No.

INTERNAL DRAINAGE BASIN WATER OFFICE
MINISTRY OF WATER
THE UNITED REPUBLIC OF TANZANIA

THE STUDY ON THE GROUNDWATER RESOURCES DEVELOPMENT AND MANAGEMENT IN THE INTERNAL DRAINAGE BASIN IN THE UNITED REPUBLIC OF TANZANIA

FINAL REPORT

SUMMARY

FEBRUARY 2008

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

OYO INTERNATIONAL CORPORATION
KOKUSAI KOGYO CO. LTD.

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Exchange rate on Jan. 2008 is US$ 1.00	= Tanzanian Shilling Tsh 1,108.83
	= Japanese Yen ¥ 114.21

PREFACE

In response to a request from the Government of the United Republic of Tanzania, the Government of Japan decided to conduct "The Study on the Groundwater Resources Development and Management in the Internal Drainage Basin in the United Republic of Tanzania" and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched a study team composed of OYO International Corporation (OYO) and Kokusai Kogyo Co., Ltd., headed by Mr. Norifumi YAMAMOTO of OYO to Tanzania between September 2005 and December 2007. In addition, JICA set up an advisory committee in order to examine the study from specialist and technical points of view.

The study team held discussions with the officials concerned of the Government of the United Republic of Tanzania, and conducted field surveys in the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to a promotion of further steps and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of the United Republic of Tanzania for their close cooperation extended to the team.

February 2008

Ariyuki MATSUMOTO
Vice President
Japan International Cooperation Agency

THE GROUNDWATER RESOURCES DEVELOPMENT AND MANAGEMENT IN THE INTERNAL DRAINAGE BASIN IN THE UNITED REPUBLIC OF TANZANIA

February 2008

Mr. Ariyuki MATSUMOTO
Vice President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit the final report entitled "The Study on the Groundwater Development and Management in the Internal Drainage Basin in the United Republic of Tanzania". The Study Team has prepared this report in accordance with the contract between Japan International Cooperation Agency and OYO International Corporation in association with Kokusai Kogyo Co. Ltd.

The Study Team has examined the present conditions related to natural and socio-economic aspects of the Internal Drainage Basin, formulated hydrogeological map and assessed groundwater development potentiality for the future plan.

The report consists of the Summary, Main Report, Supporting Report, GIS Figure Book and Data Book. The Supporting Report includes details of the Study by study-item-wise or expert-wise approach. The Main Report is made considering a storyline of the study results. The Summary summarizes the Main Report as a whole. GIS Figure Book contains major maps which were formulated through the Study including hydrogeological map, groundwater potential evaluation maps and so on. Finally, the Data Book contains all basic data and drawings used in the Study.

All the members of the Study Team wish to express grateful acknowledgements to Japan International Cooperation Agency (JICA), Ministry of Foreign Affair, and also to Tanzanian officials and individuals for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the proper development and management of groundwater resources in IDB, and that amicable relation of both countries will be promoted further by this occasion.

Yours faithfully,

Norifumi YAMAMOTO
Team Leader

EXECUTIVE SUMMARY

1. Background of the Study

The Internal Drainage Basin (hereinafter referred to as "IDB") is situated in the north-eastern part of the country. IDB is the second largest basin in Tanzania, which extends over 6 regions (Arusha, Shinyanga, Manyara, Dodoma, Singida, and Tabora) with a nominal area of 153,800km^2. The annual precipitation in almost the whole IDB ranges from 600mm to 900mm with annual evapotranspiration rate of over 2,000mm. Since it is known that the minimum annual precipitation for corn growth is 600mm, the water resources condition in IDB is considerably severe.

Moreover, there are water quality problems in IDB caused by its natural characteristics, especially the internal drainage system which leads to accumulation of inorganic salts or materials hazardous to health, such as fluoride in surface water and groundwater. In water resources development, groundwater development is an urgent issue in particular to provide adequate safe and reliable water supply under such circumstances. However, there are constraints in the planning and execution of water supply, because there is no integrated management of data and information related to the existing water supply facilities, hydrology, geomorphology, hydrogeology, water quality, socio-economy, etc.

Location Map of IDB

The Internal Drainage Basin Water Office (IDBWO) was established on 29th October 2004 to manage water resources in a comprehensive manner. However, the office has not been fully functioning due to lack of budget, equipment, human resources and so on.

2. Objectives of the Study

Under the above-mentioned circumstances, this Study was formulated and conducted in order to evaluate groundwater development potential and identify water contamination areas for planning of drinking water supply projects in IDB. Major objectives of the Study are as follows.

- To formulate hydrogeological map with necessary information for development and management plan of water resources and water supply for IDB.
- To develop the capability of counterpart personnel of Ministry of Water and other authorities concerned in the course of the Study.

3. General Description of the Study Area

3.1 Definition of IDB

The accurate boundary of IDB was redefined by analyzing data of Digital Elevation Model (DEM) by SRTM Shuttle Rader Topography Mission (SRTM). Based on the analysis, the area of Tanzanian part of IDB was found to be 143,100 km^2, which had been estimated at 153,800 km^2 previously.

3.2 Administrative Setting

Since the definition of IDB boundary is based on the hydrological condition for watershed management or river basin management, it is different from the existing administrative boundaries. IDB is covered by the parts of six regions whose related administrative organizations consist of 24 districts and 3 municipalities. Total villages and population within IDB were estimated at more than 1,650 and more than 4.5 million respectively.

3.3 Meteorology and Hydrology

The climatic type of IDB mainly belongs to “Tropical Savannah”. The season of IDB is divided into the dry season from June to October and rainy season from November to May. The average annual rainfall in most parts of IDB ranges from 600 to 900 mm/year; but the north-eastern part of IDB near the border of Kenya comes to more than 1,000 mm/year. IDB can be subdivided into nine sub-basements or sub-catchments. Almost all of the rivers in IDB are seasonal rivers which flow from December to July, but they are completely dried up as for the rest. All river water drains into lakes and swamps of varying size within IDB.

3.4 Geomorphology & Geology

Geomorphologic and geological features of IDB are closely related to “East African Rift System (EARS)”. The Eastern Rift of EARS: namely, “Gregory Rift” is running north and south, and its tectonic movement formed Lake Natron, Lake Eyasi, Lake Manyara and so on. Geology of IDB consists of three typical types of geology: i) Granitic rocks and Metamorphic rocks in Precambrian, ii) Volcanic rocks in Tertiary to Quaternary, and iii) Sediments in Neogene to Holocene distributed around Bahi Swamp and Wembere Swamp. Volcanic landforms such as Mt. Kilimanjaro and Ngorongoro Crater, which can be seen in the north-eastern part of IDB, were also built up by EARS. There are many faults caused by EARS in IDB, which are regarded as the noteworthy geological structure for groundwater exploration

3.5 Socio-economic Conditions

The socio-economic conditions in IDB can be summarized as the following according to the existing statistical data for districts in six regions.

- In IDB, which occupies 15% of the nation, there reside about 450,000 people, and 90% of them live in rural areas.
- Roughly half of the GDP in IDB is contributed by agricultural sector. The major food products

of them are maize, sorghum and rice, and the major cash crops are coffee, cotton, and cigarette.

- Rough breakdown of the livestock is: cattle (50%), goat (30%), and sheep (15%).
- The pavement ratio in IDB is 3%, which is much less than the national average of 12.2% and the electrification ratio is only 5%.
- The water supply coverage is 37.5%, which is much lower than the national average of 53.1%
- Due to lack of water resources, only 30% of the cultivated lands and irrigated areas are utilized.

The following is the result of village surveys conducted in order to understand the socio-economic conditions of the rural regions in IDB.

- The average annual household income of villages in IDB is 920,000 Tsh, and the expenditures for water and health are 5% and 3% of the income, respectively.
- For water supply, villagers prefer a traditional hand-dug well, which is cheap and easy to fetch water from, without regard of safety and stability of water.
- Water-supply issues in villages include not only distance to water sources but also poor performance of water supply facility, which causes a long waiting time to fetch water.
- Villagers understand the importance of their investment on construction and maintenance of new water facilities. However, they do not understand the idea of water-right fees very well.

4. Water Quality Analysis and Fluoride Problems

4.1 Water Quality Analysis

Simplified water quality tests were carried out at 264 points in the rainy season and at 317 points in the dry season. Laboratory tests of water quality were carried out at 157 points (139 points for existing water sources and 18 points for test drilling wells). From the results of comprehensive analysis based on the results of them, the following features of water quality in IDB were found.

- Many of the lakes in the study area are shallow lakes with the maximum water depth of 3m or less and many are alkaline lakes with extremely high concentration of fluoride in the water.
- As for surface water in the study area, high fluoride concentration in the rivers, dams and ponds was observed in Shinyanga Region (the average: 2.4 mg/l) and that in springs was observed in Arusha Region (the average: 2.6 mg/l).
- As for groundwater in the study area, the highest fluoride concentration in the shallow groundwater was observed in Arusha Region (the average: 3.0 mg/l) and the highest fluoride concentration in the deep groundwater was observed in Shinyanga Region (the average: 4.1 mg/l).
- The seasonal change of Fluoride and Electric Conductivity in water sources in the study area shows that the concentration increases slightly in the dry season.
- According to the results of the analysis by hexa-diagrams and trilinear diagrams, some of the fluoride-rich water sources in IDB have high concentration of alkaline bicarbonate ($NaHCO_3$)

and others are rich in alkaline non-carbonate (NaCl), and the water sources of alkaline bicarbonate ($NaHCO_3$) type tend to have longer residence times and higher fluoride concentration than those of alkaline non-carbonate (NaCl) type.

- The elution of fluoride from the volcanic strata and the effect (infiltration)of fluoride from the alkaline lakes are considered as a possible supply source of fluoride to the water sources in the study area.

4.2 Fluoride Problems

Overall condition of fluoride problems in IDB was checked by dental fluorosis survey.

- Dental fluorosis survey was conducted for 2,912 children of 96 villages in IDB. According to the result of this survey, 85.4%of the children had at least one tooth with more than moderate degree of dental fluorosis (Thylstrup-Fejerskov Index (TFI) >4).
- Obvious influence of dental fluorosis extends to the northern part of IDB covered by the younger volcanic rocks. The influence is also recognized around Shinyanga and Singida areas covered by granitic bedrocks with pegmatite.
- On an average of TFI by Regions in IDB, Arusha showed the worst score: TFI 4.3, Dodoma the best score: TFI 1.8 and Singida was TFI 3.4.
- Results of dental fluorosis analysis in IDB somewhat imply relationship between fluoride concentration of drinking water and dental fluorosis (TFI). However, it cannot be necessarily concluded that fluoride in the groundwater causes fluorosis, because it is considered that Magadi containing high concentration of fluoride may have more severe impact on fluorosis.
- There are several ways to remove fluoride technically from water, but it is actually not preferred to adopt them in consideration of the current socio-economic conditions of the rural areas in IDB. Awareness campaign of fluoride problems, guidance to better water sources with less fluoride concentration and discouraging consumption of Magadi as temporary measures are needed in terms of impact or risk management before full-scale countermeasure against fluorosis.

5. Organizational Conditions and Capacity Development Program

In Tanzania, water resources development and management are carried out based on the National Water Policy 2002 (NAWAPO), which introduced the concept of Integrated Water Resources Management (IWRM). Since IDBWO was newly established two years after NAWAPO, the office was not well functioning at the beginning of the Study. Therefore, capacity development programs consisting of upskilling programs and organization strengthening program were executed to raise the performance level of IDBWO.

6. Hydrogeology and Water Balance Analysis

6.1 Hydrogeology

Hydrogeological conditions in IDB were analyzed based on the water resources management database for IDB, which consists of existing data and the results of geophysical survey, test borehole drilling survey, water quality survey, satellite image analysis, socio-economic survey and so on. Groundwater productivity was evaluated based on the distribution of static water level, bedrock depth and well yield, and flow direction of groundwater. Areas with high productivity groundwater are located 1) along the fault system related on the Great Rift Valley, 2) around the volcanic mountains, 3) in the vicinity of boundary between granitic rocks and metamorphic rocks. High productivity is also expected in a fissure type of aquifer in granitic rocks. On the other hand, the areas covered by sediments have low groundwater productivity because of the accumulated fine materials. These results were assembled into the hydrogeological map.

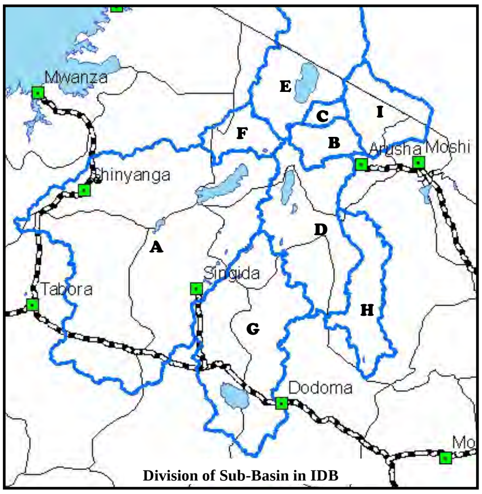
6.2 Water Balance Analysis

Water balance and groundwater recharge in each sub-basin were analyzed with meteorological, hydrological, and remote sensing data. Three kinds of water balance analyses were conducted: a) firstly, monthly macro water balance in each sub-basins in the IDB (minimum analysis unit: sub-basin), b) secondly, the analysis concentrated on grasping the distribution of the infiltration potential in each sub-basin in the rainy season (minimum analysis unit of 75 m/pixel) and c) thirdly, the analysis applied to the sub-basin G to obtain more detailed distribution of the infiltration potential under consideration of surface water runoff during rainy and dry season (minimum analysis unit of 75m/pixel). The results are as follows.

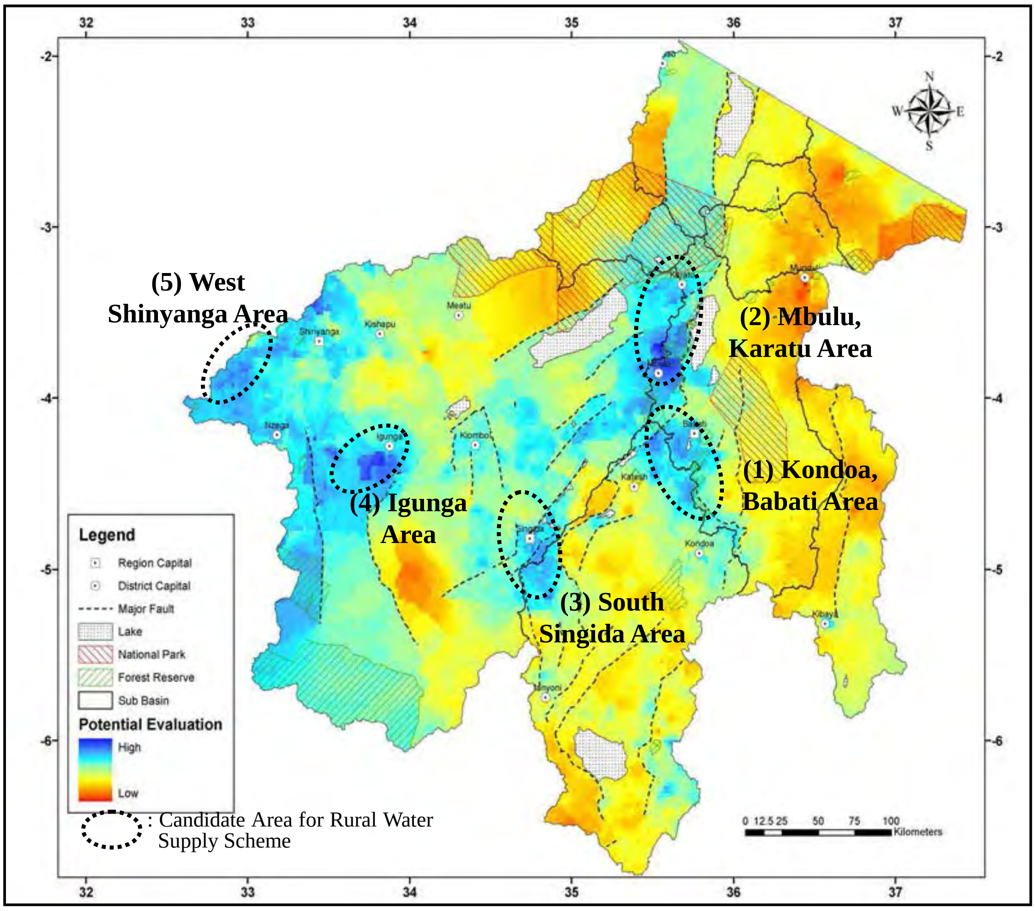
- Possible infiltration during the dry season is almost “zero” in IDB.
- Annual possible infiltration (per unit area) in IDB is higher in the northern area than that in the southern area and the monthly infiltration in the northern area is unevenly distributed in April during the rainy season. However, the monthly infiltration in the southern area during the rainy season is rather stable.
- There are high precipitation and high possible infiltration areas in and around Lake Eyasi and Lake Manyara.
- There are areas with stable monthly infiltrations but not so much in and around Tabora region.
- The runoff in the sub-basin G is around 2% to 11% during the rainy season.
- The infiltration in the sub-basin G is higher in the northeast area than in the southwest area.

7. Groundwater Potential Evaluation

Groundwater potential evaluation map was completed stakeholder friendly. Since one of the main purposes of this study is to evaluate groundwater potential in IDB from hydrogeological and hydrological points of view, high potential areas in IDB can be easily distinguished. Synthetic analysis with groundwater potential evaluation and social conditions with population density and rural water supply ratio indicate that five areas: i) Kondoa/Babati area, ii) Karatu/Mbulu area, iii) South Singida town area, iv) Igunga area and v) West Shinyanga area, have relatively high potentiality for rural water supply scheme.



Sub-basins in IDB



Groundwater Potential Evaluation and Candidate Areas for Rural Water Supply Scheme

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ABBREVIATION

ADM	Administrative
As	Arsenic (mg/L)
B.H.	Borehole
BWB	Basin Water Board
BWO	Basin Water Office
C/P	Counter Part
CDP	Capacity Development Program
CFI	Community Fluorosis Index
DB	Database
DBMS	Database Management System
DC	District Council
DDCA	Drilling and Dam Construction Agency
DEM	Digital Elevation Model
DWE	District Water Engineer
DWL	Dynamic Water Level (m)
EA	Enumeration Area
EC	Electric Conductivity (mS/m)
ETM	Enhanced Thematic Mapper
F	Fluoride (mg/L)
Fe	Iron (mg/L)
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit
IDB	Internal Drainage Basin
IDBWO	Internal Drainage Basin Water Office
IFAD	International Fund for Agricultural Development
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
LANDSAT	Land sensing Satellite
MC	Municipality Council
Mn	Manganese (mg/L)
MoF	Ministry of Finance
MoLD	Ministry of Livestock Development
MoW	Ministry of Water
MoWLD	Ministry of Water and Livestock Development
MS	Microsoft
MWE	Municipal Water Engineer
NBS	National Bureau of Statistics
NGO	Non Government Organization
NH_4	Ammonia Ion (mg/L)
NO_3	Nitrate Ion (mg/L)
NSGRP	National Strategy for Growth and Reduction of Poverty

O&M	Operation & Maintenance
OJT	On the Job Training
ORP	Oxidation Reduction Potential (mV)
OSP	Organization Strengthening Program
OST	Organization Strengthening Team
PMO-RALG	Prime Minister's Office - Regional Administration and Local Government
PRSP	Poverty Reduction Strategy Paper
RAS	Regional Administrative Secretariat
RCU	Regional Consultancy Unit
RWE	Regional Water Engineer
RWSSP	Rural Water Supply and Sanitation Programme
S	Sulphate Ion (mg/L)
SAVI	Soil Adjusted Vegetation Index
SEMA	Sustainable Environment Management Action
SMD	Surveys and Mapping Division
SRTM	Shuttle Rader Topography Mission
SWL	Static Water Level (m)
TANESCO	Tanzania Electric Supply Company
TAZARA	Tanzania and Zambia Railways
TDS	Total Dissolved Solid
TFI	Thylstrup and Fejerskov Index
TOR	Terms of Reference
TPDC	Tanzanian Petroleum Development Corporation
TPTC	Tanzanian Posts and Telecommunication
TRC	Tanzania Railways Corporation
TTCL	Tanzanian Telecommunication Company Ltd.
TWA	Technical Water Advisor
UNCSD	United Nations Commission on Sustainable Development
UNCTAD	United Nations Conference on Trade and Development
UTM	Universal Transverse Mercator
VEO	Village Executive Officer
VES	Vertical Electrical Sounding
VSW	Vegetation-Soil-Water
WFP	World Food Program
WGS	World Geodetic System
WHO	World Health Organization
WRD	Water Resources Division
WUA	Water User Association
WUC	Water User Committee
WUG	Water User Group

Chapter 1
Introduction

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

The Internal Drainage Basin (hereinafter referred to as "IDB") is situated in the north-eastern part of the country (Refer to Figure 1-1 and 2). IDB is the second largest basin in Tanzania as shown in Table 1-1, which extends over six regions (Arusha, Shinyanga, Manyara, Dodoma, Singida, and Tabora) with a nominal area of 153,800 km^2. The total population in IDB is approximately 4.5 million. The annual precipitation in almost whole IDB ranges from 600mm to 900mm with annual potential evapotranspiration rate of over 2,000mm.

Since it is known that the limiting values of annual precipitation for corn growing is 600mm, the water resources condition in IDB is considerably severe. Moreover, there are water quality problems in IDB caused by its natural characteristics, especially the internal drainage system which leads to accumulation of inorganic salts or materials hazardous to health, such as fluorides in surface water and groundwater.

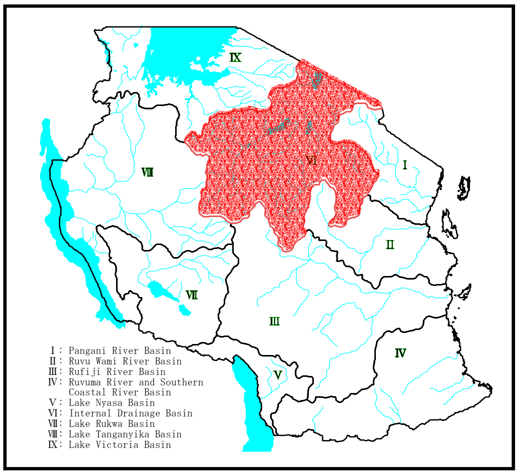


Figure 1-1 Nine River Basins in Tanzania

Table 1-1 Area of Basins

No.	Basin	Area (km^2)
I	Pangani	56,300
II	Wami/Ruvu	72,930
III	Rufiji	177,420
IV	Ruvma/Southern Coast	103,720
V	Lake Nyasa	75,230
VI	Internal Drainage	153,800
VII	Lake Rukwa	81,180
VIII	Lake Tanganyka	137,900
IX	Lake Victoria	79,570

: Study Area

Water resources development, particularly groundwater development is an urgent issue to provide adequate safe and reliable water supply under such circumstances. However, there are constraints in the planning and execution of water supply, since there is no integrated management of data and information related to existing water supply facilities, hydrology, geomorphology, hydrogeology, water quality, socio-economy etc. The Internal Drainage Basin Water Office (hereinafter referred to as IDBWO) was established on 29th October 2004 to manage water resources in a comprehensive manner. However, IDBWO has not been functioning fully because it was newly established based on the new policy: Water Policy 2002 and the new concept: Integrated Water Resources Management.

1.2 Objectives of the Study

Under the above-mentioned circumstances, this Study was formulated and conducted in order to evaluate groundwater development potential and identify water contamination areas for planning of drinking water supply projects in IDB. Major objectives of the Study are as follow.

- To formulate hydrogeological map with necessary information for development and management plan of water resources and water supply for the Internal Drainage Basin,
- To develop the capability of counterpart personnel of Ministry of Water and other authorities concerned in the course of the Study.

1.3 The Study Area

The study area is located in the north-eastern part of Tanzania as shown in Figure 1-2; it covers a whole IDB: 143,100km^2 or 16.4 percentage of the country.

Figure 1-2 Location Map of the Internal Drainage Basin

1.4 Study Schedule

The Study is scheduled to be completed in a period of approximately 28 months between the late September 2005 and the late December 2007. Total schedule of the Study is shown in Figure 1-3.

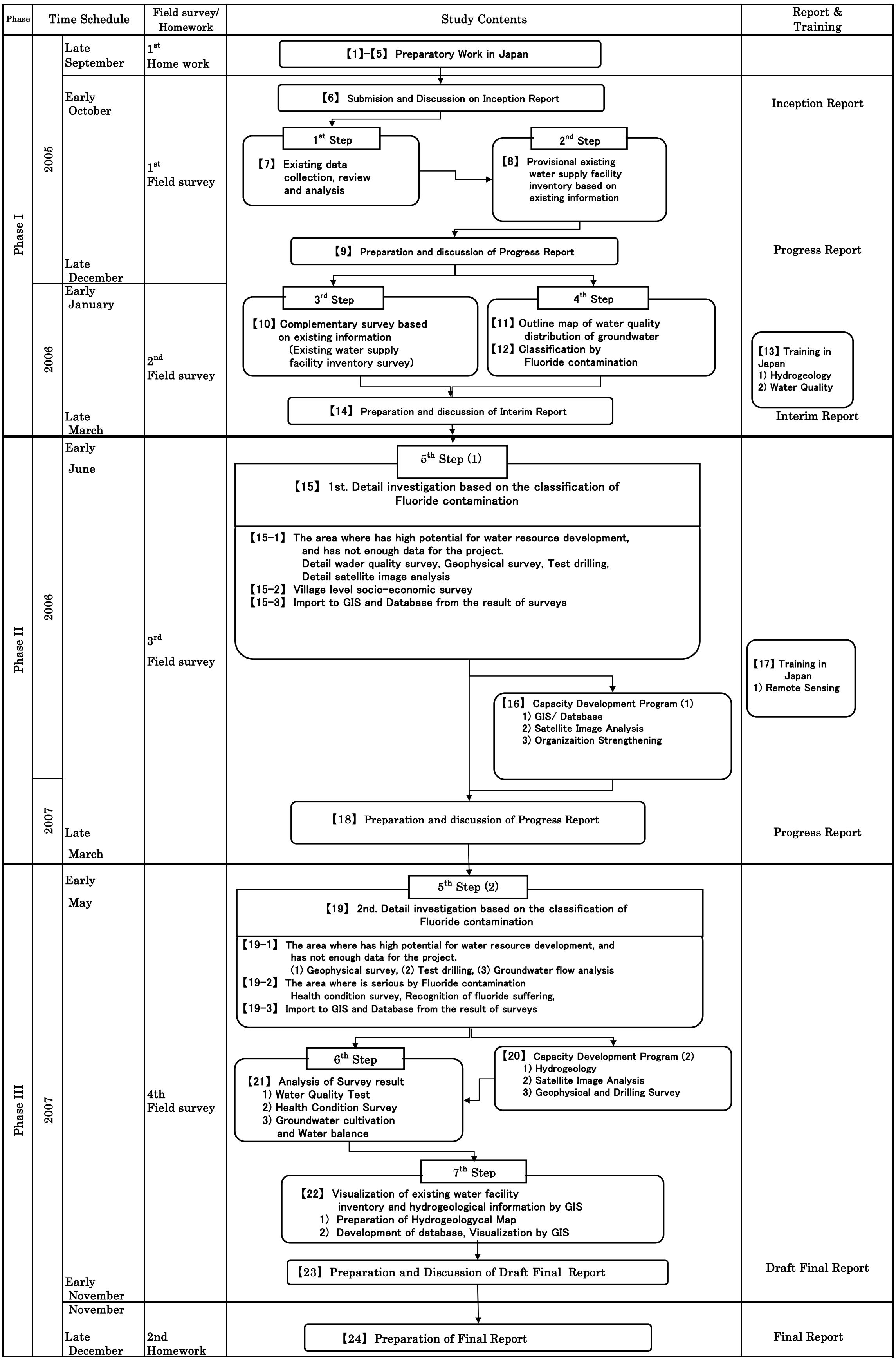


Figure 1-3 Flow Chart of the Study

1.5 Member List of the Study

The members involved in the Study and the Steering Committee for the Study are listed in Table1-2, and 1-3.

Table 1-2 Member List of the Study

Name	Assignment
<JICA>	
Mr. Hidetake AOKI	Staff / JICA Headquarters
Mr. Daigo KOGA	Assistance Resident Representative
<JICA Study Team>	
Mr. Norifumi YAMAMOTO	Team Leader
Mr. Shinichi ISEKI	Deputy Team Leader / Hydrogeologist (1)
Mr. Shigeaki MATSUO	Hydrogeologist (2) / Remote Sensing Expert
Mr. Masamichi HARAGUCI	GIS / Database Expert
Dr. Takayoshi KURATA	Water Quality Specialist
Mr. Ichiro TANAKA	Hydrologist
Mr. Jun MATSUO	Geophysicist / Test Drilling Supervisor
Ms. Rumi SAWADA	Socio-economist
Dr. Lillian D. MINJA	Health Survey Supervisor
Mr. Shinya KAWADA	Environment Consideration Expert
Mr. Takashi HARA	Coordinator
<C/P Staff>	
Mr. J.S.Nasari	Team Leader
Mr. A.H. Bwanguzo	Deputy Team Leader
Mr. N. M.Mgozi	Hydrogeologist / Remote Sensing Expert
Mr. K. Mpanda	G.I.S. Data Expert
Mr. F. Saroni	Water Quality Specialist
Mr. Y. Hema	Hydrologist
Mr. G. Lyatuu	Geophysicist / Test Drilling Supervisor
Mr. Sebastian Mundia	Socio-economist
Mr. Joseph Seni	Health Survey Supervisor
Mr. Richard Masao	Environment Consideration Expert

Table 1-3 Member List of the Steering Committee

Name	Position
<Ministry of Water (MoW)>	
Mr. Washington Mutayoba	Director, Water Resources Division (WRD)
Dr. Hassani J. Mjengera	Director, Water Laboratories
Mr. Lister R.E. Kongola	Assistant Director, WRD
Ms. Elder Mcharo	Principal Hydrogeologist, WRD
<Internal Drainage Basin Water Office (IDBWO)>	
Mr. Joseph S. Nasari	Basin Water Officer (former)
Mr. Ahmed M. H. Bwanguzo	Principal Hydrogeologist
Mr. Festo Saroni	Senior Technician - Water Quality
Ms. Paulina Duki	Personal Secretary
<Arusha Region>	
Mr. Paul M. Nginita	Representative of Technical Advisor - Water (TAW, Regional Secretariat (RS))
<Manyara Region>	
Mr. Shadrack Shoo	TAW (RS)
<Shinyanga Region>	
Mr. M. N.Mgozi	Representative of TAW(RS)
<Singida Region>	
Mr. Alphouce J. Mchome	Representative of TAW (RS)
Mr. A. A. Kusenha	Manyoni District Water Engineer
<Dodoma Region>	
Mr. Robert Mganga	Representative of Kondoa District Water Engineer

Chapter 2
General Description of Study Area

CHAPTER 2 GENERAL DESCRIPTION OF THE STUDY AREA

2.1 Definition of Internal Drainage Basin

"River Basin Management" has been applied for water resources management in Tanzania since the 80s. The national land was sub-divided into nine river basins in the Act No.10 (1981). On the other hand, "Integrated Water Resources Management (IWRM)" was applied in the "National Water Policy" (July 2002) in Tanzania which deals with water resources including river water, groundwater, lake water etc. comprehensively allocating them for the related stakeholders.

This Study is expected to play an important role in order to provide fundamental information for IWRM in IDB. At the beginning of the Study, the IDB boundary was redefined as the river basin or watershed.

IDB boundary and sub-basin boundaries were defined precisely with Digital Elevation Model (DEM) data by Shuttle Radar Topographic Mission (SRTM) as illustrated in the Figure 2-1. According to this analysis, it reveals that several sub-basins in the previous nominal area of IDB should not be included in IDB but in the neighbouring basins, namely "J" sub-basin belongs to the "Pangani Basin", "K" and "L" sub-basins belong to the "Wami Basin". "I" sub-basin is considered to be an internal basin itself. The area of IDB in the Study is 143,099km^2 which consists of Tanzanian side of "A" to "I" sub-basins as shown in Table 2-1.

Table 2-1 Area of IDB and Sub-basins

Sub-basin	Area	Tanzanian Side	Kenyan Side	Internal Drainage Basin	Note
A	64,545	64,545	-	64,545	Lake Eyasi Sub-basin
B	4,115	4,115	-	4,115	Monduli Sub-basin (1)
C	1,385	1,385	-	1,385	Monduli Sub-basin (2)
D	18,491	18,491	-	18,491	Lake Manyara Sub-basin
E	26,224	8,658	17,566	8,658	Lake Natron Sub -basin
F	4,577	4,577	-	4,577	Olduvai Sub-basin
G	26,445	26,445	-	26,445	Bahi (Manyoni) Sub-basin
H	9,313	9,313	-	9,313	Masai Steppe Sub-basin
I	14,080	5,570	2,939	5,570	Namanga Sub-basin (Internal)
J	7,122	7,122	-	-	Belong to Pangani Basin
K	1,018	1,018	-	-	Belong to Wami Basin
L	907	907	-	-	Belong to Wami Basin
Total	178,221	152,146	20,505	143,099	-

(Unit: km^2)

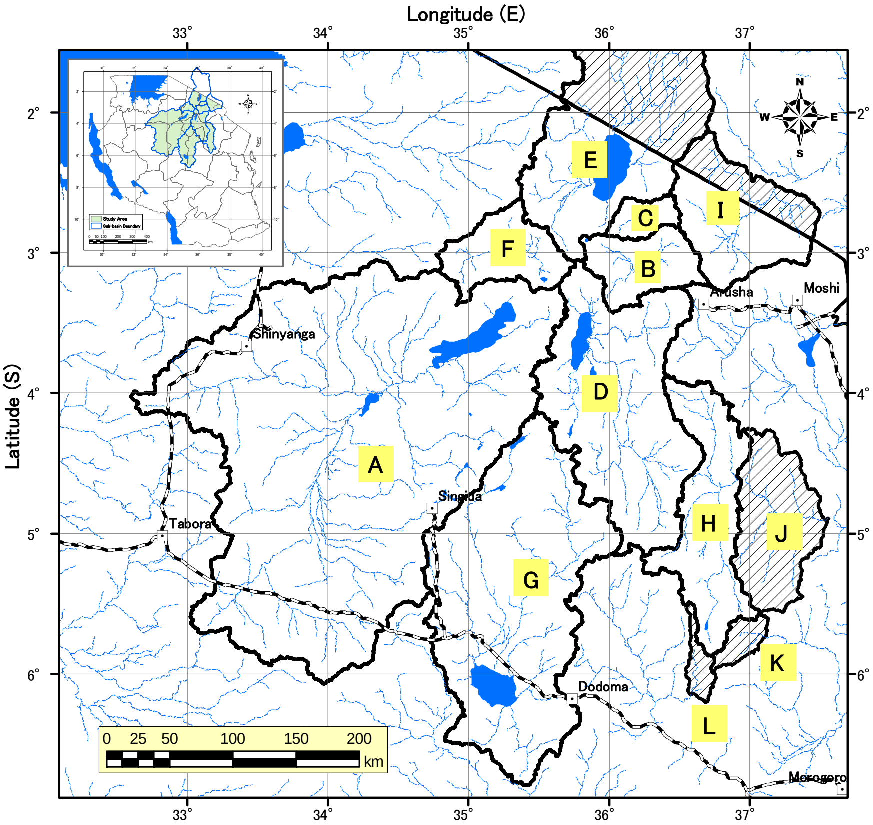


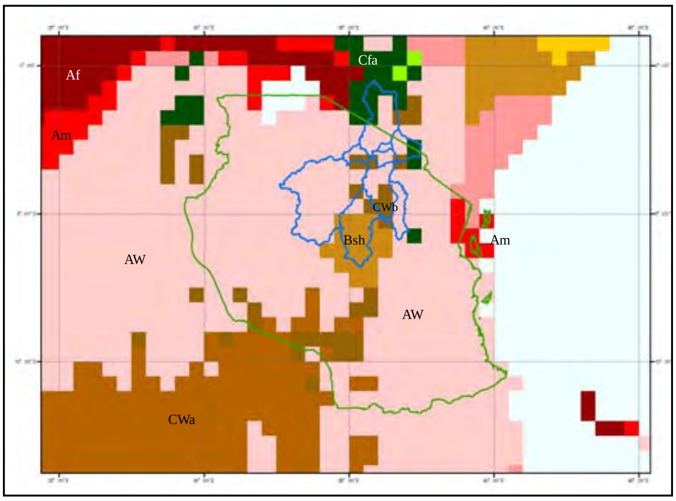
Figure 2-1 Basin and Sub-basin Boundaries of IDB

(*J, K, L sub-basins are excluded in IDB)

2.2 Meteorology and Hydrology

2.2.1 Meteorology

Climate type of Tanzania is mainly classified into "Tropical Savannah (Aw)" based on Koppen Climate Classification as shown in Figure 2-2. There are four types of climate in detail in IDB: Tropical Savannah (Aw), Steppe (Bsh), Humid Subtropical (Cwb), and Humid Subtropical (Cfa, with no dry season).



Af: Tropical Wet Climate, **Aw**: Tropical Savanna Climate, **Am**: Tropical Monsoonal Climate, **Bsh**: Steppe Climate, **Cwa/Cwb**: Humid Subtropical, **Cfa**: Humid Subtropical (No dry season)

(Source: World Map of Koppen-Geiger Climate Classification Updated, Univ. of Vienna (April 2006))

Figure 2-2 Climate Types of Tanzania and IDB

(1) Air Temperature

Air temperature of IDB was analyzed as Figure 2-3 which presents average maximum and minimum temperatures at major meteorological stations in IDB or its adjacent area. Annual variation and difference of maximum temperature among the stations is larger than those of minimum temperature. The distribution pattern of Tabora is different from others.

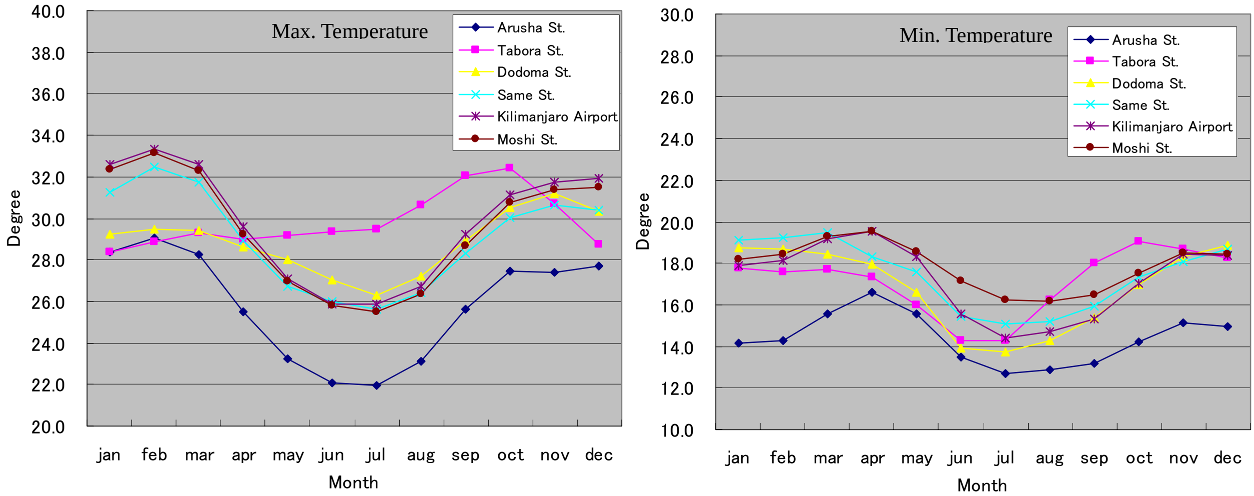


Figure 2-3 Maximum and Minimum Temperatures in IDB and its Adjacent Area

(2) Annual Rainfall

Annual rainfall distribution is the one of the most important items for water resources analysis. The results on the annual rainfall distribution are shown as Figure 2-4. The map indicates that the north-eastern area of IDB surrounding Mt. Kilimanjaro is relatively high rainfall area, but Dodoma area is under the most severe condition, where the rainfall is only 600 mm/year.

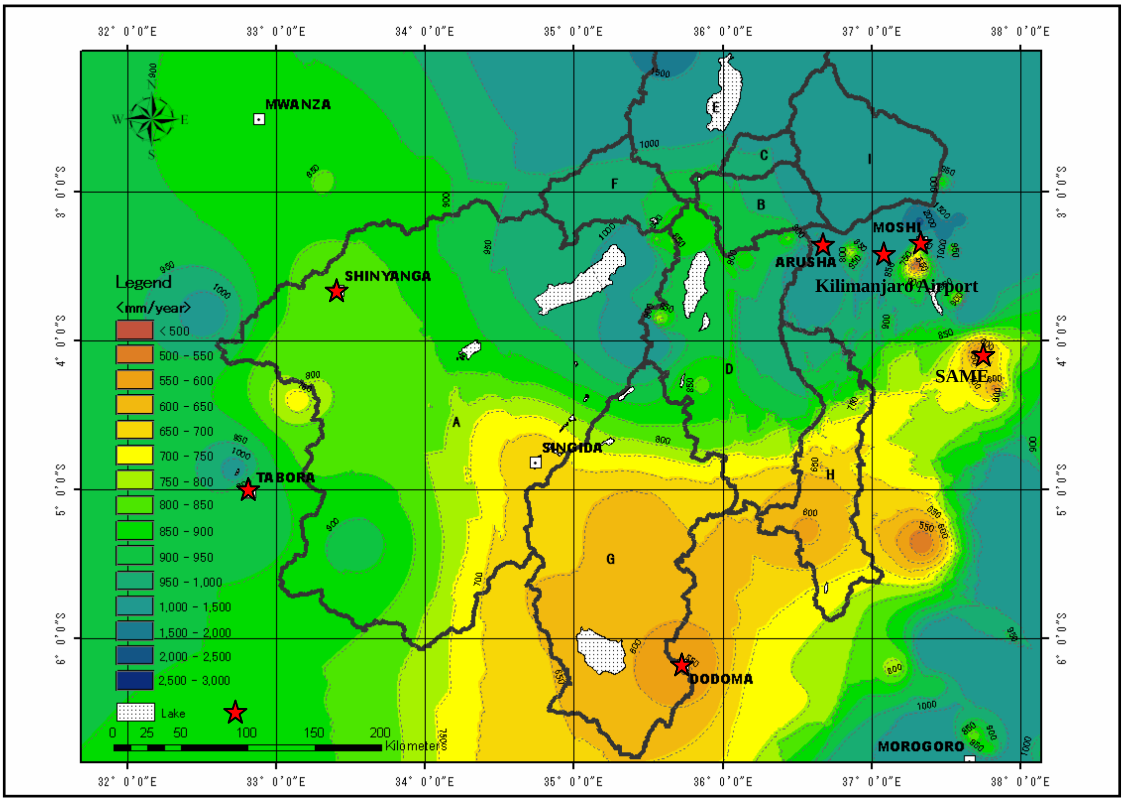


Figure 2-4 Annual Rainfall in IDB and Locations of Meteorological Stations

(3) Seasonal Change of Monthly Rainfall

Figure 2-5 presents average monthly rainfalls at major weather stations in IDB. It shows that the rainy season is from October or November to May and the dry season is from June to September.

(4) Sunshine Duration

Sunshine duration of the several stations in IDB is shown as Figure 2-6. Annual variation patterns of it among the stations are divided into two groups: i) Tabora - Dodoma group, and ii) Arusha - Kilimanjaro - Moshi group. The distributions of these two groups show completely opposite tendencies.

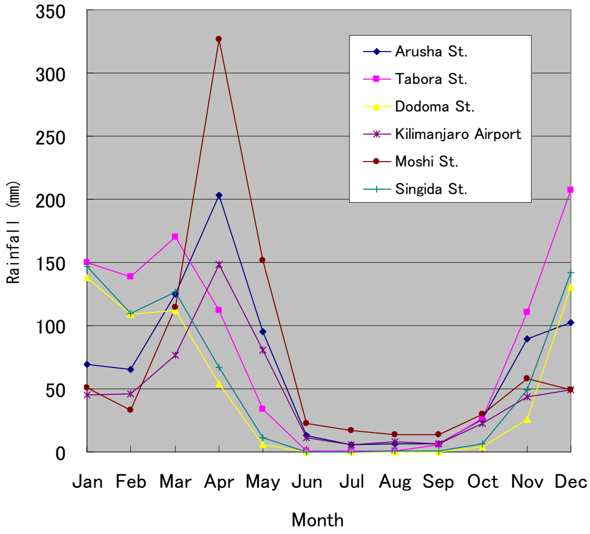


Figure 2-5 Monthly Rainfall of Major Towns in IDB and its Adjacent Area

(5) Potential Evaporation (Pan Evaporation)

Average pan evaporation of the several stations in IDB is shown in Figure 2-7. The highest value was recorded at Shinyanga weather station in October. The seasonal change of potential evaporation follows the temperature and the wind-run.

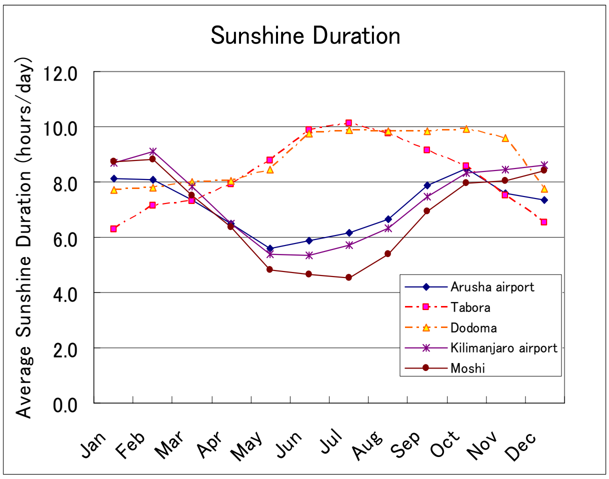


Figure 2-6 Sunshine Duration of Major Towns in IDB and its Adjacent Area

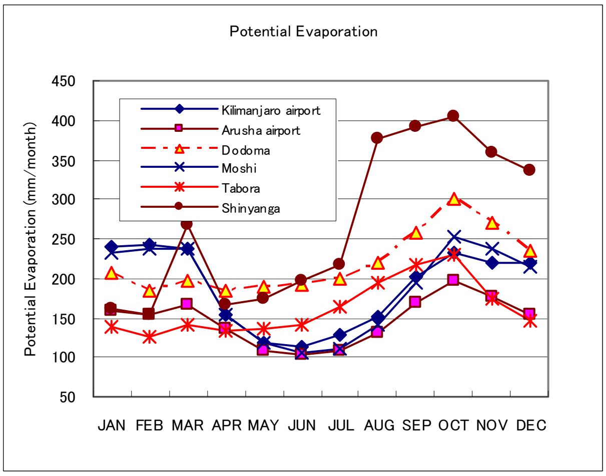


Figure 2-7 Potential Evaporation of Major Towns in IDB and its Adjacent Area

(6) Relative Humidity

Relative humidity of IDB at 9 A.M. and 3 P.M. are shown in analyzed as Figure 2-8. The figure presents A higher value than that at 3 P.M. at each station. Annual variation patterns of relative humidity among the stations are divided into three groups, which are Tabora and Shinyanga group, Dodoma group, and Arusha, Kilimanjaro, Moshi group. Dodoma group has intermediate value between the other two groups.

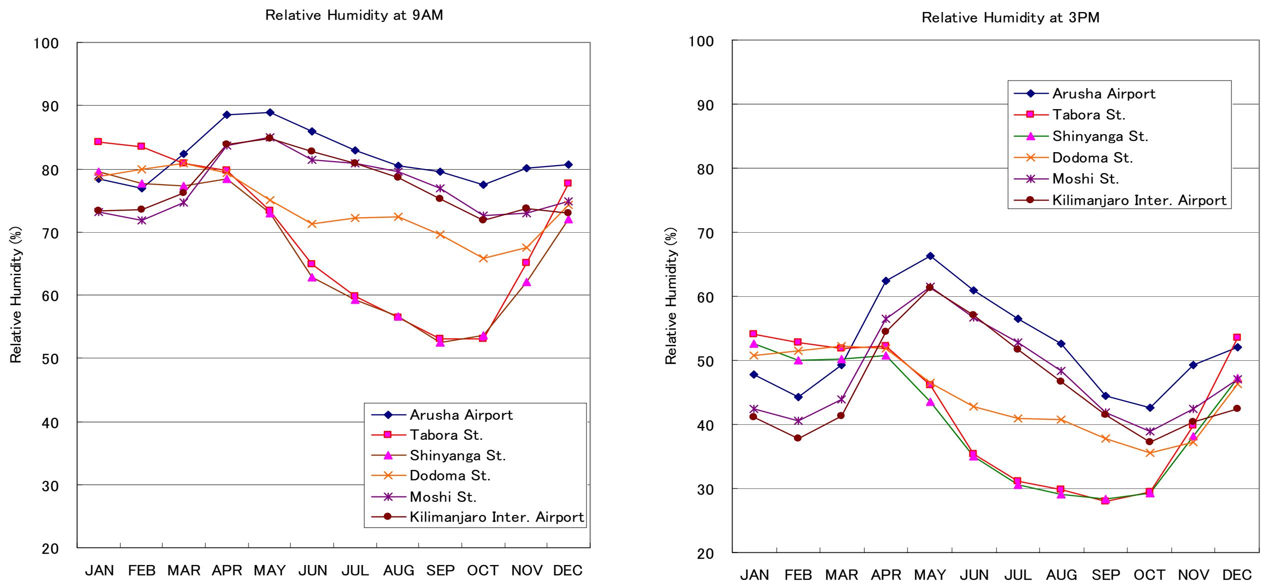


Figure 2-8 Relative Humidity of Major Town in IDB and its Adjacent Area

(7) Wind-run

Wind-run of IDB is presented in Figure 2-9. It indicates the predominant wind direction is from the east except Shinyanga station.

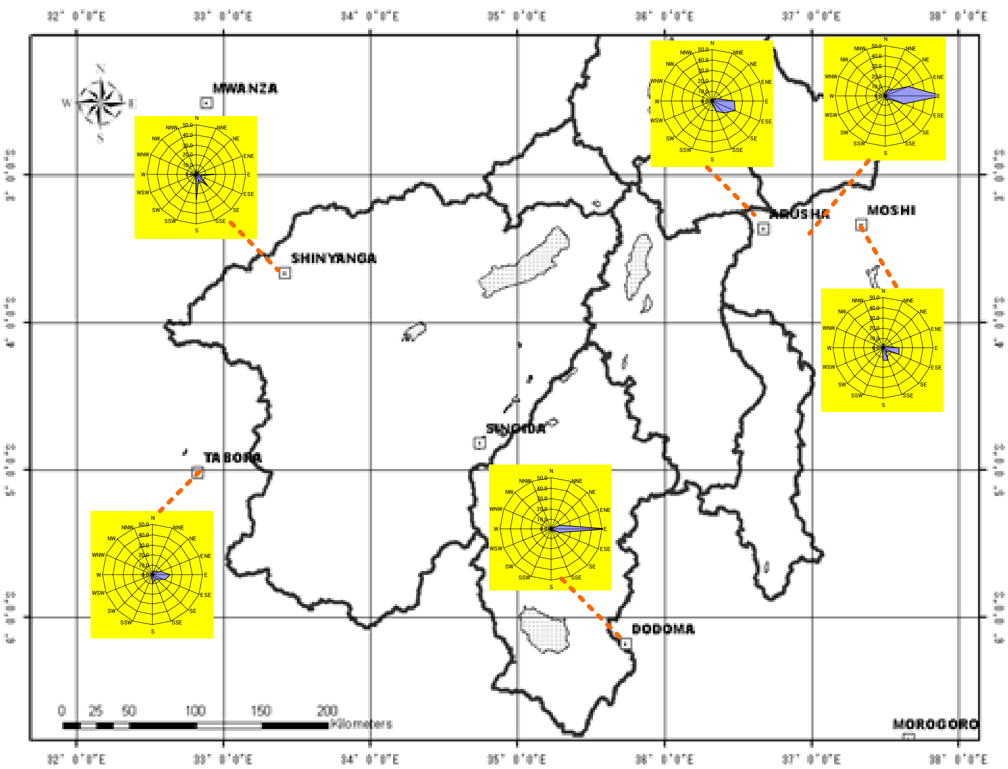


Figure 2-9 Wind Rose in IDB and its Adjacent Area

2.2.2 Hydrology

(1) River Network

River network was generated newly by using DEM (Digital Elevation Model) data and river catchments (Sub-basins) were also defined as illustrated in the Figure 2-10. The areas of each sub-basin are shown in Table 2-1.

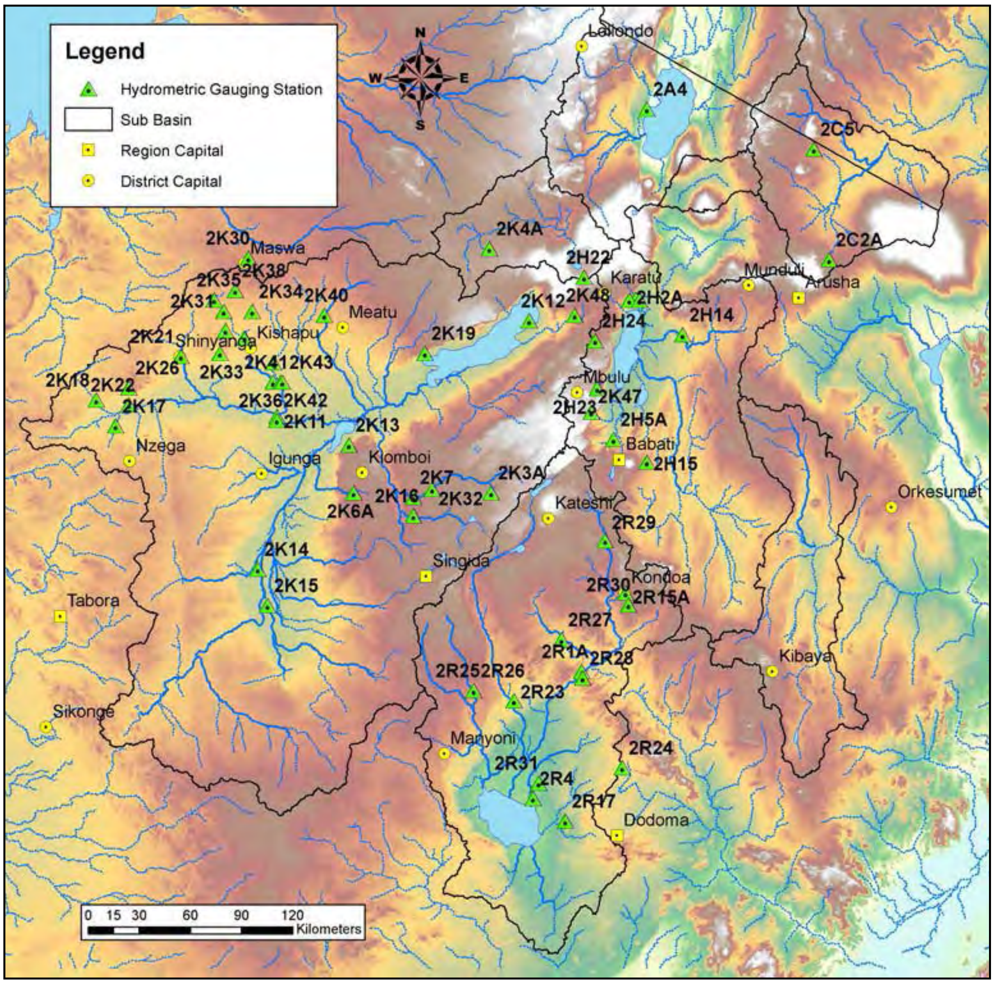


Figure 2-10 Sub-basins, River Network and Hydrometric Gauging Stations in IDB

(2) River Flow Regime

Flow duration curves of Lake Eyasi sub-basin and Bahi sub-basin in IDB show shorter flow discharge periods in a year and rapid discharge like a flash for each rainfall as shown in Figure 2-12. This means that many rivers in IDB are ephemeral rivers and unstable for water use.

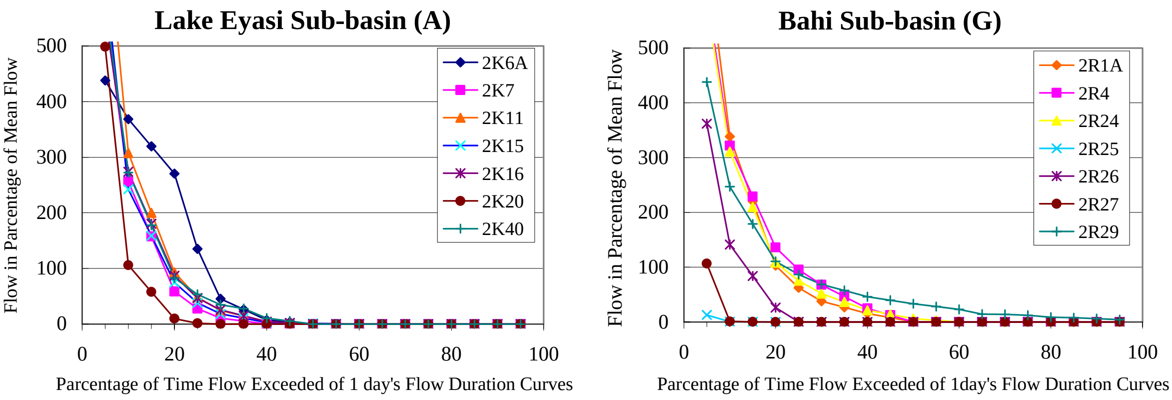


Figure 2-11 Flow Duration Curves in IDB

2.2.3 Water Use

The acquisition of data on actual water use in IDB is difficult because of the lack of systematic data collection system. Therefore, the water use was estimated by using information on registered and applied water rights as a trial. The used information was provided by IDBWO. The time stamps of the information were from 5 May 2004 to 12 January 2006. The results are shown in Figure 2-12.

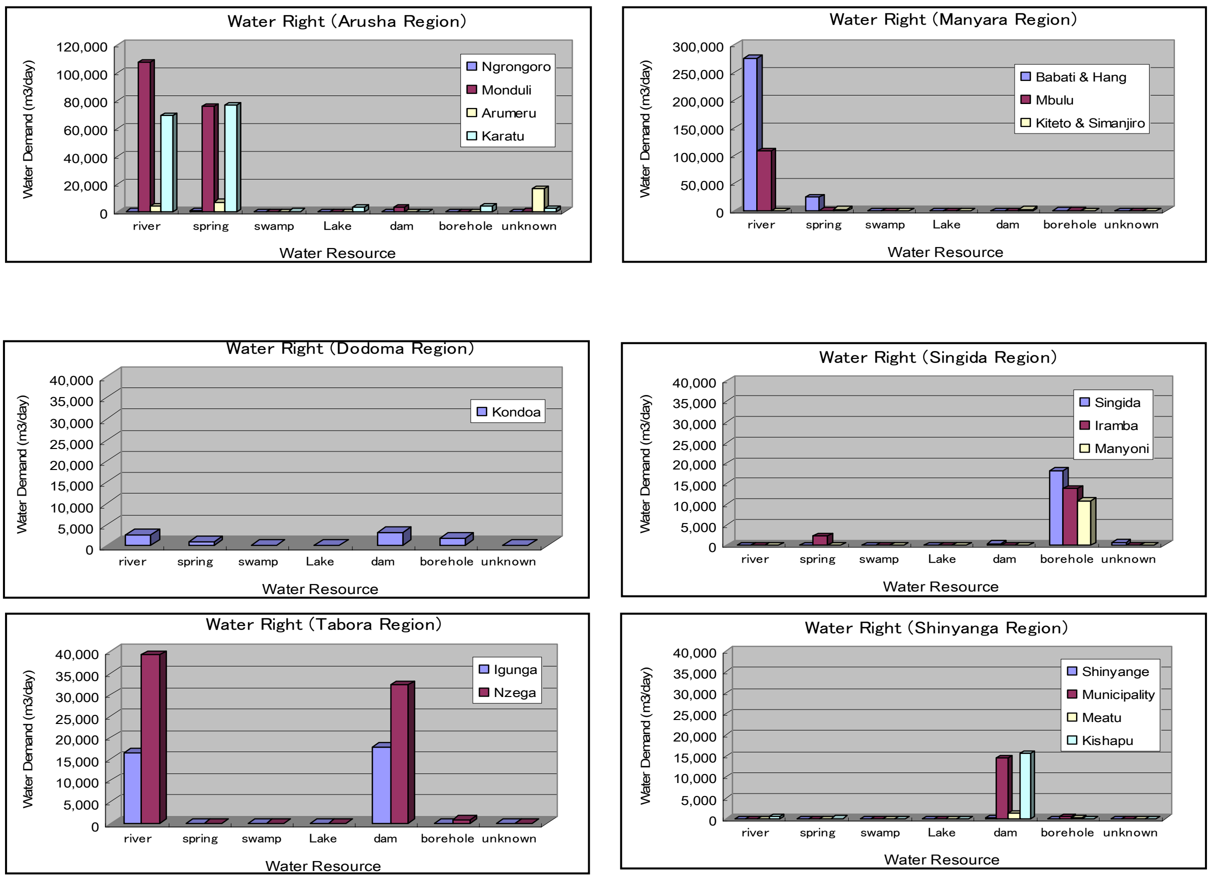


Figure 2-12 Water Use Derived from Water Right Information

2.3 Geomorphology and Geology

2.3.1 Geomorphology

The topographic image processed data of DEM (Digital Elevation Model) by SRTM (Shuttle Rader Topographic Mission) is shown in Figure 2-13, which was prepared to understand topographic features of IDB three-dimensionally. IDB is located in the southern part of "Gregory Rift Valley" as shown in Figure 2-14.

In the central and north-eastern parts of the project area, there are huge volcanoes such as Mt. Hanang (EL 3,417m), Kilimanjaro (EL 5,895m) and Ngorongoro crater (EL 2,000-3,000 m). These volcanoes are closely related to rift-faulting movements, and the nine sub-basin of IDB were formed by such geological tectonic movement.

The northern to the central part of IDB, several large lakes are located in each sub-basins, such as Lake Natron (EL; about 600m), Lake Manyara (EL; about 950m) and Lake Eyasi (EL; about 1020m). Bahi swamp is spreading over the low plain in the southern part of IDB. Many linear fault scarps were found in IDB. In the central part of IDB, the areas bounded by N-S or NE-SW trending fault are gently inclining to the northwest or west.

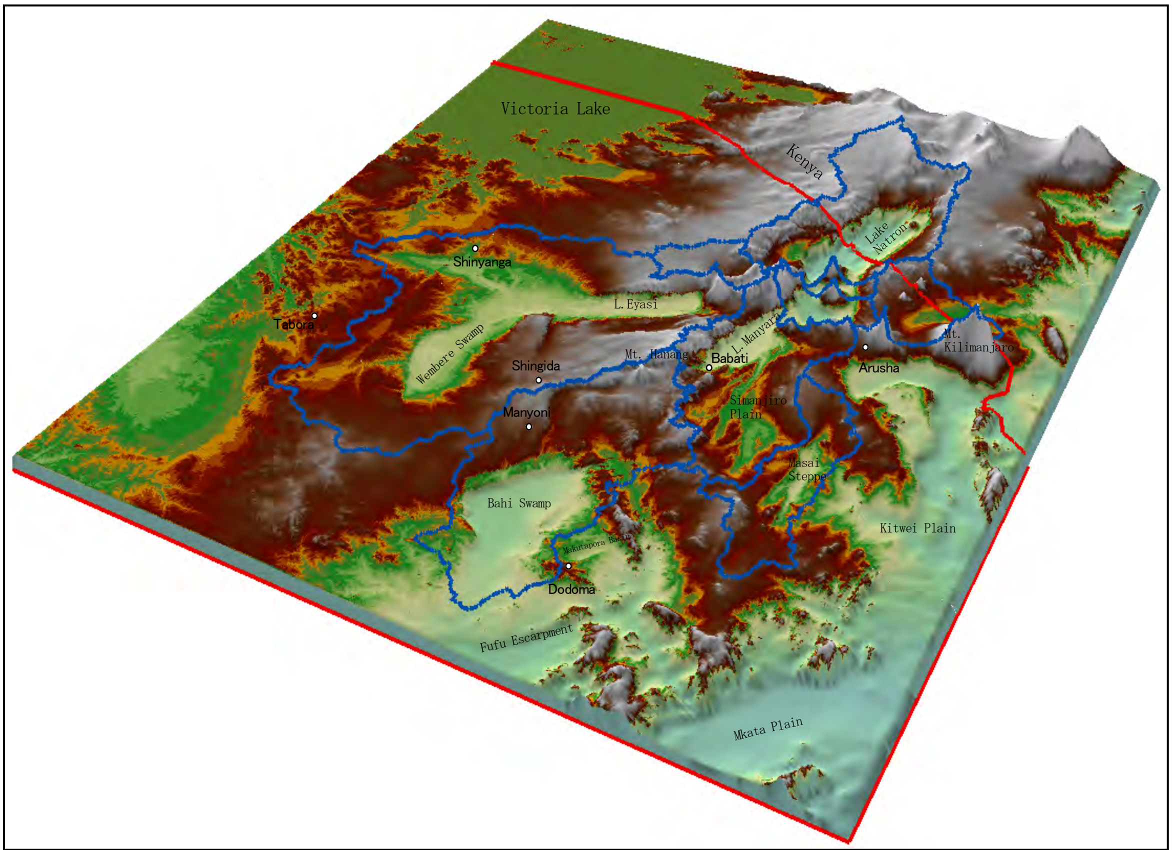


Figure 2-13 Block Diagram of IDB and Sub-basins

2.3.2 Geology

(1) General Geology

A continental rift zone is running through Ethiopia to Mozambique in the East Africa, which is called as "East African Rift Valley" (Figure 2-14). The study area is located at the east branch of it developing in the Tanzanian craton. Many authors have suggested that the eastern and western branches of the East Africa Rift represent an early stage of continental separation. Figure 2-14 shows distribution of Tertiary and Quaternary volcanic rocks. The eastern branch of the rift valley has wider distribution of volcanic rocks than the western branch. It is characterized by high rate crystal extension and bimodal distribution of basic and acid magma type. In general, most of continental rift zones accompany high alkali volcanic activity.

The faults in the eastern branch of the rift valley appear generally belong to the Neogene. In general, the faults discord from the foliation of Precambrian metamorphic rocks. The general direction of them is N-S with related faults branching to the south-west. This suggests that these activities are regarded as block fault activity bringing tectonic basins.

The second phase of fault activity in association with tilting and warping has dominated the evolution of topography since mid-Tertiary. The ground surface in the mid-Tertiary was also warped into gentle basin structure. In case of the Internal Drainage Basin, the bottom level of IDBs is changing apparently based on their sedimentation. Therefore, the rivers tend to flow along the faults laterally and wide flood planes are developed.

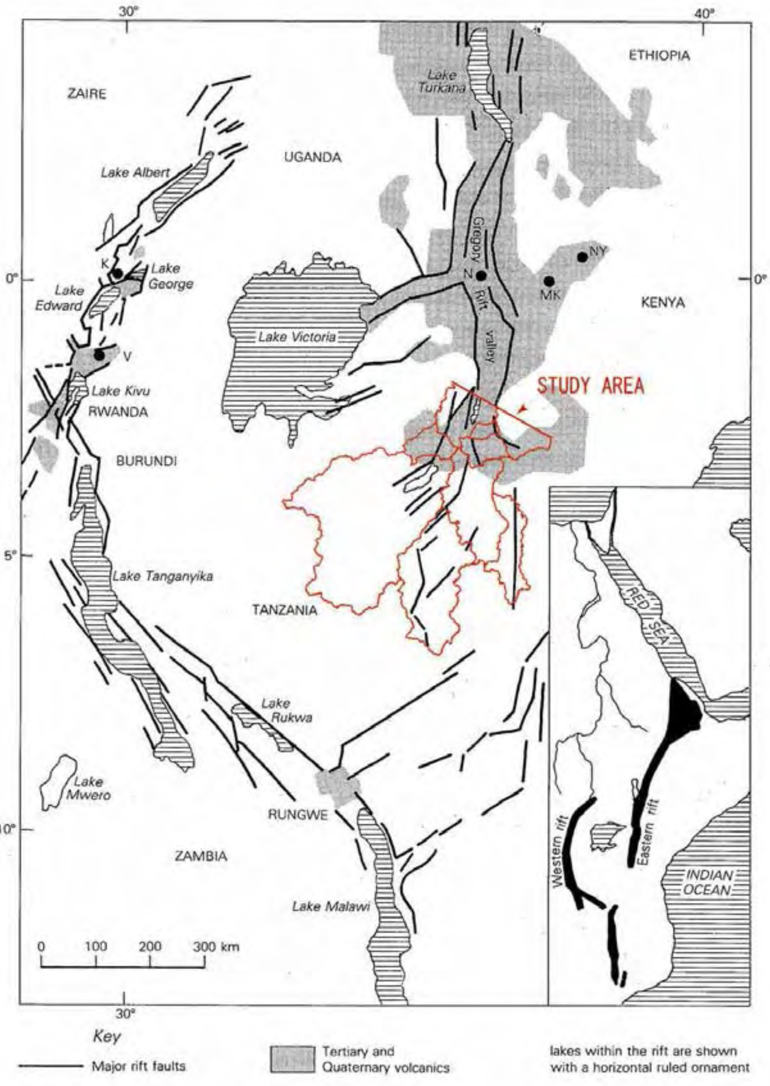


Figure 2-14 Structural Map of East African Rift System (Wilson (1989))

(2) Geology of IDB

The geological interpretation map and stratigraphy are shown in Figure 2-15 and Table 2-2, respectively. This interpretation map was produced using LANDSAT ETM false colour image (Figure3-1) and published geological maps of Tanzania (1:125,000). Furthermore, VSW indices, SAVI index and SRTM DEM images were also used for the interpretation. This interpretation images at a scale of 1:500,000 was conducted in order to extract lithological and structural characteristics for the hydrogeological analysis. Based on the results of field survey, the interpretation map was confirmed. As the result of interpretation, geological units were classified into 16 units (Table 2-2) and many lineaments and fault structures were extracted.

Table 2-2 Stratigraphy of the Study Area

Age	System	Lithology		Unit		Unit by LANDSAT Image Interpretation		
KAINOZOIC (CENOZOIC)	QUATERNARY – NEOGINE (-23.3Ma)	Aluvial; sand, gravel, silt; mud. Undifferentiated.	Typically alkaline volcanics: Olivine basalt, alkali basalt, phonolite, trachyte, nephelinenite and pyroclastics.	~	Nv	**N** **E**	**Nv, Nvd**	**N: Undiferentiated** **E: Evapolite** **Nv: Lave and Pyroclastics** **Nvd: Mainly Pyroclastics**
		Lacustrine; sand, silt, limestone, tuff		Nl		**Nl**		
		Terrestrial: sand, gravel, laterite, silcrete, calcrete.		Nt		**-**		
		Fluviatile; -marine; sand;gravel; silt; limestone.		Nf		**Nf**		
Unconformity								
PROTERO-ZOIC (570-2450Ma)	BUKOBAN	Mudstone; shale and phyllite; sandstone; arkose; quartzite; conglomerate; limestone.		B		**B**		-
ARCHEAN (2450-4600Ma)	USAGARAN	Marble; quartzite; graphitic schist; chlorite, amphibole, mica and kyanite schist; hornblend biotite and garnet gneiss; acid gneiss; granulite; charnockite.		Xs		**Xs**		**Topographic rough texture**
						Xs-a		**Topographic intermidiate texture**
						Xs-l		**Topographic smooth texture**
	KAVIRONDIAN	Quartzite; phylite.		V		**V**		-
	NYANZIAN	Banded Ironstone; metavolcanics; chlorite schist; pseudo-porphyry.		Z		**Z**		-
	DODOMAN	schist; gneiss; quartzite; amphibolite and hornblend gneiss; acid gneiss; migmatite.		D		**D**		-

Plutonic Rocks

Age	Lithology	Unit	Unit by LANDSAT Image Interpretation	
Mainly ARCHEAN	Granite and granodiorite, foliated, gneissose or migmatitic, some massive porphiyroblastic, includes intimately related regional migmatite.(Syn-orogenic)	gs	**gs**	**Topographic rough texture**
			gs-a	**Topographic intermediate texture**
			gs-b	**Topographic smooth texture. Strong weathered granite**

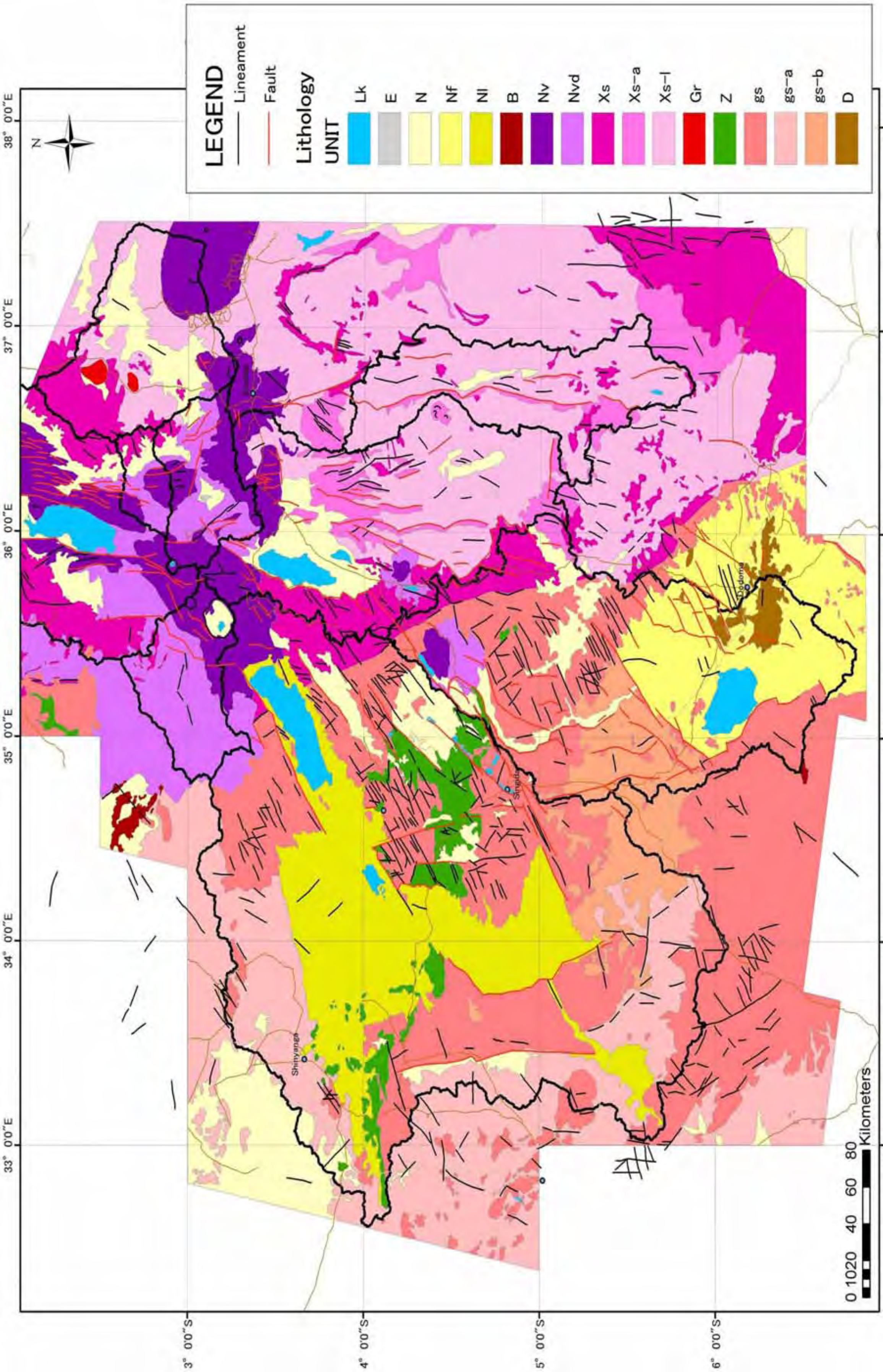


Figure 2-15 Geological Map of Internal Drainage Basin

(3) Geological Structure

A large number of lineaments and faults in association with rift-faulting movements were extracted from the almost whole of IDB as shown in Figure 2-16. From the eastern to northern part of IDB, N-S trending lineaments and faults are well developed. From the central to southern areas, a great number of NE-SW and N-S trending lineaments and faults were extracted. In the western area, N-S trending faults can be seen on the image however, lineaments are distributed sparsely and disorderly.

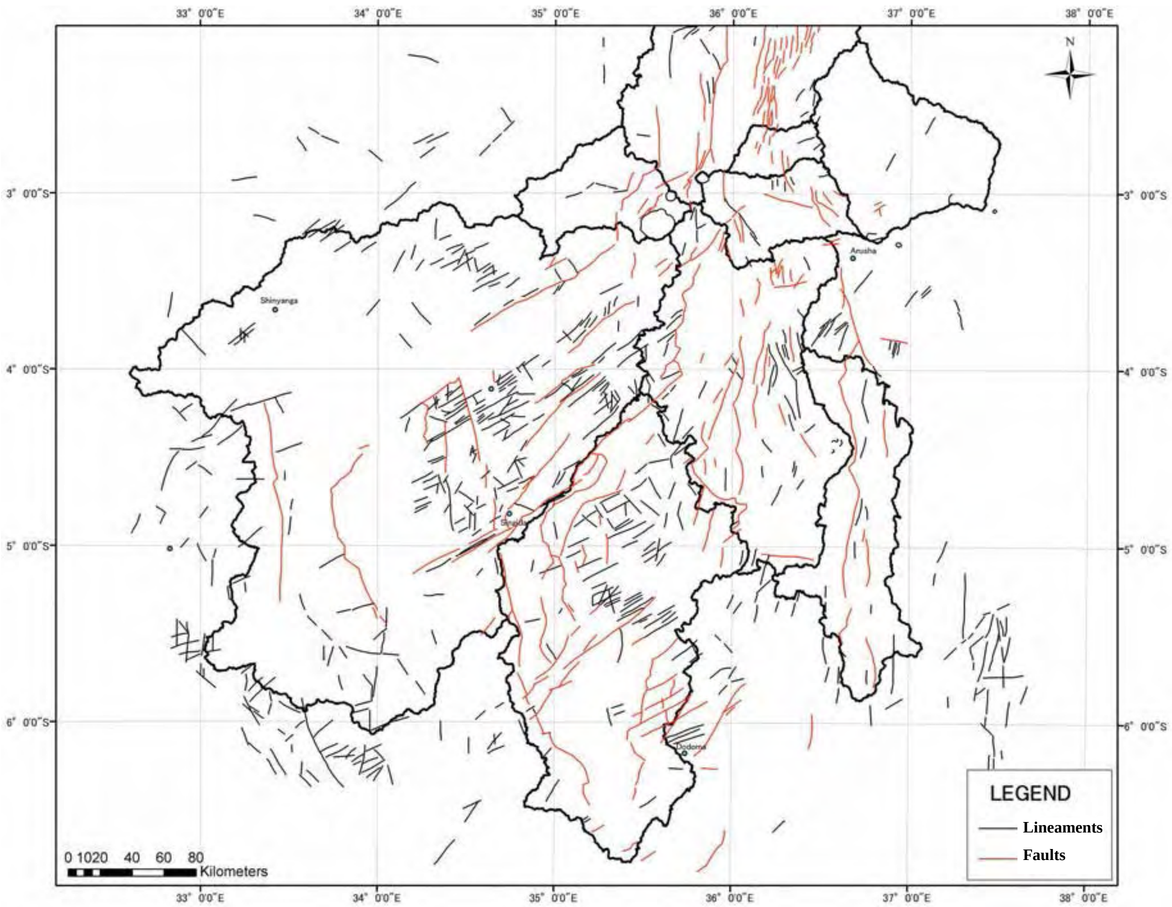


Figure 2-16 Distribution of Faults and Lineaments

2.4 Socio-economic Conditions of IDB

Socio-economic conditions of IDB are descried below. (Refer to Chapter 10 of Supporting Report for details) There are two kinds of contents: namely, overview of IDB's socio-economic conditions using existing statistic data in regional or district level, and another based on socio-economic survey by the Study Team.

2.4.1 General Socio-economic Conditions of IDB

(1) Administrative Setup and Population

- Administrative set up: 6 Regions, 24 Districts and 3 Municipalities, 432 Wards, and 1,606 Villages.

- Total Population: Approximately *6.7 Million
- Population Density: 28 persons /km^2 (39 persons / km^2 in Tanzania)
- Average Household Number: 5.3 persons (4.9 persons in Tanzania)
- Urban Population: 11.3% (23.1% in Tanzania), Rural Population: 88.7% (76.9% in Tanzania)

(*This figure was calculated by district-wise data related to IDB. Most probable number of villages and total population within IDB were examined in Chapter 13 of Supporting Report.)

(2) General Economic Conditions

1) Agriculture

- Main Food Crops: Maize, Sorghum, Paddy, Millet etc.
- Main Cash Crops: Coffee, Cotton, Tobacco, Wheat etc which are cultivated in Arusha, Shinyanga and Tabora mainly. Seventy five percent of it is exported.
- Cultivated Land: Only 33.6% of arable area is utilized.
- Irrigated Land: Only 33% of Irrigation potential area is utilized.

2) Livestock:

- Cattle 7.6 million.(50.6%), Goat 4.2 million(28.1%), Sheep 2.2 million (14.7%), Pig 0.1 million (0.7%), Poultry 0.7 million (4.6%) and Donkey 0.2 million (1.3%).
- Forestry, fisheries, beekeeping, hard wood and charcoal are popular in Tabora.

3) Industrial Sector

This sector is less developed in IDB except gold and diamond mining in Shinyanga and Tabora Region.

4) Tourism

Tourism industry is important in IDB for example Lake Manyara National Park, Arusha National Park and Ngrongoro Crater in Arusha Region.

5) General Economic Conditions

- GDP: Tsh.2,683 billion in six regions
- GDP/Capita.: Tsh.279,124
- Economic contribution of IDB: 31.1% of National GDP.

Approximately 50% of GDP from agricultural sector.

(3) Social Service Conditions

1) Water Supply & Sanitation

- Coverage of water supply: 37.5% (Tanzania: 53.1%)
- Coverage of latrine: 77.2% in IDB. Rural area or mountainous area of IDB is less than 50% (Tanzania: 79.1%)

2) Health

- Health facility: 33 Hospitals (Tanzania: 217), 64 Health Centres (Tanzania : 402), 825 Dispensaries (Tanzania : 4,179)
- Main water-borne diseases in 2003: Choleras: 1,254cases (33 deaths), Dysentery: 20,012cases (10 deaths), Diarrhoeas<5years old: 108,366cases (94 deaths),Typhoid: 8,285cases (14 deaths)

3) Education

- Literacy rate: 54% (Tanzania: 62%)
- Public primary school: 3,269 schools, enrolment: 1.6 million (Tanzania: 12,152 schools, Enrolment: 6 million)

(4) Economic Infrastructure

1) Transportation System

- Total road length in IDB: 25,984.5Km, 36% of national road network (Tanzania : 71,898.5Km)
- Paved road length in IDB: 834.1Km which is only 3% of total roads.
- One railway system: Tanzania Railway Corporation (TRC) in IDB.
- Two domestic airports have regular flight services: Shinyanga and Arusha Airport.

Singida is transit point for trucks and trailers from Dar es Salaam port to Mwanza port & Kigoma port.

2) Energy

- Ninety seven percent (97 %) of households use firewood and charcoal for cooking in IDB (Tanzania: 95%)
- Five percent (5 %) of electricity energy for lighting in IDB (Tanzania: 10%)

2.4.2 Socio-economic Survey Results

The main objectives of socioeconomic survey are to understand socioeconomic conditions, water sources and Operation and Maintenance (O&M) conditions of existing water supply facilities in IDB by using original data from the sample villages. The contents of the survey are summarized in Table 2-3 and the location of the surveyed villages is shown in Figure 2-17.

Table 2-3 Contents of Socio-economic Survey

Type of Survey	Method	Target	Item of Survey	
Village Survey	Questionnaire Survey	100 villages (one person per each village)	1. General Information	Populaation, number of households, tribes, road accessibility, power supply, telecommunication, village pattern, infrastructure, economic activity
			2. Water Sources Condition	Type/number/utilization of water resources, distance/time of main water source (rainy season/ dry season), facility of fetching and storing of water, main problem of water
			3. O&M conditions of Existing Water Supply Facilities	Existing water users organization and their activities, initial cost for construction, of water supply facilities, O&M cost, consciousness of O&M etc.
			4. Conditions of Health and Hygiene/ Sanitation	Ratio of water borne diseases, consciousness of prevention of water borne diseases, coverage rate of latrine, consciousness of hygiene/sanitation, supporting of hygiene/sanitation education etc.
			5. Condition of Fluoride Problem	Experience of fluoride problem, knowledge of fluoride problem, Idea for prevention of fluoride problem, Magadi condition and utilization of Magadi etc.
Household Survey	Questionnaire Survey	400 households (100 villages x 4 households, two men and two women)	1. General Information	Number of families, economic condition (income/expenditure), work shearing for housekeeping, load of housekeeping in women
			2. Water Sources Condition	Type/number/utilization of water resources, distance/time of main water source (rainy season/ dry season), distance to water sources, fetching time, person for fetching water, storage of water, times of fetching water a day, time zone of fetching water, main problem of water/ sanitation
			3. O&M conditions of Existing Water Supply Facilities	Existing water users organization and their activities, initial cost for construction, acknowledgement of O&M, support from village for water sector etc.
			4. Conditions of Health and Hygiene/ Sanitation	Ratio of water borne diseases, consciousness of water borne diseases, existence of latrine, consciousness of hygiene/sanitation, supporting of hygiene/sanitation from village etc.
			5. Condition of Fluoride Problem	Experience of fluoride problem, knowledge of fluoride problem, Idea for prevention of fluoride problem, Magadi condition and utilization of Magadi etc.
Supplemental Survey	Interview Survey/ Group Discussion	(1) Interview Survey 18 villages x two households (two men and two women)	Economic condition, water resources conditions, O&M conditions of existing water supply facilities, conditions of health and hygiene/ sanitation, and fluoride problem etc.	
		(2) Group discussion 2 villages (Leader, VEO*, Community members)	Economic conditions of village, water resources conditions in village, conditions of health and hygiene/ sanitation of people, O&M conditions of existing water supply facilities in village, fluoride problem, Utilization of Magadi by people, conditions of water rights & water user fee etc.	

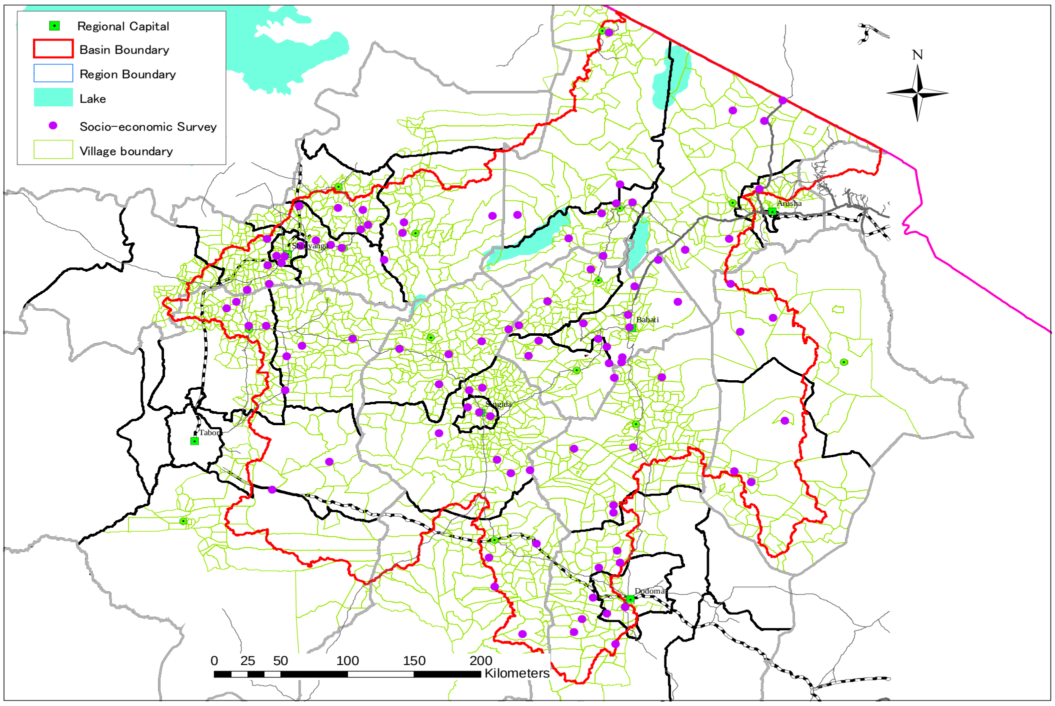


Figure 2-17 Distribution of Villages for Socioeconomic Survey

(1) Economic Activities and Balance of Households

Agriculture is the main economic activity in IDB and people earn the income for their living by practicing agriculture in combination with livestock, labour work, making/selling of charcoal, employment and others. (Refer to Figure 2-18) Since there is insufficient water in the rivers of IDB, agricultural production is limited in the rainy season. Therefore, almost of all villagers can earn their income only once in a year during the harvest season. Their average income is

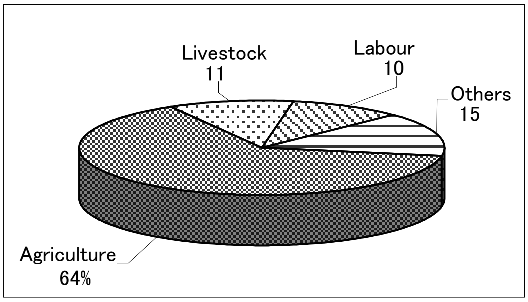


Figure 2-18 Main Economic Activity of Households

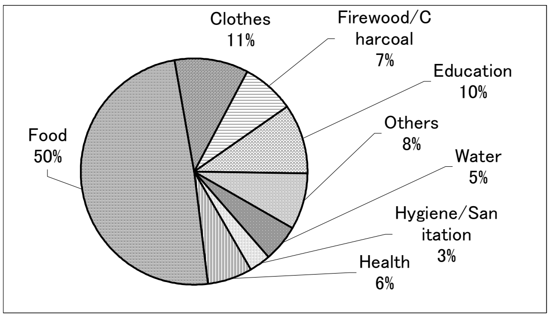


Figure 2-19 Average Annual Expenditu

approximately Tsh920, 000/year/household. As for profitability of each economic activity, villagers think higher profitability from livestock than agriculture although livestock occupies small proportion of regular income source as shown in Figure 2-20. On the other hand, the average annual expenditure is equivalent to 70 % of income as shown in Figure 2-21. The ratio of expenditure for water related matters is 5 %, sanitation and hygiene is about 3 %.

(2) Water Source and Usage

Seasonal difference of water usage by water sources is shown in Figure 2-21. Traditional dug well is high ratio in both seasons. As for borehole, the ratio of it becomes twice in dry season. Villagers intend to use traditional dug well, regardless borehole is stable and safety as water source. This means that their intention trends to more easily fetching water and economical reason yet.

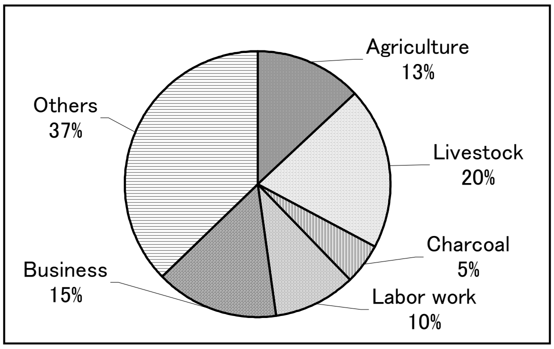


Figure 2-20 Profitability of Each Economic Activity

Daily water consumption of household is shown in Figure 2-22. More than 25% of them consume 60-120 L/day. The National Water Policy 2002 of Tanzania sets up 25 L /person/day for rural water supply as the standard unit consumption. Since average family size is 6 people based on household survey, the average unit consumption is less than the standard value. Most of the villagers usually fetch water twice a day: namely, 6 to 9 A.M. and 3 to 5 P.M.

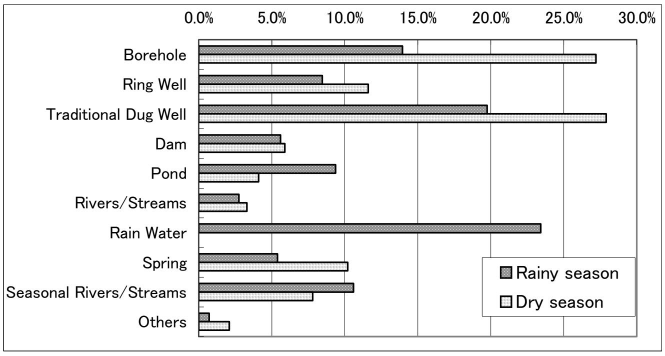


Figure 2-21 Main Water Source in Village

(3) Fetching Water

1) Distance from Water Source

A distance from water source to fetch water in rural area is set up within 400m in "National Water Policy 2002". According to the result of the household survey, 43.5% of villagers have water sources within 500m from their houses in the rainy season and 18.2% of them are obliged to go more than 2,000m away even in the rainy season. However, the ratio of villagers whose water sources are located within 500m decreases to 20.4% on average in the dry season and the ratio of villagers whose water sources are located over 2,000m away increases to 33.6% in the dry season.

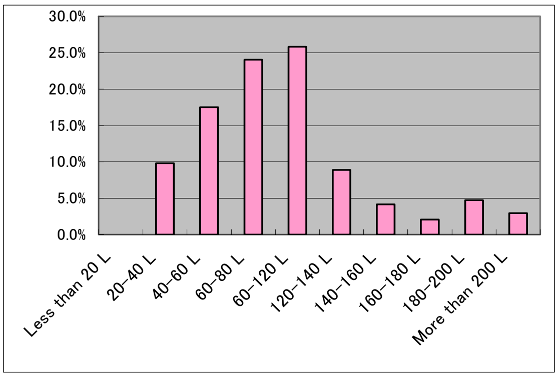


Figure 2-22 Daily Water Consumptio

2) Time for Fetching Water

In case of rural water supply scheme of Tanzania, target time for fetching water is set up within 30 minutes in "National Water Sector Development Strategy 2005". The result of the household survey shows that approximately 55.4% of the villagers are in the category in the rainy season. However, it decreases to 18.4% in the dry season and besides, 81.6% of villagers take time over 30 minutes.

As a matter of course, the fetching time is related to distance from water source but it should be paid attention to waiting time caused by congestion of water users at water source. Water supply problem in rural area is not only the distance to water source but also water supply volume.

(4) Organization for O&M of Water Supply Facility

In Tanzania, people are bound to establish an organization called WUG (Water User Group) or WUA (Water User Association) for each water supply facilities and they have to operate and maintain by themselves. WUG is the community organization for O&M of each water supply facility, and WUA are formed of several WUG, Water supply vendors, and water users in town etc.

During the supplementary survey, it was seen in some villages where some boreholes were broken. The villagers use other water sources such as traditional dug wells, rivers/streams, and ponds without repairing them. The reasons why they don't repair are "no money for maintenance" or "saving money for new water supply facilities instead of maintenance".

According to the village survey, more than half of the 57 villages, which have activated WUG/WUA, collected more than Tsh 1,000 from each household as contribution for initial cost of water supply facility in their villages. As for operation cost, approximately 40 % (23 villages) of 57 villages, which have WUG/WUA, do not collect O&M cost of water supply facility and 25 % (14 villages) of them collect more than Tsh 50 per 20L. There are 12 % (7 villages) of them, which collect "Tsh20 per 20L as the same as Tanzanian average value. The person in-charge of managing the money is either the leader of WUG/WUA or accountant of WUG/WUA or village leader.

There are some villages which they had WUG/WUA before but it is not functioning because of the reasons such as "no knowledge of O&M for water supply facility", "no support/service from the government (District council etc)", or "no money for O&M".

As to water right fee, most villagers or village leaders/chair persons did not know that all users had to pay water right fee to IDB Water Office. They can understand the initial cost to construct water supply facility and O&M cost for repair of water supply facility. However, they don't understand why they have to pay water right fee. Therefore, sustainable sensitization or education is needed to all users