MINISTRY OF WATER
THE UNITED REPUBLIC OF TANZANIA

THE STUDY ON RURAL WATER SUPPLY IN TABORA REGION IN THE UNITED REPUBLIC OF TANZANIA

FINAL REPORT

SUPPORTING REPORT

MAY 2011

JAPAN INTERNATIONAL COOPERATION AGENCY

EARTH SYSTEM SCIENCE CO., LTD

JAPAN TECHNO CO., LTD.

KOKUSAI KOGYO CO., LTD.

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ABBREVIATIONS

AIDS	Acquired Immune Deficiency Syndrome
AMO	Assistant Medical Officer
ARI	Acute Respiratory Infection
ATP	Affordability-to-Pay
B/C Ratio	Benefit/Cost Ratio
CBM	Community-Based Management
CBO	Community-Based Organization
CBRC	Community Based Resources Centre
CCHP	Council Comprehensive Health Plan
CHMT	Council Health Management Team
CI	Cast Iron
CLTS	Community-Led Total Sanitation
CO	Clinical Officer
COWSO	Community-Owned Water Supply Organization
CWSD	Community Water Supply Division
DDCA	Drilling & Dam Construction Agency
DED	District Executive Officer
DEM	Digital Elevation Model
DEO	District Education Officer
DHIS	District Health Information System
DHO	District Health Officer
DI	Ductile Iron
DN	Digital Number
DOM	District Operational Manual
DP	Development Partner
DSM	Dar es Salaam
DTH	Down The Hole Hammer
DWE	District Water Engineer
DWSP	District Water Sanitation Plan
DWST	District Water and Sanitation Team
EC	Electric Conductivity
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EIS	Environmental Impact Statement
E/N	Exchange of Notes
ESAs	External Support Agencies
ESMF	Environmental and Social Management Framework
EWURA	Energy and Water Utilities Regulation Authority

FBO	Faith-Based Organization
FIRR	Financial Internal Rate of Return
FY	Fiscal Year
GDP	Gross Domestic Product
GIS	Geographic Information System
G.L	Ground Level
GNP	Gross National Product
GPS	Global Positioning System
GSP	Galvanized Steel Pipe
HDPE	High Density Polyethylene
HIV	Human Immunodeficiency Virus
HMIS	Health Management Information System
HSSP	Health Sector Strategic Plan
IBRD	International Bank for Reconstruction and Development
IEE	Initial Environmental Examination
IGUWASA	Igunga Urban Water Supply Authority
IPD	Inpatient Department
IRR	Internal Rate of Return
JICA	Japan International Cooperation Agency
JPY	Japanese yen
JWSR	Joint Water Sector Review
JWWA	Japan Water Works Association
LGA	Local Governmental Authority
L.W.L	Low Water Level
MDG	Millennium Development Goals
MKUKUTA	Mkakati wa Kukuza Uchumi na Kupunguza Umaskini Tanzania
MMAM	Mpango wa Maendeleo wa Afya ya Msingi
MoHSW	Ministry of Health and Social Welfare
MoNRT	Ministry of Natural Resource and Tourism
MoW	Ministry of Water
MoWI	Ministry of Water and Irrigation
MoWLD	Ministry of Water and livestock Development
MWE	Municipal Water Engineer
MWST	Municipal Water and Sanitation Team
NAWAPO	National Water Policy
NBS	National Bureau of Statistics
NCD	Non-Communicable Disease
NDVI	Normalized Difference Vegetation Index
NEMC	National Environmental Management Council
NEP	National Environmental Policy

NGO	Non-Governmental Organization
NOx	Nitrogen Oxide
NPV	Net Present Value
NSGRP	National Strategy for Growth and Reduction of Poverty
NWP	National Water Policy
NWSDS	National Water Sector Development Strategy
NZUWASA	Nzega Urban Water Supply Authority
O&M	Operation and Maintenance
OPD	Outpatient Department
PAP	Project Affected Person
PE	Polyethylene Pipe
PEA	Preliminary Environmental Assessment
PEDP	Primary Education Development Programme
PHAST	Participatory Health and Sanitation Transformation
PHSDP	Primary Health Services Development Programme
PIM	Program Implementation Manual
POM	Programme Operational Manual
PP	Progect Proponent
PPP	Public Private Partnership
PRSP	Poverty Reduction Strategy Paper
PVC	Polyvinyl Chloride
PWP	Public Water Point
PWSS	Piped Water Supply Schemes
RAP	Resettlement Action Plan
RHMT	Regional Health Management Team
RPF	Resettlement Policy Framework
RWST	Regional Water and Sanitation Team
SC	Specific Capacity
SEAMIC	Southern and Eastern African Mineral Centre
SECO	Swiss State Secretariat for Economic Affairs
SEDP	Secondary Education Development Programme
SMS	Short Message
SOx	Sulfur Oxide
SR	Scoping Report
SRTM	Shuttle Radar Terrain Model
SUWASA	Sikonge Urban Water Supply Authority
S/W	Scope of Work
SWAP	Sector Wide Approach to Planning
TAC	Technical Advisory Committee
TANESCO	Tanzania Electric Supply Company

TASAF	Tanzania Social Action Fund
TDS	Total Dissolved Solid
ToR	Terms of Reference
TRC	Technical Review Committee
Tsh	Tanzania shilling
T.T.S	Tanzania Temporary Standards
TUWASA	Tabora Urban Water Supply and Sewerage Authority
UfW	Unaccounted-for water
UNDP	United Nations Development Programme
UPP	User-Pay Principle
USD	US Dollar
UTM	Universal Transverse Mercator System
UUWASA	Urambo Urban Water Supply Authority
UWSA	Urban Water Supply Authority
UWSS	Urban Water Supply and Sewarage
UWSSP	Urban Water Supply and Sewerage Programme
VEO	Village Executive Officer
VHC	Village Health Committee
VHW	Village Health Worker
V.I.P	Ventilation Improved Pit latrine
VWC	Village Water Committee
WATSAN	Water and Sanitation
WHO	World Health Organization
WSDP	Water Sector Development Programme
WSPR	Water Sector Performance Report
WSSA	Water Supply and Sanitation Authority
WTP	Willingness-to-Pay
WUA	Water User Association
WUG	Water User Group
cm	centimeter
kWh	kilowatt hour
L	liter
m	meter
masl	meter above sea level
mbgl	meter below ground level
mg	milligram
mH	meter Head
min	minute
ml	milliliter
mS	millisiemense

m^2	square meter
m^3	cubic meter
sec	second

CHAPTER 1 HYDROGEOLOGICAL EVALUATION BY SATELLITE IMAGE ANALYSIS

1.1 GENERAL

A hydrogeological overview of the whole area of Tabora region was obtained from the analysis of satellite images of LANDSAT/ETM+. The areas with the possibility to have the groundwater development potential were selected as a result. This result was used for basic data of the groundwater development potential evaluation for selection of the candidate villages for the priority project. In addition, to select the geophysical exploration points in the target villages of the priority project, detailed image interpretations of the topographical and the geological features were carried out by using the high resolution satellite images of ALOS/PRISM.

LANDSAT/ETM+ digital mosaic covers the whole Tabora region with 1:200,000 in scale. In addition, various image processing such as NDVI (Normalized Difference Vegetation Index) in rainy and dry season data, rationing in dry season data, shading and drainage extraction for SRTM (Shuttle Radar Terrain Model) were applied for interpreting hydrogeological aspects.

Image interpretation was conducted by a photo-geological method on LANDSAT/ETM+ mosaic as attracting following attentions, namely discrimination of lithofacies, extraction of geologic structures like fractures, and delineation of surface condition including surface water. Based on these results, the field investigation was performed in the whole Tabora region to understand characteristics of geology, surface condition and surface water. Field investigation sheets were prepared for describing such features in advance. The field investigation points reached 50 locations.

The surface condition map, the lithofacies map and the geological structure map of the Tabora region were made as the results.

Detailed image interpretation was carried out by using stereoscopic view of the satellite images of ALOS/PRISM with a 2.5m spatial resolution in the analysis of the target villages for the priority project.

1.2 SATELLITE IMAGE ANALYSIS FOR WHOLE TABORA REGION

1.2.1 BACKGROUND AND OBJECTIVE

Tabora region, an area of interest in this study, is widely spread in the western part of the country with approximately 76,700 km^2 in width. A satellite image analysis will be one of the most effective methodologies in such wider area as covering homogeneous interpretation over the area. This result should be reflected in Phase 2 survey in order to select the detailed survey areas for further activities like geophysical and test well drilling surveys. The satellite image analysis will be conducted for the whole region, while the forest and natural reserves sit 51,800 km^2 wide corresponding to 68 % of Tabora region, where an activity is limited in any development. These areas should be excluded for the further study.

1.2.2 METHODOLOGY

The methodology of the survey is composed of remote sensing data selection, image processing, image interpretation, field investigation based on the interpretation, compositing thematic maps, their hydrogeological interpretation and a recommendation for Phase 2 survey. In the thematic maps, there are four maps combined with the existing various data, namely a surface condition, a lithofacies, a geologic structure and a groundwater potential maps. The flow chart of the survey is shown in Figure 1.2.1.

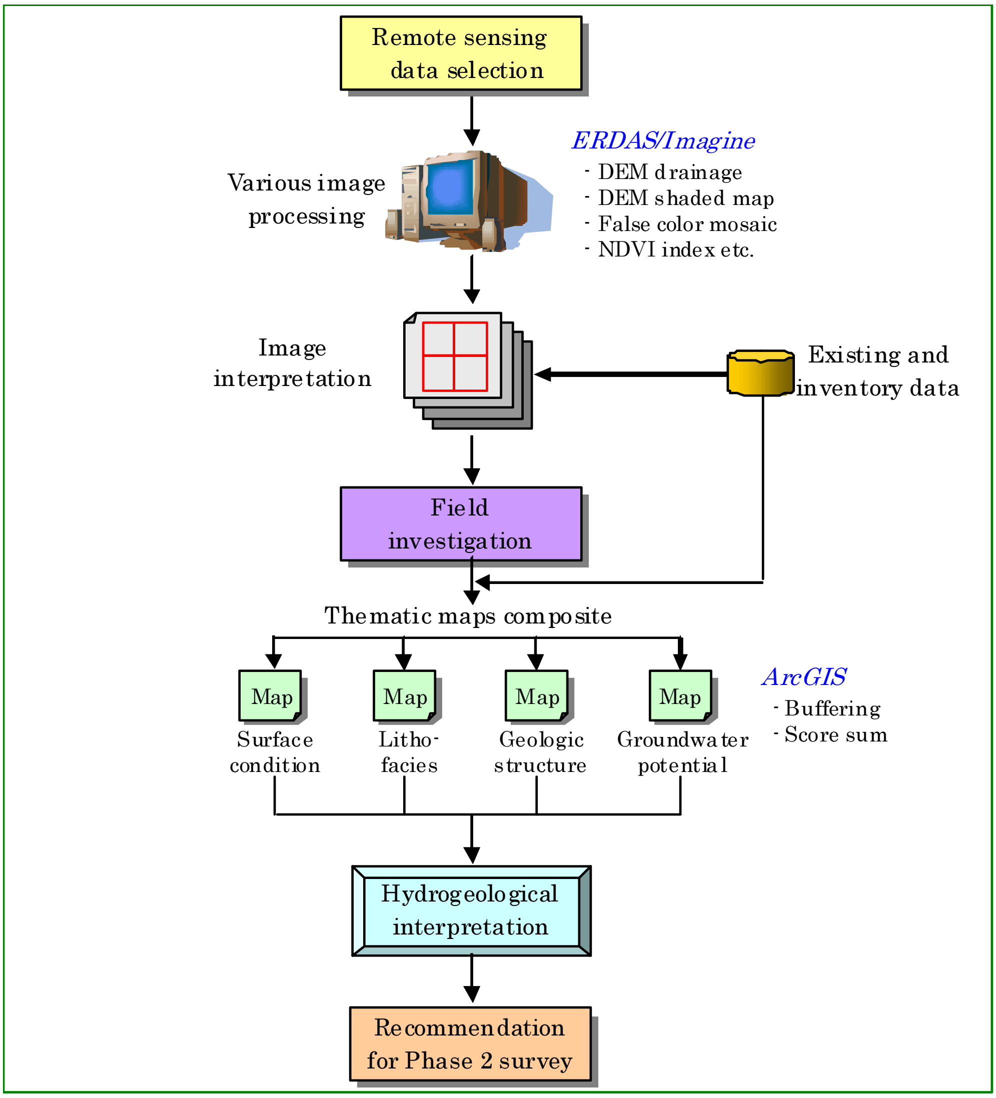

Figure 1.2.1 Flowchart of Satellite Image Analysis for Whole Tabora Region

1.2.3 IMAGE SATA USED

The image data used of the survey are LANDSAT/ETM+ and SRTM (Shuttle Radar Terrain Model) data. LANDSAT/ETM+ data have an advantage of wider coverage than other remote sensing data. A dataset in wet and dry seasons of LANDSAT/ETM+ was prepared for a hydrogeological interpretation. The SRTM is a kind of DEM (Digital Elevation Model) generated from a Space Shuttle Radar data, and it was used for various digital processing in topographic feature. The list of image data used is shown in Table 1.2.1.

Table 1.2.1 List of Image Data Used and Their Specification

Image data used	Acquisition date (dd /mm/yy)	Characteristics	Remarks
LANDSAT/ETM+ Path/ Row =169/64 Path/ Row =170/63 Path/ Row =170/64 Path/ Row =170/65 Path/ Row =171/63 Path/ Row =171/64	(Wet and dry season) 04/02/2003, 15/10/2002 18/05/2003, 19/08/2002 18/05/2003, 19/08/2002 18/05/2003, 19/08/2002 06/03/2003, 10/08/2002 09/05/2003, 10/08/2002	- Spatial resolution: 30 m - Spectral resolution: 6 bands ranging from visible to short-wave infrared through near-infrared, in addition to 1 band in thermal-infrared electro-magnetic waves - Sensor launched by NASA/JPL, USA.	- Data quality being poor in recent data set - Its life span having been expired - Not using band 6
SRTM (Shattle Radar Terrain Model)	(data open) 02/2002	- Spatial resolution: about 90 m (3 arc second) in x/y directions and 20m(circular error) or 16m(linear error)	- ASTER/G-DEM being poor quality in this region

Abbreviations,
- NASA/JPL: National Aeronautics and Space Administration/Jet Propulsion Laboratory
- ASTER/G-DEM: Global DEM generated by stereoscopic view of ASTER data mounted on TERRA sensor launched by METI/JPL, JAPAN

1.2.4 PROCESSED IMAGE DATA

Processed image data in this study are listed on Table 1.2.2 ‘ERDAS Imagine’ which is one of the most famous image processors was selected in all procedures.

Table 1.2.2 List of Processed Image Data

Image data used	Generated imagery	Scale
LANDSAT/ETM+	Digital mosaic of false color image using band 1,4 and 5 in wet season	1:200,000
	Digital mosaic of false color image using band 1,4 and 5 in wet season	1:200,000
	Digital mosaic of NDVI image in wet season	1:200,000
	Digital mosaic of NDVI image in dry season	1:200,000
	Bands 5/7 Rationing of each scene in dry season	1:200,000
SRTM	DEM shaded image	-
	Drainage and its basin extraction map	-

Remarks,
- NDVI: Normalized Vegetation Index
- Scale of SRTM products depending upon its spatial resolution
- All of image processing were conducted by using a remote sensing image processor ERDAS/Imagine.

The image processing applied for this survey is as follows,

NDVI is a normalized vegetation index calculated by DN (Digital Number) values of the images using a formula (BN4-BN3) / (BN4+BN3).

Rationing is a method to extract alteration minerals like kaolinite here in Tabora region following their reflection spectra by using a formula (BN5 / BN7).

Shading is a method generating pseudo-image to extract topographic features applied for SRTM data with low angle light source, because the satellite data here in Tabora region have higher sun elevation than other areas.

1.2.5 IMAGE INTERPRETATION

Image interpretation was conducted by a photo-geological method on LANDSAT/ETM+ mosaic as attracting following attentions,

- Discrimination of lithofacies

- Extraction of geologic structures, particularly fractures
- Delineation of surface condition, particularly surface water

The results of image interpretation were shown in Figure 1.2.2. Their features were summarized as bellow.

(1) Discrimination of Lithofacies

Lithofacies in Tabora region was discriminated into six geologic units as follows in ascending order,

- Unconsolidated materials in Quaternary (unit name Q): loose materials like sand and mud distributed along drainages and in swamps
- Sedimentary rock (unit name Sr): horizontally structured deposits distributed in the most south-western part of the region
- New granite (unit name Ng): showing intermediate resistance against surface erosion and being distributed in the south-western part of the region
- Greenstone (unit name Gs): showing rough topography and dense vegetation and emplacing in the north-eastern part of the region
- Gneiss derived from granite (unit name Gn): showing rough topography and many lineaments developed and being distributed in NW-SE direction belt at the center of the region
- Granite as a basement (unit name Gb): showing high resistance against surface erosion in the northern part and low resistance in the southern part of the region
- Dykes (unit name Dd): showing convex texture on the image and being distributed in the north-eastern limited part of the region

(2) Extraction of Geologic Structures

Following fractures were extracted from the imagery,

- Major faults: controlling general geologic structures of Tabora region developing N-S and NW-SE directions with NE-SW and E-W directions in the south-western part of the region
- Clear lineaments: showing surface linear structures like straight drainages and/or their scarf, which seem to be sub-surface fractures, in the central and northern parts of the region
- Unclear lineaments: showing surface sub-linear structures like straight drainages and/or their scarf, which seem to be sub-surface fractures, in almost the same parts as the clear lineament's distribution

(3) Delineation of Surface Condition

Surface water body was recognized on the LANDSAT/ETM+ mosaic in the wet season. They are in next areas,

- Swamps located in the most west and east areas of the region
- Swamp located in the south-western area of the region
- Manonga River situated in the north edge of the region
- Rungwa River situated in the south edge of the region
- Igombe River situated in the north-western part of the region
- Wala River situated in the south-western part of the region

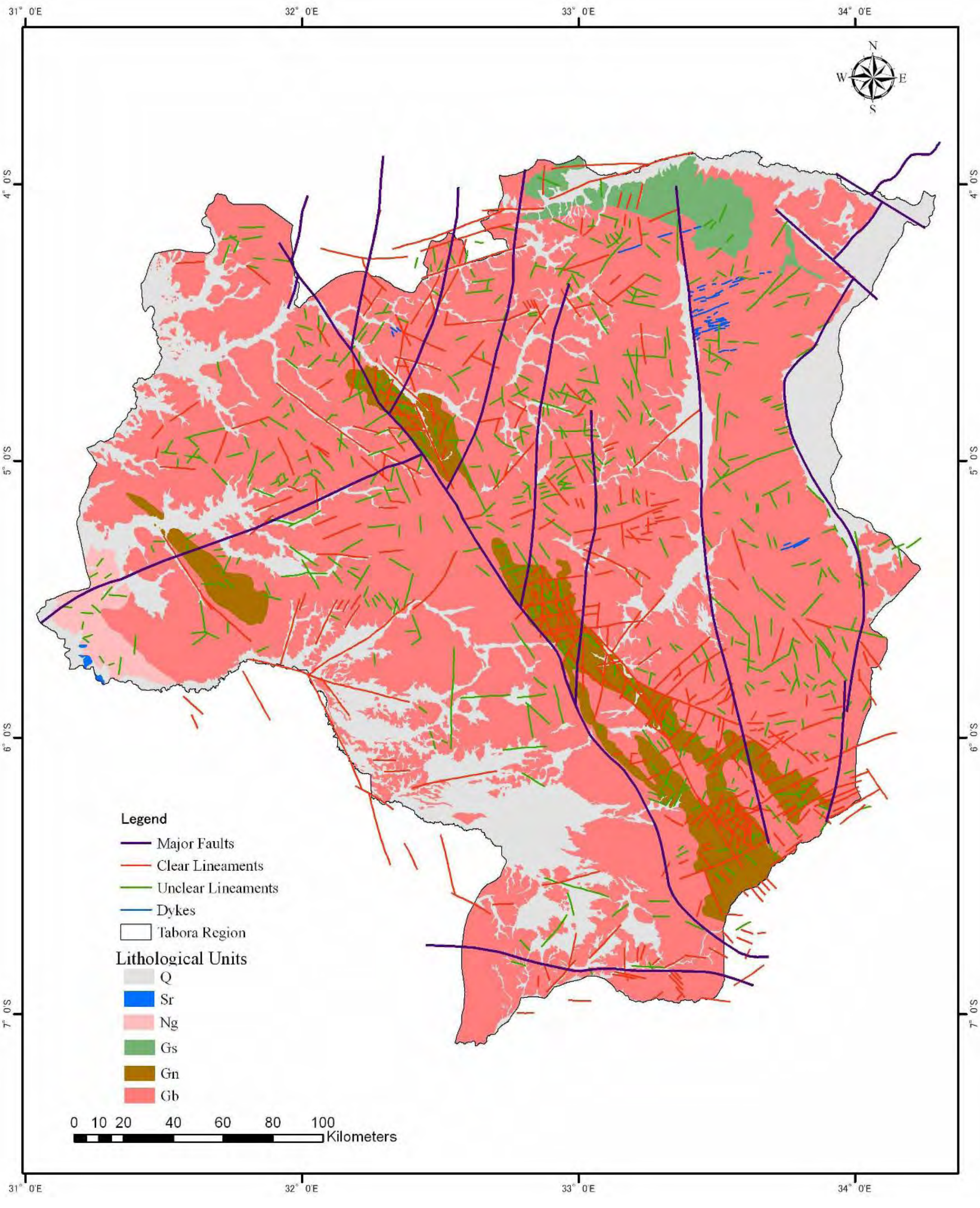

FIGURE 1.2.2 RESULTS OF IMAGE INTERPRETATION

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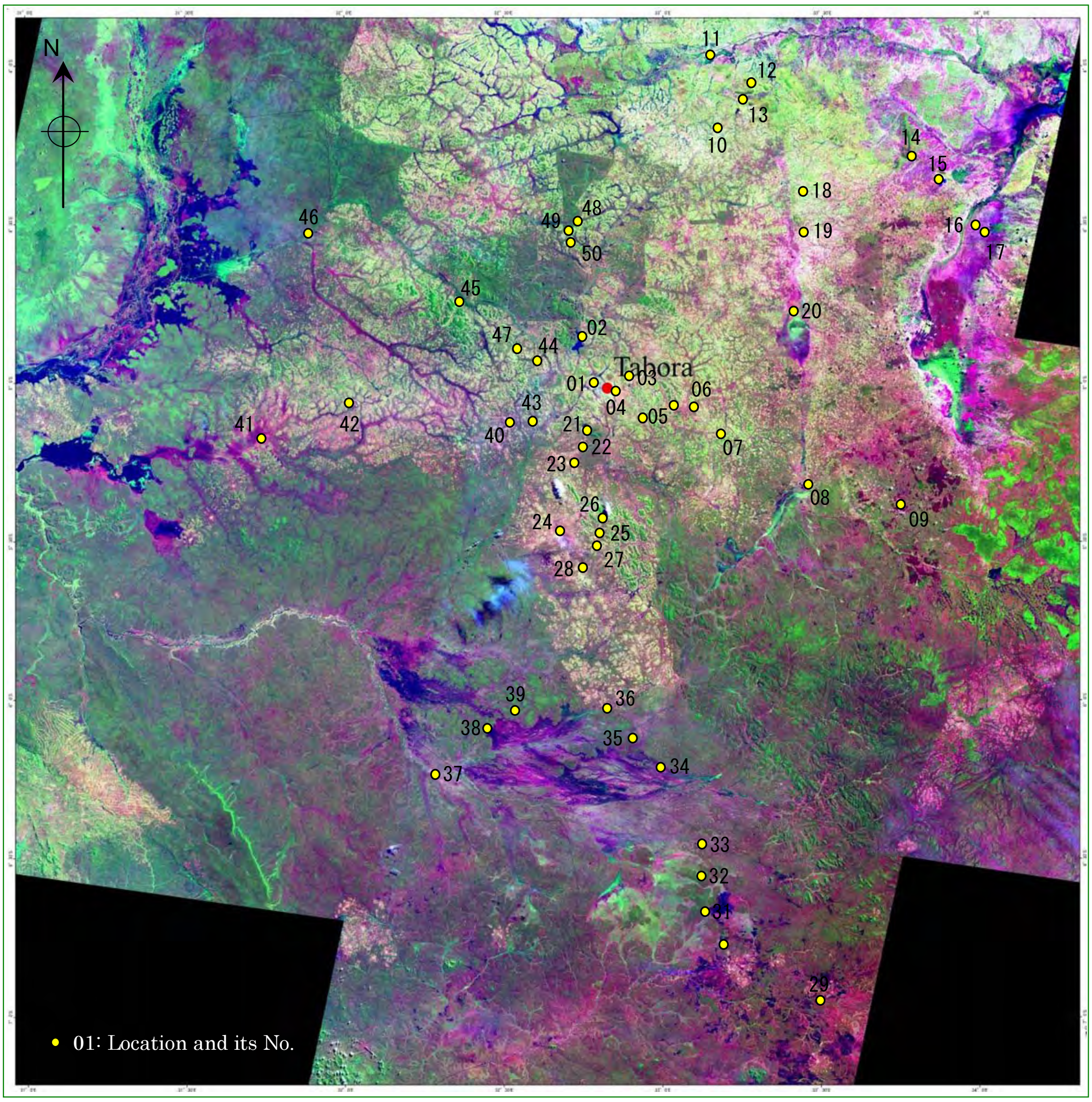
1.2.6 Field Investigation

The field investigation was performed in the whole Tabora region to understand characteristics of geology, surface condition and surface water. Field investigation sheets were prepared for describing such features in advance. Location map of field investigation is shown in *Figure 1.2.3*.



Base map: LANDSAT/ETM+ Mosaic using Band 1, Band 4, Band 5   0   50   100 km

Figure 1.2.3 Location Map of Field Investigation

The results of field investigation are summarized as follows,

(1) Igunga District

- Granite is widely distributed in all of district and greenstone is limited in the northern part as same as Nzega district.
- Groundwater level in Wembere depression was considered to be a couple of meters bellow the surface in dry season (see Figure 1.2.4).


Figure 1.2.4 Landscape of Wembere Depression and Water Basin at Location No. 16

- Fan deposits are developed very well at west margin of Wembere depression because of forming steep slopes, where infiltrating groundwater flows out at the end margin of the fans.

(2) Nzega District

- Granite is widely distributed in all of district and greenstone (see Figure 1.2.5) is limited in its northern portion.


Figure 1.2.5 Outcrops of Greenstone and Rock Texture at Location No. 12

- Ferricrete crust is more likely to be distributed between granite and greenstone distributed areas than others. Unfortunately, the boundary between these two rock facies is not recognized in the field.

- Groundwater level in Manonga River floor was approximately one meter bellow the surface even in dry season (see Figure 1.2.6).


Figure 1.2.6 Upper Stream of Manonga River and Trench at River Floor at Location No. 11

- Groundwater level in Lyella swamp seems to be a couple of meters bellow the surface in dry season judging from water wells in vicinity.
- Dolerite dykes trending E-W in direction are developed very well in this area about 30 kilometers south to Ziba village.

(3) Sikonge District

- Gneiss originated from granitoids is distributed in around Sikonge town elongating in NW-SE direction. Gneiss likely originated from sedimentary rocks is distributed widely in its south. In the Rungwa village, migmatite is distributed as well. They show different rock resistances against erosion on the image (see Figure 1.2.7).

Figure 1.2.7 Gneiss at Sikonge Town and Migmatite at Rungwa Village at Locations No. 27 and 16

- A great amount of quartz veins intrude into gneiss, and about one meter thick of the vein in maximum width was observed in the field south to Sikonge town.
- Ferricrete was observed west to Ipole village. Red soil of one to two meters in thickness overlies ferricrete layer of more than two to three meters, which is considered to be ineffective for the infiltration in mountainous areas due to its low permeability (see Figure 1.2.8).

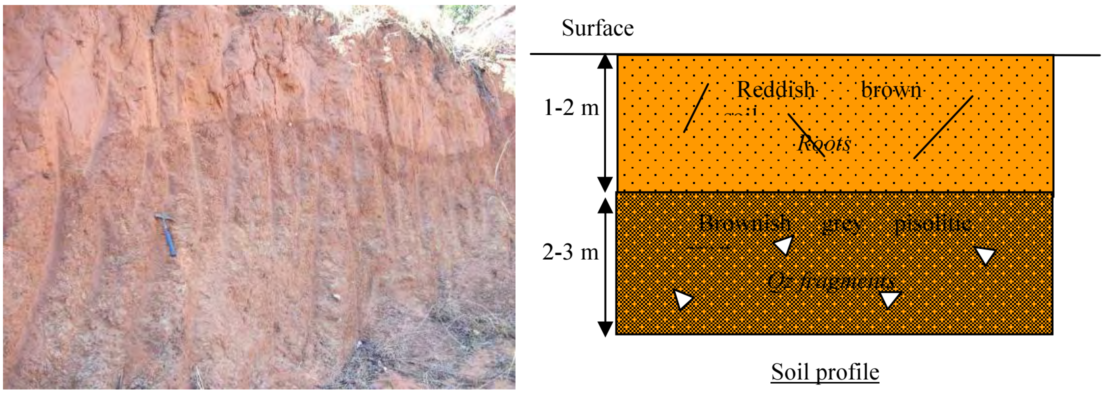


Figure 1.2.8 Ferricrete Outcrop west to Ipole Village and its Field Sketch at Location No. 39


Figure 1.2.9 Spring and its Water Basin close to Sikonge Town at Location No. 26


Figure 1.2.10 Condition of Ugalla Katumbiki River and Pit at River Floor at Location No. 37

- Water spring occurs in gneiss distribution area in northern part of Sikonge town. The area corresponds to an intersection of major faults between N-S and NW-SE trending (see Figure 1.2.9).
- There is no surface water in Rungwa River despite sitting large swamp in upper stream. Judging from water basins in vicinity, groundwater level is a couple of meters bellow the surface.
- Consecutive surface water bodies are observed in Ugalla Katumbiki River in the most south-western end of the district even in dry season. Groundwater level is one to two meters bellow the surface (see Figure 1.2.10).
- There is no surface water in Mbweni Mbuga swamp south to Sikonge town, but large amount of water is expected in wet season because of presence of sun crack and crust of snails on the surface. The condition is very similar to the one in Nzega and Igunga districts. There is no information about groundwater level.

(4) Tabora Rural District

- Granite is mainly distributed in this district.
- The groundwater level seems to be 1 meter bellow the surface judging from the field observation (see Figure 1.2.11).
- Surface water indicating about 20 ^{o}C in temperature was observed in the rice field west to Tabora Municipality, and it is considered to be water spring from lateral flow of saprolite.
- Circular structures in a couple of kilometers in diameter are clarified in the eastern part of the district. These structures are considered to be filled with surface water in wet season because of their geomorphology like depression structure and clayey materials distributed on the surface.

Figure 1.2.11 Water Sources for Irrigation and Life Use at Location No. 06

- There are many irrigation ponds around Mambali village. Water spring from a couple of centimeter thick sandy layer intercalated with saprolite was observed in one of the ponds (see Figure 1.2.12).

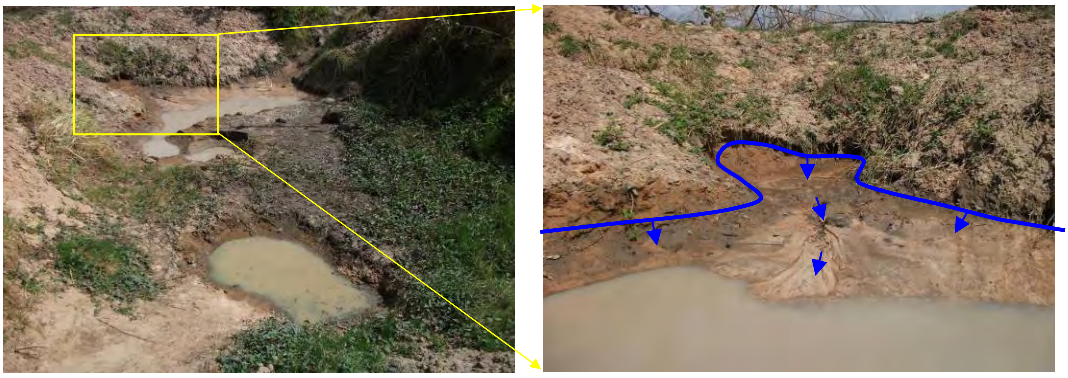


Figure 1.2.12 Water Source for Irrigation and its Surface Condition at Location No. 50

(5) Tabora Municipality

- Granite is mainly distributed in this district.

- Kazima dam, having a small recharge drainage basin, stores certain level of surface water even if it is in the end of dry season. The groundwater level should be higher than vicinity areas.

(6) Urambo District

- Granite is distributed widely and gneiss sits at the center of the region with NW-SE trending zone. Granite shows medium grained and porphyritic texture.

- Lowland is widely spread in the western part of the district. Groundwater level is approximately three meters bellow the surface at human made water well for irrigation in Makubi village. The water is silty white in color (see Figure 1.2.13).

- Urambo town is supplied by all groundwater. There are several 200 meter deep wells here, and some of them are out of order due to equipment troubles.

- There is no evidence about major faults themselves and/or water spring except for concave topography, while the intersection between two major faults is located here in Ichemba River.

- There is large amount of surface water in Igombe River, where lowland is widely spread. The river indicates about 50 meter wide and 10 meter deep at its center even in dry season. The river becomes much wider in wet season than in dry season with flood areas, where nursery bed of tobacco is formed currently in dry season (see Figure 1.2.14).

Figure 1.2.13 Human-made Water Well for Irrigation and its Groundwater Level at Location No. 41

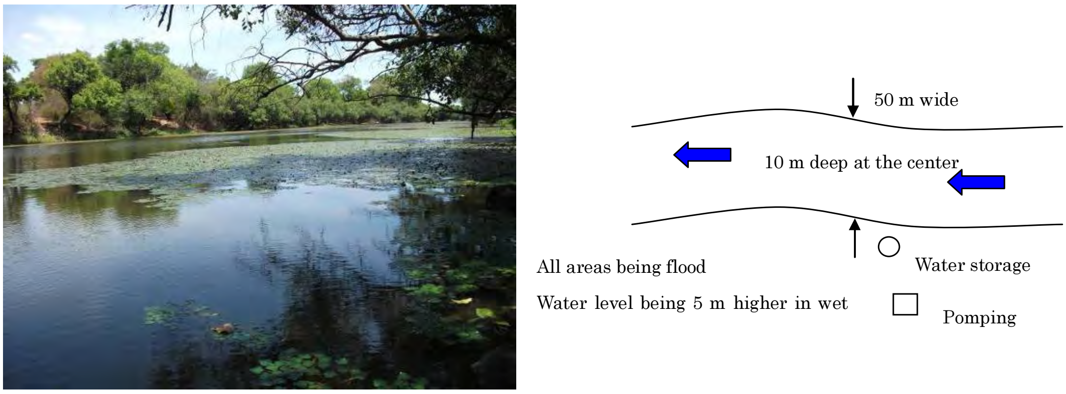


Figure 1.2.14 Condition of Igombe Down Stream and its Field Sketch at Location No. 46

1.2.7 RESULT OF ANALYSIS FOR WHOLE TABORA REGION

Thematic maps and their incorporate information in this survey are shown in Table 1.2.3.

Table 1.2.3 Generated Thematic Maps

Map	Scale	Incorporate information
Surface condition	1:200,000	- Drainage system and drainage basin - Vegetation distribution by NDVI in both dry and wet seasons - Surface water distribution in wet season - DEM shaded map
Lithofacies	1:200,000	- Lithofacies by image interpretation - Compiling existing geologic map - DEM shaded map
Geologic structure	1:200,000	- Fractures by image interpretation; major faults, certain and uncertain lineaments and dykes - Faults and dykes by existing airborne magnetic data interpretation - DEM shaded map

(1) Surface Condition Map

The surface condition map was shown in Figure 1.2.15. This thematic map clarifies following contents.

- Tabora region should be divided into four main drainage basins judging from drainage analysis using SRTM data. They are eastern, north-western, south-western and most southern drainage basins. Tabora Municipality is located in a ridge between the north-western and the south-western main drainage basins.

- Vegetation is mainly distributed in forest and game reserves of Sikonge and Urambo districts, while their distribution is different between wet and dry seasons. Artificial vegetation boundaries regarding these reserves were extracted from the imagery as well.

- The surface water is distributed in the lowlands of Igunga and Urambo districts in addition to Manonga River, Rungwa River, Igombe River and Wala River on the imagery of the wet season data.

(2) Lithofacies Map

The lithofacies map was shown in Figure 1.2.16. The existing geologic map in scale of 1:500,000 should be used as a compilation map. This thematic map clarifies following contents.

- The difference between the interpretation result and this map is in discrimination and its distribution of geologic unit Gb. The geologic unit should be separated into two sub-units based on the field investigation results.

- The geologic units both of Ng and Sr distributed in the most south-western part of the region on the interpretation result follow equivalent units on the existing geologic map.

(3) Geologic Structure Map

The geologic structure map was shown in Figure 1.2.17. This thematic map clarifies following contents.

- Major faults trending N-S and NW-SE in addition to trending NE-SW and E-W were newly extracted from DEM shaded map. There is a difficulty to extract these major faults from the satellite imagery because its high sun elevation does not show efficient shadow effect. These faults sitting extension and/or parallel to the 'Eastern African Rift' are seems to be younger than any other lineaments in the region.

- Other faults and dykes derived from the airborne magnetic survey are added on as well in order to make accuracy higher than the ones from the satellite interpretation, as subsurface structure is difficult to detect from satellite imagery in 1:200,000 scale. In fact, These dykes are very concordant with N-S trending major faults and extend further to the south.

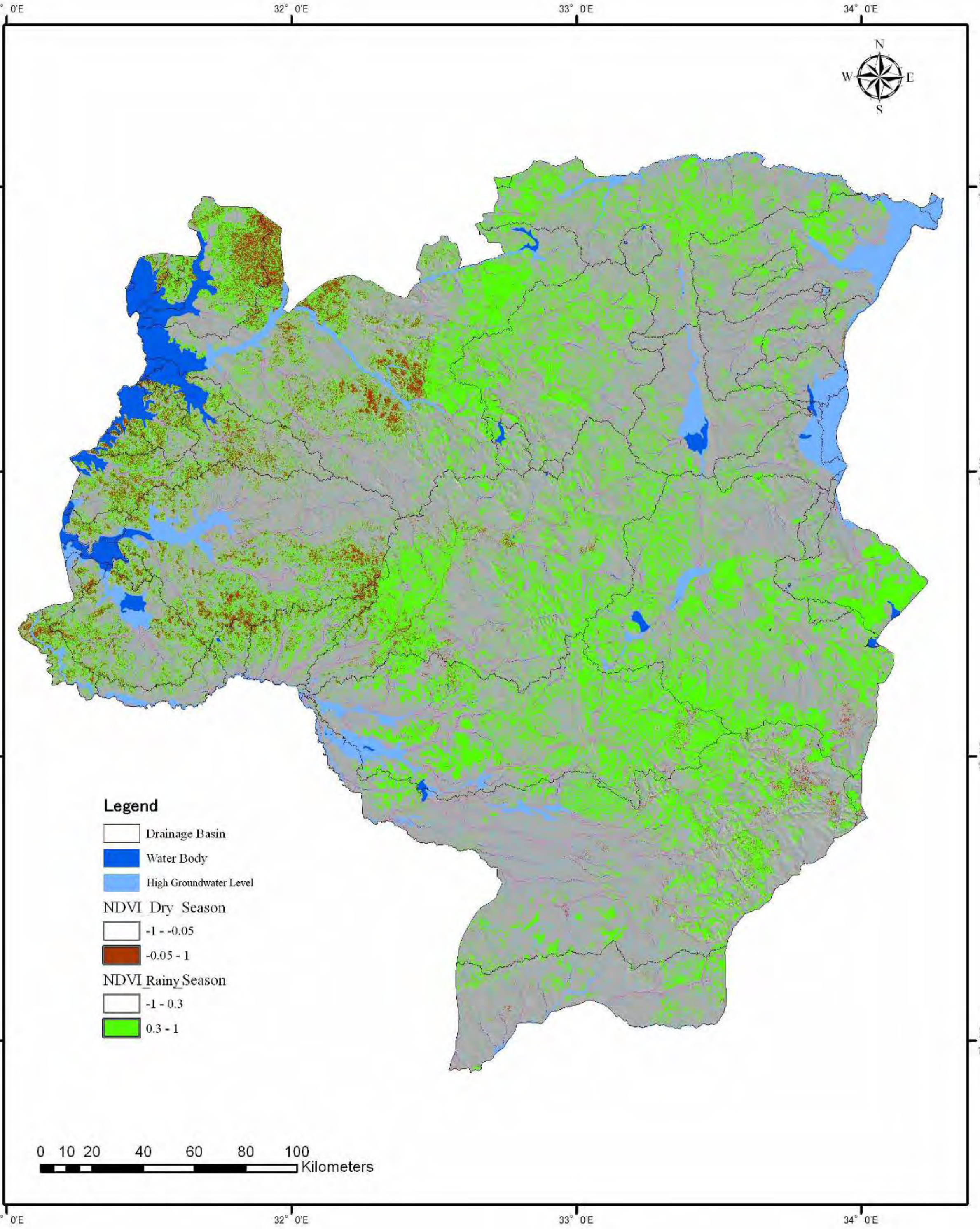


Figure 1.2.15 Surface Condition Map

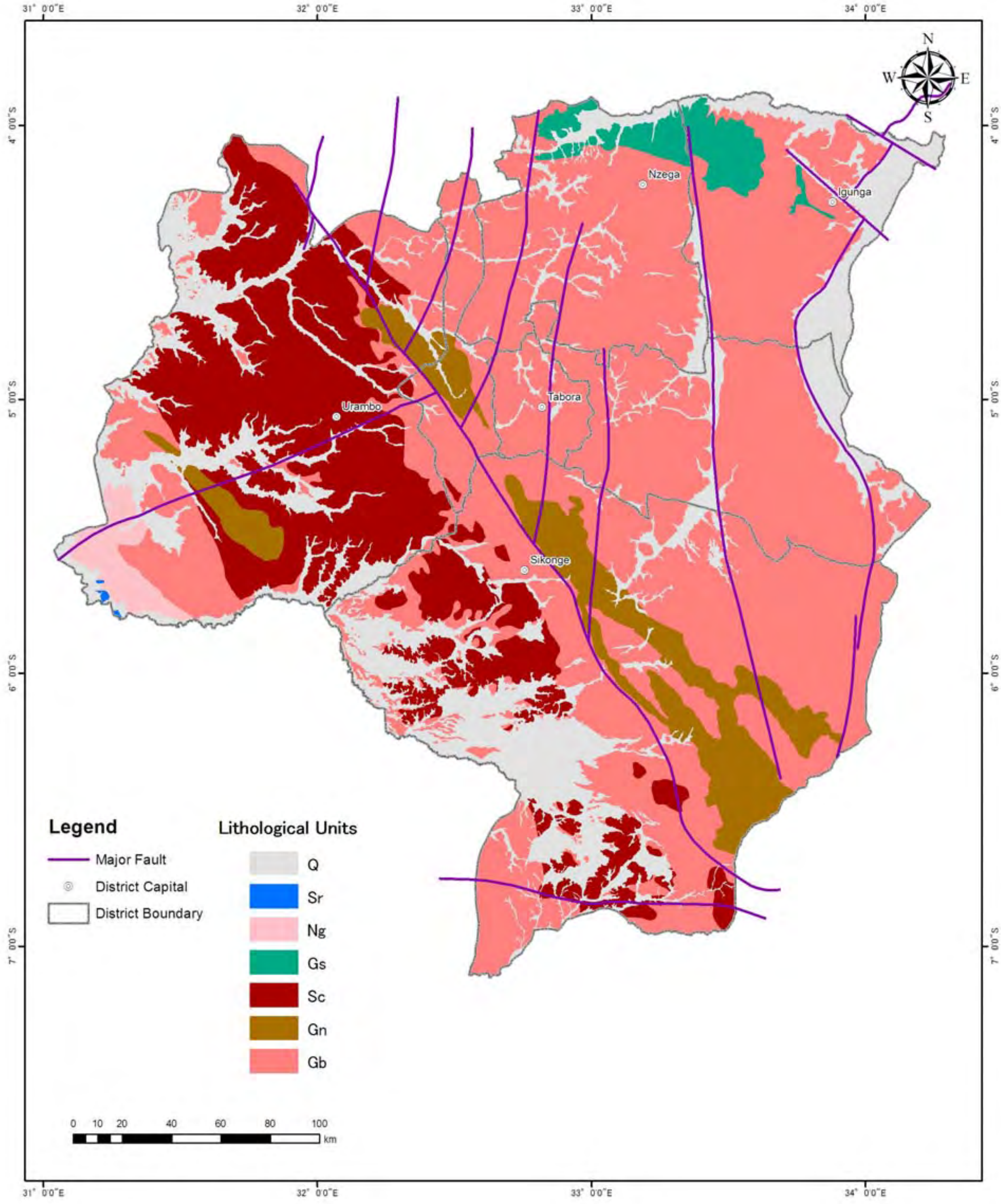


Figure 1.2.16 Lithofacies Map

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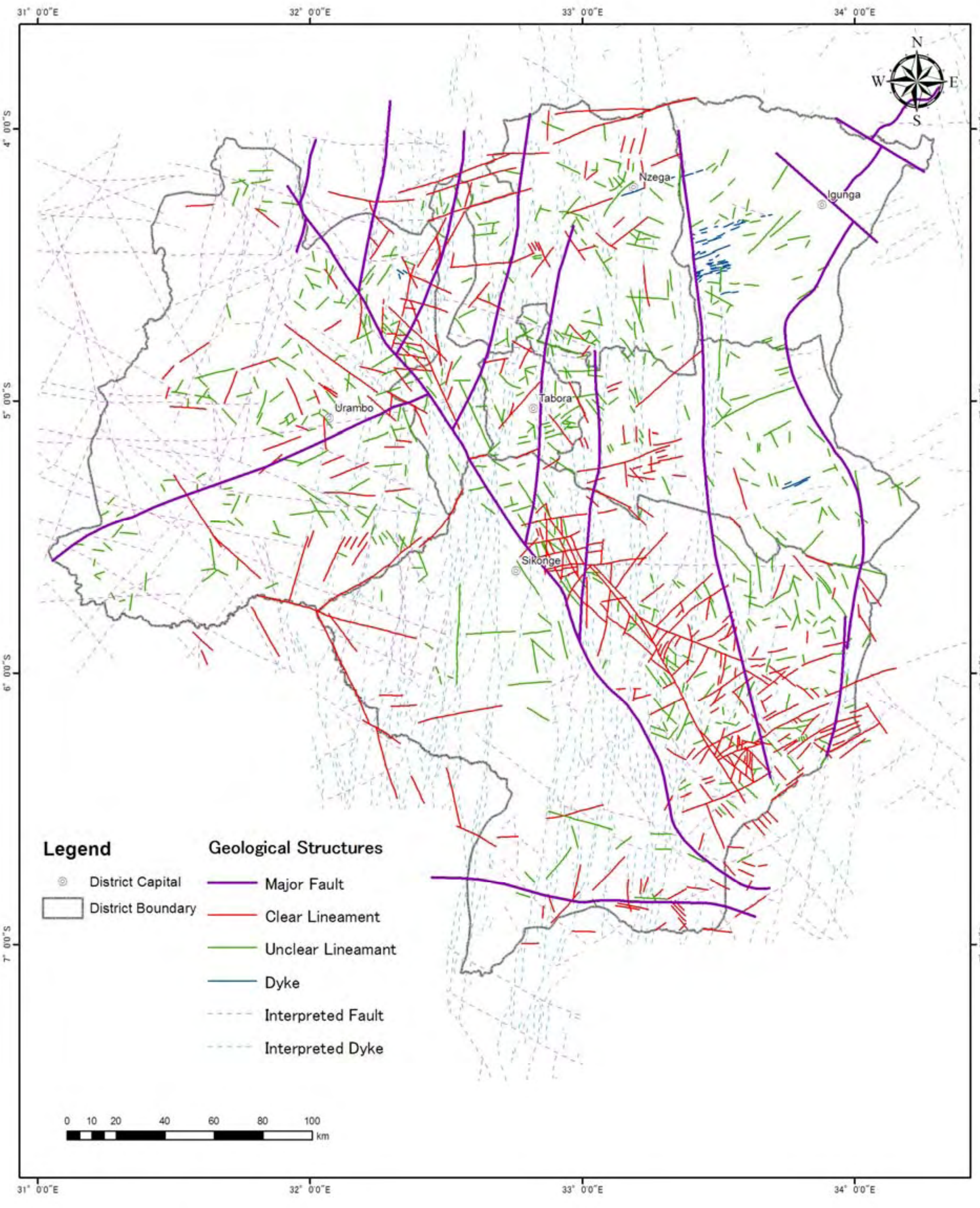


Figure 1.2.17 Geologic Structure Map

1.3 SATELLITE IMAGE ANALYSIS FORTARGET VILLAGES OF PRIORITY PROJECT

1.3.1 BACKGROUND AND OBJECTIVE

The Tanzania craton, composed of plutonic rocks such as granite, gneiss and green rock etc., is widely distributed over the area as the basement. These basement rocks are basically dense and hard and are not permeable. The weathered zones and fractured zones, however, are permeable and have high storativity. Therefore, those zones may act as aquifers with the suitable recharge condition. In certain areas, there exists the topsoil above the basement or the deposits along the seasonal drainages. They are not expected as suitable aquifers because of their limited layer thickness and distributed area and deteriorated water quality.

Accordingly, it seems that the stable water sources throughout the year in the study area, is the groundwater in weathered zones and the fractured and fault zones in the basement. Referring to the information of existing water sources, there are only approximately 10 wells that have enough water yield for Level-2 out of hundreds of drilled wells in the study area. The water well prospecting in the study area is deemed quite difficult. In addition, a high concentration of fluoride, exceeding the WHO guidelines, has been detected in several wells in the eastern area of Tabora Region. From both respects of the water quantity and the water quality, there may be many difficulties in groundwater development in the study area.

On the basis of background mentioned above, the objective of this study is to extract hydro-geologically potential points for further geophysical survey in selected Level-2 villages by the use for the collection and the analysis of existing data, high ground resolution satellite image interpretation and field reconnaissance.

1.3.2 METHODOLOGY

The methodology of the study is composed of remote sensing data selection, image processing, image interpretation, field reconnaissance based on the interpretation and hydro-geological interpretation and a recommendation for further study. A series of these studies should be done based on the database generated in Phase I study. The flow chart of the survey is shown in Figure 1.3.1.

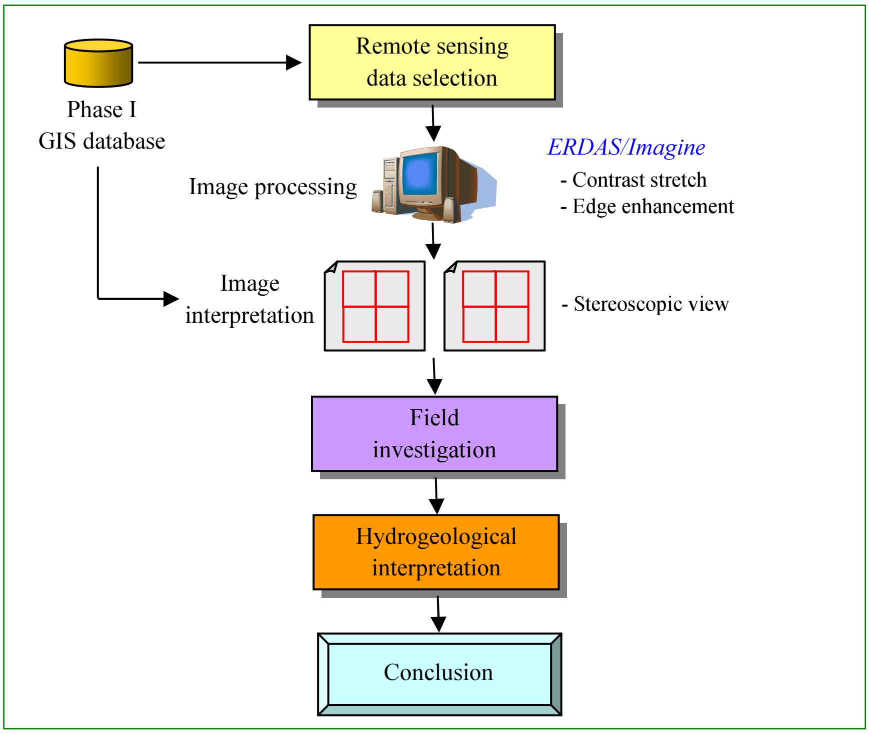
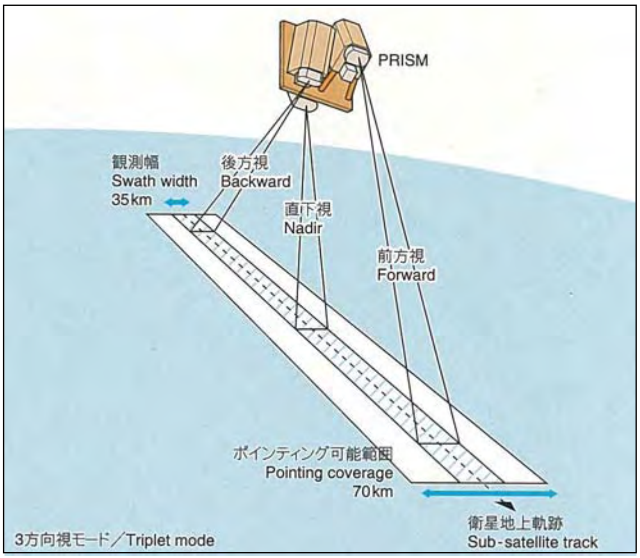


Figure 1.3.1 Flow Chart of the Study

1.3.3 IMAGE DATA USED

The image data used of the study are ALOS/PRISM data. The PRISM is an optical sensor for observing visible terrain areas with a 2.5 m spatial resolution. It has three independent optical systems to acquire terrain data including altitude data so that images for nadir, forward and backward views can be acquired at same time (see Figure 1.3.2). This enables us to get three-dimensional terrain data with a high accuracy and frequency. The list of image data used and their specification is shown in Table 1.3.1.



Derived from 'ALOS data, Products and Services' RESTEC

Figure 1.3.2 PRISM's Optical System

Table 1.3.1 List of image data used and their specification

Image data used (ALOS/PRISM)	Scene ID (N)	Acquisition date (dd /mm/yy)	Look angle	Shift
Isanga, Nzega	ALPSMN187773680	03/08/2009	N, F	+1
Usunga, Sikonge	ALPSMN091353715	12/10/2007	N, F	+1
Mpombwe, Sikonge	ALPSMN187773710	03/08/2009	N, F	-2
Mpumbuli, Tabora R.	ALPSMN196233710	30/09/2009	N, F	-2
Mabama, Tabora R.	ALPSMN140803705	15/09/2008	N, F	-1
Kakola, Tabora Mun.	ALPSMN187773695	03/08/2009	N, F	+2
Mabisilo, Nzega	ALPSMN091353695	12/10/2007	N, F	0

Characteristics

- Number of bands: 1 (Panchromatic)
- Spectral range: 0.52 – 0.77 micrometer
- Number of optics: 3 (N: Nadir, F: Forward, B: Backward)
- Base-to-height ratio: 1.0 (between Forward and Backward looking, namely 0.5 between Nadir and Forward looking)
- Spatial resolution: 2.5 m
- Swath width: 35 km in triplet mode
- S/N: > 70
- MTF: > 0.2
- Number of detectors: 14,000 / band
- Bit length: 8 bits

1.3.4 Processed Image Data

Processed image data in this study are listed on Table 1.3.2.

Table 1.3.2 List of processed Image Data

Image data used	Generated imagery	Scale
ALOS/PRISM	Panchromatic B/W images of Nadir and Forward looking in each area	1:50,000
	B/W images combined with GIS data regarding geology done in Phase I	1:50,000

Remarks

- GIS data: Major faults, Clear lineaments, Unclear lineaments, Dykes, Interpreted faults and dykes derived from existing geophysical survey and ward boundaries
- Sphere and projection: Arc 1960 and Transverse Mercator

Contrast stretch and edge enhancement are applied for image processing. In the contrast stretch, standard deviation 2.0 was calculated from contrast histogram of each image, and the image were generated by using this number as a threshold value. In the edge enhancement, 3*3 window as a edge mask was applied.

1.3.5 Image Interpretation

(1) Method of Image Interpretation

Image interpretation was carried out by using stereoscopic view of a pair of images photo-geologically. The size of PRISM image paper print in scale of 1:50,000 is approximately 72 cm wide. It is so large for a normal stereoscope that we can divide it into 9 parts whose size is about 24 cm wide to handle efficiently. The stereoscopic view, Base-Height ratio 0.5, gives us two time higher terrain impression than our naked eyes, its ratio 0.25.

Image interpretation is based on items as follows;

- General: General features in selected villages are summarized based on Phase I study.
- Geologic features about selected villages: Geology and geologic structure in selected villages are summarized based on Phase I study.
- Image data used: Index of PRISM stereo-pair is illustrated.

- Result of image interpretation: As a result of image interpretation, topography, surface condition, geology, fracture, drainage basin and others are summarized in each village.
- Selected point recommended by image interpretation：Base on the information mentioned above, its position, direction and others are recommended.
- Remarks：Other characteristics such as security and so on are added on these items above.
- Image interpretation result: These features are illustrated on the PRISM image around the village.

(2) Requirement for Groundwater Potential

It is important that we make a requirement for groundwater potential into consideration when interpreting the images. They are as follows,

- A wider drainage basin upstream to get adequate recharge for groundwater source.
- Fractures developed well in fresh rocks as a groundwater path.
- A geologic structure enough to store groundwater.
- Clay layers developed at surface to seal groundwater.
- High groundwater quality.
- Shallow groundwater.

The first three requirements are particularly necessary for hydro-geological interpretation.

<u>Recharge</u>: There are several groundwater flow systems. Local groundwater flow system is basically important in this study because of such shallow depth as 100 m bellow the surface. The groundwater flow may be inferred as a theory of ‘Sinusoidal groundwater surface’. Local groundwater flow system is so shallow that it could approach a lateral flow under the surface.

<u>Groundwater path</u>: In the crystalline rocks such as granites and gneisses, fractures sometimes make groundwater path as aquifer. Accordingly, faults and lineaments become important for this requirement. Large scale of these fractures act permeable media resulting in Phase I study. In addition, dip direction is also offer information for further study to decide detailed position such as a drilling.

<u>Groundwater storage</u>: Large scale fractures and their intersection make geologic structure to store groundwater, while low permeable dykes trap groundwater.

The drainage map of central Tabora region is illustrated in Figure 1.3.3. These data was used for further study as a background information.

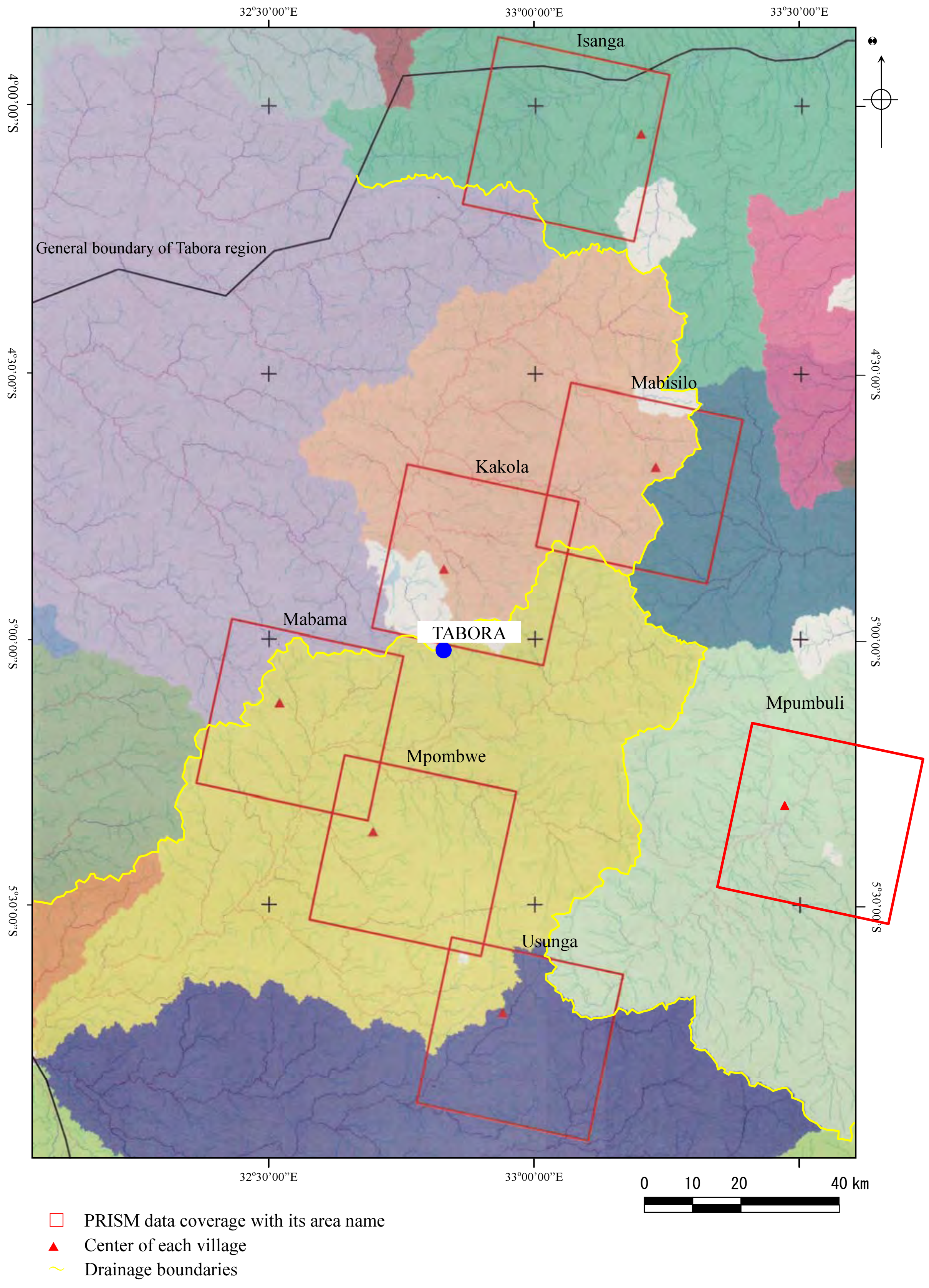


Figure 1.3.3 Drainage Map of Central Tabora Region

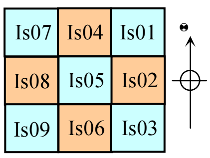
1.3.6 RESULT OF IMAGE INTERPRETATION

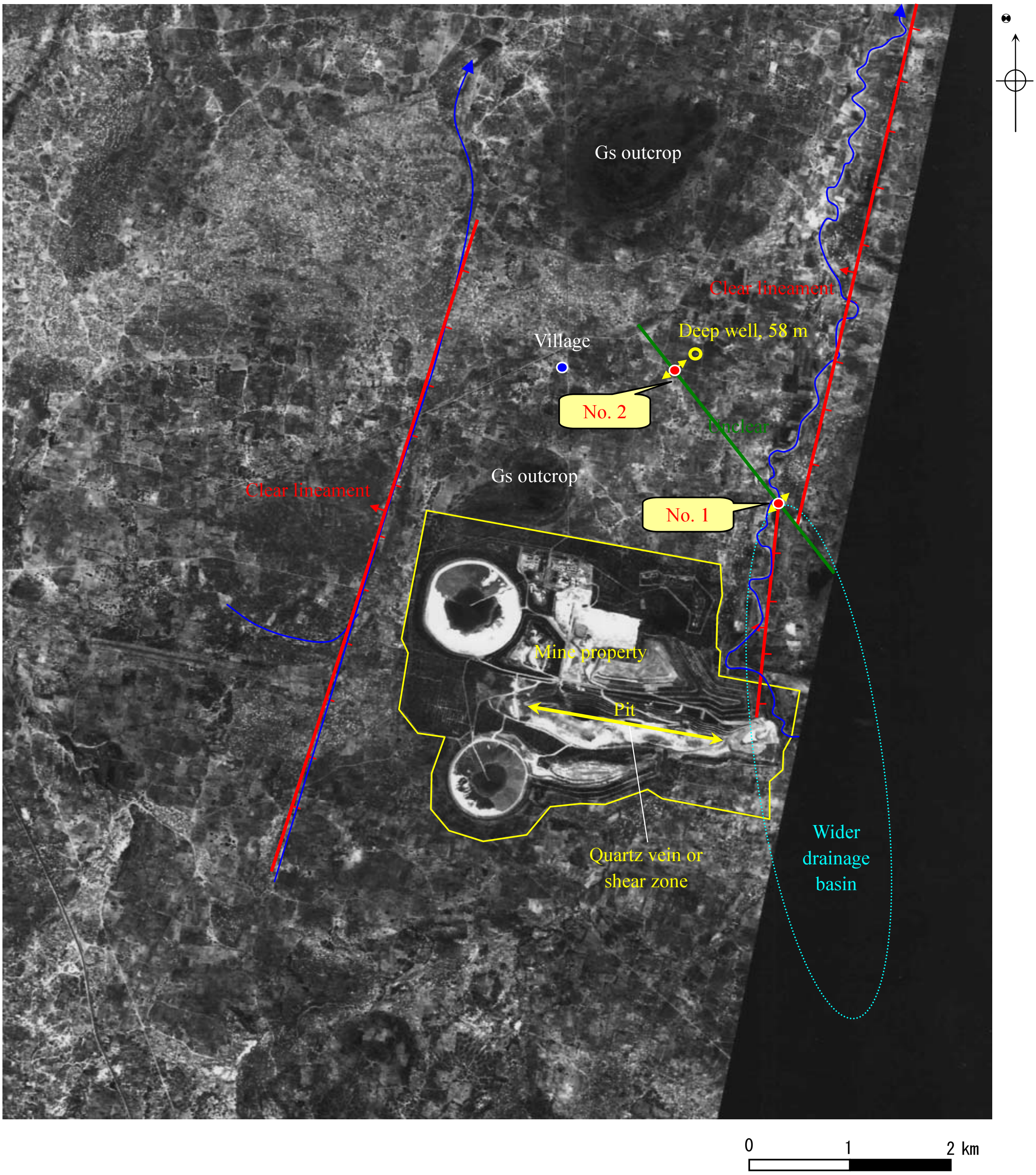
The result of image interpretation at 7 villages for Level-2 is shown as follows.

(1) Isanga village

General geology and image interpretation results in Isanga village are shown in Table 1.3.3 and Figure 1.3.4 respectively.

Table 1.3.3 Geologic Feature of Isanga Village

General	Greenstone (Gs) is widely distributed and in this village and granite (Gb) as a basement in the Tabora region is also distributed in the southern part of the village. According to a regional geologic setting, the area is located in the second structural block from the east, which is elongated in N-S direction, tilting slightly eastward. As the eastern major fault limiting its east end seems to be a reverse fault, it should dip eastward in general.
Geologic features for further study	- Clear lineaments defined in Phase I study are developed in NNE-SSW direction in this area. These are almost parallel to a major fault defined in the study sitting eastward. - Drainages are developed in these lineament positions. The eastern drainage shows wider basin upstream than the western one. - There is a water dam upstream in the eastern drainage. The dam water might be used for a mining operation of the gold mine southward.
Image data used	PRISM stereoscopic view Nadir (N) and Forward (F) Scale: 1:50,000 Index: Is01 – 09 
Image interpretation	The result of image interpretation is shown in the next page, and the following features were observed, - Topography: Showing extremely flat ground except for outcrops forming hilly landform. - Surface: Showing high level of land-use as a cultivated land. - Geology: Greenstone (Gs) is commonly distributed in the area. - Fracture: Two clear lineaments are developed in NNE-SSW direction, which are almost parallel to the major fault sitting eastward. Their dips are not clear on the image, but they might dip eastward judging from the same sense as the major fault. In addition, the unclear lineament is newly extracted, which cuts the eastern clear lineament. - Drainage: Wider basin sits in the east where the clear lineament is located. - Others: Accessible by a vehicle. There is a gold mine in the vicinity.
Point selection based on image interpretation	- Position: Points No. 1 and No. 2 shown in the next figure are selected as possible positions. - Direction: NE-SW direction could be recommended for further study. - Hydrogeology: Wider drainage basin upstream as a recharge, clear lineament as a groundwater path and intersection of lineaments as a groundwater storage would function.
Remarks	It is necessary to take safe measures for further study because of locating the gold mine in the vicinity.



Area name: Isanga (Is)

Portion: Is02N

Data: PRISM image

Scene ID: ALPSMN187773680

Acquisition date: 03/Aug./2009

Look angle: Nadir

Shift: +1

Legend

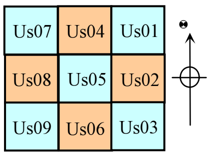
(red point with yellow arrow)	Point No. with survey direction
(blue point)	Original point (center of the village)

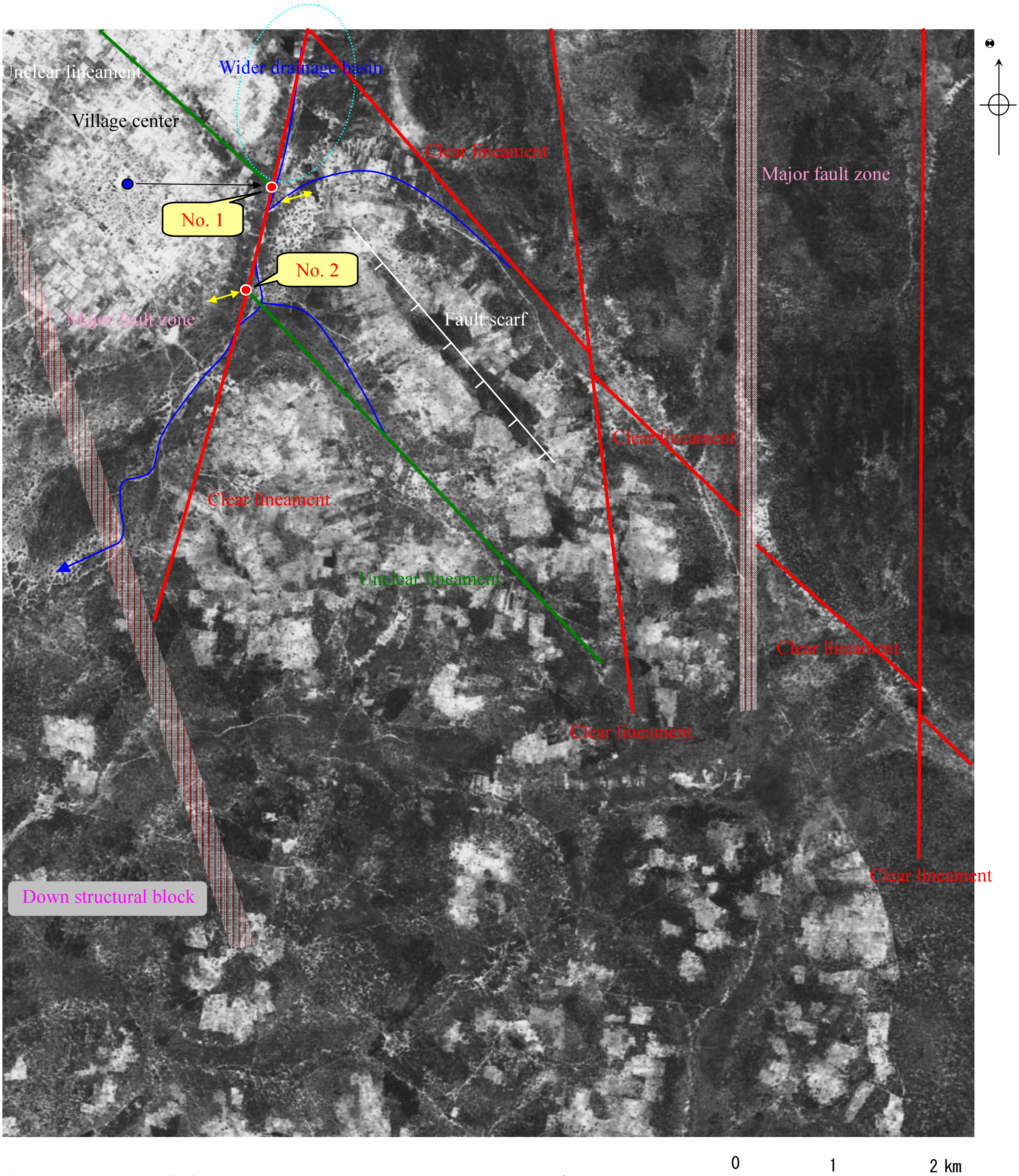
Figure 1.3.4 Image Interpretation Result in Isanga Village

(2) Usunga village

General geology and image interpretation results in Usunga village are shown in Table 1.3.4 and Figure 1.3.5 respectively.

Table 1.3.4 Geologic Feature of Usunga Village

General	Gneiss (Gn) and granite (Gb) as a basement in the Tabora region are widely distributed in this village. According to a regional geologic setting, the area is located in the most southern part of the third structural block from the east, which is elongated in N-S direction, tilting slightly eastward. As the south-western major fault limiting its south end seems to be a normal fault, it should dip south-westward in general.
Geologic features for further study	- A major fault defined in Phase I study is located 2 km southwest to the village. - An intersection between NE-SW trending clear lineament and NW-SE trending unclear lineament defined in the study is located 2 km east to the village. - An interpreted dyke defined in the study is located in the vicinity as well. - Fractures are developed very well in total around the village.
Image data used	PRISM stereoscopic view Nadir (N) and Forward (F) Scale: 1:50,000 Index: Us01 – 09 
Image interpretation	The result of image interpretation is shown in the next page, and the following features were observed, - Topography: Being composed of gentle mountains in the north-east and of hills in the southwest. - Surface: Showing natural forest in mountainous area and cultivated land in hilly area. - Geology: Typical gneiss (Gn) is distributed widely in the area. - Fracture: The N-S trending major fault and clear lineaments and the NW-SE trending clear and unclear lineaments are developed very well. These lineaments show fault scarves in some places. The major fault parallel to these NW-SE trending lineaments seems to be located southward, but it was interpreted poorly due to its gentle topography. - Drainage: There are two drainage basins elongated in NE-SW direction. The northern drainage basin is wider than the other. - Drainage: Basin elongated in NW-SE direction is wider than the other. - Others: Almost accessible by a vehicle.
Point selection based on image interpretation	- Position: Points No. 1 and No. 4 shown in the next figure are selected as possible positions. - Direction: ENE-WSW direction could be recommended for further study. - Hydrogeology: Wider drainage basin upstream as a recharge, clear lineament as a groundwater path and intersection of lineaments as a groundwater storage would function. The unclear lineament should be a branch of the major faults.
Remarks	None



Area name: Usunga (Us)

Portion: Us05N

Data: PRISM image

Scene ID: ALPSMN091353715

Acquisition date: 12/Oct./2007

Look angle: Nadir

Shift: +1

Legend

Point No. with survey direction

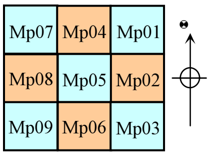
Original point (center of the village)

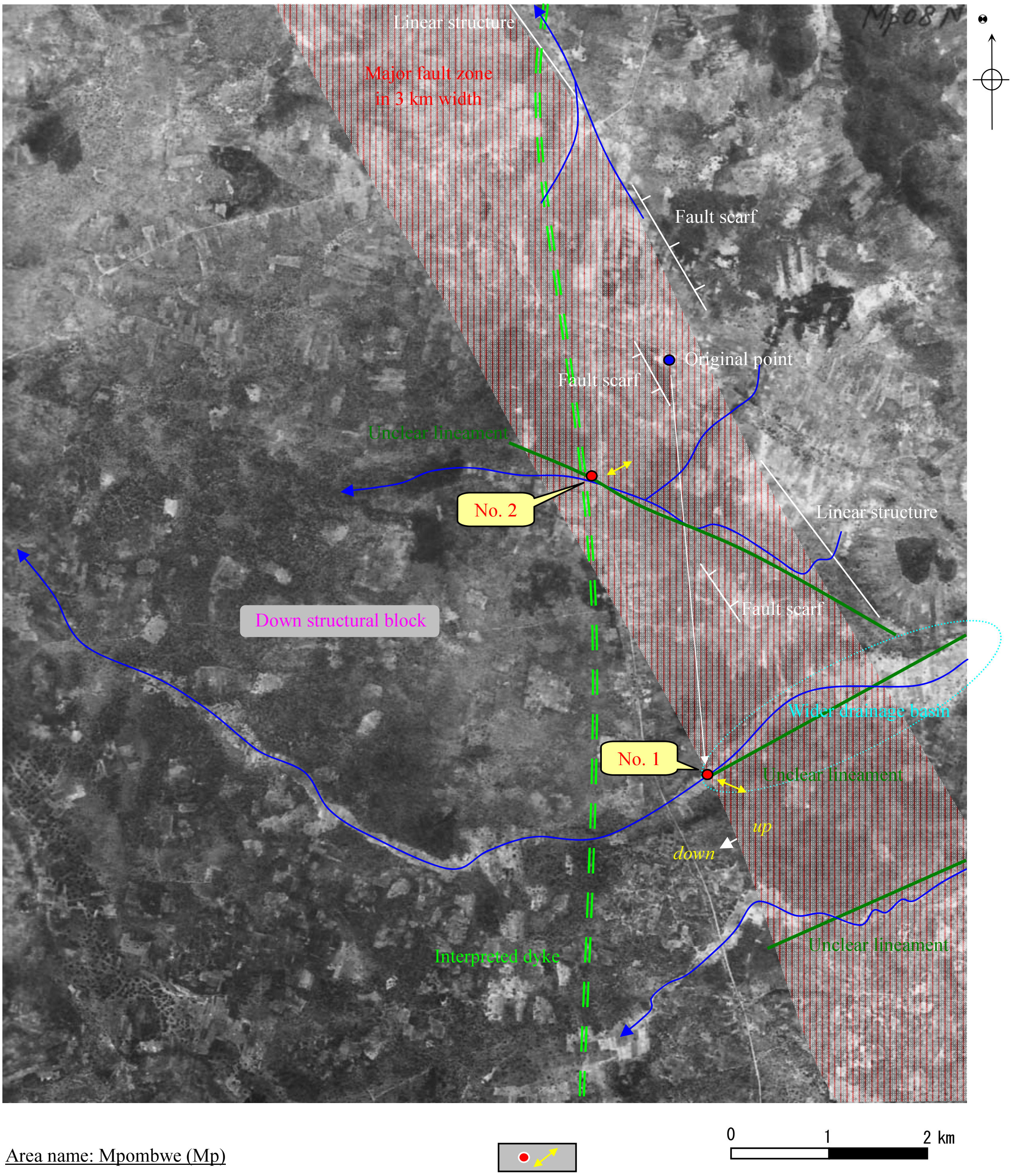
Figure 1.3.5 Image Interpretation Result in Usunga Village

(3) Mpombwe village

General geology and image interpretation results in Mpombwe village are shown in Table 1.3.5 and Figure 1.3.6 respectively.

Table 1.3.5 Geologic Feature of Mpombwe Village

General	Granite (Gb) and gneiss (Gn) as a basement in the Tabora region are widely distributed in this village. According to a regional geologic setting, the area is located in the most southern part of the forth structural block from the east, which is elongated in N-S direction, tilting slightly eastward. As the south-western major fault limiting its south end seems to be a normal fault, it should dip south-westward in general.
Geologic features for further study	- An intersection between NW-SE trending major fault and N-S trending interpreted dyke defined in Phase I study is located 2 km southwest to the village. - NE-SW and NW-SE trending unclear lineaments defined in the study are also developed well.
Image data used	PRISM stereoscopic view Nadir (N) and Forward (F) Scale: 1:50,000 Index: Mp01 – 09 
Image interpretation	The result of image interpretation is shown in the next page, and the following features were observed, - Topography: Showing hilly landform except for outcrops forming gentle mountains. - Surface: Showing high level of land-use as a cultivated land. - Geology: Granite (Gb) and gneiss (Gn) are commonly distributed in the area. - Fracture: The NW-SE trending major fault, the NE-SW and NW-SE trending unclear lineaments and the N-S trending interpreted dyke are developed well. The major fault shows 2 km wide fracture zone indicated by its fault scarves. - Drainage: There are two drainage basins elongated in NE-SW direction. The northern drainage basin is wider than the other. - Others: Accessible by a vehicle.
Point selection based on image interpretation	- Position: Points No. 1 and No. 2 shown in the next figure are selected as possible positions. - Direction: NW-SE, N-S and NE-SW directions could be recommended for further study. - Hydrogeology: Wider drainage basin upstream as a recharge, unclear lineaments as groundwater paths and fault zone and its intersection with interpreted dyke as groundwater storages would function.
Remarks	None



<u>Area name: Mpombwe (Mp)</u>

Portion: Mp08N

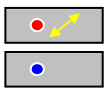
Data: PRISM image

Scene ID: ALPSMN187773710

Acquisition date: 03/Aug./2009

Look angle: Nadir

Shift: -2



Point No. with survey direction

Original point (center of the village)

Figure 1.3.6 Image Interpretation Result in Mpombwe Village