Chapter 3
Water Quality Analysis

CHAPTER 3 WATER QUALITY ANALYSIS

3.1 Introduction

Water quality survey was carried out in the Study, the purposes of which are summarized in Table3-1. Figure 3-1 shows locations of water quality survey points in IDB.

Table 3-1 Contents of Water Quality Survey

Purpose	Survey Method	Water Quality Survey Point
i) Overall picture of fluoride distribution	1) Collecting existing data of water quality survey in IDB 2) Simplified water quality test 3) Inventory survey of existing water supply facilities	Water quality data (including existing data) was collected relatively uniformly over IDB.
ii) Clarification of origin of fluoride	1) Laboratory test of water quality	In addition to item i) (above), checkpoints were selected in the areas with a conspicuously high concentration of fluoride in order to clarify the relationship between the various minerals and the fluoride concentration in the water source.
iii) Other water pollution conditions	1) Simplified water quality test 2) Laboratory test of water quality	Distributions of the other water quality items (iron, manganese, nitrate, ammonium, coli bacteria, etc.) except fluoride, were investigated at the survey points in item i) mentioned above.

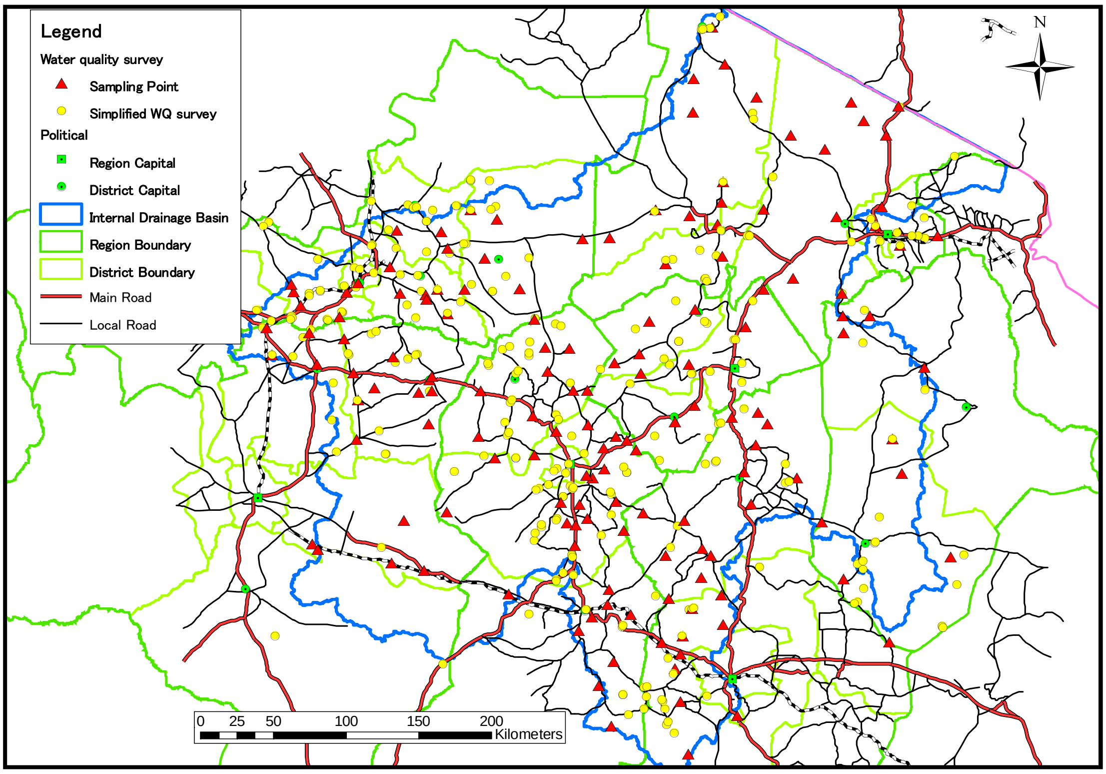

Figure 3-1 Location of Water Quality Survey Points

3.2 Surface Water Quality

3.2.1 Major Lakes

The fluoride concentration of the lakes in IDB ranges from 0.3 to 966 mg/l; the highest is Lake Natron. The lakes in IDB are characterized by their generally very shallow water depth caused by topographical or geological features of the Gregory Rift Valley, as represented by Lake Natron, Lake Manyara, and Lake Eyasi which all have a depth of several meters. Another characteristic is that these are alkaline lakes that contain very high levels of sodium (Na) and potassium (K).

3.2.2 Rivers, Dams, Ponds and Springs

Major water quality items of surface water in IDB except lakes are summarized in Table3-1.
Among the six regions, the highest fluoride levels in rivers, dams and ponds was observed in Shinyanga Region (average: 2.4mg/l) and in springs was observed in Arusha Region (average: 2.6mg/l). Seven percent of the rivers, dams and ponds and 12% of the springs exceeded the water quality standard of fluoride for drinking water in Tanzania (fluoride concentration of 4mg/l or less).

Spring water showed higher electric conductivity (EC) than the rivers, dams and ponds. Among the six regions, Dodoma Region had the highest EC (average: 111.1 mS/m) followed by Singida Region (average: 84.6 mS/m). Although Tanzania has no standard value for EC, levels exceeding 150 mS/m are generally unsuitable for drinking. Three percent of the rivers, dams and ponds and nine percent of the springs exceeded this value.

Table 3-2 Fluoride and EC of Surface Water in IDB

F

Region	Dam, Pond and River				Spring			
	No.	Minimum	Maximum	Average	No.	Minimum	Maximum	Average
Arusha	93	0.2	44.0	1.5	110	0.1	66.0	2.6
Manyara	5	0.2	5.0	2.2	12	0.0	4.0	1.3
Dodoma	3	0.4	1.0	0.7	10	0.2	2.7	1.2
Tabora	25	0.1	1.5	0.7	3	0.4	1.4	0.9
Shinyanga	25	0.8	6.4	2.4	4	1.2	3.5	2.1
Singida	24	0.0	5.0	2.2	15	0.3	8.7	2.3

Unit: mg/l

Fluoride (mg/l)	Dam, Pond and River		Spring	
	No.	%	No.	%
0-0.4	45	26	32	21
0.4-0.8	35	20	48	31
0.8-1.5	35	20	24	16
1.5-4	48	27	31	20
4-8	11	6	13	8
8-	1	1	6	4
Total	175	100	154	100

EC

Region	Dam, Pond and River				Spring			
	No.	Minimum	Maximum	Average	No.	Minimum	Maximum	Average
Arusha	93	4.0	490.0	34.3	106	6.6	324.0	56.8
Manyara	5	9.2	58.1	26.8	12	5.3	400.0	83.1
Dodoma	3	19.6	54.5	31.7	7	28.9	285.0	111.1
Tabora	23	8.3	98.9	35.0	2	13.2	33.8	23.5
Shinyanga	25	10.8	56.1	29.0	4	9.4	20.2	13.3
Singida	25	4.4	180.0	49.3	14	17.2	350.0	84.6

Unit: mS/m

EC (mS/m)	Dam, Pond and River		Spring	
	No.	%	No.	%
0-10	22	13	8	6
10-50	122	70	86	59
50-150	26	15	38	26
150-300	3	2	10	7
300-1000	1	1	3	2
1000-	0	0	0	0
Total	174	100	145	100

Water quality analysis by trilinear diagrams of the major components (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- SO_4^{2-} and HCO_3^-) shows that springs containing high fluoride belong to different type of other surface water and indicates that longer retention conditions exposes spring water to chemical reactions (such as elution and exchange reaction process from strata) which increases fluoride levels.

3.3 Groundwater Quality

3.3.1 Shallow Groundwater

Major water quality items of dug wells, shallow wells and waterholes (hereinafter referred to simply as "shallow groundwater") in IDB is shown Table 3-3 and Figure 3-2 and 3.

The highest average value of fluoride among the six regions was 3.0mg/l in Arusha Region, followed by 2.0mg/l in Singida Region. At the local level, a dug well in Esilalei Village, Monduli District in Arusha Region, had the highest concentration of 25mg/l. Eighteen percent of shallow groundwater samples exceeded the Tanzanian water quality standard for fluoride in drinking water (fluoride concentration of 4mg/l or less).

The highest average value of EC among the six regions was 98.7 mS/m in Shinyanga Region, followed by 96.4mS/m in Dodoma Region. Seventeen percent of the samples exceeded EC levels of 150mS/m.

Table 3-3 Fluoride and EC of Shallow Groundwater in IDB

Region	F (mg/l)			
	No.	Minimum	Maximum	Average
Arusha	42	0.2	25.0	3.0
Manyara	30	0.0	13.3	1.7
Dodoma	17	0.0	1.1	0.6
Tabora	38	0.0	5.9	1.2
Shinyanga	623	0.0	14.0	1.9
Singida	118	0.1	14.3	2.0

Fluoride (mg/l)	Dug well, Shallow well and Waterhole	
	No.	%
0-0.4	291	34
0.4-0.8	60	7
0.8-1.5	90	10
1.5-4	265	31
4-8	150	17
8-	12	1
Total	868	100

Region	EC (mS/m)			
	No.	Minimum	Maximum	Average
Arusha	43	7.4	688.0	86.0
Manyara	29	12.6	205.0	76.7
Dodoma	17	12.4	305.0	96.4
Tabora	38	5.5	189.1	49.4
Shinyanga	622	5.1	302.0	98.7
Singida	133	6.0	1110.0	92.2

EC (mS/m)	Dug well, Shallow well and Waterhole	
	No.	%
0-10	14	2
10-50	178	20
50-150	544	62
150-300	138	16
300-1000	7	1
1000-	1	0
Total	882	100

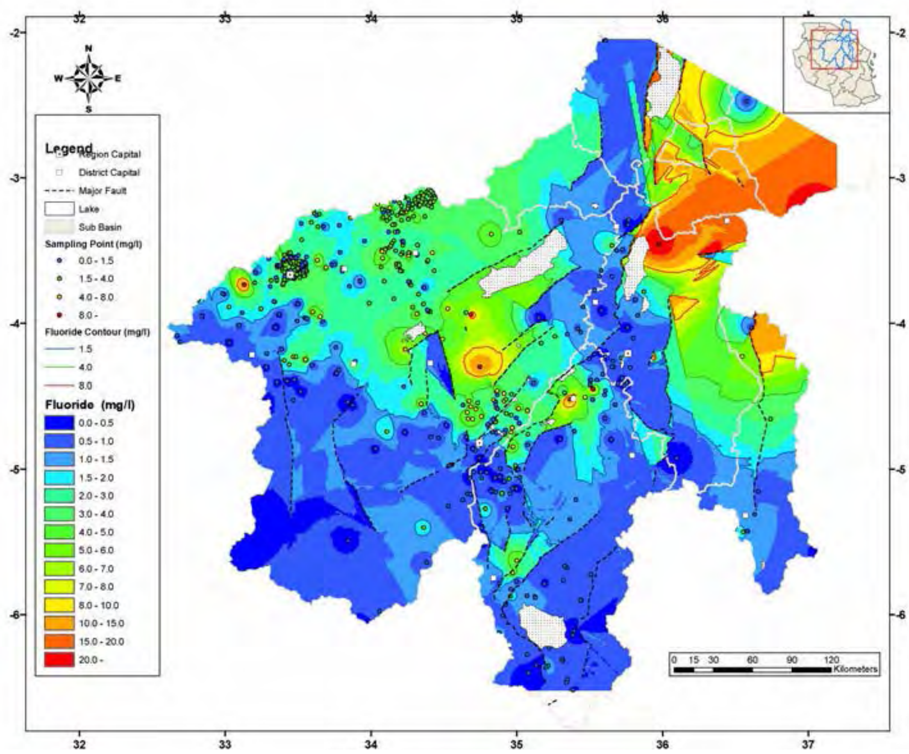

Figure 3-2 Distribution of Fluoride Concentration in the Shallow Groundwater in IDB

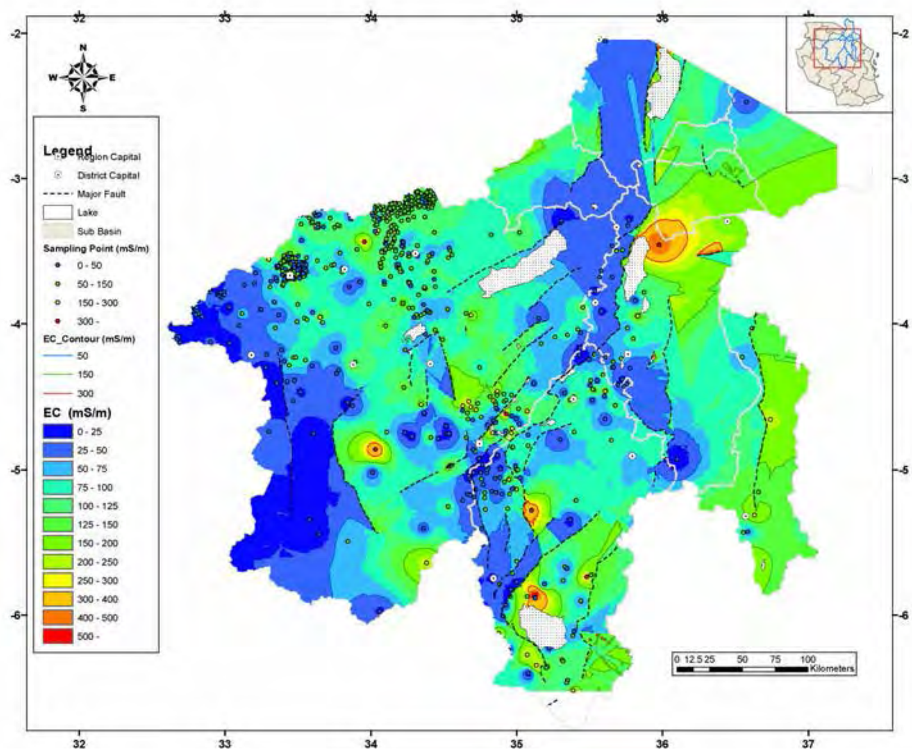

Figure 3-3 Distribution of EC in the Shallow Groundwater in IDB

Water quality analysis by trilinear diagrams imply that shallow groundwater with high fluoride levels have similar conditions as spring water in terms of water quality type and the process of fluoride contamination.

3.3.2 Deep Groundwater

Fluoride and EC of borehole (hereinafter simply referred to as "deep groundwater") in IDB are shown in Table 3-4 and their distribution are presented as Figure 3-4 and 5.

Among the six regions, the highest average value of fluoride concentration was 4.1mg/l in Shinyanga Region, followed by 2.7 mg/l in Arusha Region. At the local level, Ngofila Village, Kishapu District in Shinyanga Region, had the highest concentration of 35mg/l, followed by that in Piyaya Village, Ngorongoro District in Arusha Region with 31.8mg/l. Thirteen percent of the samples from borehole wells exceeded the water quality standard of fluoride for drinking water in Tanzania.

Among the six Regions, Shinyanga had the highest EC 166.8 mS/m on average, followed by Singida 134.9 mS/m. Thirty percent of the samples exceeded EC of 150mS/m.

Table 3-4 Fluoride and EC of Deep Groundwater in IDB

F

Region	Borehole			
	No.	Minimum	Maximum	Average
Arusha	37	0.2	31.8	2.7
Manyara	50	0.2	7.9	1.2
Dodoma	74	0.0	3.0	1.0
Tabora	28	0.4	7.9	2.1
Shinyanga	39	0.0	35.0	4.1
Singida	158	0.0	15.1	2.3

Unit: mg/l

Fluoride (mg/l)	Borehole	
	No.	%
0-0.4	23	6
0.4-0.8	40	10
0.8-1.5	119	31
1.5-4	153	40
4-8	43	11
8-	8	2
Total	386	100

EC

Region	Borehole			
	No.	Minimum	Maximum	Average
Arusha	38	7.7	903.0	133.7
Manyara	50	17.3	1090.0	145.7
Dodoma	74	16.1	693.0	136.2
Tabora	30	6.8	384.0	122.7
Shinyanga	39	11.9	983.0	166.8
Singida	182	6.1	1190.0	134.9

Unit: mS/m

EC (mS/m)	Borehole	
	No.	%
0-10	7	2
10-50	57	14
50-150	225	54
150-300	98	24
300-1000	17	4
1000-	9	2
Total	413	100

Trilinear diagrams of deep groundwater imply that deep groundwater in IDB is classified into various water quality types, which suggests the existence of a complex groundwater system.

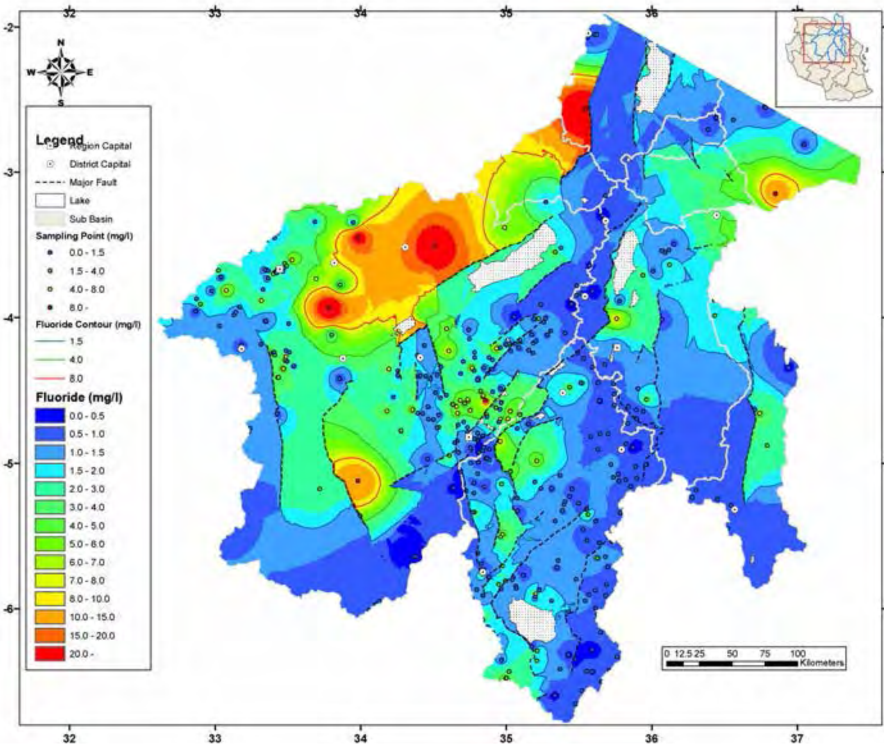

Figure 3-4 Distribution of Fluoride Concentration in the Deep Groundwater in IDB

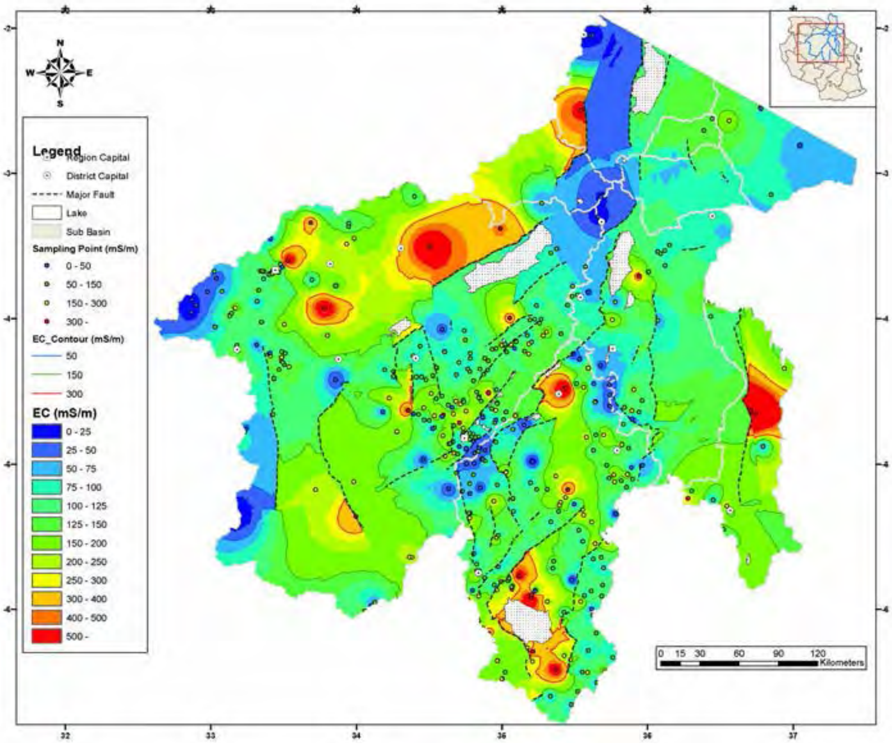

Figure 3-5 Distribution of EC in the Deep Groundwater in IDB

3.4 Relationship between Fluoride and Other Water Quality Items

The results of the analyses with hexa diagrams and above-mentioned trilinear diagrams reveal that some of the fluoride-rich water sources in IDB have a high concentration of alkaline bicarbonate ($NaHCO_3$), whereas others are rich in alkaline non-carbonate (NaCl), in addition to water sources characterized as alkaline bicarbonate ($NaHCO_3$) tend to have a higher fluoride concentration than those characterized as alkaline non-carbonate (NaCl). Gunnar Jacks and others (2005) reported the mechanism that increased fluoride concentration in the alkaline bicarbonate ($NaHCO_3$) type groundwater and explains that high fluoride concentration of groundwater in South India is closely related to the decrease of calcium (Ca) and magnesium (Mg), and an increase of sodium (Na) and bicarbonate (HCO_3^-). Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), such as carbonate minerals, release bicarbonate (HCO_3^-) through weathering. From the relationship among these water quality parameters (calcium (Ca), magnesium (Mg), sodium (Na) and bicarbonate (HCO_3^-)) and fluoride (F^-), it is believed that the enrichment of fluoride (F^-) in the groundwater takes place through the weathering of minerals with high fluoride and the precipitation of carbonate minerals via evapotranspiration, as shown in Figure 3-6.

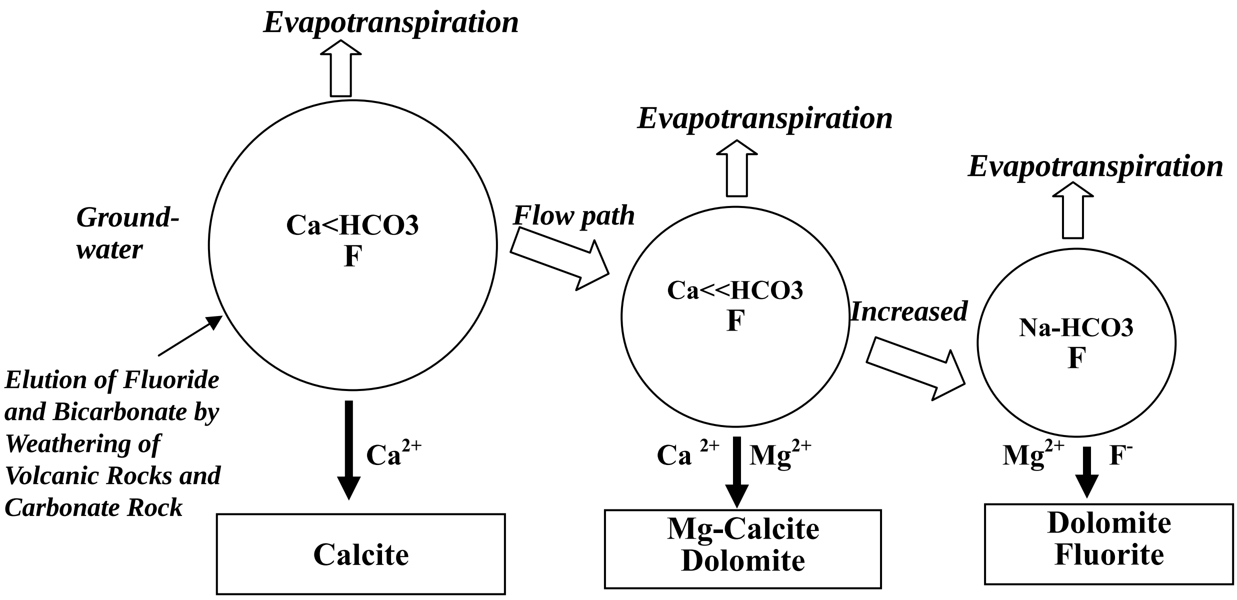

Figure 3-6 Mechanism of Formation of High Fluoride Groundwater in South India

(Source: Gunner Jacks et al (2005) "Controls on the genesis of some high-Fluoride Groundwater in India")

From the above-mentioned results, the infiltration effect of fluoride into groundwater from alkaline lakes or hot springs, as well as elution from the volcanic strata, is considered as a possible supply source of fluoride to the water sources in IDB. Groundwater is more likely to be affected by elution of fluoride from strata in the area where it is retained for an extended period. In addition to the elution, evapotranspiration and exchange reaction with carbonated minerals are considered as possible causes of extremely high fluoride concentrations in the groundwater of IDB.

3.5 Fluorosis and Water-related Diseases

3.5.1 Health Effects of Fluoride

The fluoride contained in drinking water contributes significantly to the daily fluoride intake. Increasing fluoride content in drinking water, up to about 1 mg/L is known to prevent dental caries. Higher concentrations, however, are harmful and cause fluorosis as shown in Table 3-5. Chronic fluoride toxicity induces early decalcification of tendons, ligaments and joint capsules especially in the vertebral column (Teri, 1982 in Mjengera, 1988). The clinical symptoms of skeletal fluorosis are bowlegs and knocked-knees (genu valgum), stiffness of the trunk, impeded movement of the limbs and severe joint contractions, referred to as crippling fluorosis (Nanyaro et al., 1984).

A recent study by Eliuze, (2004) reported cases of fluorosis in different age groups in Maji ya Chai village in Arusha. The study indicated that people aged between 18 and 27 years were the most susceptible to fluorosis, whereas those aged above 57 years were the least affected (Refer to Figure 3-8). Table 3-6 shows occurrence of fluorosis in school children in Maji ya Chai Village in Arusha region expressed in terms of Dean Index.

Table 3-5 Categories of Fluorosis

Fluoride Concentration of Drinking Water (mg/L)	Likely Disease	Symptoms
1.5 – 3	Dental Fluorosis	Objectionable mottling of the teeth
4 – 8	Skeletal Fluorosis	Malformation of the bones; Movement difficulties
> 10	Crippling Fluorosis	Bone functions growing together; Immobility

Source: WHO, 1994

Figure 3-7 Symptoms of Crippling Fluorosis (Eliuza, 2004)

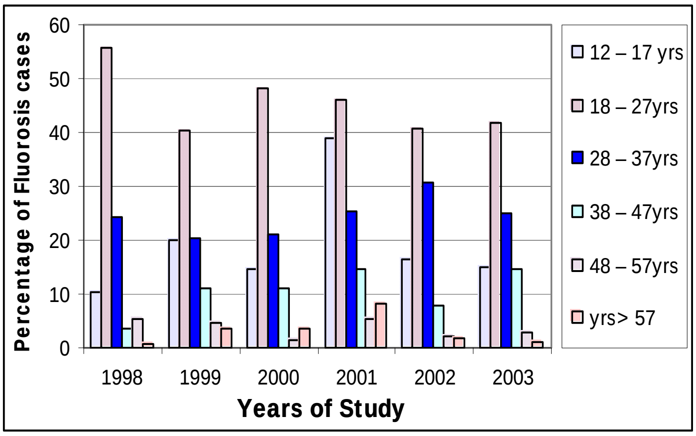

Figure 3-8 Percentage Distribution of Fluorosis Cases among Age Groups in Maji ya Chai Village, Arusha Region (Eliuza, 2004)

Table 3-6 Occurrence of Fluorosis in School Children in Maji ya Chai Ward in Arusha Region

Name of School	Fluoride (mg/L)	Total Number of Pupils	Scores												
			Normal		Trace		Very mild		Mild		Moderate		Severe		Mean CFI*
			0		0.5		1		2		3		4		
			No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
Embaseni	2.8	96	0	0	0	0	0	0	12	13	41	43	43	45	3.32
Ngurdoto	8.5	43	0	0	0	0	0	0	3	7	8	19	32	74	3.67
Kitefu	2.95	120	0	0	9	7.5	15	13	54	45	31	26	11	9.2	2.2
Nkoanekol	1.7	50	0	0	3	6	22	44	25	50	0	0	0	0	1.47

*CFI: Community Fluorosis Index
(Expressed in terms of Dean Index (modified from Eliuze, 2004)

3.5.2 Fluoride Removal Techniques

Removal hereby refers to the total effects of all possible mechanisms that remove or reduce fluoride in treated water. In one word, the removal of fluoride is defluoridation. The technology of defluoridation has been well developed and tested to some extent. Research on the technology, experimental work and application of the techniques for excess fluoride removal has been carried out in various parts of the world.

The trial methods of fluoride removal include many factors that must be considered prior to being accepted as the most appropriate methods to be adopted. Some of these methods are efficient, but they are expensive and complex, which means that they would not be the best choice for a developing country. It is difficult to give exact figures in cost analysis of various methods because of the variable factors governing treatment costs for each project. Below is a comparison of three kinds of treatment methods.

Table 3 -7 Comparison of Treatment Methods

No	Method	Working principle	Fluoride removal range	Treatment cost	Remarks
1	Activated alumina	Adsorption with activated alumina	1000 -9600 g F/m3 of media	About 22.7 kg of activated alumina costs $ 94.5*	Expensive and relatively complex
2	Bone char	Adsorption	Up to 94 %	Relatively low	Problem of removing the colour formed in the treatment process. Availability of bones in large quantities has to be considered.
3	Electrodialysis	Distillation	7.0 mg F/L to 1.4 mg F/L	Expensive depending on the plant size	A complicated process.

3.5.3 Water-related Diseases

While water-related diseases vary substantially in their nature, transmission, effects, and management, adverse health effects related to water may be organized into four categories:

- Water-borne diseases; (e.g. Cholera, Typhoid, Shigellosis, Polio)
- Water-washed (scarce) diseases; (e.g. Trachoma, Skin diseases, Leprosy)
- Water-based diseases; (e.g. Guinea worm, Schistosomiasis, Paragonimiasis)
- Water-related vector diseases; (e.g. Malaria, Yellow fever, Dengue fever, Sleeping sickness)

Present conditions of water-borne diseases in IDB are shown in Figure 3-9. The figure reveals that Shinyanga and Dodoma Regions have a high ration of water-borne disease incidence.

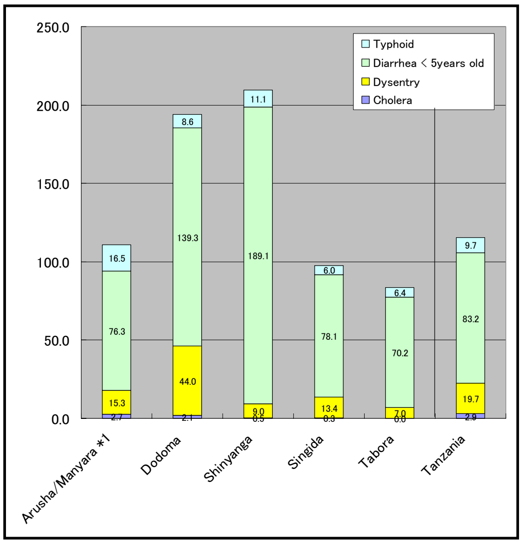

Figure 3-9 Present Conditions of Water-borne Diseases in IDB

(No. of Case / 10,000 people in 2003. Data Source: Ministry of Health)

3.5.4 Dental Fluorosis Survey in IDB

Dental fluorosis survey was conducted to determine the prevalence and severity of fluorosis in IDB. Examinees of the survey were 2,912 adolescents as aged 12 to 18 years who were born and have lived their entire life in the target villages. Each survey participant was examined for dental fluorosis. Target villages for the survey in 18 districts of IDB were chosen based on water fluoride levels higher than 1.5mg/l. From these, 96 villages were randomly selected.

Table 3-8 Thylstrup and Fejerskov Index – Diagnostic Criteria for Dental Fluorosis Scores

Score		Criteria
Sound (Better)		Normal translucency of enamel remains after prolonged air-drying.
Questionable	1	Narrow white lines corresponding to the perikymata.
Very Mild	2	Smooth surfaces: More pronounced lines of opacity that follow the perikymata. Occasionally confluence of adjacent lines. Occlusal surfaces: Scattered areas of opacity < 2 mm in diameter and pronounced opacity of cuspal ridges.
	3	Smooth surfaces: Merging and irregular cloudy areas of opacity. Accentuated drawing of perikymata often visible between opacities. Occlusal surfaces: Confluent areas of marked opacity. Worn areas appear almost normal but usually circumscribed by a rim of opaque enamel.
Moderate	4	Smooth surfaces: The entire surface exhibits marked opacity or appears chalky white. Parts of surface exposed to attrition appear less affected. Occlusal surfaces: Entire surface exhibits marked opacity. Attrition is often pronounced shortly after eruption.
Severe	5	Smooth surfaces and occlusal surfaces: Entire surface displays marked opacity with focal loss of outermost enamel (pits) < 2 mm in diameter.
	6	Smooth surfaces: Pits are regularly arranged in horizontal bands < 2 mm in vertical extension.Occlusal surfaces: Confluent areas < 3 mm in diameter exhibits loss of enamel. Marked attrition.
	7	Smooth surfaces: Loss of outermost enamel in irregular areas involving < ½ of entire surface. Occlusal surfaces: Changes in the morphology caused by merging pits and marked attrition.
	8	Smooth surfaces and occlusal surfaces: Loss of outermost enamel involving > ½ of surface.
(Worse)	9	Smooth surfaces and occlusal surfaces: Loss of main part of enamel with change in anatomic appearance of surface. Cervical rim of almost unaffected enamel is often noted.

urce: Thylstrup and Fejerskov, 1978. As reproduced in "Health Effects of Ingested Fluoride". National Academy of Sciences, 1993; pp. 171

(1) Survey Result

The prevalence of dental fluorosis was 96.3%, with the majority of examinees' teeth scoring between TFI 3 and TFI 7. Exploration of the data further revealed that 85.4 % of the examinees had at least one tooth with a TFI score of greater than or equal to TFI 4, as shown in Figure 3-10. Table 3-9 shows the overall mean of TFI for the six regions together is 3.4. The mean TFI score did not vary by age or sex. Arusha had the highest mean TFI score (4.3) followed by Shinyanga (3.5), Singida (3.4), Manyara (3.3), Tabora (2.8) and Dodoma (1.8). On the other hand, the mean TFI of each district is shown in Figure 3-26. Arumeru district had the highest TFI score (4.8) followed by Manyoni (4.2), and Meatu (4.1). Minimum levels were recorded in Singida district- urban (1.4) and Kondoa (1.5). TFI score analysis by village revealed that Kolandoto village in Shinyanga had the highest mean TFI score of 5.2, followed by Olkungwado village in Arusha with a score of 4.9, and Lemong'o (4.8). The lowest mean TFI score (0.4) was recorded at Iyumbu village in Singida region.

Table 3-9 Mean TFI of each Region

Region	No. of Children	Average TFI
Arusha	150	**4.3**
Dodoma	91	**1.8**
Manyara	330	**3.3**
Shinyanga	1,245	**3.5**
Singida	941	**3.4**
Tabora	155	**2.8**
Total	2,912	**3.4**

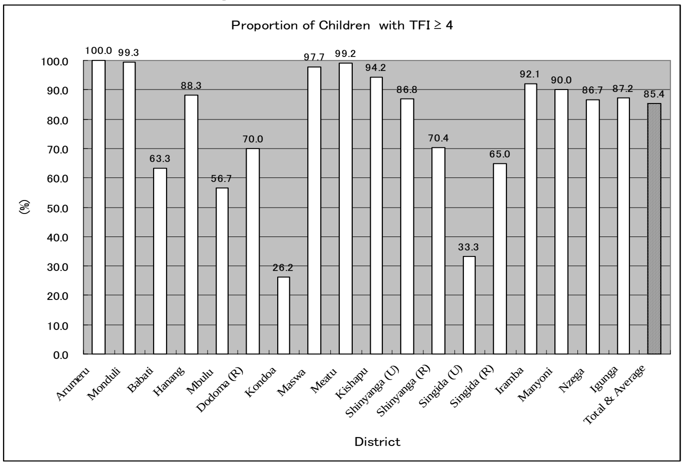

Figure 3-10 Proportion of Children with TFI ≥4

(2) Relationship between Fluoride of Water and Fluorosis

Figure 3-12 shows the relationship between TFI of each village and fluoride levels in water. The fluoride level is based on the results of the water quality survey conducted by the Study Team in the dry season of 2006. Although there are several unexpected data items in the figure, it implies a relationship somewhat between them. However, conducting accurate statistical analysis using "Pearson Correlation" indicated a non-significant association between them.

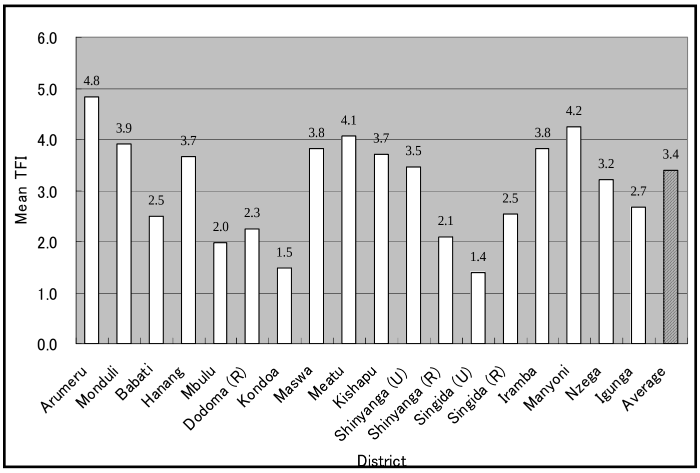

Figure 3-11 Mean TFI by District

The reason why there was not a clear correlation shown is due to the complexity of individual fluoride impact from drinking water and Magadi. The villagers are strongly affected by their living activities throughout the year. Furthermore, water sources where the water quality survey was conducted and the water sources used by the examinees did not always match. Table 3-10 shows the fluoride content in Magadi samples taken from the target villages. The variable content by region and Magadi sample is too great, so fluoride impact caused by ingestion of Magadi is extremely complicated. Distribution of mean TFI by survey village is illustrated as shown in Figure 3-13..

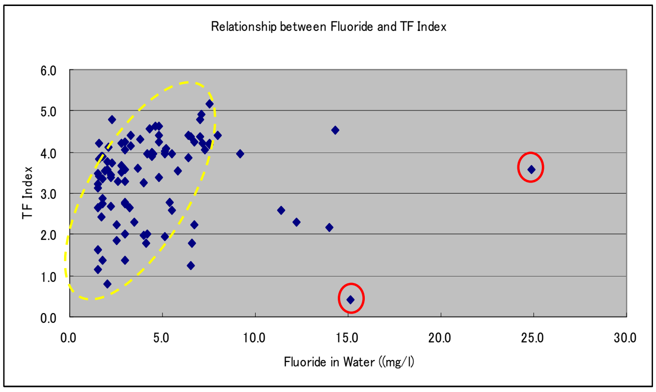

Figure 3-12 Relationship between Fluoride of Water and TFI

Table 3- 10 Fluoride Content of Magadi

Region	No. of Sample	Mean F (mg/kg)	Range of F (mg/kg)	
			Min.	Max.
Arusha	4	12,660	1,138	23,000
Dodoma	3	2,025	44	5,978
Manyara	7	222	4	1,199
Shinyanga	39	2,648	4	12,074
Singida	32	3,636	3	31,000
Tabora	5	3,455	46	11,000
Total	**90**	**3,455**	**3**	**31,000**

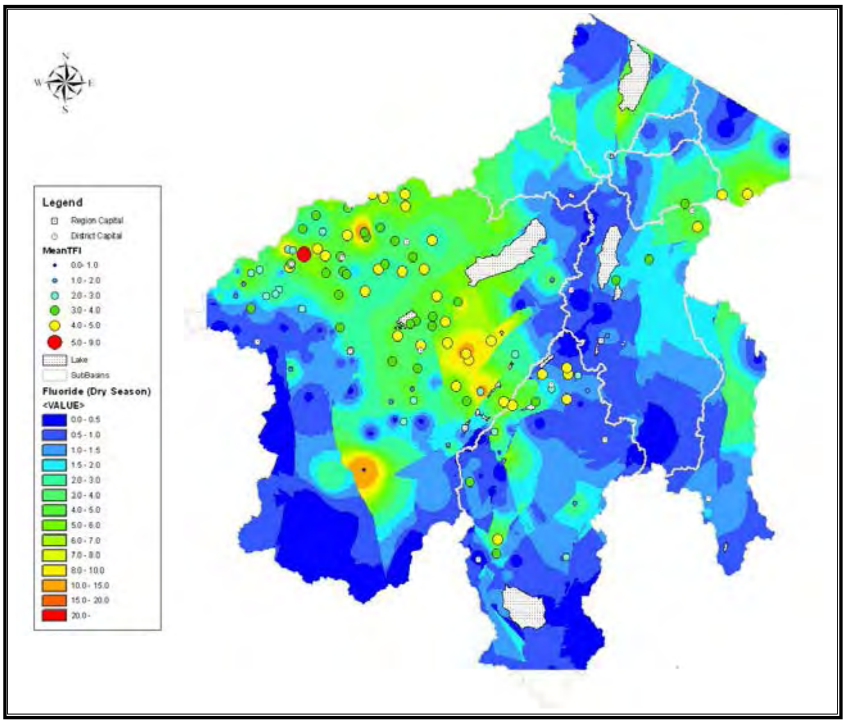

Figure 3-13 Distribution of Mean TFI by Survey Village and Fluoride Concentration of Water in Dry Season of 2006

3.5.5 Countermeasure against Fluorosis

Fluorosis in IDB was confirmed by the dental fluorosis survey of the Study. Although there are several ways to remove fluoride technically from water, but its applicability was concluded to be very difficult to IDB, particularly into the rural areas, from the socio-economical point of view. However, awareness campaigns of fluoride problems, guidance of better water sources and restriction of Magadi are possible to be conducted as an interim measure in terms of impact or risk management before full-scale countermeasure against fluorosis.

Chapter 4
Hydrogeology

CHAPTER 4 HYDROGEOLOGY

Hydrogeological conditions in IDB were investigated by analyzing the survey results from existing data survey, inventory survey of existing water supply facilities, remote sensing survey, geophysical survey and test borehole drilling survey.

4.1 Existing Data Survey

4.1.1 Borehole Database

The borehole database was established by the Study Team based on the MoW borehole catalogue adding and correcting with other borehole information. The items of the database are listed in Table 4-1. MoW Borehole Catalogue, which was assembled borehole data in the survey area uniformly, was used as basic data to understand the hydrogeological structure in IDB.

4.1.2 Water Supply Facilities Data

Water supply service coverage is shown in Figure 4-1. The coverage ratio is defined with the ratio of households with access to improved water source within all water sources. The figure shows that the water supply ratio is very low in Sikonge and Igunga in Tabora region but highest in Arumeru in Arusha region.

Database of water supply facilities was developed to grasp the usage condition of water resources. JICA Expert for MoW (2005 – 2006), requested all District Water Engineers to fill out a datasheet about water supply facilities in 2005. The Study Team collected the data from each District Water Engineer regarding to IDB and assembled the database for hydrogeological analysis.

Table 4-1 Items of Borehole Database

No.	Items	Type
1	Serial Number	Number
2	Region	String
3	District	String
4	Division	String
5	Ward	String
6	Village	String
7	Longitude (E)	Number
8	Latitude (S)	Number
9	Sub-village	String
10	Borehole Number	String
11	Year	Number
12	Location Village	String
13	Depth (m)	Number
14	Static Water Level	Number
15	Water Struck (m)	String
16	Yield (m^3/h)	Number
17	Drawdown (m)	Number
18	Nature of Aquifer	String
19	Quality Standard	String
20	Remarks	String

According to the database, the ratio of water resource type in each region is shown in Figure 4-2. Since Dam, Charco Dam and Gravity scheme (river or spring) must be using surface water, Arusha region mainly use surface water, but other regions are highly depending on groundwater.

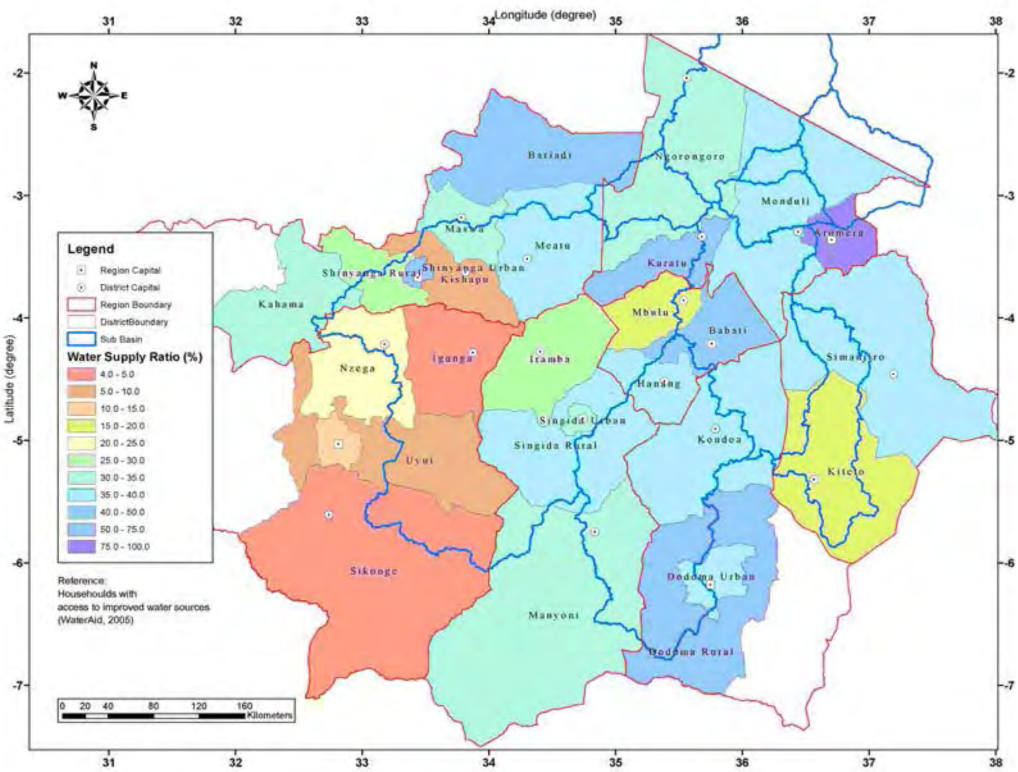

Figure 4-1 Rural Water Supply Ratio by District in IDB

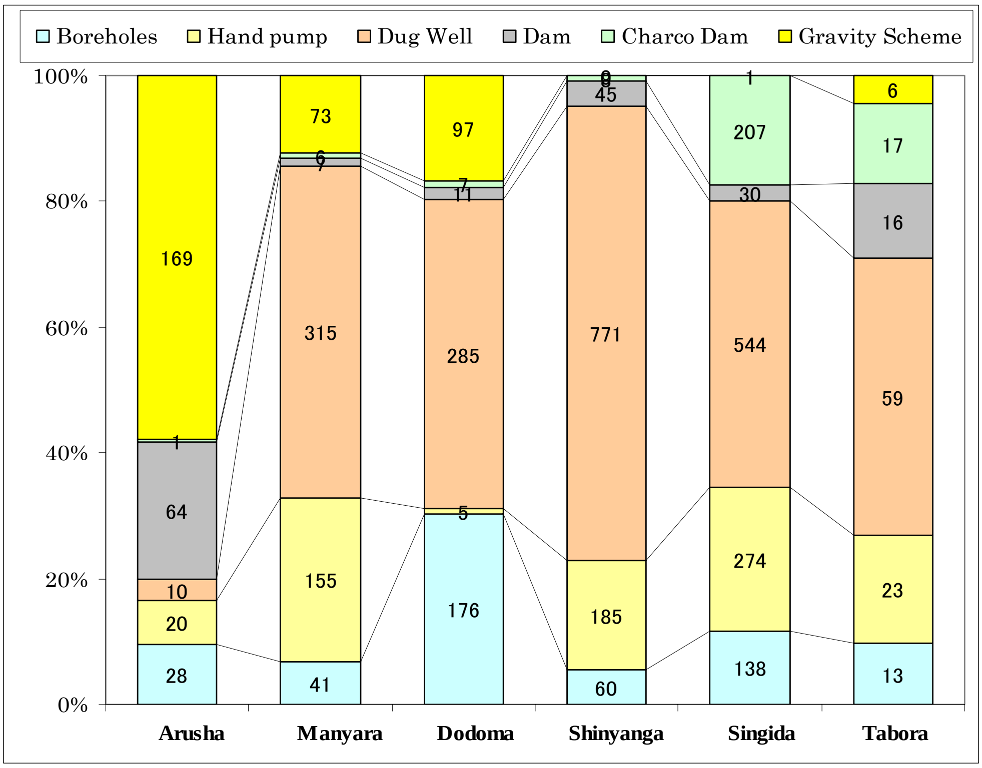

Figure 4-2 Water Source Type of Each Region

4.2 Hydrogeological Investigation

4.2.1 Inventory Survey of Existing Water Supply Facilities

Inventory survey of existing water supply facilities was conducted at 500 villages in IDB which were selected for the survey from the borehole catalogue, because the result of the inventory survey was to be applied to the analysis of the hydrogeological conditions in IDB.

(1) Drilling Depth Distribution

Drilling depth distribution of existing borehole is shown in Figure 4-3. Although each borehole has different conditions, this distribution indicates the actual depth of aquifer in IDB. The drilling depth is shallower in the western part and central part than the south-eastern and the north-eastern part of IDB.

(2) Static Water Level Distribution

Static water level distribution of existing boreholes is shown in Figure 4-4. This distribution is including the results of test borehole drilling survey in this study. The figure indicates that the static water level in the south-eastern part of IDB is deeper than the north-western part of it.

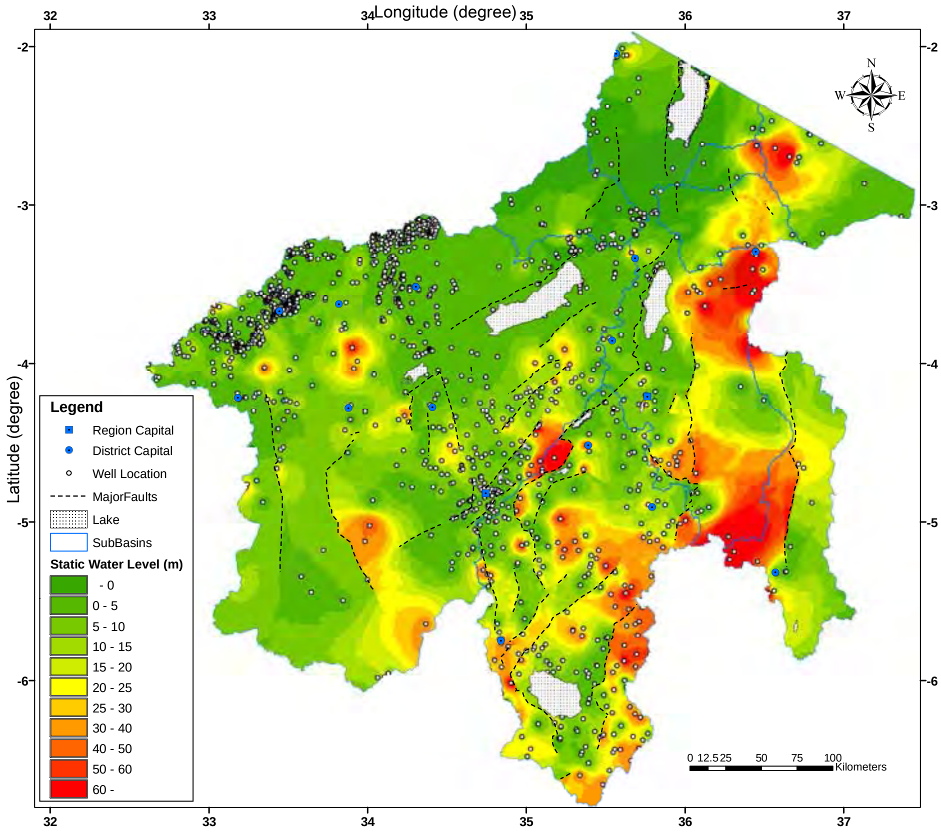

Figure 4-3 Distribution of Drilling Depth

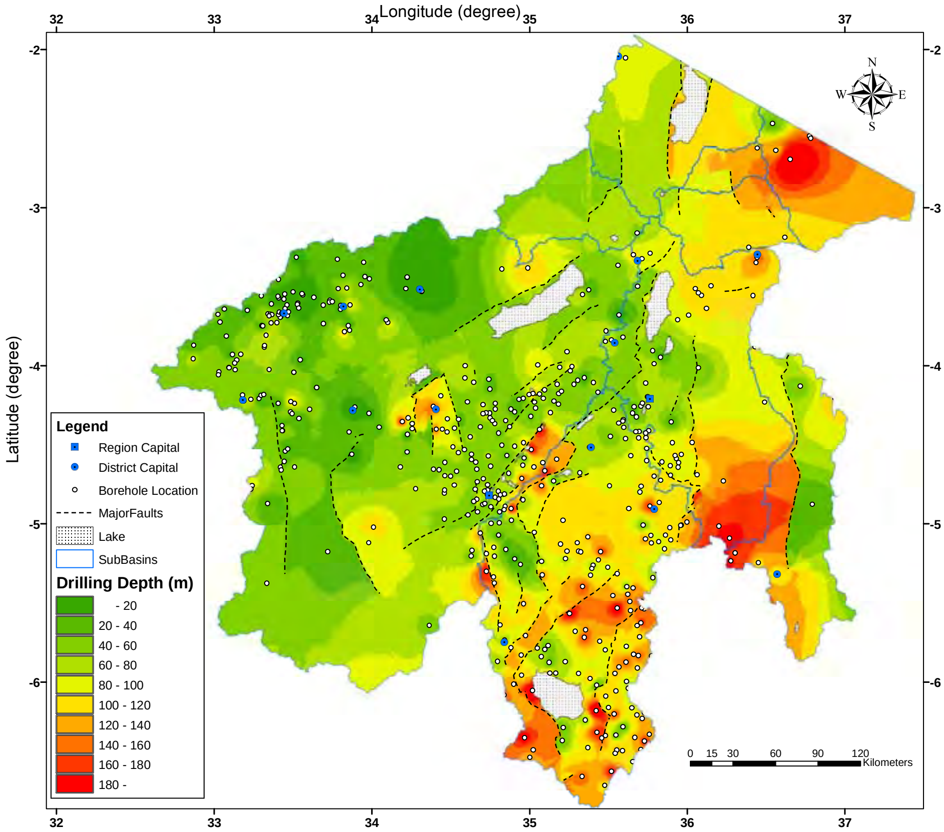

Figure 4-4 Distribution of Static Water Level

4.2.2 Remote Sensing Survey

Thirteen scenes of LANDSAT ETM data were analyzed for this survey to grasp the geo-morphological characteristics in IDB. SAVI image and VSW image are shown in Figure 4-5 and Figure 4-6.

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 south-western 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 all large lakes and swamps in magenta colour suggest mixed spectra of soil and water because of shallow water depth. Figure 4-7 shows land cover map that was produced by VSW image and SAVI image.

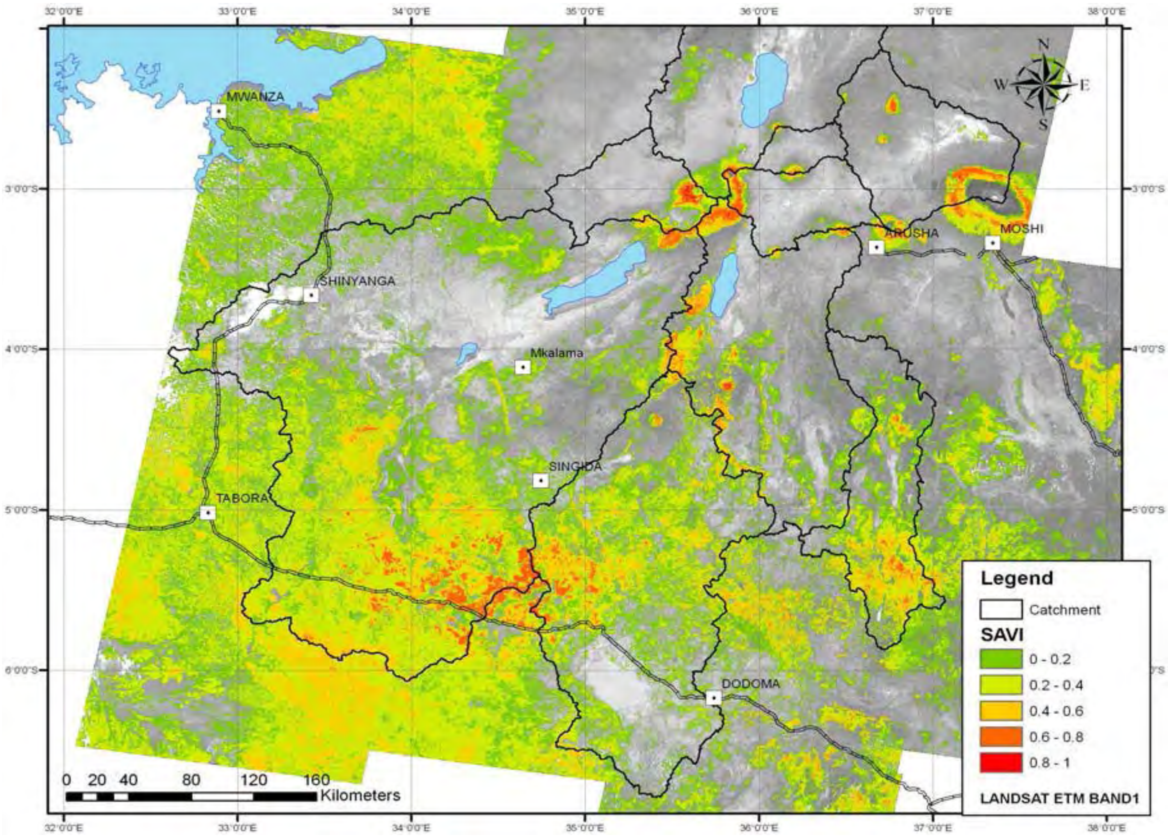

Figure 4-5 SAVI (Soil Adjusted Vegetation Index) Image

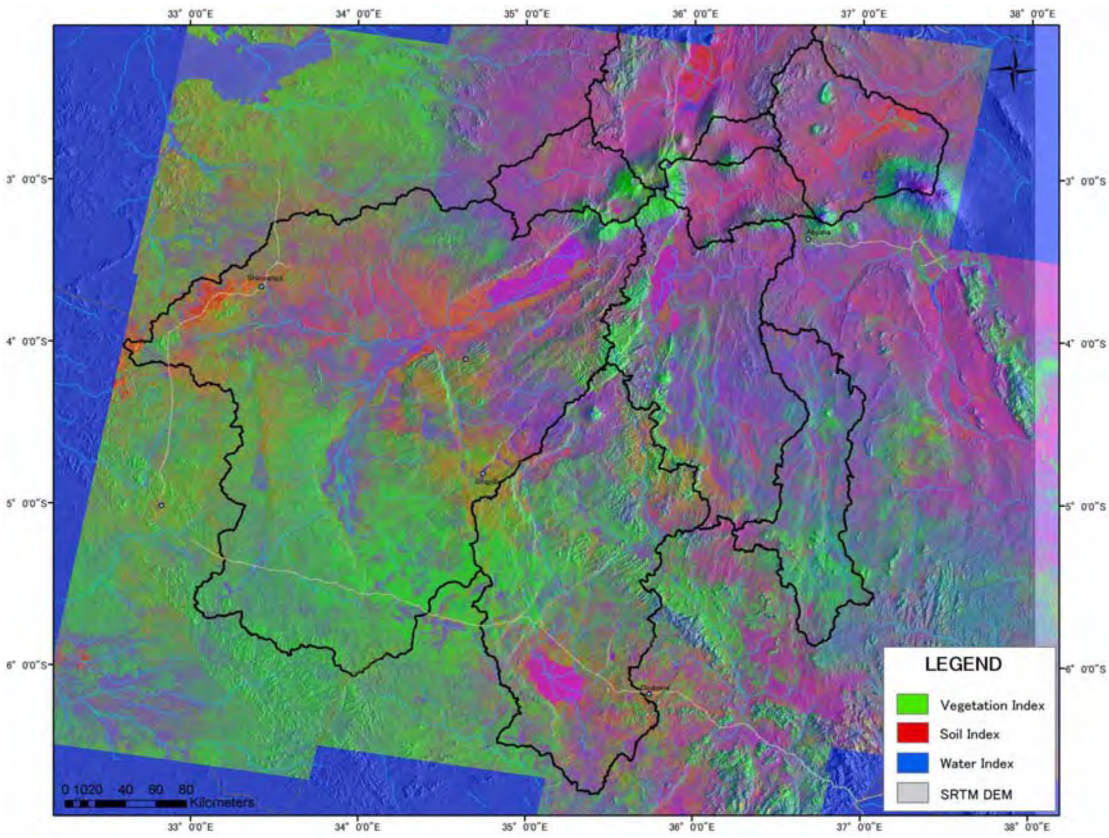

Figure 4-6 VSW Image (V; Vegetation, S; Soil, W; Water and Moisture) of IDB

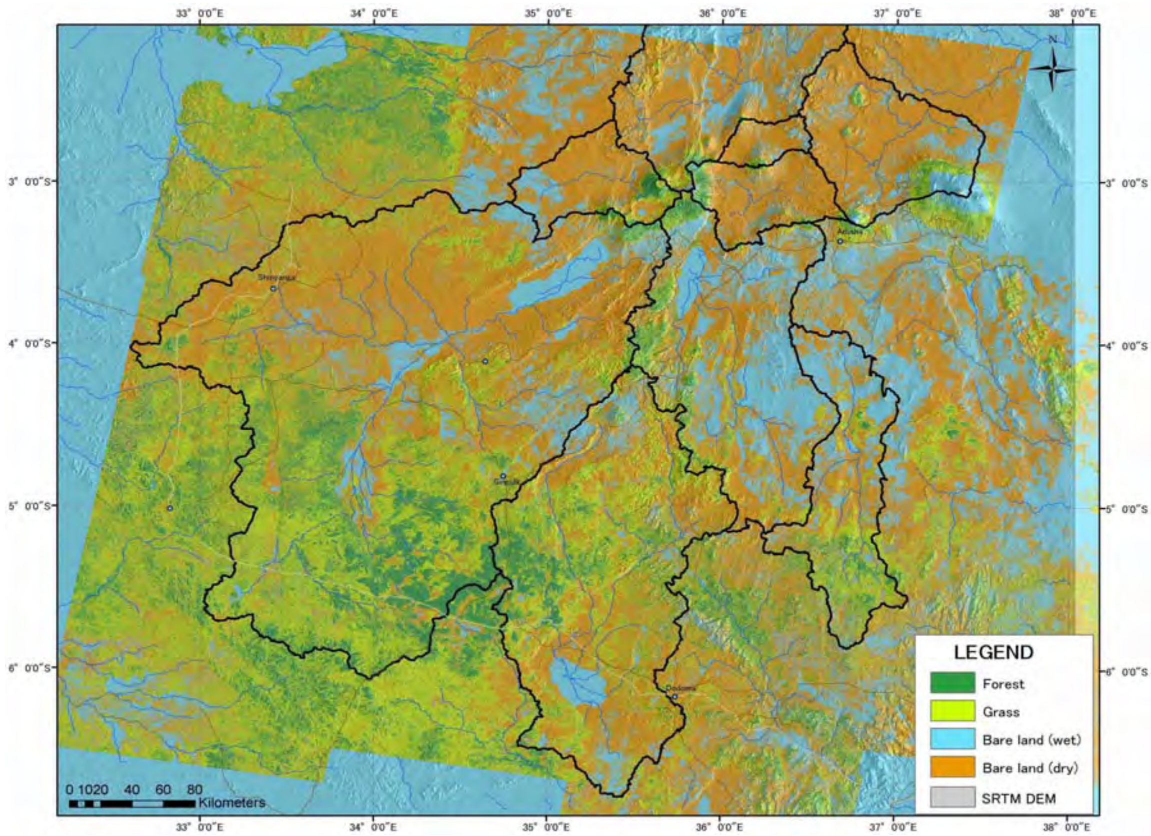

Figure 4-7 Land Cover Classification of IDB

4.2.3 Geophysical Survey

Geophysical survey was conducted at more than two hundred points in IDB. The purpose of the survey is shown as follows:

- ✓ To figure out the general geological structure of the whole IDB
- ✓ To clarify the aquifer structure around the survey points.
- ✓ To determine the test borehole drilling sites

(1) Bedrock Depth

A distribution of the bedrock depth based on the survey results is shown in Figure 4-8. The feature of the distribution is described in Table4-2. These are also well-corresponding to the geological distribution.

Table 4-2 Feature of Bedrock Depth Distribution

Very Shallow Area	Very Deep Area
Shinyanga, Meatu, Maswa,	Manonga and Wembere river area
Uyui, Manyoni, Singida	Magugu (Babati district)
Kondoa, Mbulu and Kiteto	Ndedo and Makame (Kiteto district)

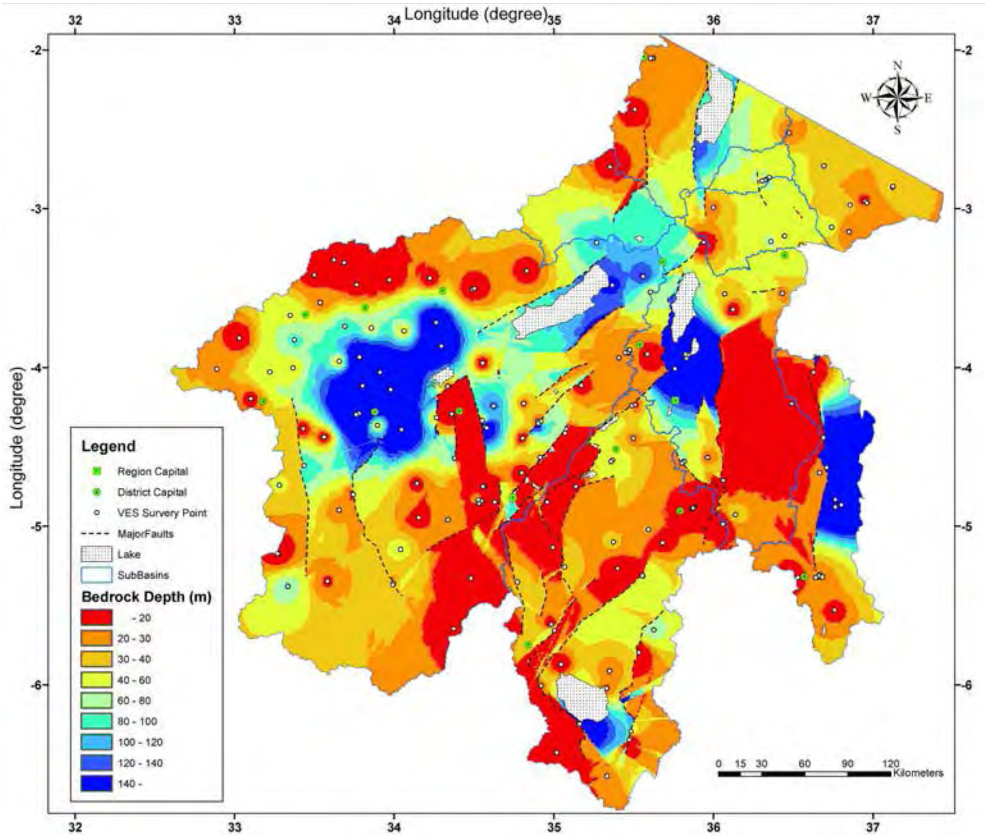

Figure 4-8 Distribution of Bedrock Depth based on Geophysical Survey

(2) Test Borehole Drilling Sites

Three types of geophysical survey were adopted to determine the test borehole drilling sites. The Vertical Electrical Sounding (VES) was carried out to figure out the outline of geological structure in the candidate area of the boreholes. In the case of layered aquifer, two-dimensional resistivity survey or magnetic survey was carried out on appropriate line in the area. Finally, the test drilling sites were determined as shown in Figure 4-9 based on geophysical survey results including accessibility and topographic feature.

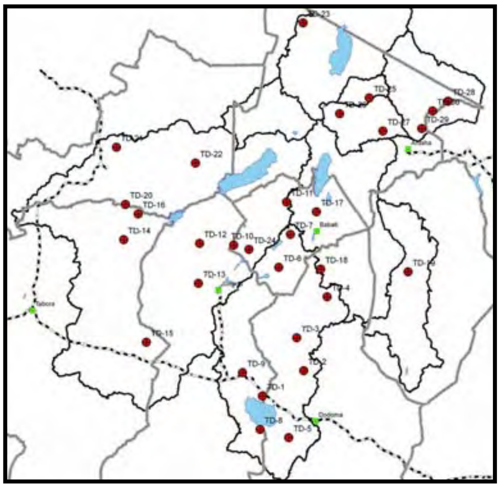

Figure 4-9 Test Borehole Drilling Sites

4.2.4 Test Borehole Drilling Survey

This survey was carried out to obtain fundamental data of geological and hydrogeological conditions. The data contributed to establish hydrogeological map and evaluate groundwater potential in IDB.

Furthermore, the test boreholes will be utilized as groundwater monitoring borehole. The results of the survey are shown in Table 4-3 and schematic diagram of test borehole is presented in Figure 4-10.

Table 4-3 Results of Test Borehole Drilling Survey

Boring No.	National BH No.	Region	District	Village	Drilling Depth (GL- m)	Well Depth (GL- m)	Presumed Target Aquifer	Aquifer: Nature of Aquifer	Aquifer: Depth (GL- m)	Aquifer: Hydraulic Conductivity (m/min)	Aquifer: Transmissivity (m^2/min)	Aquifer: Storativity	Water level (m)	Critical Yield (m^3/hour)	Water Condition: Electrical Conductivity (mS/m)	Water Condition: Fluorid (mg/l)
TD-1	654/2006	Singida	Manyoni	Lusilile	100	40	Sediments	Fractured granite	16.4-22.3, 28.2-37.05	—	—	—	12.05	—	1,190.0	0.555
TD-2	640/2006	Dodoma	Dodoma Rura	Kongogo	105	100	Weathered/ Fractured rock	Fractured granite	57.5	4.16E-04	1.59E-02	8.29E-01	29.39	22.0	90.1	1.590
TD-3	636/2006	Dodoma	Kondoa	Bubutole	80	80	Weathered rock	Fractured granite	44, 65	7.02E-05	9.16E-04	1.64E-01	28.3	3.6	158.2	1.187
TD-4	381/2006	Dodoma	Kondoa	Loo	100	100	Fractured rock	Fractured gneiss	47.5-55, 75	1.13E-04	3.39E-03	9.48E-01	6.47	6.0	106.3	0.049
TD-5	638/2006	Dodoma	Dodoma Rura	Nholi	105	103	Fractured rock	Weathered/ Fractured gneiss	80-90	5.11E-04	1.53E-02	6.75E-01	14.51	15.0	163.3	0.330
TD-6	366/2006	Manyana	Hanang	Numbeta	120	74	Weathered volcanic rock	—	—	—	—	—	N/W.L.	—	—	—
TD-7	371/2006	Manyara	Babati	Bermi/Seloto	80	78	Fault	Weathered/ Fractured gneiss	42-45, 58-74	5.99E-03	1.76E-01	2.11E-03	31.2	33.1	17.3	0.560
TD-8	637/2006	Singida	Manyoni	Ikasi	120	120	Fault	Weathered/ Fractured granite	42-48, 70-76, 95-100	1.42E-05	1.10E-03	4.39E-02	30.9	15.0	261.0	0.273
TD-9	162/2006	Singida	Manyoni	Ilalo	135	135	Fractured rock	—	—	—	—	—	N/W.L.	—	—	—
TD-10	372/2006	Manyara	Hanang	Hirbadaw	147.5	147.5	Fracture zone	Fractured granite	115-130	3.57E-06	8.54E-05	1.99E-01	31.75	1.0	82.4	0.354
TD-11	370/2006	Manyara	Mbulu	Tlawi	101	100	Fracture zone	Fractured schist	63-86	3.35E-05	7.91E-04	2.85E-01	11.2	5.6	79.7	0.180
TD-12	651/2006	Singida	Iramba	Misingi	100	100	Fractured/ weathered rock or sediments	Fractured granite	44-92	2.15E-03	6.36E-02	7.64E-01	7.0	20.4	84.8	4.650
TD-13	642/2006	Singida	Singida	Sepuka	45	42	Weathered rock	Fractured granite	40	9.90E-05	5.84E-04	2.34E-02	3.2	1.6	136.6	3.138
TD-14	161/2006	Tabora	Igunga	Igogo	100	100	Weathered rock	—	—	—	—	—	N/W.L.	—	—	—
TD-15	650/2006	Tabora	Uyui	Nkongwa	60	60	Sediment or weathered rock	Weathered/ Fractured granite	30-37, 47-58	1.81E-04	4.27E-03	1.88E+00	7.7	4.7	384.0	1.270
TD-16	644/2006	Tabora	Igunga	Kininginila	80	80	Sediments	Calcareous Clay	62-68	—	—	—	40.5	—	1,600.0	—
TD-17	652/2006	Manyara	Babati	Mapea	80	80	Sediments	Clayey sand/ Weathered gneiss	27, 40, 72	7.61E-05	2.68E-03	2.20E-01	8.38	4.7	195.1	7.910
TD-18	385/2006	Dodoma	Kondoa	Masange	70	69	Fractured rock	—	—	—	—	—	68.9	—	—	—
TD-19	635/2006	Manyara	Kiteto	Makeme	75	72	Fractured rock	Fractured gneiss	44-50, 68	9.87E-04	2.71E-02	6.29E-01	35.5	16.0	1090.0	0.991
TD-20	653/2007	Shinyanga	Kishapu	Ngofila	75	75	Sediments	Sand	50	3.20E-05	9.61E-04	9.61E-03	4.33	0.8	687.0	34.950
TD-21	522/2007	Shinyanga	Maswa	Mwasayi	70	70	Fractured or weathered rock	Weathered/ Fractured granite	35	6.67E-06	3.14E-04	8.20E-02	4.3	2.4	414.0	1.410
TD-22	523/2007	Shinyanga	Meatu	Mwangudo	100	62	Fractured or weathered rock	—	—	—	—	—	N/W.L.	—	685.0	26.500
TD-23	526/2007	Arusha	Ngorongoro	Loliondo	100	75	Fractured or weathered rock	Sediment	65, 70, 80, 85	1.36E-03	4.52E-05	2.50E-03	13.09	4.0		
TD-24	527/2007	Manyara	Hanang	Bassotu	100	100	Fractured rock	Fractured schist	52, 60, 70	—	—	—	—	—	—	—
TD-25	520/2007	Arusha	Longido	Orkejuloongishu	50	45	Fault	—	—	—	—	—	N/W.L.	—	—	—
TD-26	518/2007	Arusha	Monduli	Engaruka Chini	130	115	Sediment	—	—	—	—	—	N/W.L.	—	—	—
TD-27	519/2007	Arusha	Monduli	Mfereji	100	98	Fractured or weathered rock	—	—	—	—	—	N/W.L.	—	—	—
TD-28	524/2007	Arusha	Longido	Olmolog	100	90	Fractured or weathered rock	—	—	—	—	—	N/W.L.	—	—	—
TD-29	521/2007	Arusha	Arumeru	Uwiro	105	100	Fractured rock	Weathered/Fractured basalt, agglomerate	30, 45, 60	3.17E-05	2.15E-03	1.12E-01	25.5	8.6	95.3	15.390
TD-30	525/2007	Arusha	Longido	Tingatinga	130	129	Sediment	—	—	—	—	—	N/W.L.	—	—	—

4.3 Groundwater Flow

Groundwater flow direction can be presumed by tracing altitude of static water level. Figure 4-11 shows the groundwater flow map which shows horizontal direction of the flow. The data of the altitude was collected from the existing borehole data, spring data and test borehole drilling data in this project. The length of the arrows in the figure does not mean their flow rate.

Groundwater flow velocity also can be estimated by the altitude of static water level. The velocity is calculated by Darcy’s law as follows.

$$V=K(dH/dL),$$

where, V is the velocity (m/min), K is the hydraulic conductivity (m/min), H is the piezometric head, and L is the distance between two points which the piezometric heads are measured. (dH/dL) is called the hydraulic gradient. Table 4-4 shows the results of groundwater flow velocity.

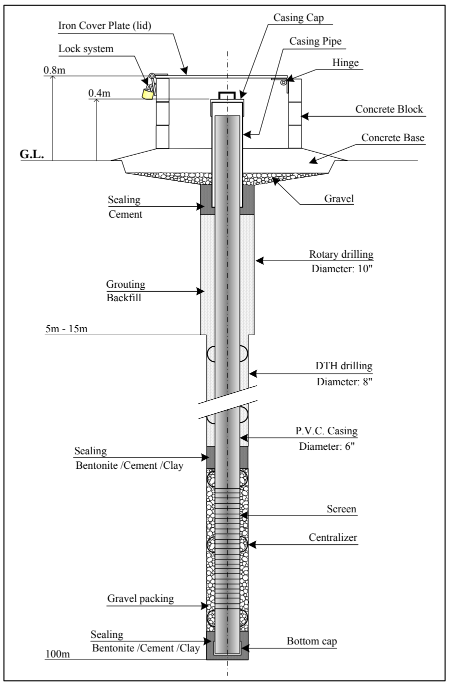

Figure 4-10 Schematic Diagram of Test Borehole

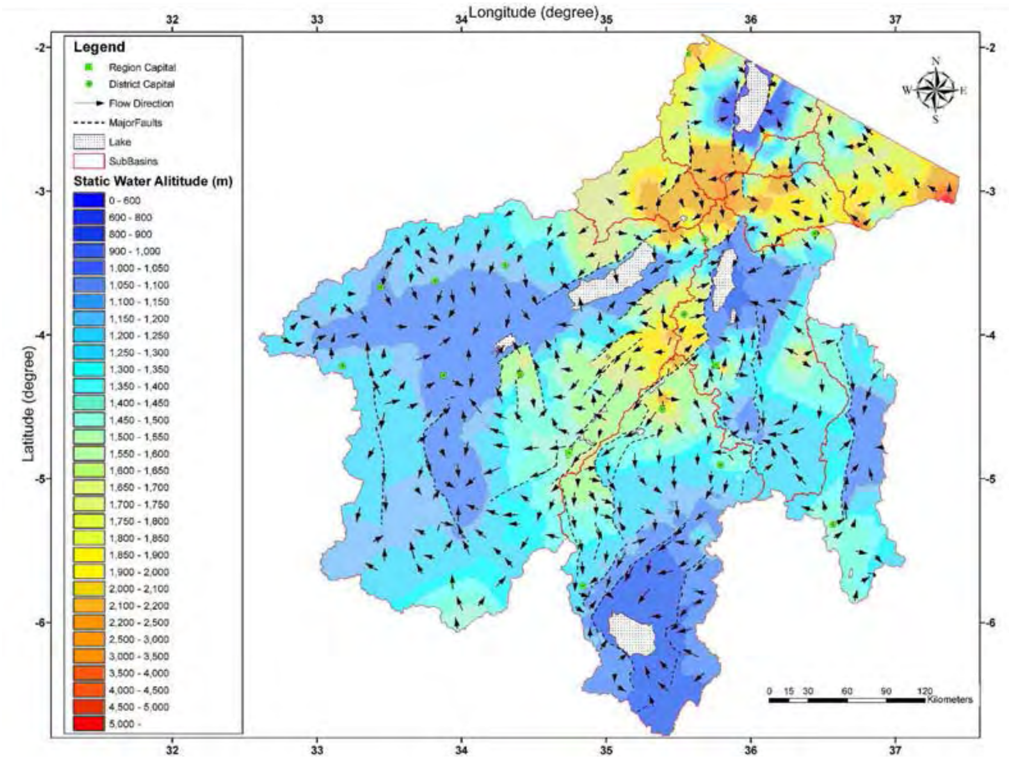

Figure 4-11 Groundwater Flow Direction Map

Table 4-4 Groundwater Flow Velocity around Test Borehole Drilling Sites

Borehole No.	Nature of Aquifer	Hydraulic Conductivity (m/min)	Distance between Contour (m)	Contour Interval (m)	Velocity (m/year)	Remark
TD-2	Fractured granite	4.16E-04	20,399	100	**1.07**	–
TD-3	Fractured granite	7.02E-05	14,439	100	**0.26**	–
TD-4	Fractured gneiss	1.13E-04	8,345	100	**0.71**	–
TD-5	Weathered / fractured granite	5.11E-04	14,484	100	**1.85**	–
TD-7	Weathered / fractured granite	5.99E-03	8,193	100	**38.43**	Fault area
TD-8	Weathered / fractured granite	1.42E-05	691	100	**1.08**	Fault area
TD-10	Fractured granite	3.57E-06	6,005	100	**0.03**	–
TD-11	Fractured schist	3.35E-05	7,108	100	**0.25**	–
TD-12	Fractured granite	2.15E-03	4,426	100	**25.53**	Fault area
TD-13	Fractured granite	9.90E-05	26,945	100	**0.19**	–
TD-15	Weathered / fractured granite	1.81E-04	16,653	100	**0.57**	–
TD-17	Clayey sand, Weathered gneiss	7.61E-05	1,841	100	**2.17**	–
TD-19	Fractured gneiss	9.87E-04	370	100	**140.4**	Sediment area
TD-20	Sand	3.20E-05	24,072	100	**0.07**	–
TD-21	Weathered / fractured granite	6.67E-06	25,110	100	**0.01**	–
TD-29	Weathered / fractured basalt, agglomerate	3.17E-05	1,891	100	**0.88**	–

4.4 Productivity Analysis and Hydrogeological Map

Productivity of groundwater was analyzed by taking consideration of the geological condition, yield of existing wells, rainfall, topographic feature and the result of satellite image analysis in order to formulate the hydrogeological map of IDB. The result of productivity analysis is summarized in Table 4-6.

Hydrogeological Map of IDB was completed adding the geological distribution, water quality and water level to the productivity distribution as shown in Figure 4-12. Steep slope areas, which are cliff of fault and top of mountain area, are shown as impossible area for development of groundwater. Groundwater potential by district is roughly evaluated based on the hydrogeological map. Score of the evaluation is divided into three. The criteria are shown in Table 4-5. The result is shown in Table 4-7. According to this result, Karatu district and Babati district have high potential for groundwater development. Detailed potential evaluation is discussed in chapter 5.

Table 4-5 Criteria of the Evaluation of Groundwater Potential

Score / Item	Good (○)	Fair (△)	Poor (×)
Drilling Depth (m)	less than 80	80 - 150	over 150
Static Water Level (m)	less than 20	20 - 40	over 40
Productivity (m^3/h)	over 10	2 - 10	less than 2
EC (mS/m)	less than 100	100 - 300	over 300
Fluoride (mg/l)	less than 1.5	1.5 - 4.0	over 4.0

Table 4-6 Groundwater Productivity Condition in IDB

Evaluation	Estimated Productivity (m^3/h)	Place	Description
Excellent	over 20	Along large scale fault	Fracture zone related to the Great Rift Valley System
Very Good	10 - 20	The belt area from west of Mbulu district through east of Hanang disrtrict and west of Babati district to Kondoa district	Boundary area between granitic rock area and Usagaran metamorphic rock area.
		Foot of volcanoes	Much amount of recharge is expected from mountains.
		South of Loliondo	Much rainfall in Usagaran metamorphic rock area
Good	8 - 15	The west of Shinyanga town, around Maswa town, north of Tinde village, south of Igunga district, west of Singida rural district, northwest of Dodoma town, around Loliondo town. Uyui and Sikonge district	The place which has many fault or lineament and inselberg in granitic rock area
		Karatu district	Much amount of recharge is expected from Ngorongoro mountain.
		Around Loliondo	Much rainfall in Usagaran metamorphic rock area
Fair A	5 - 10	Kishapu district, Igunga district, the north of Igunga district	Most of granitic rock area
		Around Kiteto town, Mbulu district	Hilly area of Usagaran metamorphic rock
		Around Lake Manyara,	Lake Manyara sediment has groundwater recharge from surounding mountain.
Fair B	3 - 7	Between Maswa and Kishapu districs	Plateau of granitic area has low recharge of groundwater.
		Bahi lowland area	Clayey sand
		southern part of Monduli district and the northeast of Babati	Usagaran metamorphic rock (Xs-a)
Fair C	2 - 4	Eastern part of Meatu district	Fresh granitic rock is distributed
		Lowland surrounding Manonga river, Lake kitangiri, Lake Eyasi, and Wembere swamp	Clayey sediment
		Masai Steppe	Less rainfall
Poor	1 - 3	Shinyanga Rural district	Less recharge of groundwater
		Oldubai to Lake Natron	Less recharge of groundwater
		West of Longido	Volcanic ash
Very Poor	0.5 - 1.5	West of Uyui district, east of Meatu town	Less fracture of granitic rock
		Lowland surrounding Kitumbeine mountain	High evaporation

Table 4-7 Outline of Groundwater Development Potential by District

Region	District	Drilling Depth	SWL	Productivity	Salinity	Fluoride	Other Information
Arusha	Monduli	×	×	×	△	△	Northern part: relativeru good Southern part Poor
	Arumeru	×	×	○	△	×	High fluoride contents
	Ngorongoro	△	○	△	△	△	Nothern highland and Southern part are good Eastern and western lowlands are poor
	Karatu	○	○	○	○	○	–
Manyara	Babati	○	○	○	○	○	Highland is good, Magugu area has saline groundwater
	Mbulu	○	△	△	○	○	–
	Hanang	×	×	△	△	×	Around Mt. Hanang: high fluoride, Basotu lowland has saline water
	Kiteto	×	×	×	×	△	Ndedo, Makame lowland has saline groundwater
	Simanjiro	×	△	×	×	△	–
Dodoma	Dodoma	×	△	○	△	○	Bahi lowland has saliine groundwater
	Kondoa	×	△	○	○	○	–
Singida	Singida	△	0	△	△	×	High productivity area along faults
	Manyoni	△	△	△	○	○	–
	Iramba	△	○	△	△	×	Locally high salinity groundwater
Shinaynga	Shinynga	○	○	△	×	×	Locally high Fluoride contents, West sided of Shinyanga town has high productivity
	Maswa	○	○	△	×	×	Around Maswa town has high productivity
	Meatu	○	○	△	×	×	High fluoride and salinity area
	Kishapu	○	○	△	×	×	High fluoride and salinity area
Tabora	Igunga	○	△	△	△	△	Locally high fluoride contents, Lowland area has saline groundwater
	Nzega	○	○	△	△	○	–
	Uyui	○	△	△	○	○	Locally high saline groundwater andhigh fluoride contents near Wembere swamp
	Sikonge	○	△	△	○	○	–

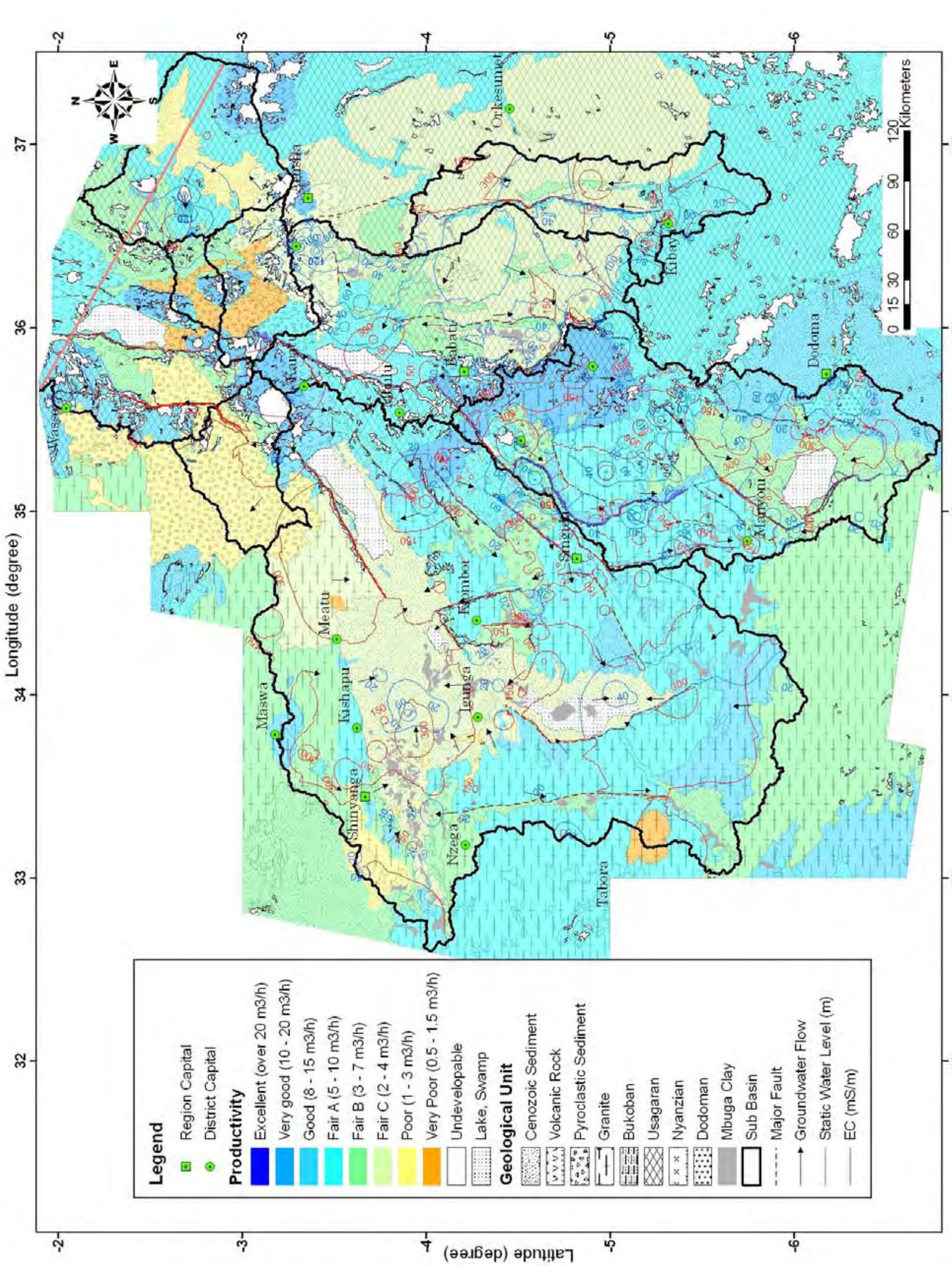

Figure 4-12 Hydrogeological Map of Internal Drainage Basin

Chapter 5
Groundwater Potential Evaluation

CHAPTER 5 GROUNDWATER POTENTIAL EVALUATION

5.1 Introduction

Hydrogeological maps are specialised maps on which groundwater resources and, as far as necessary, surface-water features are depicted on a base of topography and geology. Apart from their importance to hydrogeologists and groundwater specialists, hydrogeological maps are required also for use by non-specialists, such as administrators and economists, engineers in charge of town and country planning, technicians in agricultural, industrial and domestic water supplies, as well as by farmers, industrialists and private individuals. (Source: International Legend for Hydrogeological Maps; UNESCO (1970))

However, it is actually unfamiliar and difficult for general stakeholders to use hydrogeological map for their purposes. Therefore, groundwater resources potential evaluation maps were made using the same data for mapping of the hydrogeological map of IDB and results of water balance analysis to be easy understanding and practical use.

5.2 Schematic Water Balance and Groundwater Recharge

Schematic water balance and groundwater recharge in each sub-basin were analyzed by using meteorological and hydrological data and remote sensing techniques. The purpose of the analysis is to delineate areas with high groundwater recharge potential, in other words, high infiltration potential in IDB.

5.2.1 Method of Water Balance in Each Sub-basin

Schematic analysis of water balance was applied to all sub-basins of IDB. (Refer to Figure 5-1) The water balance is expressed by following equation.

$$P = E + R \pm I \quad \cdots\cdots (1)$$

P: Rainfall, E: Evapotranspiration, R: Runoff, I: Infiltration. Each sub-basin in IDB has no outlet of surface water so that the runoff term is neglected in this analysis.

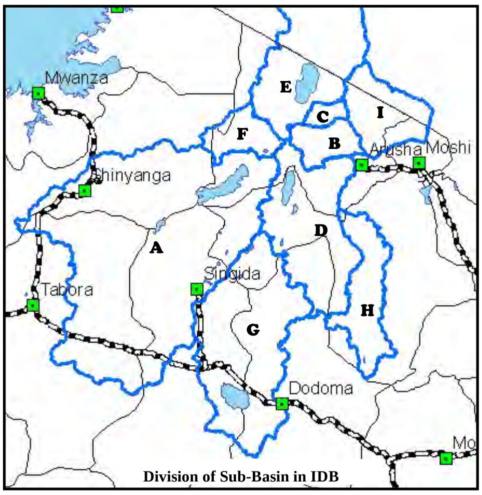

Figure 5-1 Sub-basins in IDB

(1) Estimation of Rainfall

Rainfall was calculated at each pixel of the LANDSAT images from a distribution map of monthly average rainfall in February, which is derived from “Summary of Rainfall in Tanzania” (1975: East Africa Community, Nairobi).

(2) Estimation of Evapotranspiration

Makkink equation (Makkink, 1957) was applied to estimate potential evapotranspiration ET (mm/day). The equation is defined as follows,

$$ET_{mak} = \frac{\Delta}{\Delta + \gamma} \frac{Rs}{\lambda} \quad \cdots\cdots (2)$$

In addition, the following equation (3) (ERSDAC, 2005, Nagai, 1993) were adopted for estimation of actual evapotranspiration because of various ground conditions of each sub-basin.

$$ET = \alpha[\ (a - A)\ \frac{\Delta}{\Delta + \gamma} \frac{Rs}{\lambda} + b] \quad \cdots\cdots (3)$$

Where, Rs (cal/cm2/day) is the total solar radiation, Δ (mbar /°C) is the slope of the saturation vapour pressure curve, γ (in mbar/ °C) is the psychrometric constant, λ (cal/g) is the latent heat, a and b are local constant values. A is Albedo and α is conversion value to actual evapotranspiration ($0< \alpha =<1.0$). Rs: the total solar radiation is calculated by using following equation.

$$Rs = Ra\ (0.18+0.55n/N)$$

Where, Ra is the outer space solar radiation, n is the observed sunshine hours and N is the possible sunshine duration.

$\{\Delta / (\Delta + \gamma)\}$ is dimensionless parameter and approximated by using the following equation.

$$\frac{\Delta}{\Delta + \gamma} = 1 / [1.05 + 1.4 \exp(-0.0604T)]$$

Where, T is the observed temperature. λ (latent heat) is calculated by using following equation.

$$\lambda = 2.5 - 0.0025T$$

Observed meteorological data used in this calculation are as follows, Temperature, sunshine hours and pan evaporation data from 1974 to 2004, derived from "Tanzania Meteorological Agency". As a result, the actual evapotranspiration in IDB is estimated by using following equation.

$$ET = \alpha\ [\ (1.28 + 0.05 - A)\ \frac{\Delta}{\Delta + \gamma} \frac{Rs}{\lambda}\ -1.452] \quad \cdots\cdots (4)$$

Although evapotranspiration needs water on ground and soil moisture, actual evapotranspiration estimated by above equation is not necessarily real evapotranspiration. Therefore, it should be properly called "possible evapotranspiration".

5.2.2 Possible Groundwater Recharge in Each Sub-basin during Rainy Season

Water balance analysis was applied to each sub-basins of IDB to grasp the areas with high groundwater recharge potential in each sub-basin during rainy season. This analysis was implemented by using the LANDSAT/ETM satellite image in February 2000 as a representative of rainy season. The minimum unit of spatial resolution of the remote sensing image is set to 75m x 75m by using nearest neighbour interpolation method.

(1) Rainfall

The rainfall map shows that the southern area of Ngorongoro Crater (north sides of Lake Eyasi and Lake Manyara) and the area near Tabora region have much rainfall than the others. On the other hand, the Masai Steppe (the sub-basin I) has little rainfall. (Refer to Figure 5-2)

(2) Possible Evapotranspiration Map

The possible evapotranspiration distribution in the whole IDB is strongly affected by the sunshine hours. In addition, the possible evapotranspiration in areas where have especially higher elevation such as Mt. Kilimanjaro and Mt. Hanang is affected by the temperature. The possible evapotranspiration in southern sub-basins has higher value than that in northern sub-basins. (Refer to Figure 5-3)

(3) Possible Infiltration (Groundwater Recharge) Map

The possible infiltrations of each sub-basin in February as a representative of rainy season are summarized in Table 5-1 and presented in Figure 5-4. The possible infiltration quantity (mm/month) and infiltration rate (%) has the highest value in the sub-basin A. The second highest group consists of sub-basin D (Lake Manyara sub-basin), E (Lake Natron sub-basin), F (Olduvai sub-basin) and G (Bahi sub-basin). The lowest possible infiltration group consists of sub-basin B {Monduli (1) sub-basin}, C {Monduli (2) sub-basin}, H (Masai Steppe sub-basin) and I (Namanga sub-basin).

Table 5-1 Summary of Water Balance Analysis for IDB in February

Sub-basin		Area (Km^2)	Rainfall (million m^3/month)	Evapo -transpiration (million m^3/month)	Possible Infiltration		
					(million m^3/month)	(%)	(mm/month)
A	Lake Eyasi	64,545	8,068	3,550	4,518	56	70
B	Monduli (1)	4,115	296	214	82	28	20
C	Monduli (2)	1,385	100	72	28	28	20
D	Lake Manyara	18,491	1,886	1,072	814	43	44
E	Lake Natron	26,224	2,229	1,180	1,049	47	40
F	Olduvai	4,577	476	220	256	54	56
G	Bahi (Manyoni)	26,445	2,962	1,613	1,349	46	51
H	Masai Steppe	9,313	764	596	168	22	18
I	Namanga	14,080	986	704	282	29	20

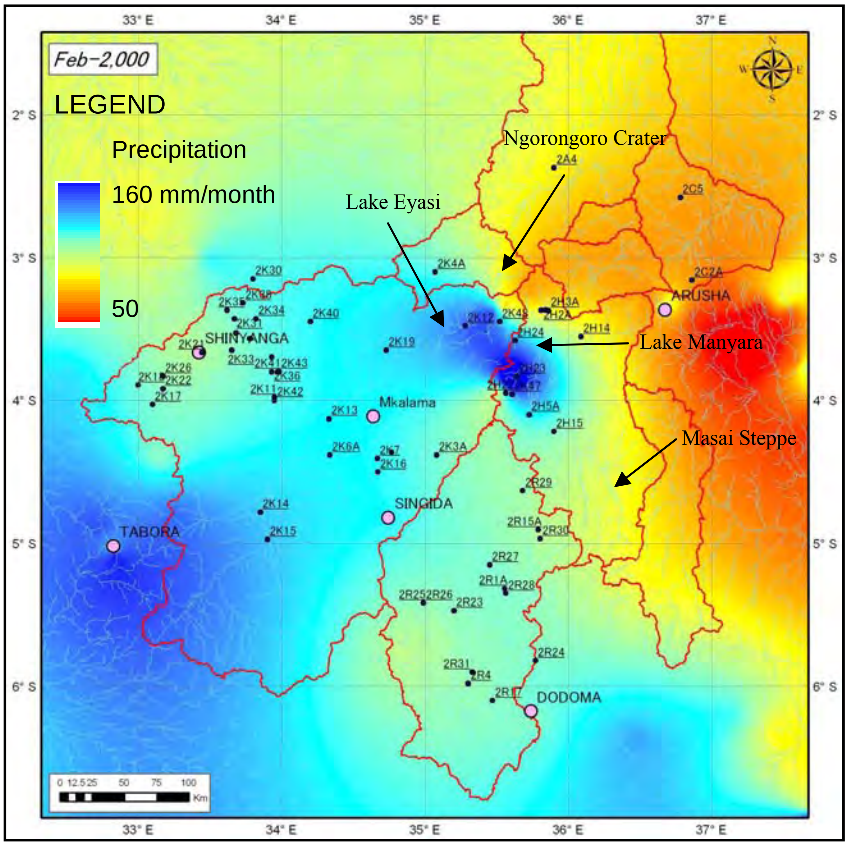

Figure 5-2 Rainfall Map in February

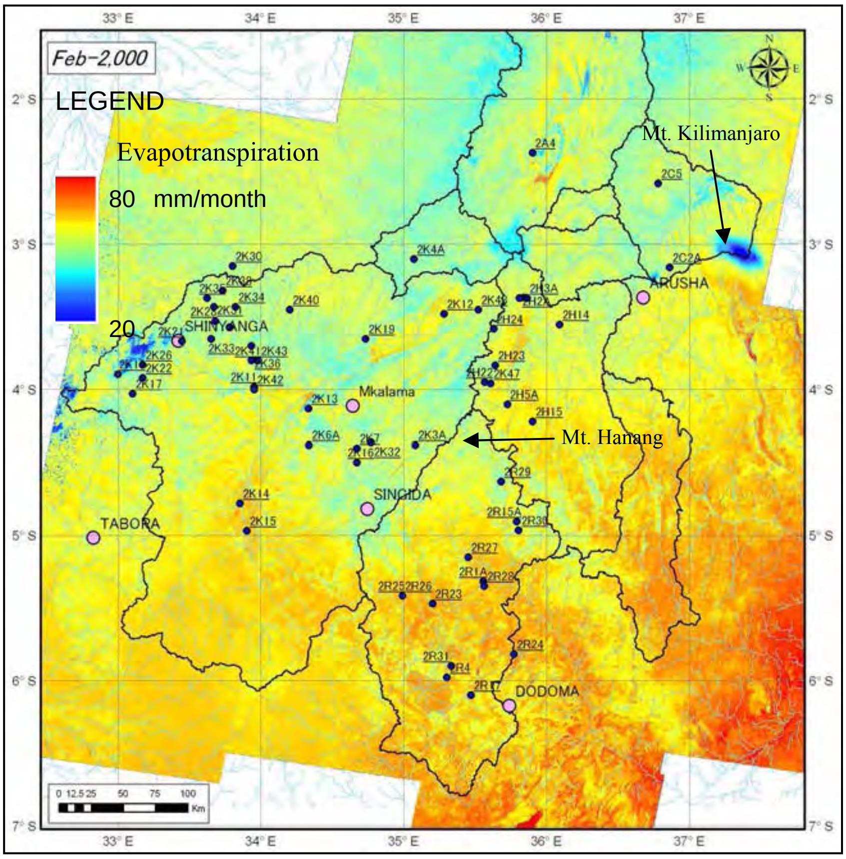

Figure 5-3 Possible Evapotranspiration Map in February

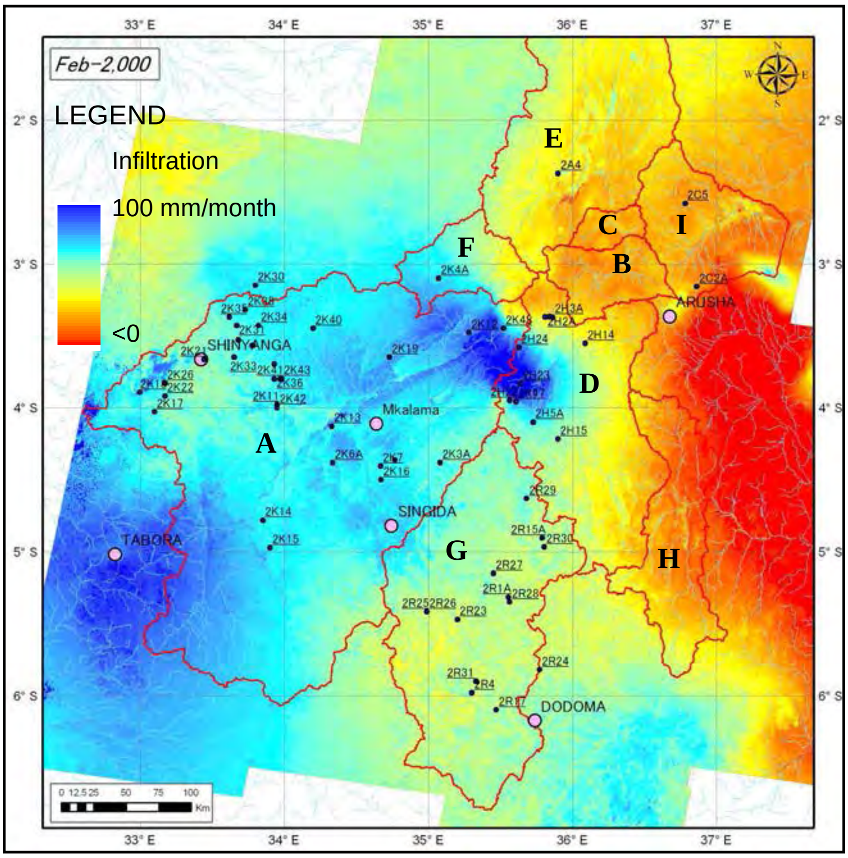

Figure 5- 4 Possible Infiltration Map (P-ET) in February

5.3 Groundwater Potential Evaluation

Based on the results of the hydrogeological analysis and water balance analysis, groundwater potential for development was evaluated as follows. Five indices: namely, 1) borehole yield, 2) static water level, 3) drilling depth, , 4) electric conductivity and 5) fluoride concentration of groundwater, were selected in order to evaluate basic potentiality of groundwater from hydrogeological point view. Infiltration, which was estimated by water balance analysis, was regarded as potentiality of groundwater recharge, was selected from hydrological point of view. Apart from importance of these six indices to natural conditions, social conditions are required also for actual groundwater development for rural water supply, which seems to be most probable needs for stakeholders in IDB. Therefore, two typical social indices: population density and rural water supply ratio by district in IDB were selected.

Table 5-2 shows allocation of evaluation scores by above-mentioned indices to evaluate groundwater potential in IDB.

5.3.1 Case Study on Groundwater Potential Evaluation

Regarding the following five cases, groundwater potential in IDB was evaluated.

Table 5-2 Allocation of Evaluation Scores by Each Index

Score		Natural Condition												Social Condition	
		Basic Condition										Recharge			
		(1)Yield (m^3/h)		(2)Static Water Level (m)		(3)Drilling Depth (m)		(4)Water Quality [EC] (mS/m)		(5)Water Quality [Fluoride] (mg/L)		(6)Infiltration (mm)		(7)Water Supply Ratio (%)	(8) Population Density ($person/km^2$)
10		60 <	Exl	< 5	Exl	< 10	Exl	-		-		100 <	Exl	< 5	150 <
9	Better	20 - 60		5 - 10		10 - 20		< 25	Exl	< 0.5	Exl	80 - 100		5 - 10	100 - 150
8	↑	15 - 20	Very good	10 - 15	Very good	20 - 30	Very good	25 - 50		0.5 - 1.0		60 - 80	Very good	10 - 15	80 - 100
7		10 - 15		15 - 20		30 - 40		50 - 75	Very good	1.0 - 1.5	Very good	50 - 60		15 - 20	65 - 80
6		6 - 10	Good	20 - 30	Good	40 - 50	Good	75 - 100		1.5 - 2.0		40 - 50	Good	20 - 25	55 - 65
5		2 - 6		30 - 40		50 - 70		100 - 125	Good	2.0 - 2.5	Good	30 - 40		25 - 30	40 - 55
4		1.5 - 2	Fair	40 - 50	Fair	70 - 100	Fair	125 - 150		2.5 - 3.0		20 - 30	Fair	30 - 40	30 - 40
3		1 - 1.5		50 - 70		100 - 150		150 - 200	Fair	3.0 - 3.5	Fair	10 - 20		40 - 50	20 - 30
2	↓	0.5 - 1	Poor	70 - 100	Poor	150 - 200	Poor	200 - 250		3.5 - 4.0		0 - 10	Poor	50 - 70	10 - 20
1	Worse	< 0.5		100 <		200 <		250 - 300	Poor	4.0 - 8.0	Poor	< 0		70 <	< 10
0		-		-		-		300 <		8.0 <		-		-	-

➢ **Case-1: Basic Indices for Natural Conditions**

Five indices: well yield, static water level, drilling depth, EC and fluoride, were selected for evaluation of groundwater development potential in terms of basic natural conditions. These indices were summed up at every one square kilometre calculation grid in IDB for the synthetic evaluation. The result illustrated in Fig. 5-5.

➢ **Case-2: Basic Indices and Infiltration**

Five basic indices and infiltration was calculated for the total natural conditioned. The results are shown in Figure 5-16.

➢ **Case-3: Two Times Weighted of Fluoride in Case-1**

Weighting factor of fluoride was applied two times in Case-1. Figure 5-7 shows Shinyanga area, western of Singida and Hanang area become lower potentiality of groundwater development.

➢ **Case-4: Case-2+Population Density**

Figure 5-8 shows groundwater potential evaluation based on Case-2 and population density in addition. The figure indicates that Shinyanga area, western of Singida and Hanang area become lower potentiality of groundwater development.

➢ **Case-5: Case-4 and Water Supply Ratio**

The final case: Figure 5-9, shows groundwater potential evaluation based on Case-4 and rural water supply ratio; namely, all layers were calculated. Since Tabora Region has many districts whose ratio is low, potentiality in the western part of IDB is increased.

5.3.2 Conclusion of Groundwater Potential Evaluation

Since one of the main purposes of this study is to evaluate groundwater potential in IDB from hydrogeological and hydrological points of view, high potential areas in IDB can be easily distinguished. Although the resolutions of analysis using water supply ratio in district level is not enough, the case study for rural water supply, which is most probable development plan in IDB, was carried out as shown in Figure 5-9. Synthetic analysis with groundwater potential evaluation and social conditions with population density and rural water supply ratio indicate that i) Kondoa/Babati area, ii) Karatu/Mbulu area, iii) South Singida town area, iv) Igunga area and v) West Shinyanga area, have relatively high potentiality for rural water supply development.

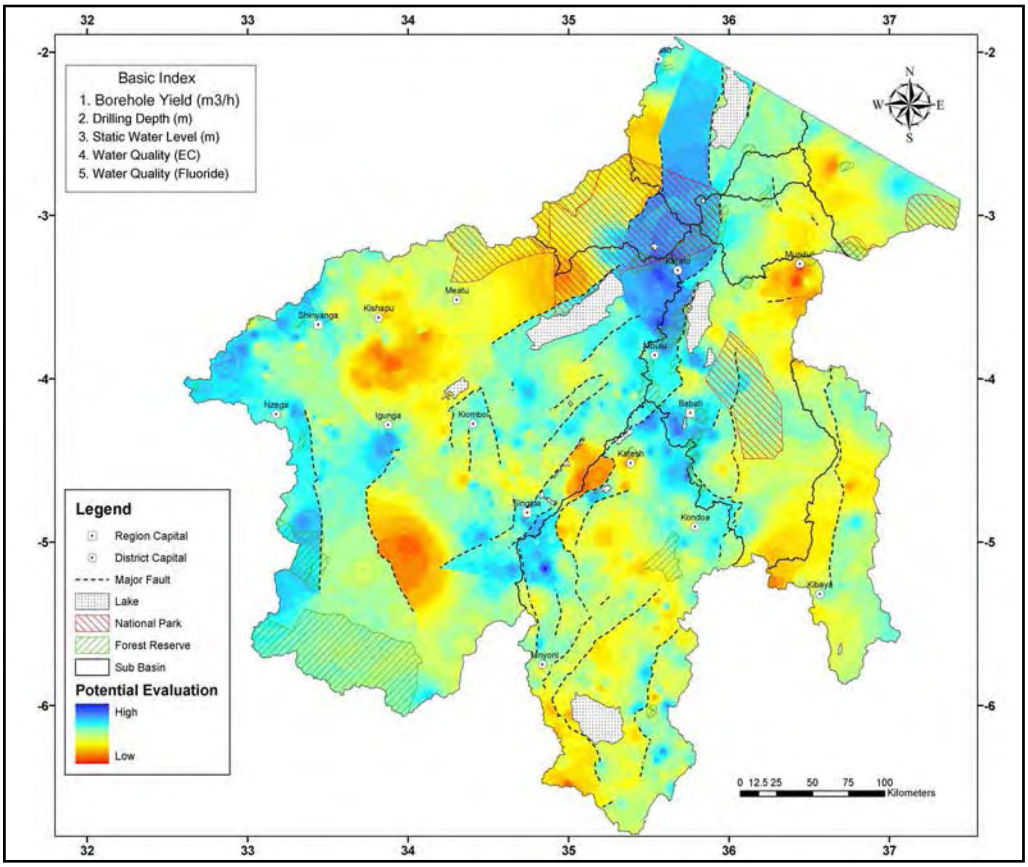

Figure 5-5 Case-1: Groundwater Potential Evaluation (Basic)

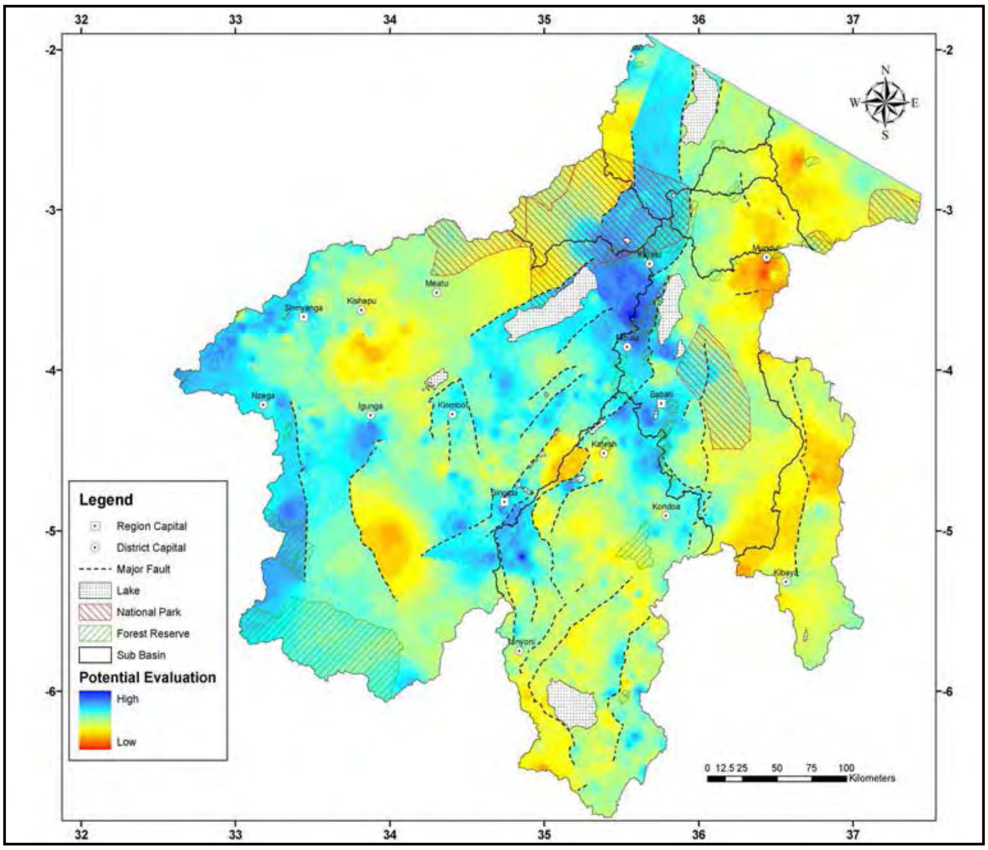

Figure 5-6 Case-2: Groundwater Potential Evaluation (Basic + Infiltration)

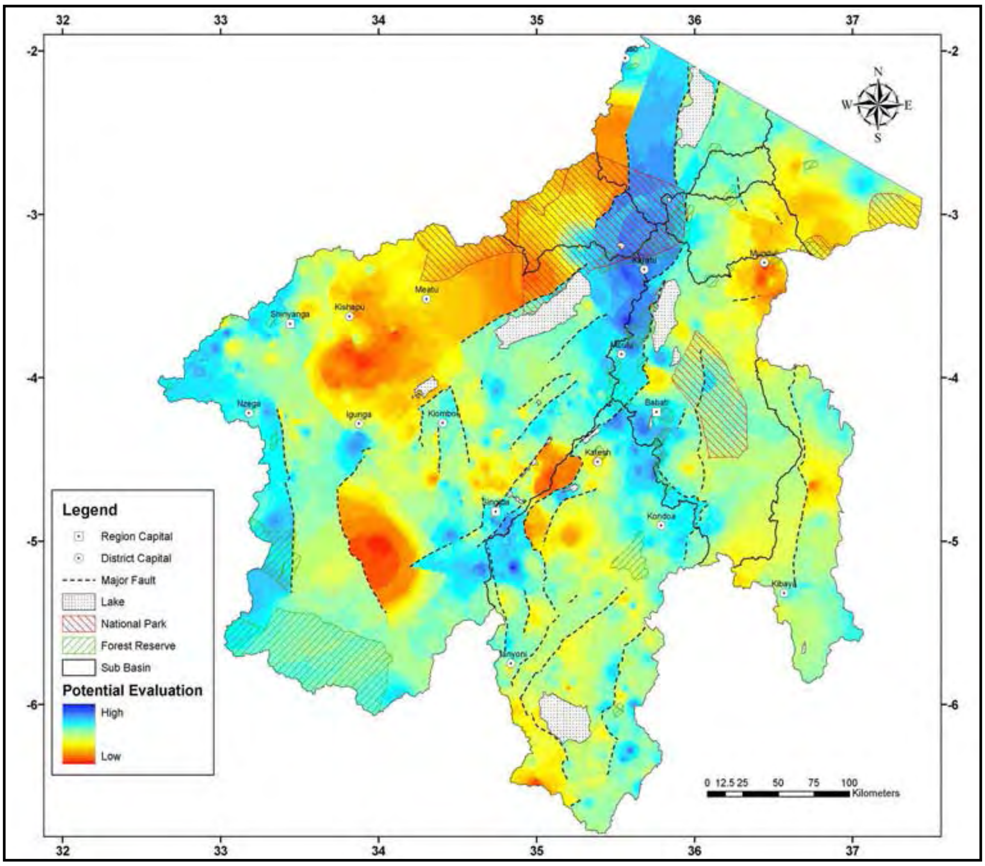

Figure 5-7 Case-3: Groundwater Potential Evaluation (Basic, 2 X Fluorides)

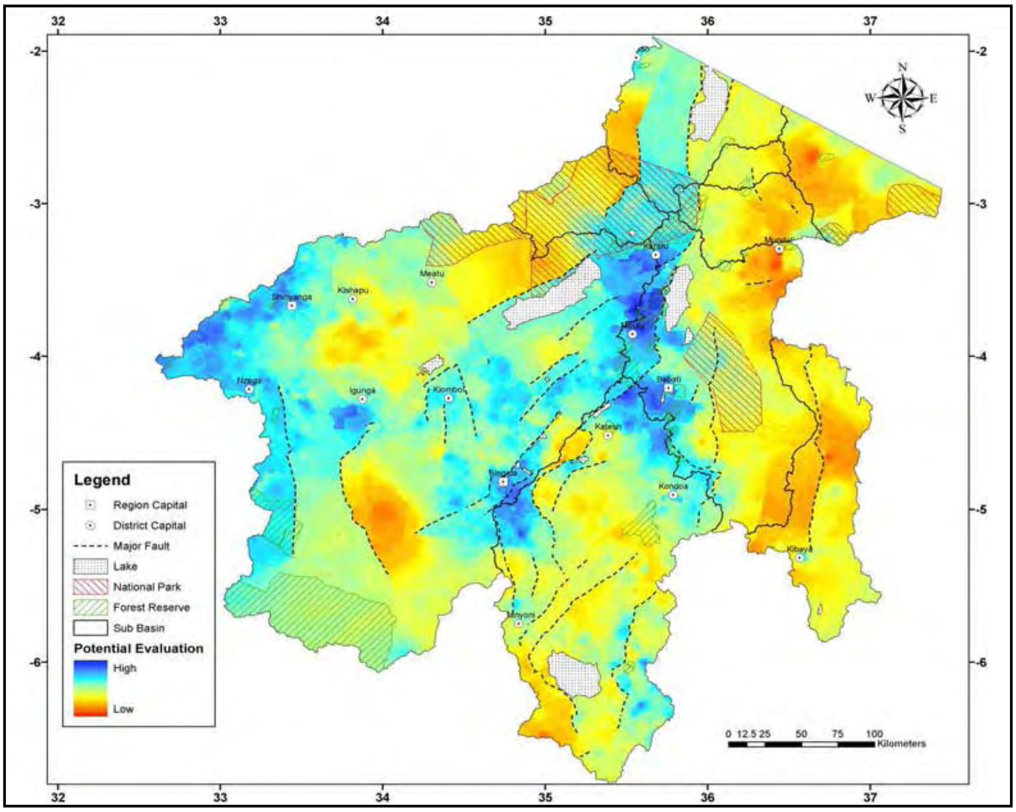

Figure 5-8 Case-4: Groundwater Potential Evaluation (Case-2 + Population Density)

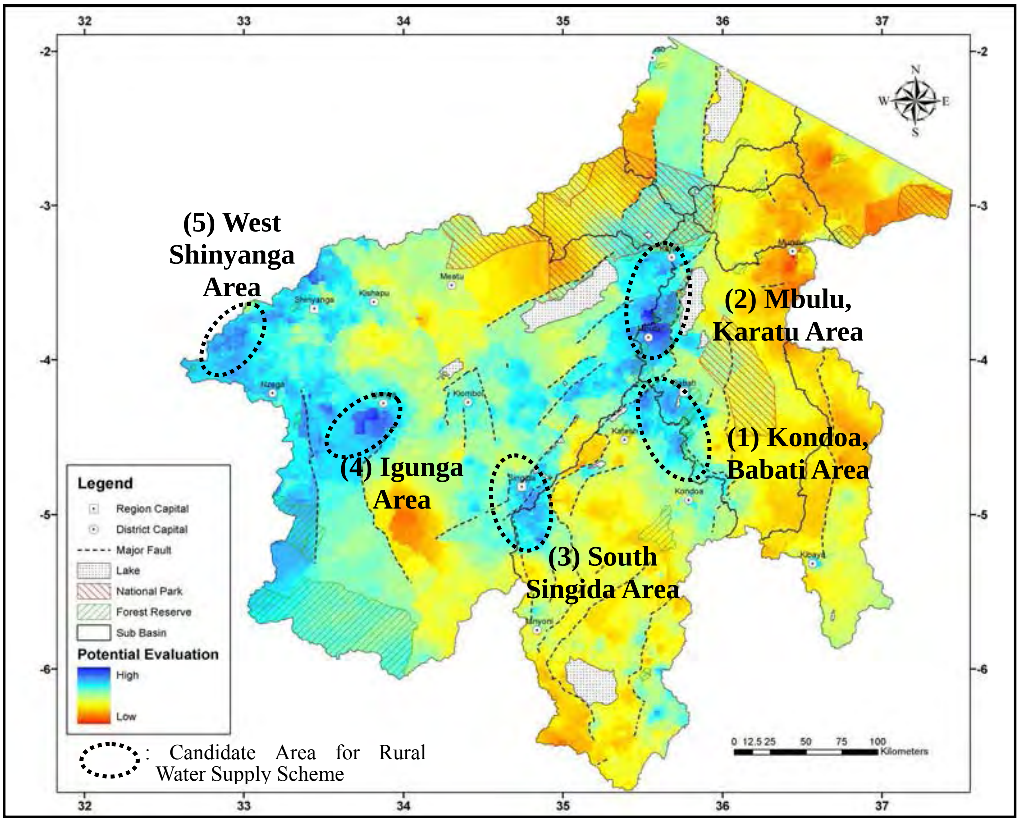

Figure 5-9 Case-5: Groundwater Potential Evaluation (Case-4 + Water Supply Ratio) and Candidate Areas for Rural Water Supply Scheme

Chapter 6
Organizational System for Water Sector

CHAPTER 6 ORGANIZATIONAL SYSTEM FOR WATER SECTOR

6.1 Organizational System for Water Resources Development and Management

6.1.1 National Development Plan for Water Sector

Water resources development and management is carried out based on the National Water Policy 2002 (NAWAPO) in Tanzania. This policy was formulated based on the National Development Vision 2025 (Vision 2025) and the Poverty Reduction Strategy Paper (PRSP), which is currently revised and called as the National Strategy for Growth and Reduction of Poverty (NSGRP), and also by revising the 1991 National Water Policy.

The target of Vision 2025 to water and sanitation sector is to access safe water by 2025 through involving private sector, strengthening local government and communities, and promoting broad-based grass root participation through mobilizing their knowledge and experience. In the NSGRP, it is aimed to increase proportion of rural population with access to clean and safe water from 53% in 2003 to 65% by 2009/2010 within 30 minutes of time spent on collection water, and to increase urban proportion with access to clean and safe water from 73% in 2003 to 90% by 2009/2010.

The main aim of NAWAPO is to provide a comprehensive framework for sustainable development and management of the national water resources for economy-wide benefits and an increase availability of water supply and sanitation services. NAWAPO also incorporates the decentralization policy in the public service sector into the Local Government Reform Policy.

Following NAWAPO, Ministry of Water (MoW) prepared the National Water Sector Development Strategy (NWSDS) as a single strategy document for Water Sector Development in June 2004 and was revised in 2006. NWSDS suggests immediate priorities and methodologies to solve the constraints in the water sector. NWSDS adopted a new framework for water resources management to harmonize "development" with "environment". For this challenge, NWSDS shows role or responsibility of each related organizations and express that the role of the government will change from public service provider to coordinator of policy, formulation of guidelines and regulations, and that the related various organizations and staff will participate in water resources management and promote basin water offices to function on a financial autonomy basis.

6.1.2 Organizational System for Water Sector

(1) Organization Structure of MoW

The organization structure of MoW is shown in Figure 6-1, which was presented at AWEC (Annual Water Experts Conference) in January 2007 as "Provisional Organization Structure of MoW. The Water Resources Division is the executive and responsible agency for the study.

(2) Basin Water Offices

"River Basin Management Approach" was applied for water resources management since 1980s in Tanzania and nine basins were set up by Act No. 42 of 1974 (amendment Act No. 10 of 1981). Basin Water Office (BWO) was established in Pangani Basin in 1991, Rufiji Basin in 1993 and Lake Victoria Basin in 2000. Moreover, the concept of IWRM (Integrated Water Resources Management) was introduced in National Water Policy 2002, and Basin Water Boards (BWBs) and BWOs were established in all basins. The reformed present institutional framework of water resources management is shown in Figure 6-2.

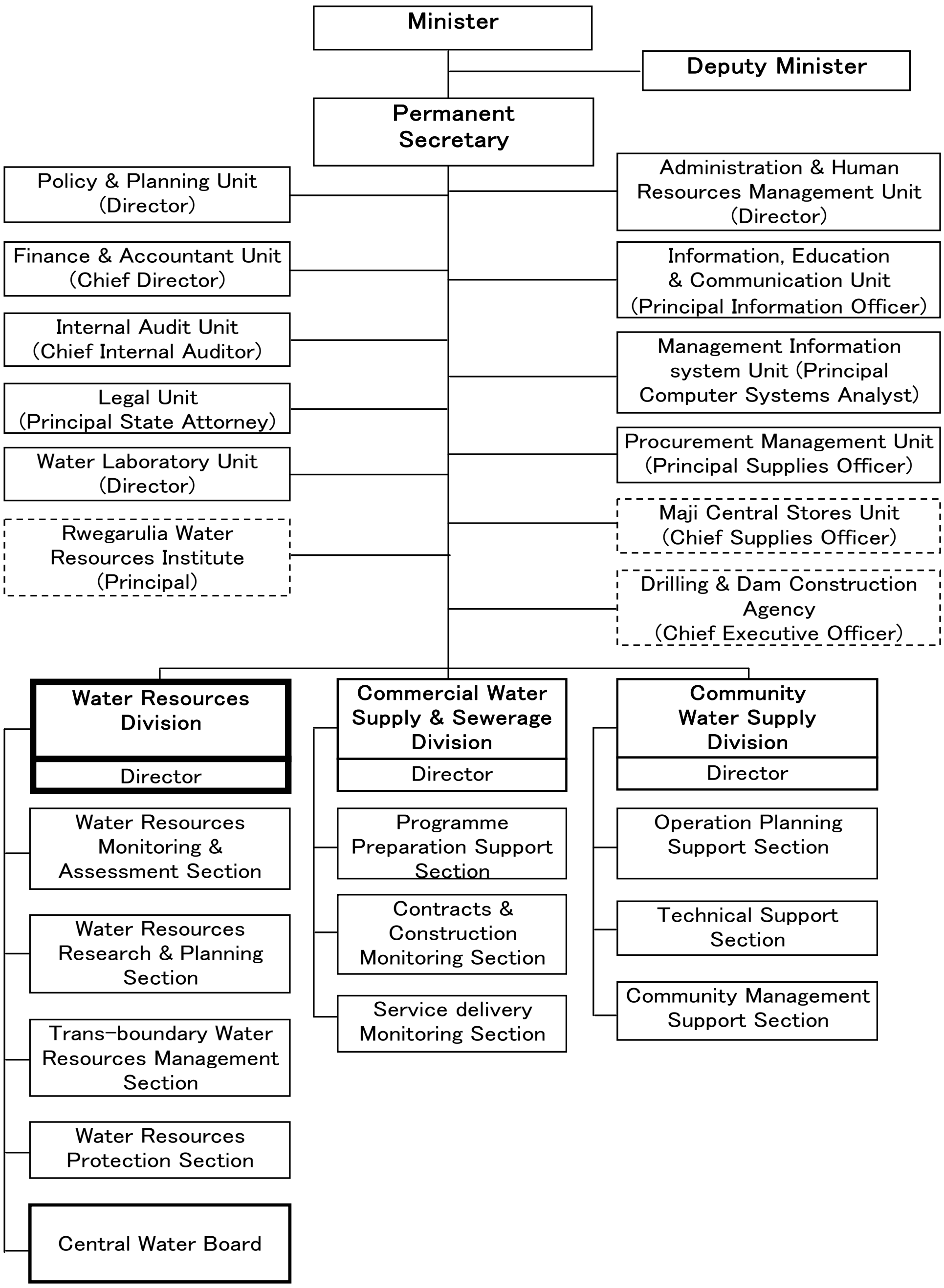

Figure 6-1 New Organization Structure of MoW

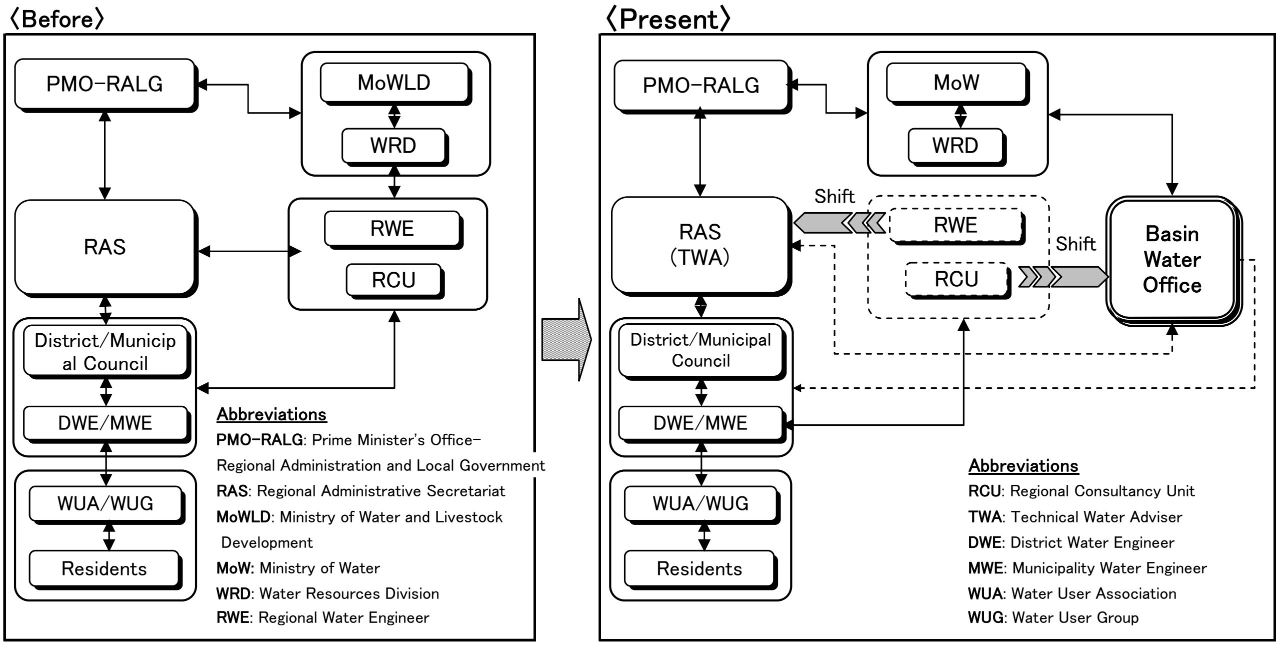

Figure 6-2 Present Institutional Framework of Water Resources Management

6.2 Internal Drainage Basin Water Office (IDBWO)

This Study started just one year after establishment of the Internal Drainage Basin Water Office (IDBWO), which was established in Singida on 29th October 2004. During the first phase of the Study (Oct. 2005 – Mar. 2006), the JICA Study Team could not regard IDBWO as well-functioned office but its function was under developing. The JICA Study Team and C/P personnel shared common recognition of the following issues on the function of IDBWO.

- Shortage and Insufficiently Trained Staff
- Few Inner Meeting
- Incomplete Operation Transfer under Reorganization of Water Sector
- Difficulty of Performing Tasks in the Vast area of IDB
- Poor Work-sharing and Communication System among Sub-basin Offices

Based on the above-mentioned situation of IDBWO, the Study Team listed immediate issues to be resolved as follows.

- Awareness of Basin Management and IDBWO for Stakeholders
- Cooperation with Related Organization and Demarcation of Roles
- Capacity Building of Staff in IDBWO
- Difficulty of Leadership and Necessity of Deputy System of Leadership in IDBWO
- Inefficient Collection System of Water User Fees and Shortage of Operational Revenue

6.3 Capacity Development

6.3.1 Purpose of CD

Capacity Development Program (CDP) was additionally planned and conducted as the possible assistance by JICA Study Team to improve such issues of IDBWO. This program was designed to upgrade staff's capacity and strengthen the organization of IDBWO.

6.3.2 Contents of CD

Upskilling technology program was carried out as shown in Table 6-1.

Table 6-1 Upskilling Technology Program

Theme	Overall Goal	Target	Method	Schedule
Hydrology / Meteorology	Acquire technology on investigation and data analysis	IDBWO staff	Lecture & Practice	Oct. 2006
GIS / Database	Acquire Basic Knowledge of GIS/DB and Understand Outline of Application in Groundwater Development /Management	IDBWO staff /Other Basin Water Office staff	Lecture & Practice	Mar.2007
Remote Sensing	Acquire Basic Knowledge and Techniques of Remote Sensing	IDBWO staff /Other Basin Water Office staff	Lecture & Practice	Aug.2007
Geophysical Survey / Drilling Supervision	Acquire technique and knowledge for implementation and data analysis	IDBWO staff	Lecture & Practice	Aug. & Sep.2007
Hydrogeology	Acquire technique and knowledge for utilization of Hydrogeological map	IDBWO staff	Lecture & Practice	Oct. & Nov. 2007

6.3.3 Organization Strengthening Program (OSP)

Contents of OSP were shown in Table 6-2. "Organization Strengthening Team" (OST) was organized in IDBWO whose members were selected from the IDBWO. Main activities were; understanding actual situation of IDBWO, arrangement of job description for basin water management, problem analysis of management of IDBWO, consideration for demarcation or relationship between IDBWO and related organization, and so on. Finally, they prepared the management manual and the action plan for future activity. The staff of IDBWO could understand regarding basic information and problem of IDBWO or the contents of basin water management by themselves through this program.

6.3.4 Evaluation of Capacity Development

Capacity development program was conducted to improve the performance of IDBWO in order to turn over, utilize and expand the Study results. Although the program succeeded in bottom-up of IDBWO considerably, continuous assistances from MoW or other donor organizations are expected to let IDBWO perform their tasks properly and independently.

Table 6-2 Organization Strengthening Program (OSP)

Theme	Main Item	Person in Charge	Method	Schedule
Fixing organizaion structure in IDBWO	Checking present conditions of IDBWO	All Staff of IDBWO	PCM Workshop	October, 2006
	Checking sctivities for watershed management by IDBWO			
	Formulation of Operation & Management Manual for IDBWO	Organization Strengthening Team	Discussion	
Clarification of role demarcation among IDBWO and other related organizations and formulation of cooperation system	Confirmation of cooperative tasks among IDBWO and major related organizations	Organization Strengthening Team	Discussion	November, 2006
	Meetings with DWE and TWA in related six regions			
	Confirmation of practical methods to cooperate with related organizations			
Formulation of Operation and Management Plan	Explanation of IDBWO's tasks for basin water resources development & management to IDBWO's staffs	All Staff of IDBWO	Workshop	March, 2007
	Formulation of improvement plan for IDBWO's organization system	Organization Strengthening Team	Discussion	
	Formulation of action plan for IDBWO's staff	Section Leaders of IDBWO		

6.4 Recommendation for IDBWO after OSP

The reorganization of MoW was conducted in 2007 as shown in Figure 6-1 and the arrangement of job description of each section is on going. The organization structures of all BWOs were integrated along this reorganization. Figure 6-3 shows the organizational framework of IDBWO revised by OST through OSP based on new ideas from MoW.

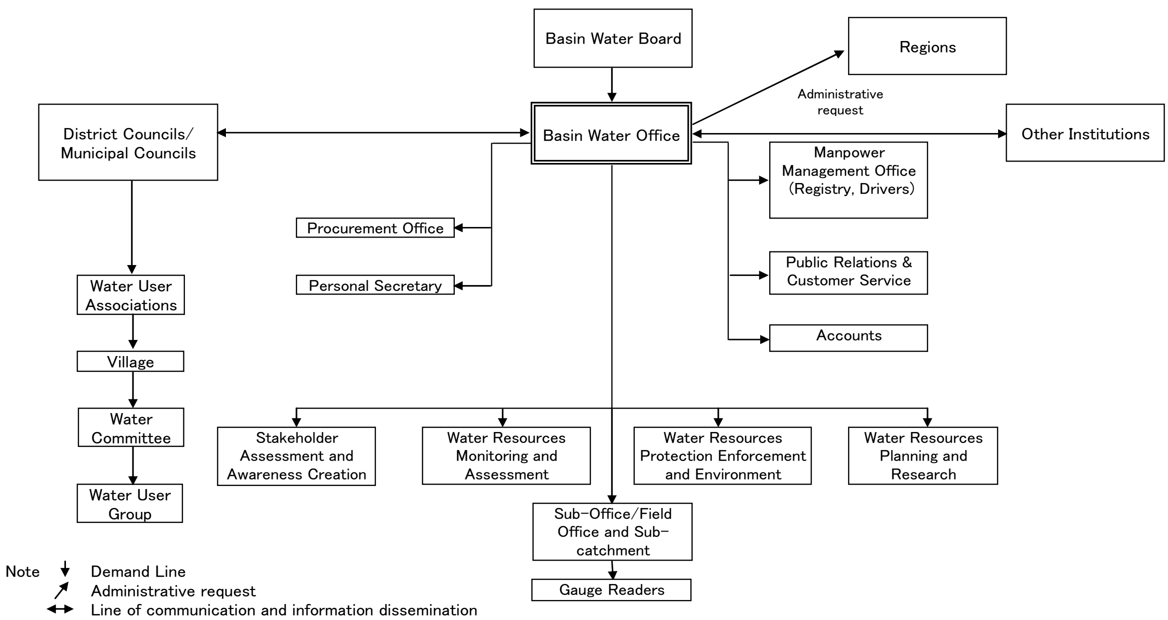

Figure 6-3 Organizational Framework for IDBWO

(1) To Hold Management Meeting

IDBWO needs to hold the regular management meeting for the purposes as follows.

- Planning and implementation of basin water management work
- Monitoring and management of IDBWO's daily business
- Improvement of organization system
- Back-up system in absence of Water Officer.

(2) To Discuss Water User Fees

Water user fees are important part of the revenue of IDBWO and it will become more important for self-support accounting system. IDB is vast and has few big water users because of disadvantaged surface water and dependence of groundwater. Therefore, IDBWO has to collect water user fees effectively from many small water users. Discussion items are listed below.

- To promote awareness of stakeholders that IDBWO is responsible office to collect water user fees.
- To coordinate with District/Municipality to make people understand about water user fees.
- To establish database of Water user feess in cooperation with District/Municipality.
- To set up effective collection system of water user fees. For example, it may be possible to apply the same collecting system as for O/M cost by WUG/WUA , and to link bank transfer system and the collecting system as shown Figure 6-4.

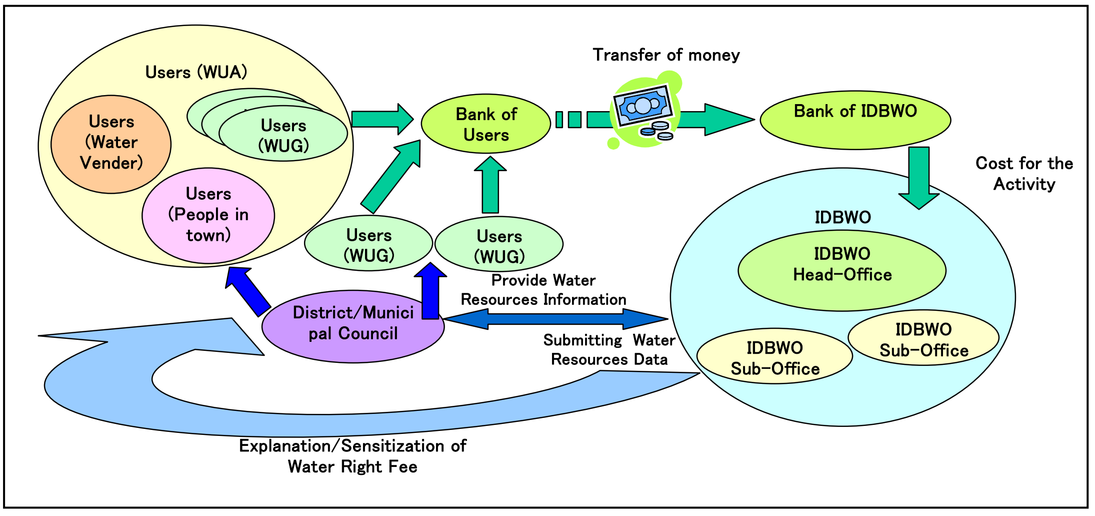

Figure 6-4 Water User Fees Collection System with Bank Transfer System

(3) To Establish Data Collecting and Monitoring System

The data collection and analysis on water resources in IDB have been conducted by JICA Study Team during the Study. The outcome and activity will be inherited to IDBWO and MoW, and the result will be provided to the related stakeholders. At the same time, IDBWO has to continue collecting the data and update their database. There are two kinds of data that should be collected by IDBWO: i) existing/new water supply facility data belong to District/Municipal Council or MoW and ii) data from river gauging stations, meteorological stations, and monitoring boreholes constructed by JICA. IDBWO made their plans for them during OSP as shown in Figure 6-5 and6. These systems should be made to function actually as soon as possible

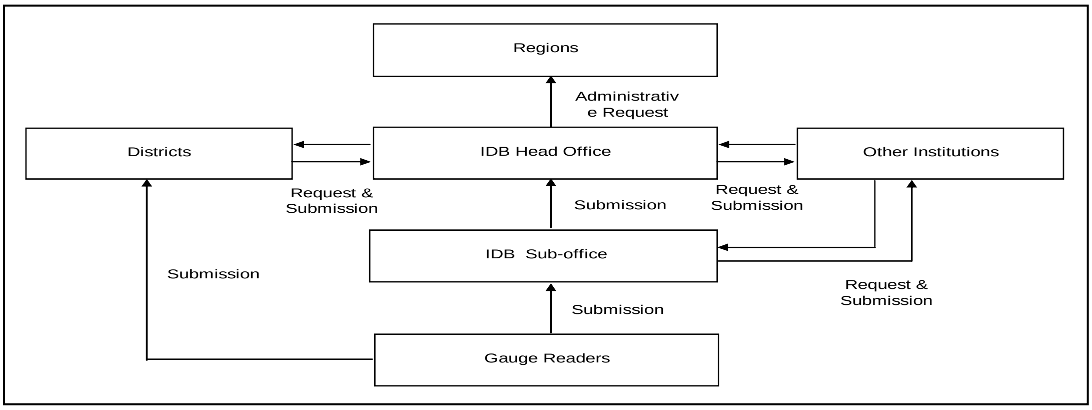

Figure 6-5 Tentative Flow Chart of Data Collection from Related Other Organizations

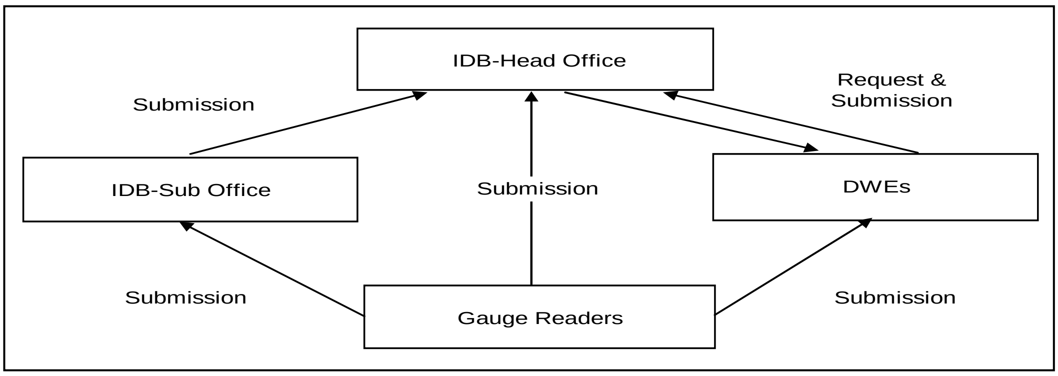

Figure 6-6 Tentative Flow Chart of Data Collection from Monitoring Borehole

Chapter 7
Conclusion and Recommendations

CHAPTER 7 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

This Study has been carried out for approximately two year and half since September 2005. Wide-ranged data for water resources management and the survey results conducted during the Study were accumulated into the water resources management database of IDB.

Various types of figures for synthetic analysis to understand the natural and socio-economic conditions of IDB were drawn by GIS and they were compiled as GIS Figure Book. Hydrogeological map and the groundwater potential evaluation map were finally established based on such figures as the final output. The former is the first version of full-scale hydrogeological map covering 143,000 km^2 of IDB. It is expected to play important role as a provider of the fundamental information for water resources development and management in water-scarce IDB. However, it is not always user-friendly for not only general stakeholders but also engineers in other field. Therefore, the latter was drawn to supplement it.

The groundwater potential evaluation map assesses potentiality of groundwater resources in IDB with six indices of hydrogeological conditions to a resolution accuracy of one km^2 grid by the spatial analysis function in GIS for easily understanding and practical use. In conclusion, the five candidate areas for rural water supply scheme, which is the most feasible use of groundwater resources in IDB, could be nominated by the above-mentioned method considering with two social conditions in addition to their natural conditions. They are（i) Kondoa/Babati area, ii) Karatu/Mbulu area, iii) South Singida town area, iv) Igunga area and v) West Shinyanga area.

There have been fluoride problems caused by drinking water contaminated with high fluoride in IDB. According to the dental fluorosis survey in the Study, almost of all children living in the villages where water sources were contaminated with more than 1.5mg/l fluoride in the northern part of IDB, had moderate level of its symptom. The survey results implied that the major cause of the dental fluorosis was not only contaminated water but high fluoride contained in Magadi. As for removal technology of fluoride from water, several methods are confirmed their capability technically but its applicability was concluded to be very difficult to IDB, particularly into the rural areas, from the socio-economic point of view. Awareness campaigns of fluoride contamination, guidance of better water sources and restriction of Magadi are needed to be as an interim measure.

On the other hand, technology transfer and capacity development programs were conducted in the Study. They consisted of on-the-job training, technical training courses in Japan for three C/P personnel, and capacity development program including the five items of the upskilling technology programs and the organization strengthening program. The capacity development program was conducted to improve the performance of IDBWO in order to take over, utilize and expand the Study results. Although the program succeeded in bottom-up of IDBWO considerably, continuous assistances from MoW are needed to have IDBWO perform their tasks properly and independently.

This Study was started from the redefinition of accurate basin boundary and conducted full-scale groundwater resources assessment for the first time within nine basins in Tanzania, and regarded as the important first step to the goal of "Integrated Water Resources Management" (IWRM). It is also strongly expected that the results and experiences throughout the Study which was conducted in the second largest basin in Tanzania: IDB, would be referred to as a typical model of groundwater resources assessment for the other basins.

7.2 Recommendations

7.2.1 Water Resources Development and Water Quality

(1) Water Resources Development

Since surface water resources in IDB are not suitable for drinking water supply due to unstable quantity resulting from hydrological characteristics of IDB and treatment cost, it is inevitable to depend on groundwater resources especially in the case of rural water supply scheme. Rural water supply master plans and feasibility studies targeting for the five areas: i) Kondoa/Babati area, ii) Karatu/Mbulu area, iii) South Singida town area, iv) Igunga area and v) West Shinyanga area, should be carried out immediately.

(2) Groundwater Quality Problem

Main groundwater problems in IDB are fluoride and salinity. Since high cost purification methods such as ion exchange or reverse osmosis are only applicable against saline water, groundwater development should be planned in the low risk area using the distribution map of EC (TSD) drawn in the Study.

(3) Necessity of Detailed Epidemiological Investigation for Fluorosis

Fluorosis in IDB was confirmed by the dental fluorosis survey of the Study. However, how much of an impact is contributed by the fluoride in drinking water and the high-level fluoride content in Magadi, which people are accustomed to use for daily cooking, is not clear. Therefore, detailed epidemiological investigation should be conducted immediately not only for risk management to fluorosis but awareness campaign of fluoride contamination, guidance to better water sources with less fluoride concentration, and discouraging consumption of Magadi as temporary measures.

7.2.2 Monitoring System and Update of the Study

(1) Groundwater Monitoring

Long-term monitoring is fundamental for groundwater resources management. It is necessary to set up a monitoring system and start monitoring immediately at least for the monitoring wells that were newly constructed during the Study.

(2) Restructuring Monitoring and Collection System of Basic Data for Water Resources Management

Water resources management needs a wide range of data not only natural conditions but social conditions. Even basic data: namely, precipitation, river flow discharge, groundwater level, and water quality data, are lacking and in poor quality. Furthermore, village or ward-wise economic data is also important. It is still the case that IDBWO cannot figure out water resources volume and allocate them for water resources management. Although the Study Team used satellite data to supplement lacking data, it is not almighty. Therefore, a long-term effort to accumulate basic data is necessary by any means. Simultaneously, awareness campaign for necessity of water resources assessment to the related organizations is also important.

(3) Continuation and Update of the Study

Database for IDBWO was constructed by accumulating a wide range of data for water resources management as much as possible during the Study. The results of the Study were based on the many kinds of analysis using the database. IDBWO should enhance quality of the database by accumulating more existing data and monitoring hydrological and hydrogeological conditions in IDB; and update the Study results.

(4) Use of GIS

Many maps in “GIS Figure Book” are only an output for the purpose of the Study based on the database covering wide-range fields. Since GIS is not only a mapping tool but can be used for various purposes of users with the same GIS database, the availability of GIS established in the Study should not be limited so other relevant organizations as well as IDBWO can share the usefulness. Therefore, GIS resources, such as software, hardware and human resources, of those organizations should be further developed as necessary.[k1]

7.2.3 Organization Strengthening of IDBWO

Organization strengthening of IDBWO should be continued to accomplish the above-mentioned recommendations based on the issues to be solved, which are recognized by IDBWO staff themselves through the organization strengthening program in the Study. Since the organization strengthening only by IDBWO’s self-supporting effort has limitations, it is strongly desired that Ministry of Water should support its effort without interruption.