Chapter 9
Hydrogeology

CHAPTER 9 HYDROGEOLOGY

Hydrogeological conditions in the Internal Drainage Basin (IDB) were investigated by using the following method;

(1) collecting the existing data,
(2) conducting the inventory survey of existing water supply facilities,
(3) satellite image analysis,
(4) geophysical survey, and
(5) test borehole drilling survey.

Satellite Image analysis (3), geophysical survey (4), and test borehole drilling (5) have been already explained in chapter 3, chapter 5 and chapter 6, respectively. The existing data and the inventory survey are expressed in this chapter. After the explanation, analytical results are expressed in detail.

9.1 Collection of Existing Data

In order to investigate the hydrogeological condition, the following existing borehole data were collected from:

- MoW Borehole Catalogue (Whole Tanzania),
- DDCA Borehole Catalogue,
- RWSSP-WADATA (2002, Shinyanga region),
- Water Supply and Health Project in Marginal Areas (2002, Dodoma region),
- Arusha Region Water Master Plan (2000, Arusha region and Manyara region),
- Tabora Region Water Master Plan (1978, Tabora region),
- The Study on the Groundwater Development for Hanang, Singida Rural, Manyoni and Igunga Districts (1998, JICA Study),
- The Feasibility Study on Monduli Town and the Surrounding Area Water Supply (1995, JICA Study),
- Water Supply Facility Data requested from JICA expert, to each district, and
- Borehole Completion Form.

Each region has various databases, for example, some regions have database in computer, and other regions manage borehole data in notebooks. However, these databases are not in uniform format and items. Only MoW Borehole Catalogue is arranged uniformly for whole Tanzania in MS-EXCEL format. A borehole database and a water supply facilities database have been compiled from these data in this study.

9.1.1 Borehole Database

The borehole database was established based on the MoW borehole catalogue by adding and correcting with other borehole information.

(1) MoW Borehole Catalogue

MoW Borehole Catalogue, which is assembled borehole data in the survey area uniformly, is used for basic data to understand the hydrogeological structure in IDB. The feature of this catalogue is as below.

- ✓ 3,456 borehole data in this catalogue for 6 regions as the study area: Borehole catalogue has a lot of borehole data since 1937.
- ✓ Abandoned boreholes are mentioned in this catalogue: Dry holes or high saline water wells are described. These are very important information for understanding hydrogeological situation.
- ✓ Drilling depth, static water level, water struck depth, water yield, drawdown depth and aquifer geology are described.
- ✓ Borehole position is not mentioned but village name only. It is very difficult to identify the location of the borehole.
- ✓ There are many deficit items in the table.

It spent so much time to confirm the village position in the borehole catalogue. For example, the “village location” is not village name; some data is added “school” or “hospital” after some name. while the “village location” is included a different name from the village list published from National Bureau of Statistics. Therefore, the “village location” could not match to the village list.

Insufficient items in the borehole catalogue were supplied from other borehole information. Borehole position, division name, ward name and village name was described in the borehole database of this project.

(2) Other borehole Information

The most reliable data for borehole is “borehole completion form”, which is submitted to Regional Water Engineer after completion of borehole construction. MoW’s borehole catalogue and other lists were assembled from this information. However, these forms are scattered and lost now. Some of these forms were able to be collected from DDCA, former Regional Water Engineer’s office in each region.

Other sophisticated borehole data were collected from “Arusha Region Water Master Plan”, “Tabora Region Water Master Plan”, “Borehole Catalogue of DDCA” and “Borehole Database in Shinyanga Region (RWSSP-WADATA)”. The features of each data are mentioned as follows.

i) DDCA Borehole Catalogue

This data is basically same contents as MoW borehole catalogue. The data have been accumulated since 1997 when the DDCA went independent from MoW.

ii) Arusha Region Water Master Plan

Although the list in this master plan is basically same contents as MoW borehole catalogue, there are many different data from the MoW borehole catalogue.

iii) Tabora Region Water Master Plan

This master plan was published in 1978. Data is before 1978 only. Although the data in it is not so much, each borehole data is described in detail.

iv) RWSSP-WADATA

This database has not only well data but also dam, river and project activity. This database was made by MS-ACCESS. Data have coordination by UTM. The "well" table in the database has over 3,000 data but most of data are on dug wells.

v) Borehole Completion Form

This form has detailed data for borehole specification. Even in this form, many deficit data exist. Some of the forms were described geological information in detail.

(3) Borehole Database

The provisional borehole database was compiled from the MoW borehole catalogue and the other borehole information mentioned above. Actually, it was based on the MoW borehole catalogue, and added and corrected data referring to the other borehole information.

The principle of adding and correcting data is described below.

- ✓ Borehole completion form is recognized as correct. The records different from the completion form were corrected.
- ✓ If the borehole catalogue based on the borehole completion forms had some mistakes obviously, the data were corrected with reference to the previous water resources master plans or the borehole completion forms as the original date source. For example, some borehole catalogue data had been described in feet and gallon unit..
- ✓ Village name was corrected to match to the corresponding one in the census list. Additionally, division name and ward name were added in this database.

The item of the database is listed in **Table 9-1**.

Table 9-1 Item of Provisional 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

9.1.2 Water Supply Facilities Data

Water supply service coverage (Rural Water Supply Division, MoWLD, 2004) of rural area in IDB is shown in **Table 9-2**. The region which has the highest coverage rate is Dodoma region with 76%. It is 54% even in Arusha Region. The rate of other 4 regions is lower than 50%. The lowest is only 17% in Sikonge district.

Table 9-2 Rural Water Supply Service Coverage in IDB (as of Dec. 2004)

S/N	Region	District	No. of village water committees	No. of village water funds	Savings in the village water funds	Population		% of service
						Total pop.	Pop. served with water	
1	Tabora	Nzega	134	61	5,391,000	417,097	137,642	33.0
		Igunga	96	51	8,023,890	325,547	113,942	35.0
		Uyui	93	68	4,793,205	282,282	121,381	43.0
		Sikonge	43	19	251,000	133,388	22,676	17.0
		Total	**366**	**199**	**18,459,095**	**1,158,314**	**395,641**	**34.2**
2	Singida	Singida Rural	138	138	92,845,015	400,377	188,177	47.0
		Manyoni	75	63	21,722,103	206,570	90,900	44.0
		Iramba	122	120	36,140,000	368,131	112,000	30.4
		Total	**335**	**321**	**150,707,118**	**975,078**	**391,077**	**40.1**
3	Dodoma	Dodoma Rural	114	109	94,871,691	440,555	326,010	74.0
		Kondoa	137	139	41,338,130	429,824	335,263	78.0
		Total	**251**	**248**	**136,209,821**	**870,379**	**661,273**	**76.0**
4	Shinyanga	Kishapu	109	108	9,540,000	240,086	107,379	44.7
		Maswa	451	450	15,463,738	274,362	152,345	55.5
		Meatu	445	445	14,000,000	233,473	114,114	48.9
		Shinyanga Rural	337	292	17,520,000	277,518	129,362	46.6
		Total	**1,342**	**1,295**	**56,523,738**	**1,025,439**	**503,200**	**49.1**
5	Arusha	Arumeru	50	50	51,000,000	550,242	330,145	60.0
		Monduli	63	57	28,636,160	198,806	81,511	41.0
		Karatu	35	30	30,900,000	189,890	89,451	47.1
		Ngorongoro	17	17	335,000	141,267	63,590	45.0
		Total	**165**	**154**	**110,871,160**	**1,080,205**	**564,697**	**52.3**
6	Manyara	Babati	79	69	4,600,000	302,253	141,967	47.0
		Mbulu	40	16	5,521,581	237,280	102,000	43.0
		Simanjiro	32	32	28,517,000	141,136	68,005	48.2
		Kiteto	40	37	2,943,651	152,296	55,740	36.6
		Hanang	53	48	7,239,000	204,640	104,555	51.1
		Total	**244**	**202**	**48,821,232**	**1,037,605**	**472,267**	**45.5**
Grand Total		**-**	**2,703**	**2,419**	**521,592,164**	**6,147,020**	**2,988,155**	**48.6**

Another data source is available from Water Aid, which is NGO of United Kingdom. Data are shown in **Table 9-3** and the water supply ratio map is shown in **Figure 9-1**. The definition of water supply ratio is slightly different from above data. This data is shown the ratio of improved water source within all water sources. The improved water sources are treatment water from river or dam, borehole, and protected dug wells. While, all water source may include river, pond, charco dam, unprotected dug well, and traditional dug wells. Additionaly, this data is not including the area which is covered by urban water supply., e.g. Singida, Manyoni, etc. The urban area has much higher ratio.

In this data, the water supply ratios are very low in Sikonge and Igunga in Tabora region. The highest ratio is Arumeru in Arusha region. This result is used to consider the potential evaluation for groundwater development.

Table 9-3 Ratio of Households with Access to Improved Water Source

District	Population	% Using improved	Breakdown by type of source (%)			
			Piped	Protected	Unprotected	Other
Arusha Region	854,491	**63.4**	52.6	10.8	39.5	0.8
Monduli	160,521	**39.2**	29.1	10.1	60.7	0.1
Arumeru	421,495	**81.8**	71.5	10.3	16.8	1.4
Karatu	168,514	**61.3**	53.3	8.00	38.6	0.1
Ngorongoro	122,838	**30.8**	12.9	17.9	69.1	0.1
Dodoma Region	1,478,782	**50.3**	38.6	11.7	49.6	0.1
Kondoa	409,877	**36.5**	28.9	7.6	63.5	0.1
Dodoma Rural	431,001	**50.8**	39.8	11.0	49.2	0.0
Dodoma Urban	173,631	**38.2**	19.6	18.6	61.8	0.0
Manyara Region	896,886	**33.7**	22.2	11.5	65.8	0.5
Babati	260,664	**48.7**	36.7	12.0	51.3	0.0
Hanang	185,081	**40.3**	30.3	10.1	59.7	0.0
Mbulu	218,159	**16.5**	3.6	12.9	83.5	0.0
Simanjiro	99,672	**36.6**	16.2	20.4	62.4	1.0
Kiteto	133,310	**18.1**	14.0	4.1	79.7	2.2
Shinyanga Region	2,540,578	**33.7**	6.0	27.6	65.7	0.6
Maswa	279,466	**31.7**	12.7	19.0	68.3	0.0
Shinyanga Rural	275,357	**26.5**	0.6	26.0	69.1	4.3
Kahama	528,840	**32.6**	3.0	29.6	67.3	0.1
Meatu	241,389	**36.1**	5.4	30.6	63.8	0.2
Shinyanga Urban	60,755	**60.6**	19.3	41.3	36.9	2.5
Kishapu	226,136	**9.6**	3.2	6.4	90.3	0.1
Singida Region	938,081	**33.9**	10.3	23.6	66.1	0.0
Iramba	334,355	**29.7**	10.3	19.4	70.3	0.0
Singida Rural	379,613	**38.1**	4.7	33.4	61.9	0.0
Manyoni	167,164	**33.6**	23.9	9.8	66.3	0.0
Singida Urban	56,949	**32.0**	6.5	25.5	68.0	0.0
Tabora Region	1,490,581	**11.8**	0.5	11.3	88.1	0.0
Nzega	385,877	**20.5**	0.0	20.5	79.5	0.0
Igunga	303,952	**5.0**	0.3	4.7	94.8	0.2
Uyui	276,793	**10.4**	1.1	9.3	89.6	0.0
Sikonge	123,493	**4.0**	0.1	4.0	96.0	0.0
Tabora Urban	60,118	**10.9**	5.3	5.7	89.1	0.0

Source: Water Aid (2005): Water and Sanitation in Tanzania

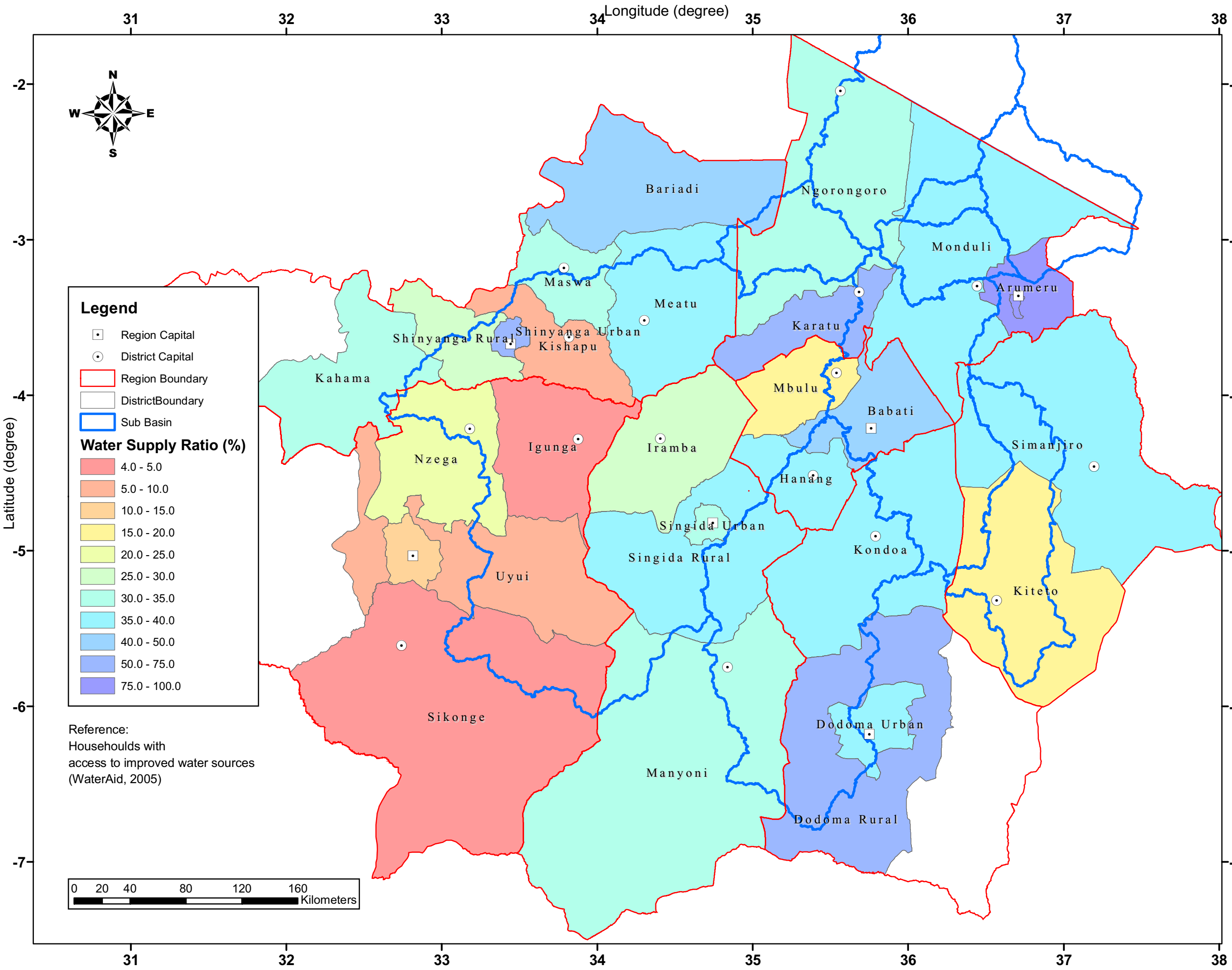

Figure 9-1 Rural Water Supply Ratio by District in IDB

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

The aggregated result of the provisional water supply facilities database is shown in **Table 9-4**. The ratio of water resource type in each region is shown in **Figure 9-2**.

Table 9-4 Aggregated Result of Water Supply Facilities

Region	District	Village	Piped Boreholes			H/P Boreholes			Dug Well			Dam			Charco Dam			Gravity Scheme		
			F	N/F	Ratio (%)	F	N/F	Ratio (%)	F	N/F	Ratio (%)	F	N/F	Ratio (%)	F	N/F	Ratio (%)	F	N/F	Ratio (%)
Arusha	Monduli	65	17	0	100.0	1	0	100.0	1	0	100.0	60	0	100.0	0	0	0.0	28	0	100.0
	Karatu	45	0	0	0.0	15	1	93.8	9	0	100.0	0	0	0.0	1	0	100.0	0	0	0.0
	Arumeru	146	8	0	100.0	4	0	100.0	0	0	0.0	4	0	100.0	0	0	0.0	126	0	100.0
	Ngorongoro	37	3	0	100.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	15	0	100.0
	Sub-total	***293***	***28***	***0***	***100.0***	***20***	***1***	***95.2***	***10***	***0***	***100.0***	***64***	***0***	***100.0***	***1***	***0***	***100.0***	***169***	***0***	***100.0***
Manyara	Babati Rural	43	0	1	0.0	61	16	79.2	6	1	85.7	0	0	0.0	0	0	0.0	13	4	76.5
	Babati Urban	14	1	0	100.0	15	1	93.8	0	0	0.0	0	0	0.0	0	0	0.0	11	2	84.6
	Hanang	63	0	3	0.0	4	10	28.6	8	6	57.1	1	0	100.0	0	0	0.0	20	0	100.0
	Kiteto	48	21	0	100.0	0	0	0.0	2	0	100.0	0	0	0.0	0	0	0.0	6	0	100.0
	Mbulu	71	0	0	0.0	33	12	73.3	62	25	71.3	0	0	0.0	0	0	0.0	8	0	100.0
	Simanjiro	47	19	2	90.5	42	9	82.4	237	14	94.4	6	0	100.0	6	0	100.0	15	0	100.0
	Sub-total	***286***	***41***	***6***	***87.2***	***155***	***48***	***76.4***	***315***	***46***	***87.3***	***7***	***0***	***100.0***	***6***	***0***	***100.0***	***73***	***6***	***92.4***
Dodoma	Dodoma Rural	131	84	55	60.4	0	0	0.0	165	17	90.7	6	0	100.0	0	0	0.0	0	0	0.0
	Dodoma Urban	9	9	0	100.0	0	0	0.0	22	0	100.0	0	0	0.0	0	0	0.0	1	0	100.0
	Kondoa	171	83	15	84.7	5	0	100.0	98	6	94.2	5	0	100.0	7	0	100.0	96	7	93.2
	Sub-total	***311***	***176***	***70***	***71.5***	***5***	***0***	***100.0***	***285***	***23***	***92.5***	***11***	***0***	***100.0***	***7***	***0***	***100.0***	***97***	***7***	***93.3***
Shinyanga	Maswa	103	2	2	50.0	0	0	0.0	0	0	0.0	23	3	88.5	0	0	0.0	0	0	0.0
	Meatu	64	2	0	100.0	0	0	0.0	392	37	91.4	1	0	100.0	1	0	100.0	0	1	0.0
	Kishapu	103	4	1	80.0	0	1	0.0	172	0	100.0	9	0	100.0	7	0	100.0	0	0	0.0
	Shinyanga Urban	26	33	36	47.8	185	51	78.4	0	0	0.0	8	0	100.0	0	0	0.0	0	0	0.0
	Shinyanga Rural	106	19	0	100.0	0	0	0.0	207	0	0.0	4	4	50.0	0	0	0.0	0	0	0.0
	Sub-total	***402***	***60***	***39***	***60.6***	***185***	***52***	***78.1***	***771***	***37***	***95.4***	***45***	***7***	***86.5***	***8***	***0***	***100.0***	***0***	***1***	***0.0***
Singida	Singida Municipal	19	23	15	60.5	59	5	92.2	249	175	58.7	13	1	92.9	178	4	97.8	0	0	0.0
	Singida Rural	146	33	30	52.4	40	25	61.5	230	194	54.2	4	0	100.0	8	0	100.0	0	0	0.0
	Iramba	125	40	3	93.0	159	59	72.9	56	71	44.1	0	0	0.0	16	12	57.1	0	0	0.0
	Manyoni	73	42	7	85.7	16	10	61.5	9	29	23.7	13	0	100.0	5	4	55.6	1	0	100.0
	Sub-total	***344***	***138***	***55***	***71.5***	***274***	***99***	***73.5***	***544***	***469***	***53.7***	***30***	***0***	***100.0***	***207***	***20***	***91.2***	***1***	***0***	***100.0***
Tabora	Igunga	43	3	0	100.0	11	17	39.3	8	6	57.1	5	0	100.0	15	0	100.0	0	0	0.0
	Nzega	128	7	0	100.0	0	0	0.0	1	0	100.0	7	0	100.0	0	0	0.0	5	0	100.0
	Uyui	29	3	0	100.0	12	4	75.0	12	14	46.2	2	0	100.0	0	0	0.0	0	0	0.0
	Sikonge	53	0	0	0.0	0	0	0.0	38	13	74.5	2	0	100.0	2	0	100.0	1	0	100.0
	Sub-total	***253***	***13***	***0***	***100.0***	***23***	***21***	***52.3***	***59***	***33***	***64.1***	***16***	***0***	***100.0***	***17***	***0***	***100.0***	***6***	***0***	***0.0***
Total		**1,889**	**456**	**170**	**72.8**	**662**	**221**	**75.0**	**1,984**	**608**	**76.5**	**173**	**7**	**96.1**	**246**	**20**	**92.5**	**346**	**14**	**96.1**

F: Functioning N/F: Not Functionaing

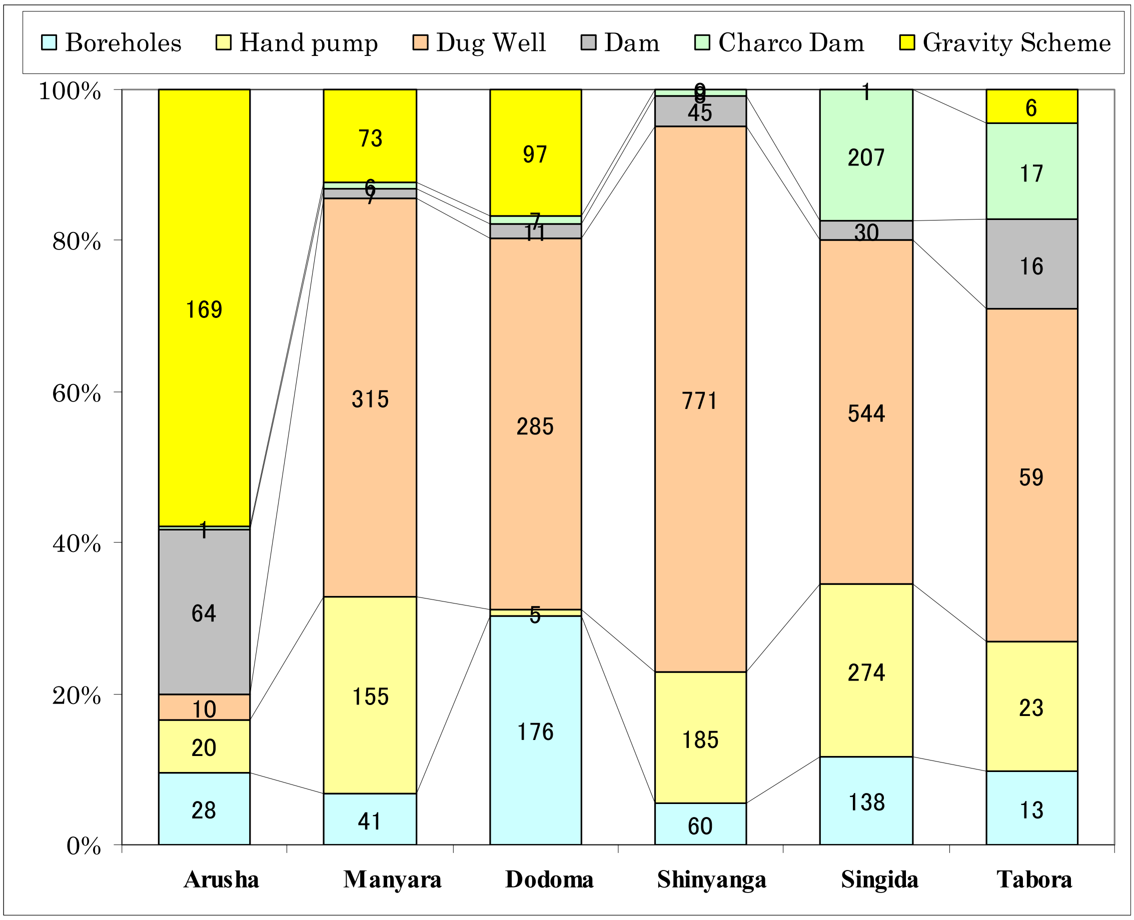

Figure 9-2 Water Source Type of each Region

Piped Borehole, H/P Borehole and Dug well is recognized as using groundwater. Dam, Charco Dam and Gravity scheme (river or spring) is recognized as using surface water.
Whereas the dependence rate for surface water in Arusha Region is 80%, other regions are highly depending on groundwater.

9.2 Inventory Survey of Existing Water Supply Facilities

In order to obtain the basic information for hydrogeological conditions in IDB, the inventory survey of existing water supply facilities was conducted. As mentioned above, almost all of the collected existing data have no position data. To understand the hydrogeological condition of very wide area such as IDB, it is necessary to know the position of each data. The purpose of inventory survey is to check the borehole positions.
500 villages, which were mentioned in the borehole catalogue and were able to know approximate locations, were selected for the inventory survey. The selected villages were distributed evenly in IDB area.
Survey team measured the positions of boreholes at the field survey. In addition, water level of the well and water quality, which items are same as the simplified water quality survey, were measured at same time.
Inventory survey targeted at borehole. As the result of the inventory survey was to analyze the hydrogeological conditions in IDB, boreholes were selected for main water source as a water supply facilities. However, when survey team visited the selected village, there were many cases here the target borehole did not exist. In this case, survey team tried to select alternative water source such as dug well or dam or spring.

9.2.1 Survey items

Survey items for the inventory survey are shown in **Table 9-5**.
First, survey team visited the village office, and asked village officer the administrative locations (division, ward and village name) and the position of water source (borehole). Next, survey team visited the water source, and measured the position by GPS, and measured water level and water quality. Additionally, they interviewed the inhabitants about water usage. As for borehole specification, they investigated at the DWE's office as much as possible.

Table 9-5 Survey Items of Inventory Survey

No.	Item	Sub-item
1	No.	Serial No.
2	Political location	Region
3		District
4		Division
5		Ward
6		Village
7		Subvillage
8	Position	Latitude (S)
9		Longitude (E)
10		Altitude (m)
11		Accuracy (m)
12	SWL	S.W.L. (m)
13	Borehole Specification	Borehole No
14		Construction Date
15		Constructed By (Donor)
16		Depth (m)
17		Static Water Level (m)
18		Water Struck (m)
19		Yield (m^3/h)
20		Pump Type
21		Dynamic Water Level (m)
22		Diameter (inch)
23		Screen Depth (m)
24		Geology
25		Aquifer Type

No.	Item	Sub-item
26	Water quality	Temperature (℃)
27		EC (mS/m)
28		pH
29		ORP (mV)
30		S [mgS/L] (ppm)
31		F [mgF-/L] (ppm)
32		As [mgAs3+/L] (ppm)
33		NH4 [mgNH_4^+/L] (ppm)
34		NO3 [mgNO_3^-/L] (ppm)
35		Fe [mgFe/L] (ppm)
36		Mn [mg/L Mn] (ppm)
37		Coliform
38	Facility	Faucet Type
39		Faucet No per B/H
40		Tank Capacity (m^3)
41	Hygine Condition	Fence around B/H
42		Comment
43		Dis. Nearest Toilet (m)
44		Comment
45		Drainage around the faucet
46		Comment
47	Water use condition	Users' Number
48		Water use quantity

No.	Item	Sub-item
49	Water source in the village	Dam
50		River
51		Streams
52		Spring
53		Borehole
54		Dug well
55		Shallow well
56		Water hole
57		Pond
58		Rain water
59		Others
60		Remarks

9.2.2 Inventory Survey Result

Total number of villages and the distribution of surveyed points are shown in **Figure 9-3** and **Table 9-6** respectively.

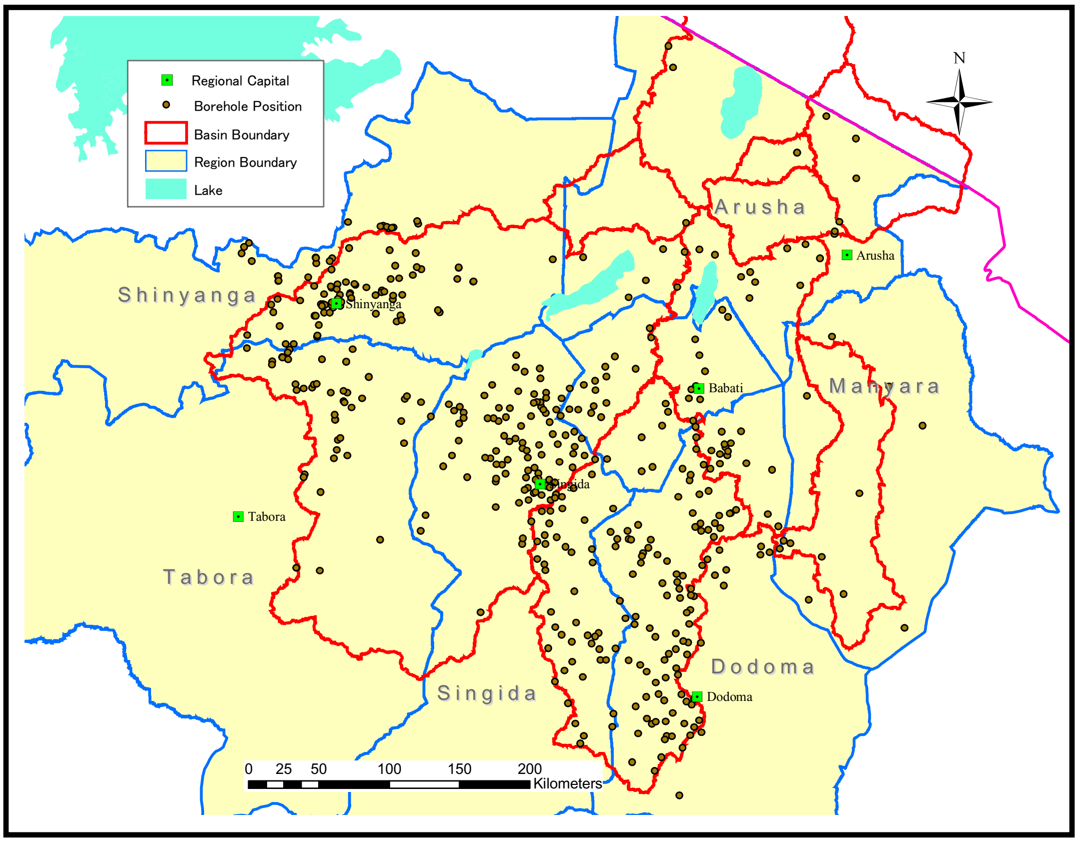

Figure 9-3 Distribution map of Surveyed Points for Existing Water Supply Facilities Inventory Survey

Table 9-6 Number of Surveyed Village and Points in Each District

Rigion	District		Planed village No.	Surveyed village No.	Surveyed Point No.
Singida	1	Iramba	49	49	53
	2	Manyoni	27	26	28
	3	Singida Rural	41	41	44
	4	Singida Urban	23	23	24
Tabora	5	Igunga	29	22	27
	6	Nzega	11	11	17
	7	Sikonge	1	1	1
	8	Uyui	2	2	2
Shinyanga	9	Kishapu	14	11	17
	10	Maswa	13	10	17
	11	Meatu	7	7	8
	12	Shinyanga Rural	22	22	28
	13	Shinyanga Urban	26	23	31
Arusha	14	Arumeru	5	5	5
	15	Karatu	8	8	8
	16	Monduli	17	17	17
	17	Ngorongoro	4	4	4
Manyara	18	Babati	23	23	23
	19	Hanang	18	18	18
	20	Kiteto	6	6	6
	21	Mbulu	25	25	25
	22	Simanjiro	7	7	7
Dodoma	23	Dodoma Rural and Urban	51	49	51
	25	Kondoa	71	70	73
Total			**500**	**480**	**534**

Some villages, which were specified before survey, could not be surveyed, because of extremely bad condition of roads or no alternative points available. However, the surveyed points reached 534 in total including alternative points. The results of the borehole inventory survey are shown in the Database.
The drilling depth in the survey item was shown as drilling depth distribution. Next, the static water level. These results were used for hydrogeological analysis and groundwater development evaluation. These are related to economic condition of well construction as explained below.

(1) Drilling Depth Distribution

Drilling depth distribution of existing boreholes is shown in **Figure 9-4**. Although each borehole has different condition, this distribution can be considered to show the feature of the effective aquifer depth in this area. Unless it is test well drilling like this project, it can be considered that it shows the depth which has no other choice to drill in order to be secured of the required quantity of groundwater. Additionally, this distribution can be considered to show the economic condition of well construction. Because, the drilling cost rises more as deeper the borehole is drilled.

The drilling depth is shallower in the western part and central part than the southern east and the northern east part of IDB.

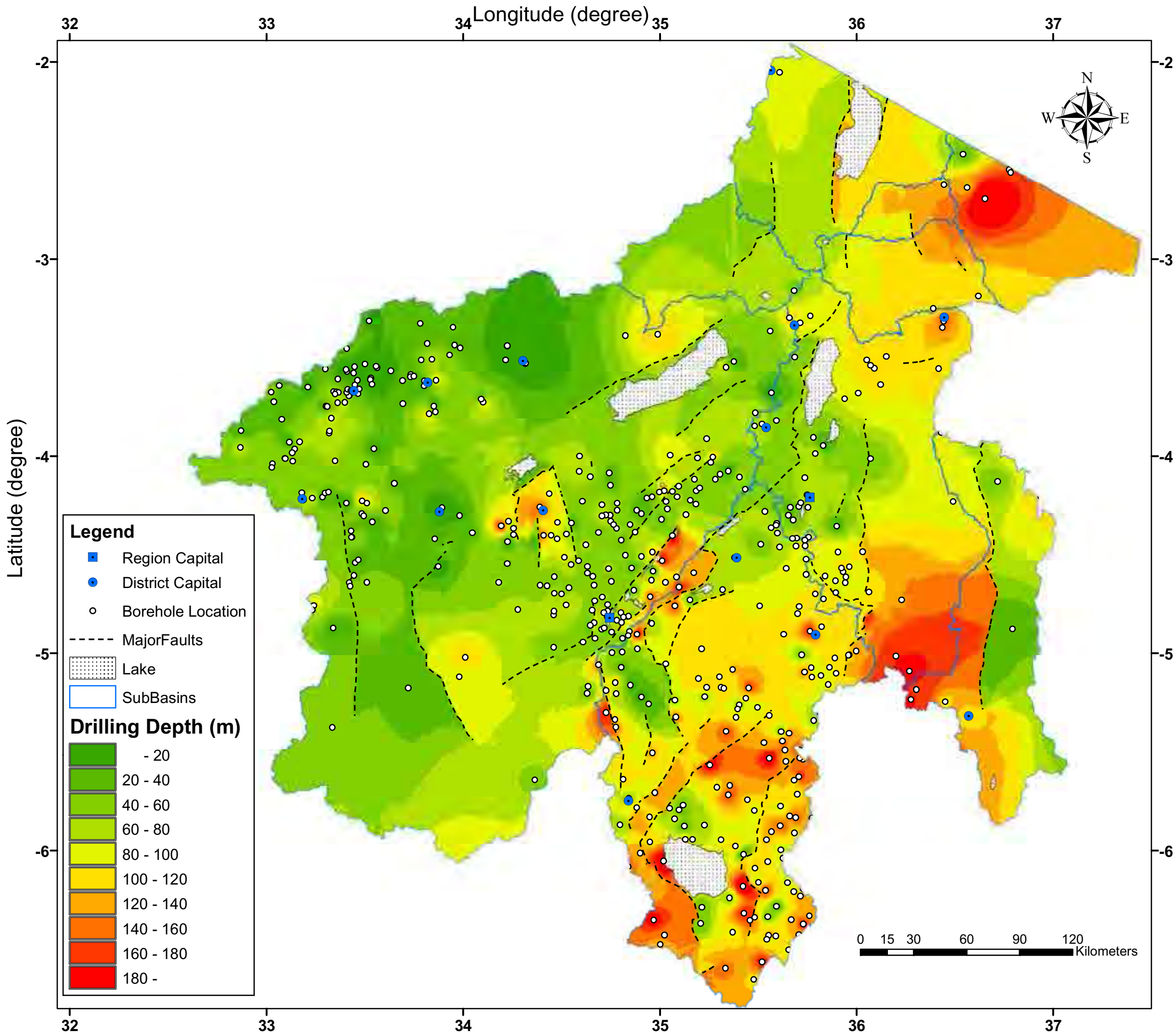

Figure 9-4 Drilling Depth Distribution Based on Inventory Survey

The drilling depths in each area are shown as follows:

- ✓ Arusha region (except Karatu district): 100-200m,
- ✓ Kiteto and Kondoa district: 80m - 200m,
- ✓ Karatu, Mbulu, Babati, Simanjiro and Hanang district: 40-100m,
- ✓ Dodoma and Manyoni district: 80-180m,
- ✓ Singida, Iramba district: 40-140m,
- ✓ Igunga, Nzega, Uyui and Sikonge district: 20-100m,
- ✓ Shinyanga, Kishapu, Meatu and Maswa district: 20-60m,
- ✓ Western part of Hanang and Eastern part of Singida: 80-200m.

(2) Static Water Level Distribution

Static water level distribution of existing boreholes is shown in **Figure 9-5**. This distribution is including the results of test well drilling in this project.

Static water level is related to the running cost. Because, it needs a higher power of pump at deep static water level area. While, in shallow area, a hand pump is considered to be enough. Static water level distribution is similar shape as the drilling depth distribution. The features of static water level distribution are shown as follows:

- ✓ Arusha region (except Karatu district): 50-100m,
- ✓ Kiteto and Kondoa district: 40m - 100m,
- ✓ Simanjiro, Karatu, Mbulu, Babati district: 15-30m,
- ✓ Western part of Dodoma and Northeastern part of Manyara district: 100-140m,
- ✓ Southwestern part of Manyara: 25-40m,
- ✓ Singida, Iramba, Igunga, Nzega, Uyui and Sikonge district: 5-20m,
- ✓ Shinyanga, Meatu, Kishapu and Maswa district: 5-15m, and
- ✓ Hanang, eastern part of Singida, western part of Kondoa and eastern part of Dodoma district: 30-50m.

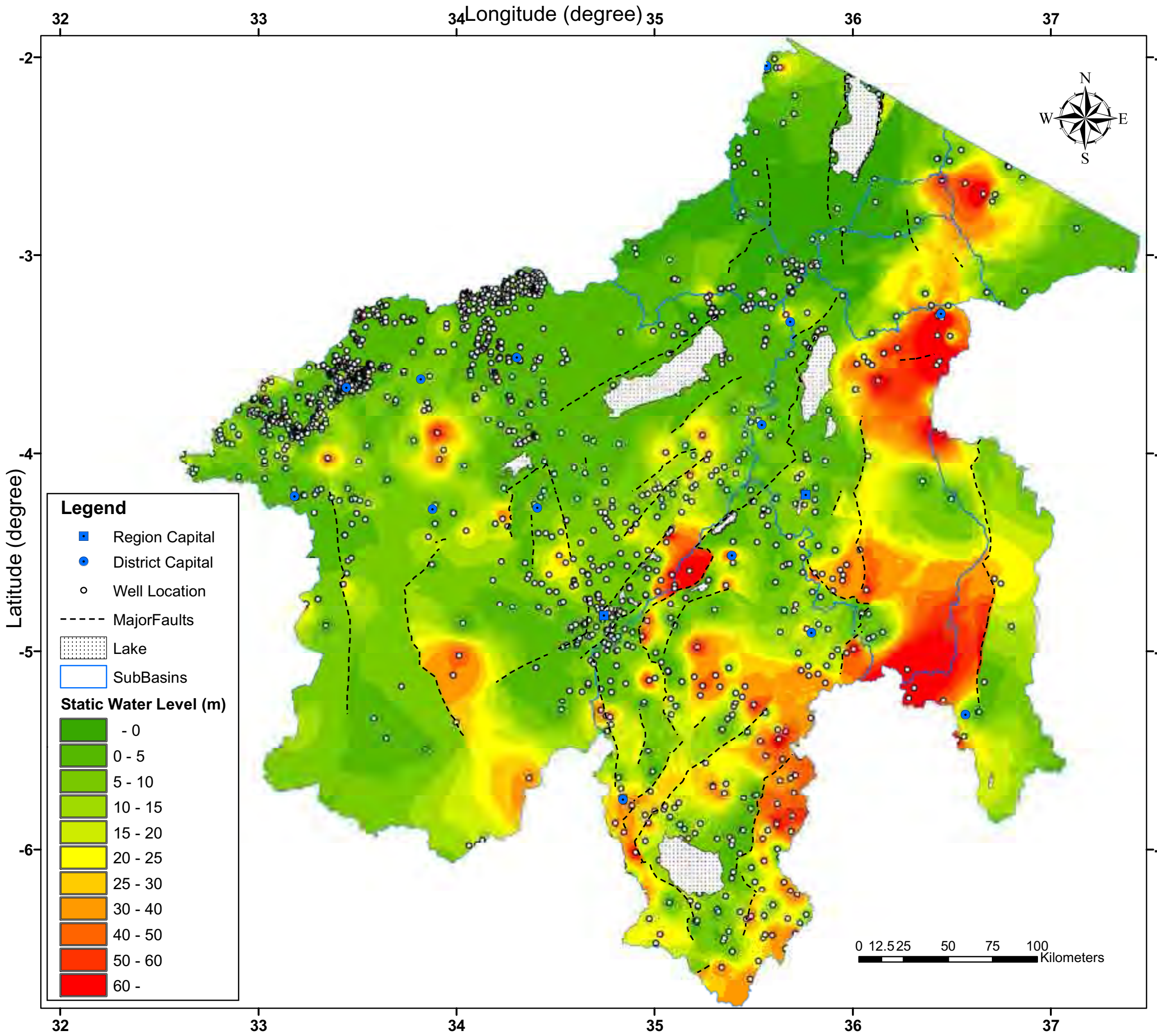

Figure 9-5 Static Water Level Distribution in IDB

9.3 Hydrogeological Condition on each Geological Unit

Geological condition was mentioned in chapter 3. In this section, hydrogeological condition in IDB is expressed based on each geological unit. Stratum aquifer is expected to be in the Tertiary and recent sediment area. Other rocky areas, which are granitic rock, Metamorphic rock, and volcanic rock areas, are expected as fissure aquifer.

9.3.1 Granitic rock area (gs, gs-a, gs-b)

Granite is distributed widely in Shinyanga, Tabora, Singida, and Dodoma Region. Granite is a coarse grained igneous rock. Characteristically, granite is easy to be weathered and has many fractures near the surface. Weathered granite forms sandy state near surface. Clay mineral called "Kaoline" derives from weathered granite. The low land such as pocket or small basin accumulates this clay called "Mbuga". This is good material for brick. Additionally, fractures occur not only vertical but also horizontal in granitic rocks. Through weathering processes, many small hills of granite called "Inselberg" with more resistant rock masses are observed in granite area.

This granite area is formed in Archean period mainly. The granite was uplifted, followed by weathering and erosion of the uplifted mountain, and finally pediplain was formed. Inselberg is a remaining hill in such a pediplain.

Inselberg in Singida

Groundater in weathered zone, which is regarded as stratum water, and fissure water in fissure zone are expected in the granite area. However, both of the aquifers are different from ordinary aquifer in stratum like sand or gravel layer. It is more complex structures. Therefore, thickness of the weathered layer or the place which has much fissure has to be investigated for groundwater development. Additionally, it is also known that granite contains relatively much minerals which contain fluoride. Especially, pegmatite is distributed in some places in the granites area. Fluoride is concentrated in pegmatite as fluorite occasionally. The groundwater which passed through this rock has possibility of high fluoride contents.

Granitic rock area was classified into three units in the Geological map, i.e. "gs", "gs-a" and "gs-b". These are derived by satellite image analysis and existing geological map. The differences among these units are rough texture (gs), intermediate grade (gs-a) and smooth texture (gs-b) of topographic feature on the satellite images.

(1) Rough texture (gs):

Many inselbergs are remaining in this area. Each inselberg is expected to be a special recharge place for groundwater in rainy seasons. Surrounding the inselberg or the places which have many faults or lineaments are expected high possibility of groundwater development. When the investigations are conducted, the existence and direction of faults and lineaments will be confirmed by geological maps or satellite images. In the field survey, both resistivity and magnetic or electromagnetic surveys shall be conducted to confirm the area's thickness of weathered zone or existence of fissure and faulted zones.

Since the surface of this area are covered by granitic sand which is high hydraulic conductivity, groundwater is expected at the lower part of weathered zone, i.e. the upper part of fresh rock. The place which has deep bedrock depth area has advantage in such a weathered area. This area can be surveyed by resistivity method. On the other hand, fissure zone can be detected by magnetic or electromagnetic survey. Although the resistivity survey method can be applied for fissure zone, the magnetic or electromagnetic surveys are more effective. However, the place which has high resistivity (over 500 Ωm) without weathered zone is very difficult to get groundwater.

Expected drilling depth in this area is 30 to 60 m.

(2) Intermediate grade (gs-a):

This area is covered by thick weathered granites. Therefore, groundwater is expected in the weathered layer. Mainly resistivity survey is used in this area. If much amount of water is required, fissure zone shall be investigated, but it is more difficult than "gs" area.

Expected drilling depth is 50 to 70 m.

(3) Smooth texture (gs-b):

This flat area is covered by hard sediment layer called "Kilimatinde Cement" which is accumulated by calcite or silicate. Since the Kilimatinde cement has a low hydraulic conductivity, groundwater recharge from the surface is not very much expected. It needs to confirm the existence of fault or inselberg using geological maps or satellite images. Since the thickness of Kilimatinde cement is expected to have a maximum 30 m, groundwater is expected under this layer if there is such a geological formation around the area.

Expected drilling depth is 50 to 100 m.

9.3.2 Metamorphic Rock area, Usagaran system (Xs, Xs-a, Xs-l)

Metamorphic rock called "Usagaran" as a part of the Mozambique metamorphic belt is distributed in the north part of Arusha, Manyara and Dodoma regions. The areas consist of older granitic and sedimentary rocks were metamorphosed by the orogenic movement of intrusion of granites. Therefore, some large scale foldings are lain in the axis of north-south direction. The rock is mainly gneiss.

Hydrogeological condition is almost same as granite.

Gneiss, which is origin by a granite, is more easy to be weathered than granite, and it forms wide pediplain. Massai Steppe is one of such kind of pediplains. Though this area has no rainfall gauges, and since the rainfall in Massai Steppe is supposed to be very small, this area is one of the most difficult place for groundwater development.

Usagaran was classified into three units in the Geological map, i.e. "Xs", "Xs-a" and "Xs-l". These were derived by satellite image analysis and existing geological map. The differences among these geological units are rough texture (Xs), intermediate grade (Xs-a) and smooth texture (Xs-l) of topographic feature on the satellite images.

(1) Rough texture (Xs):

Gneiss is distributed in this area. This area is in a high altitude. Weathered gneiss is considered to form colluvial deposits around inselbergs. Inselbergs in this metamorphic rock area have wider skirts than one in granite area. Hydrogeological condition is almost same as granite (gs). Surrounding of the inselberg or the place which has many faults or lineaments are expected to have high possibility of groundwater development. The place which has deep bedrock depth area has advantage in such a weathered area. This area can be interpreted by resistivity survey. On the other hand, fissure zone can be detected by magnetic or electromagnetic survey methods. Although the resistivity survey can be applied for fissure zone, the magnetic or the electromagnetic survey methods are more effective.

Mountain of Gneiss at Mbulu

Expected drilling depth is 40 – 80 m.

(2) Intermediate grade (Xs-a):

This area is corresponding to gs-a in the granite area. Xs-a is lain like a hilly band along the axis of folding in the Geological map. These hilly areas are expected as a recharge area of groundwater, and the recharged water can be expected to form aquifer in the weathered zone. Therefore, the resistivity survey is used in this area mainly. If much amount of water is required, fissure zone should be investigated, though it is more difficult than "Xs" area.

Stripes on Gneiss at Kiteto

Expected drilling depth is 50 to 100 m.

(3) Smooth texture (Xs-l):

This flat area is covered by thick weathered layer, and formed pediplain called "Massai Steppe". In this area, the existing geological map shows scarcely any fault or lineament. Since the weathered layer has high hydraulic conductivity, groundwater is in the deep part of weathered layer. Resistivity survey is effective for presuming the thickness of weathered layer.

River Bed at Kondoa

Expected drilling depth is 70 to 150 m.

9.3.3 Dodoman System (D)


Outcrop of Dodoman Formation

Dodoman System, which is the oldest formation in Tanzania, is distributed in the central part of Dodoma region. This consists of the metamorphic rocks, which are metamorphosed from sedimentary and granitic rocks in Archean. the rocks are schist, gneiss, and migmatites, etc.
Since the rock of Dodoman system is very dense and is hard to weathering, it forms hilly land around Dodoma town. Hydrogeological condition is almost same as "gs" area in the granite area. Weathered layer or fracture zone in Dodoman series can be developed for groundwater.
Test borehole drilling (TD-5) was drilled at the end of Dodoman series area and boundary of granite area. TD-5 encountered a fissure aquifer in granite zone of Dodoman System
Expected drilling depth is 70-120 m.

9.3.4 Nyanzian System (Z)

Nyanzian System consists of metamorphic rock, which were metamorphosed from sedimentary and igneous rocks. It is distributed in the northern part of Tabora region, the southern part of Shinyanga region, the northern part of Singida region, and a part of Manyara region. Discriminative rock is a banded ironstone, which is distributed in Igunga district, and others are schists and quartzites in this system. Banded ironstone is very dense and hard, groundwater is not expected in the rock. Schist and quartzite are also dense, but some groundwater is expected in fissure part of the rocks. Nyanzian system is surrounded by granite at many places. The place which contacts with granite is expected to have many fractures.
Magnetic or elctromagnetic survey is recommended to investigate the fissure zone. Resistivity survey is not suitable for this area, because the weathered zone is expected very thin.


Amphibolite Schist and Pegmatite dike of Nyanzian formation in Iramba District


Banded Ironstone of Nyanzian formation in Igunga District.

Test borehole drilling (TD-14) was at the foot of hill of Nyanzian formation. Although groundwater was expected on the upper part of Nyanzian rock, a thick clay layer was encountered, there is no groundwater.
Test borehole drilling (TD-10) was expected to be drilled in the Nyanzian formation, however granitic rock was encountered at a shallow depth. Finally, groundwater was obtained from fissure zone in the granite.
Expected drilling depth is 40-100 m.

9.3.5 Volcanic Area (Nv and Nvd)

Lava flow, volcanic ash and pyroclastic flow sediment from the recent volcano in Neogene are distributed in Arusha region and a part of Manyara regon. Almost all volcano consist of alkaline type volcanic rocks such as alkali basalt or trachyte. These volcanic activities occurred during the same period as the movement of the Great Rift Valley. Hot springs are flown out along the Great Rift Valley, e.g. the west shore of Lake Manyara and the east of Singida region, etc.

Volcanic products which include much fluoride were erupted from some volcano locally. Especially, Mt. Oldoinyo Lengai,, the active volcano, erupts a special kind of lava called “carbonatite”, which is including much fluoride. Mt. Meru, which is in the back of Arusha town, is presumed to erupt carbonatite lava also.


Mt. Oldoinyo Lengai

Volcanoes in this area are classified into old and young volcanoes. Old volcanoes erupted a low viscosity lava, i.e. flood basalt, in the wide range. These volcanoes formed very wide volcanic rock area from Mt. Kilimanjaro to Mt. Ngorongoro. Young volcanoes, which are Mt. Oldoinyo Lengai, Mt. Meru, or Mt. Hanang etc., are considered to erupt materials which include much fluoride.

Groundwater development in this area is very difficult. It needs much consideration in order to decide a drilling site. However, if an aquifer is found, the yield of borehole can be expected to be high.

Volcanic products in this area are volcanic ash, scoria, pyroclastic flow and basalt lava. Volcanic ash is powdered state, it goes up in the sky, and it is diffused to wide area by wind. Scoria is fizzy grain, which is from several millimeters to several dozen millimeters in diameter. Pyroclastic flow is the phenomena that the eruption products flow down with high speed and with high temperature involving surrounding rocks from the top of volcano. Lava is molten material of rock extruded from volcano, and becomes solidified by cooling rapidly. Volcanic ash has high hydraulic conductivity generally. However, for its fine grain, when volcanic ash accumulates and solidified with water, it becomes low hydraulic conductivity. Scoria and pyroclastic flow sediments are also relatively high hydraulic conductivity. Basaltic lava has many cracks on the upper and lower part which were facing air and ground, and these part has high hydraulic conductivity. From these characteristics, volcanic area can be considered to have much possibility of groundwater development because of high hydraulic conductivity. Additionally, this mountainous area has much rainfall and high water retentivity. However, the water level becomes very deep due to the very thick volcanic ash and pyroclastic sediments, which has high hydraulic conductivity. Therefore, groundwater development is very difficult.

Basaltic materials have relatively low resistivity itself. It is difficult to decide the drilling point and its depth by resistivity survey method only. Topographic feature and the position of springs are very important information for selecting the drilling point.

Expected drilling depth is 100-250 m.

9.3.6 Tertiary and Recent Sediment (N, Nl, and Nf)

Sand and clay are thickly accumulated in the end of drainage system by river flowing. In IDB area, river is never flowing out to the ocean. River water which dissolved much mineral by passing through the underground flows to lakes or swamps as the end of each sub-basin, and later evaporates there. Lakes and swamps increase the concentration of the minerals by evaporation, and hence the accumulation of salts of various types. Therefore, the groundwater in the lake sediments has much concentration of such kind of salts.

Villagers are taking salt from edge of Bahi swamp in dry season

Clay layer has very low permeability. It behaves as aquiclude. Sand layer and gravel layer has high permeability. These layers are expected as good aquifer in this area. However, even when a good aquifer is found, the water is expected to be saline.

Vertical electric sounding is suitable to investigate the bedrock depth for this area. Most of these areas have very low resistivity, which shows below 10 Ωm, because of clay minerals. Relatively high resistivity layer, which shows 30 to 50 Ωm, is expected as aquifer.

Expected drilling depth is 30-200 m.

9.3.7 Fault System related to the Great Rift Valley

The structural feature of fault system within IDB is related to the Great Rift Valley. Many large scale faults trend north-south or northeast-southwest direction in this area. Basically, these faults which are related to the Great Rift Valley are normal fault; the fracture zone of these faults is presumed to store much groundwater.

Resistivity survey in close to fault scarp (Test borehole No. TD-8, Ikasi, Manyoni).

Some places along the Great Rift Valley have hot springs. Some hot springs are far from active volcano. For example, the west shore of Lake Manyara and the eastern valley of Singida Region are far from any active volcano. The water quality of the hot springs is always poor, because the water is including much mineral.

The dip angle and dip direction of the fault should be considered for the drilling site selection for groundwater development. The dip angle is presumed very steep with consideration of normal fault. Therefore, the drilling site shall be selected in very close to the scarp to be within the width of fault. Expected drilling depth is 70-200 m.

9.4 Groundwater Flow Analysis

Groundwater flow was analyzed by static water level of boreholes and water quality data.

9.4.1 Altitude of Static Water Level

There are two kinds of groundwater level mainly; piezometric head and natural water table, corresponding to the confined aquifer and the unconfined aquifer. The piezometric head varies by the pressure of each confined aquifers. However, in the existing data in this study, the data had to be treated uniformly, although the data were not clear what kind of aquifer or what kind of water level. Most of the result of the test well drilling in this project showed the confined aquifer, if it encountered the aquifer. The confined aquifer usually makes water level rise above the top of the aquifer up to corresponding pressure of the aquifer. The data items in the borehole catalogue are only 5 items; drilling depth, static water level, water struck, yield, and drawdown. Although the borehole catalogue doesn't mention whether it was confined or unconfined, the static water level data which are enough higher than the water struck was recognized as the confined water level. Although it is difficult to dig till confined aquifer in the dug-well, there were some data which could be recognized as the piezometric head by the difference of dug depth and water level. Therefore, some data of shallow wells were used for analysis. Additionally, the spring altitudes which are shown in geological map and are sampled by water quality survey were also used for the hydrogeological analysis, because the spring is recognized as groundwater that comes to the ground surface.

Figure 9-6 shows the groundwater altitude distribution. The altitude of the static water level were calculated from the altitudes of wells measured by GPS and their static water levels measured by deeper.

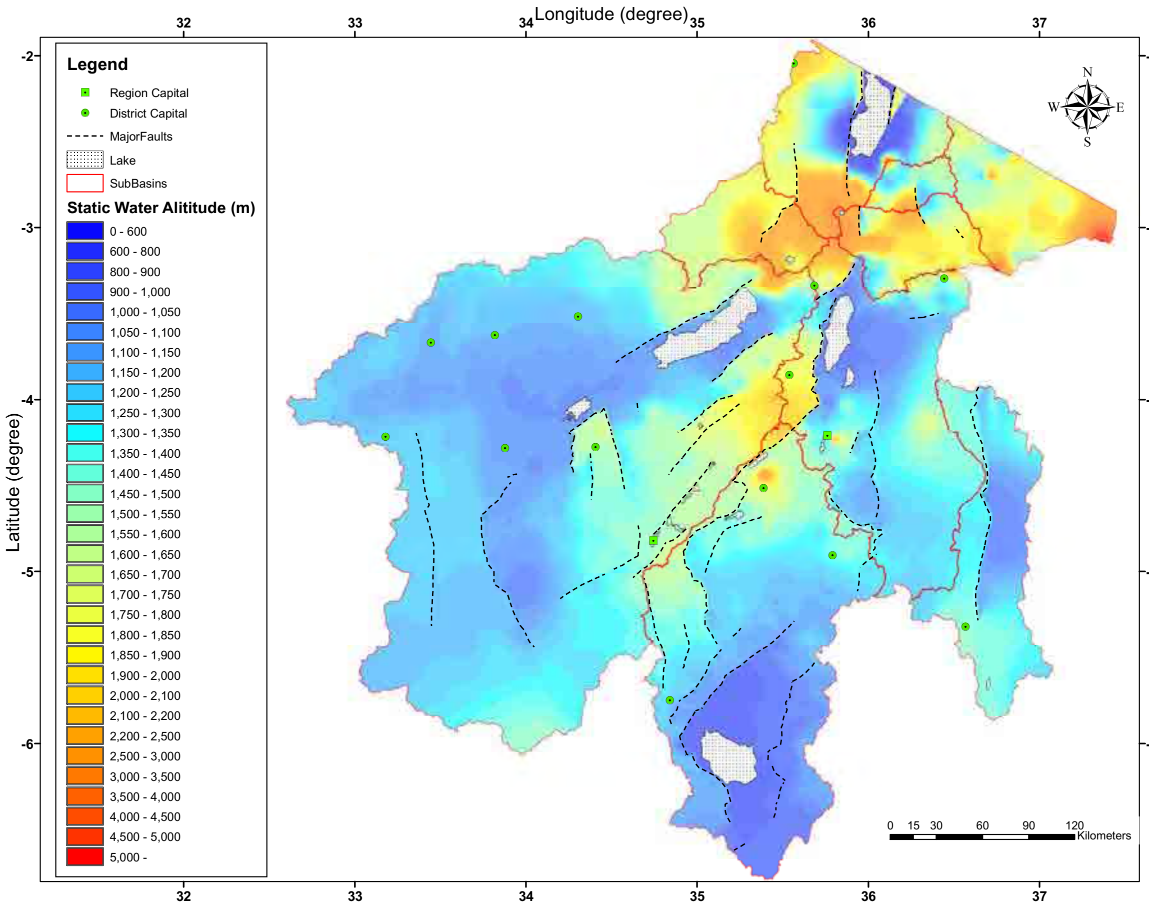

Figure 9-6 Distribution of the Altitude of Static Water Level

9.4.2 Water Quality Hexa-diagram Analysis

Water infiltrates to underground, passes through soil and rock, dissolves minerals from surrounding rock, and flows underground while changing the water quality. Therefore, water flow can be analyzed by comparing water quality in upstrem and downstream of groundwater.

The distribution of water quality hexa-diagram is shown in **Figure 9-7**. The parameters of water quality are Sodium and Potassium(Na^{+}+K^{+}), Calcium(Ca^{2+}), Magnesium(Mg^{+}), Chloride(Cl^{-}), Bi-carbonate(HCO_3^{-}), and Sulfate and Nitrate(SO_4^{2-}+NO_3^{-}). Additionally, the color of the diagram is shown by water source; blue color shows borehole, light blue shows spring, yellow shows shallow well, and orange color shows surface water.

Generally, surface water forms narrow shape as the diagram because the dissolved mineral is few.

Shallow groundwater in shallow well include relatively much bicarbonate. The downstream of groundwater or the constipated groundwater tends to be wider of the width of the diagram because of dissolving various minerals. Especially, the widths of Sodium and Chloride become wider in the downstream side. The dissolutions of Calcium, Magnesium and Sulfate are depending on the geological condition. For comparison, the hexa-diagram of seawater shows cocktail glass shape which only the widths of Sodium and Chloride are wide and others are narrow.

The hexa-diagram of both of borehole and shallow well shows wide width shape in the north of Shinyanga region.

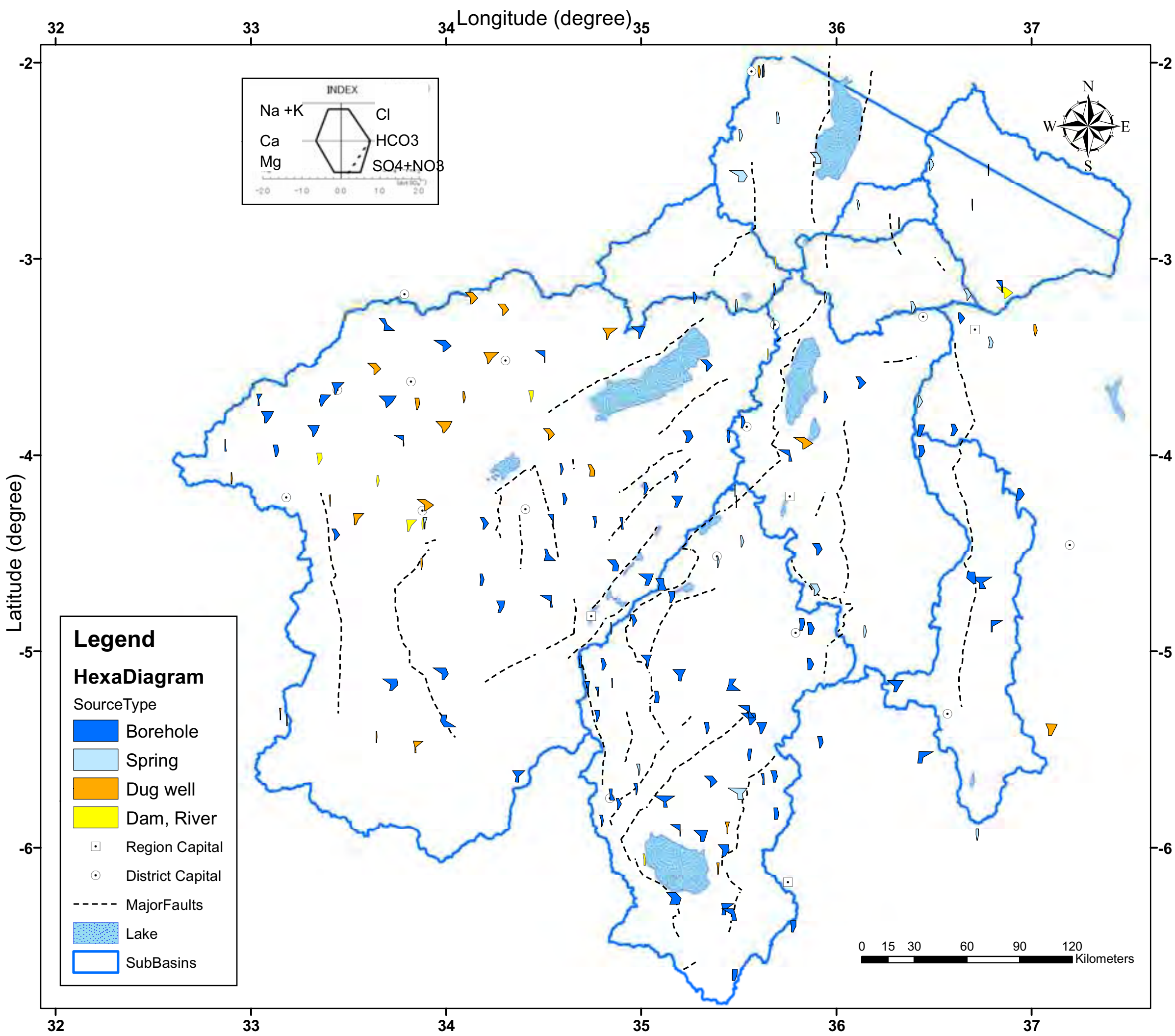

Figure 9-7 Hexa-diagram of water quality in IDB

9.4.3 Groundwater Flow

Groundwater is flowing from high position to low position by gravity. This is the same as the flow of surface water. Therefore, groundwater flow direction can be presumed by tracing the altitude of static water level. Additionally, changing of water quality, which can be recognized by the distribution of hexa-diagram, was considered for groundwater flow analysis. **Figure 9-8** shows the groundwater flow map. This map is showing only horizontal direction of the flow, and the length of the arrow is not showing the flow rate.

Groundwater flow velocity is also estimated from the altitude of static water level. the velocity is calculated by following equation, which is Darcy's law.

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

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.

Groundwater flow velocities are calculated at the test borehole drilling site. The result is shown in **Table 9-7**.

Table 9-7 Groundwater Flow Velocity around Test Borehole Drilling Site

Boring No.	Nature of Aquifer	Hydraulic Conductivity (m/min)	Distance between contour (m)	Interval of the contour (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 gneiss	5.11E-04	14,484	100	1.85	
TD-7	Weathered/Fractured gneiss	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	140.40	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	

The velocities in the granitic rock and metamorphic rock areas are very slow. On the other hand, the velocity in the fault area is faster.