JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

THE MINISTRY OF NATURAL RESOURCES,
THE GOVERNMENT OF THE REPUBLIC OF UGANDA

THE STUDY ON RURAL WATER SUPPLY IN MPIGI, MUBENDE AND KIBOGA DISTRICTS IN THE REPUBLIC OF UGANDA

FINAL REPORT

VOLUME TWO:

SUPPORTING REPORT

SEPTEMBER, 1996

SANYU CONSULTANTS INC. JAPAN

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1.1. Geology, Hydrogeology and Groundwater

1.1.1. Geography and Topography

(1) General Features of Uganda

Uganda is a landlocked country which is surrounded by Sudan to the north, Kenya to the east, Zaire to the west and Rwanda and Tanzania to the south. The country has rectangular features and is located between lat. 1° 28´ S and 4° 15´ N and long. 29° 34´ E and 35° 00´ E. The average axis is approximately 470 km east-west and 530 km in the rest with the total area of 236,000 km^2.

Uganda's topographical features have a close relationship as the results of mountain-building movement in Cambrian time and rift movement formed Western Rift Valley after late-Cretaceous. The latest stages of formation of the Rift gave rise to renewed volcanic activity and a general sag in the center of the country which produced the Lake Kyoga drowned valley system and Lake Victoria.

The plateau, which forms the major landscape element of the country occupies about 85% of the land area, is directory underlain by gneisses and granitized rocks of Precambrian, and is mainly flat northern part of the country but produce hilly terrain in the peripheral parts of the country: in the south and south-west the generally less-metamorphosed Precambrian formations give rise to a more incised topography. The surfaces of the plateau are remnants of an old dissected peneplane and three altitude levels of the surface have been identified. These surfaces are of some importance to the occurrence of groundwater in weathered or fractured zones in Precambrian aquifers.

The sedimentary infill of the Western Rift Valley floor produces a low relief which is diversified in the south by the Pleistocene lava and ash crater fields. In the east the country is dominated by Miocene volcanoes in various stages of erosion.

Most of Uganda lies within the upper part of the White Nile basin, which consists of seven major catchments. About 17% of Uganda is covered by lakes and swamps. The present drainage pattern is largely the result of upwarping and faulting along the Rift. This caused a reversal of flow in many of the originally westward-flowing rivers as wells impeding the flow of rivers draining the plateau to form extensive swamp areas and lakes.

(2) Study Area

(a) General Features of the Study Area

The study area is situated in the south-western area of Uganda, and average axis is approximately 110 km east-west and 135 km north-south with the total area of 17,102 km^2. The altitude ranges from 700 to 1,800 meters.

The topographical features of the study area are represented by flat topped plateau like hills rising generally to much the same height, broadly rounded plateau and valleys which are filled by papyrus swamp, high grass or forest (see Figure 1.1.1.).

Flat topped hills are especially characteristic of the southern half of the area. Their summit shows a remarkable similarity of altitude and the tops lie consistently between 1,300 and 1350 m. Their profiles commonly show a relative steep upper slopes of about 24° to 27°, rapidly flattening to long pediment slopes averaging hills 5° to 7° inclination.

In the most part of the study area are rounded, dome-like plateau, lower than the flat topped hills with constant or slightly sinusoidal slopes averaging 5° to 7°. Flatter profiles are found to the north of Kiboga District where 3° to 4° are more common. Occasionally the rounded hills are surmounted by a steeper pimples, and in part of Mubende which are underlain by Singo Series and granite special conditions give rise to rounded hills with much steeper sinusoidal slopes. They represent remnants of former flat topped hills, from which the laterite cover has been removed.

Although there are few major rivers as, for instance, the Mayanja, Katonga and Kafu, they flow the boundaries of the study area. There are very many tributaries of moderate size with valleys narrower than the major water courses, but most of the valleys are dry in hot season. The valleys display comparatively little flat ground consisting of swamps or seasonally flooded forest or grassland. Many valleys are markedly rectilinear, or only slightly curved, and water-courses and swamps do not show the sinuosity and meanders in low valley gradients. In general the river network bears little relation to geological structure in the area of sedimentary rocks, but in gneiss and granite areas rectilinear character of the streams are well structurally controlled.

In the south there is a large swamp filled depression known as Lake Wamala. The drainage in the south area is towards Lake Victoria, either directly or by way of Lake Wamala and River Katonga. The drainage in the north belongs to the Victoria Nile catchment and towards River Kafu.

(b) Kiboga District

Kiboga is the most northern district of the study area, and the capital, Kiboga town, is over

110 km from Kampala. Major topographic units of the area include flat topped hills, dome like rounded plateau and relatively low gradient valleys.

In the northern area of Kiboga which occupies nearly 80% of the land area of the district, relative relief is low, seldom more than 20 to 30 meters, and valleys are wide. Most of this area, the rivers are slow-flowing and tributary to River Kafu and Mayanja. The topographical characteristics accelerate the deposition of fine grained soils and as the results find difficulty in the rate of vertical surface water infiltration to underlying formations. The area is underlain by gneisses of Pre-Cambrian .

Southward from this northern plain which range from 700 to 1,100 masl, the plateau level rises towards the lake Victoria watershed ranging from 1,000 to 1,500 masl. The topography of the area is controlled by the lithology and structure of the underlying rocks. In the belt underlain by the relatively unmetamorphosed Buganda-Toro System (see Figure 1.1.15) there is a tendency for the development of ridges and valleys aligned parallel to the axes of folding, due to differential erosion in the alternating erosion-resistant and weak strata. The drainage tends to follow the main direction of cleavage in the rocks. Valley formation has also taken place along fault lines in the System. The main rivers in the area are the Kitumbi and Kizingu, which drain into the Kafu.

The topographical and geological characteristics show that the area accelerates the rate of vertical infiltration from the riverbeds to the underlying aquifers.

(c) Mubende District

The district is encompassed by Kiboga, Mpigi, Masaka and Kabarole Districts. The Kampala-Fort Portal road crosses the center of the district and the railway passes along the northern shore of Lake Wamala and then cuts across to the southern bank of River Nabakazi. Kiboga town is over 150 km from Kampala.

Most of the area is undulating hilly country and the relative relief varies between 50 and 150 meters. Nearly all the hills rise to a level of 1,200 to 1,400 masl, with occasional higher residuals. These hills are characteristic by the flat topped ridges and remarkably similar profiles which commonly show a relatively steep upper slope averaging 25° passing into more gentle pediment slope of between 5° and 10° . The hill top is generally capped by laterite. These high steep sloped hills consist of sandstone of Buganda-Toro System, Singo Series and Mubende granites.

Another type of hill is conical with rounded top. The upper slopes vary between 15° and 20° . These hills are often slightly steeper near the summit, but their flanks have a more gentle slope less than 5° and usually only 45 meters above the valley bottoms.These low hills are composed of fine grained sedimentary rocks of Buganda-Toro System.

The most rivers in the area flow to the south and into River Katonga bounding the study area to the south. In the northern part the rivers flow to the north and into River Kitumbi bounding Kiboga District. Remarkable drainage in the area is Lake Wamala which is large swamp-filled depression. It is linked by the Kibimba valley to the River Katonga, and 29 km long and about 12 km wide at its broadest point. The geological formations in the depression dip toward Lake Wamala, and it is considered that the depression were formed by a tectonic movement of the end-Tertiary (Geological Sheet 69, Uganda Geological Survey, 1960).

(d) Mpigi District

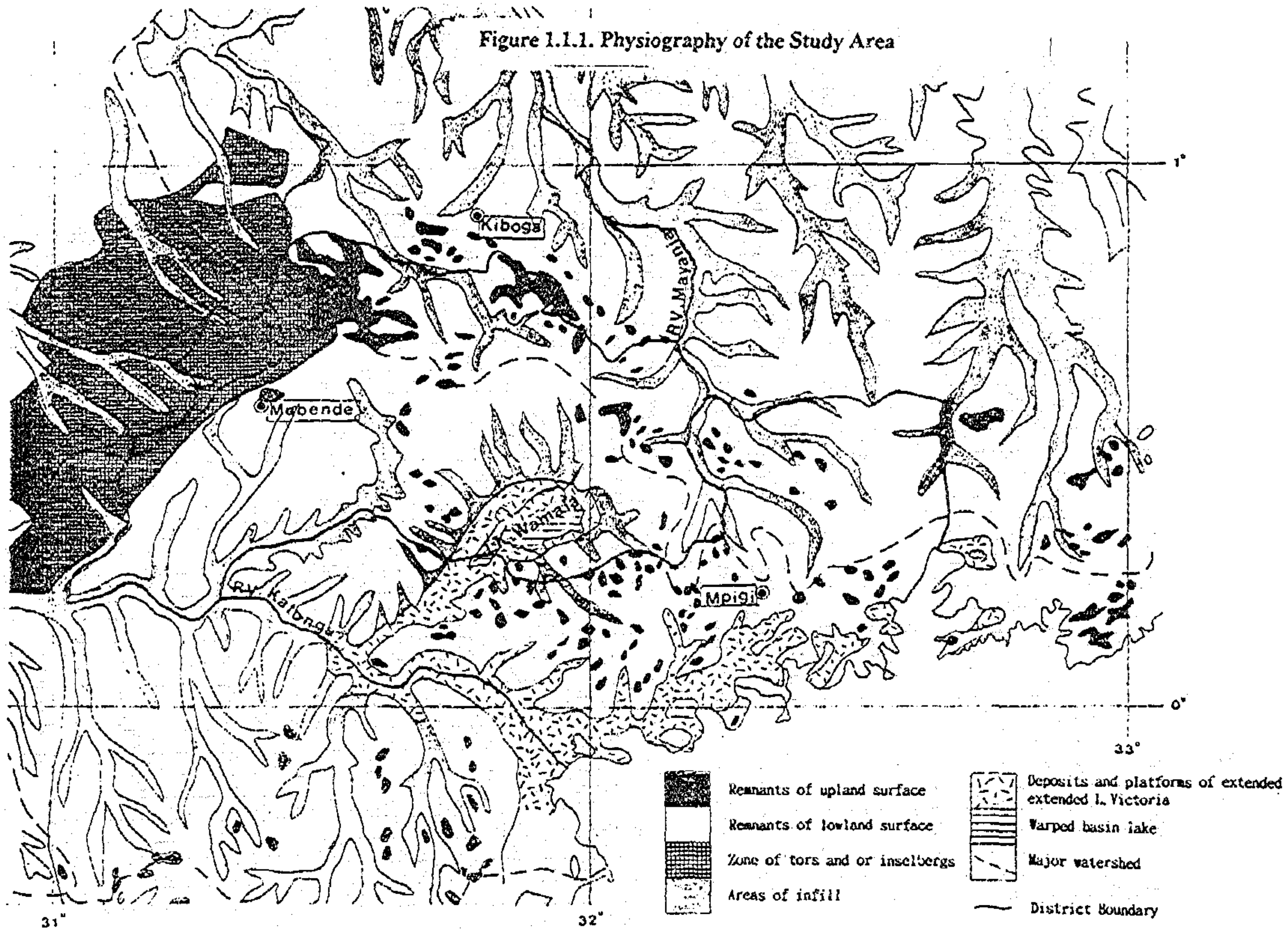
Mpigi is the most southern district of the study area, and has rectangular features with the axis of 180 km east-west. The proposed villages are largely divided into two areas which are contrast in topographical and geological features: one is Gomba, Butambala and Mawokota County in the west of Mpigi town, and another is Busiro and Kyadondo County in the north of Kampala.

The former is mainly underlain by Buganda-Toro System dominating schist and sandstone and is undulating hilly country of which hill top is characteristic by a remarkable similarity of altitude. The conical with broadly rounded hill top, however, is found in the western area of River Kibimba, and the hills have gentle slopes less than 5° and relative relief is usually less than 40 m. The valleys in the area are short and rectilinear, and are towards Lake Victoria directory and by way of River Katonga.

The area of the north of Kampala is highly populated and rich agricultural country in the economic circle of Kampala. Gneisses predominate in this area and topographical features are characteristic by the conical with broadly rounded hill top. The hills are often slightly steeper near the summit, however, the flanks have very gentle slopes and usually low relative relief between hill top and river floor. The valleys filled by papyrus swamps are usually broad in width and flat in gradient. The river network shows generally rectilinear character controlled by geological structures. The streams in the area are towards north and flow into River Kafu through River Mayanja and Lugogo.

Figure 1.1.1. Physiography of the Study Area

Figure 1.1.1. Physiography of the Study Area



Source: Atlas of Uganda, 1969

1.1.2. Meteorology and Hydrology

(1) General Meteorology and Hydrology

(a) Meteorology

Most of Uganda has fairly well-marked wet and dry seasons related to the movement of the sun across the equator and the influence of South-East and North-East Monsoons which tend to move with the sun.

The mean annual rainfall ranges from more than 1,600 mm along the coastal line of Lake Victoria to less than 500 mm in the north-eastern part (see Figure 1.1.2.).

Rainfall of about 1,200 to 1,500 mm occurs in the northern area of Lake Victoria and along the western boundary of Uganda. The Lake Victoria zone is characterized by flat topped hills of uniform height, extensive swampy lakes and valleys. The central and eastern area of Mpigi District includes in this zone. The primary vegetation is short grass on the hill top and forests in the valley, giving way to papyrus swamps. The climate of this zone displays comparatively small seasonal variations of temperature, humidity and wind throughout the year. The western boundary zone is fairly described as a transition zone between the Zaire forest and Uganda savanna climates. The rainfall increases with height.

Rainfall in north-east zone (Karamoja) ranges from 400 to 1,000 mm/year, intense dry and hot season comes from November to March when the streams dry up.

The southern Lake Kyoga zone which includes Mubende and Kiboga Districts is hilly region, with flat topped hills in the southern parts and largely flat in northern parts. The rainfall ranges from 800 to 1,200 mm falling on 140 to 170 days per year.

The mean temperatures over the whole of Uganda show no great variation, apart from those of the mountainous districts of western area and around Mt. Elgon. The highest temperatures occur generally in February but occasionally in January or March, and the lowest temperature in July or August. In the south and in Karamoja the temperatures reach 32 to 35℃ during the dry season and 27℃ during rain season. The daily variation is 1 to 4℃ in the whole country.

(b) Hydrology

The country's hydrology is dominated by the extensive lake system. The total surface area of Uganda and the proportions covered by open water and swamps are as follows (Atlas of Uganda, 1967):

-Land area of Uganda	; 235,810 km^2
-Area covered by open water	; 36,278 km^2 (15%)

-Area covered by swamps ; 5,183 km^2 (2.2%)

Most of southern part of the country drains into Lake Victoria from the Victoria, water passes through the Owen Fall Dam into the Victoria Nile and so by way of Lake Kyoga to lake Albert; it then flows out of Lake Albert, as the Albert Nile, at the same end as it flows in. All of the country's rivers ultimately reach to the White Nile. Because of upwarping and faulting of the land surface, many of the perennial streams of the plateau clogged with swamps. Major rivers and their length in Uganda are as follows:

	km		km
Victoria Nile	459	Albert Nile	217
Aswa-Moroto	358	Mayanja Kato	183
Depeth-Okok	315	Katonga	177
Pager	233	Mpologoma Malaba	174

(c) **Meteorological and Hydrological Stations**

The location and inventory of meteorological and hydrological stations in the study area are shown in Figure 1.1.3. and Table 1.1.1. and 2. Availability of the records is shown in Table 1.1.3. and 4.

Nine meteorological stations are in the study area. Entebbe station has recorded rainfall, air temperature, relative humidity, sunshine hours, wind velocity and pan evaporation. Other stations have partially recorded.

Nine hydrological stations are in the study area, and three out of nine stations in River Katonga have recorded flow, and others recorded only water level. The three flow gauging stations in River Katonga, however, have stopped record from 1985.

Table 1.1.1. Inventory of Meteorological Stations in the Study Area

Station Name	Coordinates	Elevation (masl)
Entebbe	32° 27'-0° 24'	1,290
Mubende	31° 22'-0° 35'	1,128
Kawanda	32° 32'-0° 25'	1,177
Namulonge	32° 35'-0° 32'	-
Nabbingo	32° 27'-0° 18'	1,200
Kiboga	31° 46'-0° 55'	1,200
Vuumba	31° 44'-0° 56'	1,170
Naluggi	31° 56'-0° 36'	1,200
Lunnya	31° 50'-0° 47'	1,305

Table 1.1.2. Inventory of Hydrological Stations in the Study Area

NO.	Station Name	Coordinates (E-N)	Type
81362	RV. Katonga at Nkonge Road Bridge	31° 10'00"-0°	Flow
81319	RV. Katonga at Bugomola	33° 26'00"-1°	Flow
81359	RV. Katonga at K'la-Masaka Road	31° 56'00"-0°	Flow
81260	RV. Kibimba at Kanoni-Mubende Road	-	Level
82217	RV. Kagoye at Luwero-Gulu Road	-	Level

Table 1.1.3. Availability of Rainfall Records

Station Name	'85	86	87	88	89	90	91	92	93	94	95
Entebbe	-----	-----	-----		-----	-----	-----	-----	-----	-----	-----
Kiboga	1947 - 1977										
Namulonge	-----	-----	-----	-----	-----	-----	-----				
Mubende					-----	-----		-----	-----		

Note: dotted line show the period for which continuous records are available

Table 1.1.4. Availability of Hydrological Records

Station NO.	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
81362	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----			
81319	-----	-----	-----	-----	-----	-----	-----	-----	-----							
81359	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----			
81260	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----					
82217	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----					

Note: dotted line shows the period for which continuous records are available

(2) Meteorology in the Study Area

(a) Rainfall

Figure 1.1.4. - 6. show mean monthly rainfall from 1985 to 1995 at Entebbe station, from 1958 to 1977 at Kiboga station and from 1983 to 1995 at Mubende station. The monthly rainfall at Entebbe station varies 54.8 mm in February to 289.3 mm in May, and average yearly rainfall is 1,556.1 mm. There is a relatively dry season between December and March, and another in June and July. The consequence is a pattern with rainfall well-distributed throughput the year and peaks in March-April-May, and October-November, the earlier one being the principal one. The rainfall occurs on the average on 160 to 170 days each year. The central and southern area of Mpigi District belong to same rainfall

pattern.

Kiboga and Mubende show similar rainfall pattern as shown in Figure 1.1.5 and 6. The area is a hilly region and the altitude of both stations are 1,130 and 1,200 masl. The yearly average rainfall is 1,197 mm at Kiboga station and 1,166 mm in Mubende station. Two peaks associated with the Equatorial Through are evident, one during March-May, the other September-November. Two dry season occur in June-July, and the other between December and February. The rainfall is falling on 90 to 130 days per year. The western area on Mpigi District and most of Mubende and Kiboga Districts belong to this climatic pattern, however, a much drier zone with mean annual totals below 875 mm extends from western Mpigi District to near Lake Wamala: Maddu in Mpigi, Kiganda, Myanzi and southern Kitenga in Mubende (Atlas of Uganda, 1969).

(b) Air Temperature

Mean maximum and minimum air temperature records at Entebbe and Mubende stations are presented in Figure 1.1.7 and 8. The data are recorded on a monthly basis and averaged throughout the period during 30 years at Entebbe and recent 5 years at Mubende. The mean maximum and minimum temperatures in the study area show no great variation. The maximum monthly temperature ranges from 25.0 to 26.8°C at Entebbe and from 26.2 to 28.6°C at Mubende. The highest monthly mean temperatures occur during dry season in January or February. The minimum temperature ranges from 16.1 to 17.9°C at Entebbe and from 14.7 to 15.7°C at Mubende. The lowest minimum temperatures occur in June or July. The daily variation of temperature is about 7°C in average at Entebbe station located at the shore of the lake, while about 11°C in average at Mubende located about 70 km far from the Lake edge.

(c) Relative Humidity

Humidity Records at Entebbe and Mubende stations, averaged throughout the recorded years, are shown in Figure 1.1.9. and 10. Records indicate that Entebbe located on the shore of the Lake maintain high percentage of humidity, reaching a high of 90% in June. In most months humidity is reaching 80% at Mubende, however, in the afternoon during dry season lowered near 50% in Mubende. The difference of humidity during dry season is reaching about 10% between Entebbe and Mubende.

(d) Sunshine Hours

Figure 1.1.11. shows the sunshine hour record at Entebbe station, and record period for 20

years. averaged annual sunshine is 6.2 hours/day, and the shortest sunshine occurs appear in August at 5.4 hours.

(e) Wind Velocity

Figure 1.1.12. shows the wind velocity recorded at Entebbe station for 25 years; the records are measured at 9:00 a.m. local time. As the monsoon season approaches, the wind begins harder, but decreases during the dry season. The averaged annual wind velocity is 9.3 km/hour.

(f) Pan Evaporation

Evaporation data at Entebbe and Namulonge stations measured by evaporation pan are shown in Figure 1.1.13. Namulonge is located in 50 Km far from the Lake and evaporation is lower 0.5 to 1.0 mm than Entebbe which is on shore of the Lake and precipitates on average on 160 to 170 days each year. Variation in mean monthly evaporation from year to year is much smaller than variation in mean monthly rainfall.

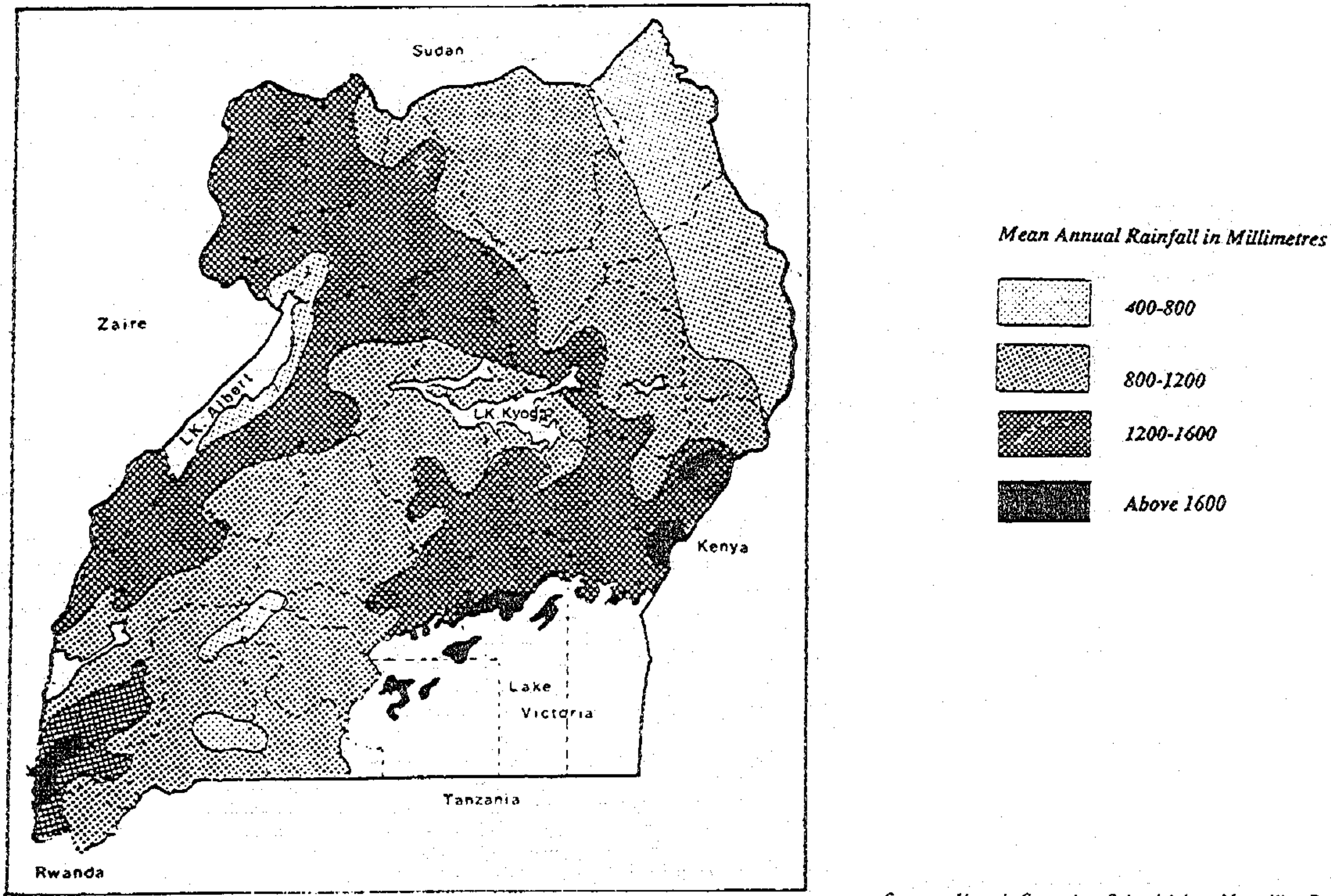
(3) Hydrology in the Study Area

The major rivers in the study area are the Kafu, Mayanja, Mpongo, Katonga, Kibimba and Nabakazi: the Mayanja and Mpongo are the tributaries of the Kafu which is in the Victoria Nile catchment area and flow to north, and the Nabakazi is a tributary of the Katonga which is in the catchment area of Lake Victoria and flows to south. These tributaries are originate in the hill region excepting the Kibimba originated in Lake Wamala.

In the study area river gauging stations are located for the Katonga, and no station for the Kafu. The locations of the stations are shown Figure 1.1.3. River discharge of the study area is largely affected by the presence and scale of swamps which function as storage. Runoff coefficient of two stations at the Katonga which is calculated by UNDP is shown below:

Station No.	Catchment Area	Runoff Coefficient
81324	3,870 km^2	11.24 %
81359	13,930 km^2	0.64 %

Figure 1.1.2. Rainfall Pattern



Source: Uganda Secondary School Atlas, Macmillan Publishers Ltd., 1989

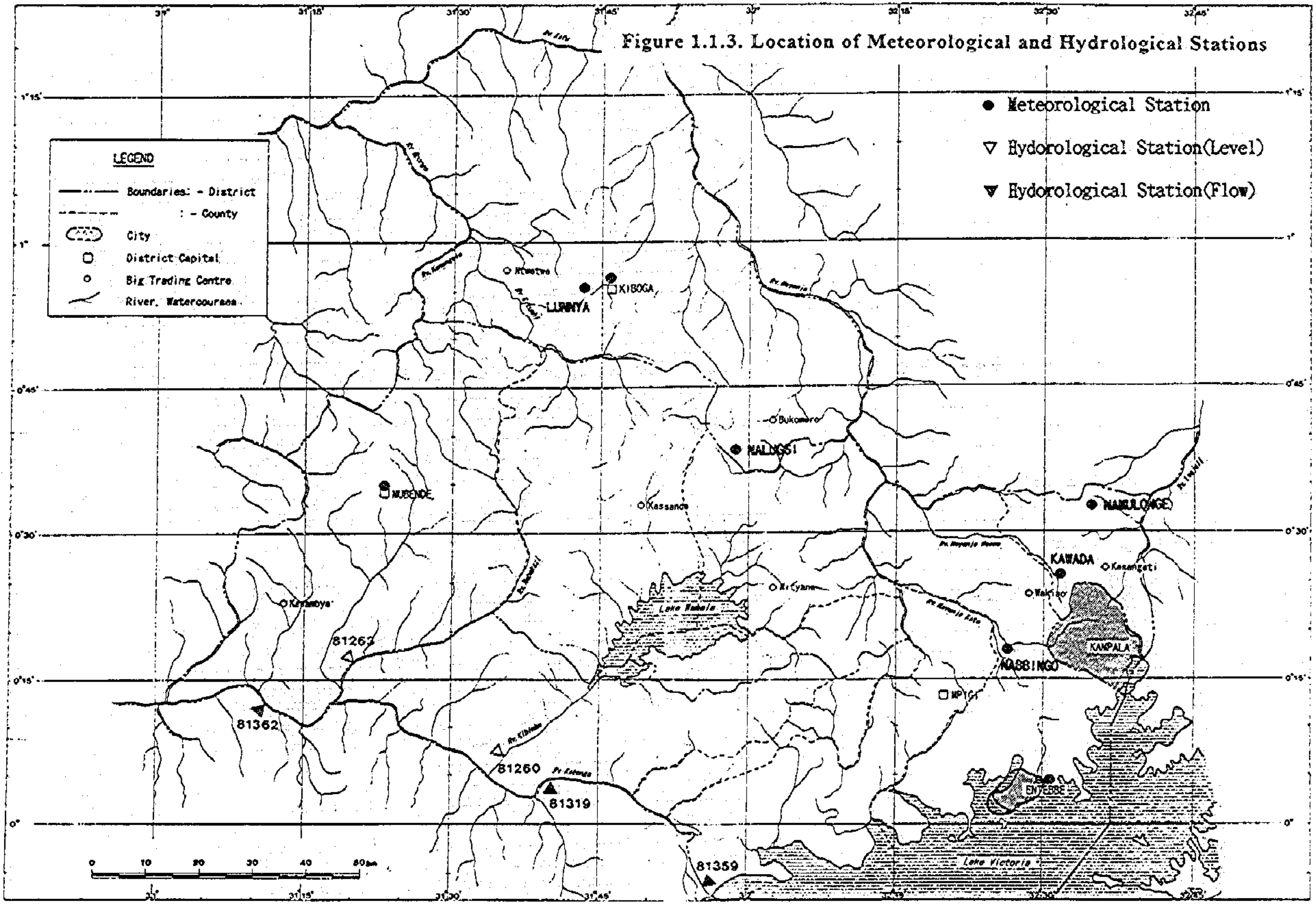


Figure 1.1.3. Location of Meteorological and Hydrological Stations

Figure 1.1.4. Mean Monthly Rainfall
Entebbe

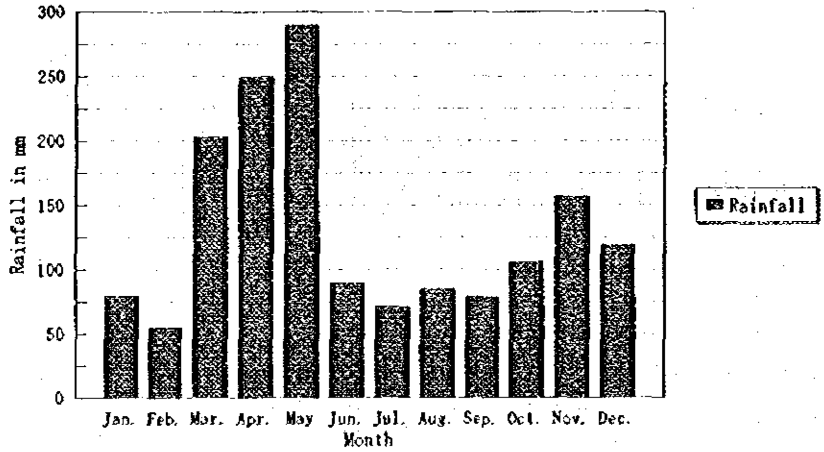


Figure 1.1.5. Mean Monthly Rainfall
Kiboga

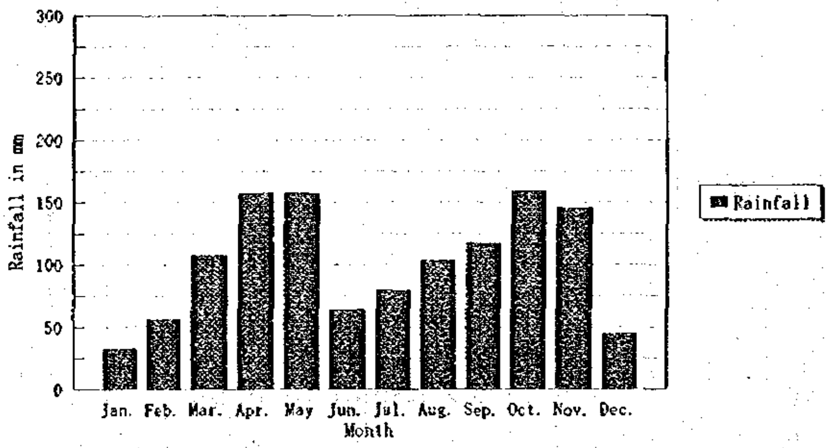


Figure 1.1.6. Mean Monthly Rainfall
Mubende

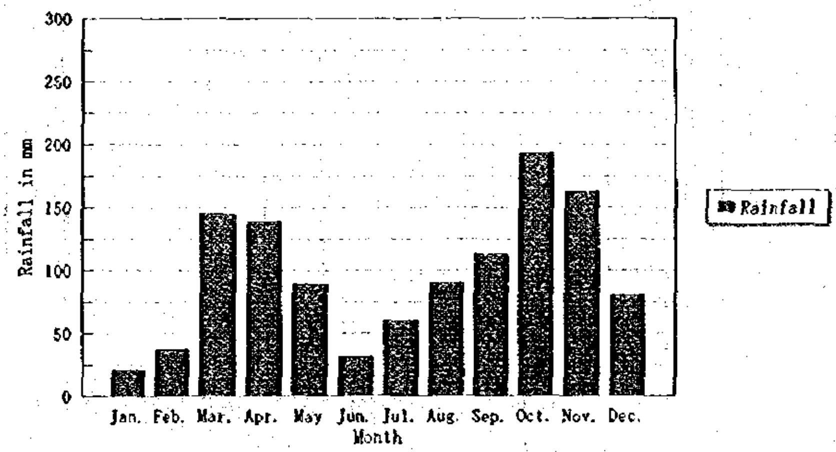


Figure 1.1.7. Monthly Temperature (Mean Max. and Min.)
Entebbe

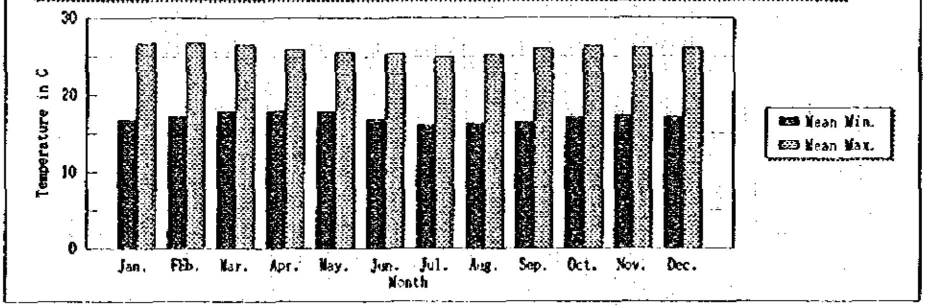


Figure 1.1.8. Monthly Temperature (Mean Max. and Min.)
Mubende

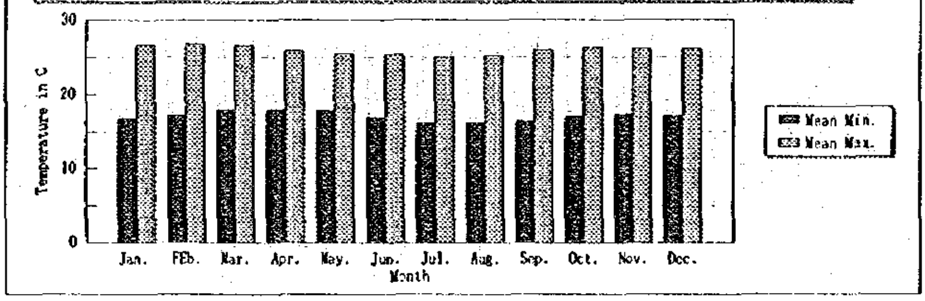


Figure 1.1.9. Mean Monthly Humidity
Entebbe

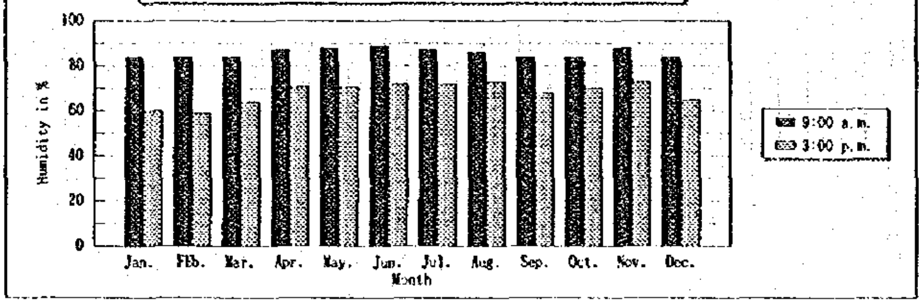
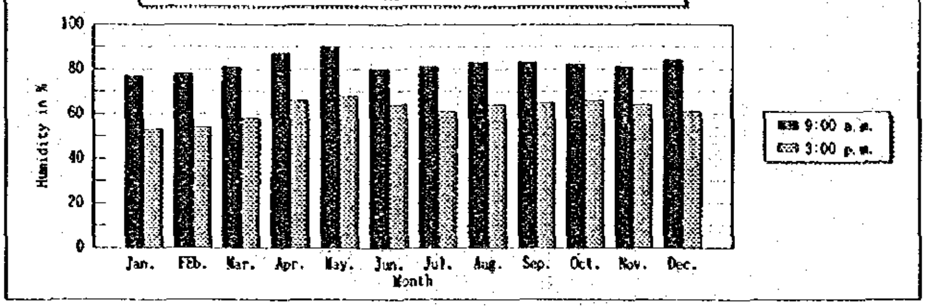


Figure 1.1.10. Mean Monthly Humidity
Mubende



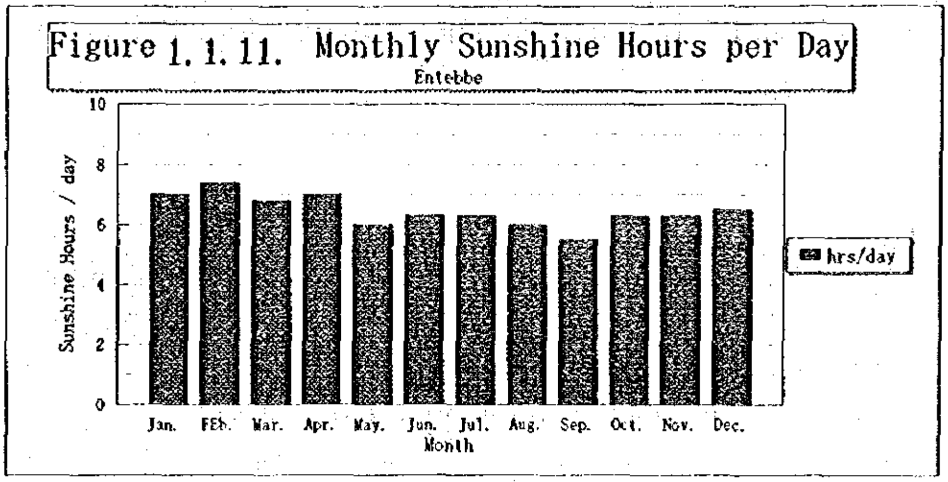


Figure 1.1.11. Monthly Sunshine Hours per Day
Entebbe
Sunshine Hours / day
10
8
6
4
2
0
Jan.
FEb.
Mar.
Apr.
May.
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Month
hrs/day

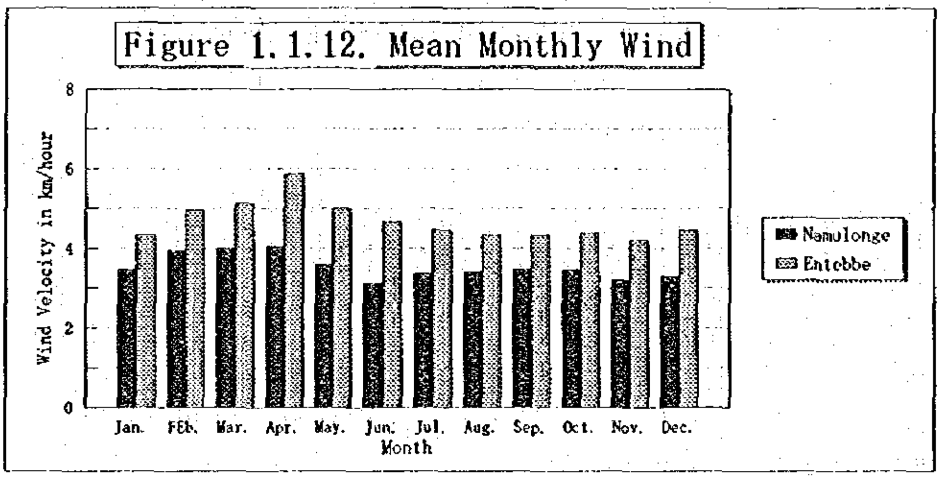


Figure 1.1.12. Mean Monthly Wind
Wind Velocity in km/hour
8
6
4
2
0
Jan.
FEb.
Mar.
Apr.
May.
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Month
Namulonge
Entebbe

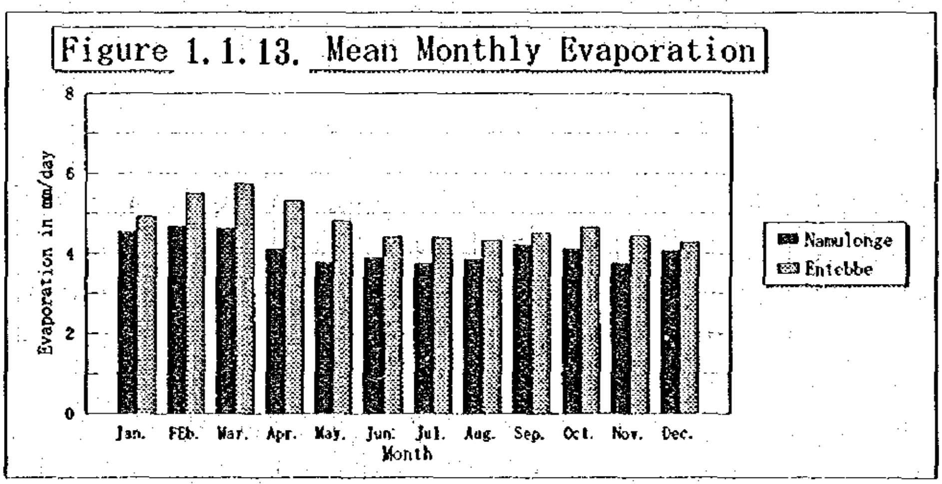


Figure 1.1.13. Mean Monthly Evaporation
Evaporation in mm/day
8
6
4
2
0
Jan.
FEb.
Mar.
Apr.
May.
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Month
Namulonge
Entebbe

1.1.3. Geology, Hydrogeology and Groundwater

(1) Geology

(a) General Geology of Uganda

Geology of Uganda consists of Precambrian rocks distributed in the whole country, Karoo shales of Paleozoic in very limited area, volcanic rocks of Tertiary to late-Cretaceous in the western Rift Valley, and volcanic rocks distributed in western and eastern volcanic activity areas and sediments of Quaternary in the whole country. A simplified geological map is shown in Figure 1.1.14. and geological succession in Table 1.1.5.

Table 1.1.5. Simplified Geological Succession

Pleistocene - Recent	Plateau deposits, black soils, outwash fans, lake shore deposits Pleistocene volcanics (late-Pleistocene) Western Rift Valley deposits
Mesozoic - Tertiary	Eastern volcanic sediments
	Kisegi beds of Western Rift Valley
	Karamoja beds: grits, tuff, basalt
Mesozoic	Karoo shales
Precambrian	Cover formation grits, sandstone, conglomerates, shales, schists, quartzites, phyllites
	Gneissose formation granitized and metamorphosed quartzite, schists, sandstone, phyllites, amphibolites and gneisses
	Basolith body mobilized and intrusive granites

Precambrian rocks are largely divided into three formations: cover formation, gneissose formation and mobilized and intrusive granites.

The gneissose formation called Gneiss Complex overlies the country extensively. The formation is mainly composed of granitized and metamorphosed gneisses including elements of covered formation.

The cover formation is found widespread in the southern region including the study area. The formation is divided into eight formations and three of them are distributed in the study area: Mityana Series, Singo Series and Buganda-Toro System. The Series and System in the study area predominate in metamorphosed sedimentary rocks such as sandstone, conglomerate, schist, phyllite and quartzite. Mityana and Singo Series are distributed in limited area, but Buganda-Toro System is the most extensive in the area. Schist, shale and phyllite predominate in the study area,. The System, in general, appears to lie upon Gneiss Complex, but in some places, it is difficult to distinguish from granitized Buganda-Toro System.

Intrusive granites are extensively found in north-west region including the study area. These rocks are in general medium to coarse grained, and porphyritic granites occur in Mubende District.

The Mesozoic and Cenozoic rocks of Uganda are composed chiefly of Rift Valley Sediments, volcanic formations and more recent alluvial overburdens and are affected by structural movement. Alluvial deposits are broadly distributed along valleys.

The major geological structures of Uganda was formed by organic fold and shear in the Precambrian, rift movement of late-Cretaceous to Tertiary. By the rift movements the Western Rift Valley was formed and filled with sediments, 1,800m in places. The latest stage of the rift movements gave rise to renewed volcanic activity in the center of the country which produced the Lake Kyoga drowned valley system and Lake Victoria.

(b) Geology of the Study Area

The study area is underlain by the cover formation, Gneiss Complex and intrusive granites of Precambrian, and sediments of Pleistocene to recent. Summarizes geological map is shown in Figure 1.1.15. Three formations of cover formation are distributed in the area: Mityana Series, Singo Series and Buganda-Toro System.

The Mityana Series is composed of shales, sandstone and conglomerate, and underlain by in the catchment area of Lake Wamala. The Series predominates in silicified sandstone, but shale and conglomerate beds are alternating. The rocks are normally hard and massive, and many springs are found along faults. They are underlain by the Buganda-Toro System.

The Singo Series consists of arkose, sometimes with coarse conglomerates at the base and mudstone. The rocks are distributed in north-west and north-east of Mubende District and south-east of Kiboga District.

The Buganda-Toro System is broadly distributed in the study area, but very poorly exposed. The rocks consist of schists, phyllites, shales, sandstones, conglomerates and quartzites. Weathered formations are normally thick, in some places in Mubende District reaching 60m or less. Fresh formations of argillites are soft and have scarce fissures. Argillites predominate and sandstones and conglomerates are frequently thinly bedded. In throughout much of the area, quartzite separates Buganda-Toro System from underlain Gneiss Complex. The thickness of the System has been estimated of the order of 900m or less in the south of Mpigi District (The Geology of Southern Mengo, Geological Survey of Uganda, 1959), but it is presumed from the existing borehole records that the System is more thick in western region than in eastern region.

Gneiss Complex is mainly composed of fine to coarse grained gneiss of granitic composition and granitic gneiss with bands of quartz-feldspar pegmatite. The highly weathered formations are normally thin, 20m or less, and fresh formations are hard and have large fractures, especially along faults.

Intrusive granites are distributed in the west and north of Mubende District. The granites are usually coarse and porphyritic, but fine and medium grained varieties occur. The rock is hard and has usually scarce fractures.

Most of the valleys throughout the area are filled with a variable thickness of silt, clay and sand.

(c) Geology of Kiboga District

The area is underlain by alluvium, Buganda-Toro System and Gneiss Complex; but last two are exposed at the very limited surface.

Alluvium is composed of unconsolidated layers, and distributed in the river floors and the broad flood plane in the north with 5 to 30 m thick. The layers are composed of silt, clay and sand, but sand beds are normally not expected as aquifers because of poor thickness and their discontinuity.

Buganda-Toro System lies to the south of the district and forms hilly land ranging from 1,000 to 1,500 masl. It is composed of alternations of sandstones, schists, shales and conglomerates. The area where the system is distributing is separated into two part topographically and geologically: the highly populated area along the Kampala-Kiboga road and low population density area in the hilly lands. The highly populated area is located in the valley formed by a fault extending for about 50 km in N.N.W. The area has many boreholes which are drilled along the faults and extracting large yields. In the hilly land, many faults are found by the interpretation of aerophotographs and those form steep slopes which make hard accessibility to villages. Along the faults aquifers with high yields are expected. The test boreholes are drilled near the faults and have gotten good results.

Gneiss Complex consists mainly of gneiss and granitic gneiss and is distributed in extensive area of north of the district. The area is overlain by thick alluvium and highly weathered formation of the rocks reaching 30 to 50m in depth. The complex in the area has poor fractures.

(d) Geology of Mubende District

The area is underlain by alluvium, Mityana Series, Buganda-Toro System, Gneiss Complex and intrusive granites. These rocks are exposed in very limited surface.

Alluvium is broadly distributed on river floors, especially around Lake Wamala. Characteristics of the formation is same with Kiboga District, and not expected as aquifers.

Mityana Series is composed of sandstones, conglomerates and shales, and distributed around Lake Wamala. The formations dip gently on all sides towards the center of the Lake. The lithology is silicified hard and massive, but good aquifer when borehole is drilled along faults. Large amount of yield from boreholes drilled in Mityana town and in some villages. Many springs are found along faults.

Buganda-Toro System is distributed extensively. Schists and Phyllites predominate and silicified sandstones are partially distributed. The depth of the formations is not reported, but the test borehole drilled in Kiganda Sub-County is more than 100 m and in Butayunja Sub-County 35 m. The System is underlain by Gneiss Complex, and the existing borehole records show that many boreholes are drilled successfully when they penetrate the System and encounter the fractures in Gneiss Complex.

Gneiss Complex is distributed in western region: Kasambya and Kitenga Districts. It is poorly foliated and massive. The borehole records reveal that the total depth of boreholes are deep and yield is low.

Intrusive granites are distributed in the north-west of Lake Wamala and in the most western area. The rocks are normally massive, hard and poorly fractured. There are few successful borehole records in the area.

(e) Geology of Mpigi District

The District is underlain by alluvium, Buganda-Toro System, and Gneiss Complex, but last two are exposed in very limited surface.

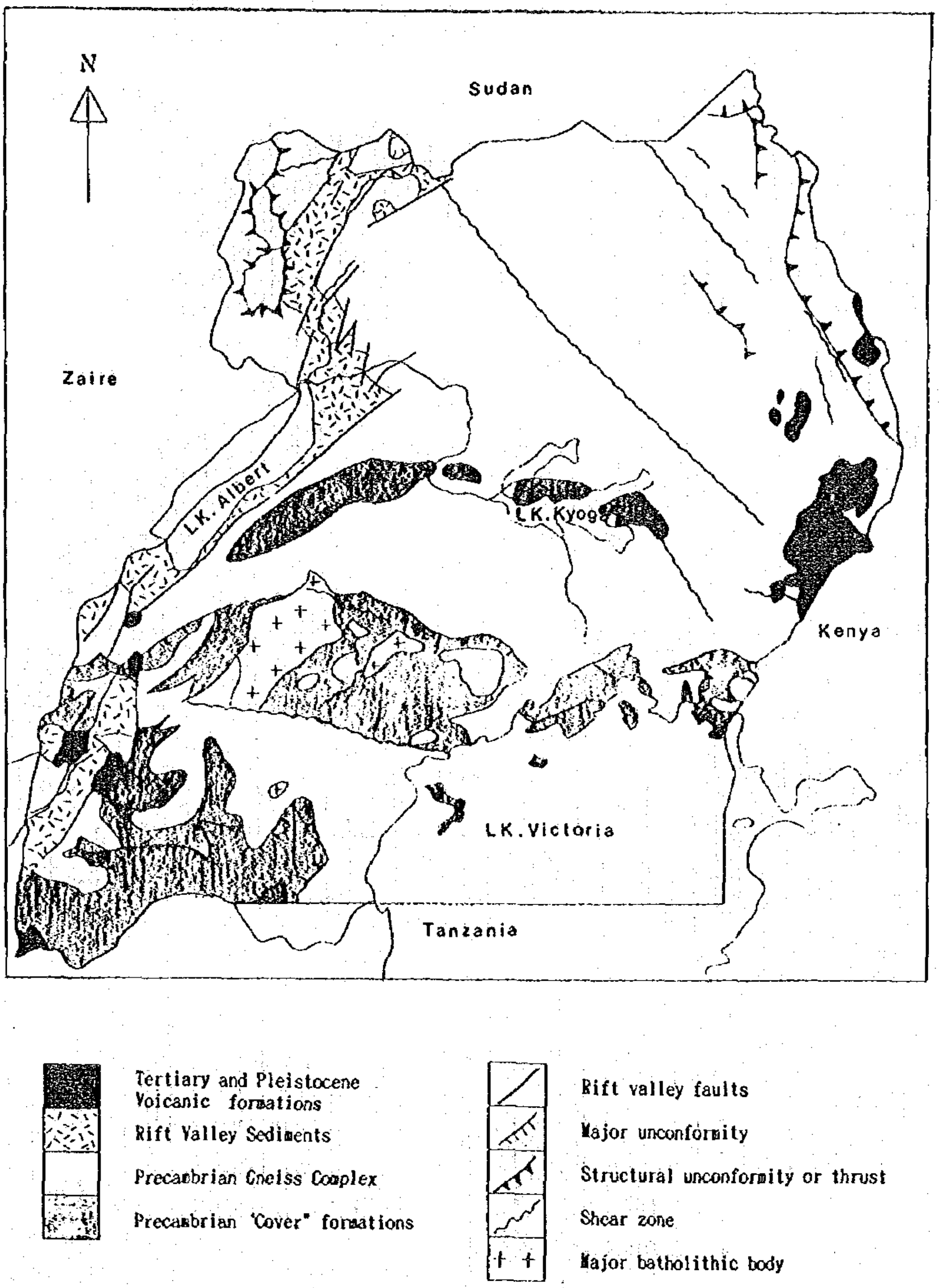
Alluvium is distributed in river floors and forms large water pools which have sealed bottoms by impermeable sediments. The mouths of tributaries are dammed by their mother rivers and form water pools. The formation is usually not expected as aquifers because of discontinuous and thin coarse grained beds. Dug wells are normally constructed in the formations.

Buganda-Toro System lies widely in the district excepting the north-east region distributing Gneiss Complex. The existing borehole records reveal that the thickness is deep in the west and thinner towards east: more than 150m in Maddu Sub-County and less than 60m in Kiziba Sub-County.

Gneiss Complex is distributed in the north-east region: Kizibi, Nangabo and Wakiso

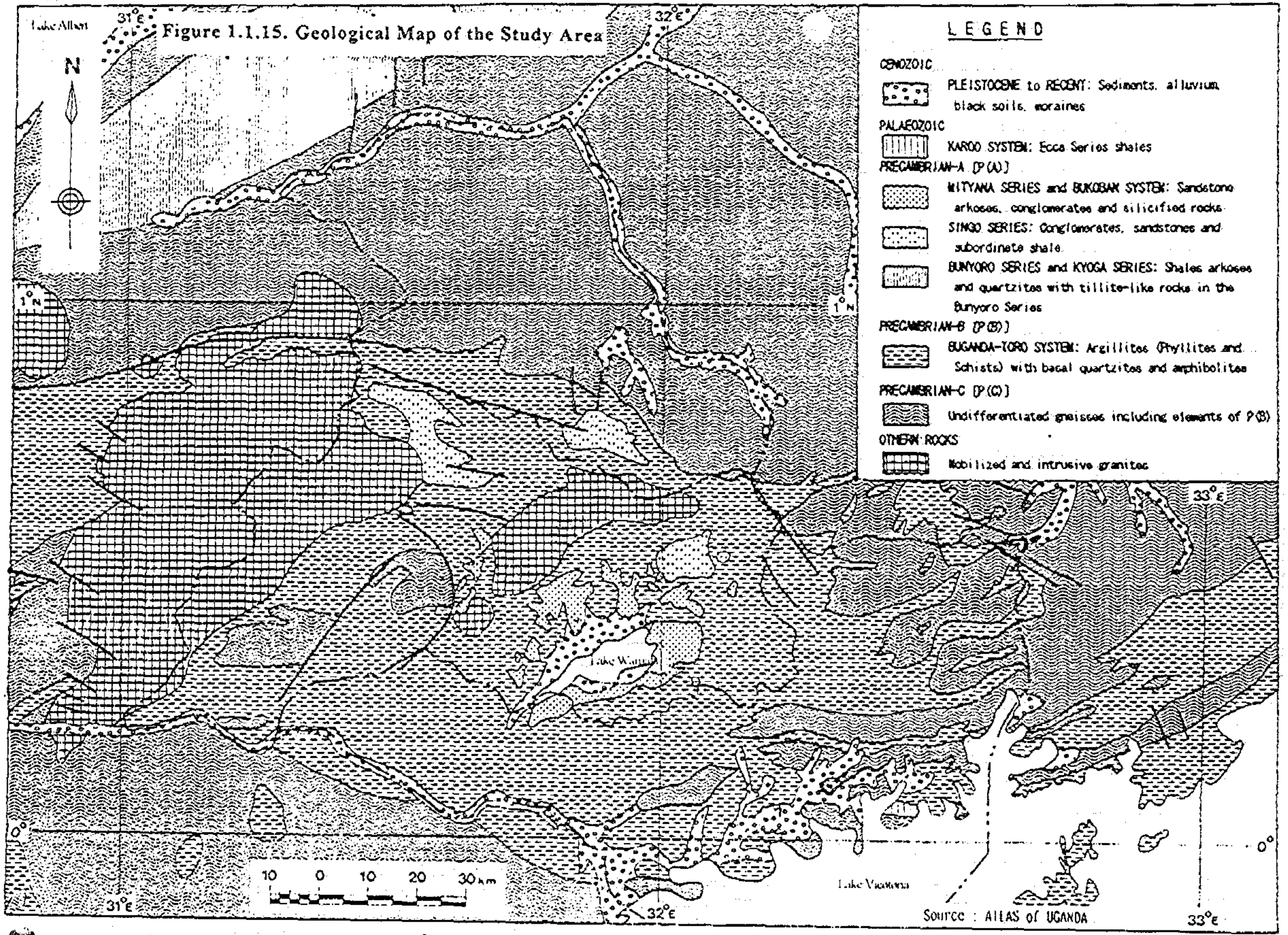
Districts, and underlain by Buganda-Toro System. It is composed of coarse to fine grained well banded gneiss with granitic composition and granitic gneiss. The rocks are normally hard and massive, but in places where faults and contact zone between formations many boreholes are successfully drilled.

Figure 1.1.14. Geology of Uganda



Source: Atlas of Uganda, 1969

Figure 1.1.15. Geological Map of the Study Area



(2) Hydrogeology and Groundwater

(a) Hydrogeology of the Study Area

Aquifer system in the study area lie only of fractures in rocks of which size and extent vary in location due to weathered conditions and grain size of rocks, geological structures etc. Information on aquifer characteristics in each hydrogeological unit are not available with the exception of personal experience. The discontinuous fractures and incomplete drilling records give difficulty in siting and construction of successful boreholes. Table 1.1.6. shows the summary of existing borehole records.

Although the rivers are mostly overlain by alluvial formations, sand and gravel beds have not enough extent for aquifers.

The major aquifers distributing in the area are Mityana Series, Buganda-Toro System, Gneiss Complex and Intrusive Granites as shown in Figure 1.1.15..

Mityana Series is distributed around Lake Wamala and predominates siliceous sandstone and conglomerate. Many boreholes are drilled in Mityana town and its surrounding villages. A large scale fault runs from north to south through Mityana town area for about 20 km, and small faults crossing the major fault are detected by aerophotographs. Groundwater is expected along the faults and successful existing boreholes are extracting water from the fractures resulting from the faults. The average yield is greatest within the four formations listed in Table 1.1.6., but fractures with water are discontinuous and potential in some areas is relatively low. The existing boreholes in the Mityana town are affected by drawdown of groundwater table because of relatively low potential and overpumping. Resistivity of the rocks ranges from 250 to 3,500 ohm-m and aquifers from 250 to 1,800 ohm-m.

Buganda-Toro System predominates in schists and phyllites, and the average yield is lower than other formations as shown in Table 1.1.6. Some boreholes drilled in the area, however, have high yield, and it is considered from the evaluation of the existing borehole records that those penetrated the System and are drilled into underlain Gneiss Complex. Those boreholes are mostly found in east and north areas where the System is not deep. The resistivity of the System ranges from 400 to 2,000 ohm-m and aquifers from 40 to 500 ohm-m.

Gneiss Complex is most reliable aquifer in the area, and fractures are able to detect easily as high conductivity by geo-magnetic survey. The average yield of the whole area is 2.0m^3/hr, however, in Kiboga District only 1.0m^3/hr. In the north-east region of Mpigi District it is more than 3.0m^3/hr in average. Resistivity of the rocks ranges from 50 to 4,000 ohm-m and aquifers from 50 to 1,000 ohm-m.

Intrusive granites is distributed in the limited area and the average yield is 1.3 m^3/hr. The granites are normally hard and massive, and resistivity ranges from 50 to 4,000 ohm-m and aquifer from 50 to 1,000ohm-m. High yield is not expected from the rocks because of few fractures and topographical features forming hilly land.

(b) Kiboga District

The summary of the existing borehole records in each sub-county and hydrogeological map are shown in Table 1.1.7. and Figure 1.1.16. The average yield is lowest in Ntwetwe where topographic features consist of hilly land and broad swamps, and highest in Kiboga and Butemba where granitic gneiss and sandy rocks are distributed. Buganda-Toro System ranges from 0.9 to 2.1 m^3/hr in the average yield and Gneiss Complex from 0.5 to 1.5 m^3/hr. The average static water level is 31.1 m. The remarkable hydrogeological characteristics are low static water level and deep pump location: average static water level is 31.1m and pump setting depth is 48.7 m.

Low water potential areas, which are recommended alternative water resources, are found: Kiboga town and some villages in mountain region.

Kiboga town is located on the half way of the hill which is highly populated, and underlain by hard and massive granitic gneiss which have few fractures. Three boreholes are located in the proposed area and water level affection is expected. High groundwater potential, however, is expected along River Nakayenga about 1.5 km far from the town.

Mwezi, Bukasa and Muwanga villages in mountain region are located on hill top or half way with steep slopes. The topographical features show very deep groundwater.

(c) Mubende District

The average yield is highest in Myanzi which faces Lake Wamala and is underlain by Mityana Series consisting of sandy rocks, and lowest in Butayunaja underlain by schists. Argillites of Buganda-Toro System are broadly distributed in the district and the potential of the formation is low. The average yield is lower in west than central and east region. The average total depth is 90m and static water level is 25m. The district is also characterized by low groundwater level and deep borehole depth: average total depth is 90 m and static water level is 25 m.

The summary of existing borehole records and hydrogeological map are shown in Table1.1.8. and Figure 1.1.17.

Three areas are identified as low groundwater potential area: Kabbo Parish in Kasambya Sub-County, Kiganda Sub-County and Mityana town.

Kabbo Parish is located on the top of hills with steep slope and large relative relief. The existing borehole records show deep water level and few fractures in granitic rocks.

Kiganda Sub-County area is underlain by deep and fine grained sedimentary rocks and small recharge area. Many drilling including a test borehole in Manyogaseka are tried, however many of them are failed.

Mityana town has 16 boreholes in the town and their water levels are affected by overpumping. Mityana Series distributed in the area has good aquifers, but increase of boreholes will lead deterioration of aquifers.

(d) Mpigi District

The area is clearly divided into two hydrogeological areas: west area consisted mainly of argillites of Buganda-Toro System has low potential ranging from 0.6 to 1.0 m^3/hr in average yield, and east area distributed by Gneiss Complex has comparatively high yield ranging from 1.1 to 2.9m^3/hr. Total borehole depth and groundwater level are shallower in east area than west area.

The summary of existing borehole records and hydrogeological map are shown in Table1.1.9. and Figure 1.1.18.

Kyaayi Parish and Wakiso Trading Center are found as low groundwater potential area. Kyaayi Parish is dry area with low precipitation and small watershed. Wakiso Trading Center is located on the edge of watershed and has low groundwater level.

Table 1.1.6. Summary of Existing Borehole Records and Resistivity

Hydrogeological Unit	Location	Existing Borehole Record			Resistivity	
		Avg. Total Depth (m)	Avg. Yield (m3/hr)	Avg. SWL (m)	Unit (ohm-m)	Aquifer (ohm-m)
Mityana Series	Lake Wamala	80.2	2.2	25.6	250-3,500	200-1,800
Buganda-Toro System	Whole District	91.7	1.3	25.3	40-2,000	40- 500
Gneeiss Complex	Whole District	72.8	2.0	22.2	50-4,000	50-1,000
Granites	Mubende	70.1	1.3	26.4	50-4,000	50-1,000

Resistivity/Unit:range of apparent resistivity of formations
Aquifer:range of apparent resistivity of aquifers

Table 1.1.7. Summary of Existing Boreholes in Kiboga District

Sub-County		Total Depth(m)		Length of Blank Casing (m)		Length of Screen (m)		Depth of Pump (m)		Yield (m3/hr)		SWL (m)		S.C. (m3/hr/m)
Lwamata	Avg.	67.7		58.1		12.2		45.4		0.9		33.6		
	Max.-Min.	76.3	59.2	61.3	54.9			71.7	19.1	1.2	0.6	50.3	16.8	
Ntwetwe	Avg.	100.4		45.7				52.5		0.6		44.8		
	Max.-Min.	145.5	70.2	61.6	36.0			61.0	45.8	1.6	0.0	97.6	7.6	
Bukomero	Avg.	66.1		32.3				40.1		1.0		20.5		
	Max.-Min.	120.0	27.0	60.0	15.9			61.0	19.2	3.0	0.1	39.0	7.6	
Kiboga	Avg.	68.7		26.0				51.9		1.2		22.6		
	Max.-Min.	147.0	21.0	35.1	21.0			67.1	42.7	2.5	0.4	26.9	19.2	
Butemba	Avg.	81.8		48.5				53.4		1.2		34.1		
	Max.-Min.	152.5	33.6	59.3	32.6			67.1	42.7	2.1	0.6	57.0	11.6	
Total	Avg.	76.9		42.1	0.0	12.0		48.7		1.0		31.1		
	Max.-Min.	128.3	42.2	55.5	32.1	12.0	12.0	65.6	33.9	2.1	0.3	54.2	12.6	

Table 1.1.8. Summary of Existing Boreholes in Mubende District

Sub-County		Total Depth (m)	Length of Blank Casing (m)	Length of Screen (m)	Depth of Pump (m)	Yield (m3/hr)	SWL (m)	S.C. (m3/hr/m)
Kasambya	Avg.	95.4	30.9		51.4	0.7	32.7	
	Max.-Min.	140.9 51.0	44.2 12.0		79.3 30.0	1.5 0.1	79.3 4.5	
Bagezza	Avg.	92.8	43.3		42.0	1.0	41.4	
	Max.-Min.	158.6 42.7	54.6 24.0		58.0 31.8	1.9 0.3	75.0 15.0	
Kiyuni	Avg.	63.9	30.5		47.8	1.1	28.8	
	Max.-Min.	76.3 47.1	47.0 11.0		58.0 30.4	1.6 0.6	39.7 14.0	
Kitenga	Avg.	99.5	28.0		43.0	1.2	24.0	
	Max.-Min.	139.7 50.3	41.2 13.1		74.4 31.4	2.4 0.4	36.9 9.8	
Madudu	Avg.	82.8	46.8		55.4	1.0	24.5	
	Max.-Min.	100.7 49.1	67.4 30.2		78.6 42.7	1.5 0.5	27.5 20.1	
Kiganda	Avg.	98.9	39.5		52.9	2.3	26.6	
	Max.-Min.	183.0 24.1	92.1 20.4		61.0 48.2	4.9 0.8	48.2 11.9	
Kassanda	Avg.	49.5	61.6		48.8	2.2		
	Max.-Min.	74.7 30.2	61.6 61.6		48.8 48.8	2.2 2.2	31.3	
Bukuya	Avg.	96.9	38.1		53.2	2.0	51.6 7.6	
	Max.-Min.	152.5 48.2	49.1 21.0		61.0 45.5	4.1 0.4		
Myanzi	Avg.	86.0	45.2		52.6	3.2	32.1	
	Max.-Min.	134.2 62.2	68.6 11.0		85.4 31.8	6.1 0.9	49.1 7.6	
Maanyi	Avg.	113.4	77.0		18.7	2.5	19.0	
	Max.-Min.	131.5 100.4	107.5 45.8		19.1 18.3	4.4 1.2	38.1 8.5	
Butayunja	Avg.	83.3	58.9			0.5	31.4	
	Max.-Min.	83.3 83.3	58.9 58.9			0.5 0.5	31.4 31.4	
Kakindu	Avg.	104.7	64.2		50.8	0.9	21.9	
	Max.-Min.	152.5 60.6	114.1 30.0		56.8 50.8	1.4 0.4	26.5 22.9	
Malangala	Avg.	60.2	30.9		37.8	0.6	11.5	
	Max.-Min.	123.8 61.3	54.9 22.9		67.1 42.7	1.6 0.7	18.0 11.9	
Mityana TC	Avg.	100.0	33.9		56.3	1.4	21.0	
	Max.-Min	150.1 63.0	40.9 28.4		73.0 30.8	2.7 0.4	32.9 3.1	
Mityana	Avg.	114.1	31.0		40.3	2.0	26.3	
	Max.-Min.	183.0 55.0	51.2 17.7		50.6 34.8	5.9 0.3	52.8 15.3	
Bulera	Avg.	56.6	25.4		32.1	2.2	14.1	
	Max.-Min.	75.3 27.5	50.3 2.1		54.9 16.7	3.0 1.7	38.1 1.8	
Sekanyoni	Avg.	120.8	51.8		60.7	0.6	17.7	
	Max.-Min.	183.0 68.3	70.2 38.5		66.4 54.9	1.2 0.4	23.8 12.8	
Total	Avg.	89.3	43.4		44.0	1.5	25.0	
	Max.-Min.	131.9 54.4	63.2 26.4		58.7 34.7	2.8 0.7	38.2 11.2	

Table 1.1.9. Summary of Existing Boreholes in Mpigi District

Sub-County		Total Depth (m)	Length of Blank Casing (m)	Length of Screen (m)	Depth of Pump (m)	Yield (m3/hr)	SWL (m)	S.C. (m3/hr/m)
Maddu	Avg.	99.5	44.7		50.4	1.3	34.0	
	Max.-Min.	152.5 57.0	57.3 4.3		85.4 0.0	5.0 0.1	41.2 19.5	
Kabulasoke	Avg.	87.2	46.0		41.4	1.5	25.0	
	Max.-Min.	138.2 50.3	78.6 20.7		59.8 26.0	5.5 0.6	45.5 6.1	
Ngando	Avg.	111.6	64.4		48.8	0.9	30.5	
	Max.-Min.	111.6 111.6	64.4 64.4		48.8 48.8	0.9 0.9	30.5 30.5	
Mpenja	Avg.	107.8	56.9		70.2	0.9	29.7	
	Max.-Min.	122.0 79.3	67.1 39.7		79.3 61.0	1.1 0.8	37.4 305.0	
Namayumba	Avg.	108.1	28.8		48.2	1.1	6.3	
	Max.-Min.	137.0 54.9	43.0 11.0		76.0 32.3	2.0 0.6	14.6 2.1	
Kiziba	Avg.	51.7	34.7		27.4	2.0	18.2	
	Max.-Min.	95.8 22.0	48.0 15.9		42.7 15.0	4.1 0.5	35.0 10.7	
Wakiso	Avg.	86.5	47.5		44.8	1.7	18.7	
	Max.-Min.	152.5 31.7	72.6 20.7		79.3 24.1	4.1 0.5	35.0 10.7	
Kyambogo	Avg.	51.9	26.6		29.5	4.1	11.1	
	Max.-Min.	152.5 20.7	45.0 14.6		32.2 24.9	11.8 0.4	28.9 3.7	
Nangabo	Avg.	63.6	35.2		32.4	2.9	15.0	
	Max.-Min.	152.5 0.0	62.8 0.0		79.3 0.0	13.1 0.0	36.6 0.0	
Total	Avg.	85.3	42.8		43.7	1.8	20.9	
	Max.-Min.	135.0 47.5	59.9 21.3		64.8 25.8	5.3 0.5	33.8 43.1	

Figure 1.1.16. Hydrogeological Map of Kiboga District

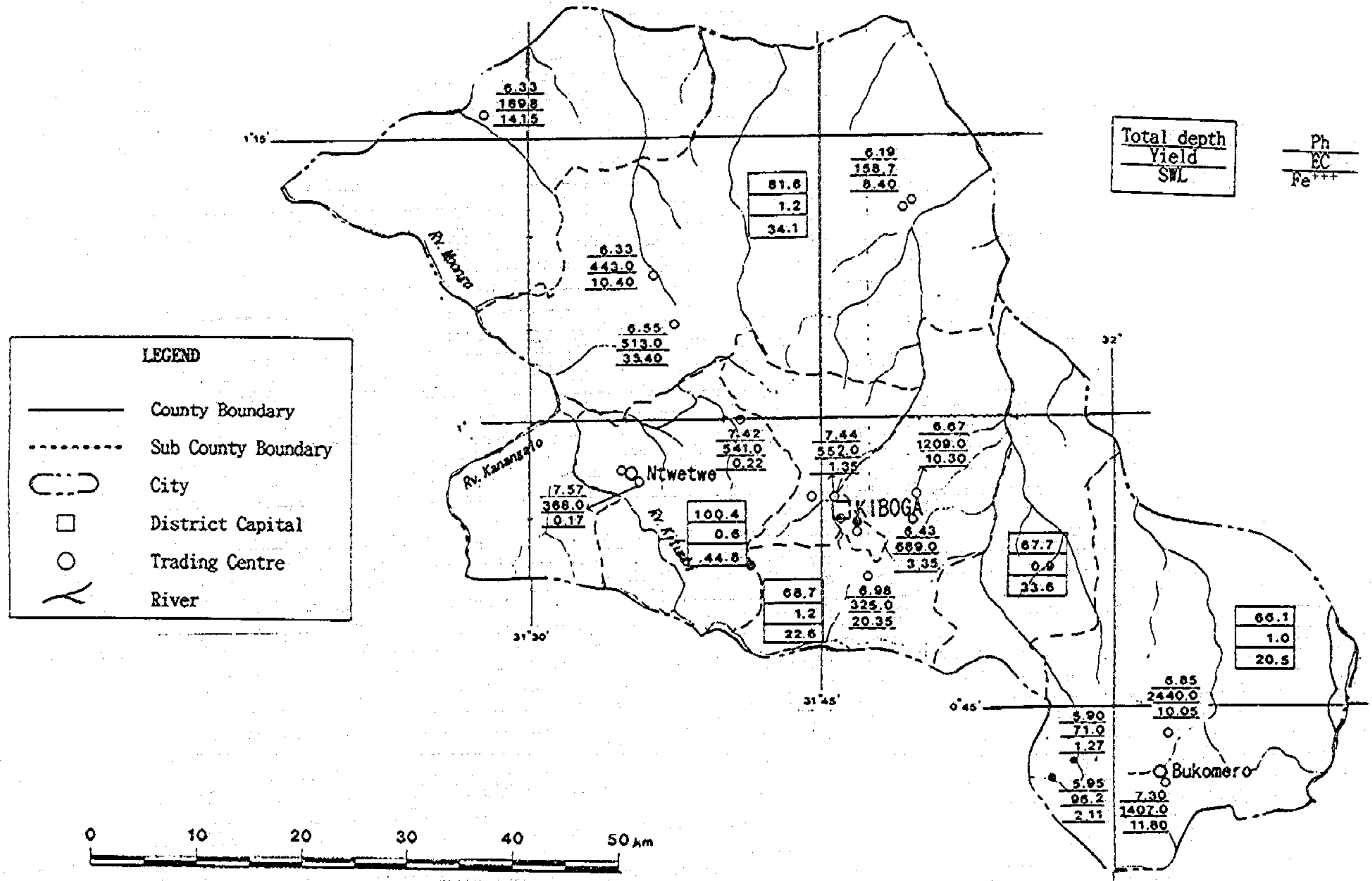


Figure 1.1.17. Hydrogeological Map of Mubende District

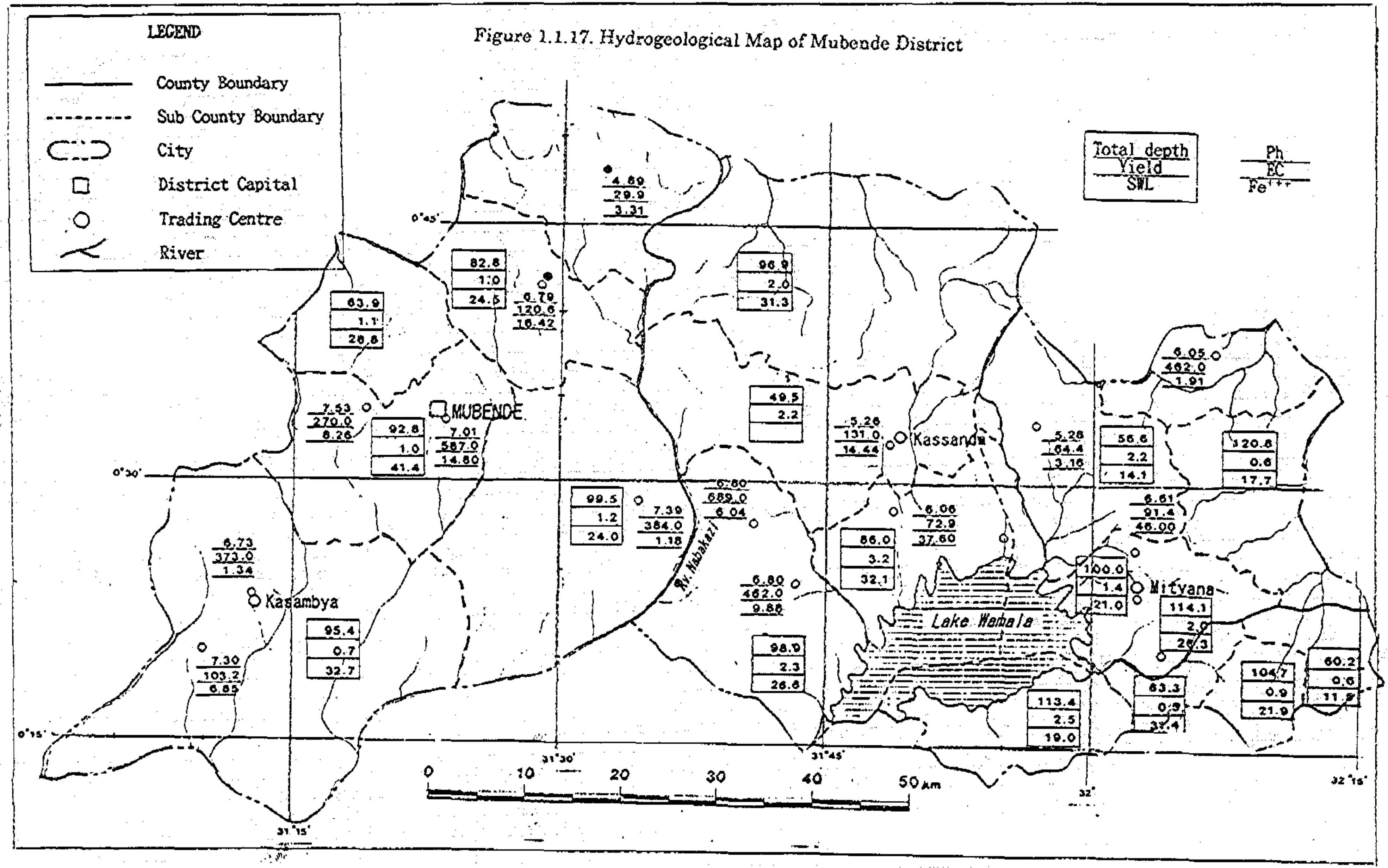
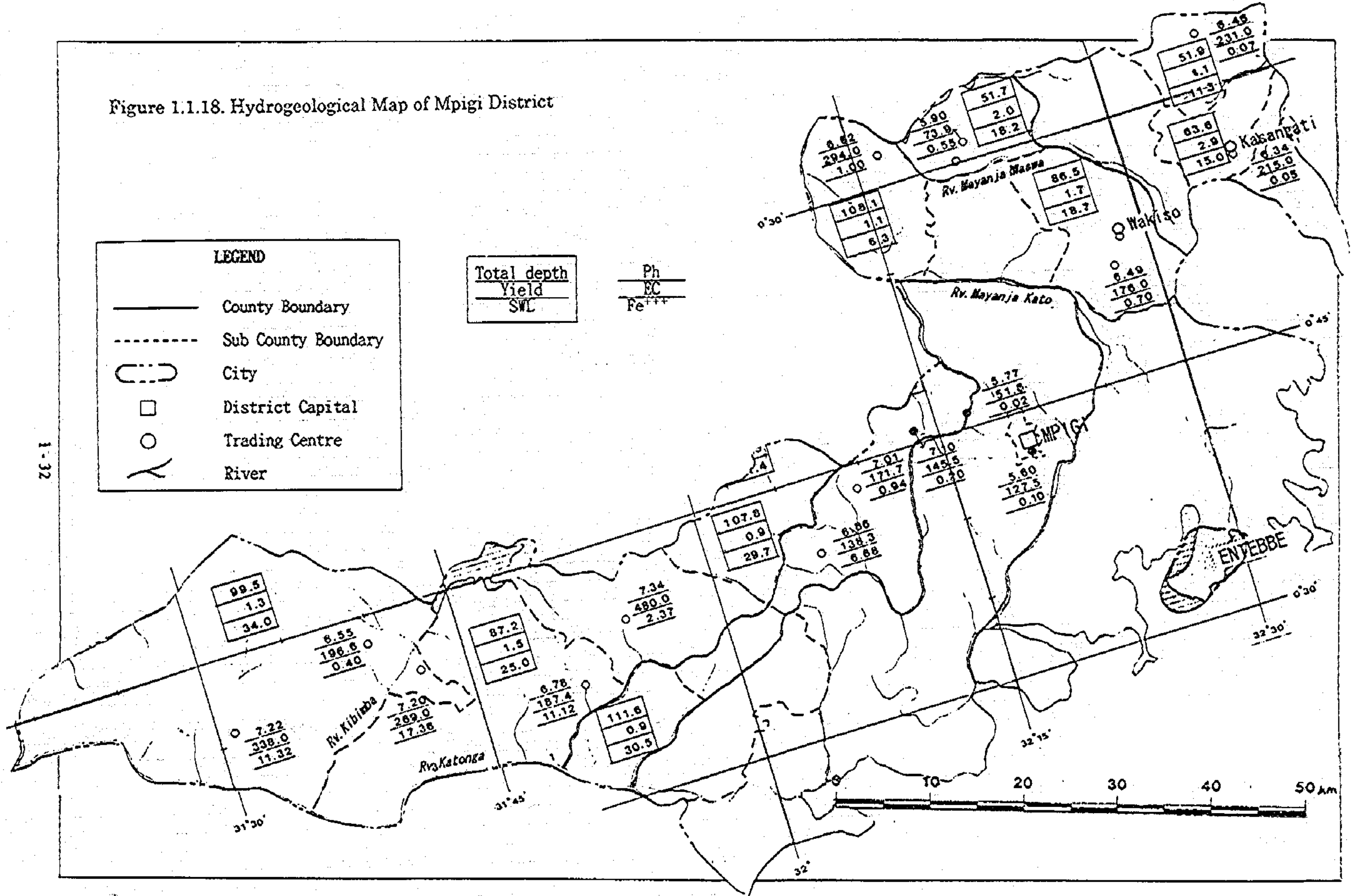


Figure 1.1.18. Hydrogeological Map of Mpigi District



(3) Water Quality

The water quality of existing boreholes, springs and rivers is analyzed by two type of methods: in-situ and laboratory test. 102 water sources are visited and surveyed from the view points of groundwater conditions, operation and maintenance and social environment before the sampling for laboratory test. Samples are taken from 58 water points and those are sent to the DWD Entebbe laboratory. The location of the in-situ test and sampling points is shown in Figure 1.1.19. and the summary is shown in Table 1.1.10 and 12.

(a) Type of Quality

The results of the laboratory test are plotted on Trilinear Diagram (see Appendix A.3.4.). The diagram shows that the water samples taken from the boreholes are plotted on two zones: a carbonate hardness zone which is generally represented by the quality of deep groundwater, and carbonate hardness zone to intermediate zone which is generally represented by the quality of shallow groundwater. Further understandings on the quality type are difficult due to the lack of the information of the boreholes.

(b) Results of Field Test

pH values of the boreholes range from 5.65 to 7.65 and springs from 4.98 to 6.16. The value of one spring is lower than 5.0, and 57.5% of water points lower than 6.5 which is the lowest limitation of WHO's recommended standard for drinking water (see Table 1.1.11.).

Electric conductivity (E.C.) ranges from 91 to 2,420 μ S/cm and high in Kiboga of which taste is slightly salty. These boreholes are drilled in Gneiss Complex.

Simple paper tests were performed for the investigation of biological contamination, and the results show that 45% of the boreholes and 67% of the springs are contaminated biologically. The contamination is more severe in Mubende.

Color of water is rusty or milky in 52% of boreholes and 32% of springs. The color of many boreholes reduces after short or long time pumping.

Table 1.1.10. Summary of Field Water Quality Test

	TestedN	pH	E.C.(μ S/cm)	Biological	Color
Kiboga	B/H 17	6.14-7.65	176-2,420	27.3%	41.2%
	S/P 4	5.75-6.13	18- 537	0.0%	50.0%
Mubende	B/H 25	5.69-7.32	115-1,046	68.1%	65.4%
	S/P 2	4.98-5.45	75-	100.0%	33.3%
Mpigi	B/H 22	5.65-7.10	91- 841	39.1%	47.8%
	S/P 6	5.41-6.16	52- 145	100.0%	11.1%
Total	B/H 67	5.65-7.65	91-2,420	44.8%	51.5%
	S/P 12	4.98-6.16	18- 537	66.7%	31.5%

Table 1.1.11. National Guideline for Drinking Water Quality

Item	National Guideline	National Guideline	WHO
pH	5.0-8.0	5.0-8.0	6.5-8.5
Turbidity (TUR)	20.0	20.0	5.0
Total Hardness	800	600	500
Na+ (mg/l)	-	-	200
Total Fe (mg/l)	2.0	2.0	0.3
Mn++ (mg/l)	1.0	1.0	0.1
F- (mg/l)	2.0	2.0	1.5
Cl- (mg/l)	600	600	250
NO3- (mg/l)	20	20	50
SO4-- (mg/l)	600	600	250
TDS (mg/l)	1,500	1,500	1,000

(c) Results of Laboratory Test

The samples taken from 58 water points are sent and analyzed by DWD Entebbe laboratory. The results are shown in Table 1.1.12. and Appendix A.3.1. The tables show that the many samples taken from the boreholes exceed the National Guideline for Water Quality Guideline (see Table 1.1.11.). The characteristics are as follows:

- Color; 34 out of 48 samples are colored in yellowish to brownish and many of them include rust and silt,

- Turbidity; 25 out of 48 samples exceed the permissible limit of the guideline,
- Total iron; 31 out of 48 samples exceed greatly the permissible limit,
- Electric conductivity (E.C.); there is no standard for E.C., but the values areexcessively high as compared with the normal values in Japan, that is, lower than 100-350 μ S/cm of groundwater, 250 μ S/cm of water supply of Tokyo and lower than 100 μ S/cm of river water,
- Chlorides: the values are in the permissible limit, but in Kiboga high,
- There is a relationship between color, turbidity and total iron, that is, water colored ⇔ turbidity large ⇔ total iron large,
- There is no relationship between color and pH value,
- Some of springs are colored, but they are muddy and not rusty, and turbidity is in the permissible limit,
- Two samples of spring exceed the permissible limit of total iron, but slightly.

(d) Evaluation

The results of the laboratory test reveal that more than 70% of the existing boreholes exceed the permissible limit of drinking water quality guideline of Uganda in the value of total iron, turbidity and color. It is considered that the reason of high iron concentration is derived from the corrosion of iron materials of boreholes using in the study area.

Corrosion can be prevented through the deposition of a protective coating of calcium carbonate. Saturated Index (Langelier Index) is normally used in Japan to evaluate a protective coating by $CaCO3$. Saturation Index is calculated from pH, calcium and bicarbonate by using the following formula:

$$I = pH - pHs$$

where:

$$pHs = pCa^{++} + pAlk + pK_2 - pKs$$

$$pCa^{++} = \log(1/Ca^{++})$$

$$pAlk = \log(1/HCO_3)$$

$$pK_2 = 10.25$$

$$pKs = 8.33$$

p = common logarithm of reciprocal

Calcium carbonate is produced when $I>0$ and does not produce when $I<0$. The result of the calculation for the samples is shown in Table 1.1.13. The table shows that the index of most samples is lower than zero which means that the groundwater in the area has tendency to corrode steel. High value of electric conductivity and chloride accelerates corrosion.

The biological pollution is big problem in the study area. 45% of the existing boreholes and 67% of the springs are contaminated by bacteria and or coliform. It is considered that the reasons are poor construction of borehole facilities and poor sanitary conditions. The quality of cement grouting and platform of many boreholes is poor, and waste water flows and infiltrates into the boreholes through concrete cracks and from ground. The contamination of the springs is derived from infiltration of waste water located on the slope above the springs.

Figure 1.1.19. Location Map of Water Quality Test

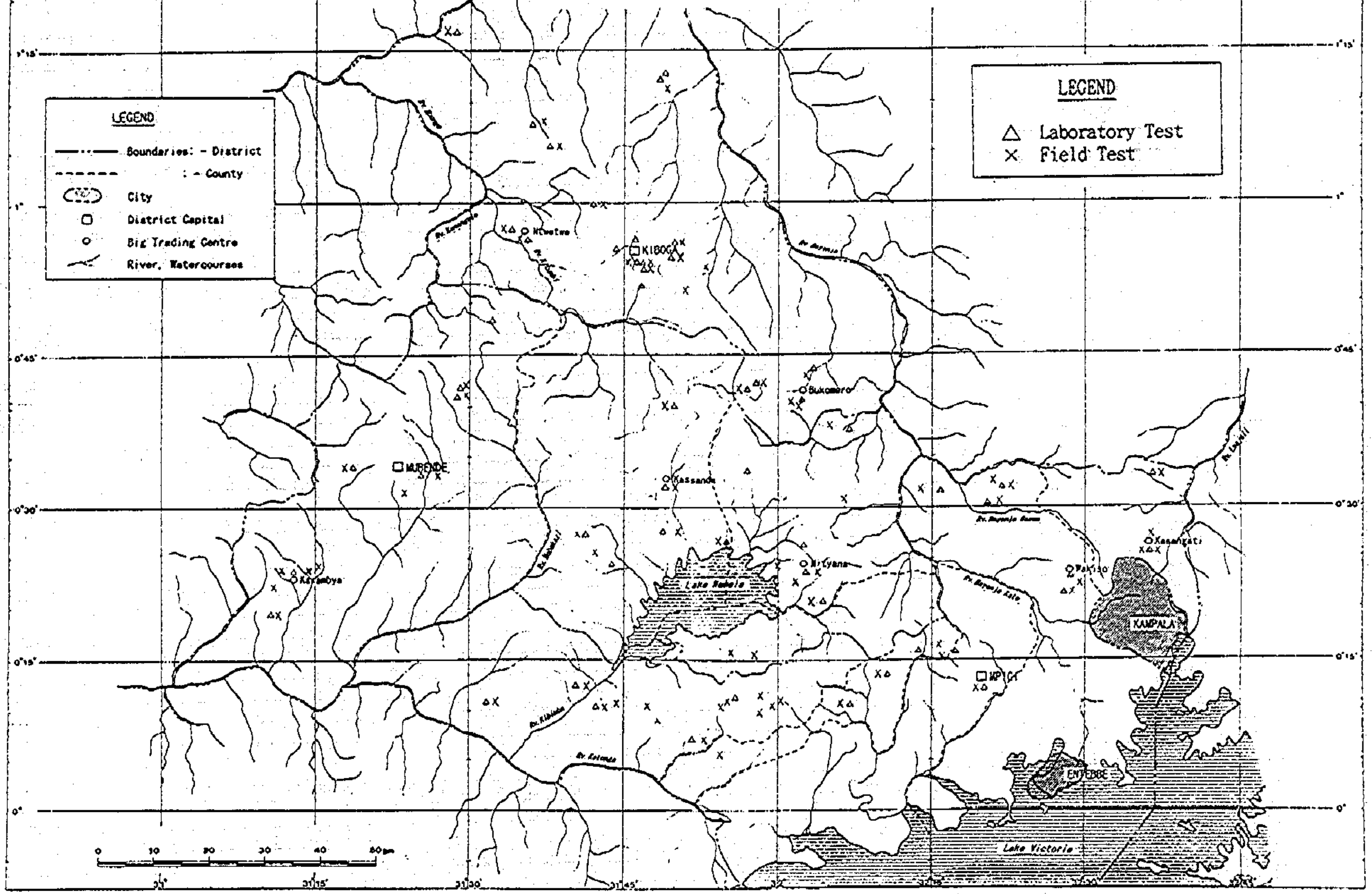


Table 1.1.12. Results of Water Quality Test

Ec		Ca	Mg	Na	K	Fe	HCO3	SO4	Cl	NO3	Mn	pH	Ec	TDS
171.7	MP/BH-1	5.46	12.01	14.00	12.00	0.94	96.30	2.00	2.00	0.50	0.01	7.0	171.7	86.0
138.3	MP/BH-2	5.46	7.87	12.00	2.00	6.68	70.70	4.00	8.00	0.00	0.02	6.9	138.3	
269.0	MP/BH-3	10.23	12.01	28.00	4.00	17.36	98.74	11.50	35.00	0.00	0.02	7.2	269.0	135.6
196.6	MP/BH-4	9.55	5.53	22.00	4.00	0.40	31.69	24.00	15.00	0.80	0.00	6.6	196.6	98.8
480.0	MP/BH-5	17.73	28.16	42.00	4.00	2.37	99.96	23.00	64.00	1.20	0.01	7.3	480.0	240.0
338.0	MP/BH-6	12.96	20.29	34.00	6.00	11.32	160.91	13.00	18.00	0.00	0.02	7.2	338.0	169.7
294.0	MP/BH-7	15.00	10.35	30.00	10.00	1.00	156.03	4.00	5.00	0.00	0.02	6.8	294.0	148.5
73.9	MP/BH-8	2.05	2.97	11.00	3.00	0.55	43.88	0.00	4.00	3.96	0.02	5.9	73.9	40.7
120.6	MP/BH-9	7.51	4.55	12.00	2.00	1.05	54.86	0.00	4.00	0.00	0.15	6.4	120.6	60.4
94.9	MP/BH-10	5.46	3.31	8.00	1.00	0.09	20.72	0.00	9.00	14.92	0.01	5.4	94.9	47.5
215.0	MP/BH-11	16.37	9.53	13.00	6.00	0.05	85.33	0.00	7.00	12.32	0.01	6.3	215.0	108.2
231.0	MP/BH-12	15.00	10.35	17.00	6.00	0.07	96.30	11.80	7.00	6.16	0.02	6.5	231.0	116.1
187.4	MP/BH-13	5.46	8.28	24.00	5.00	11.20	64.61	12.50	18.00	0.01	0.02	6.8	187.4	93.7
176.0	MP/BH-14	13.64	6.63	15.00	3.00	0.70	97.52	0.00	5.00	0.00	0.01	6.5	176.0	86.2
373.0	MB/BH-1	29.33	13.25	40.00	3.00	1.34	158.40	4.00	16.00	11.00	0.02	6.7	373.0	187.6
103.2	MB/BH-2	69.56	48.87	60.00	3.00	6.85	218.20	50.00	113.00	0.00	0.02	7.3	103.2	516.0
587.0	MB/BH-3	30.69	36.03	45.00	3.00	14.80	192.60	0.00	55.00	0.00	0.02	7.0	587.0	295.0
270.0	MB/BH-4	21.32	11.18	18.00	4.00	8.26	199.92	0.00	9.00	0.00	0.02	7.5	270.0	135.0
120.6	MB/BH-5	8.87	0.41	12.00	5.00	16.42	59.73	0.00	8.00	0.00	0.03	6.8	120.6	60.4
317.0	MB/BH-6	23.87	8.28	35.00	2.00	2.07	157.25	20.00	5.00	0.30	0.02	6.5	317.0	158.0
131.0	MB/BH-7	3.14	3.31	18.00	2.00	14.44	25.60	5.00	15.00	2.50	0.02	5.3	131.0	66.2
262.0	MB/BH-8	9.55	11.60	30.00	6.00	42.10	108.49	0.00	27.00	0.00	0.03	6.7	262.0	131.0
462.0	MB/BH-9	17.73	19.88	45.00	3.00	9.88	117.02	19.00	61.00	3.00	0.02	6.8	462.0	231.0
689.0	MB/BH-10	41.60	15.74	70.00	10.00	6.04	113.37	18.00	116.00	0.00	0.01	6.8,	689.0	345.0
384.0	MB/BH-11	30.00	13.67	40.00	4.00	1.18	176.76	3.00	18.00	3.00	0.02	7.4	384.0	192.0
50.6	MB/BH-12	2.73	1.66	4.00	1.00	1.80	7.31	3.00	5.00	3.00	0.05	5.1	50.6	25.3
64.4	MB/BH-13	2.05	2.90	9.00	2.00	3.16	23.16	10.00	5.00	0.00	0.06	5.3	64.4	33.6
462.0	MB/BH-14	32.06	16.15	35.00	4.00	1.91	93.86	11.90	38.00	35.20	0.02	6.1	462.0	231.0
221.0	MB/BH-15	6.14	6.21	30.00	15.00	24.80	60.95	8.00	28.00	0.00	0.03	5.6	221.0	
72.9	MB/BH-16	1.37	1.65	11.00	2.00	37.60	36.57	0.00	8.00	0.00	0.05	6.1	72.9	36.5
91.4	MB/BH-17	3.41	2.90	4.00	1.00	46.00	69.48	10.00	4.00	0.00	0.02	6.6	91.4	45.8
235.0	MB/BH-18	6.82	15.74	19.00	2.00	1.79	118.24	9.00	10.00	30.80	0.02	6.6	235.0	115.0
189.8	KB/BH-1	7.50	12.01	16.00	25.00	14.15	85.33	16.00	5.00	0.00	0.02	6.3	189.8	95.3
443.0	KB/BH-2	17.73	12.01	55.00	100.00	10.40	98.74	12.00	78.00	0.00	0.02	6.3	443.0	221.0
158.7	KB/BH-3	6.14	1.03	21.00	25.00	8.40	71.92	3.00	9.00	0.00	0.03	6.2	158.7	78.9
513.0	KB/BH-4	38.88	17.81	40.00	50.00	35.40	158.74	2.00	72.00	0.00	0.02	6.6	513.0	256.0
368.0	KB/BH-5	33.30	9.60	35.00	50.00	0.17	143.84	13.00	31.00	13.20	0.02	7.6	368.0	196.6
570.0	KB/BH-6	33.30	12.84	55.00	100.00	5.55	42.67	38.00	91.00	2.64	0.05	6.2	570.0	284.0
541.0	KB/BH-7	64.79	14.70	35.00	50.00	0.22	287.68	17.50	8.00	2.64	0.01	7.4	541.0	270.0
1262.0	KB/BH-8	88.66	40.59	80.00	100.00	4.69	146.28	58.00	207.00	3.96	0.10	6.5	1262.0	632.0
689.0	KB/BH-9	42.28	13.67	80.00	12.50	3.35	135.31	38.00	77.00	3.96	0.02	6.4	689.0	342.0
1209.0	KB/BH-10	71.16	42.24	90.00	150.00	10.30	308.41	21.00	212.00	0.00	0.02	6.7	1209.0	614.0
552.0	KB/BH-11	63.76	8.91	40.00	3.00	1.35	234.05	18.00	21.00	17.60	0.01	7.4	552.0	276.0
872.0	KB/BH-12	48.76	22.36	70.00	6.00	4.86	78.02	32.00	146.00	26.40	0.02	6.3	872.0	436.0
229.0	KB/BH-13	1.70	2.28	40.00	3.00	10.35	64.61	12.00	26.00	0.00	0.02	6.4	229.0	115.2
1407.0	KB/BH-14	47.74	63.78	115.00	4.00	11.80	262.09	51.00	309.00	0.00	0.01	7.3	1407.0	704.0
2440.0	KB/BH-15	171.9	89.45	200.00	5.00	10.05	317.72	10.00	507.00	0.00	0.01	6.9	2440.0	1221.0
325.0	KB/BH-16	25.55	8.28	17.00	2.00	20.35	140.19	10.00	19.00	0.00	0.02	7.0	325.0	163.2
145.5	MP/SP-1	15.00	4.56	8.00	1.00	0.20	73.14	0.05	8.00	1.00	0.02	7.1	145.5	72.8
51.8	MP/SP-2	4.78	2.58	3.00	1.00	0.02	24.88	0.05	1.00	5.72	0.02	5.8	51.8	53.2
127.5	MP/SP-3	6.14	7.87	14.00	6.00	0.10	19.50	0.05	11.00	16.72	0.03	5.6	127.5	63.9
63.2	MB/SP-1	2.73	1.24	10.00	5.00	0.36	17.07	12.00	4.00	6.00	0.02	5.8	63.2	31.6
29.9	MB/SP-2	2.05	1.24	3.00	1.00	3.31	9.75	0.05	4.00	13.20	0.02	4.9	29.9	14.9
527.0	KB/SP-1	38.88	30.65	19.00	30.00	0.12	103.49	52.00	27.00	8.80	0.05	6.2	527.0	265.0
96.2	KB/SP-2	4.43	1.45	7.00	2.00	1.27	24.38	6.00	3.00	0.05	0.01	5.9	96.2	35.5
190.3	KB/SP-3	5.46	2.48	9.00	1.00	2.11	29.26	10.00	5.00	0.01	0.10	6.0	190.3	48.1
506.0	KB/SP-4	28.64	5.59	30.00	5.00	0.53	54.86	18.00	12.00	9.68	0.02	6.4	506.0	95.4

Table 1.1.13. Saturation Index (Langelier Index)

NO.	Ca	HCO3	pH	Ca++(mol/l)	HCO3-(mol/l)	pCa++	pHCO3-	Index
MP/BH-1	5.46	96.30	7.0	0.00014	0.00158	3.86574	2.80185	-1.58
MP/BH-2	5.46	70.70	6.9	0.00014	0.00116	3.86574	2.93605	-1.86
MP/BH-3	10.23	98.74	7.2	0.00026	0.00162	3.59305	2.79098	-1.10
MP/BH-4	9.55	31.69	6.6	0.00024	0.00052	3.62292	3.28455	-2.28
MP/BH-5	17.73	99.96	7.3	0.00044	0.00164	3.35422	2.78565	-0.72
MP/BH-6	12.96	160.91	7.2	0.00032	0.00264	3.49032	2.57889	-0.77
MP/BH-7	15.00	156.03	6.8	0.00037	0.00256	3.42684	2.59226	-1.12
MP/BH-8	2.05	43.88	5.9	0.00005	0.00072	4.29117	3.14321	-3.45
MP/BH-9	7.51	54.86	6.4	0.00019	0.00090	3.72729	3.04622	-2.32
MP/BH-10	5.46	20.72	5.4	0.00014	0.00034	3.86574	3.46908	-3.81
MP/BH-11	16.37	85.33	6.3	0.00041	0.00140	3.38888	2.85437	-1.82
MP/BH-12	15.00	96.30	6.5	0.00037	0.00158	3.42684	2.80185	-1.69
MP/BH-13	5.46	64.61	6.8	0.00014	0.00106	3.86574	2.97517	-1.98
MP/BH-14	13.64	97.52	6.5	0.00034	0.00160	3.46811	2.79638	-1.69
MB/BH-1	29.33	158.40	6.7	0.00073	0.00260	3.13562	2.58572	-0.91
MB/BH-2	69.56	218.20	7.3	0.00174	0.00358	2.76057	2.44662	0.17
MB/BH-3	30.69	192.60	7.0	0.00077	0.00316	3.11593	2.50082	-0.53
MB/BH-4	21.32	199.92	7.5	0.00053	0.00328	3.27414	2.48462	-0.15
MB/BH-5	8.87	59.73	6.8	0.00022	0.00098	3.65500	3.00928	-1.79
MB/BH-6	23.87	157.25	6.5	0.00060	0.00258	3.22508	2.58888	-1.28
MB/BH-7	3.14	25.60	5.3	0.00008	0.00042	4.10600	3.37723	-4.14
MB/BH-8	9.55	108.49	6.7	0.00024	0.00178	3.62292	2.75008	-1.55
MB/BH-9	17.73	117.02	6.8	0.00044	0.00192	3.35422	2.71721	-1.19
MB/BH-10	41.60	113.37	6.8	0.00104	0.00186	2.98383	2.73097	-0.83
MB/BH-11	30.00	176.76	7.4	0.00075	0.00290	3.12581	2.53809	-0.19
MB/BH-12	2.73	7.31	5.1	0.00007	0.00012	4.16677	3.92155	-4.92
MB/BH-13	2.05	23.16	5.3	0.00005	0.00038	4.29117	3.42073	-4.35
MB/BH-14	32.06	93.86	6.1	0.00080	0.00154	3.09696	2.81299	-1.78
MB/BH-15	6.14	60.95	5.6	0.00015	0.00100	3.81476	3.00050	-3.11
MB/BH-16	1.37	36.57	6.1	0.00003	0.00060	4.46621	3.22235	-3.55
MB/BH-17	3.41	69.48	6.6	0.00009	0.00114	4.07017	2.94361	-2.32
MB/BH-18	6.82	118.24	6.6	0.00017	0.00194	3.76914	2.71271	-1.77
KB/BH-1	7.50	85.33	6.3	0.00019	0.00140	3.72787	2.85437	-2.17
KB/BH-2	17.73	98.74	6.3	0.00044	0.00162	3.35422	2.79098	-1.74
KB/BH-3	6.14	71.92	6.2	0.00015	0.00118	3.81476	2.92862	-2.47
KB/BH-4	38.88	158.74	6.6	0.00097	0.00260	3.01320	2.58479	-0.97
KB/BH-5	33.30	143.84	7.6	0.00083	0.00236	3.08048	2.62759	-0.06
KB/BH-6	33.30	42.67	6.2	0.00083	0.00070	3.08048	3.15535	-1.96
KB/BH-7	64.79	287.68	7.4	0.00162	0.00471	2.79142	2.32656	0.38
KB/BH-8	88.66	146.28	6.5	0.00221	0.00240	2.65520	2.62029	-0.70
KB/BH-9	42.28	135.31	6.4	0.00105	0.00222	2.97679	2.65414	-1.12
KB/BH-10	71.16	308.41	6.7	0.00178	0.00505	2.75069	2.29634	-0.30
KB/BH-11	63.76	234.05	7.4	0.00159	0.00384	2.79838	2.41616	0.31
KB/BH-12	48.76	78.02	6.3	0.00122	0.00128	2.91486	2.89327	-1.40
KB/BH-13	1.70	64.61	6.4	0.00004	0.00106	4.37248	2.97517	-2.91
KB/BH-14	47.74	262.09	7.3	0.00119	0.00430	2.92405	2.36702	0.09
KB/BH-15	171.9	317.72	6.9	0.00429	0.00521	2.36775	2.28343	0.28
KB/BH-16	25.55	317.72	6.9	0.00064	0.00521	3.19554	2.28343	-0.55

1.1.4. Geophysical Prospecting and Test Borehole

(1) Geophysical Prospecting

(a) Purpose and Methodology

Geophysical sounding was performed in the potential areas selected by preliminary hydrogeological survey. The purpose and method of sounding are as follows:

- to detect the fracture zone by the electro magnetic (EM) sounding,
- to detect depth to the fracture zone by the resistivity sounding,
- to detect thickness and litho-facies of overburden and highly weathered layers of bed rocks by the resistivity sounding using Wenner method,
- to study geophysical conditions in the study area through above sounding.

(b) Results of EM Prospecting

EM prospecting was carried out in the following geological areas:

Geology/District	Kiboga	Mubende	Mpigi
Quaternary	-	1	1
Mityana Series	-	3	-
Buganda-Toro System	5	1	2
Gneiss Complex	8	-	7
Total	13	5	10

The results of the prospecting show in Appendix A.6.1. and thesurveyed location in Figure 1.1.20. The conditions of each hydrogeological formation are as follows:

Quaternary deposits and Buganda-Toro System have not shown a typical peak which means a fracture zone except the site conducted at Bukomero Senior Secondary School, Kiboga District. The conditions will be caused by soft and fine grained formations.

High peaks of conductivity are detected in Mityana Series which is composed of hard rocks and predominates in sandstone and conglomerate.

In Gneiss Complex high peaks are detected, and the values of peaks which are fracture zones are generally more than 20 μ S/m.

(c) Results of Resistivity Prospecting

ρ-a curves and ohm-m resistivity are shown in Appendix A.1.6. and A.1.7. shows the summary of ohm-m resistivity. Geological information taken from the existing borehole records are written in some ρ-a curves. The prospecting was carried out in the following area:

Geology/District	Kiboga	Mubende	Mpigi
Quatenary	-	3	2
Singo Series	2	-	-
Mityana Series	-	6	-
Buganda-Toro System	3	6	5
Gneiss Complex	15	4	7
Granite	-	12	-
Total	20	31	14

Singo Series consisting of coarse grained rocks is distributed in the limited area of Kiboga and Mubende and has resistivity of lower than 1,500 ohm-m. The resistivity of aquifers is lower than 100 ohm-m.

Mityana Series ranges from 55 to 3,800 ohm-m and aquifers from 200 to 1,800 ohm-m resistivity.

Buganda-Toro System, ranges from 6 to 5,000 ohm-m resistivity, however, the resistivity of upper layers up to 70 to 100 m in depth show low resistivity of less than 500 ohm-m in Mpigi and Mubende. The aquifers ranges generally from 40 to 1,000 ohm-m resistivity.

Gneiss Complex are generally divided into three layers, that is, upper layer of 10 to 20 m in depth and 100 to 1,000 ohm-m resistivity, middle layer of 10 to 50 m in depth and 500 to 1,500 ohm-m resistivity and lower layer below than 30 m in depth and 1,500 ohm-m resistivity. The aquifers ranges from 40 to 2,000 ohm-m. Fractures in the rocks are well detected by geo-physical prospecting.

Granite is distributed in limited area of Mubende and consists of hard and massive rocks. The resistivity shows the characteristics by the curves increasing the values with depth. The borehole records reveal that the rocks have few opportunity to encounter the aquifers, but fractures of rocks are detected in low resistivity of less than 500 ohm-m.

(d) Results of Test Borehole Siting

Geo-physical prospecting for the test boreholes is conducted in 15 villages of the three districts. The table shown below is the numbers of prospecting of the drilled sites. Location map of each drilled village and the results of the prospecting are shown in Appendix A.1.6.

<Kiboga District>

Figure 1.1.21. shows EM and ρ-a curve of drilled sites of JA-2 and 3, Ssinde and Kawawa. Two lines of EM and one point of resistivity prospecting are performed in Ssinde. The profile is composed of three to four layers, but they can be divided into upper, middle and lower resistivity layers from the interpretation. Aquifers are estimated at 20 to 25 m and 70 to 80 m, and expected at 10 and 25 m. The profile and interpretation of Kawawa's site are divided into two layers.

District	No. of EM Line	No. of Resistivity Point
Kiboga	4	7
Mubende	20	34
Mpigi	5	6
Total	29	47

<Mubende District>

Five sites of four villages are drilled in the district, that is, Manyogaseka, Kitebere, Bekina and Namyeso. Figure 1.1.22 shows the curve of the JA-5, Bekina. Layers are divided into five from interpretation and aquifers are estimated in third layer located in 20 to 55 m.

<Mpigi District>

Six villages are surveyed in the district and Seeta and Magere are finally decided as the sites. Figure 1.1.24 shows EM and ρ-a curve of both sites. The interpretation of Seeta is divided into four layers and aquifers are expected in the depth below 20 m. Magere is divided into four layers and aquifers estimated is in 20 to 30 m.

Figure 1.1.20. Location Map of Geophysical Prospecting

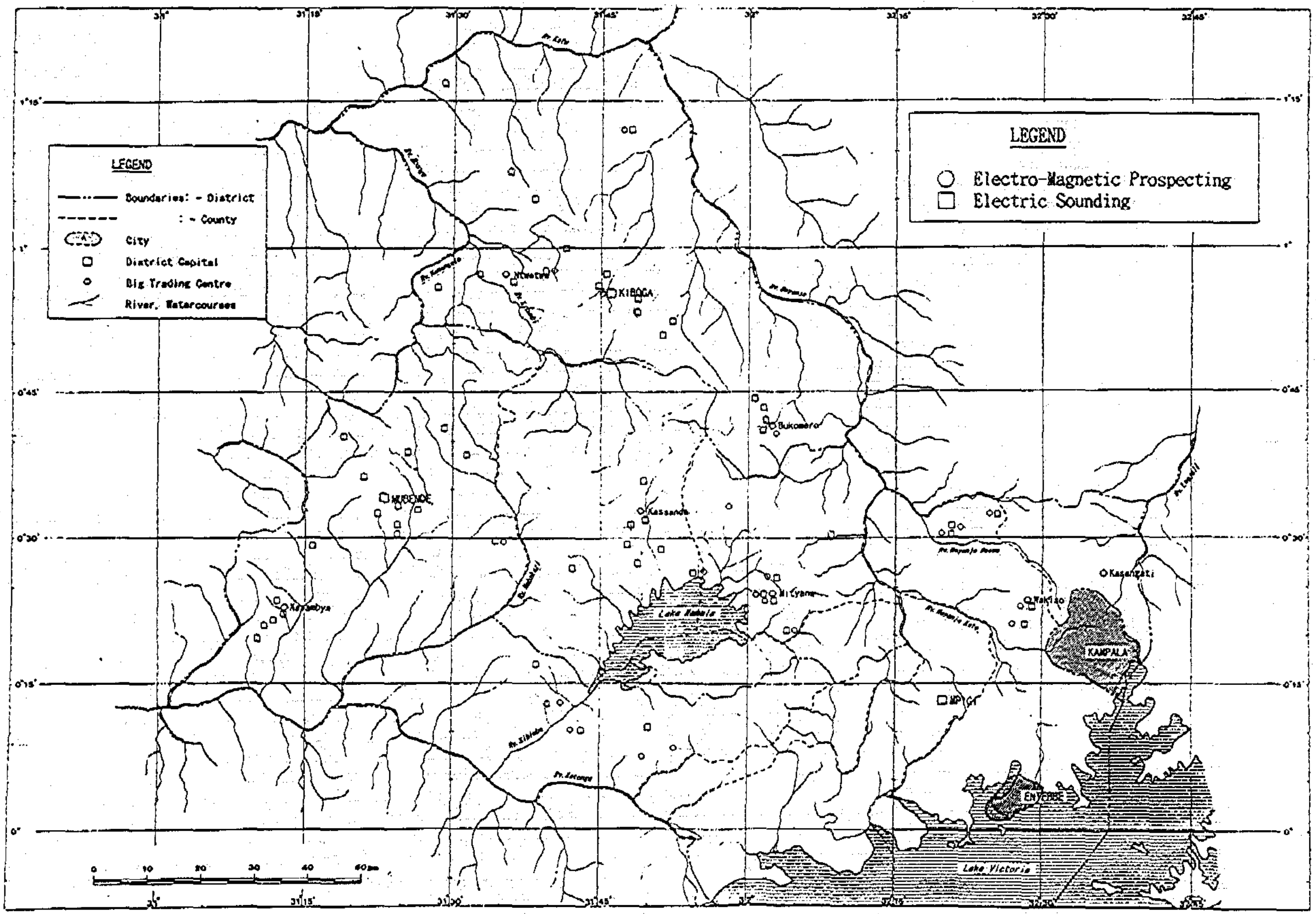
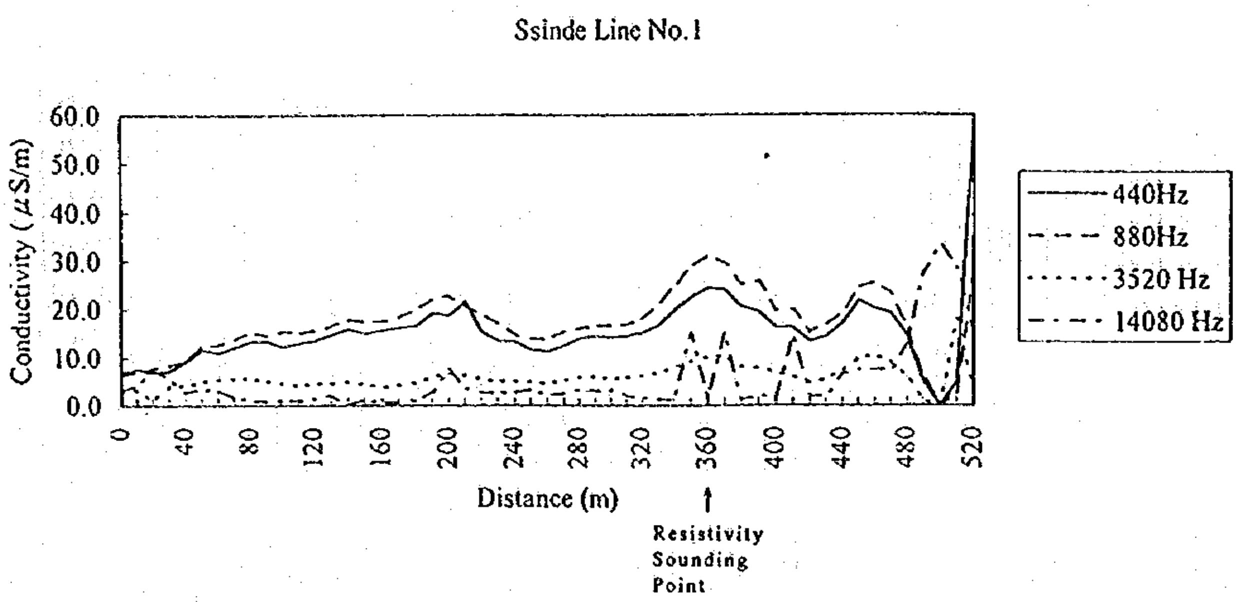


Figure 1.1.21. Geophysical Prospecting at JA-2



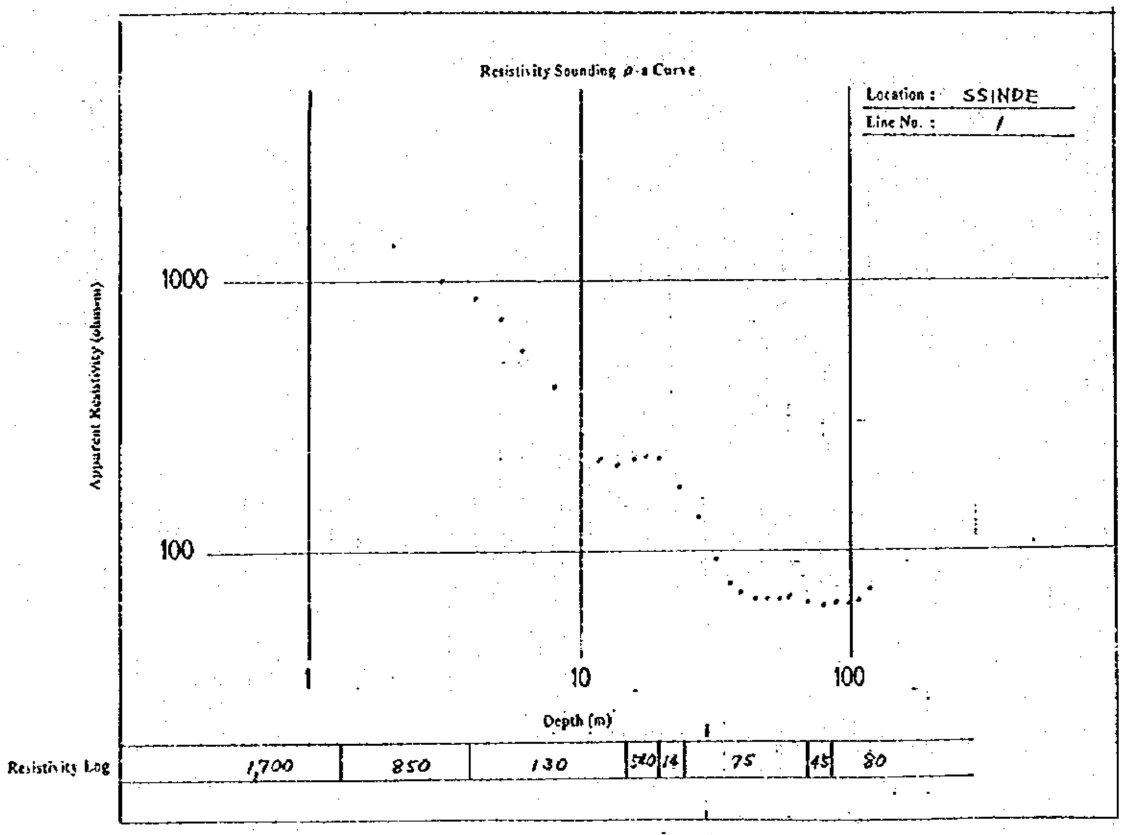
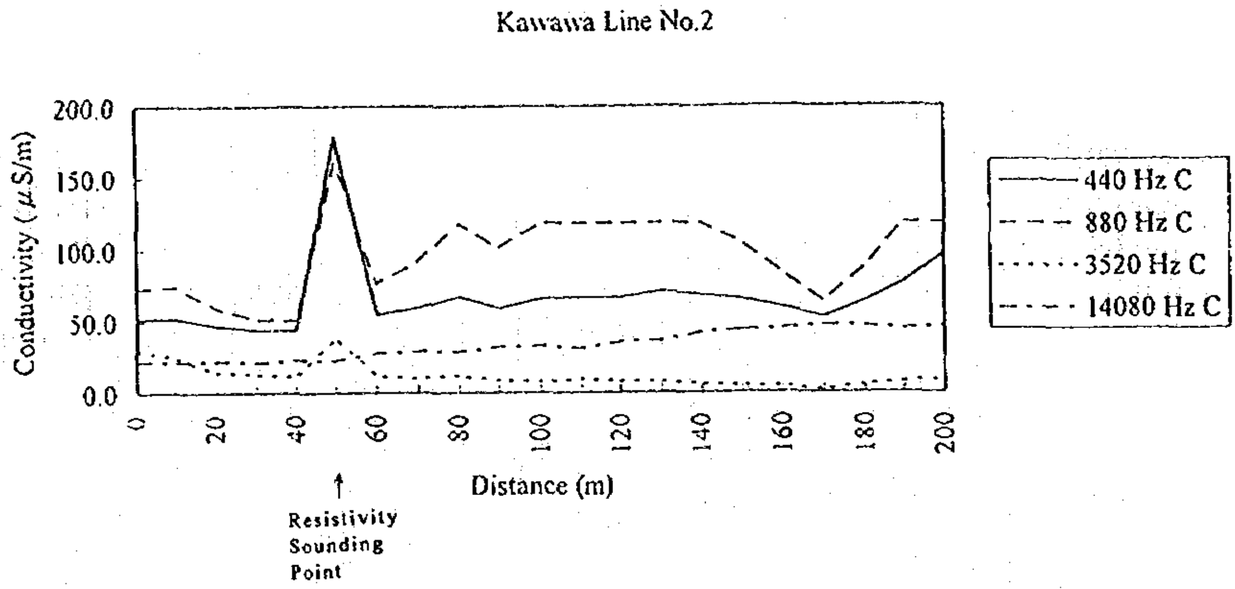


Figure 1.1.22. Geophysical Prospecting at JA-3



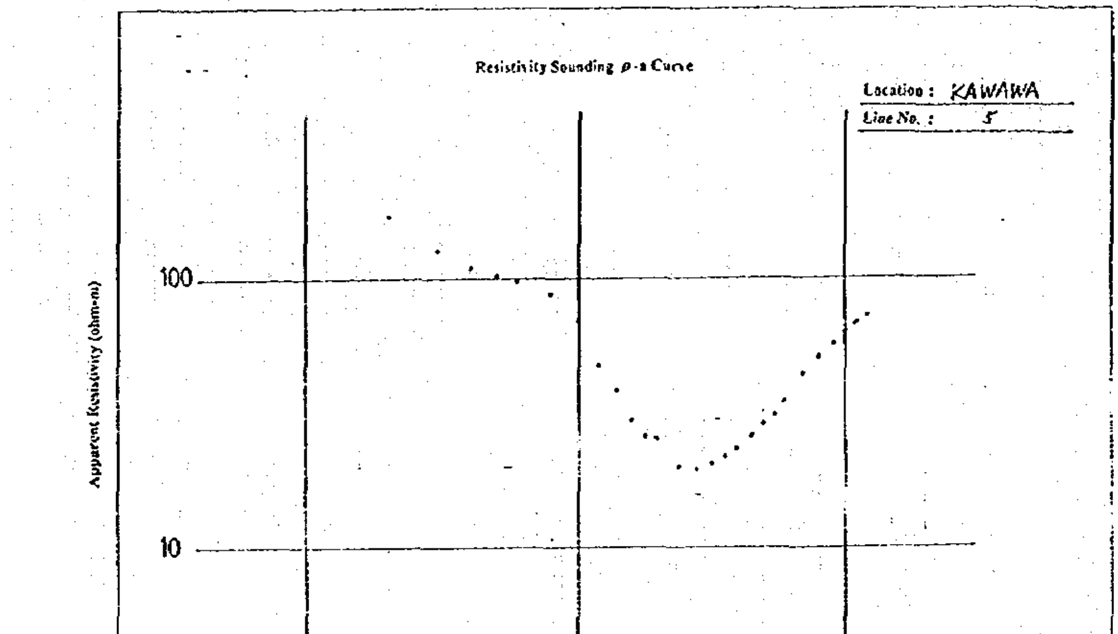
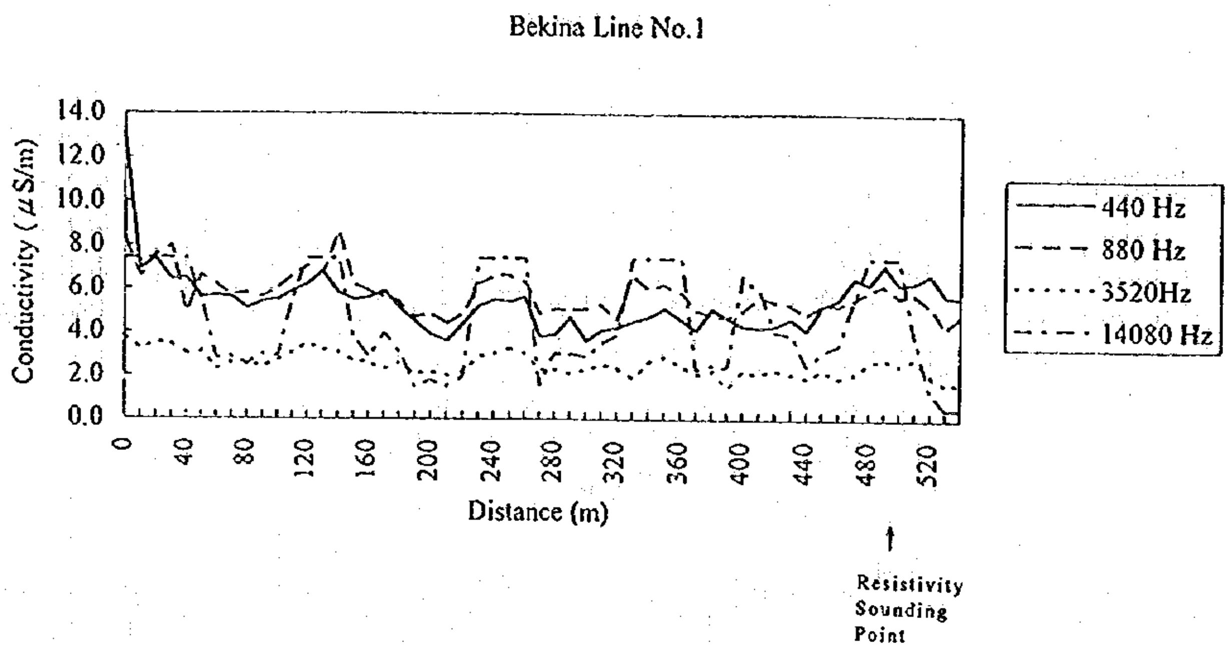


Figure 1.1.23. Geophysical Prospecting at JA-5



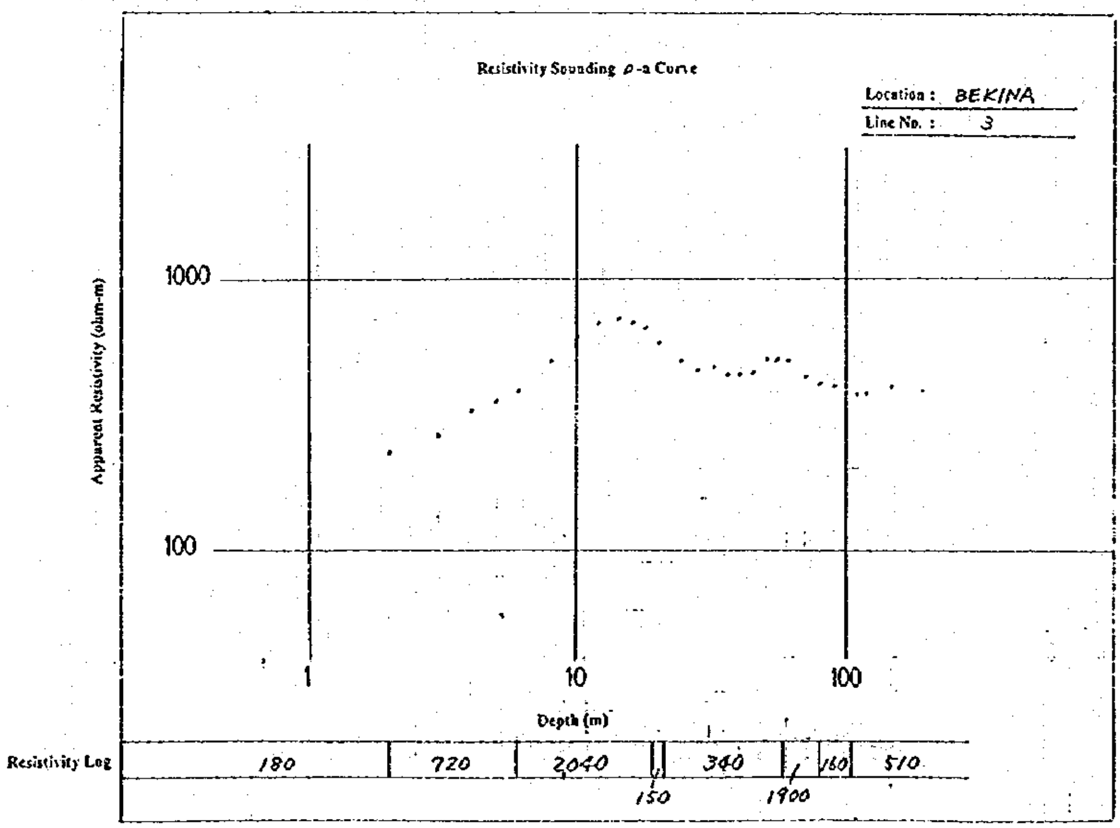
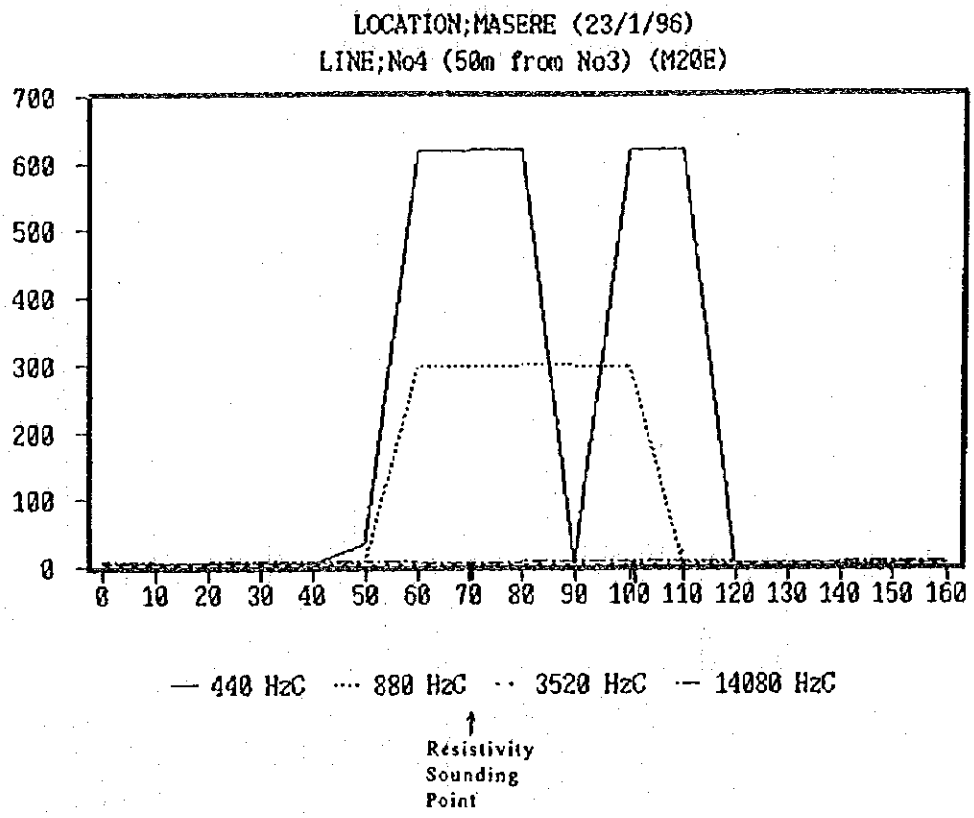


Figure 1.1.24. Geophysical Prospecting at JA-8



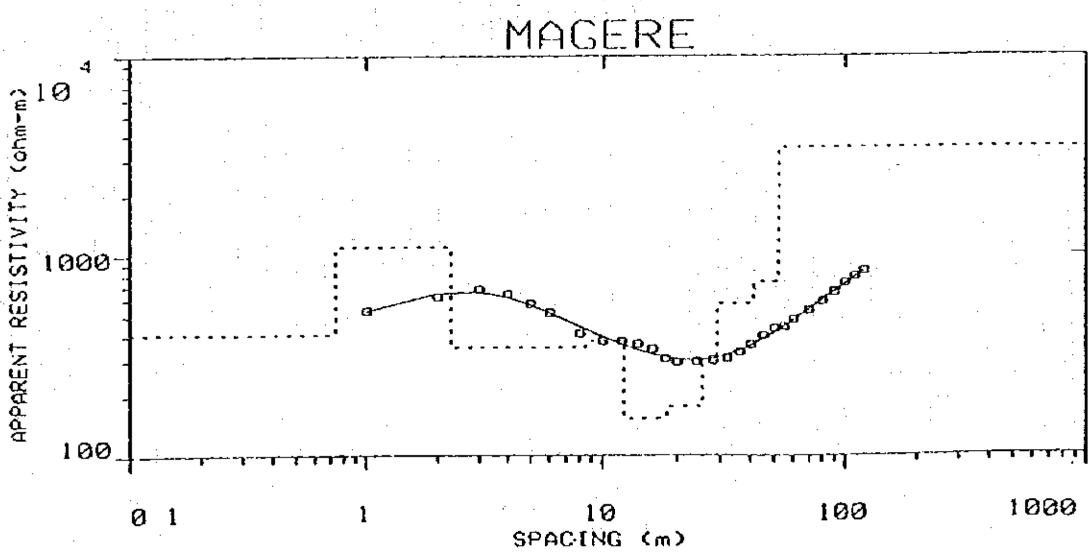
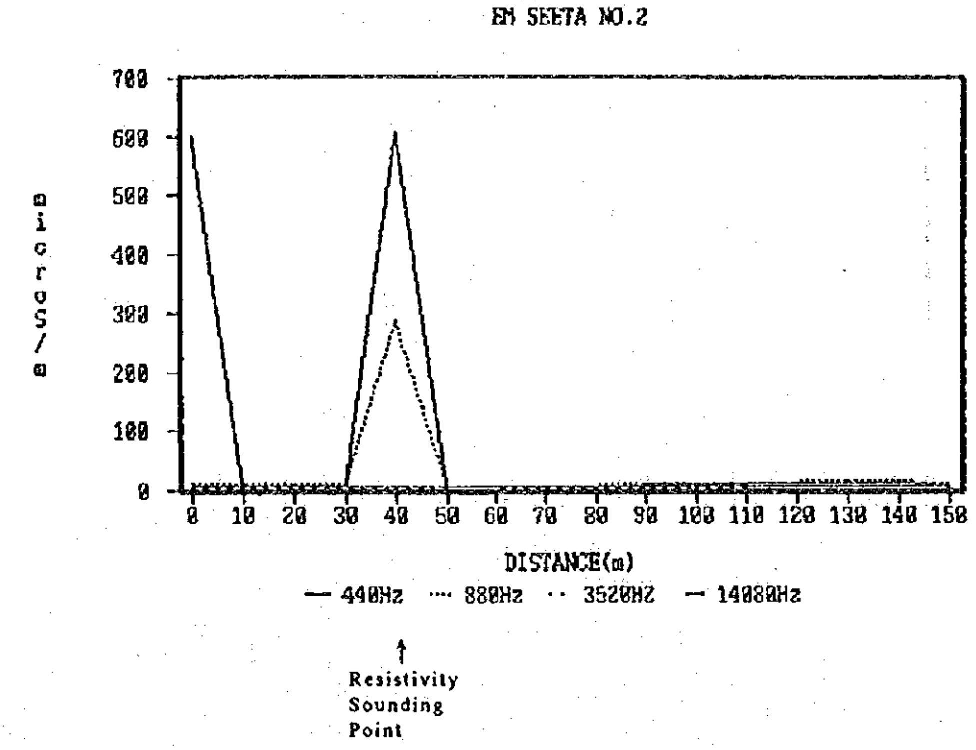
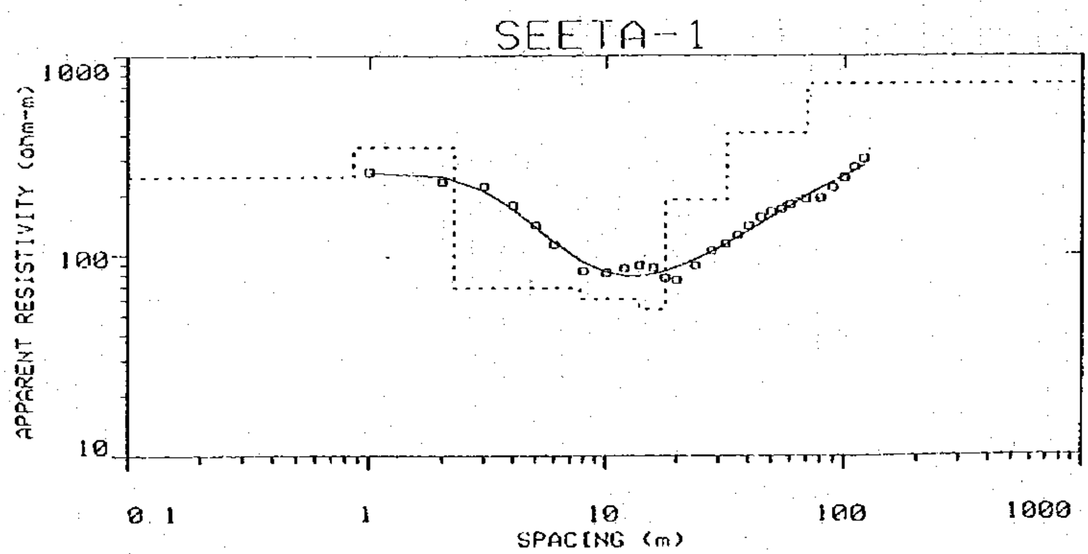


Figure 1.1.25. Geophysical Prospecting at JA-9





(2) Test Borehole

(a) Outline of the Work

Ten test boreholes have been drilled and pumping facilities of the five boreholes out of ten, two in each of Mpigi and Kiboga Districts and one in Mubende District, have been constructed. The locations of test boreholes are shown in Figure 1.1.26.

The objectives of work are to study the community participation and to obtain the hydrogeological conditions of the study area, including:

- to compare the community participation, hygiene and O/M of the four villages, which receive a borehole without any further intervention, with two villages, which are exposed to community participation and others,
- to obtain aquifer characteristics and potential,
- to obtain groundwater quality.

After the interpretation of topographic maps and aerophotographs, the drilling sites are determined by geo-magnetic and geo-electric prospecting.

The borehole construction is contracted with a local drilling contractor in Uganda. Truck mounted rotary and air hammer drilling rigs are used for the drilling, and water-based fluid with polymer is applied during the drilling procedure. Mud circulation method is not applied because of no technique and equipment in the country.

Three types of borehole logging, spontaneous potential, resistivity and gamma logging, are performed to identify aquifers and aquicludes after the drilling completed. An interpretation of the geological logs assists in determining the location of screen with above borehole logging.

Total ten boreholes have been drilled, five struck on aquifers, four in Mubende District were dry and one in Kiboga District was capped due to high iron concentration of water. The inventory of test boreholes is shown in Table 1.1.14.

After completion of the drilling of successful five boreholes, PVC casing of five inches diameter and screen with 1-1.5mm slot opening, are installed in the boreholes. The opening ratio of the screens is about 10%, respectively. The borehole structures are shown in Appendix A.1.4.

(b) Results of Drilling

<Kiboga District>

The boreholes in Kiboga District are drilled in Buganda-Toro System consisting of sandstone and located near the boundary between the System and Gneiss Complex. The area is located in the broad valley which is formed along a shear zone. In Ssinde three boreholes drilled: first is failed by drop of a drilling bit, second named Ssinde-1 is capped because of high iron concentration of water and third named Ssinde-2 is successful. Ssinde-1 has large yield of 5.4 m^3/hr, and it is presumed that the high iron concentration is caused by lateritic soil which is located just above screens of the borehole. Ssinde-2 is stopped drilling at the boundary between the formations, but more large yield will be expected when drilled more deeper into Gneiss Complex.

<Mubende District>

Five boreholes are drilled and four are dry hole. The rocks of failed boreholes are composed of schist, phyllite, shale, sandstone, conglomerate, quartzite and granite of Buganda-Toro System and Mityana Series. Fractures in the rocks with apparent resistivity ranging from 100 to 1,000 ohm-m are detected by electoro-magnetic and resistivity prospecting, but these bear few or no water. The successful borehole of Bekina, JA-5, consists of phyllite, granite and quartzite of Buganda-Toro System. The quartzite is highly weathered and bears large quantity of water, but finally yielded only 0.6 m^3/hr yields due to very poor drilling technique.

<Mpigi District>

The geology of the boreholes drilled in Mpigi District consists of alluvium, quartzite of Buganda-Toro System and granitic gneiss of Gneiss Complex. The area is located near the boundary between the System and Complex, and lineaments extending for N.N.E. are interpreted by aerophotographs. The lithology of the aquifers is composed of sand, quartzite, sandstone and granitic gneiss which are highly weathered and saturated. In Secta two boreholes drilled and first is failed because of borehole wall collapse by poor drilling technique.

(c) Results of Pumping Test

Aquifers are tested by three types of pumping tests: step-drawdown test, constant discharge test and recovery test. Four steps of increasing discharge at regular three hour intervals are applied for the step-drawdown test. Steps of some boreholes, which have low yield less than 0.6 m^3/hour, are decreased because of difficulty of discharge control by a valve.

The rate of constant discharge test is usually the same as a discharge for the final step in the step-drawdown test. Water is continuously pumped for 24 hours, and when pumping stop, recovery of the water level is measured until it attains 90% of a starting water level of constant discharge test.

A submergible pump with capacity of 1.4 l/sec with a 60 m TDH is used for the test. Discharge is measured by 20 and 200 liter drums.

Drawdown data are plotted versus the time to obtain transmissivity and strativity, and the results are analyzed by Jacob and recovery model through the program of "GW" provided by UN. Analysis chart attached in Appendix A.5. Results of the test are summarized in Table 1.1.14.

The aquifers of all the boreholes are Buganda-Toro System consisting of sandstone, conglomerate and quartzite. Yield ranges from 0.6 to 7.2 m^3/hr and transmissivity is low ranging from 0.5 to 68.9 m^2/day. JA-2 and 8 indicate comparatively high yield and these are located in shear zones. The low yield is not only derived from the characteristics of the aquifers, but also comes from poor drilling technique which can not use mud drilling method. Deep weathered soft formations which have normally large yield are cased by blank casing because of collapse of drilling wall and the boreholes lost the opportunity to get water from the soft formations. More careful drilling works by using mud circulation system are required in low potential formations such as the study area.

(d) Water Quality

The water quality of test boreholes is analyzed by in-situ and a laboratory test. Water samples from all successful boreholes are taken at the final stage of the constant discharge test. The items and the results of the analysis are shown in Table 1.1.15.

The sample from JA-2, Ssinde-1, is slightly bitter in taste, yellowish-brown in color with turbidity of 160.0 NTU and total iron of 30.5 mg/l. The values are above the recommended National Guideline values of 2.0 mg/l for iron and 20.0 NTU for turbidity respectively. Although these poor features are not a health hazard, nevertheless they make the water less appealing to users and the borehole is likely to be abandoned by the community. JA-7, Ssinde-2, is newly drilled near Ssinde-1 from the above reason.

The samples from JA-3, Kawawa, and JA-9, Seeta are slightly acidic with low bicarbonate alkalinity. These features may enhance corrosion of pipes. Other samples have also low bicarbonate alkalinity, and these low values are a disadvantage for pipes. Otherwise the samples are good for drinking water.

Figure 1.1.26. Location of Test Boreholes

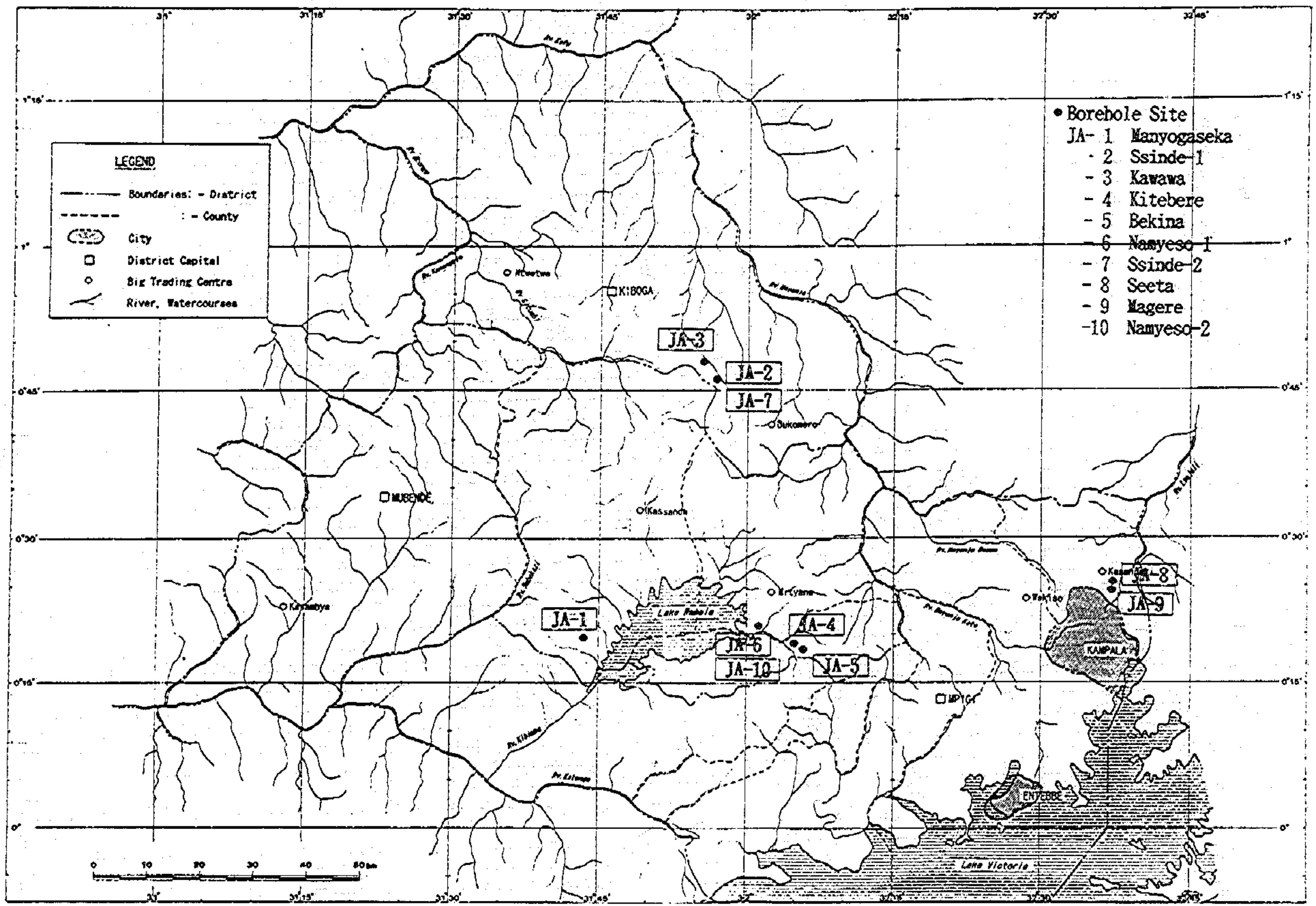


Table 1.1.14. Inventory of Test Boreholes

BH No.	Location	Sub-County	District	Total Depth(m)	B/H Dia. (mm)	Casing (m)	Screen (m)	Pump (m)	Aquifer Geology	Aquifer Depth(m)	SWL (m)	Yield (m3/hr)	D/d (m)	S.C. (1/s/m)	T (m2/d)	Remarks
JA-1	Manyogaseka	Kiganda	Mubende	97.0					(schist)		-	-	-	-	-	dry hole
JA-2	Ssinde-1	Lwamata	Kiboga	28.0	270/200/150	0-19	11-17	13.0	sandstone	12-19	6.90	5.40	4.12	0.36	68.9	high Fe++
JA-3	Kawawa	Lwamata	Kiboga	13.9	270/200/150	0-13.9	10-13	12.0	sandstone	8-14	6.20	0.60	3.63	0.05	3.4	
JA-4	Kitebere	Butayunja	Mubende	86.7					(sch/ss/gr)		-	-	-	-	-	dry hole
JA-5	Bekina	Butayunja	Mubende	59.0	270/200/150	0-59	30-45	40.0	quartz	33-53	21.39	0.60	15.1	0.01	0.5	
JA-6	Namyeso-1	Busimbi	Mubende	77.0					(ss/cg)		-	-	-			dry hole
JA-7	Ssinde-2	Lwamata	Kiboga	50.1	300/150	0-30	Open	31.0	sandstone	30-50	5.75	1.00	24.03	0.01	0.5	
JA-8	Seeta	Nangabo	Mpigi	50.1		0-42.5	30.5-36.5	30.0	qz/gn	30-37	3.90	7.20	6.22	0.32	30.7	redrilled
JA-9	Magere	Nangabo	Mpigi	63.0		0-50	24-36	35.0	quartz	24-36	8.08	0.78	15.60	0.01	0.8	
JA-10	Namyeso-2	Busimbi	Mubende	98.1	270/150				(shale)		-	-	-	-	-	dry hole

Casing:Cased depth

Screen:Location of screen

Pump :Pump depth

SWL :Static Water Level

D/d :Drawdown

S.C. :Specific capacity

T :Transmissivity

Table 1.1.15. Water Quality Test of Test Boreholes

NO	JA-2	JA-3	JA-5(1)	JA-5(2)	JA-7	JA-8	JA-9
Location	Ssinde-1	Kawawa	Bekina	Bekina	Ssinde-2	Magere	Seeta
Colour	yellow-brown	clear	clear	clear	clear	clear	clear
Odour	no	no	no	no	no	no	no
Taste	slt. bitter	no	no	no	no	no	no
pH	6.05	5.93	6.15	6.49	6.40	6.36	5.96
Turbidity	160.00	0.00	0.00	0.00	2.18	0.00	0.00
E.C.	136.40	143.00	69.80	68.50	310.00	116.80	126.20
Alkalinity	34.00	36.00	12.00	12.00	0.00	24.00	36.00
Ca++	4.80	4.80	2.00	2.00		2.00	7.50
Total Hard.	20.00	30.00	10.00	7.00	142.00	13.00	32.40
CaCO3	12.00	12.00	5.00	5.00	103.00	5.00	18.76
Mg++	1.94	4.37	1.21	0.49	9.50	1.94	3.31
Na+	10.00	20.00	8.00	8.00	13.40	14.00	15.00
K+	1.00	0.00	1.00	1.00	1.60	2.00	3.00
Fe++	0.10	0.08	0.00	0.00	0.01	0.00	0.05
Fe+++	30.50	1.82	0.25	0.17	0.06	0.08	0.08
Mn++	0.14	0.02	0.03	0.02	0.04	0.02	0.01
F-	1.00	0.10	0.35	0.35	0.20	0.85	0.60
CO3--	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCO3-	41.45	43.88	14.63	14.63	153.70	29.26	43.88
PO4--	0.00	0.05	0.05	0.00	0.19	0.43	0.26
Cl-	23.00	20.00	0.00	0.00	6.00	3.00	2.00
NO2-	0.00	0.01	0.02	0.01		0.00	0.02
NO3-	0.00	2.20	2.64	0.00	0.00	0.00	5.28
SO4--	0.00	0.00	2.00	2.00	23.00	0.00	10.00
TDS	68.30	71.70	35.00	34.40	154.00	88.50	63.10

1.1.5. Synthetic Analysis of Hydrogeology

(1) Aquifer System

(a) General

Aquifer system of the study area lie only of the fractures in rocks of which size and extent vary in location due to geological structures, weathered conditions, grain size etc. Information on aquifer characteristics of hydrogeological units are not available excepting with borehole records reported by drillers. The lack of hydrogeological information including geophysical prospecting, geological log observed by geologists, logging test, pumping test etc. give difficulty to evaluate aquifer systems. The characteristics of each hydrogeological unit which are estimated from the existing records and test boreholes are stated in next paragraph. Major hydrogeological units in the area are composed of Mityana Series, Buganda-Toro System, Gneiss Complex and Granites as shown and reported in above Chapters.

Unconsolidated deposits are broadly distributed in rivers, however, these consist of limited extent of sand and gravel, and water quality is normally less accessible as drinking water.

(b) Mityana Series

In the area where the Series is distributed, many boreholes have been drilled. A large fault runs north to south near Mityana town for about 15 km and small faults cross the fault. The rocks are siliceous, hard and massive, but in the area where fault is detected boreholes are generally successfully drilled. Fractures, however, are discontinuous, that is, in Namyeso where one existing borehole is closely located and test boreholes JA-6 and 10 have been drilled and failed even fractures are clearly detected near faults and bear few or no water. The yield of existing boreholes is 2 m^3/hr in average.

(c) Buganda-Toro System

The system predominates in schist and phyllite which are aquicludes and high yield is normally expected. The average yield is 1.3 m^3/hr. Many boreholes have been drilled in the system, and some of them have large yield. It is considered from drilling records that those high yield comes from fractures in Gneiss Complex overlain by the System. Those boreholes are mostly found in east and north area where the System is not deep and easily penetrate it. From the geo-physical prospecting the depth of the System are generally more than 100 m in the west and south area, however, development of Gneiss Complex overlain by the System is also required in those areas.

(d) Basement Complex

The unit consisting of gneisses is most reliable aquifer in the area, and fractures are able to detect as high conductivity by geo-magnetic survey. The average yield of the study area is 2.0 m^3/hr, however, in the north of Kiboga District it is 1.0 m^3/hr. The north-east area of Mpigi District, Kiziba, Kyambogo and Nangabo, has more than 3.0 m^3/hr in average yield.

(e) Granites

The distribution of the unit is limited in Mubende District. The rock is generally hard and massive, and weathered layer less than 20 m. The average yield is 1.3 m^3/hr and high yield is not expected in the distribution area, especially on slope and top of hill.

(2) Groundwater Quality

Seventy (70)% of the samples taken from the existing boreholes exceed permissible limit recommended by National Guideline for Drinking Water Quality in the values of total iron, turbidity and color. Those high values are derived from corrosion of galvanized steel casing using in the area. Saturation Index calculated shows characteristics of groundwater to corrode steel. In the study area introduction of corrosion resistant materials is recommended.

Forty five (45)% of boreholes and 67% of springs are contaminated biologically. The contamination comes from poor facility construction and poor sanitation. Strengthening of supervise for contractor and education of hygiene and O/M for users are recommended.

(3) Low Groundwater Potential Area

Low groundwater potential areas where groundwater development is not expected are listed in Table 1.1.16. The areas are selected by the conditions of topography and hydrogeology through the field survey and test boreholes. The detail of each area is stated in 1.1.3.(2) Hydrogeology and Groundwater. The areas are recommended alternative water sources.

Table 1.1.16. Low Groundwater Potential Area

No.	Village	Parish	Sub-county	Groundwater Conditions
Mpigi District				
1116	Kyetume	Kyaayi	Maddu	consisting of deep schist, small watershed, no spring
1117	Kyengera			
1118	Kirimanyaga			
1119	Nakaseeta			
1120	Nabugayo			
1419	Wakiso T/C	Kisimbiri	Wakiso	located on hilltop, deep water table, many springs
Total	6			
Mubende District				
2114	Kabbo	Kabbo	Kasambya	top of steep hill, deep water table, no spring
2115	Nakawala			
2116	Lwegura			
2219	Kalaga	Kigalama	Kiganda	small rechage area, composed of schist with deep soft zone, no spring
2220	Kamusenene	Kamusanene		
2221	Manyogaseka	Manyogaseka		
2222	Kasawo	Kinoni		
2223	Lwenyange	Lutunku		
2224	Mbale	Nsozinga		
2308	Mityana		Mityana T/C	composed of sandstone and conglomerate, concentration of BH water table down
2309	Mityana			
2310	Mityana			
Total	12			
Kiboga District				
3112	Mwezi A	Mwezi	Bukomero	top of steep hills, deep water table, and difficult access
3113	Mwezi B			
3138	Bukasa	Kibaale	Kibiga	
3171	Muwanga	Muwanga	Muwanga	
3139	Kiboga		Kiboga T/C	top and halfway of hill composed of gneisses, deep water table, many springs
3140	Kiboga			
3141	Kiboga			
3142	Kiboga			
3143	Kiboga			
3144	Kiboga			
Total	10			
	28			

1.2. Water Resources and Their Development

1.2.1. Water Balance

(1) General

Along with the development of groundwater resources, several types of water balance studies have been created to evaluate the groundwater potential and to obtain a reasonable limit of its utilisation.

As the global water balance, it must exist between the quantity of water supplied to the basin and the amount leaving the basin. Inadequate data base, however, makes any assessment of water balance for the study area more or less questionable, especially lack of data for change of groundwater storage.

More simplified, but fundamental water balance equation which applies the climatological and hydrological water balance, can be expressed as follows:

$$P = R + E + \delta S \qquad \text{...............(1)}$$

Where: P = Precipitation

R = Runoff

E = Evapotranspiration

δ S = Change in storage of surface and groundwater

A series of groundwater level observation record is one of important parameter to calculate the change of groundwater storage, however, groundwater observation network is not yet set in the study area. So that it couldn't be verified by the measured data of groundwater table.

An initial calculation of the groundwater budget is tried by monthly basis in the drainage of River Mawokota Kato in Mpigi District, River Katabaranga in Mubende District and River Nakayenga in Kiboga District (see Figure 1.2.1). The areas aretopographically composed of gentle sedimentary and crystalline rock hills, plain and broad extended river floors which are filled by soils. The drainage areas are 91.7 km^2 in River Mawokota Kato, 198.3 km^2 in River Katabaranga and 59.5 km^2 in River Nakayenga.

(2) Calculation of Parameters

(a) Meteorological Network

Five meteorological stations are in the study area; that is, Entebbe, Naluggi, Kiboga, Lunnya and Mubende. Entebbe station represents the physiographic characteristics of Mpigi District, and Kiboga station, which is same altitude with Naluggi and Mubende stations, represents the Mubende District and southern area of Kiboga District. The climatic data of 1990 is utilised for the calculation of Mpigi District and 1959 for Mubende and Kiboga.

(b) Precipitation

Data of Entebbe station on 1990 is estimated 10 years recurrence intervals of annual rainfall from 1985 to 1994, and data of Kiboga station on 1959 is estimated 35 years from 1943 to 1977. The data can be used for the calculation. Daily rainfall of the two stations mentioned years are tabulated in Appendix A.1.1.

(c) Runoff

Surface runoff is composed of three components, that is, surface runoff, flood runoff and base flow. The surface runoff occurs immediate after the rainfall, but runoff coefficient varies depends on soil condition of the ground surface. Field evidence of each watershed shows that the areas are composed of heavy soil covered by grass and plants.

No gauging stations are located in the study area. River Kakinga, which is a tributary of River Katonga, has similar topographical conditions with the three areas. The flow record from 1970 to 1977 is applied to estimate a runoff coefficient. The rainfall record of Entebbe station is applied for the calculation. Calculated average annual runoff coefficient is 21.4%.

DWD Entebbe has estimated the base flow ofRiver Kakinga with 3.33 mm/year and 38.1% of runoff by the record from 1969 to 1978 (see Appendix A.7.).

(d) Evapotranspiration

Daily potential evaporation in the country has been calculated by D. A. Rijks et al. (Potential Evaporation in Uganda, WDD, 1970) and the evaporation in Entebbe and Namulonge stations are shown in Table 1.2.2.

The averaged evaporation is applied for the estimation of total amount of potential. Distribution of daily rainfall is an important parameter to estimate potential evaporation. On a calculation procedure, daily potential evaporation can be subtracted from a daily rainfall, but a debt shouldn't carry over to succeeding days. It can not be counted if no rainfall is recorded. Transpiration factor for Evapotranspiration is assumed at 0.2. Table 1.2.3. shows the monthly evapotranspiration in the study area.

Table 1.2.1. Runoff Coefficient in River Kakinga

River	Kakinga (No.81316)
Catchment Area (km^2)	996
Annual Rainfall (mm)	1,559
Total Rainfall (MCM)	1,506
Total Discharge (MCM)	322
Runoff Coefficient (%)	21.4

(3) **Calculation of Groundwater Budget**

The calculation of groundwater budget in the selected three drainage areas are tried by using above parameters. The result is summarised in Table 1.2.4.

The table shows that change in storage of groundwater in the Mawokota Kato catchment area is estimated at 478 mm/ann. which is 31 % of total rainfall. In the Katabaranga and Nakayenga area, the change is estimated at 433 mm/ann. which is 28 % of total rainfall. Groundwater recharge to the areas can be estimated by the following equation:

$GR = \delta S \times$ catchment area =

Mawokota Kato	= 478.4 mm x	91.7 km^2	= 43.87 MCM
Katabaranga	= 432.8 mm x	198.3 km^2	= 85.82 MCM
Nakayenga	= 432.8 mm x	59.5 km^2	= 25.75 MCM

Major part of recharge induced during the month of March, April and May and it takes out during dry season from December to February. Base flow discharge may probably compensate deficient.

Figure 1.2.1. Area of Water Balance Study

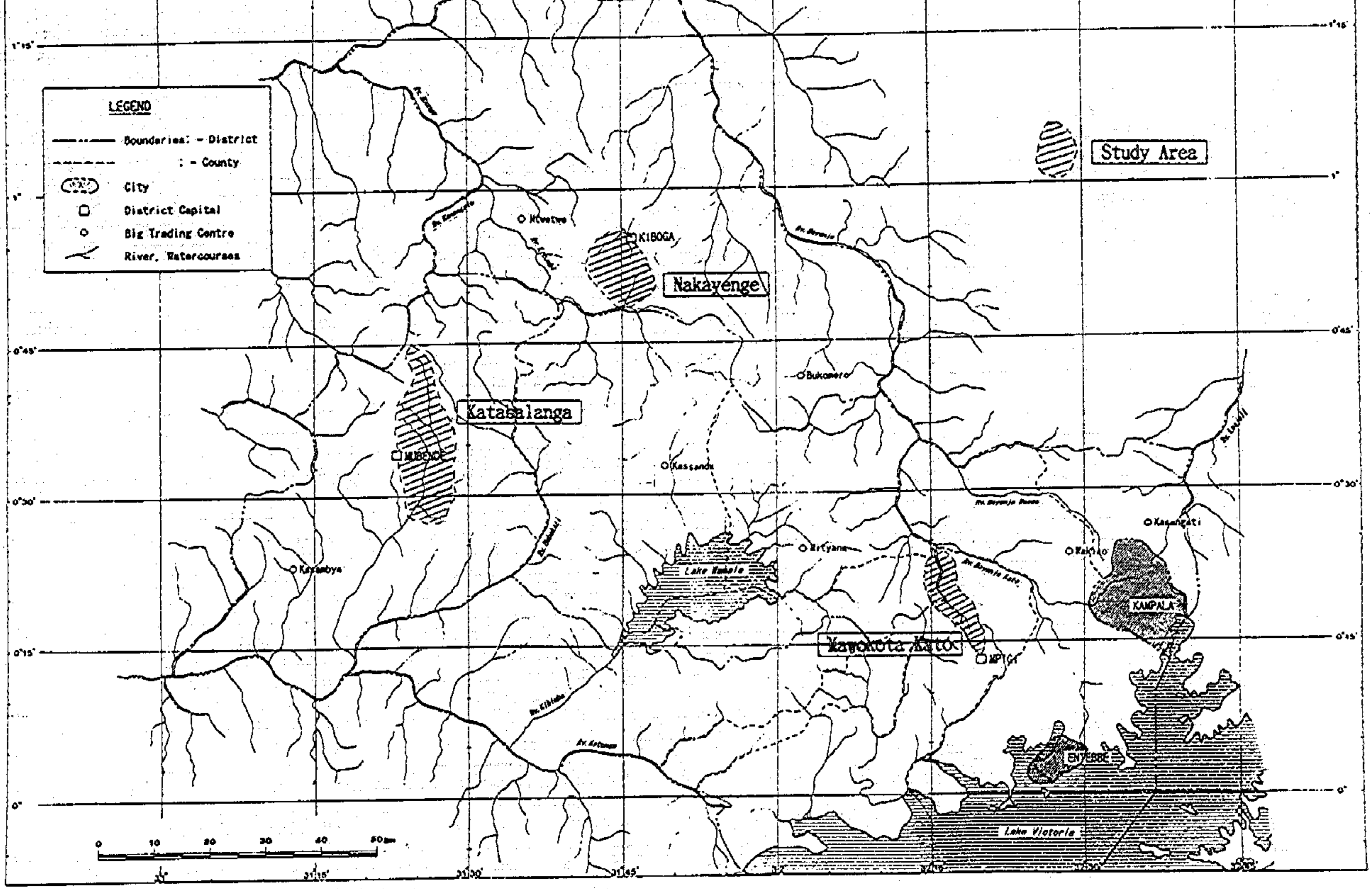


Table 1.2.2. Average Daily Potential Evaporation in Entebbe and Namulonge

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Entebbe	5.1	4.8	5.1	4.9	4.9	4.7	4.4	4.6	5.0	4.9	4.8	4.8
Namulonge	4.8	4.8	5.0	4.6	4.5	4.1	3.9	4.2	4.7	4.7	4.6	4.7

Table 1.2.3. Monthly Evapotranspiration in the Study Area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Entebbe	27.7	33.8	143.8	57.4	77.4	27.7	22.8	41.0	36.6	34.7	43.1	48.2
Kiboga	6.96	23.04	26.4	46.2	61.92	18.36	22.32	43.08	36.48	58.44	64.08	6.36

Table 1.2.4. Summary of Groundwater Budget in Selected Areas

(mm)

Month			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mawokota Kato	Rainfall		42.2	32.7	390.6	261.8	233.8	68.6	45.8	132.4	59.3	43.7	130.5	99.0	1540.4
(Mpigi)	Runoff	SR	4.0	0.0	31.0	21.7	11.1	5.4	2.7	8.5	1.6	0.0	11.3	6.4	103.7
		FR	5.3	7.2	54.9	35.9	40.3	9.7	7.4	20.6	11.4	9.6	17.4	15.4	235.2
		BF	3.5	2.7	32.7	21.9	19.5	5.7	3.8	11.1	5.0	3.7	10.9	8.3	128.8
	ET		27.7	33.8	143.8	57.4	77.4	27.7	22.8	41.0	36.6	34.7	43.1	48.2	594.3
	sigmaS		1.7	-11.1	128.2	125.0	85.4	20.1	9.1	51.2	4.7	-4.2	47.8	20.7	478.4
Katabaranga	Rainfall		5.8	82.3	98.8	116.8	276.4	19.3	82.3	117.3	74.7	109.7	226.8	5.3	1215.5
(Mubende)	Runoff	SR	0	6.7	8.1	6.5	23.4	0	5.6	9	4.1	4.2	17	0	84.6
Nakayenga		FR	1.3	11.4	13.6	19.2	37.4	4.2	12.5	16.8	12.3	19.9	32.9	1.2	182.8
(Kiboga)		BF	0.5	6.9	8.3	9.8	23.1	1.6	6.9	9.8	6.2	9.2	19.0	0.4	101.6
	ET		6.96	23.04	26.4	46.2	61.92	18.36	22.32	43.08	36.48	58.44	64.08	6.36	413.6
	sigmaS		-2.9	34.3	42.4	35.1	130.6	-4.9	35.0	38.6	15.5	18.0	93.9	-2.7	432.8

Note: SR = Surface runoff, 10% of rainfall more than 16mm is counted
FR = Flood runoff, 22% of rainfall minus SR
BF = Base flow, 38.1% of (SR + FR)
ET = Evapotranspiration
sigmaS = Change in storage of groundwater

Table 1.2.5. Summary of Groundwater Potential

Geological Unit	Area		Borehole Depth (m)	Standard B/H Yield (m3/hr)	Tested Data		Success Rate of Borehole (%)
					T (m2/day)	S.C. (l/s/m)	
Mityana Series			80	2.0	-	-	75
Buganda-Toro System	Mpigi	West	110	1.3	-	-	73
		Central	100	0.9	-	-	
		North-East	70	2.1	0.8-30.7	0.01-0.32	
	Mubende	West	100	0.8	-	-	62
		Central	100	1.5	0.5	0.01	
		East	95	1.0	-	-	
	Kiboga		65	0.9	0.5-68.9	0.01-0.36	80
Basement Complex	Mpigi		70	2.5			86
	Mubende		95	0.8	-	-	64
	Kiboga		70	1.0	-	-	70
Granite	Mubende		70	0.6	-	-	70

T:transmissivity

S.C.:specific capacity