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

SUPPORTING REPORT

FEBRUARY 2008

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

OYO INTERNATIONAL CORPORATION
KOKUSAI KOGYO CO. LTD.

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ABBREVIATION

ADM	Administrative
As	Arsenic (mg/L)
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
B.H.	Borehole
BSF	Belgium Survival Fund
BWB	Basin Water Board
C/P	Counter Part
CFI	Community Fluorosis Index
DB	DataBase
DBMS	DataBase Management System
DC	District Council
DDCA	Drilling and Dam Construction Agency
DECE	Environmental Compliance and Enforcement
DEIA	Directorate of Environmental Impact Assessment
DEICO	Directorate of Environmental Information, Communication and Outreach
DEM	Digital Elevation Model
DEPR	Directorate of Environmental Planning and Research
DWE	District Water Engineer
DWL	Dynamic Water Level (m)
EA	Enumeration Area
EC	Electric Conductivity (mS/m)
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ERSDAC	Earth Remote Sensing Data Analysis Center
ETM	Enhansed Thematic Mapper
F	Fluoride (mg/L)
Fe	Iron (mg/L)
FK	Foreign Key
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit
IDB	Internal Drainage Basin
IDB Office	Water Basin Office of Internal Drainage Basin

IDBWO	Internal Drainage Basin Water Ofiice
IEE	Initial Environmental Examination
IFAD	International Fund for Agricultural Development
IMR	Infant Mortality Rate
IVS	Inventory Survey
JICA	Japan International Cooperation Agency
LANDSAT	Land sensing Satellite
LUT	Look Up Table
MC	Municipal Council
Mn	Manganese (mg/L)
MoF	Ministry of Finance
MOFA	Ministry of Food security Agriculture
MoLD	Ministry of Livestock Development
MoW	Ministry of Water
MoWLD	Ministry of Water and Livestock Development
MS	MicroSoft
MWE	Municipal Water Engineer
NAWAPO	National Water Policy
NBS	National Bureau of Statistics
NEMC	National Environment Management Council
NGO	Non Government Organization
NH4	Ammonia Ion (mg/L)
NO3	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)
OST	Organization Strengthening Team
PK	Primary Key
PMO-RALG	Prime Minister's Officer - 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
TCRS	Tanzanian Children's Refugee Service
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
U5MR	Under Five Mortality Rate
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
WQS	Water Quality Survey
WRD	Water Resources Division
WUA	Water User Association
WUC	Water User Committee
WUG	Water User Group

Chapter 1
Meteorology and Hydrology

CHAPTER 1 METEOROLOGY AND HYDROLOGY

Meteorological and hydrological data such as temperature, rainfall, sunshine hours, evaporation humidity, wind speed, and river discharge have been collected and analyzed. The results are described below. These data are used for a water balance analyses in IDB.

1.1 Purpose of Survey

The meteorological and hydrological study consists of data collection, the analysis, and river flow discharge measurement. The study was carried out to obtain the following information and to be used for water balance analyses.

- Meteorological condition of IDB.
- Hydrological condition of IDB

1.2 Meteorology

1.2.1 Meteorological Network

Figure 2-1 shows the distribution of the meteorological stations operated by Tanzania Meteorological Agency and the rainfall stations where data collected in and adjacent to IDB. The numbers of the stations are a few by comparison with the largeness of IDB. The monthly records on rainfall, air temperature, sunshine hour, relative humidity, pan evaporation, and wind-run are available at the meteorological stations. The covering period of those weather data is since 1975 to 2004 (30 years).

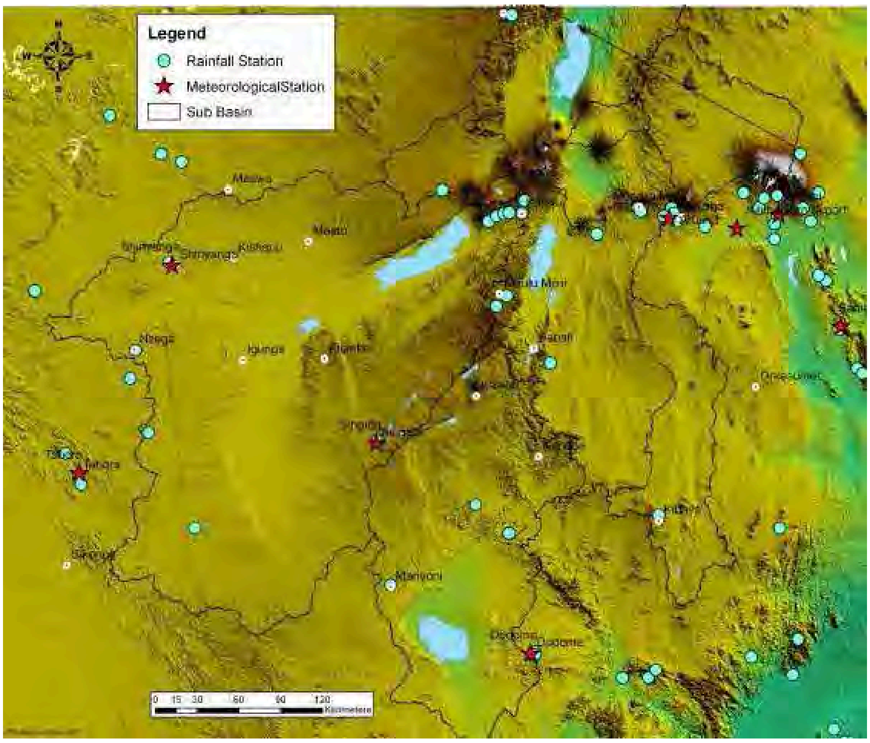
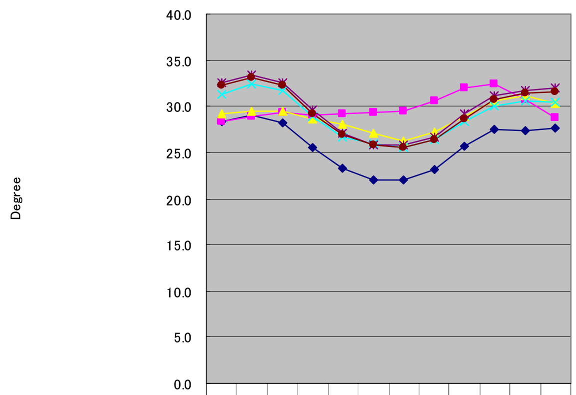


Figure 1-1 Current Weather Stations in IDB and its Adjacent Area

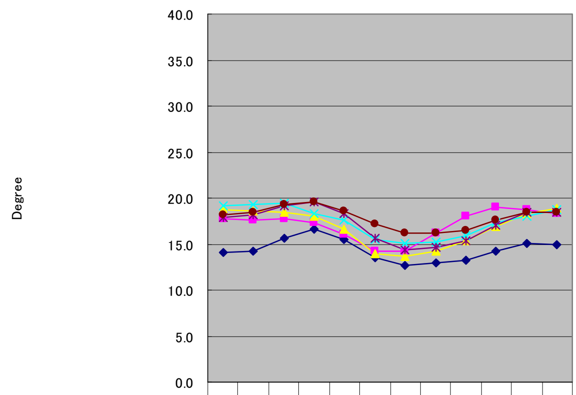
1.2.2 Meteorological Data Analysis

(1) Air Temperature

Air temperature of the several stations in IDB was analyzed as Figure 1-2. This figure 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.



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Arusha Meteological Station	28.4	29.1	28.2	25.5	23.2	22.1	22.0	23.1	25.6	27.5	27.4	27.7
Tabora Meteological Station	28.4	28.9	29.3	29.0	29.2	29.4	29.5	30.6	32.0	32.4	30.7	28.8
Dodoma Meteological Station	29.2	29.5	29.4	28.6	28.0	27.0	26.3	27.2	28.9	30.5	31.2	30.3
Same Meteological Station	31.3	32.4	31.8	28.9	26.7	26.0	25.6	26.4	28.3	30.0	30.7	30.4
Kilimanjaro Airport	32.6	33.4	32.6	29.6	27.1	25.9	25.8	26.7	29.3	31.1	31.8	31.9
Moshi Meteological Station	32.3	33.2	32.3	29.2	27.0	25.8	25.5	26.4	28.7	30.7	31.4	31.5



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Arusha Meteological Station	14.1	14.3	15.6	16.6	15.6	13.5	12.7	12.9	13.2	14.2	15.1	14.9
Tabora Meteological Station	17.8	17.6	17.7	17.3	16.0	14.3	14.3	16.3	18.0	19.0	18.7	18.3
Dodoma Meteological Station	18.7	18.7	18.5	18.0	16.6	13.9	13.7	14.3	15.4	16.9	18.3	18.9
Same Meteological Station	19.1	19.2	19.5	18.3	17.6	15.5	15.1	15.2	15.9	17.3	18.1	18.7
Kilimanjaro Airport	17.9	18.1	19.2	19.5	18.3	15.6	14.4	14.7	15.3	17.0	18.4	18.4
Moshi Meteological Station	18.2	18.4	19.3	19.5	18.6	17.2	16.2	16.2	16.5	17.5	18.5	18.4

Figure 1-2 Averaged Maximum and Minimum Temperatures in Major Towns in IDB and its Adjacent Area

(2) Annual Rainfall

Annual rainfall distribution as the one of the most important items for water resources analysis needs many data in terms of as much the number of observation points in IDB and as longer their monitoring duration as possible. Since enough rain gauge stations and weather stations have not been operated so far, data from "Summary of Rainfall in Tanzania" (1975): East Africa Community, Nairobi) has been used for the purpose. The results on the annual rainfall distribution are shown as Figure 1-3. The number of rain gauge stations applied for the map is more than 100 and their monitoring duration is more than 30 years. 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 sever condition, where has rainfall with only 600 mm/year.

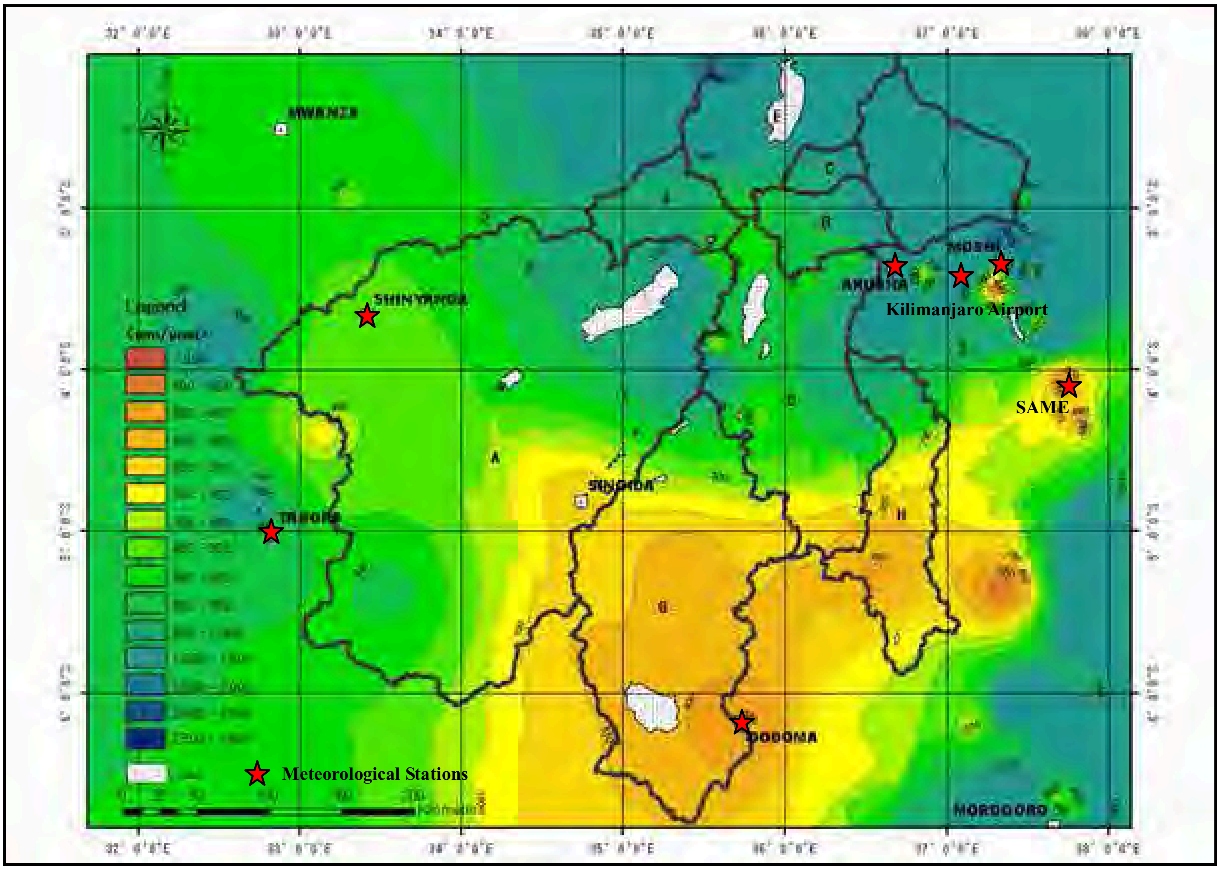
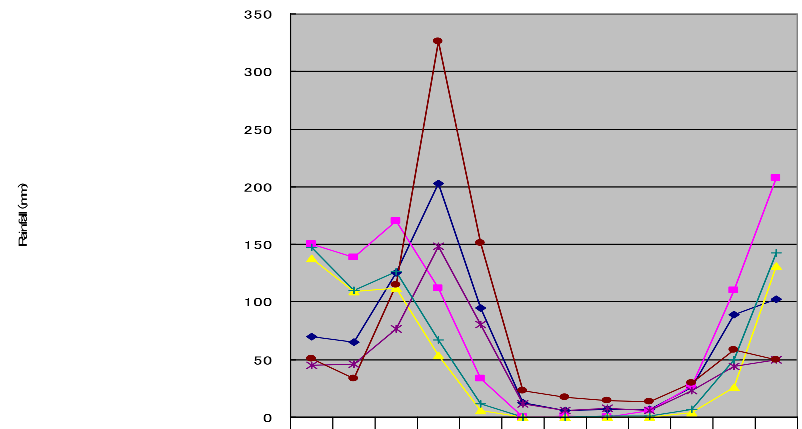


Figure 1-3 Distribution Map of Annual Rainfall in IDB and its Adjacent Area

(3) Seasonal Change of Monthly Rainfall

Seasonal change of monthly rainfall of the several weather stations in IDB was analyzed as Figure 1-4. This figure presents average monthly rainfalls at major weather stations in IDB. The rainy season begins in late October or November and finishes in May. There are almost no rainfall from June to September. Monthly variation patterns of rainfall among the stations are divided into two groups, which are Tabora, Dodoma and Singida group and Arusha, Kilimanjaro, Moshi group. The stations of former group are located on hillside, and the rainfall pattern does not have sharp peak of monthly rainfall. On the other hand, the stations of the latter group are located on mountainous area, and the monthly rainfall pattern has sharp peak on April.



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Arusha Meteorological Station	70	65	125	203	95	13	6	7	6	26	89	103
Tabora Meteorological Station	150	139	170	112	34	0	1	0	5	27	110	207
Dodoma Meteorological Station	138	109	112	54	5	0	0	0	0	4	26	131
Kilimanjaro Airport	45	46	76	149	80	11	6	8	6	23	44	50
Moshi Meteorological Station	51	33	115	326	151	23	17	14	13	30	58	49
Singida Meteorological Station	147	110	126	67	11	0	0	1	1	7	49	142

Figure 1-4 Averaged Monthly Rainfall in Major Towns in IDB and its Adjacent Area

(4) Sunshine Duration

Sunshine duration of the several stations in IDB was analyzed as Figure 1-5. This figure presents average monthly sunshine duration at major weather stations in IDB. Annual variation patterns of sunshine duration among the stations are divided into two groups, which are Tabora and Dodoma group, and Arusha, Kilimanjaro, Moshi group. The distributions of these two groups show completely opposite tendencies.

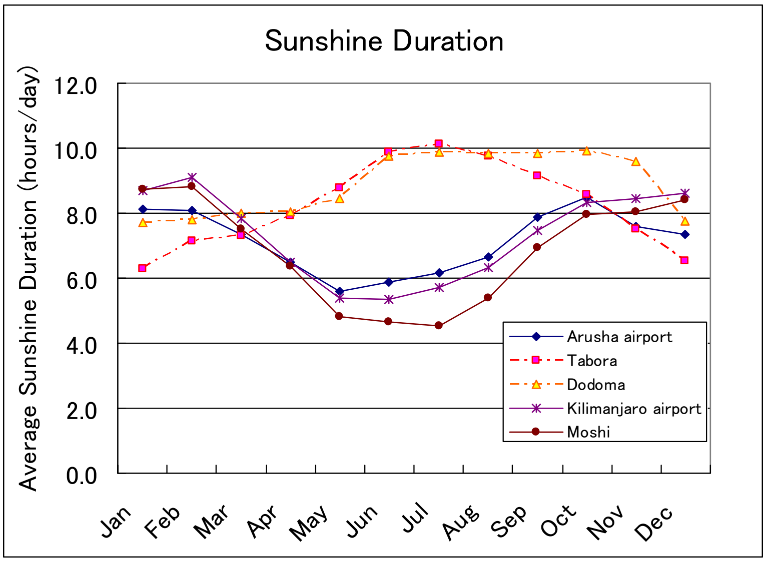


Figure 1-5 Averaged Sunshine Duration in Major Towns in IDB and its Adjacent Area

(5) Potential Evaporation (Pan Evaporation)

Pan evaporation of the several stations in IDB was analyzed as Figure 1-6. Figure 1-6 presents monthly average pan evaporation at major weather stations in IDB. Average pan evaporation shows the highest value on October at each station. The highest value was recorded at Shinyanga weather station. The seasonal change of Pan evaporation follows the temperature and the wind-run.

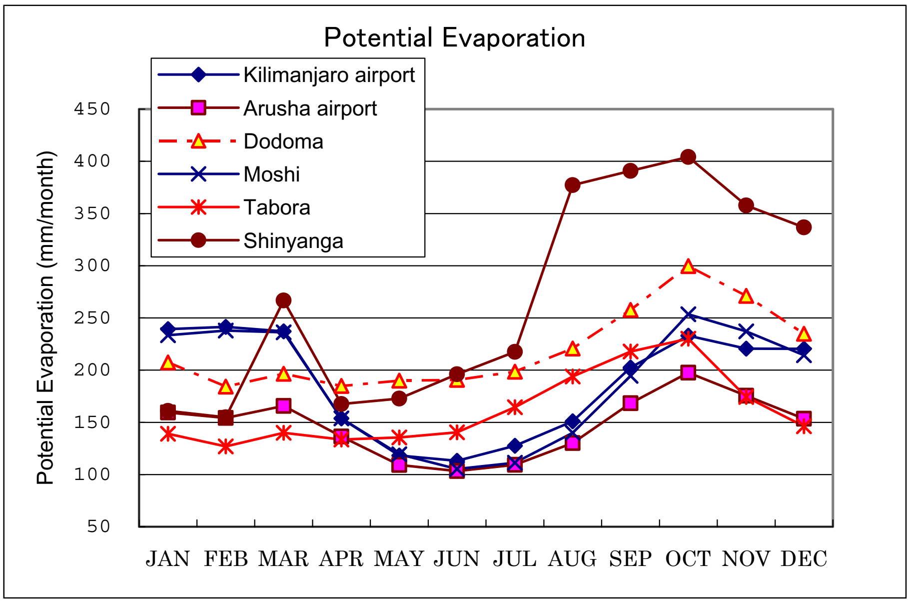
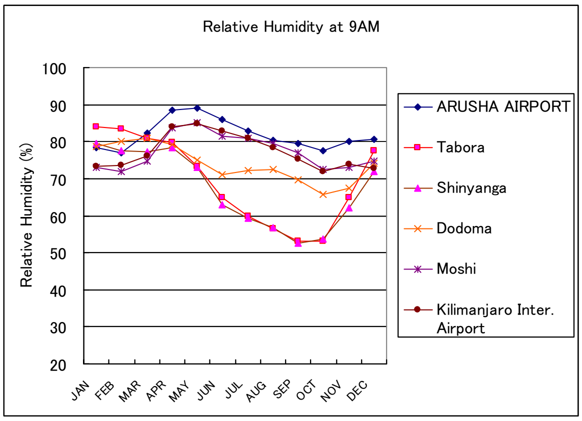


Figure 1-6 Averaged Pan Evaporation in Major Towns in IDB and its Adjacent Area

(6) Relative Humidity

Relative humidity of the several stations in IDB was analyzed as Figure 1-7. The figure presents monthly average relative humidity at 9 A.M. (the left figure) and 3 P.M. (the right figure) at major weather stations in IDB. Average relative humidity at 9 P.M. shows 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.



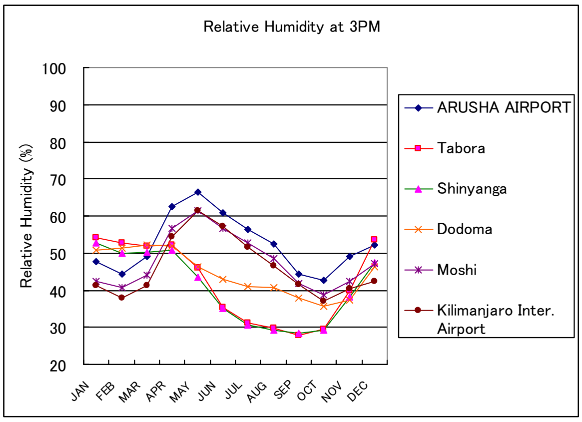


Figure 1-7 Averaged Relative Humidity in Major Towns in IDB and its Adjacent Area

(7) Wind-run

Wind-run of the several stations in IDB was analyzed as Figure 1-8. The figure presents the yearly average of appearance frequency of the wind directions at major weather stations in IDB. The appearance frequency of the wind from the east predominated except Shinyanga station.

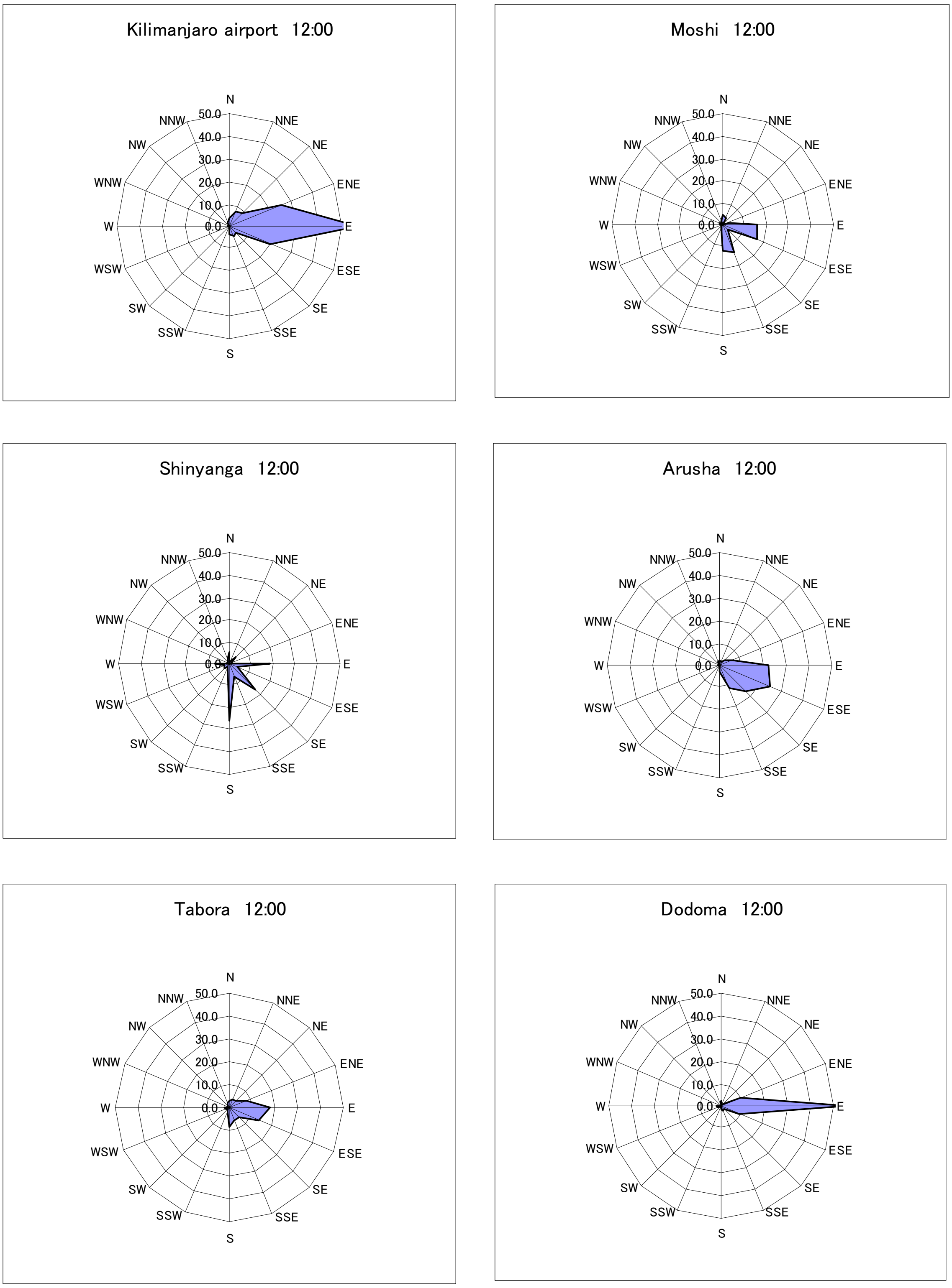


Figure 1-8 Wind Rose in IDB and its Adjacent Area

1.3 Hydrology

1.3.1 River Network

River network was generated newly by using DEM (Digital Elevation Model) data and river catchments (Sub-basins) were also defined by SRTM (Shuttle Radar Topographic Mission) data as illustrated in the Figure 1-9. The areas of each sub-basin are shown in Table 1-1. According to this analysis, it reveals that several sub-basins should not be included in IDB but in the neighboring 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 international sub-basin itself. Approximately 35% of the international sub-basin is located in Kenya. “E” sub-basin is also an international one; it has “Lake Natron”, the whole sub-basin area is considerably big such as 26,224 km2, Tanzanian side of it is 33%. On the basis of the existing definition of IDB, its area is 152,146 km2; however, an area of the newly defined basin becomes 143,099 km2 as shown in Table 1-1.

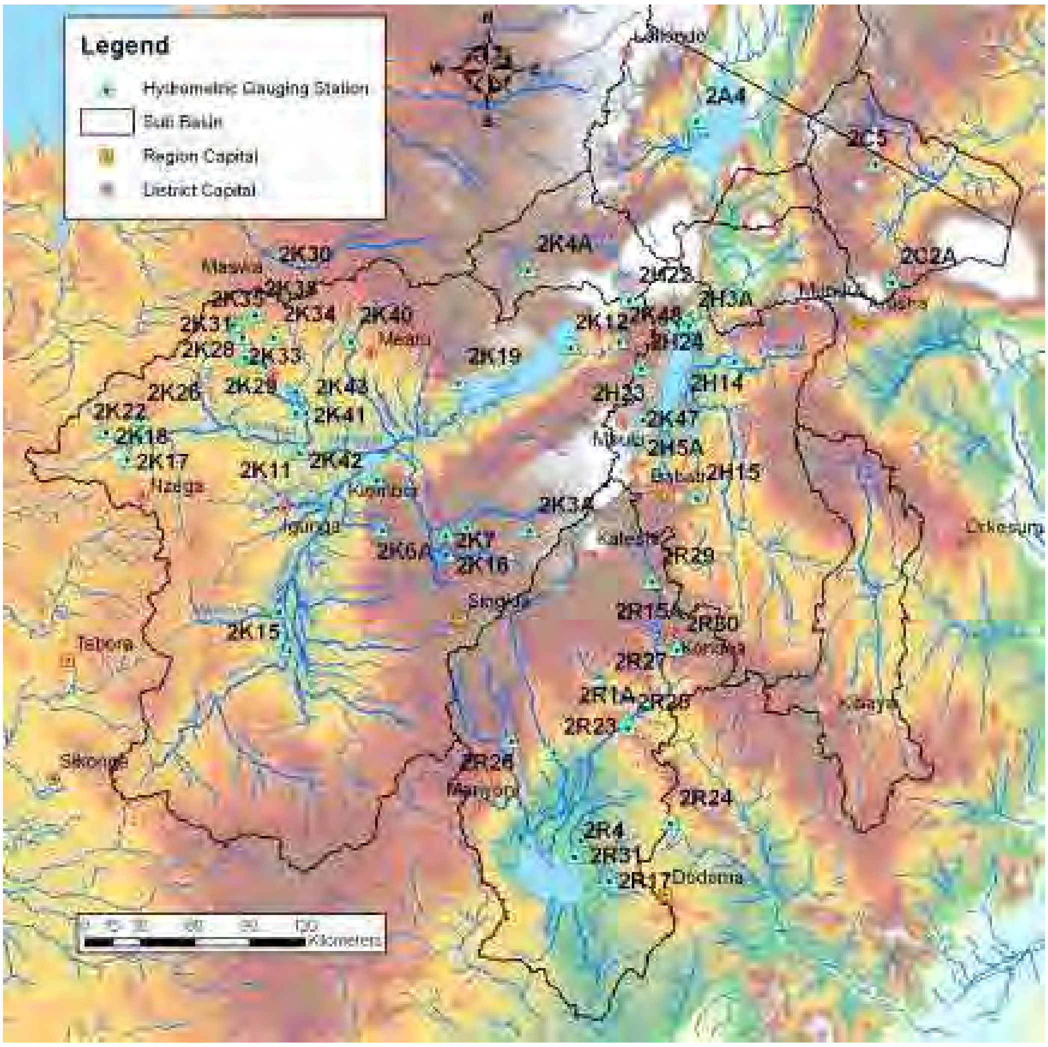


Figure 1-9 Sub-basins, River Network and Hydrometric Gauging Stations in the Internal Drainage Basin

Table 1-1 Area of Sub-basins in the Internal Drainage Basin

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 Flowing out to Kenya
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 : Km2

1.3.2 River Regime

(1) Flow Regime

Flow duration curves of the hydrometric gauging stations in the Tanzania were analyzed as Figure 1-10. Flow duration curves in IDB (Lake Eyasi sub-basin and Bahi sub-basin) show shorter flow discharge periods in a year and rapid discharge like a flash for each rainfall event compared with those in the other areas of Tanzania. This means that a lot of rivers in IDB are ephemeral rivers and unstable for water use.

In comparison with the observation periods of the collected data on river flow discharge, there is the largest number of hydrometric observation data at year of 1974. Therefore the monthly averaged river flow discharges at various stations at the year of 1974 in IDB were analyzed as Figure 1-11. All observation results have almost the same tendency that the river flow discharge gradually increases from December, records the maximum value on April, and then decrease and disappears on June or July. It corresponds to the seasonal rainfall condition.

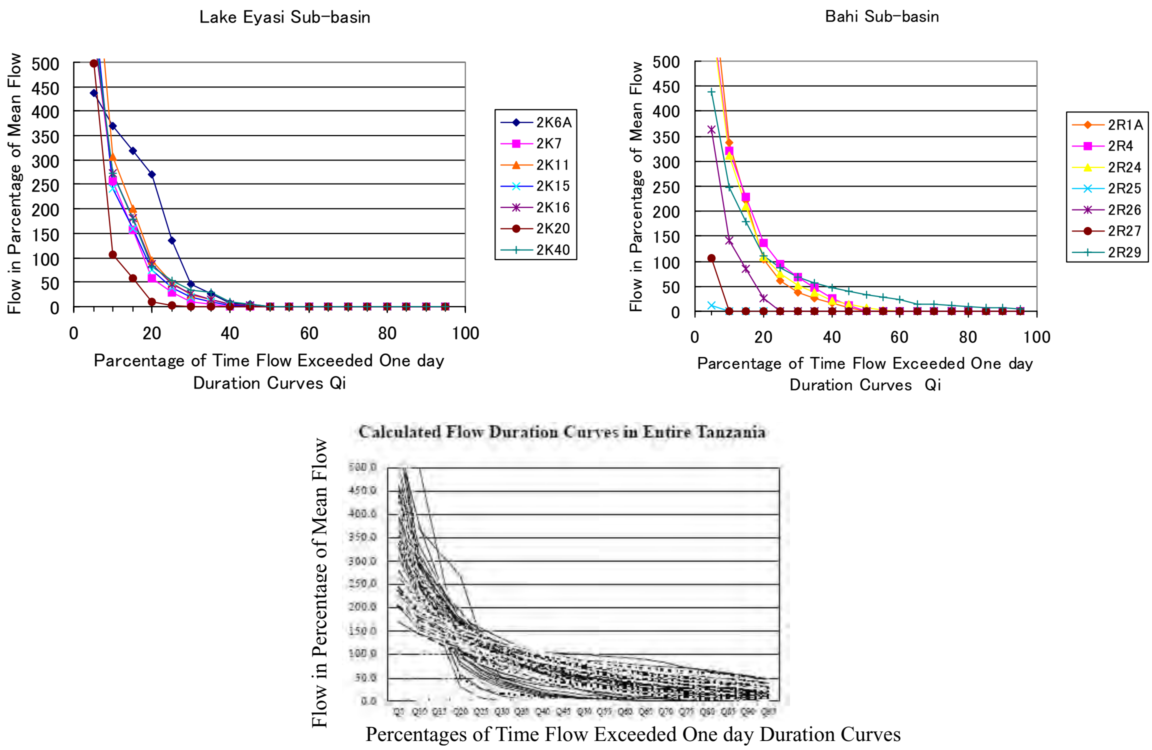


Figure 1-10 Flow Duration Curves

Source: The Study on the National Irrigation Mater Plan in the United Republic of Tanzania, 2002 November, JICA

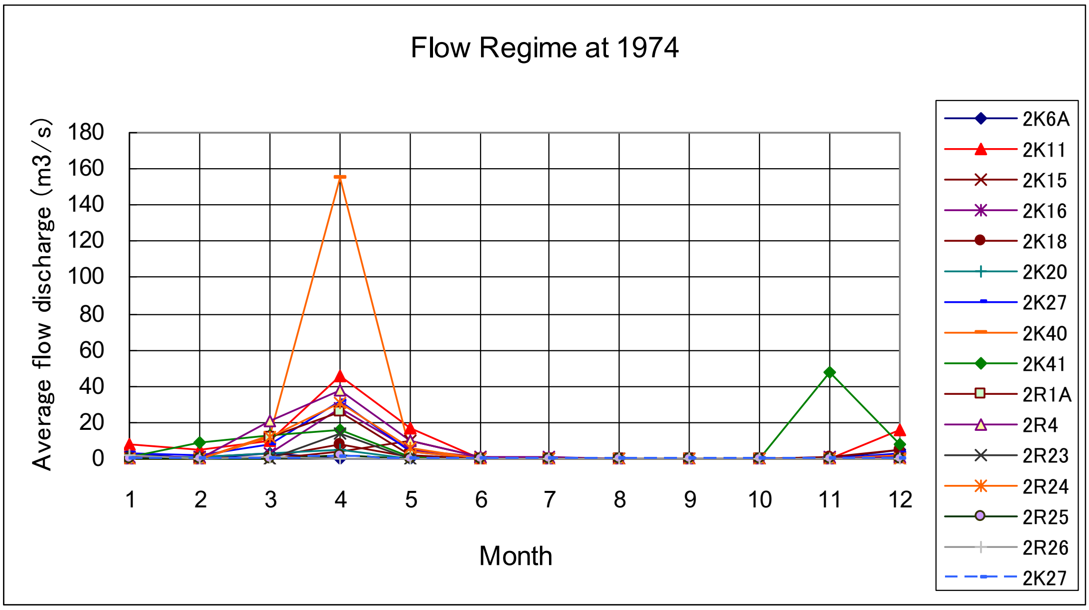


Figure 1-11 Monthly Averaged River Flow Discharges at 1974

(4) Lake Water Level

Lake water level of the 2K13 gauging station at the Kitangiri Lake in Lake Eyasi sub-basin was analyzed as Figure 1-12. The figure presents average daily water level at Kitangiri Lake. Annual trend of water level change of the station is that the water level goes up during rainy season and goes down during dry season. The difference of the water level between the beginning and the end of each year corresponds to the change of storage volume in the lake during the corresponding year. For example, the water levels at each June went down from 1979 to 1982. It means that the storage volume of the lake decreased in this period.

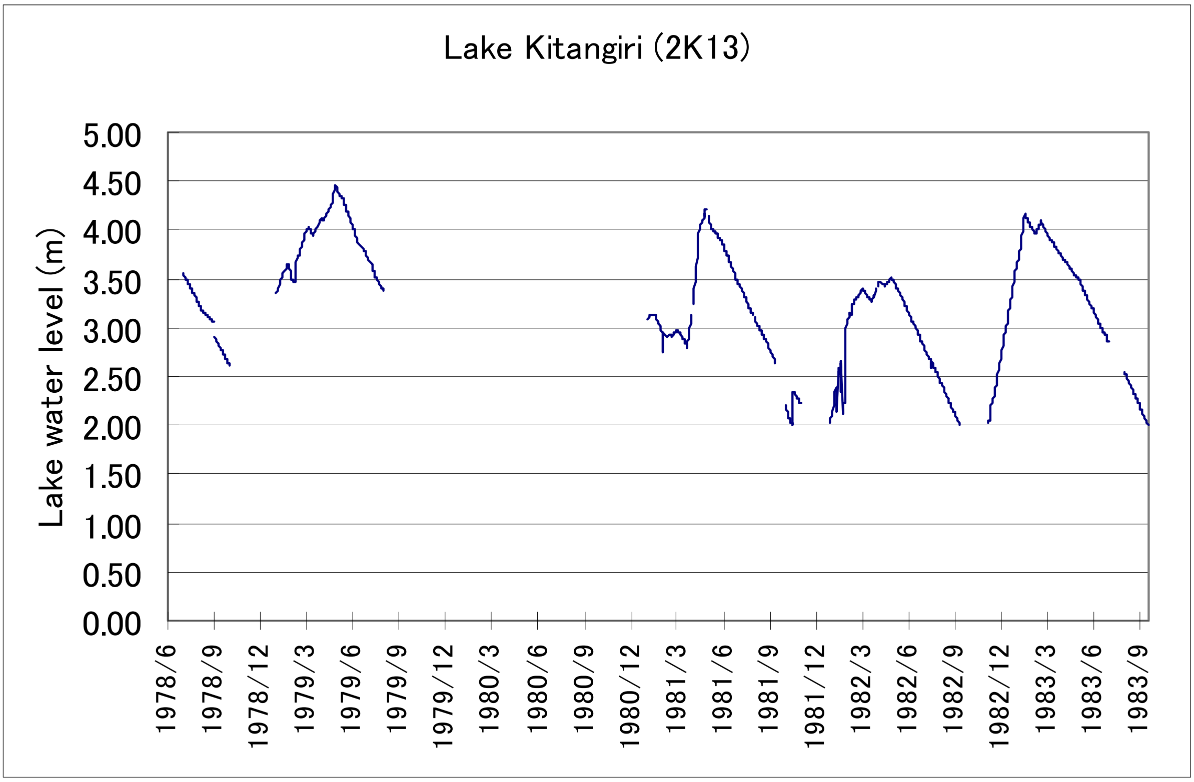


Figure 1-12 Water Level Change of Lake Kitangiri (2K13)

1.3.3 River Flow Discharge Measurement

(1) Purpose

The main purpose of the river flow discharge measurements was initially to add new data to the existing rating curves for each hydrometric gauging station, and estimate validities of the existing rating curves. However, our collected information says that suitable river flow discharge measurements for achieving the initial purpose in IDB are very difficult due to the shortest time of the flow discharges like a flashing. Therefore, we set additional purpose that is to provide river flow discharge information to some hydrometric gauging stations now being operated.

(2) Selected Hydrometric Gauging Stations

As a result, five (5) hydrometric gauging stations are selected as measurement points. Their name and locations listed in Table 1-2 and are shown in Figure 1-13.

Table 1-2 Selected Hydrometric Stations

Station No.	Station Name	LOCATION	LAT	LONG
2H1A	Kirurumo	Mto wa Mbu Br.	-3.36809	35.84044
2H5A	Dudumera	Kiru Rd.Br.	-4.09114	35.72419
2K6A	Kironda	Kirondatal	-4.37876	34.33479
2K27	Tungu	Lubaga	-3.57176	33.78125
2R1A	Bubu	Farkwa Rd.Br.	-5.31486	35.55566

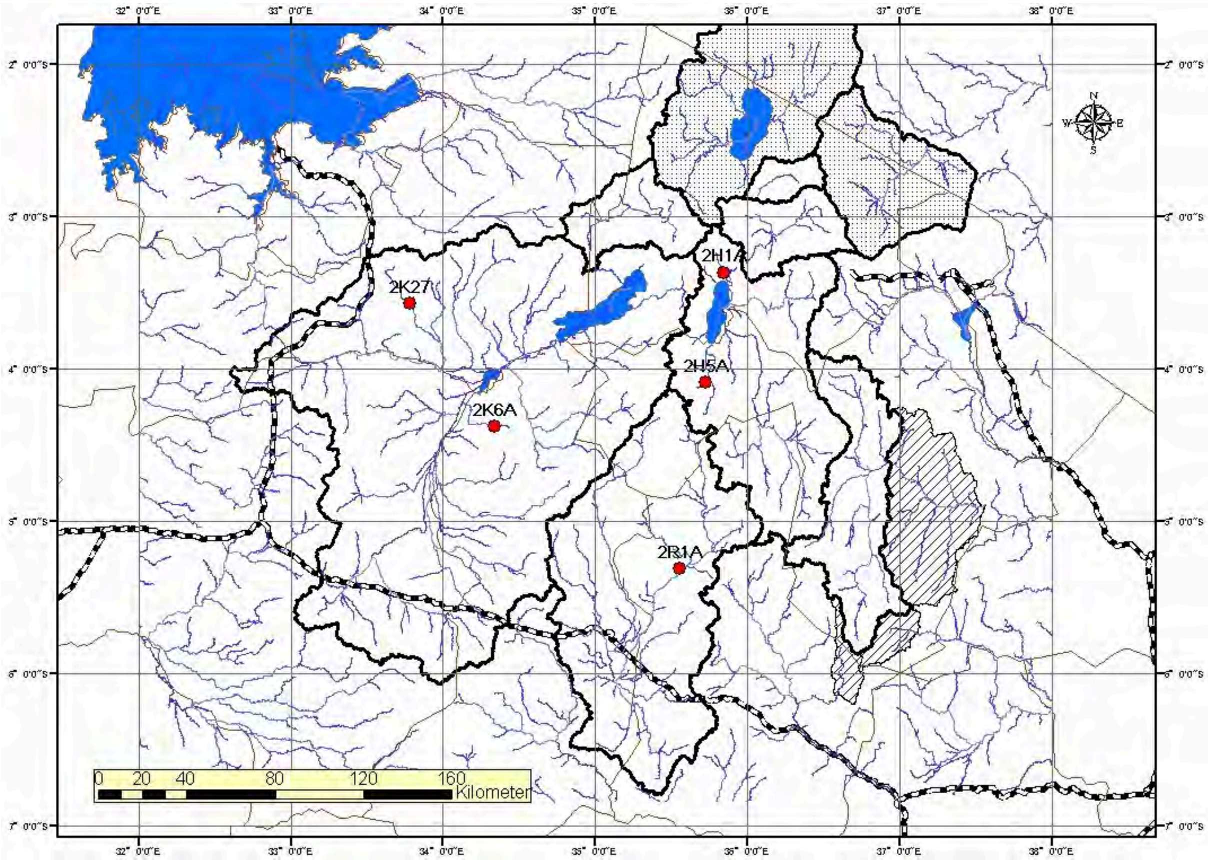


Figure 1-13 Locations of River Flow Discharge Measurement Points

(3) Method of River Flow Discharge Measurement

The flow measurement were implemented in compliance with Tanzanian standards, which is shown in "MANUAL ON PROCEDURES IN OPERATIONAL HYDROLOGY, VOLUME 3, STREAM DISCHARGE MEASUREMENTS BY CURRENT METER AND RELATIVE SALT DILUTION, 1979".

(4) Measurement Results

The measurement results are shown in below.

Table 1-3 Measurement Results of River Flow Discharge

Station No.	Station Name	Flow discharge (m3/s)	Date & time	LAT	LONG
2H1A	Kirurumo	1.03	2006/3/17	-3.36809	35.84044
2H5A	Dudumera	1.12	2006/3/17	-4.09114	35.72419
2K6A	Kironda	0.56	2006/3/16	-4.37876	34.33479
2K27	Tungu	0.05	2006/3/19	-3.57176	33.78125
2R1A	Bubu	0.20	2006/3/16	-5.31486	35.55566

1.4 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 IDBO. The time stamps of the information were from 5 May 2004 to 12 January 2006. The results are shown in Figure 1-14 and Figure 1-15. The perceived tendency from these figures is shown below.

(1) Arusha Region

The main water resources are river and spring water. The main purpose of the water use is domestic use. There are small water uses for irrigation, livestock and commercials.

(2) Manyara Region

The main water resource is river water. The main purpose of the water use is domestic use. There are small water uses for irrigation.

(3) Dodoma Region

In this region, the data obtained is the one for Kondoa district only. The main water resources in Kondoa district are river, dams and borehole water. The main purpose of the water use is domestic use

(4) Singida Region

The main water resource is borehole water. The main purpose of the water use is domestic use. There is small water use for livestock.

(5) Tabora Region

The main water resources are river and dam water. The main purpose of the water use is irrigation and the next is domestic use. There is small water use for mining.

(6) Shinyanga Region

The main water resource is dam water. The main purpose of the water use is domestic use. There are small water uses for commercials and mining.

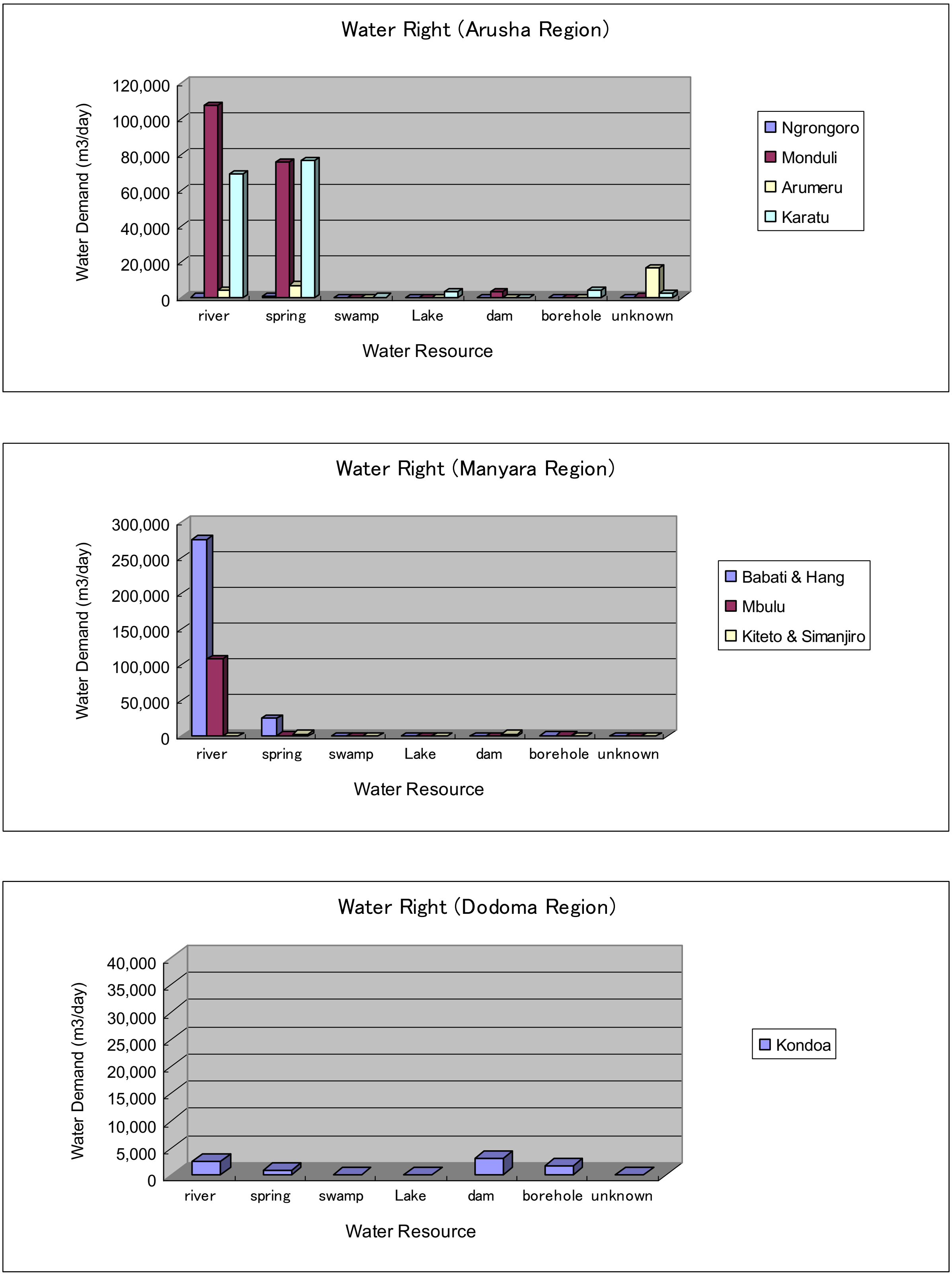
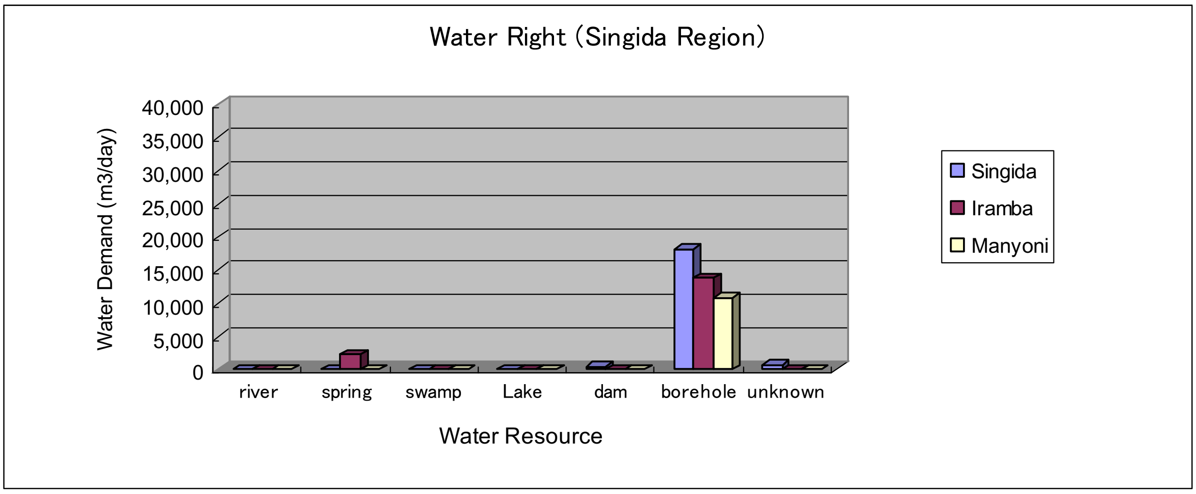
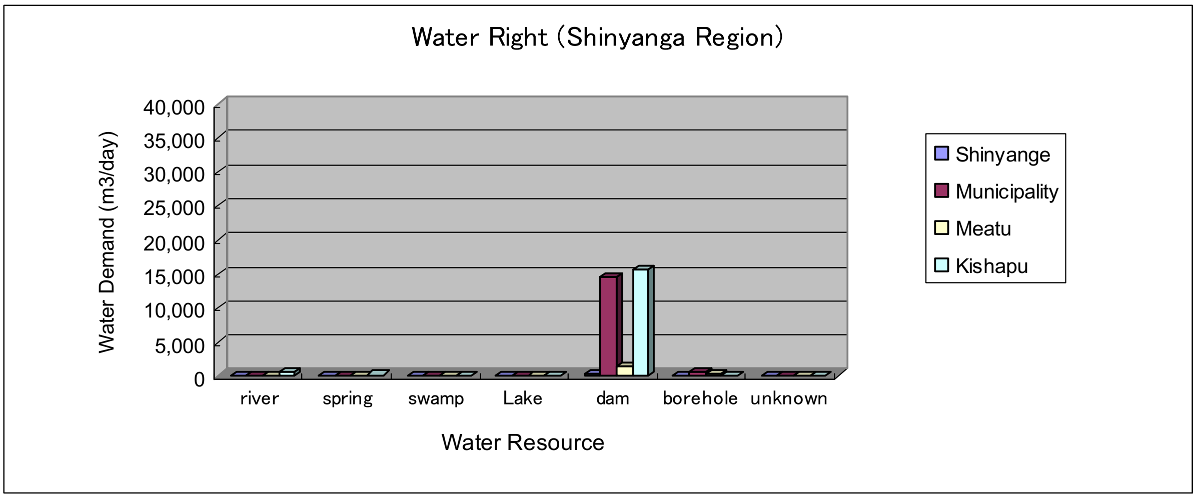


Figure 1-14 Water Use derived from Water Right Information (1)





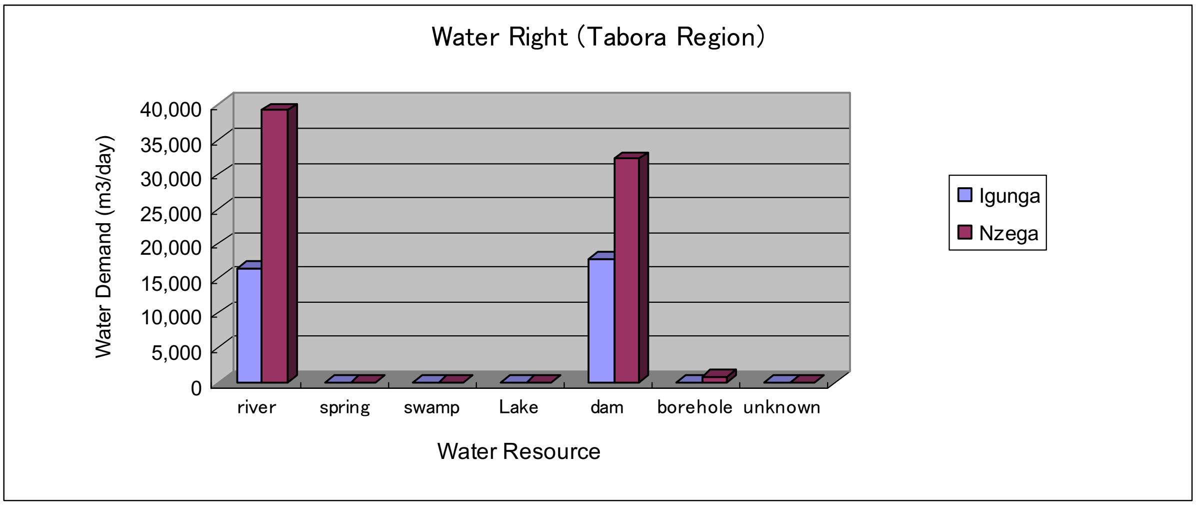


Figure 1-14 Water Use derived from Water Right Information (2)

Chapter 2
Geomorphology

CHAPTER 2 GEOMORPHOLOGY

2.1 Purpose of Survey

The objective of the survey is to grasp the geo-morphological characteristics in the study area.

2.2 Survey Area

The survey covers the whole study area, that is, the Internal Drainage Basin (IDB). The Study area is located in the eastern side of "East African Rift Valley" (Figure 3-1 in Chapter 3).

In the central and northeastern parts of the study area, huge volcanoes such as Mt. Hanang, Kilimanjaro, Ngorongoro crater are situated. These volcanoes and "Basin and Swell" structure are closely related to rift-faulting movements and nine sub-basins in IDB were formed by these topographic and geologic features.

2.3 Methodology of Geomorphologic Analysis

2.3.1 Used Remote Sensing Data

Thirteen scenes of LANDSAT ETM data were prepared for this study. Used LANDSAT/ETM+ images are listed up in Table 2-1. Figure 2-1 shows Location of used LANDSAT/ETM+ data.

SRTM-DEM (Shuttle Rader Topography Mission-Digital Elevation Model), calculated from radar data acquired by the Space Shuttle Radar System, was used in order to understand topographic features, drainage networks and catchments area. Used SRTM-DEM data covers the study area and is bounded by the following coordinates: 2° 00'- 6° 00'S and 32° 00'- 36° 00'E.

SRTM DEM data had been obtained from following website:http://www2.jpl.nasa.gov/srtm/.

Table 2-1 List of Used LANDSAT/ETM Data

No.	Path	Row	Acquisition Date
1	167	63	2001/3/4
2	167	64	2001/1/15
3	168	62	2000/2/21
4	168	63	2000/2/21
5	168	64	2001/3/11
6	168	65	2000/2/21
7	169	61	2000/1/27
8	169	62	2000/2/12
9	169	63	2000/2/12
10	169	64	2000/2/12
11	170	62	2001/5/12
12	170	63	2000/1/18
13	170	64	2000/1/18

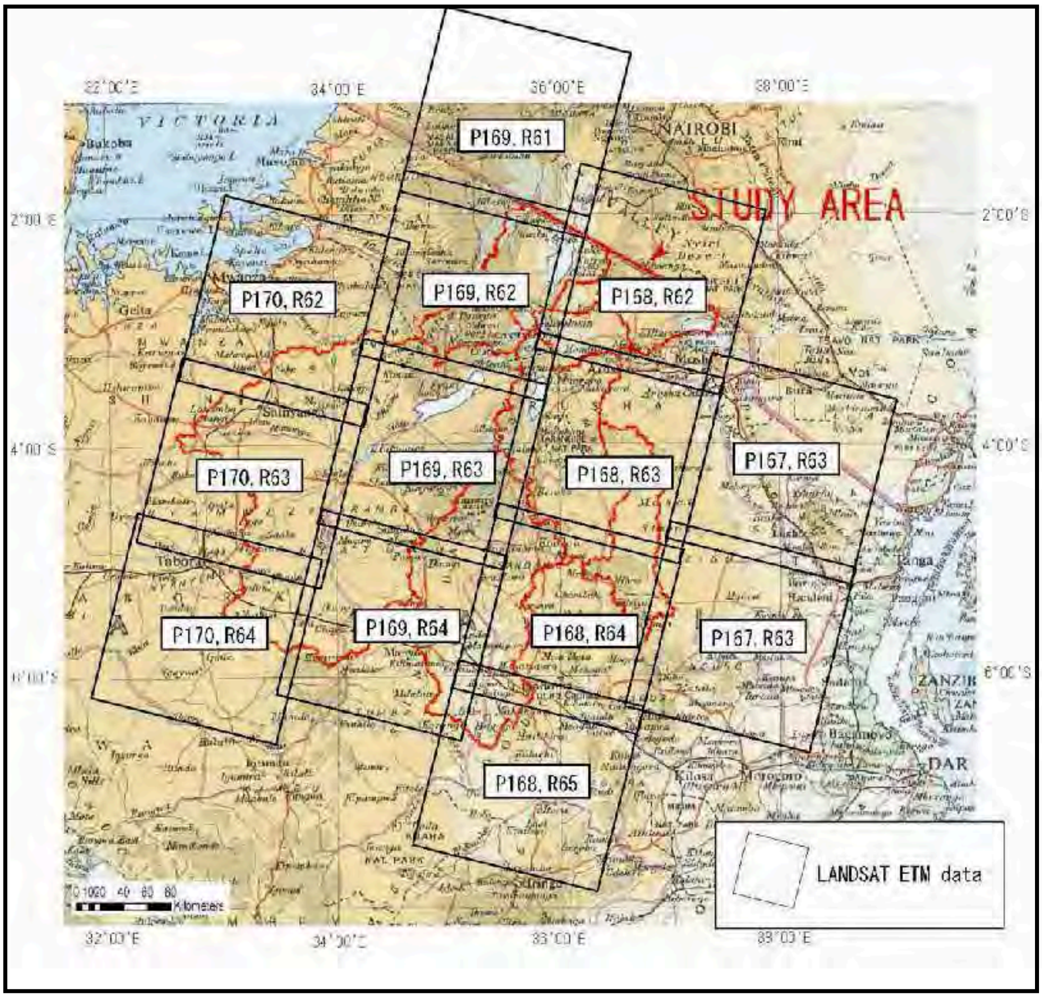


Figure 2-1 Location of used LANDSAT/ETM+ data

2.3.2 Data Processing and Analysis

(1) SRTM DEM Processing

SRTM DEM data was used to generate drainage networks and to extract sub-basin areas based on the following procedure.

- To generate drainage networks using drainage direction matrix.
- To delineate of sub-basin areas with proper size after the consideration of geomorphologic feature and so forth.

These results were described in “**1.3** Hydrology”.

The SRTM DEM data also used to extract the significant geological structures such as lineaments, faults and warping structure.

(2) LANDSAT ETM Mosaic Image

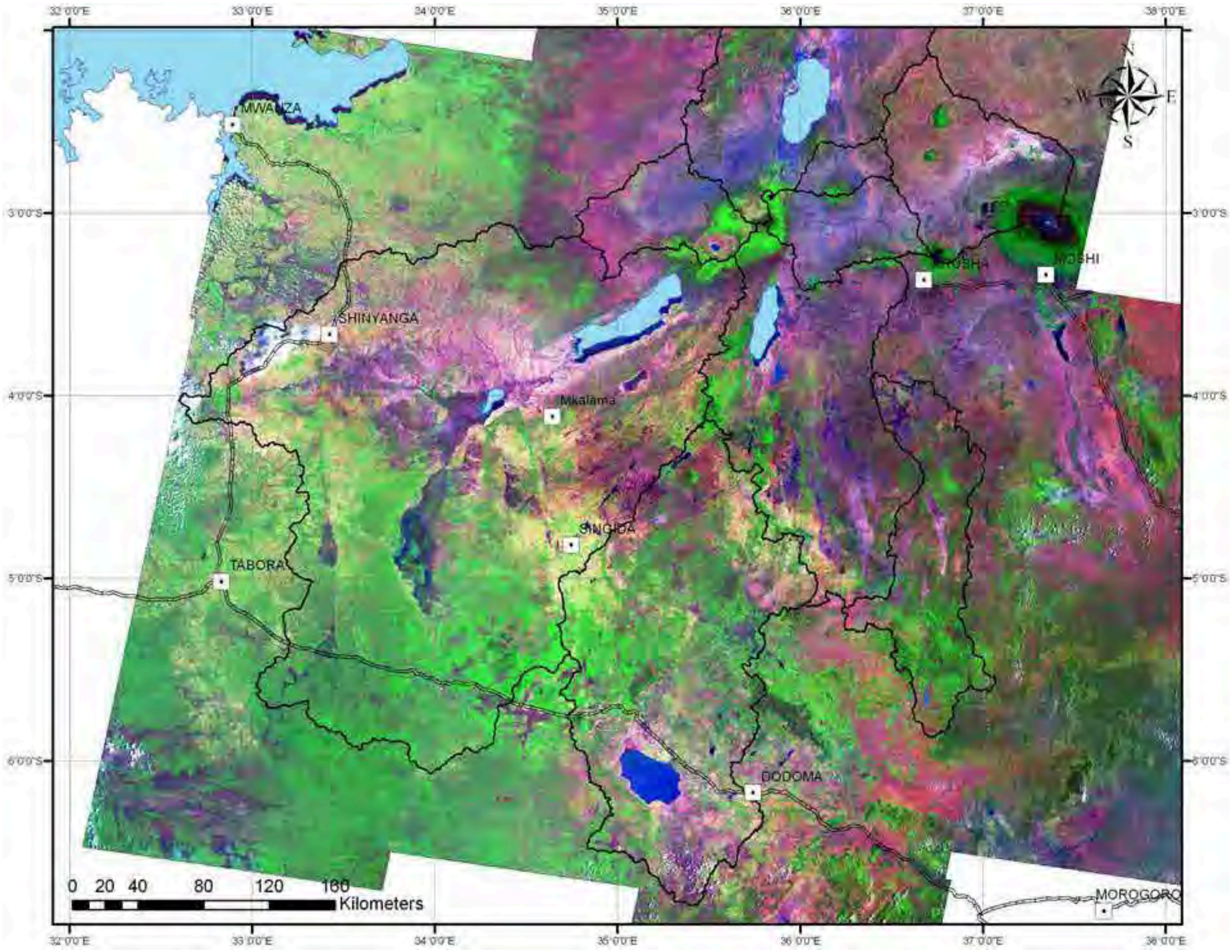


Figure. 2-2 LANDSAT ETM False Color Image (B, G, R: band1, band4, band5)

Twelve scenes of LANDSAT ETM images were generated using band 1, 4 and 5 of ETM data, assigned to blue, green and red, respectively. This band combination has the advantage of emphasizing the color variations of rocks, soil and vegetation. LANDSAT mosaic image is shown in Figure 2-2.

(3) SAVI (Soil Adjusted Vegetation Index) Image

The SAVI image was used to analyze the vegetation density and activity, using LANDSAT ETM band3 and band4. The SAVI considered an influence of soil spectra.

The SAVI is defined as by following equation.

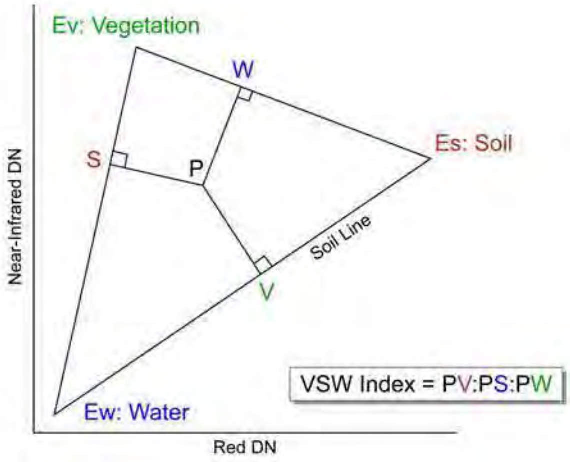
$$SAVI = \frac{Band4 - Band3}{Band4 + Band3 + L} * (1 + L)$$

L: non-dimensional correction factor, from 0 to 1.

(4) VSW (Vegetation-Soil-Water Indices) Image

The VSW indices show vegetation, soil and water parameters of grand surface. The concept of VSW shows Figure 2-3. The end member spectral points for vegetation, soil and water (VSW) were determined on the digital number diagram using Landsat ETM band3 and band4.

Landsat ETM Band4



Landsat ETM Band3

Figure 2-3 Concept of Vegetation, Soil and Water(VSW) Indices

(5) Land Cover Image

The land cover map was produced based on the results of VSW indices and existing data.

2.3.3 Field Survey

Based on the results of preliminary interpretation of remote sensing data, a field survey was carried out in order to check the geology and geomorphology. The field survey has revealed following points mainly.

- Distribution area of the Nyanzian System; From Shinyanga to Iramba.
- Boundary of plutonic rocks and metamorphic rocks (USAGARAN System).
- Distribution area of Neogene sediments; Shinyanga, Igunga, Monduli, Kiteto, Dodoma and Singida areas.
- Distribution range of Neogene volcanic rocks; Hanang, Babati, Monduli and Arumeru areas.
- Surface feature of lineaments and faults.
- Vegetation and land use of each area.
- Hot spring; Lake Manyara.

The Locations of field survey points are shown in Figure 2-4. The results of field survey are described "**3.4** Results of Field Survey"

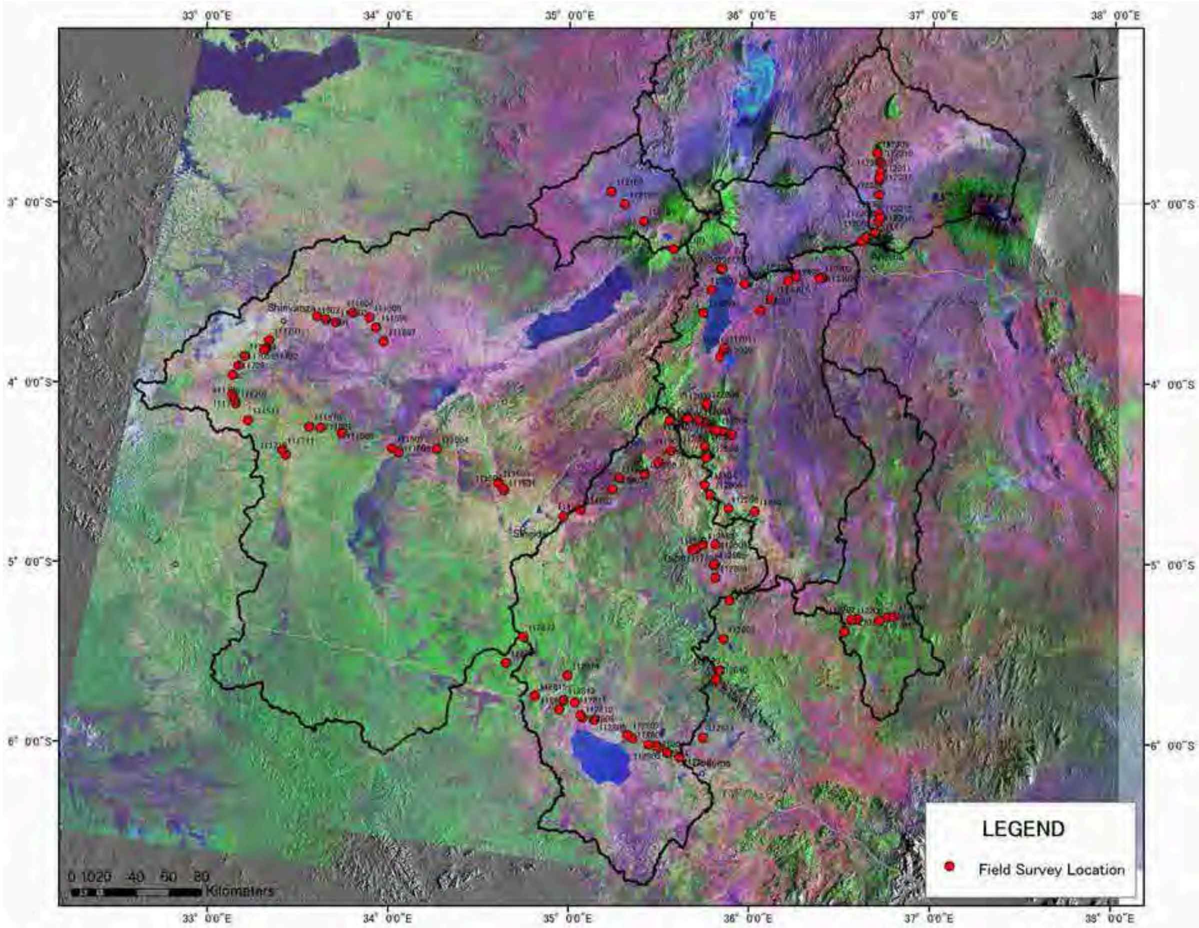


Figure2-4 Location of Field Survey Points

2.4 Geomorphologic Characteristics

2.4.1 Topography

The topographic image processed SRTM DEM is shown in Figure 2-5. This image shows the elevation by color level slice. On the other hand, Figure 2-6 was prepared by DEM data to understand topographic features of IDB three-dimensionally.

The Study area is located in the eastern side of "East African Rift Valley". In the central and northeastern 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 and "Basin and Swell" structure are closely related to rift-faulting movements.

In northern to central part of the study area, several large lakes are located in each sub-basin, such as Lake Natron (EL; about 600m), Lake Manyara (EL; about 950m) and Lake Eyasi (EL; about 1,020m). 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. The nine sub-basins in IDB are formed by these topographic and geologic features.

There are several hot springs in IDB. In this field survey, one of hot springs was observed at the bottom of the fault scarp in the western margin of Lake Manyara as shown below.


Photographs of Hot Spring near Lake Manyara

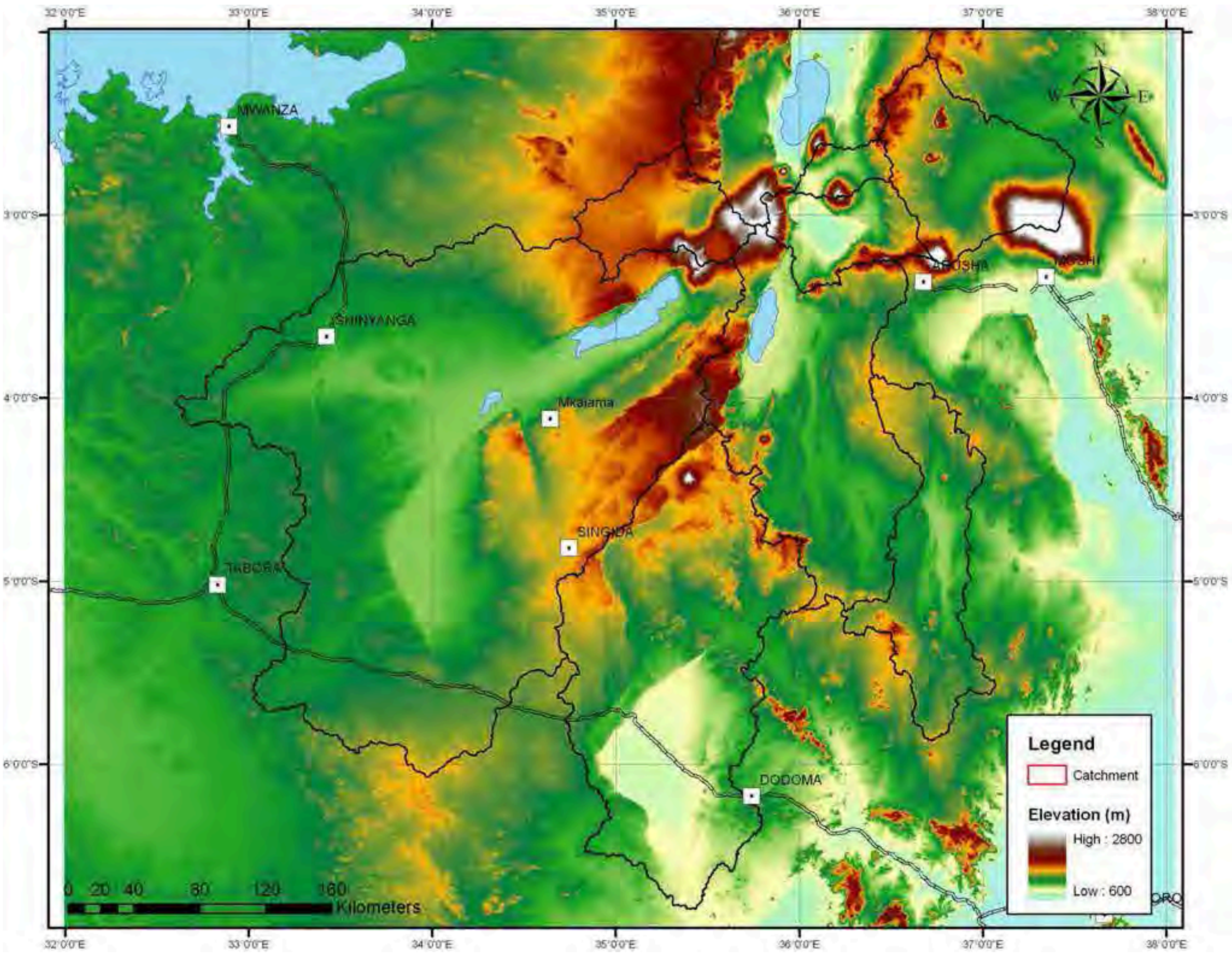


Figure 2-5 SRTM DEM Image

2.4.2 Nature of Ground Surface

SAVI image and VSW image are shown in Figure 2-6 and Figure 2-7 respectively. During January and February when LANDSAT data were acquired, high vegetation index features the two types of areas. One corresponds to high elevation area (above EL1500-2000m) and the other corresponds to the southwestern part of IDB along railroad (about EL1000-1400m). The latter also corresponds to smooth topographic characteristic area where is covered by thick weathering zone of granitic rocks.

VSW image shows that high soil index distributes in the northern part of IDB, high water index distributes in eastern low elevation area. Almost large lakes and swamps in magenta color suggest mixed spectra of soil and water because of shallow water depth.

Figure 2-8 shows land cover map that was produced by the results of VSW image and SAVI image.

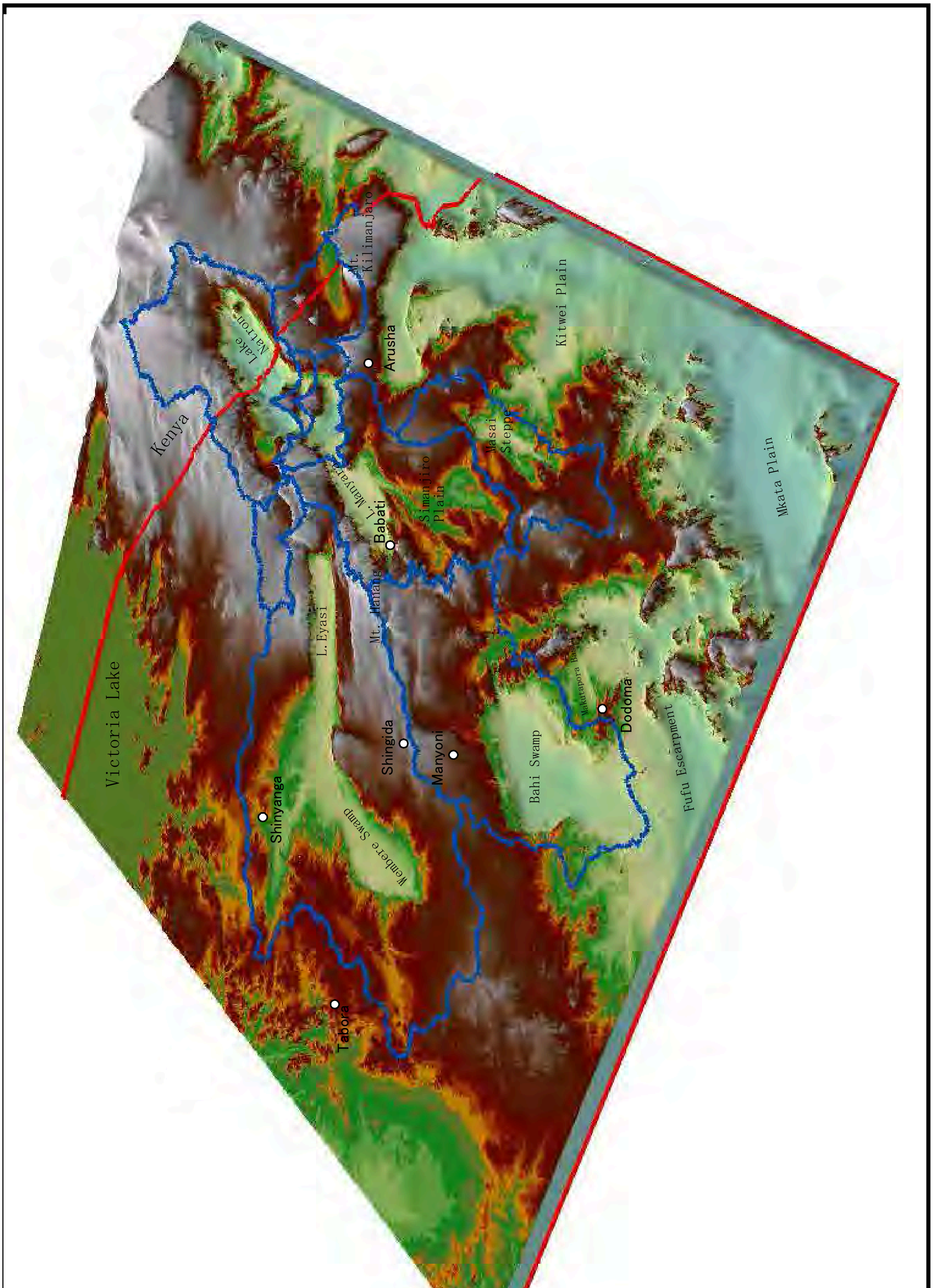


Figure 2-6 Three Dimensional Topographic Map of the Internal Drainage Basin

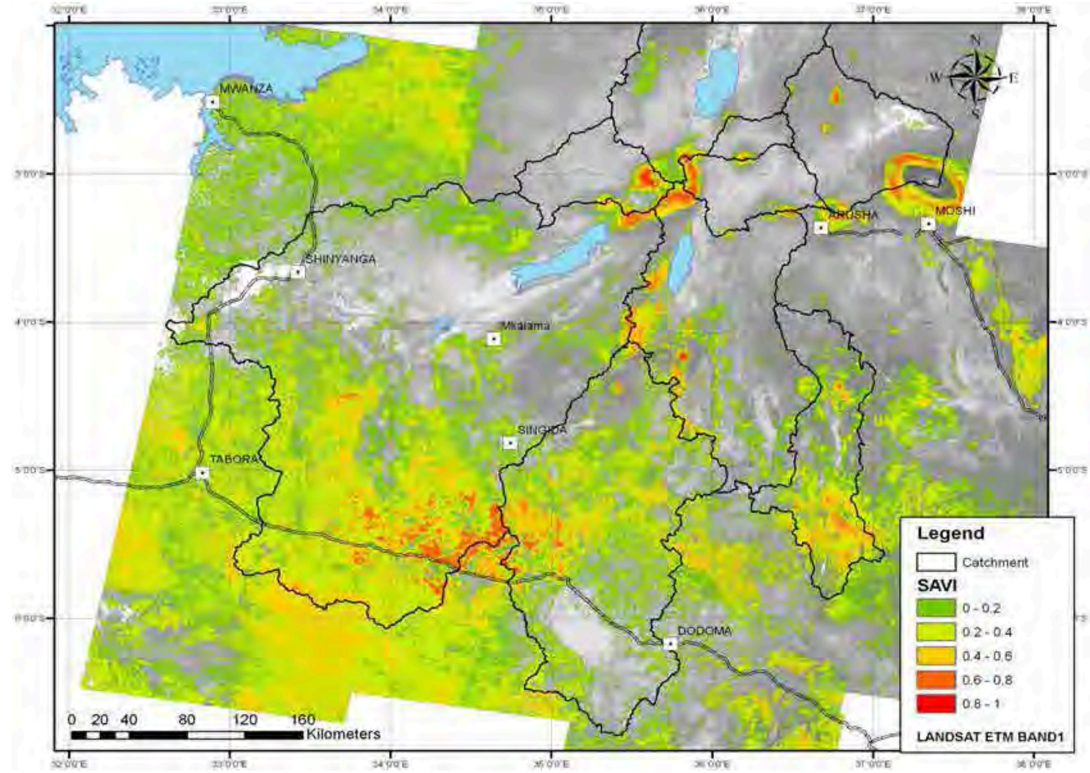


Figure 2-7 SAVI (Soil Adjusted Vegetation Index) Image

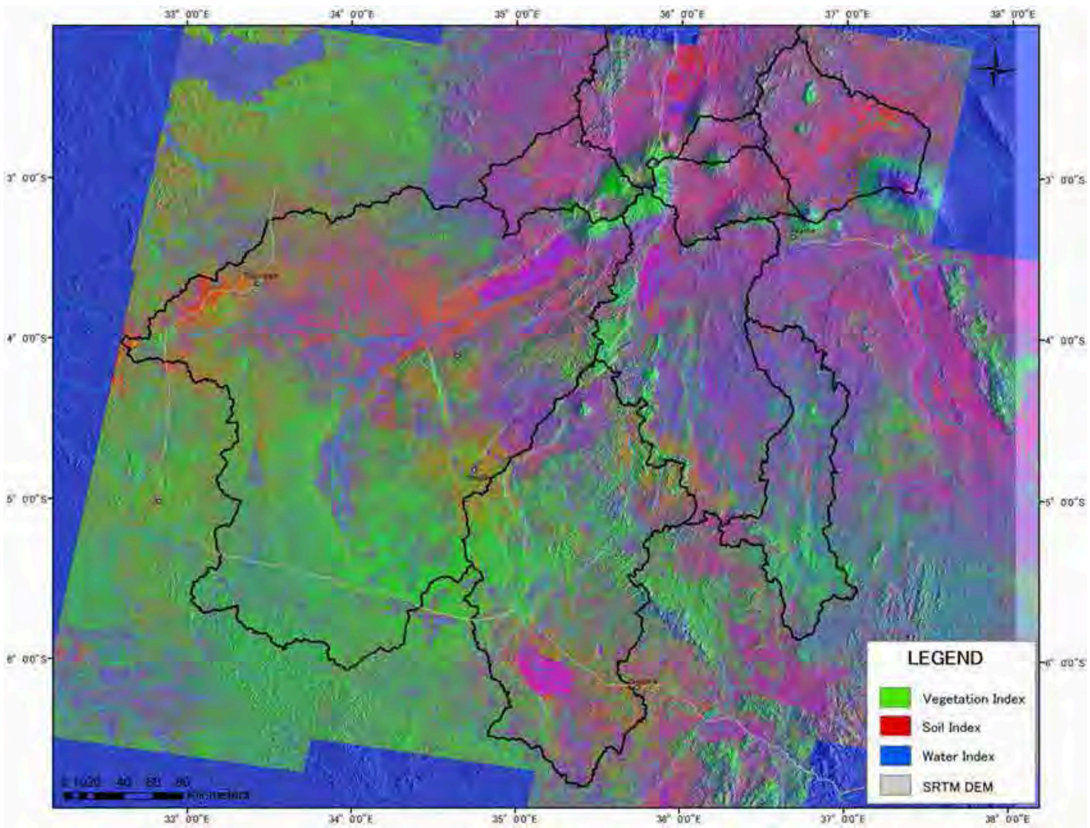


Figure 2-8 VSW Image (V; vegetation, S; Soil, W; Water and Moisture)

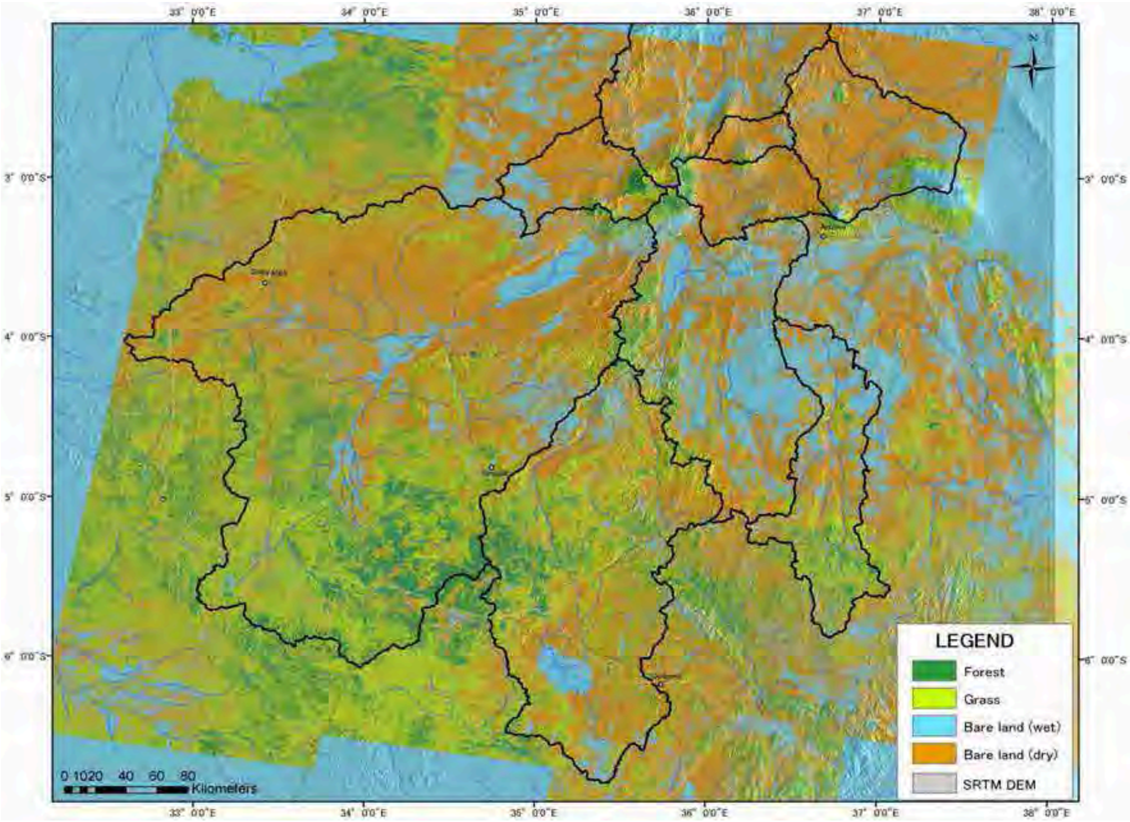


Figure 2-9 Land Cover Map.

Chapter 3
Geology

CHAPTER 3 GEOLOGY

3.1 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 3-1). 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 African Rift represent an early stage of continental separation. Figure 3-1 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's 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. However there's no evidence that this fault activity happened in Paleogene. In general, the faults discoed 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 the basins is changing apparently based on their sedimentation. Therefore, the rivers tend to flow along the faults laterally and wide flood planes are developed.

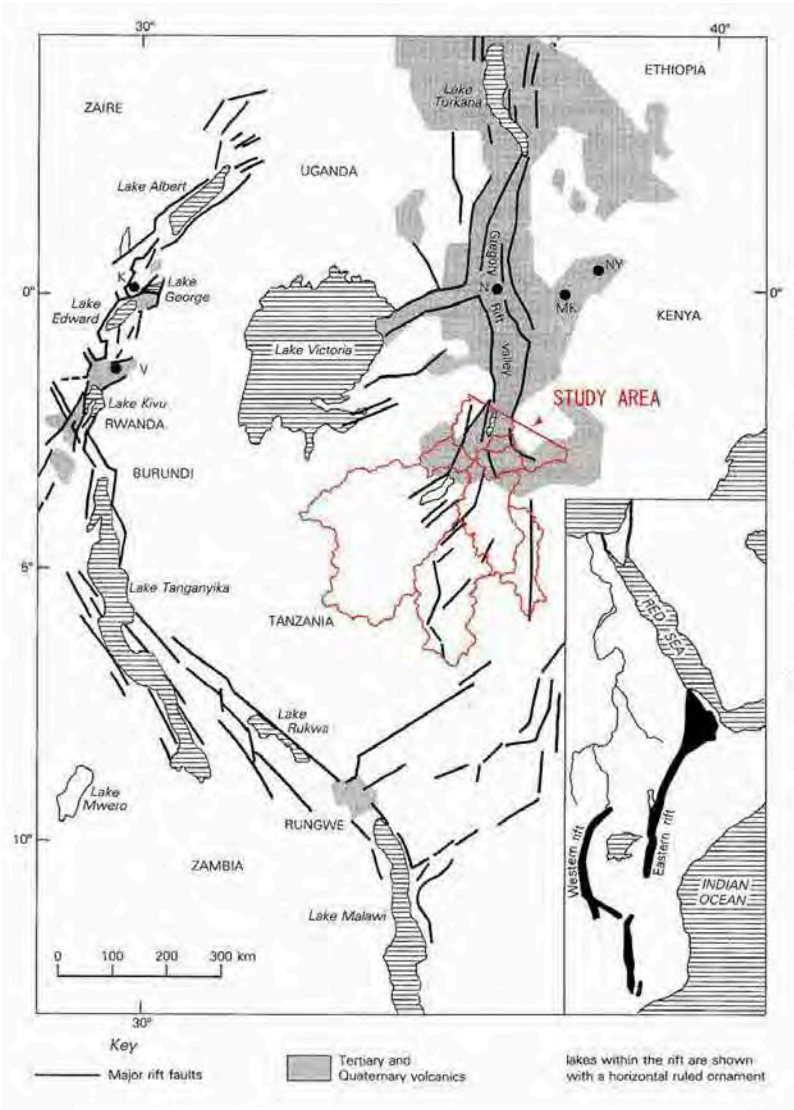


Figure 3-1 Structural Map of East African Rift System (Wilson (1989))

3.2 Geological Description

The geological interpretation map and stratigraphy are shown in Figure 3-2 and Table 3-1, respectively. This interpretation map was produced using LANDSAT ETM false colour image (Figure3-2) 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 3-1) and many lineaments and fault structures were extracted

Table 3-1 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;		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**

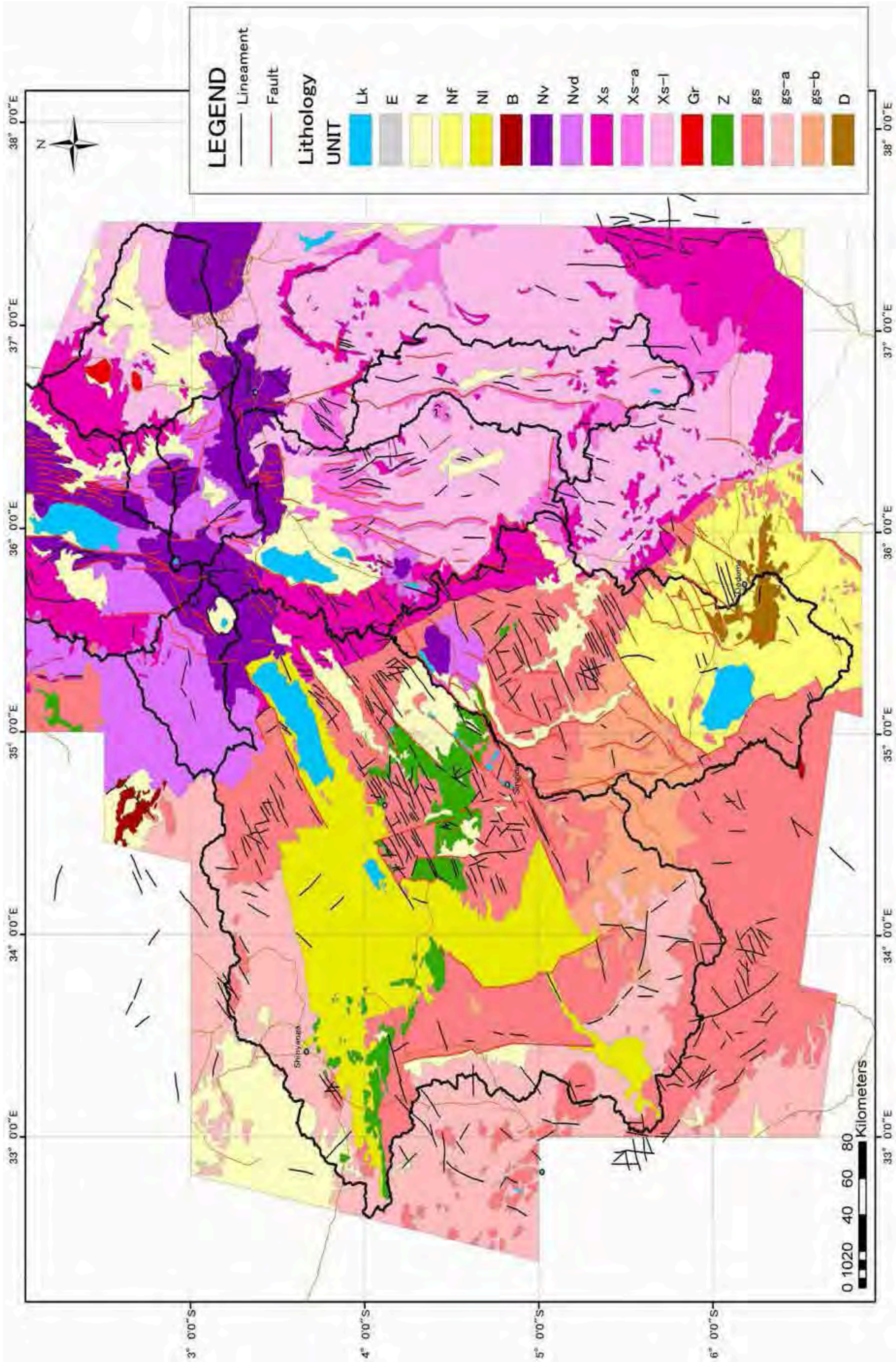


Figure 3-2 Geological Map of the Internal Drainage Basin

3.2.1 Precambrian Basement Rocks

(1) Dodoman System (Archean): D

The Dodoman system is the oldest formation in Tanzania which consists of schist, gneiss and migmatite. It is distributed around Dodoma town.

(2) Nyanzian System (Archean): Z

The Nyanzian system consists of banded ironstone, metavolcanics and chlorite schist. They are distributed in Shinyanga, Nzega, Igunga and Iramba district.

Since their surface soil characteristically shows dark reddish brown in colour, this system can be easily distinguished on LANDSAT Images. At the north of Singida town, outcrops of gabbros were observed.

(3) Kavirondian System (Archean): V

The Kavirondian system consists of quartzite and phyllite. Outcrops of the rocks are confined at the limited area near Nzega.

(4) Usagaran System (Archean): Xs, Xs-a and Xs-l

The Usagaran system consists of marble, schist, gneiss and migmatite. These rocks crop out the large area of the eastern part of the Basin

This formation can be classified into three units; “Xs”, “Xs-a” and “Xs-l” based on their topographic features.

Some migmatite distributed in “Xs-a” and “Xs-l” units can be delineated on the LANDSAT images.

(5) Bukoban System (Proterozoic): B

The Bukoban system consists of sedimentary rocks; mudstone, shale, sandstone, etc. Exposures of the rocks are confirmed at the limited area in the southern part of the Bahi Swamp.

(6) Plutonic Rocks (mainly Archean); gs, gs-a, gs-b and Gr

Plutonic rocks consist of granite and granodiorite, gneissose or migmatitic rocks. Plutonic rocks are widely distributed from the central to the western part of the Basin.

Plutonic rocks can be classified into three units based on degree of weathering zone analyzed by their topographic features.

Unit “gs” widely distributed in almost whole area of plutonic rocks is characterized rough texture on the LANDSAT images and high altitude. Unit “gs-b” distributed along Tanzanian Railroad at

Manyoni to the northwest is characterized very smooth texture. Unit "gs-b" corresponds to the thick weathered zone which are named as "Kilimatinde cement" in the published geological map. Unit "gs-a" has intermediate feature between "gs" and gs-b. Unite "Gr" located near the country border at the north of Arusha forms raise being surrounded by Usagaran system (Xs-l).

3.2.2 Kainozoic (Cenozoic) Formations; N, E, Nf, Nl

During late Neogene, lacustrine sediments, terrestrial sediments, fluviatile sediments, marine sediments and alluvial sediments deposited in the lakes and shallow basins formed by the warping of the surface that accompanied rift-faulting movements. These sediments are distributed in the centre of each basin and characterized by low plane in topography. Based on published geological map, these Cenozoic sediments were classified into four units (N, Nl, Nf and E). Since it is very hard to differentiate these units except evaporite in topographic features and also spectral features, their classification was adopted to Figure 3-2.

3.2.3 Volcanic Rocks; Nv, Nvd

From the central to the north-western part of the Basin, extensive volcanic activity in association with rift-faulting movements can be seen from Mt. Hanang, Mt. Kilimanjaro and northward into Kenya. These huge volcanic massifs consisting of extensive alkaline lava and pyroclastics are accumulated. These volcanic activities have been continuing in small scale. In general, alkaline type volcanic rocks have high volatile contents such as H_2O, CO_2, F and so on.

Distribution of volcanic lavas and pyroclastics can be delineated on the LANDSAT false colour image. In interpretation map, Cenozoic volcanic rocks are divided into "Nv" and "Nvd". "Nv" consists of lava and pyroclastic rocks and forms volcano body.

3.3 Geological Structure

Distribution map of faults and lineaments is shown in Figure 3-3.

A lineament is defined to be "straight and/or semi-curve linear features on the surface, which seems to reflect subsurface geological structures such as fracture. In this study, fault can be distinguished from the presence of step structure along lineament.

A large number of lineaments and faults in association with rift-faulting movements were extracted from the almost whole of all the study area. From the eastern to northern part of the Basin, 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.

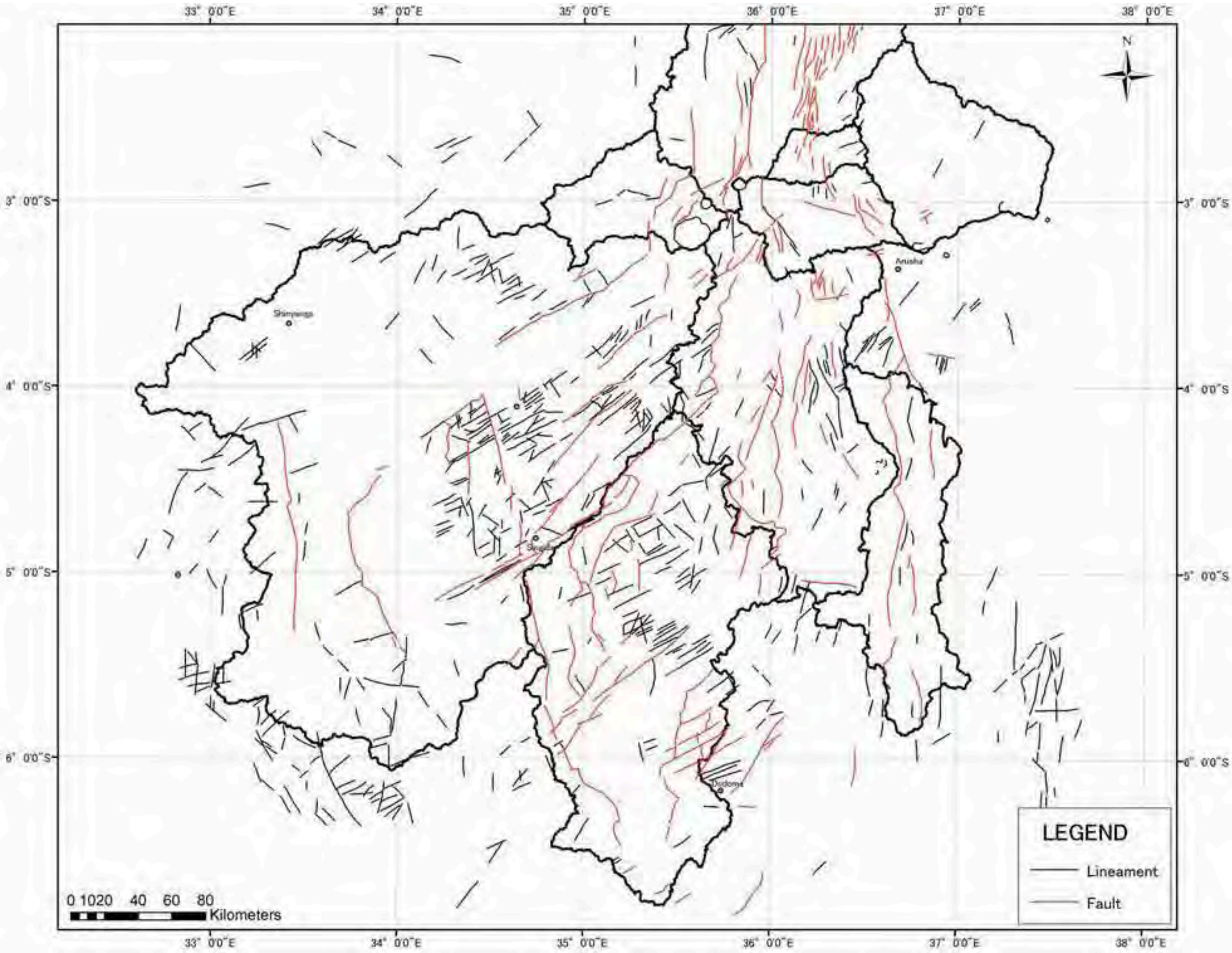


Figure 3-3 Distribution of Faults and Lineaments

3.4 Results of Field Survey

Based on the results of preliminary interpretation of remote sensing data, a field survey was carried out in order to check the geology and geomorphology. The field survey has revealed following points mainly.

- ✓ Distribution area of the Nyanzian System; From Shinyanga to Iramba.
- ✓ Boundary of plutonic and metamorphic rocks (Usagaran System)
- ✓ Distribution area of Neogene sediments; Shinyanga, Igunga, Monduli, Kiteto, Dodoma and Singida areas.
- ✓ Distribution range of Neogene volcanic rocks; Hanang, Babati, Monduli and Arumeru areas.
- ✓ Surface feature of lineaments and faults.
- ✓ Vegetation and land use of each area.
- ✓ Hot spring; Lake Manyara.

The Locations of field survey points are shown in Figure 3-4.

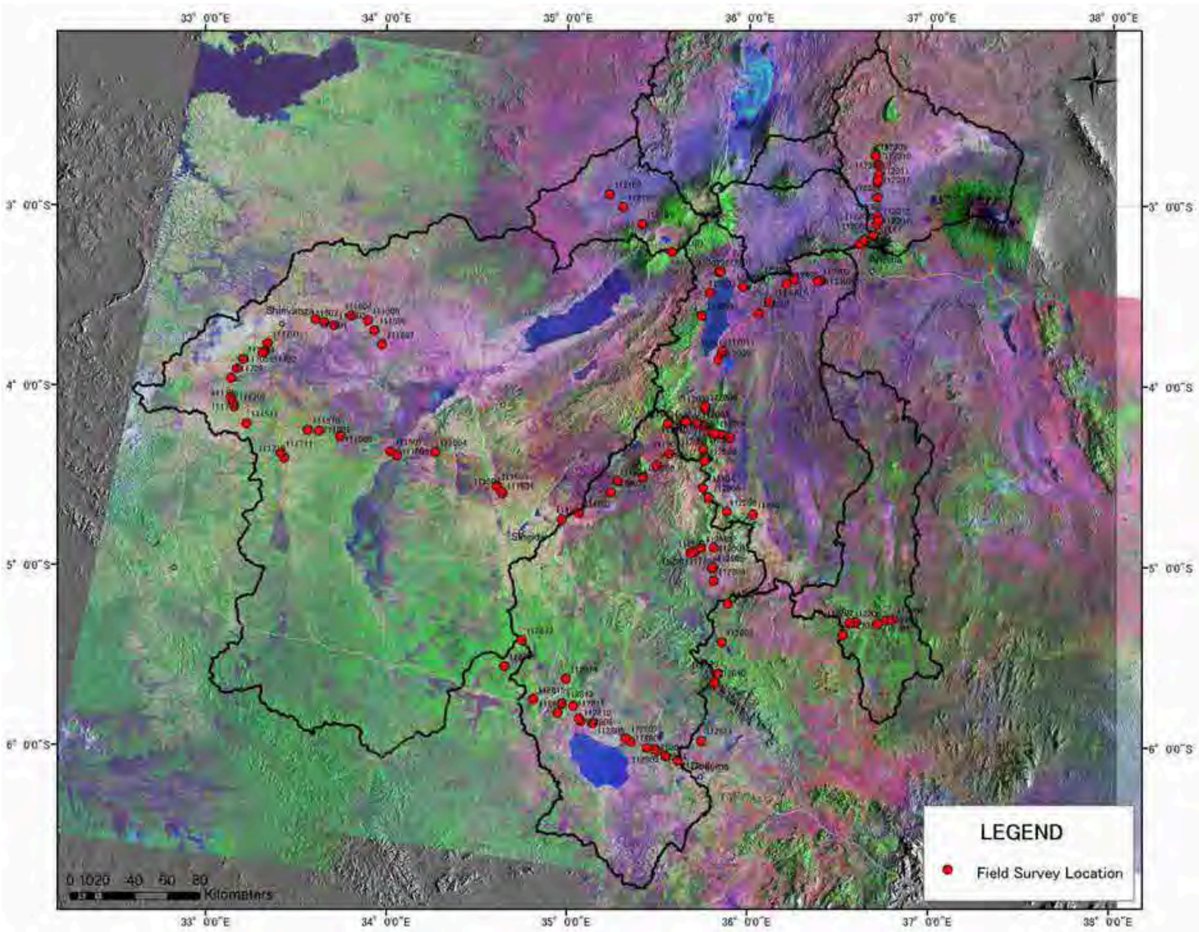


Figure3-4 Location of Field Survey Points

(1) Kainozoic (Cenozoic) Sediments of Manonga River Catchment

Location No.; 111601 to 111607, 111701 to 111706

The boundary between the granitic rock of basement (gs-a) and the lake deposits (Nl) was identified at Loc. 111509 (P- 01). The topography of the zone along this boundary shows gentle inflection point where the basements area is level flat on north side and the lake deposits area is gentle slope dipping to south. The soil colour of granitics area shows yellowish light grey, other hand lake deposit shows gray colour. The lake deposit areas of east of Igunga have low vegetation covering comparatively (P- 01).

At location 111705, outcrops of sand, silt and calcrete were observed. Along the Manoga River, the soil colours show dark gray to gray, and the rice fields are distributed in this area (loc. 111706, P-02).

P-01: Ground feature of lake deposits (Nl) area (Location 111509)

P-02: Ground feature around Manonga River (Location 111706)

(2) The distribution of Nyanzian(Z) system and plutonics of basement (gs and gs-a) between Shinyanga and Singida.

Location No.; 111501-111510, 111702, 111708, 111709

In area of Nyanzian system (Z), crystalline schist and gabbroic rocks were observed. The distributions of Nyanzian system were characterized by dark reddish brown to reddish brown soil that can be distinguished from the distribution of granitic rocks (gs and gs-a).

Along the east side of Wembere River, large-scale N-S trending fault scarp was recognized by remote sensing data. The lithology around the fault consists of crystalline schist (P- 03). Conglomerate of quartzite showing terrace-like distribution was identified at Location No.111508.

P-03a: Out crop of green schist (Location 111504)

P-03b: Ground feature of Wembere River catchment, view from edge of fault scarp (Location 111504)

(3) The Fault of South of Nzega

Location 111710-111711

In the west margin of study area, Large-scale fault scarp trending N-S direction was newly-extracted by using remote sensing data. On the edge of fault scarp, fine-grained granitic rock (gs) was exposed occasionally (Loc 111711). Along this top of fault scarp, cultivated field are distributed (Loc 111711).

(4) Lineaments of East Singida

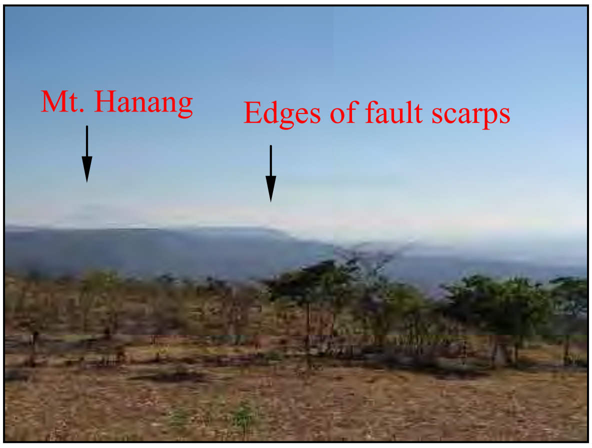
Location; 111901-111902

The NE-SW large-scale fault is developing on the boundary of sub-basins A and G between Singida and Babati, and several lineaments were developed in sub-parallel to this large fault (P-05).

The topographic feature of NE-SW lineaments is observed as gentle valley (P- 06). Massive granitic rock (gs) and foliated granitic rock (gs) were observed. The soil colour shows light gray to gray.

P-04: Cultivated area (gs) on the top of fault scarp (Location 111711)

Gabbroic rock presumed as Nyanzian system (Z) was identified at Location 111902. This soil colour shows reddish brown characteristically.



P-05: Ground features of edge of fault scarp (Location 111901)

P-06: Ground feature of lineament (Location 111901)

(5) Distributions of Volcanic Rocks (Nv and Nvd) of Related Hanang and Kwaraha Volcanoes

Location 1119003 to 111910 and 112001 to 112008

The distributions of pyroclastic rocks (Nvd) were observed around Hanang and Kwaraha volcanoes. Particularly, south area of Mt. Hanang (Loc 111904), a lot of volcanic crators were observed.

In the LANDSAT ETM image, the area of pyroclastics has some spectral variations caused temporally by such as agricultural activity.

Gneissose granite and gneiss (Xs) is observed at west of Babati (Loc.111910) where presuming thin pyroclastic rocks were overlain in partially.

(6) Drainage Feature around Babati

Location; 112005

The Lake Babati (upstream of Dudumera River) is pure water and not dried up for whole year (P-07). In the LANDSAT image, this lake shows dark tone as compared to other lakes, it is presumed that deference of water depth is reflected. The East of Mt Hanang, the upper portion of Bubu River flows north to south, and shows high vegetation activity characteristically ranging about 20km. Therefore, in this area, high water resources potential are presumed, derived from infiltration water surrounding mountain.

P-07: View of Lake Babati, from Location 112006

(7) Neogene Sediments and Hot Springs around Lake Manyara

Location; 112009, 112202, 112203, 112501

Around the Lake Manyara, the low plane consisting of Neogene sediments is wide spreading. Evapolite is observed at Loc.112501 (P-08).

One of hot springs of Lake Manyara that is forming small pond and grass covered was observed at the bottom of the fault scarp in the western margin of Lake Manyara.(Loc.112203, P-09).

P-08: Evaporite of Neogene sediment (Location 112501)

P-09: Hot Spring of Lake Manyara (Location 112203)

(8) Ngorongoro area

Location; 112012, 112101 to 112103

East side of Ngorongoro area, N-S trending Large-scale fault is developing. The fault scarp exposes intermediate alkaline type lava and basement metamorphic rocks. At location 112012 (P-10), intermediate lava was observed.

P-10: Large-scale Fault scarp and Lake Manyara (Left), and Outcrop of Andesitic lava (Right) (Location 112012).

In Serengeti plane, pyroclastic rocks (Nvd) that derived from Neogene volcano such as Ngorongoro crater were widespread, and several NE-SW and EW trending lineaments and faults can be recognized on LANDSAT image., foliated granitic rock (gs) of basements is identified (location

112103, P-11) where the stream flows along the lineaments. Accordingly, Pyroclastics of this area is presumed as thin layer.

(9) Volcanic of Arusha and Monduli

Location 112401 to 112406

Along the road between Arusha and Lake Manyara, lava flow and pyroclastic rocks of intermediate alkaline type were observed (Location 112402, P-12). In addition, N-E trending fault scarps that is tens of meter height were developed.

(10) Ground Feature of Sub-basin I

Location 112304 to 112313

Along the road between Arusha and Namanga, distribution of evaporite (E) and gneiss (Xs-l) were observed.

(11) Faults in Sub-basin B

Location; 112302

In sub-basin B area, NW-SE trending faults are extracted by using remote sensing data, the edges of fault scarps can be viewed from location 112302(P-14). Fault structures presume normal faults system, because the south-west blocks of faults are drop down, north-east block of faults is gently dipping to north.

P-11: Ground feature of lineament in Serengeti area (Location 112103).

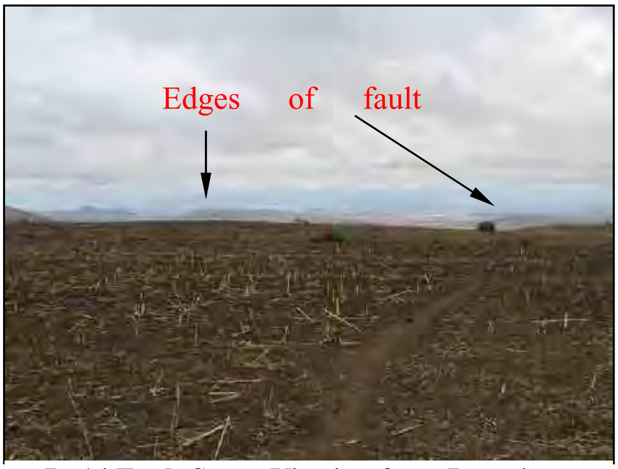
P-12: Lava flow (Location 112402)

P-13: Outcrop of Evaporite (Location 112402)

(12) The boundary between unit gs and Xs near Kondoa

Location; 112601 to 112604

The contact of granitic and metamorphic rocks is not observed directory. In east side of boundary, crystalline schist is observed, in west side of it, granitic having mylonitic texture was observed.



P- 14 Fault Scarp Viewing from Location 112302

(13) East of Kondoa and "Masai Steppe"

Location; 112506-112507

In East of Kondoa, large-scale fault scarp trending NW-SE direction is developed along the boundary between geologic units Xs and Xs-l. The fault scarp consists of gneissose rocks. Area of Xs-l along the fault scarp, outcrops of gneissose rocks were observed locally. Topographic feature of Xs-l area show N-S trending gentle swell structure characteristically and occasionally developing small peaks probably exposing basement rocks. The soil colour of Xs-l area shows reddish brown to light brown.

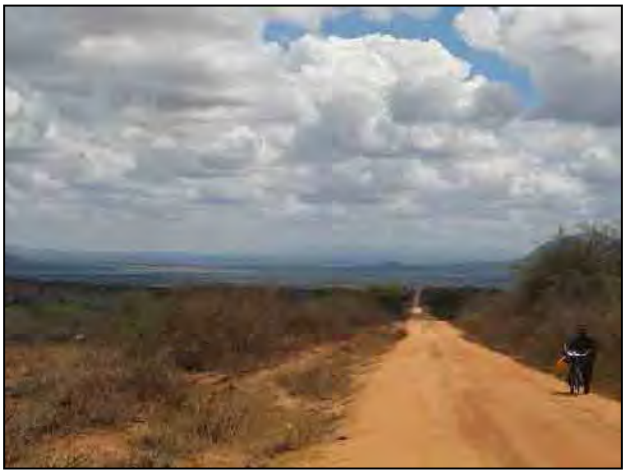
P-15: Masai Steppe (Unit Xs-l Area), View from location 112505.

P-16: Stream (location 112506) and Ground feature of Xs-l area (location 112507).

(14) East of Kibaya

Location; 112701 to 112706

The Topographic feature shows N-S trending gentle ridges (Xs-a) and low planes (Xs-l). The fault scarps is not developed in this area. A part of low plane area is underlain by swamp deposit.



P-17: Ground feature of east Kibaya, east view (location 112704).

(15) Neogene Terrestrial Sediments around Dodoma

Location; 112801-112806

Northeast side of the Bahi swamp distributing the Neogene sediments, ground covering is low dense vegetation and sparse cultivated area. The soil colour shows light gray.

In north side of the Bahi swamp (Loc112808, P- 20), granitics rock of basement is observed.

P-18: Ground feature of north of Bahi swamp, west view (Location 112806).

P-19: Out crops of granitic rocks, north of Bahi swamp (Location 112806).

(16) Faults of Manyoni

Location; 112810 to 112813

In Manyoni area, NNW-SSE trending large-scale fault is developed and this fault intersect with several NE-SW trending faults. (refer to P-23) Weathered granitic rocks forming fault scarp are observed (P-22). The gentle trough was developed along under fault scarp of NE-SW trending fault of north side. The gap of fault scarps is up to 200m.

P-20: Edge of fault scarp(Location 112810)

P-21: Strong weathered granitic rocks(gs-b)

P-22: Fault scarp, east of Manyoni

(17) Ground feature around Manyoni

Location; 112814-112817

Level plane described"Kilimatinde cement" in geologic map, wide spreads north of Manyoni. The remote sensing data of this area suggest highly vegetation activity and level flat topographically. The ground covering is growing high dense trees, which are about two or three meter in height. The soil colour is light yellowish gray.

3.5 Detailed Analysis of Sub-basin G by Remote Sensing

3.5.1 Purpose of Survey

The purposes of survey are as follows:

- To clarify the relationship between the geology and water contamination.
- To produced a detailed geological map by the interpretation of ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) false colour image, band-ratio image, ASTER DEM and SRTM DEM (Shuttle Rader Topography Mission-Digital Elevation Model).
- To understand the geology and distribution of water resources by implementing a field survey based on the results of preliminary interpretation of remote sensing data.
- To obtain basic information for a water balance analysis.

3.5.2 Survey Area

Taking consideration of the Phase I study, such as fluoride contamination, population and ground water potential, the sub-basin G area was selected as a detailed survey area (Figure3-5).

The sub-basin G is located in the south central part of the Internal Drainage Basin (IDB). Two contrasting topographic features are observed in the basin, separated by ENE-WSW trending fault scrap. In the area north of fault, mountain and high land area (approximately EL 1,000-1,800m) are distributed and in the area south of the fault, on the other hand, low plain, Bahi swamp and gentle hills (approximately EL 800-1,00m) are widespread. River network system converges into the Bahi swamp. The main river in the basin is Bubu River, which flows from the northern end of basin down to the Bahi swamp.

3.5.3. Used Remote Sensing Data and Product Images

For the study, seventeen scenes of ASTER data, ten scenes of LANDSAT ETM+ data and SRTM DEM data (approximately 37,800km^2) were used.

The ASTER data were prepared for detailed geological and water resources surveys. The images used for the study are listed in Table 3-2. The data acquisition months of the main part of the survey area were September 2000 and November 2005. ASTER mosaic false colour image are shown in Figure 3-5, and ASTER DEM topographic image is shown in Figure 3-6.

Table 3-2 List of Used ASTER Data

No.	Granule ID	Acquisition Date
1	ASTL1A 0509210806430509250014	2005/9/21
2	ASTL1A 0509210806510509250018	2005/9/21
3	ASTL1A 0509210807000509250016	2005/9/21
4	ASTL1A 0511010800330511030419	2005/11/1
5	ASTL1A 0511010800420511030420	2005/11/1
6	ASTL1A 0511010800510511030421	2005/11/1
7	ASTL1A 0511010801000511030422	2005/11/1
8	ASTL1A 0511010801090511030423	2005/11/1
9	ASTL1A 0009230822100302110386	2000/9/23
10	ASTL1A 0009230822190302110387	2000/9/23
11	ASTL1A 0009230822270302110388	2000/9/23
12	ASTL1A 0009230822360302110389	2000/9/23
13	ASTL1A 0009230822450302110390	2000/9/23
14	ASTL1A 0601270806170601300527	2006/1/27
15	ASTL1A 0601270806260601300528	2006/1/27
16	ASTL1A 0506260801080507010634	2005/06/26
17	ASTL1A 0506260801170507010635	2005/06/26

The following ASTER data were processed for extracting natures of surface, water resources and geology.

- ✓ ASTER false colour mosaic image (B, G, R, : Band1, Band3, Band6)
- ✓ ASTER DEM shaded elevation map
- ✓ ASTER SAVI (Soil Adjusted vegetation index) image
- ✓ ASTER ratio image (B, G, R : Band4/Band6, Band4/Band1, Band2/Band1)

The Geological interpretation map was produced from above images together with published geological maps of Tanzania (1:125,000).

- ✓ Geological interpretation map at a scale of 1:500,000

For estimation of water balance, the following LANDSAT ETM+ data images of dry and wet seasons were processed.

- ✓ LANDSAT ETM false colour mosaic Image (B, G, R : Band2, Band4, Band5)
- ✓ SAVI (Soil Adjusted vegetation index) image
- ✓ VSW indices image (V: vegetation, S: soil, W: water area)
- ✓ Land cover map.
- ✓ Albedo map
- ✓ Evapotranspiration map
- ✓ Precipitation map (from observation data)
- ✓ Runoff coefficient
- ✓ Infiltration map

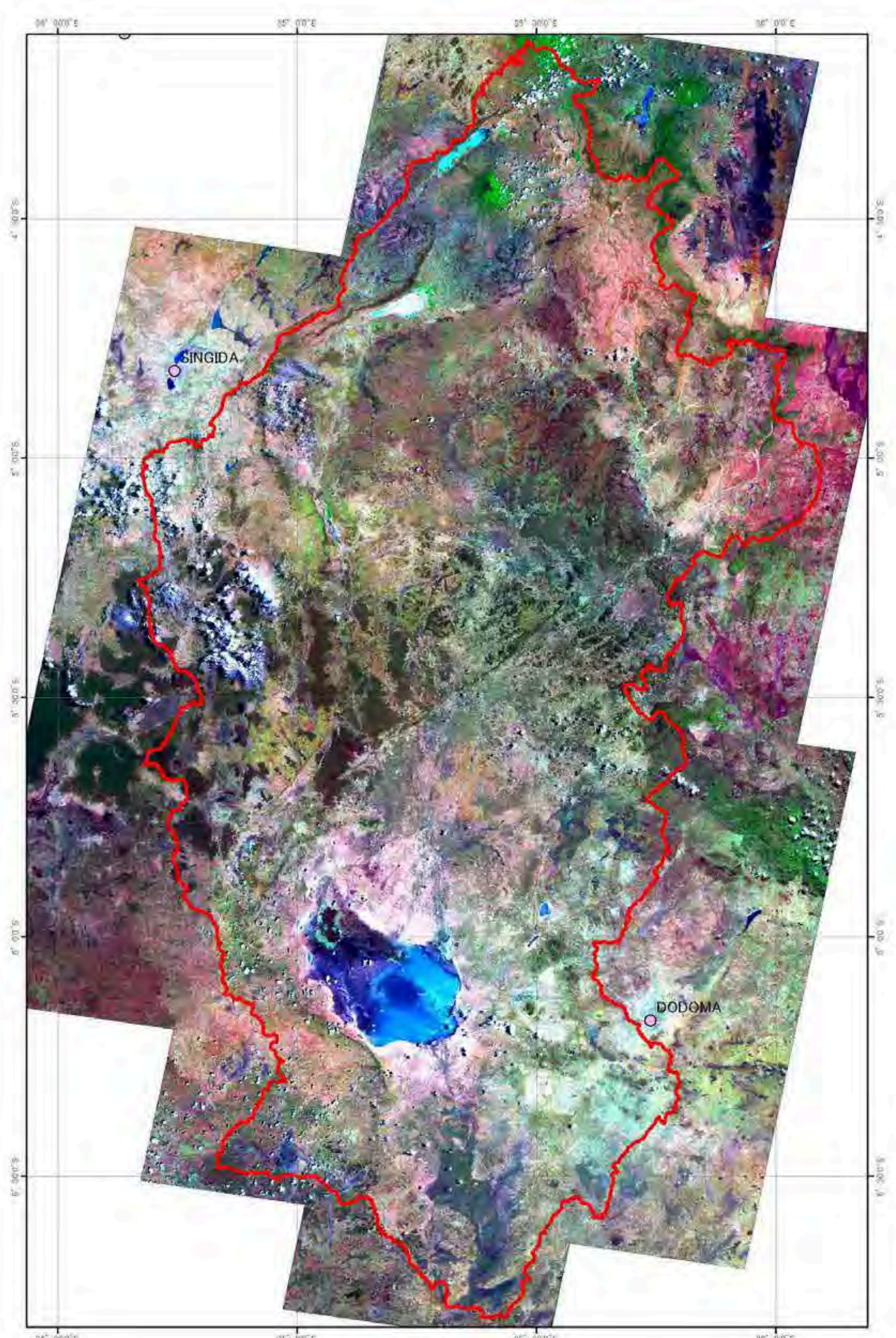


Figure 3-5 ASTER False Colour Mosaic Image (B, G, R : Band1, Band3, Band6)

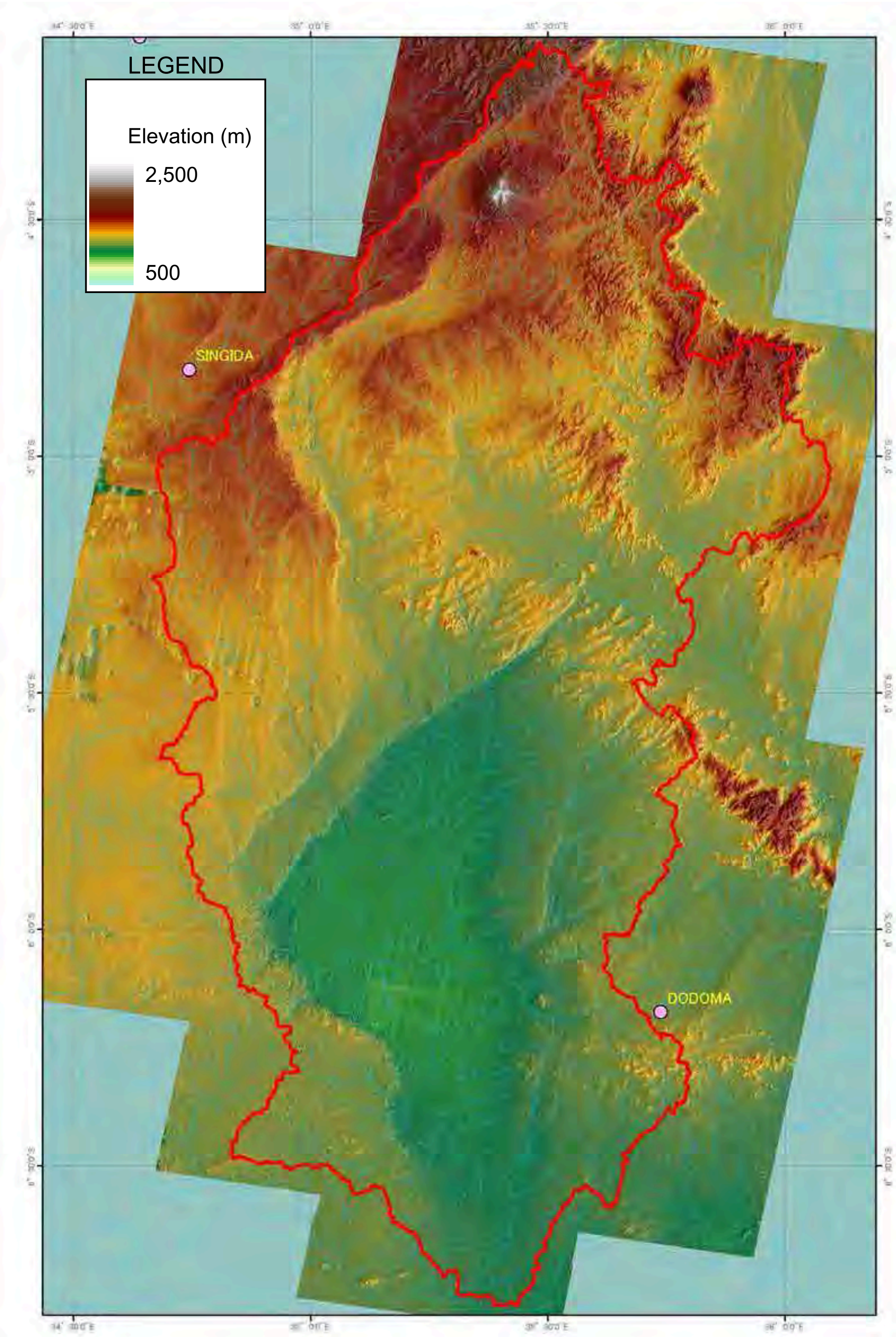


Figure 3-6 ASTER/DEM Shaded Elevation Image

3.5.4 Survey Results

The locations of field survey points are shown in Figure 3-7.

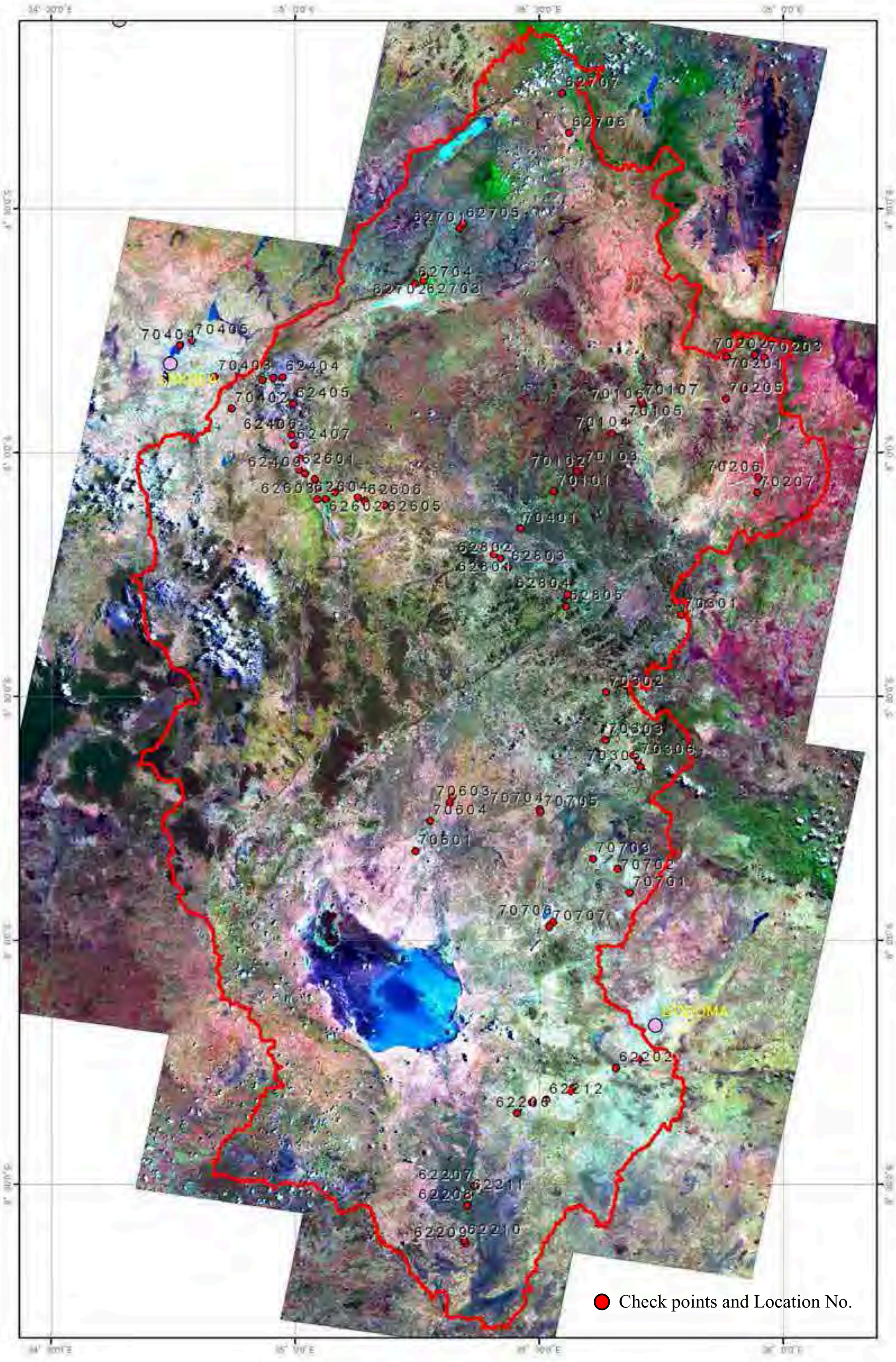


Figure 3-7 Check Points of Field Survey

(1) Water Recourses

In generally, vegetation activity of the dry season in semi-arid area is low. If high vegetation activity area is found in dry season, it is expected that the area is closely related to high level ground water potential or spring. In this study, SAVI (Soil Adjusted Vegetation Index) image were processed from ASTER data obtained in less rainfall seasons, in order to evaluate the water resources potential of the sub-basin G (Figure 3-8). Based on results of the analysis, field surveys were conducted.

1) SAVI (Soil Adjusted Vegetation Index) image

In the whole area, SAVI values show less than 0.1. The area with High SAVI value are found in areas of Mt. Hanang, along northeast border of this sub-basin, parts of some rivers and surrounding some lakes.

Based on SAVI value, topography and geological structure, several high potential areas of water resources were extracted. These areas are also shown in Figure 3-8

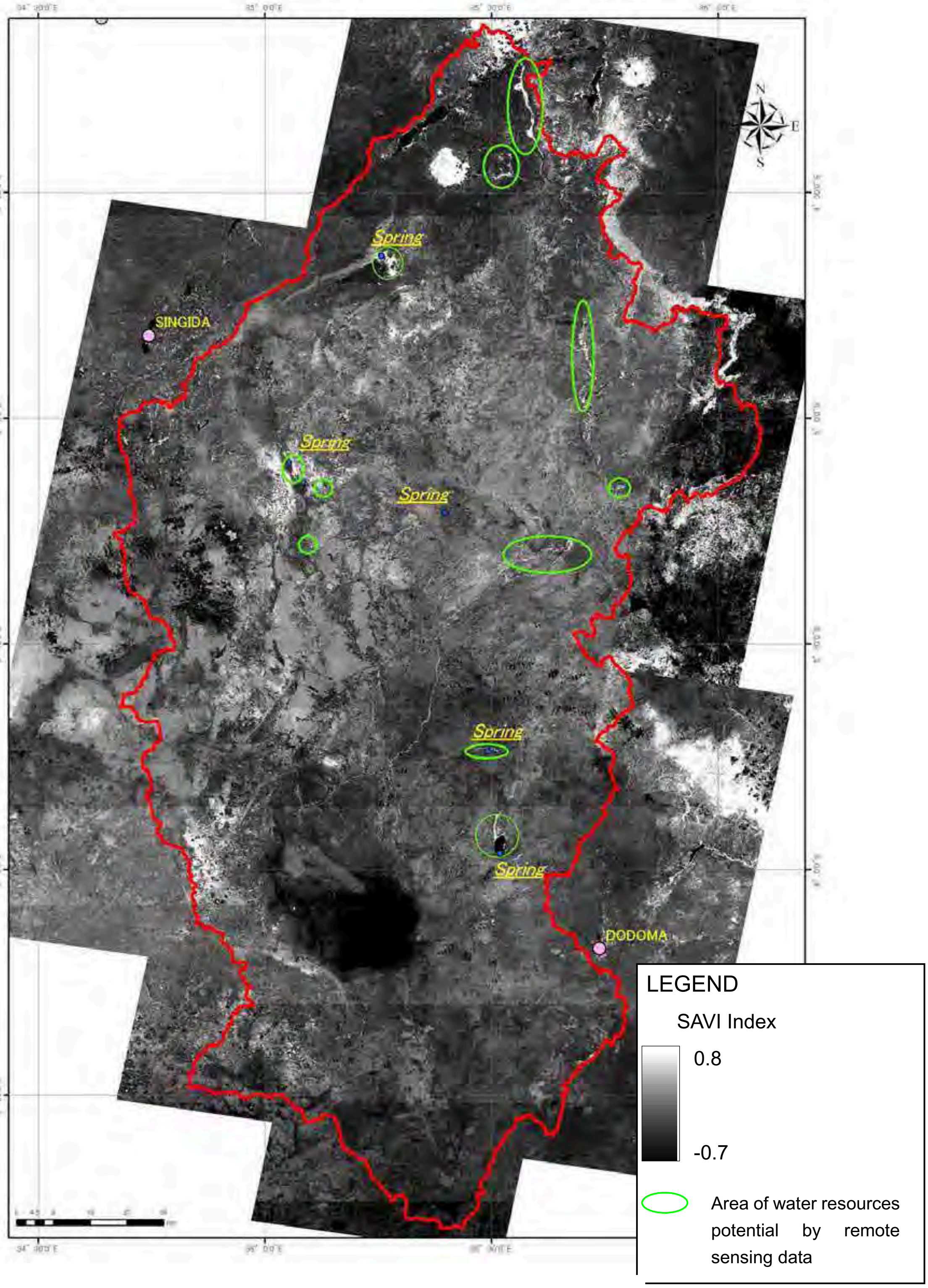


Figure 3-8 ASTER SAVI Image

2) Field Survey

Figure 3-7 shows check points of field survey and the descriptions of major check pints are given below.

i) Check point 62702

Location; Latitude 4.63870 °S, Longitude 35.26650 °E, Elevation 1,404m

This check point is high SAVI area located on northeast margin of the Lake Balangida Lehu. This area is characterized by high density of vegetation and wet lands and some springs occur in the wet land.

The water of the springs is fresh water and it is used for water supply. This area is located also at end of slope that consists of volcanic sediments and the water of springs is presumed to be derived from infiltrated water of the slope.

P-23 Spring and Wet Land of Lake Balangida Lehu.

ii) Check point 62602

Location; Latitide 5.09549 °S, Longitude 35.06259 °E, Elevation 1,218m

This area is located along the river at the foot fault scarp. Hot Springs sporadically occur distributed in N-S trending, forming lakes and wet lands. The water is saline water and the water temperature is about 35 °C.

P-24 Hot Spring and Wet land, Fault Escarpment

iii) Check point 62801

Location; Latitude 5.20873 °S, Longitude 35.40615 °E, Elevation 1,223m

There are several springs, and small ponds are found on gentle hill. Fresh water seems to be discharged from the springs throughout the year. In the vicinity of springs, granitic rocks with shear joints are exposed and the springs are derived from rock aquifer.

P-25 Spring and Outcrop of Granitic Rock with Fractures

iv) Check point 62805

Location; Latitude 5.31493 °S, Longitude 35.55545 °E, Elevation 1,092m

Flat plain are widespread where Bubu River and their several branches are joined. The water flow of Bubu River is not observed during this survey, but vegetations show high density and high activity. Accordingly, the free ground water level is presumed to be high. In the photograph, there is gauging station at the bridge

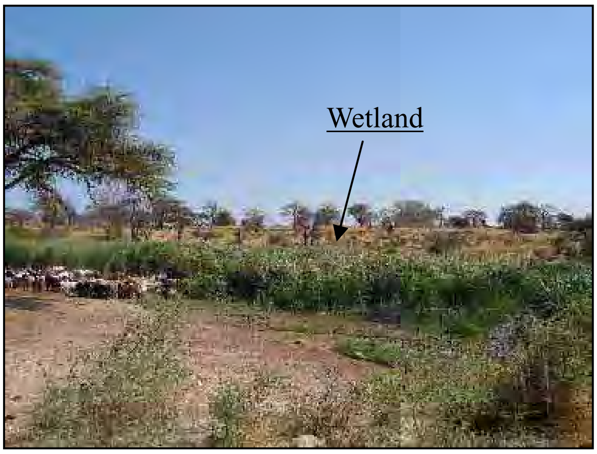
P-26 Ground Feature of Flat Plain along Bubu River

v) Check point 70704

Location; Latitude 5.73083 °S, Longitude 35.50046 °E, Elevation 970m

There are several springs along river. The discharge rate of the springs seems to be large throughout the year. The water is weak saline and is used for human and livestock.

Vegetation density is high along the stream. In upper part of this river, a flat plain consisting of Neogene sediments is widespread.



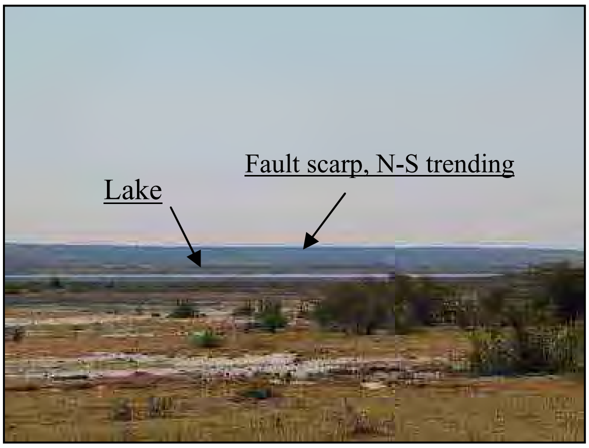
P-27 Spring and Wetland

vi) Check point 70706

Location; Latitude 5.96209 °S, Longitude 35.52918 °E, Elevation 957m

A spring is observed at the east margin of lake. The discharge of the spring is small throughout the year. The water is fresh water, and used for human activities.

Geologically, this lake is located at junction between N-S fault and NE-SW trending faults. The basement rock of this area is granitic rocks, and the surface is covered by probably thin Neogene sediments. High vegetation activity areas are found not only around the lake but also along the N-S fault, therefore, large potential area of ground water is presumed to be spread along the fault



P-28 Small Spring and Ground Feature of the Lake

(2) Geology and Geological Structure

The geological interpretation map and stratigraphic sequence of the area are shown in Figure 3-9 and Table 3-3, respectively. This interpretation map was produced using ASTER false colour image (Figure 3-7) and published geological maps of Tanzania (1:125,000). Furthermore, ASTER Ratio images Band4/Band6, Band4/Band1, Band2/Band1 (Figure 3-10) and ASTER DEM image were also used for the interpretation. This interpretation work of images at a scale of 1:500,000 was conducted in order to extract lithological and structural characteristics for the hydro-geological analysis. Based on the results of field survey, the interpretation map was confirmed.

The details discussion is given following the results of field survey.

Table 3-3 Stratigraphy of the Study Area by Detailed Analysis

Age	System	Lithology		Unit		Unit by ASTER 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 Nm:Drak grey clay (Mbuga) E: Evapolite Nf: Fluviatile sediments Nf-l: Younger fluviatile Nv: Lave and Pyroclastics Nvd: Mainly Pyroclastics and volcanic sediments
		Lacustrine; sand, silt, limestone, tuff		Nl		Nl		
		Terrestrial: sand, gravel, laterite, silcrete, calcrete.		Nt		-		
		Fluviatile; -marine; sand;gravel; silt; limestone.		Nf		Nf, Nf-l		
		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;		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		Topographic rough texture
						D-l		Topographic smooth texture

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

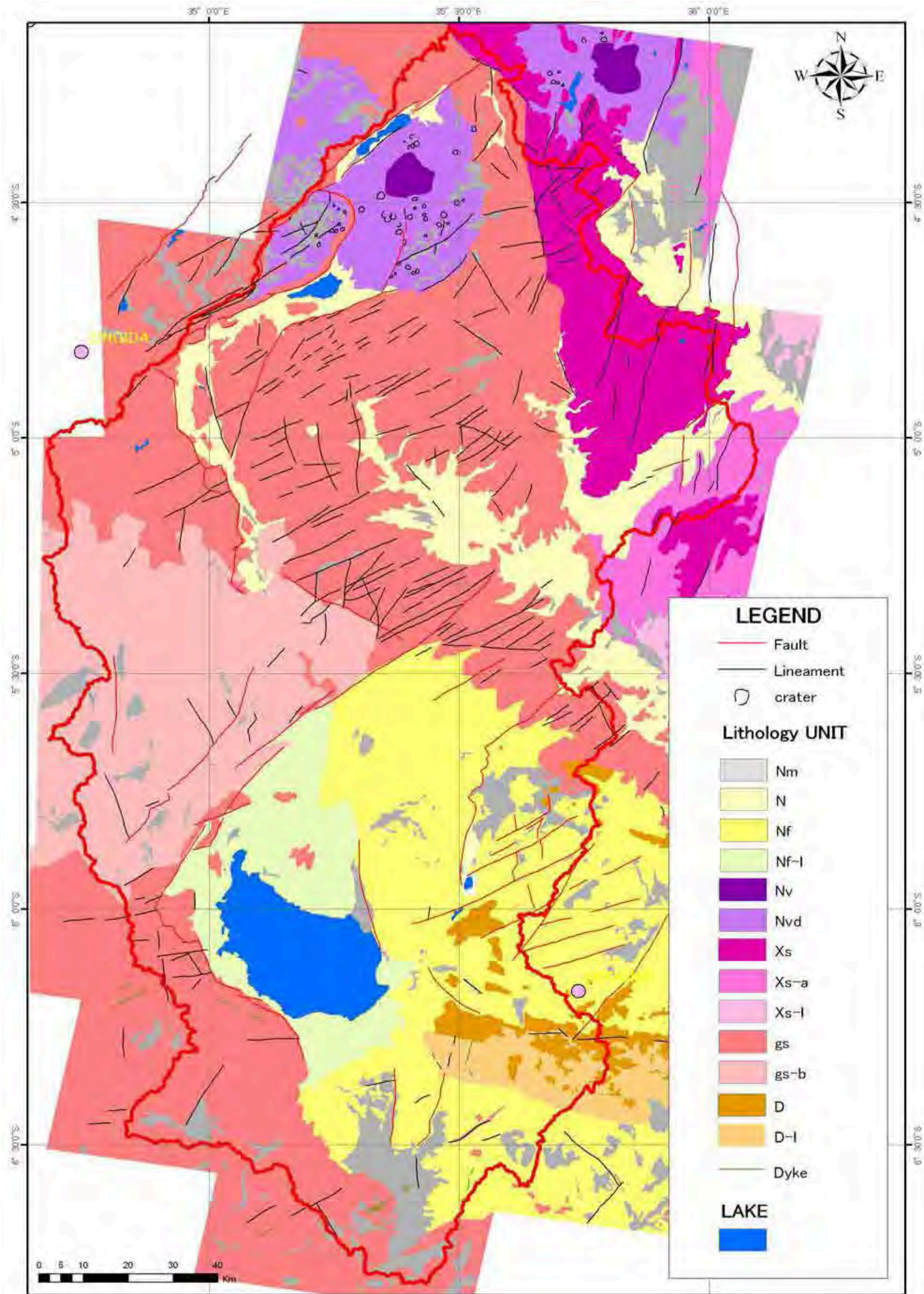


Figure 3-9 Geological Interpretation Map of Sub-basin G Area

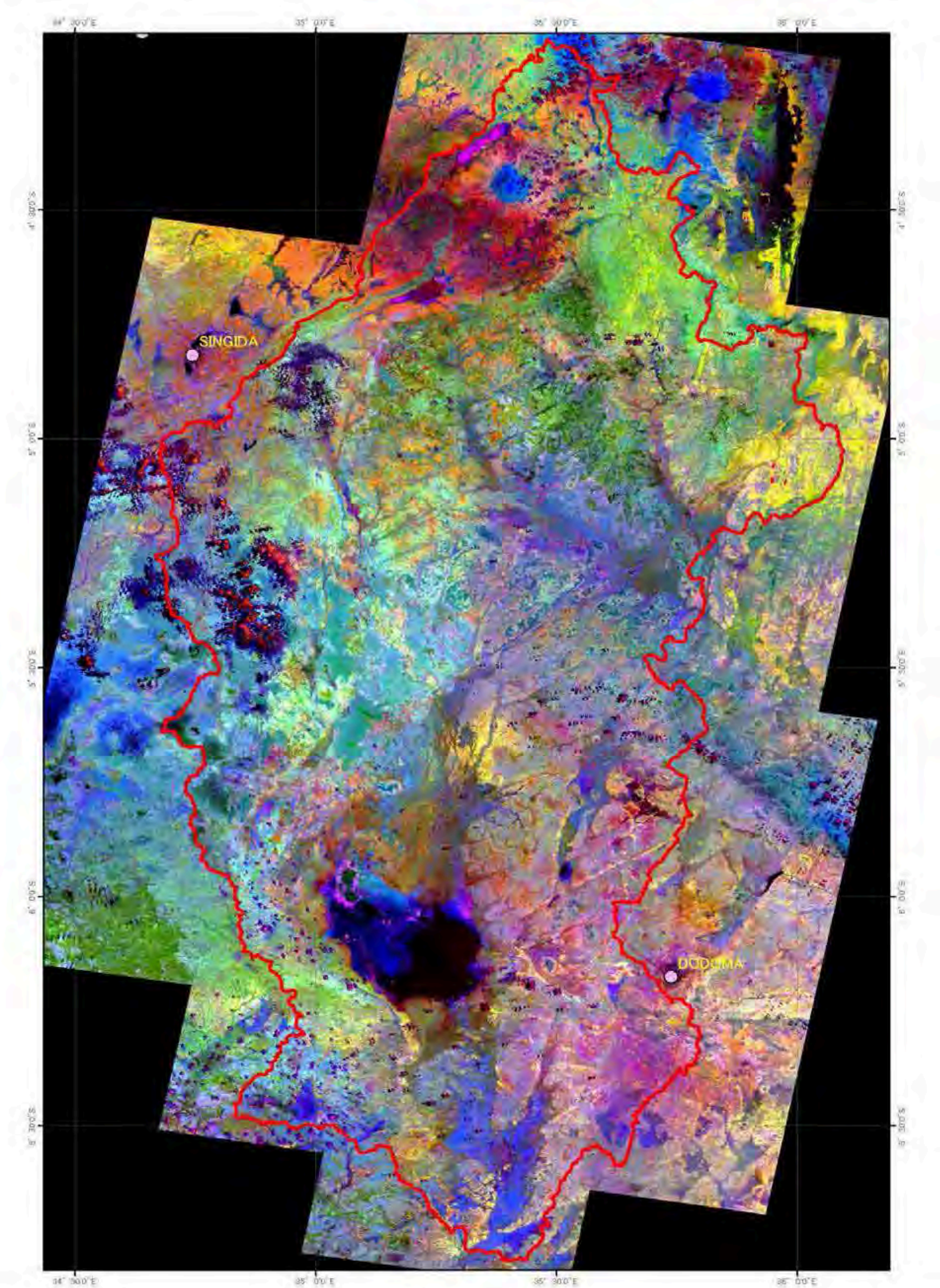


Figure 3-10 ASTER Ratio image (B, G, R: Band4/Band6, Band4/Band1, Band2/Band1)

1) Precambrian Basement Rocks

i) Dodoman System (Archean): D, D-l

Check point: 62201-62206, 62212

The Dodoman system is the oldest formation in Tanzania which consists of schist, gneiss and migmatite. It is distributed south of Dodoma city. This system can be classified into two units; "D" and "D-l" based on their topographic features. In ASTER false colour image (Figure 3-7), Unit "D-l" area shows characteristic lighter white colour.

Schist and leucocratic gneiss are exposed at Location 62203-62204.

Ground surface feature of "D-l" area is, generally, characterized by light grey to grey colour soil and sparse vegetation.

P-30 Leucocratic gneiss (62203) and light grey soil (62203) of "Unite "D-l"

ii) Usagaran System (Achaean): Xs, Xs-a and Xs-l

Check point: 70201-70207

The Usagaran system consists of marble, schist, gneiss and migmatite. These rocks crop out in the eastern part of the survey area. This system can be classified into three units; "Xs", "Xs-a" and "Xs-l" based on their topographic features. The soil colour, generally, is light grey.

P-31 Gneiss of the Dodoman System (70201)

iii) Bukoban System (Proterozoic): B

The Bukoban system consists of sedimentary rocks such as mudstone, shale, sandstone and others. Exposures of the rocks are confirmed only in the limited area in the southern part of the Bahi Swamp.

iv) Plutonic Rocks (mainly Archean); gs, gs-a, gs-b

Check point: 62604, 62605, 62801, 70101-70107, 70403

Plutonic rocks consist of granite, granodiorite and gneissose or migmatitic rocks. Plutonic rocks are widely distributed from the central to the northern part of the basin and west side of Bahi.

Plutonic rocks can be classified into three units based on degree of weathering analyzed by their topographic features. Unit “gs” widely distributed in almost whole area of plutonic rocks is characterized by rough texture on the LANDSAT images and topographically high altitude. Unit “gs-b” distributed along Tanzanian Railroad at Manyoni in the northwest is characterized by very smooth texture. Unit “gs-b” corresponds to the intensely weathered zone, named as “Kilimatinde cement” in the published geological map. Unit “gs-a” has intermediate feature between “gs” and gs-b.

In this field survey, granitic mylonite and granitic cataclasite are observed sporadically. Near the boundary between “gs” and “Xs”, the rocks are foliated.

P-32 Granitic Rock and Ground Feature of Unit “gs” (62604)

P-33 Cataclastic granite (70103).

2) Kainozoic (Cenozoic) Formations

Check point: 062401-062410, 062601-062603

During late Neogene, lacustrine sediments, terrestrial sediments, fluviatile sediments, marine sediments and alluvial sediments deposited in the lakes and shallow basins formed by the warping of the surface that accompanied by rift-faulting movements. These sediments consist of sand, silt, evaporite, clay and conglomerate. These sediments are mainly distributed in the centre of central to southern part of the basin where characterized by topographically low plane. In northern part of basin, these sediments are distributed along the Bubu River system and along large fault scarp of north-western part. Based on published geological map and ASTER image interpretation, these Cenozoic sediments are classified into five units of N, Nf, Nf-l, E and Nm. Unit “Nf-l” are distributed in north of the Bahi Swamp where characterized by delta fan structure. Consequently, this unit is considered younger sediment than Unit "Nf". By using ASTER ratio image (Figure 3-10), Unite "Nf-l" can be clearly distinguished from other Neogene formations. Unit "Nm" consists of dark grey clay, which is locally called as "Mbuga", and it is sporadically distributed in a whole area. This unit occurs in topographically flat low plain, some of which forming swamp in wet season. In the southern end of the basin, this unite is extensively distributed.

P-34 Feature of Ground Surface of Unit "N" (62406)

P-35 Reddish Sand of Unit "N", showing Cross Lamina (062601)

P-36 Ground Surface of Unit "Nf-l" (70601)

P-37 Dark Grey Clay of Unit "Nm" (62208)

3) Volcanic Rocks

Check point: 62701-62707

In the northern end of the basin, volcanic rocks occur around Mt. Hanang. These volcanic massifs consist of an accumulation of extensive alkaline lava and pyroclastics. In general, alkaline type volcanic rocks have high volatile components such as H_2O, CO_2, F and so on.

Distribution of volcanic lavas and pyroclastics can be delineated on the ASTER Ratio image. In the interpretation map, Cenozoic volcanic rocks are divided into "Nv" and "Nvd". "Nv" consists of lava and pyroclastic rocks which are forming Mt. Hanang. "Nvd" consists of pyroclastic rocks, volcanic sediments and calcareous tuff.

P-38 Volcanic Sediments of Unit "Nvd" (62705)

4) Geological Structure

Distributions of lineaments and faults are shown in Figure 3-9. A large number of lineaments and faults are extracted by structural analysis using ASTER image and DEM.

In this study, fault was identified by a presence of step structure along lineament.

Faults and lineaments can be classified into two systems with different trend. One is NE-SW trending system and another is N-S trending system. NE-SW trending faults and lineaments are predominant and extracted from the almost whole of basin. N-S trending faults and lineaments are continuous; however, they occur less frequently than NE-SW system. Both systems develop not only in the basement rocks but also in Neogene sediments of unit "N". It seems that N-S trending system cut the NE-SW trending lineaments.

P-39 Large N-S Trending Fault Escarpment (62404)

P-40 Ground Feature of N-S Trending Faults in Unit "N"(70701). Soil shows reddish brown colour.