2.3.2 Geology

(1) General Geology

One of the oldest geological units in the world is distributed in Uganda. Eighty percent of the country comprises Precambrian formations, which were formulated 3 billion to 600 million years ago. These rocks are metamorphosed by orogenic movements, which were activated during Precambrian. Although the geology is classified by the period, types, magnitudes of metamorphism and so on in each area, most of the rocks are classified into Gneisses and Granites. After the time to now, The Basin has been on the continental crust and never sunk into the ocean except only once when the transgression of Karoo was happened. The volcanic activities began in the middle Tertiary: 23 million years ago concurrently with the formulation of the Great Rift Valley. It formulated some volcanoes in the eastern part of Uganda, for example: Mt. Elgon.

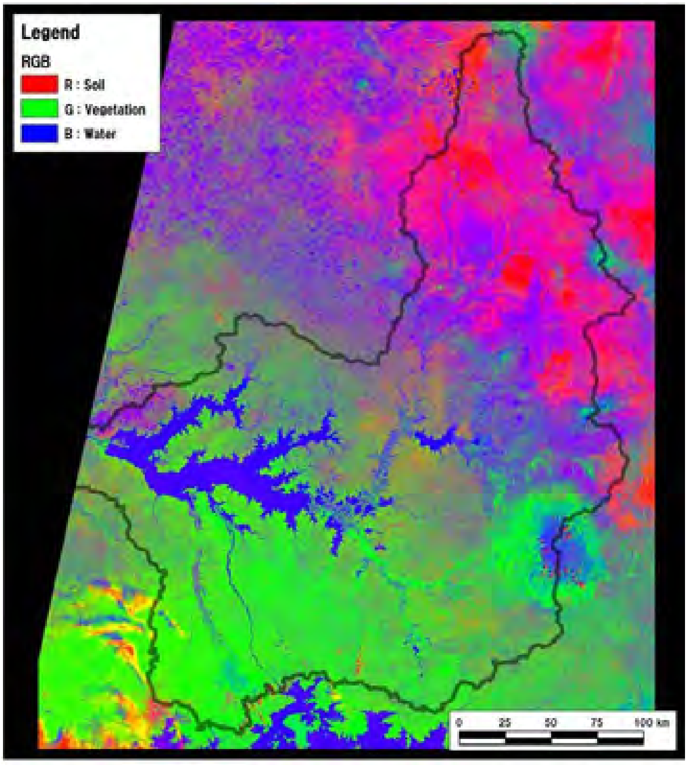


Figure 2-19 VSW Index Image in January 2003

In addition, in the period of forming eastern volcanoes, Mt. Elgon was higher than the current Mt. Kilimanjaro (5,895m), and rivers in Uganda were flowing east to west. However, after forming the Western Rift Valley, a long and thin lake (Lake Obweruka) was formed as combining the current Lake Edward and Lake Albert, and then Ruwenzori Mountains were uplifted, rivers which couldn’t flow to west, formed Lake Victoria and Lake Kyoga. River Nile was formed about 30,000 years ago.

Figure 2-21 shows the geological map of Lake Kyoga Basin. The stratigraphy of the Basin is shown in Table 2-5.

Table 2-5 Stratigraphy of Lake Kyoga Basin

Era	Period	Epoch	Name	Age (Ma)	Symbol	Lithology
Cenozoic	Quaternary	Pleistocene to Recent	Quaternary Sediments	0 - 1.6	P1	Sediments, alluvium, black soils and moraines
Cenozoic	Tertiary	Miocene	Volcanic	12.5 - 25	T	Volcanic Rocks and Associated sediments; Nephelinite, Phonorite,.....
Cenozoic	Tertiary	Miocene - Oligocene	Carbonatite Centre	20 -35	TC	Carbonatite and Syenite
Paleozoic	Lower Permian		Karoo System	256 - 290	KR	Shales
Precambrian	Proterozoic		Aswa Shear Zone	600 - 700	CM	Cataclasite, mylonite
Precambrian	Proterozoic		Karasuk Series	700 - 800	KS	Mozambique Belt: acid gneiss, amphibolites, quartzites, marbles, and granulite facies rocks
Precambrian	Proterozoic		Kioga Series	800 - 1,000	K	Shales, arkoses, quartzites, and tillite
Precambrian	Proterozoic		Granite	1,000 - 1,350	G	Mobilized and intrusive granites
Precambrian	Proterozoic		Buganda-Toro System	1,800 - 2,500	B-T	shales, argillites, phylites, mica-schists, basal quartzites, and amphibolite
Precambrian	Archean		Nyanzian System	2,400 - 2,700	NZ	Metavolcanics, banded ironstones, cherty quartzites and greywackes
Precambrian	Archean		Aruan Techtonic	2,600	A	Banded gneiss
Precambrian	Archean		Watian Series	2,900	W	Granulite facies rock: charnokites, enderbites and retrograded derivatives
Precambrian	Archean		Gneissic -Granulitic Complex	-3,400	GC	Undifferenciated gneiss and granulite facies rock in the north: gneiss, granite, amphibolite, charnockite, enderbite, quartzite
Precambrian	Archean		Gneissic -Granulitic Complex	-3,400	GZ	Granitoid and highly granitized rocks

1) The Atlas of Uganda (1962); Department of Geological Survey and Mines, Ministry of Energy and Mineral.
2) Uganda Geology (2004); Department of Geological Survey and Mines, Ministry of Energy and Mineral.
3) Geology of East Africa (1997);Thomas Schluter, Gebruder Borntraeger.

(2) Geological Structure in Lake Kyoga Basin

The result of image interpretation is shown in Figure 2-20. The clearest lineaments, which can be traced from the northwestern to the central part of the Basin as shown in Figure 4-2, correspond to the Aswa Fault, a zone of mylonites in the Precambrian Basement Complex. Some lineament zones are observed near the northern border of the Basin and Mt. Elgon, but its continuous distribution is not clear.

The beddings are mainly observed in the northern and southwestern part of the study area; the Precambrian banded gneisses are distributed in the northern part, and the Precambrian Toro System composed largely of argillaceous sediments (mainly phyllite and schist) and folded tightly is predominant in the Southwestern part. The circular structures extracted as a cone near Mount Elgon and Napak correspond the carbonatite ring complex, which related to the Cretaceous to Miocene soda-rich volcanism.

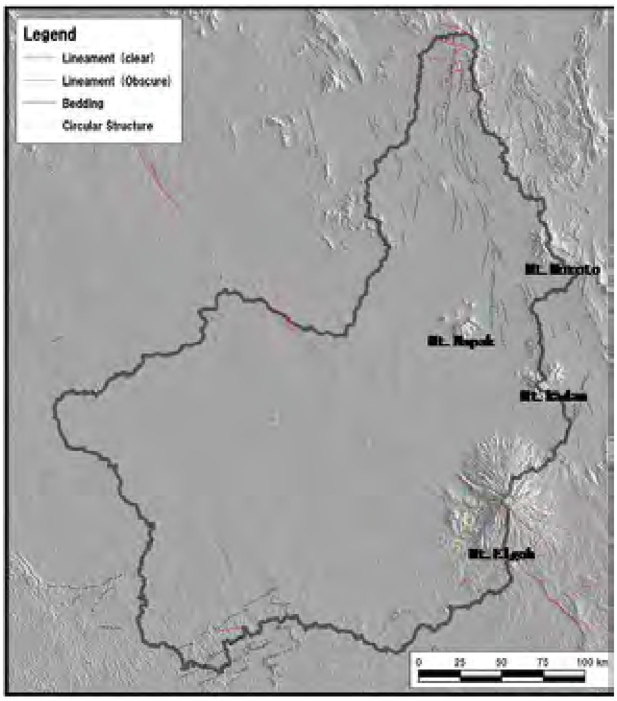
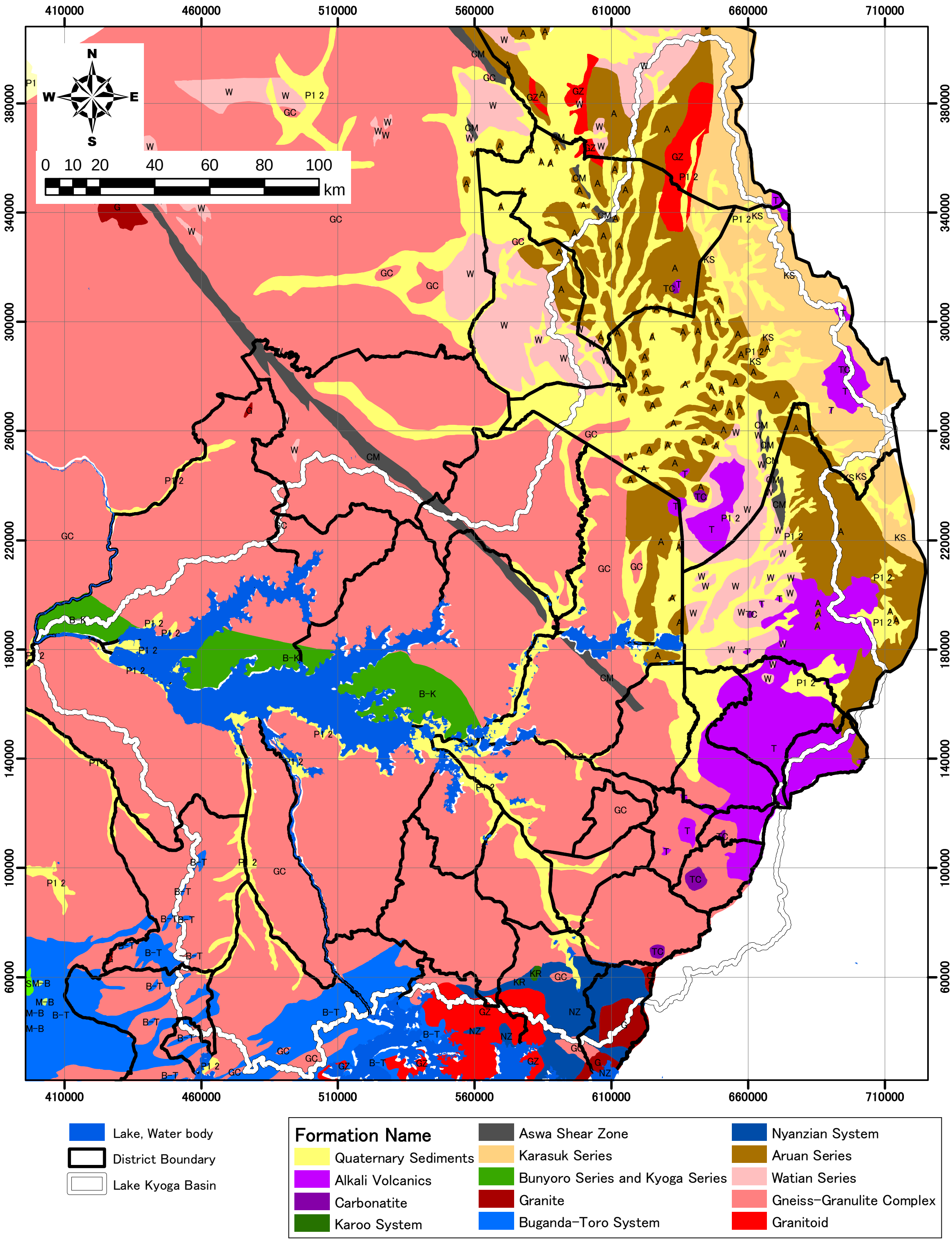


Figure 2-20 Faults and Lineaments in Lake Kyoga Basin



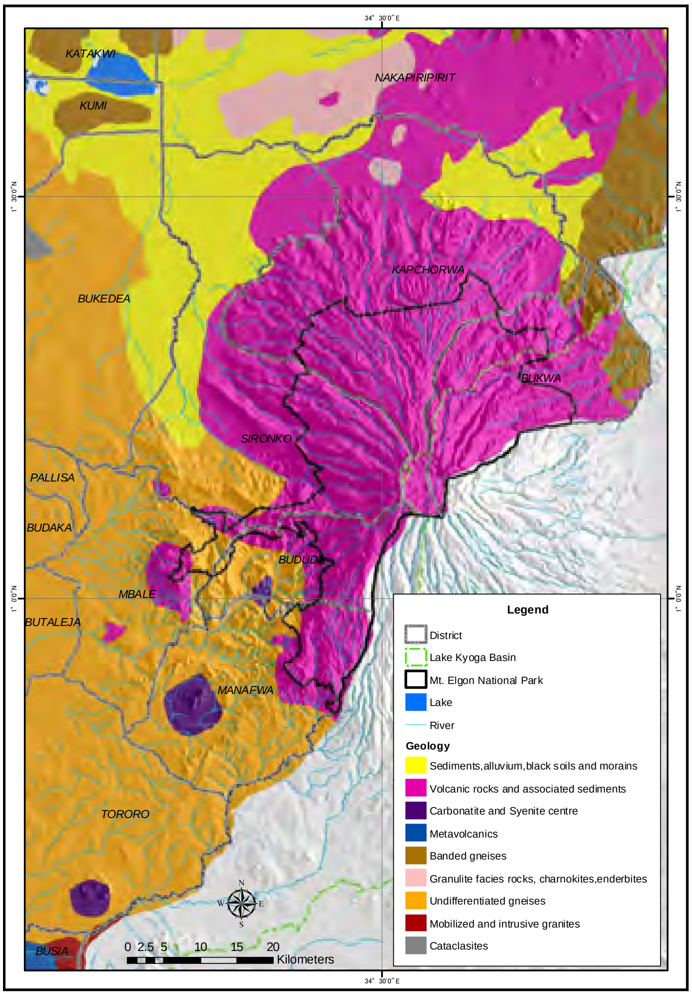
Source:Uganda Geology (2004)

Figure 2-21 Geological Map of Lake Kyoga Basin

2.3.3 Geomorphology and Geology around Mt. Elgon

Top of Mt. Elgon is above sea level 4,310m and considered as a stratovolcano in Cenozoic, of which original magma is alkali basalt. The mountain body has a sandwich structure together with lava and tuff made by pyroclastic flow and volcanic ash. (refer to Figure 2-22)

Since the lava is strong against weathering but the tuff is weak, topography around Mt. Elgon is generally formed terrace structure as shown in Figure 2-23. Rocky cliffs around Mt. Elgon tend to collapse following toppling type as illustrated in Figure 2-24.



Data Source: GIS data of National Biomass Study (1996), Forest Department

Figure 2-22 Geology in and around Mt. Elgon Area

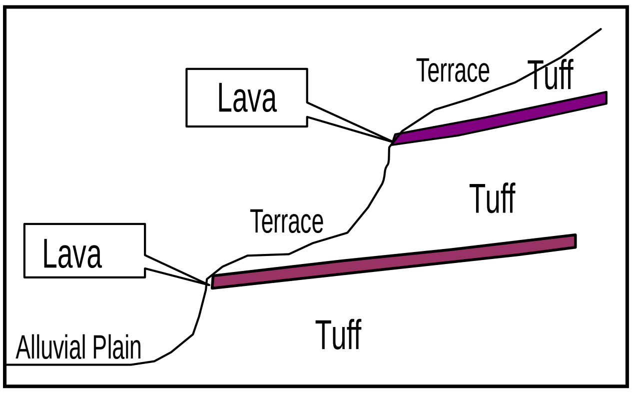
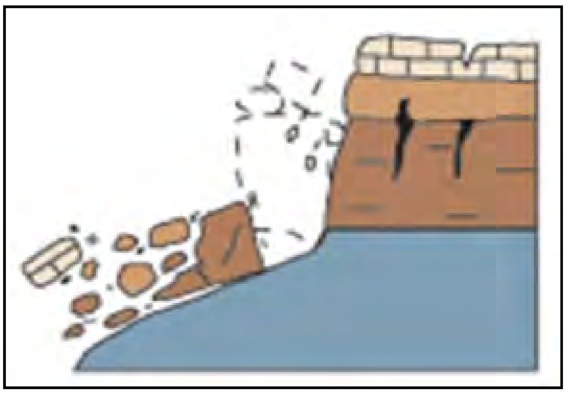


Figure 2-23 Geological and Geomorphologic Feature around Mt. Elgon



Source：USGS HP

Figure 2-24 Toppling Type of Collapse

2.4 Water Quality

2.4.1 Water Quality Standard

In Uganda, there are drinking water standards for urban and rural water supplies, industry wastewater standards, and sewage discharge standards. The drinking water standards are shown in Table 2-6. There are two standards. One is for urban and the other is for rural. The rural drinking water standard is not so strict as compared to the urban standard in terms of the number of items and its values. In addition, the rural standard has Maximum Allowable Concentration (MAC) in Water Quality Standards (March 2007).

Table 2-6 Drinking Water Standards

No.	Items	Urban Drinking Water Standard	Rural Drinking Water	
			Standard	Max. Allowable Concentration (MAC)
1	Color	10 (Platinum scale)	—	—
2	Odor	Unobjectionable	—	—
3	Taste	Acceptable	—	—
4	Turbidity	10 NTU	10 NTU	30 NTU
5	Total Dissolved Solids	500 mg/l	1000 mg/l	1500 mg/l
6	PH	6.5 — 8.5	5.5 — 8.5	5.0 —9.5
7	Total Hardness (CaCO3)	500 mg/l	600 mg/l	800 mg/l
8	Calcium (Ca)	75 mg/l	—	—
9	Sodium (Na)	200 mg/l	—	—
10	Magnesium (Mg)	50 mg/l	—	—
11	Barium (Ba)	1.0 mg/l	—	—
12	Iron (Fe)	0.3 mg/l	1 mg/l	2 mg/l
13	Copper (Cu)	1.0 mg/l	—	—
14	Aluminum (Al)	0.1 mg/l	—	—
15	Manganese (Mn)	0.1 mg/l	1 mg/l	2 mg/l
16	Zinc (Zn)	5.0 mg/l	—	—
17	Arsenic (As)	0.05 mg/l	—	—
18	Lead (Pb)	0.05 mg/l	—	—
19	Selenium (Se)	0.01 mg/l	—	—
20	Chromium (Cr 6+)	0.05 mg/l	—	—
21	Cadmium (Cd)	0.01 mg/l	—	—
22	Mercury (Hg)	0.001 mg/l	—	—
23	Nitrates (NO3)	10 mg/l	20 mg/l	50 mg/l
24	Nitrates (NO2)	—	0 mg/l	3 mg/l
25	Chloride (Cl)	250 mg/l	250 mg/l	500 mg/l
26	Fluoride (F)	1.0 mg/l	2 mg/l	4 mg/l
27	Phenol substances	0.001 mg/l	—	—
28	Cyanide	0.01 mg/l	—	—
29	Poly Nuclear Aromatic Carbons	Nil	—	—
30	Residual, free chlorine	0.2 mg/l	—	—
31	Mineral oil	0.01 mg/l	—	—
32	Anionic detergents	0.2 mg/l	—	—
33	Sulfate	200 mg/l	250 mg/l	500 mg/l
34	Pesticides	Trace	—	—
35	Carbon chloroform	0.2 mg/l	—	—
36	Microscopic organisms	Nil	—	—
37	Escherichia Coliforms	0/100ml	0/100ml	50/100ml

2.4.2 Field Survey for Water Quality

(1) Overview of the Survey

The Study Team investigated the entire basin except the restricted area to enter for security reasons, to examine the water quality condition of the water sources. The survey was conducted in rainy season and dry season as follows.

- Rainy season; Survey was carried out from May 20 to June 10 in 2009.
- Dry season; Survey was carried out from January 19 to February 7 in 2010

The analysis items are shown in Table 2-7. There are 25 items for understanding the basic aspect and pollution aspect as well as hydrogeological aspect. Sampling points were totally 200 points their consisting of 10 lakes, 39 rivers, 95 deep wells (boreholes), 20 shallow wells and 36 springs. Their locations are shown in Figure 2-25.

(2) Survey Result

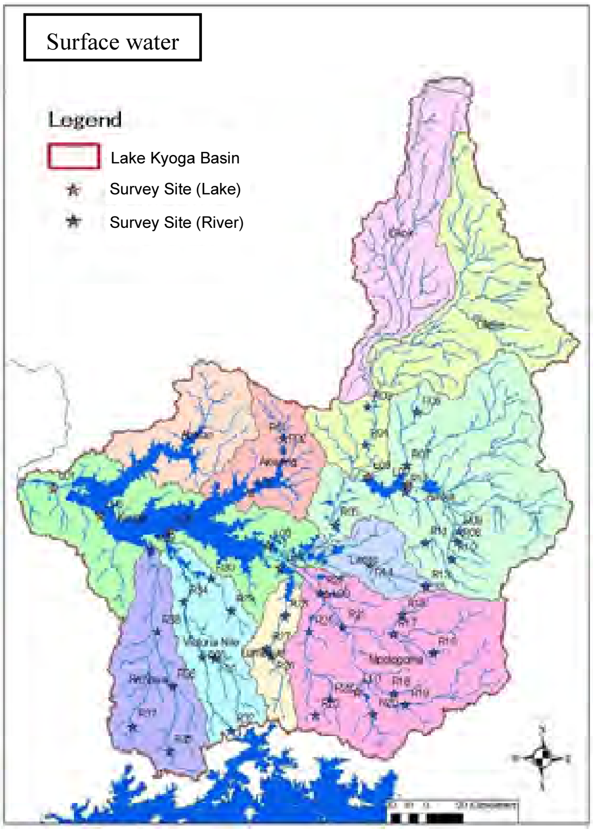
The average values of the important water analysis parameters for different types of water sources: lake, river, borehole, protected spring, and shallow well in each sub-basin are shown in Table 2-8. Values highlighted in yellow and red in Table 2-8 exceed the urban and rural drinking water standard, respectively.

Table 2-7 Water Quality Items in the Study

Analysis Item			Water Quality Standard		WHO Guideline	Remarks
			Urban	Rural		
On site Analysis	1	Water Temperature	-	-	-	Basic aspect
	2	pH	+	+	-	ditto, corrosiveness
	3	Electrical Conductivity (EC)	-	-	-	Indicator of inorganic pollution
	4	Coliform Bacteria	+	+	+	Indicator of excrement pollution
Laboratory Analysis	5	Alkalinity	-	-	-	Basic aspect
	6	Suspended Solids (SS)	-	-	-	ditto
	7	Turbidity (NTU)	+	+	+	ditto
	8	Hardness ($CaCO_3$)	+	+	-	ditto
	9	Total Dissolved Solid (TDS)	+	+	+	ditto
	10	Ammonium (NH_4)	-	-	+	Indicator of excrement pollution
	11	Fluoride (F)	+	+	+	Inorganic (hazardous)
	12	Arsenic (As)	+	-	+	ditto
	13	Nitrite Nitrogen (NO_2)	-	+	+	ditto
	14	Total Iron (Fe)	+	+	+	ditto
	15	Manganese ion (Mn)	+	+	+	ditto
	16	Nitrate Nitrogen (NO_3)	+	+	+	ditto, for hydrogeological analysis
	17	Chloride ion (Cl)	+	+	+	for hydrogeological analysis
	18	Sulfuric ion (SO_4)	+	+	+	ditto
	19	Sodium (Na)	+	-	+	ditto
	20	Potassium (K)	-	-	-	ditto
	21	Magnesium (Mg)	+	-	-	ditto
	22	Calcium (Ca)	+	-	-	ditto
	23	Hydrogen Carbonate (HCO_3)	-	-	-	ditto
	24	BOD	-	-	-	Indicator of organic pollution. Only for river, lake
	25	COD	-	-	-	ditto

1) Water Quality of Surface Water (Rivers, Lakes)

Water in rivers is neutral with pH values of around 7.0, but lakes have slightly higher pH values though they still satisfy the water quality standard in terms of pH. However, three out of eight rivers show their turbidity exceeding the MAC. In addition, coli concentration of rivers and lakes exceeds the MAC despite the low BOD values which indicate a low organic pollution level. Therefore, those water sources are inappropriate



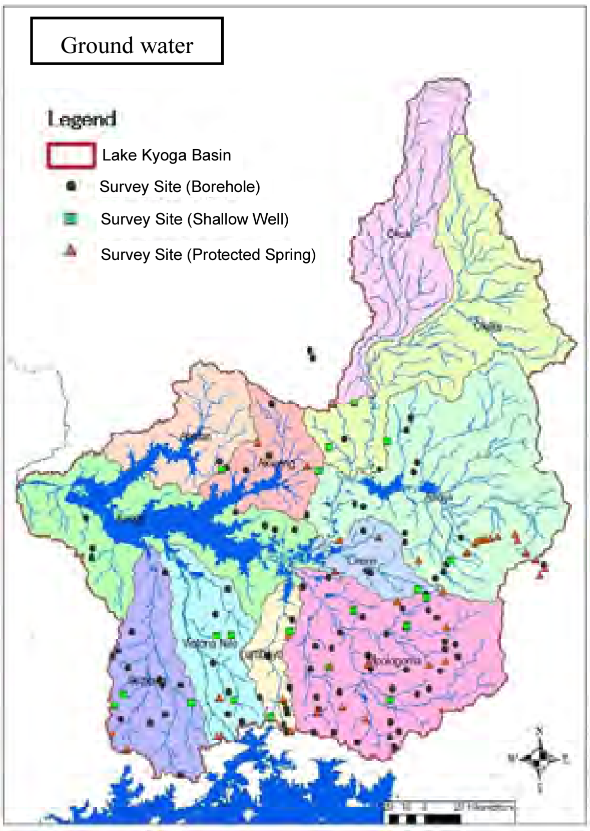


Figure 2-25 Location of Water Sampling Points

for drinking as they are without treatment. Among various substances, the iron levels of seven rivers and one lake out of four exceed the MAC whereas other parameters such as arsenic and fluoride levels meet the safety standard.

2) Water Quality of Groundwater (Borehole, Shallow well, Protected Spring)

The pH, turbidity, iron, and coli level in many sub-basins were found exceeding the safety standard. Average pH values of many sub-basins are lower than that of the urban drinking water standard. Turbidity of groundwater in some sub-basins exceeds the MAC, and it exceeds the urban drinking water standard in many sub-basins. This shows that groundwater in many sub-basins are not appropriate for drinking. Arsenic and fluorine concentration meets the safety standard whereas the iron level in the sub-basin 11 exceeds the MAC. Coliform groups were detected in some measurement sites, although many sites had those below the detectable level. The average Coliform group concentration of every sub-basin was above the urban drinking water standard (0/100ml). One possible source of the coli is influx of contaminated surface water.

2.4.3 Analysis of the Existing Water Quality Data

(1) Outline of Existing Water Quality Measurement

Existing water quality measurement data is available in reports from the water quality monitoring network and well drilling reports from contractors. Refer to the supporting report for details of the data.

1) Water Quality Monitoring Network

There are 30 water quality monitoring sites in the Basin, and measurements of lake, river, groundwater, urban water, and drinking water have been performed since 1998.

2) Well Drilling Data

Of various data we obtained, water quality data of 2,003 wells are available, and 1,532 of them have details such location and depth.

(2) Summary of Existing Water Quality Measurement Data

1) Water Quality Monitoring Network

Minimum, maximum and mean of various data for each water source were considered using the water quality analysis data from the water quality monitoring network.

DWRM monitors the water quality of wetlands and urban rivers that are considered contaminated. According to their measurements, contamination of lakes such as the Lake Victoria had not changed since the last survey. However, high levels of many parameters such as electrical conductivity (EC) and turbidity were observed. In particular, BOD and COD exceeded 100 mg/l which shows severe contamination. For rivers, the Nile shows good water quality except for the existence of Coliform groups monitoring points for municipal and industry discharge , however, are severely contaminated with turbidity, iron, Coliform groups values exceeding the MAC, and they show very high BOD and COD of 130 mg/l and 97 mg/l, respectively.

2) Water Quality Data upon Well Drilling

Water quality data obtained upon well has been organized to find average values per district. Many districts have Turbidity, Colour, Ca, Mn, and Fe values exceeding the urban drinking water standard. Kumi and Namutumba districts have Fe, and Sironko has Mn values exceeding the rural MAC standard.

Table 2-8 Results of Water Quality Survey

(Surface Water)

SOURCE TYPE	Subbasin	Number of Samples	Basic Items: pH	Basic Items: Turbidity (NTU)	Basic Items: TDS (mg/l)	Basic Items: Hardness (CaCO3) (mg/l)	Harmful Items: Mn (mg/l)	Harmful Items: As (*1) (mg/l)	Harmful Items: F (mg/l)	Harmful Items: Fe (mg/l)	Pollution Items: E.C. (μS/cm)	Pollution Items: Coliform Group (group/100ml)	Pollution Items: BOD5 (mg/l)	Pollution Items: NH4 (mg/l)
Lake	3 Awoja	2	7.3	1.1	247	156	0.11	< 0.001	0.49	0.060	464	TNTC	1.5	0.11
	5 Akweng	1	7.9	8.8	121	75	0.00	< 0.001	0.40	0.230	276	TNTC	2.8	0.08
	7 Kyoga lakeside	5	7.8	8.8	101	53	0.01	< 0.001	0.27	0.352	196	TNTC	4.3	0.14
	8 Mpologoma	2	7.4	17.6	186	110	0.00	< 0.001	0.28	2.140	261	TNTC	3.3	0.17
	Total	10	7.6	9.0	149	87	0.03	< 0.001	0.33	0.639	271	TNTC	3.4	0.13
River	2 Okere	2	6.7	10.8	172	113	0.06	< 0.001	0.28	1.398	296	TNTC	2.5	0.13
	3 Awoja	8	7.1	32.0	137	68	0.02	< 0.001	0.25	3.064	227	TNTC	4.0	0.22
	4 Lwere	2	6.7	24.3	123	72	0.10	< 0.001	0.25	5.288	218	TNTC	6.0	0.08
	5 Akweng	2	6.5	2,063.1	98	65	0.07	< 0.001	0.12	4.552	169	TNTC	2.5	0.27
	8 Mpologoma	11	7.1	182.8	124	83	0.07	< 0.001	0.37	4.710	218	TNTC	5.1	0.09
	9 Lumbuye	3	6.8	3.6	244	119	0.16	< 0.001	0.62	2.372	982	TNTC	3.7	0.06
	10 Victoria Nile	6	7.3	17.9	205	101	0.01	< 0.001	0.25	0.662	241	TNTC	1.8	0.07
	11 Sezibwa	5	7.2	17.0	65	45	0.06	< 0.001	0.27	2.440	238	TNTC	4.7	0.22
	Total	39	7.04	193.0	140	80	0.06	< 0.001	0.31	3.133	283	TNTC	4.0	0.14

*1 TNTC means, 'Too Numerous To Count'.

(Ground Water)

SOURCE TYPE	Subbasin	Number of Samples	Basic Items: pH	Basic Items: Turbidity (NTU)	Basic Items: TDS (mg/l)	Basic Items: Hardness (CaCO3) (mg/l)	Harmful Items: Mn (mg/l)	Harmful Items: As (*1) (mg/l)	Harmful Items: F (mg/l)	Harmful Items: Fe (mg/l)	Pollution Items: E.C. (μS/cm)	Pollution Items: Coliform Group (group/100ml)
Borehole	2 Okere	2	6.5	12.3	144	82	0.02	< 0.001	0.20	0.638	258	9
	3 Awoja	13	6.6	13.0	300	187	0.02	< 0.001	0.48	0.660	538	31
	4 Lwere	3	6.1	12.2	118	46	0.04	< 0.001	0.43	1.092	164	8
	5 Akweng	4	6.6	29.1	145	70	0.01	< 0.001	0.33	1.311	256	7
	6 Abalan	1	6.7	4.8	105	41	0.00	< 0.001	0.33	0.525	180	2
	7 Kyoga Lakeside	7	6.6	14.7	283	187	0.04	0.002	0.34	0.942	505	15
	8 Mpologoma	35	6.4	4.9	316	183	0.01	0.001	0.43	0.441	469	<1
	9 Lumbuye	8	6.2	6.4	154	72	0.03	0.001	0.35	0.146	247	<1
	10 Victoria Nile	7	6.6	0.8	264	136	0.01	< 0.001	0.41	0.085	451	<1
	11 Sezibwa	15	6.5	35.2	194	119	0.03	0.001	0.46	3.817	310	<1
	Total	95	6.4	11.9	258	150	0.02	0.001	0.42	0.962	414	<1
Protected Spring	2 Okere	1	5.6	55.7	60	28	0.12	< 0.001	0.02	1.335	99	1
	3 Awoja	13	6.4	6.9	113	68	0.00	< 0.001	0.27	0.362	224	<1
	4 Lwere	2	5.9	60.5	89	29	0.06	< 0.001	0.22	0.562	186	<1
	5 Akweng	2	6.3	29.3	78	23	0.01	< 0.001	0.09	0.668	122	20
	8 Mpologoma	10	6.4	13.9	133	76	0.01	< 0.001	0.27	0.507	237	<1
	9 Lumbuye	3	6.1	1.8	185	98	0.02	< 0.001	0.43	0.068	286	<1
	10 Victoria Nile	3	6.5	0.6	172	88	0.00	< 0.001	0.34	0.046	632	<1
	11 Sezibwa	2	5.8	7.9	56	43	0.01	< 0.001	0.17	0.109	133	24
	Total	36	6.3	13.7	121	67	0.01	< 0.001	0.26	0.397	250	<1
Shallow Well	2 Okere	2	5.9	34.0	175	79	0.01	< 0.001	0.08	1.940	302	36
	3 Awoja	2	6.6	22.5	212	148	0.01	< 0.001	0.38	0.890	359	<1
	4 Lwere	1	6.4	6.1	220	73	0.01	< 0.001	0.42	1.453	321	<1
	5 Akweng	2	6.7	6.4	136	68	0.02	< 0.001	0.37	0.548	248	4
	8 Mpologoma	5	6.4	26.5	305	197	0.02	< 0.001	0.29	0.787	516	<1
	9 Lumbuye	2	6.2	7.8	131	49	0.03	< 0.001	0.46	0.439	281	<1
	10 Victoria Nile	3	6.5	0.7	359	194	0.00	< 0.001	0.40	0.038	654	48
	11 Sezibwa	3	6.2	37.8	94	50	0.04	< 0.001	0.21	3.496	170	<1
	Total	20	6.37	19.8	220	124	0.02	< 0.001	0.31	1.181	388	<1

Standards	Basic Items: pH	Basic Items: Turbidity (NTU)	Basic Items: TDS (mg/l)	Basic Items: Hardness (CaCO3) (mg/l)	Harmful Items: Mn (mg/l)	Harmful Items: As (*1) (mg/l)	Harmful Items: F (mg/l)	Harmful Items: Fe (mg/l)	Pollution Items: E.C. (μS/cm)	Pollution Items: Coliform Group (group/100ml)	Pollution Items: BOD5 (mg/l)	Pollution Items: NH4 (mg/l)
Standards for urban treated drinking water	6.5- 8.5	10 NTU	500mg/l	500mg/l	0.1 mg/l	0.05 mg/l	1.0 mg/l	0.3 mg/l		0 /100ml		
Rural drinking water Standards	5.5 - 8.5	10 NTU	1000mg/l	600mg/l	1.0 mg/l		2.0 mg/l	1.0 mg/l		0 /100ml		
Rural drinking water Maximum Allowable	5.0 - 9.5	30 NTU	1500mg/l	800mg/l	2.0 mg/l	0.5 mg/l	4.0 mg/l	2.0 mg/l		50/100 ml		
WHO criteria (drinking water)		5 NTU	1000mg/l		0.1 mg/l	0.01 mg/l	1.5 mg/l	0.3 mg/l		0/100 ml		1.5 mg/l
Drinking water criteria (Japan)	5.8-8.6	2 NTU	500mg/l	300mg/l	0.05 mg/l	0.01 mg/l	0.8 mg/l	0.3 mg/l		Nil		
Ambient Standards (Lake, Type C :Japan)	6.0- 8.5											
Ambient Standards (River, Type C :Japan)	6.5- 8.5										5mg/l	

*1 As for Arsenic, the values in the table shows the test results obtained in japan.

*Evaluate Average Value : [yellow] : Over Criteria value (Urban drinking water)、 [pink] : Over Criteria value (Rural drinking water MAC)

* As for average of Coliform Groups, ' < 1' means there are some sites which result is ' TNTC'.

2.5 Hydrogeology

2.5.1 Hydrogeological Analysis

Data from NGWDB were used for hydrogeological analysis mainly. Since the data have many mistakes on the position data, correction of position data was necessary. First, unification of position data was necessary, because both of Latitude - Longitude system and UTM system are used as position data in the database. The numbers of data, which were used for analysis, are shown below.

- Drilling Depth data: 4,709
- Static Water Level Data: 4,094
- Pumping Test Data: 4,416
- Depth to Bedrock: 3,834
- Water quality (TDS) data: 1,530

Table 2-9 shows the summary of drilling depth, static water level, well yield, and depth to bedrock in each geological formation.

Table 2-9 Drilling Depth, Static Water Level, Well Yield and Depth to Bedrock of each Geological Unit

	Formation Name	Symbol	Drilling Depth		Static Water Level		Well Yield		Depth to Bedrock	
			Data No.	Average (m)	Data No.	Average (m)	Data No.	Average (m3/h)	Data No.	Average (m)
1	Quaternary	P1 2	190	66.1	166	16.2	178	1.9	151	26
2	Alkali volcanics	T	49	64.6	47	15.9	46	2.3	32	28
3	Carbonatite	TC	17	58.7	16	19.4	15	2.2	11	35
4	Karoo System	KR	5	78.9	3	16.0	3	4.6	5	28
5	Aswa Shear Zone	CM	53	64.9	51	8.0	53	2.5	50	26
6	Karasuk serise	KS	15	78.8	15	29.4	14	1.7	7	11
7	Kyoga Series	B-K	65	69.4	58	20.9	62	4.0	50	39
8	Granite	G	75	55.2	71	12.6	72	1.9	57	31
9	Buganda-Toro System	B-T	338	69.9	238	19.5	302	1.8	284	35
10	Nyanzian System	NZ	98	55.1	86	13.7	92	2.5	69	32
11	Aruan Series	A	77	85.2	64	23.3	71	2.0	62	24
12	Watian Series	W	75	71.4	63	21.7	66	2.7	49	34
13	Gneiss-Granulite Complex	GC	3551	62.5	3127	13.9	3345	1.9	2946	28
14	Granitoid	GZ	101	56.1	89	15.3	97	2.0	61	28
			4709	63.5	4094	14.7	4416	2.0	3834	29

2.5.2 Results of Hydrogeological Analysis

(1) Drilling Depth Distribution

A drilling depth distribution map of the existing boreholes is shown in Figure 2-26. Although each borehole has been drilled in different conditions, this distribution appears to indicate the actual depth of the aquifer that is needed to secure sufficient amount of water. Therefore, a drilling depth relatively represents the well construction cost. The average drilling depth is 64 m. The central and southern parts of the basin have relatively shallow drilling depths. On the other hand, the drilling depth is deeper in the Karamoja area, north-eastern part of Lake Kyoga Basin, Apac district, Nakasongola district, Kumi district around the Lake Kyoga, and Kapchorwa district in the northern part of Mt. Elgon.

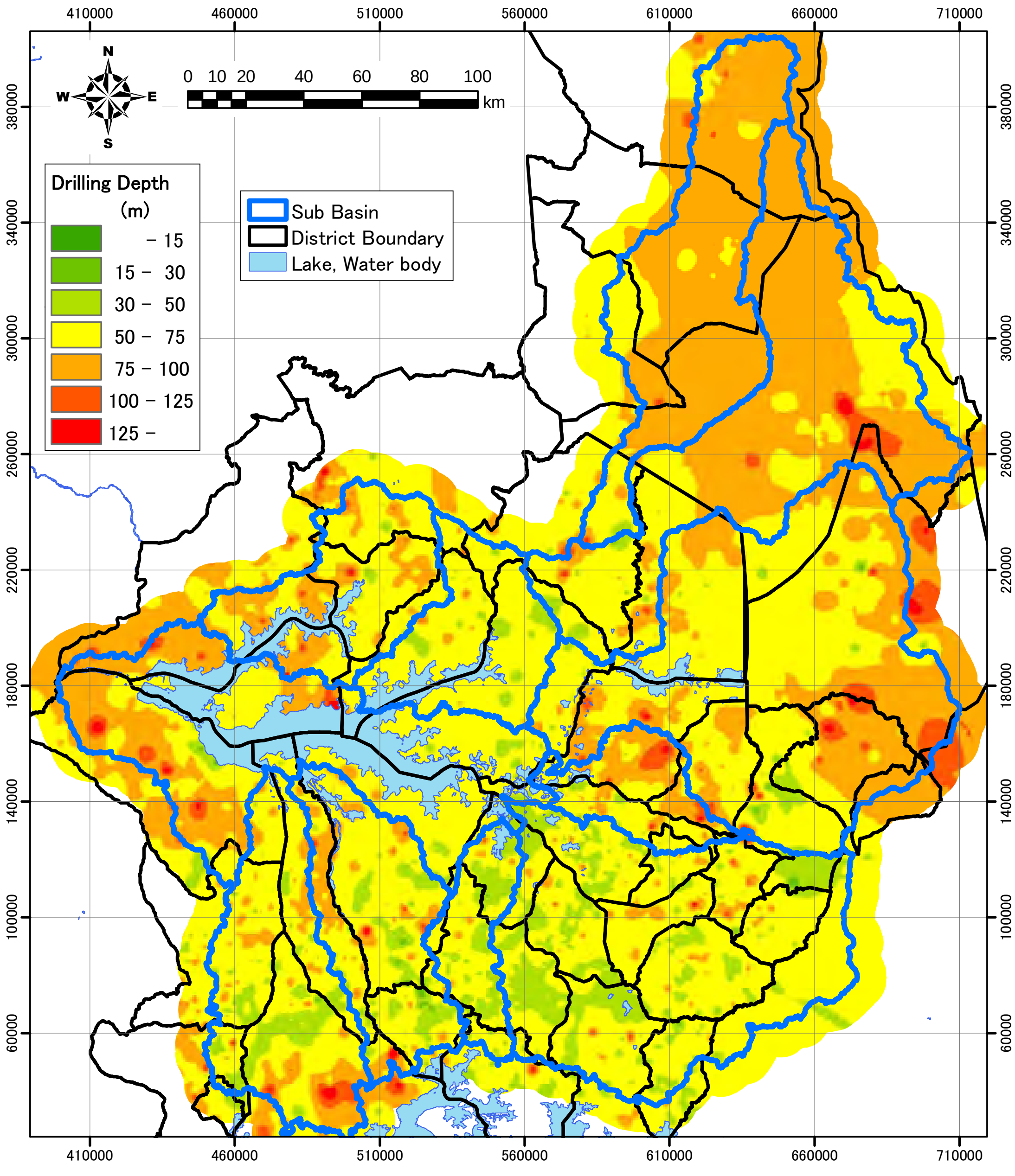


Figure 2-26 Drilling Depth Distribution

(2) Static Water Level Distribution

Static water level distribution of the existing boreholes is shown in Figure 2-27.

The belt-like zone from north-northwest to south-southeast in the central part of Lake Kyoga Basin show shallow static water levels. On the other hand, the static water levels are low in the Karamoja area in the north-eastern part of Lake Kyoga Basin, Apac district, Amolatar district, Nakasongola district, Kayunga district, and Kamuli district around the Lake Kyoga.

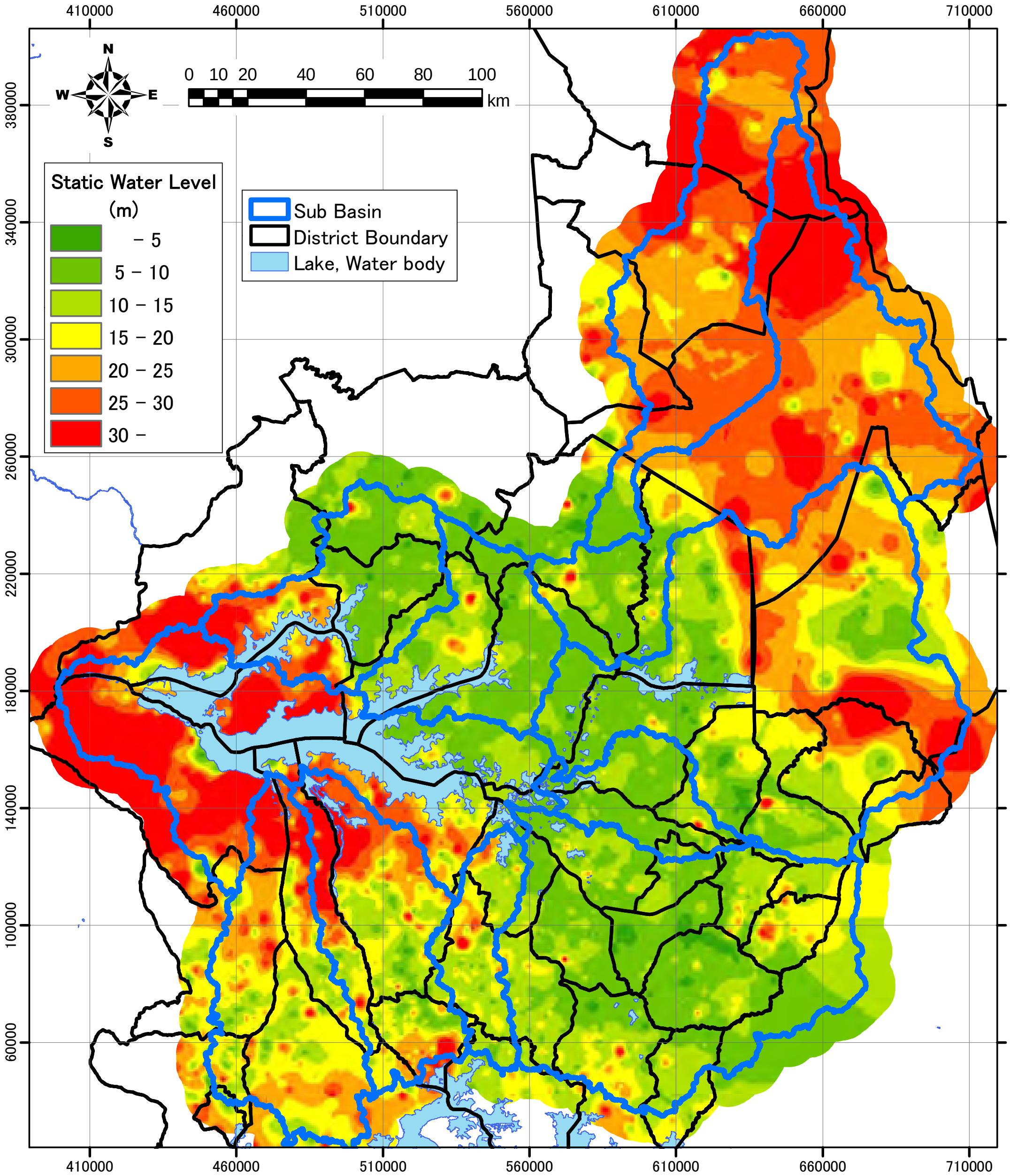


Figure 2-27 Static Water Level Distribution

(3) Well Yield Distribution

Distribution of the well yield from the existing wells is shown in Figure 2-28. The results of constant pumping tests are used as well yield data for this analysis because this parameter is available for many wells from NGWDB.

The Karamoja area in the north-eastern part of the Lake Kyoga basin, Sorotit, Amolatar, Apac, Dokolo, and Kaberamaid districts in the northern shore of Lake Kyoga have a large yield per well whereas the southern area of Lake Kyoga has a relatively low yield.

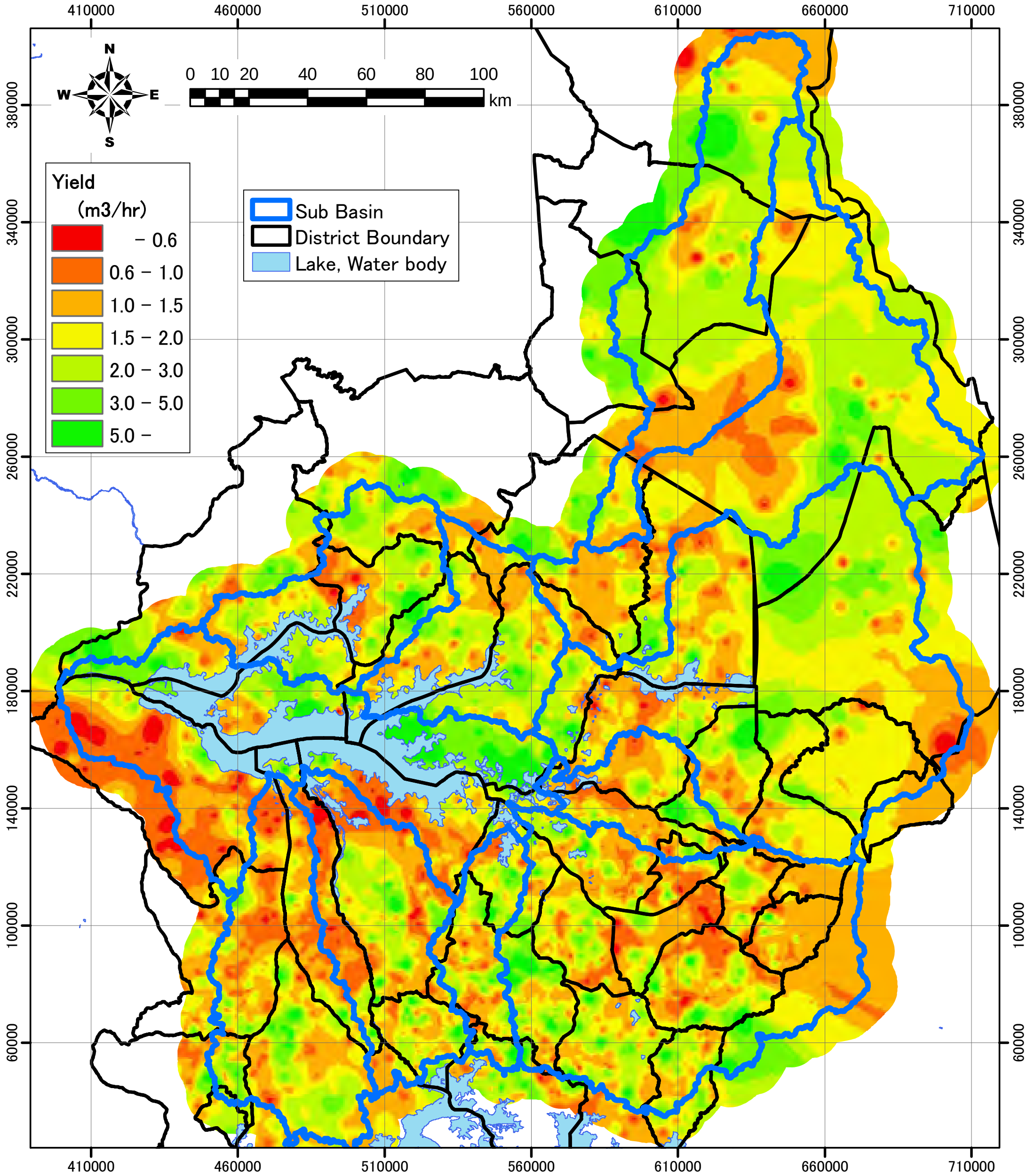


Figure 2-28 Well Yield Distribution

(4) Water Quality Distribution (TDS)

A distribution map of Total Dissolved Solid (TDS) is shown as a water quality map in Figure 2-29. TDS is a good indicator of the comprehensive water quality including salinity and iron content. Surroundings of Lake Kyoga, especially the Apac district, Amolatar district, and Kaliro district shows a high value in TDS, which indicates high salinity in the ground water.

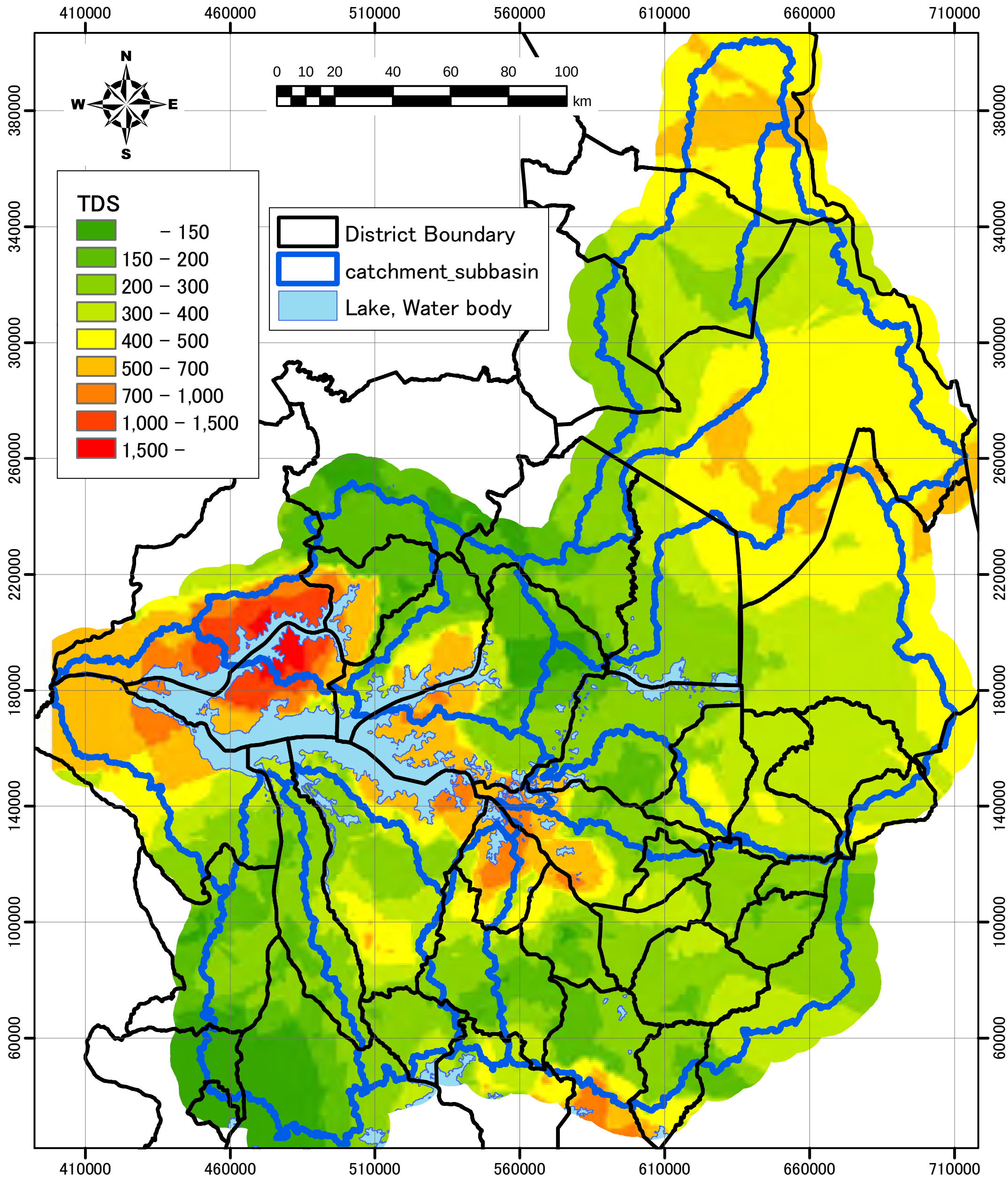


Figure 2-29 Total Dissolved Solid Distribution

(5) Hydrogeological Item of Water Quality

Figure 2-30 shows a typical trilinear diagram (called "Piper diagram") obtained from the water analysis performed in this survey. The key diagram in the middle of the figure is divided into four areas as:

I. Ca (HCO_3) type: river water and shallow groundwater
II. $NaHCO_3$ type: freshwater of artesian groundwater
III. $CaSO_4$, CaCl type:
IV. Na_2SO_4, NaCl type: seawater, fossil water, hot spring, mine water

Since most of spring, shallow and deep groundwater obtained in this survey is plotted within I and II, their origin of water seems to be surface water or shallow groundwater. (refer to the supporting report for more detail information)

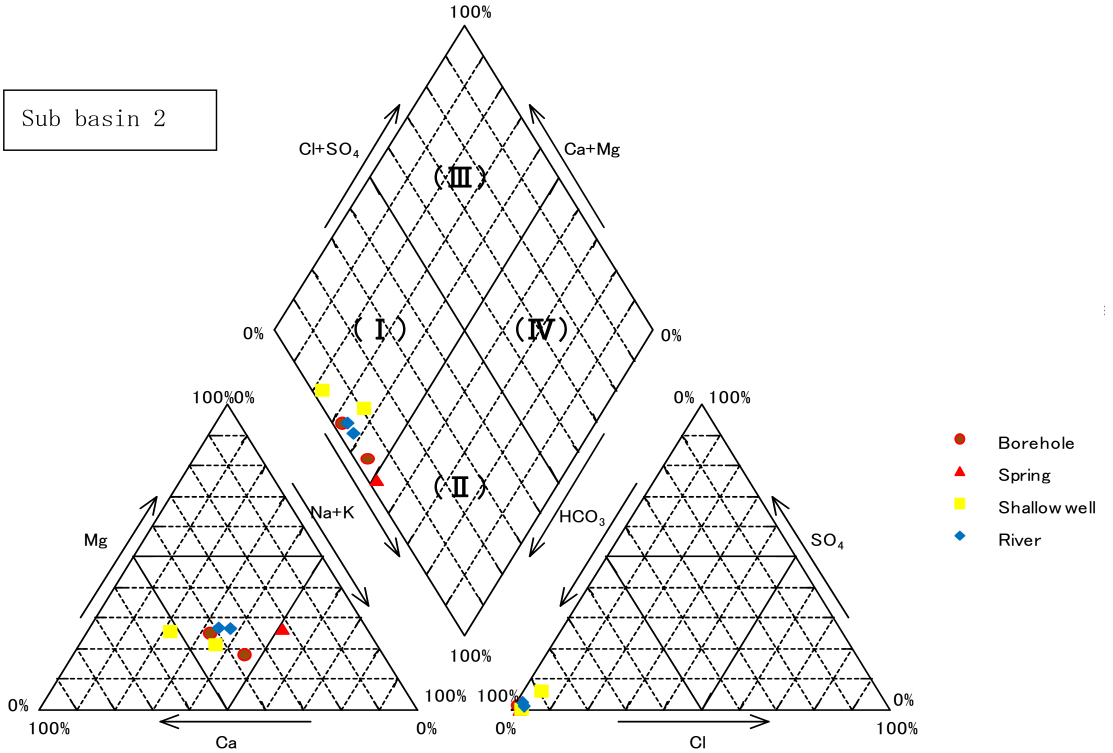


Figure 2-30 Piper Diagram (Okere Sub-Basin)

2.5.3 Direction of Groundwater Flow

Groundwater analysis was performed based on the data from NGWDB. Groundwater flows toward points with a lower potential head. Therefore, groundwater flow can be estimated by drawing curves perpendicular to contours of the groundwater surface level. Figure 2-31 shows that most of the groundwater flow toward Lake Kyoga, but there are some exceptions with local water storage.

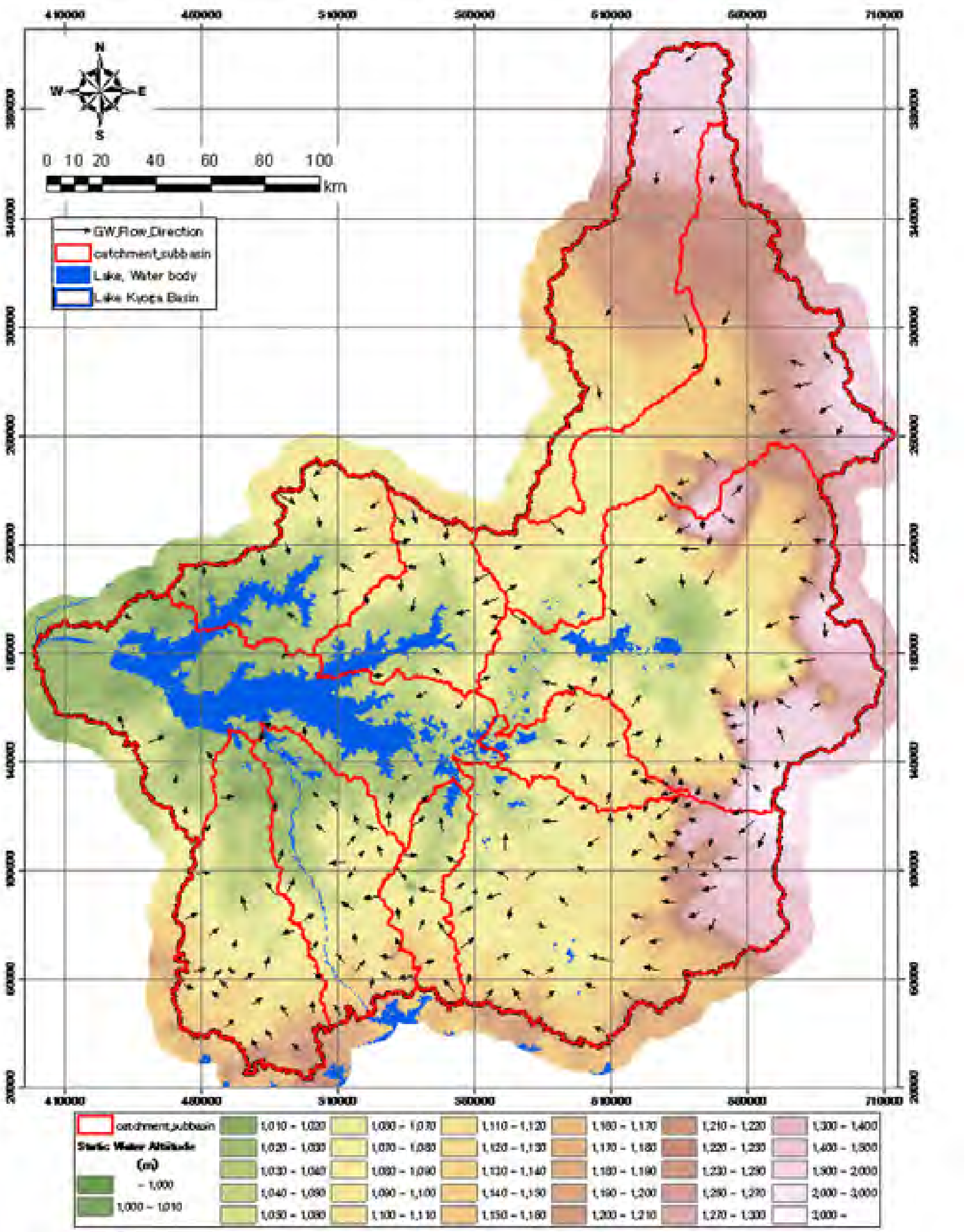


Figure 2-31 Direction of Groundwater Flow

2.5.4 Hydrogeological Condition by Geological Unit

Geological properties of the gneissic, sedimentary, and gneissic-granitic areas in the Pre-Cambrian period, volcanic-rock areas in the Tertiary, and sediments in the Quaternary are described below.

(1) Pre-Cambrian

The geology of Pre-Cambrian in the Lake Kyoga Basin can be categorized into gneissic-granitic and sedimentary rock areas. The gneissic-granitic area occupies a very large area in the central Lake Kyoga Basin. The sedimentary rock area corresponds to the Buganda-Toro System, Kyoga Series, and Karoo System in Palaeozoic. It is distributed over the north shore of Lake Kyoga and small parts of the Mukono, Jinja, and Bugiri districts.

1) Gneissic-Granitic Rock Area

Granite is a coarse-grained igneous rock. Gneiss as a metamorphic rock has coarse grain and banded structure. The original rock seems to be granite in this area. Characteristically, granite or Gneiss 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 the clay. Although the clay formulates aquiclude layer, this is good material for brick. Therefore, brick production area seems to be bad groundwater recharge.

Additionally, fractures occur not only vertical but also horizontal in granitic rocks. Many small hills of granite called "Inselberg" with more resistant rock masses, which formed through weathering process, are observed in granitic area.

Groundwater in weathered zone, which can be regarded as stratum water, and fissure water in fissure zone are expected in the granite area. However, both of these 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 more fissures has to be investigated for groundwater development.

2) Sedimentary Rock Area

Although these rocks are sedimentary rocks, these were formulated in Pre-Cambrian era, Since they have very high consolidation and cementation, it is not expected that the pore zone in the rock has water. Therefore, fissure water is expected in the bedrock as the same as granitic rock. However, if the weathered zone is relatively thick, deep groundwater is expected around the lower part of weathered zone and the upper part of bedrock.

(2) Volcanic Rocks in Tertiary

The areas distributing volcanic rocks are eastern part of Lake Kyoga Basin, Kapchorwa district, Sironko district. Water level is very deep, and it is difficult to apply geophysical survey. Development of spring is suitable in this area. If protection facility for taking the spring water will be constructed, it can be avoid the contamination by constructing protection at the place where the spring is flowing out from rock or confined water is coming up directly.

(3) Sediments in Quaternary

Sands and gravels layer in alluvium are very suitable layer for taking shallow groundwater. In Lake Kyoga Basin, especially around Lake Kyoga, alluvium area becomes swamp in rainy season, and it is difficult to develop groundwater in such an area. However, Karamoja area is higher than wetland around Lake Kyoga, and much alluvium area along rivers. It is reasonable to develop shallow groundwater in Karamoja area.