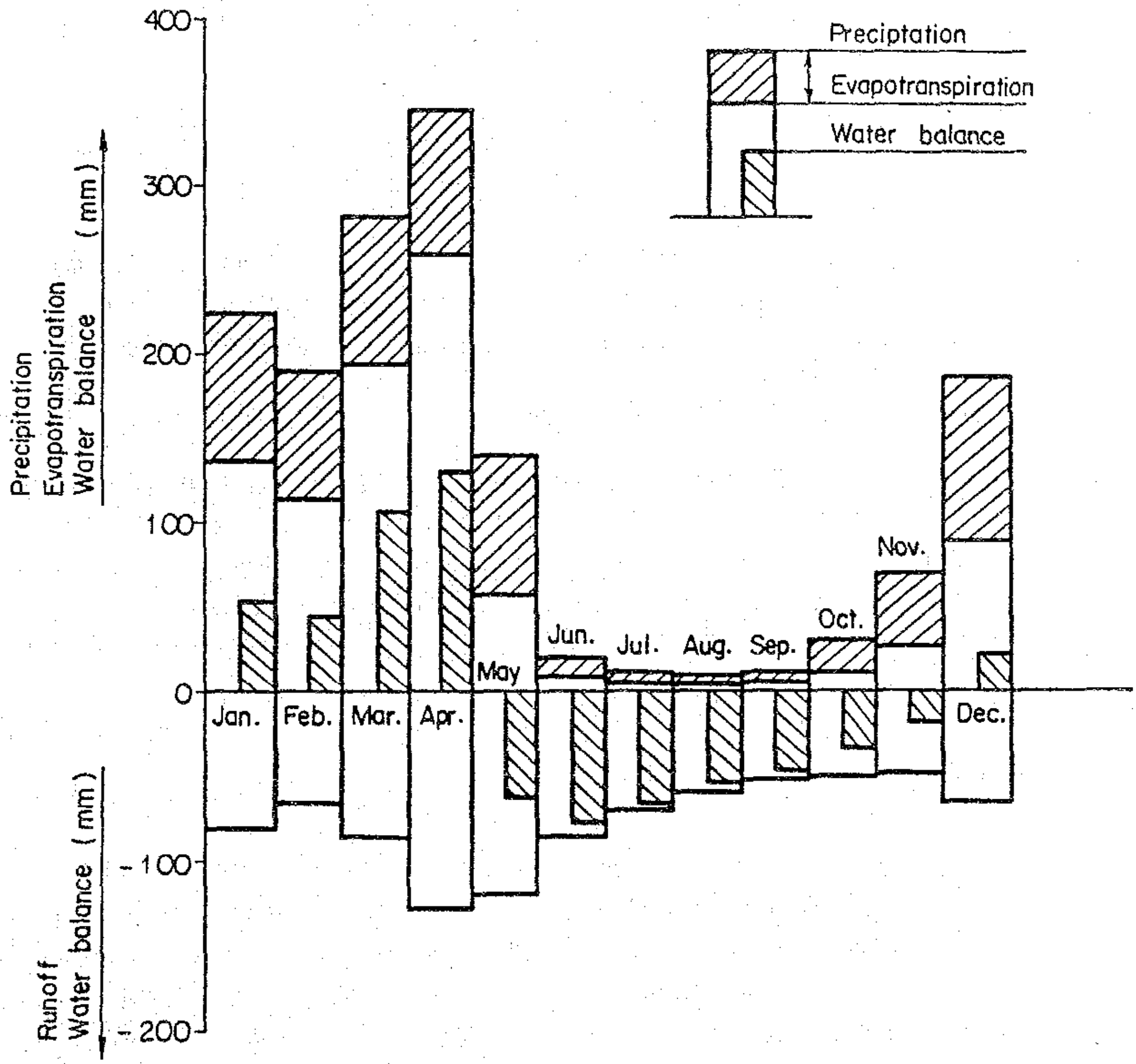
The characteristics of runoff discharge are as follows:

- Runoff reaches its maximum level in April or May corresponding to the latter of the rainy season and then decreases by degrees to the lowest level in October or November, the end of the dry season.

- Although there is very little rainfall during the dry season, the discharge keeps relatively higher level than other rivers near the Kihansi River. According to the water balance shown in Fig. 6-9, almost half an effective rainfall (after removing the evaporation) must be stored in the groundwater to meet the ample base flow during the dry season. This can be explained by the topographic and geological aspects, that is gentle hilly land, many depressions and thick weathered rock layer of laterite which has a high infiltration and storage ability.

- The response to the rainfall is dull because the rainfall distribution is so concentrated and the duration is so short that the rapid and huge peak flow hardly takes place over the whole basin area

Fig. 6-9 Water Balance in the Kihansi Basin



adding to the topographic and geological reasons above-mentioned.

- The specific mean annual runoff of 1KB28 is larger than that of NC1 by 1.26 times. This difference is owing to the annual rainfall distribution and each annual rainfall is estimated as below if the evapotranspiration from the basin area is assumed to be equal.

| | | Annual Discharge | Evapotrans-piration | Annual Rainfall |
|---|---|---|---|---|
| NC1 basin | (373 km$^2$) | 720 mm | 610 mm | 1,330 mm |
| 1KB28 basin | (618 km$^2$) | 910 mm | 610 mm | 1,520 mm |
| Residual basin (1KB28 - NC1) | (245 km$^2$) | 1,200 mm | 610 mm | 1,810 mm |

From the point of view of the monthly runoff, the difference between 1KB28 and NC1 is predominant in April and May and this phenomenon is based on the meteorological characteristics discussed in Section 6.1.3 Rainfall.

### 6.1.6 Hydrological Cycle

It is considered that the climatic phenomena show a certain hydrological cycle in the long term observation and the grasp of this cycle is important to formulate the reservoir operation rule as well as to estimate the energy generation. According to the previous studies, there are two opinions about a series of driest year. One is the Rufiji Basin Hydropower Master Plan submitted by Norconsult in 1984 which reported that the driest period of recent years in the Kihansi Basin was estimated to continue from 1957 to 1962 on the basis of runoff data and significant drought could not be admitted during the forties. The other is the Power Sector Development Plan submitted by ACRES in 1985 (reviewed in 1989) and they insisted that the two significant drought periods (1952 to 1956 and 1974 to 1977) occurred in both the Great Ruaha and Pangani River systems and moreover, the period 1940 to 1954 was significantly drier than the period 1956 to 1979.

This conceptual difference on the driest period resulted in adoptation of the different reference hydrologic records respectively. The Master Plan adopted the period from 1955 to 1979 and the Power Sector Development Plan from 1940 to 1979.

Fig. 6-10 shows the variation of annual rainfall at Ifakara which has long series of data and is thought to represent the Kihansi Basin fully, because the distance between the Kihansi River and Ifakara is only 100 km. Actually, the correlation coefficient between the monthly rainfall at Mapanda situated in the Kihansi Basin and that at Ifakara is 0.861. According to this figure, there are two tendencies at the boundary of mid 1950's, that is, the rainfall before then is generally less than the rainfall after 1950's. This phenomenon is indicated clearer by means of the mass-curve shown in Fig. 6-11. The dotted line of this figure means the mass-curve of annual discharge of the Zambezi River flowing through Zimbabwe and this curve resembles the mass-curve of annual rainfall at Ifakara very much in spite of some time lag. Moreover, the water level of Lake Victoria is thought to be an index of not only the variation of rainfall in Eastern Africa but also the climatic cycle in the whole tropical regions and the variation of it corresponds to the above two curves. The water level record of Lake Victoria has been observed since the end of 19th century. Although the water level was very high in 1870's, it lowered year by year until the beginning of 20th century and kept relatively constant height for almost sixty years. It, however, increased after 1962 rapidly and such a condition has continued until now.

**Fig. 6-10 Variation of Annual Rainfall at Ifakara**

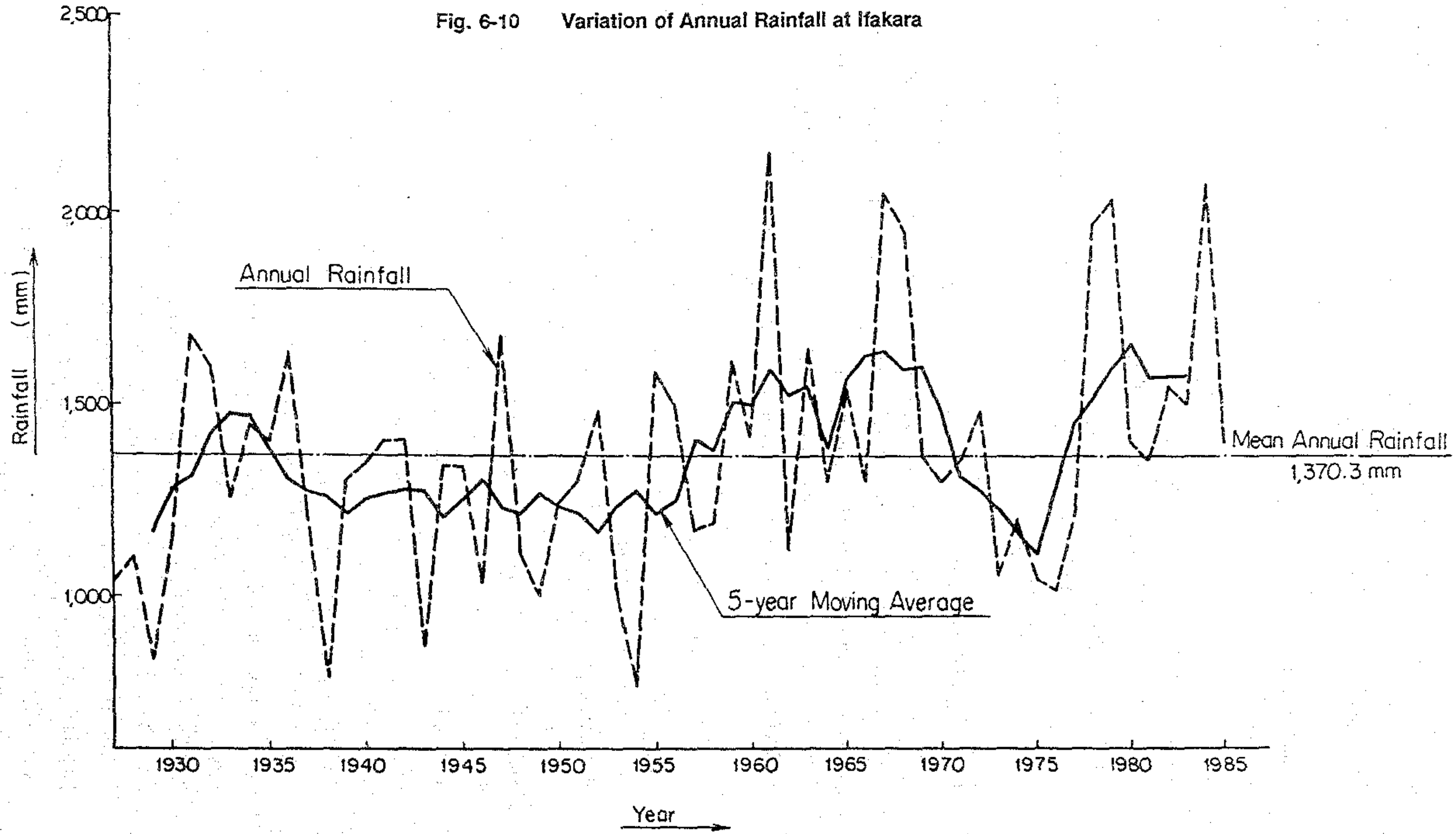
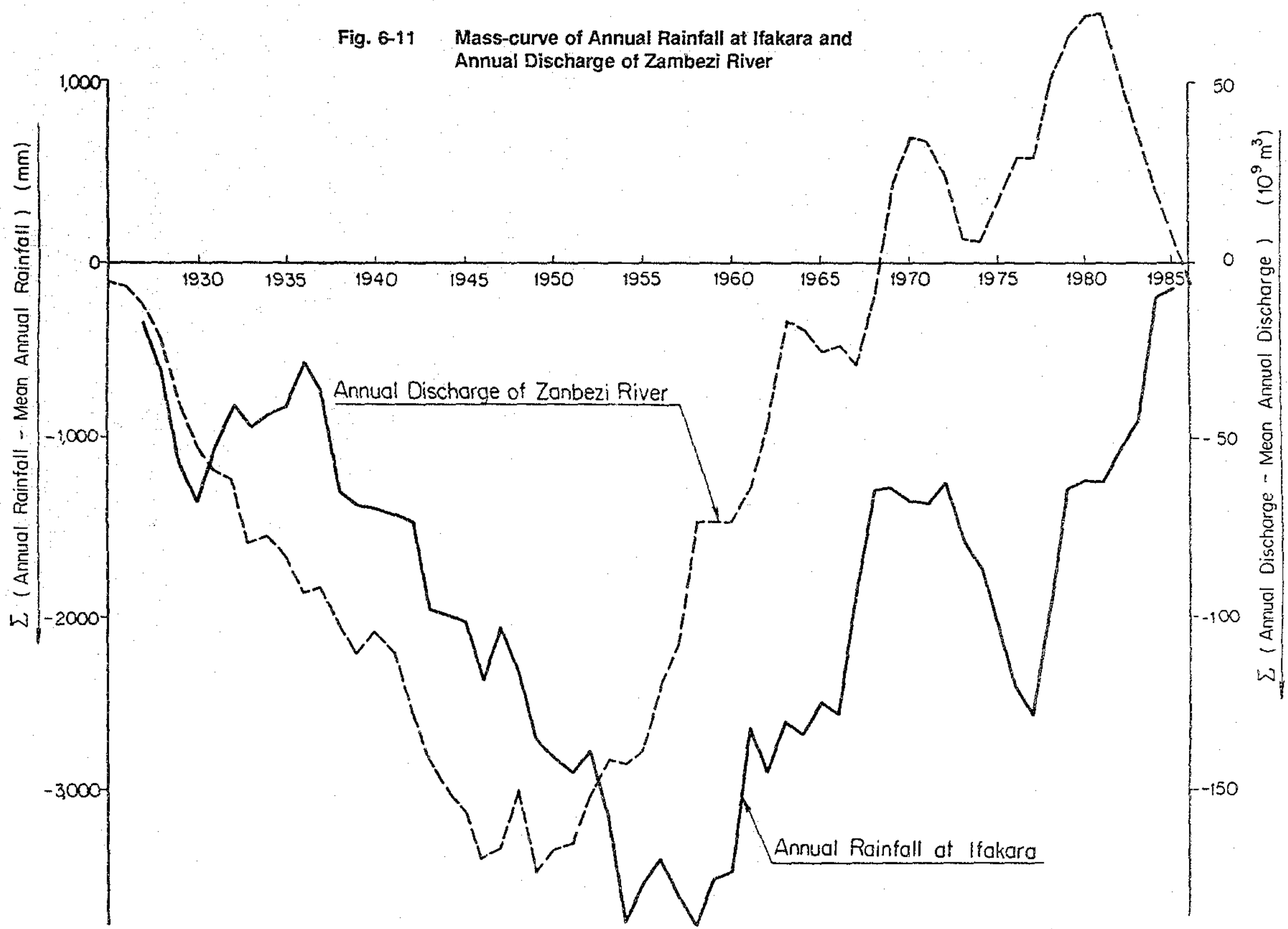


Fig. 6-11 Mass-curve of Annual Rainfall at Ifakara and Annual Discharge of Zambezi River



Accordingly, the hydrologic records should be expanded as long as possible before 1955 in order to estimate the appropriate energy generation and above all the firm energy reflecting both wet and dry years.