CHAPTER 4
BASELINE PHYSICAL ENVIRONMENT

4.1 INTRODUCTION

Uganda - The Pearl of Africa with geographical area of 236,040 sq. km is a landlocked country bordered on the east by Kenya, on the north by Sudan, on the west by the Democratic Republic of the Congo, on the southwest by Rwanda, and on the south by Tanzania. The southern part of the country includes a substantial portion of Laka Victoria. Uganda takes its name from the Buganda Kingdom, which encompassed a large portion of the south of the country including the capital Kampala. The official languages are English and Swahili, although multiple other languages are spoken in the country. Water area covers about 18% of total area of the country with large lakes, roaring rivers and water falls.

Uganda's equatorial climate provides plentiful sunshine, moderated by the relatively high altitude in most areas of the country. Mean annual temperatures range from about 16° C in the south-western highlands to 25° C in the northwest; but in the northeast, temperatures exceed 30° C. Except in the north-eastern corner of the country, rainfall is well distributed. The southern region has two rainy seasons, usually beginning in early April and again in October. Little rain falls in June and December. In the north, occasional rains occur between April and October, while the period from November to March is often very dry. Mean annual rainfall near Lake Victoria often exceeds 2,100 millimeters, and the mountainous regions of the southeast and southwest receive more than 1,500 millimeters of rainfall yearly. The lowest mean annual rainfall in the northeast measures about 500 millimeters.

Uganda is equipped with large renewable sources of energy and amongst them Hydro Power is the major and cheapest source. Most of hydro power potential is concentrated along White Nile with an estimated potential of more than 2000MW. In addition to that there are several perennial rivers/streams in different part of the country which can be harnessed for mini and micro level hydro power schemes.

The Project area of Karuma HPP is located in Kiryandonga and Oyam district of Uganda on the banks of river Kyoga Nile, on the Kampala-Gulu Highway and is thus well connected both from Kampala and Gulu. The river flows in South - North direction in its upper reaches from the origin, and then flows in East - West direction after Karuma falls. The main tributaries of Nile River up to

Karuma falls are river Okole, Tochi on the right bank and river Nanda on the left bank up to Karuma falls. The catchment area up to the proposed diversion site is 3,46,000 sq. km. The geographic coordinates of the dam site is 1°29’45” N, 32°49’45” E and the river bed level is 1019m respectively.

4.2 LAND ENVIRONMENT

4.2.1 Geology

4.2.1.1 Regional geology

The African Continent mainly consists of Precambrian Shield areas with a mobile belt of younger rocks stretching NE from southwest Africa to the Red Sea. The northeastern part of this mobile belt is known as the East African Rift Zone. Northward from Lake Nyasa, the rift zone branches out as the Eastern and Western rift. Both the rifts are characterized by continuous belts of normal faults and graben structures. The western rift valley runs the length of Uganda on the west and it constitutes the Lake Edward, George and Albert basins and the Ruwenzori mountains horst block.

The rift movements have become very important through Tertiary time, both for the filling of the Western Rift Valley, and in the later stage (Late Pleistocene) has resulted in the general sag in the centre of Uganda which produced the Lake Kyoga drowned valley system and Lake Victoria. The sagging through Central Uganda caused the reversal of the westerly flowing rivers to produce the two way flow of the Kafu and other rivers and the drowned valley lake system of Lake Kyoga.

The project site is located within the Tanzanian Craton, bounded by the Western and Eastern branch of the East African Rift System and a series of normal faults. While the shield separating the two branches of the rift system is of Precambrian age, the rift itself consists of asymmetrical basins bounded by alternate high-angle normal fault segments on one side & a series of smaller normal faults. Major rock mass are undifferentiated gneisses of the Precambrian age and are composed of granitic gneisses and well foliated darker gneisses with a biotite and hornblende content with several NE trending amphibolites dykes. Structural geology of the area is controlled by tectonics associated with the East African Rift System. The Project area is located within the Shield area, but only 50-100 km from the western rift system & about 70 km south of the Aswa Fault zone.

The regional geological map of Uganda, shown in **Figure 4.1**, indicates that in and around the Project area, predominantly undifferentiated Basement Complex comprising granitoid gneisses including elements of Aruan Gneiss (2,600 Ma), possibly some older charnockites on the north side of the Albert Nile and intrusive granite and granitoid gneisses (Nyanzlan - Kavirondian granites) on the southern side. Supra-cratonic sedimentary sequences belonging to the Bunyoro Group of unknown age but stratigraphically younger than the Aruan occur unconformably over the Basement Complex.

The Bunyoro Group is part of a poorly exposed assemblage of sedimentary rocks exposed in Bunyoro (Hoima and Masindi) and Lango (Maruzl County) on the north side of Lake Kyoga. The other dominant cover sequence constituting the Kyoga Group is exposed around Teso. The Bunyoro Group is made up of shales and phyllites with larger quantities of grit and arkose higher in the succession and also tillites. The litho-assemblage of this group is gently folded, unmetamorphosed and underlain by the undifferentiated Basement complex. Outcrops of this group are recorded at the junction of the Kampala - Gulu Highway and the Masindi - Masindi Port road, between Kafu Bridge and Kigumba on the Bunyoro side, while a lens abuts the Albert Nile in Maruzl County on the Lango side. A major air photo feature (possibly Rift Fault line) and trending NE for approximately 25 km cuts the Nile between rivers Ayago and Kiba.

Banded gneisses (with a tendency to be flaggy and micaceous) occur downstream of the confluence of river Juma with the Nile; gneiss with biotite occurs around the headwaters of river Ayago and an unnamed river east of river Kamchio; while amphlbolitic gneisses underlie areas around river Kiba. Migmatites exhibiting contorted foliations is noticed at the bend in the Nile further downstream of west of river Juma.

Powell (1956) described that exposures of Basement Complex are confined to the Nile and the mouths of its tributaries, which have cut down below the peneplain surface and its laterite cover. The peneplain surface around Kamdini appears to step along an escarpment line normal to the Nile about one and a half miles west of the river Juma. Above the Karuma Falls, the laterite extends to the Nile water level. At the Kamdini Hydrological Department gauging station, laterite ironstone at the top of 30 ft bank passes downwards into reddish clay.

The basement rocks in this area are gneisses and granulites, often very rich in biotite and amphibole. They are well foliated and generally composed of bands rich in minerals of micaceous habit (amphibole, mica, and chlorite) alternating with bands rich in quartz and feldspar.

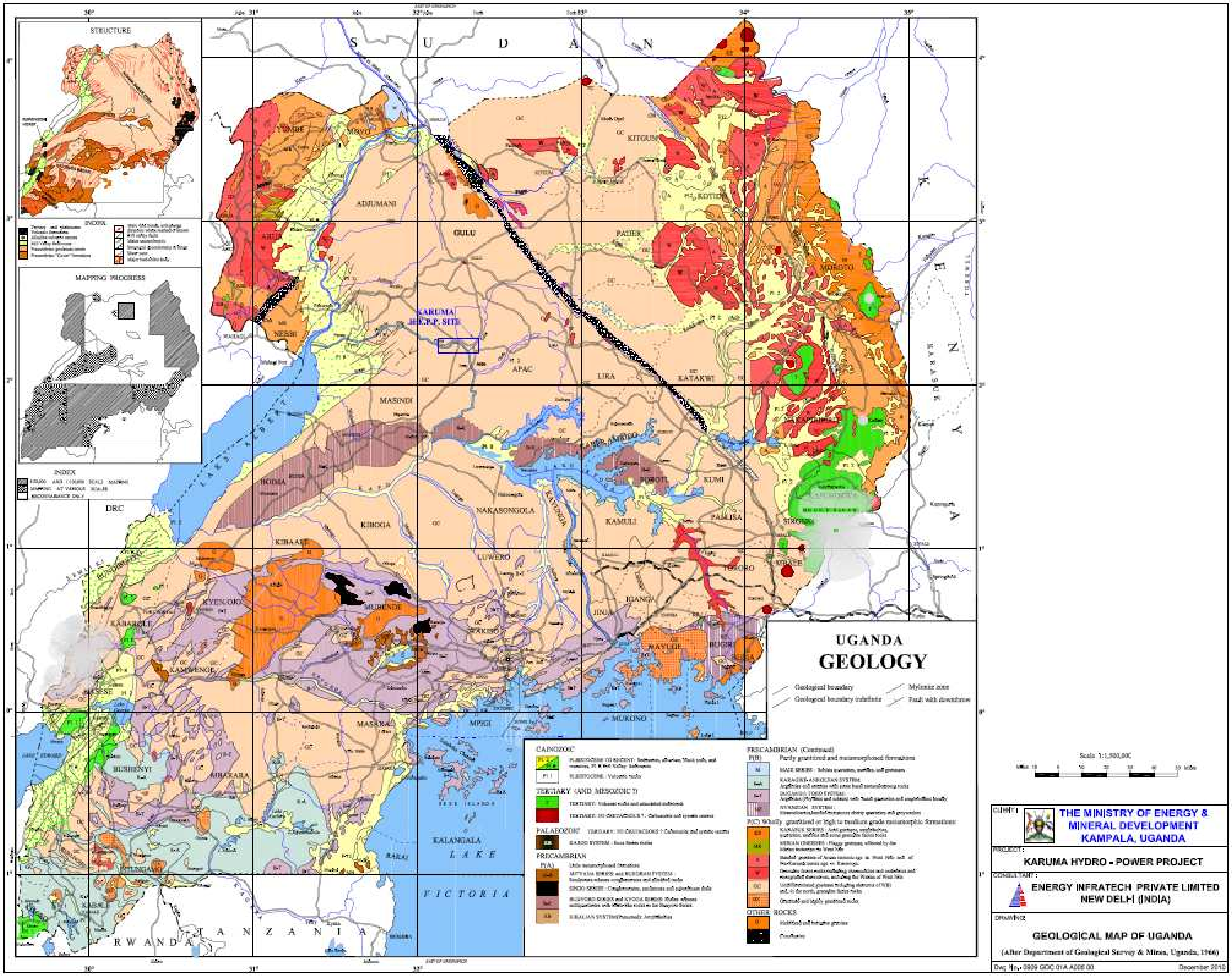


Figure 4.1: The regional geological map of Uganda

4.2.1.2 Geology of the Project area

Except the diversion structure, diversion channel and TRT outfall all other project components are proposed to be underground. Thick forest cover, presence of elephant grass / swamps along the river banks, abundance of wild life and about 8km long stretch of the Project, falling in Karuma Wildlife reserve and Conservation area were the difficulties faced during the investigation stage for preparation of Detailed Engineering Report for the project. In addition, paucity of rock outcrops, except along the road cut section near the Karuma Bridge and the river banks which in majority of cases are inaccessible, rendered the task of geological / geotechnical interpretation along the proposed underground structures very difficult. All efforts were taken to access the available outcrops along the river banks and within the river, however in many cases it was a futile exercise. Mesoscopic structural data were recorded in the rock outcrops to decipher the macroscopic structural set up of the area, and the possible thickness of overburden was estimated on the basis of vertical to moderately dipping cliffs and quarry sections available on either bank of the river. Detailed geological mapping on 1:1000 scale was carried out along the project layout and along south and north banks of the river, wherever accessibility was possible. Broadly the geological set up of the Project area can be subdivided in to two categories, viz., overburden and bed rock.

(a) Overburden

Thick residual soil resulted by in situ chemical weathering of the bed rock is exposed in major part of the project area. Topographically gentle relief, flat enough to prevent erosion and leaching of the products of chemical weathering, humid tropical to temperate climate and long period of tectonic stability of the area are the main factors to develop deep in situ soil profile. The study of different sections exposed in quarries, trench and pits excavated during the course of present investigation revealed the presence of various stages in the reduction process of the rock to soil.

Generally below a top layer (< 0.50 m) of humus, a 3 to 4 m thick lateritic soil of brick red colour is present, which is underlain by a weathered zone comprising admixture of brick red colour clay and sand – silt (varying in volume percent from 20 – 30%). At places, the aforesaid lateritic soil is underlain by a saprolite horizon having light brownish to grayish white to light yellowish coloured soil still exhibiting the original fabric of the bed rock. The boundaries between various fractions of the residual soil and underlying saprolite horizon are gradational in nature.

In the marginal parts of the Karuma plateau, at places laterites occur at the top of the residual soil profile, varying in thickness from 0.50 m – 2.5 m forming near vertical scarp and extending along the strike between 50 m and 350 m. Laterites exposed in the area are dark brown in colour, friable, of very low strength and comprise aggregate of iron mottles, pisolites, pseudomorphs, nodules and concretions of variable dimension cemented together in a ferruginous matrix. The ferruginous matrix constitutes about 10 to 15 volume percent; however, at places it is less than 5 volume percent. The formation of iron mottles, nodules and concretions in laterite horizon may be attributed to the movement and precipitation of dissolved iron due to capillary action.

The soil profiles studied in different sections have revealed that the lateritic soil is remarkably uniform in terms of its geotechnical behavior. It has uniform grain size distribution, close texture with high degree of bonding resistant to the rain water saturation.

Moderately to gently sloping zone located in between the Kyoga Nile River bed and the near flat terrain (above El. 1052 m) exposes residual soil overlain by fallen blocks (0.5 m x 1.5 m) of dark brown laterite. The rolled down blocks of laterite have accumulated in the river bed and at the base of the slope.

(b) Bed Rock

The lithounits exposed in Karuma area are undifferentiated gneisses, referred to as the Gneissic Complex comprising of granitized and gneissic formations in the regional geological map of Uganda. Bed rock outcrops are noticed to occur along the road cut section near the Karuma Bridge and on either banks of the Kyoga Nile River. Within the river bed, isolated outcrops of the bed rock forming islands are present in the upstream and downstream reaches of the proposed dam axis. The rocky islands covered by thick forest are inaccessible, and similarly bed rock outcrops exposed around Karuma Falls and on the right bank upstream of the Karuma bridge are inaccessible due to the high discharge and steep cliffs. Isolated bed rock outcrops are exposed downstream of the Karuma – Gulu Highway along and adjacent to the proposed TRT alignment at about 650 m and 1.65 km distances. Similarly a few bed rock outcrops have been observed in TRT Outfall area.

Detailed geological mapping on 1:1000 scale over 6.68 sq. km area was carried out in and around different project components for preparing the detail engineering report, viz., dam axis, diversion channel, Power House, Surge System, TRT, TRT Outfall, Access Tunnels and Adits. Bed rock outcrops, overburden were delineated and their geotechnical properties were recorded. The gneissic complex over and in which various proposed structures will be founded, comprises granite gneiss, amphibolite gneiss and amphibolite. Granite gneiss and amphibolite gneiss together constitute more than 90 volume percent of the bedrock. The thickness of individual variant of the gneiss varies from one meter to a couple of meters; however, the strike continuity of individual bands could not be traced out due to the presence of thick overburden. The bed rock exposed in the area except in the TRT outfall area is mostly fresh, but at places skin thick surface weathering and iron staining is noticed.

Along and adjacent to the TRT alignment, thick overburden comprising residual soil is noticed. Initial 2.37 km length of the proposed Tail Race Tunnel (TRT) System, located to the upstream or east of Karuma – Gulu Highway is overlain by 20 m to 56 m thick overburden comprising laterite, soil and moderately to highly weathered bed rock. Downstream of the Highway, isolated outcrops of granite gneiss are exposed at places along and adjacent to the TRT alignment. Bed rock has been subjected to surfacial iron staining and superficial weathering, otherwise is fresh, hard, compact and strong to very strong in strength. Near the outfall area of the TRT, after descending the plateau, along the river bank isolated outcrops of moderately to completely weathered granite gneiss are exposed within residual soil. In this reach, along the foot tracks of Hippo’s, 5 to 10m thick, red and sticky in situ soil is expected to occur.
Different litho units exposed in the area are fresh, hard, compact, strong to very strong, high to very high strength and moderately to closely joint Brief mesoscopic description of each litho unit exposed in the area is given below.

Granite gneiss is light grey to greenish grey, fine to medium grained, very hard, compact, thinly to thickly foliated and of high to very high strength, comprising of feldspar, quartz and amphiboles in descending order of abundance. Amphiboles constitute less than 10 volume percent of the rock. At places thin bands (0.10 - 0.20 m thick) of amphibole are noticed, however, in general gneissic texture to the rock is imparted by thin alternate layers of felsic and mafic minerals.

Amphibolite gneiss is dark green, fine to medium grained, very hard, compact, thinly to thickly foliated and of high to very high strength, comprising predominantly of amphibole and feldspar in descending order of abundance. The rock at many locations exhibits brownish green colour resulted by the release of ferric oxide from the amphiboles. Gneissic appearance to the rock has resulted due to the metamorphic segregation of mafic and felsic minerals. Feldspar rich layers also show necking and intrafolial nature indicating their involvement during deformation of the rock. The thickness of the felsic layers varies from a few mm to 0.50 m. Amphibolite gneiss is exposed along the left bank about 350 m downstream of the proposed dam axis.

Amphibolite is light green, fine grained, very hard, compact, thinly foliated and of high to very high strength, comprising predominantly of amphibole and feldspar in almost equal proportion. The rock at many locations exhibits brownish green colour resulted by the release of ferric oxide from the amphiboles. Amphiboles and plagioclase crystals exhibit strong preferred orientation defining the foliation in the rock, and suggesting its involvement during deformation along with other variants of the gneissic complex.

(c) Structures

The rocks bear imprints of at least three phases of deformation. The first phase of deformation (F_1) is represented by mesoscopic, tight isoclinal, rootless to intrafolial folds having very high amplitude to wave length ratio. These folds having long drawn-out hinge, could be deciphered on the basis of the quartzo - feldspathic bands present within the gneissic complex. Superimposition of the second phase of deformation has given rise to hook shaped interference pattern.

The second phase of deformation (F_2) is manifested by mesoscopic to macroscopic, close to open, symmetrical to asymmetrical folds with broad hinge zone. These folds have variable inter limb angle and wave length to amplitude ratio. The third phase of deformation (F_3) is represented by open warps, having very high wave length to amplitude ratio.

(d) Discontinuities

The bed rock exposed in the project area is dissected by four sets of discontinuities (S_1, S_2, S_3 & S_4). The rocks bear imprints of three phases of deformation, as a result foliation joints exhibit wide variation in their strike and reversal in dip direction. Based on the frequency of the outcrops and data acquired during detailed geological mapping, the area had subdivided into four sectors, viz., right bank, left bank, TRT and TRT outfall to have a better appreciation of the discontinuities. For each sector, the poles of foliation planes / joints and other discontinuities were plotted separately in the lower hemisphere of the stereographic projection to get average as well as range of strike and dip of each discontinuity.

(e) Faults

During the course of detailed geological mapping, no major fault / fault zone could be located but each rock outcrop was studied in detail to observe the mesoscopic structural fabric of the rock mass in detail and evaluate the structural setup of the project area. Mesoscopic faults were recorded at several isolated outcrops.

4.2.2 Geomorphology

Geomorphologically the area represents a mature topography and the project area may be subdivided in to three categories, such as, Peneplain, denudation slopes and river valley. On the north and south banks of the river Kyoga Nile, the area extending between Murchison Falls (d/s of TRT outfall) and Lake Kyoga (u/s extent of the reservoir), is predominantly near flat terrain giving rise to peneplain topography. Small raised grounds forming hummocks and ridges are also noticed at different locations, giving rise to rolling topography. Ground elevations in the project area vary between EL. 960 m to EL. 1075 m.

The peneplain area is characterized by the presence of several plateaus which are extensively cultivated and occur at different elevations. Isolated, individual plateaus have given rise to typical Mesa structures. The margins of these Plateaus are characterized by gentle to moderate slopes, forming denudation topography characterized by the erosion of soil.

The area adjacent to the proposed Dam & Power Intake Structure, where the underground Power House Complex will be constructed is characterized by a relatively flat topped peneplain located about 30 to 50 m above the river bed. Along the left bank (South Bank) near the proposed Dam axis and Power Intake areas the abutment exhibits gentle (15°-20°) to moderate (30° to 40°) slope from river bed (EL. 1030 m) up to EL. 1048.5 m to EL. 1047.5 m, and afterwards 1.5 m to 2.5 m near vertical cliff is observed. The flat topped peneplain is covered with residual soil resulted by the weathering and disintegration of the gneissic rocks.

In general, the right bank of the Kyoga Nile River between the proposed dam axis and the bridge is flanked by gentle to moderately sloping surface , however, downstream of the bridge, near vertical to moderately sloping surfaces are observed up to the proposed Tail Race Tunnel outfall. Along the right bank (North bank), at several places gentle slopes (10 to 50m wide) exposing bed rocks are noticed, which may be attributed to the lateral erosion caused by the river.

4.2.3 Seismicity

The seismicity of eastern Africa is dominated by the East African rift system (refer Figure 4.2). Potentially, this rifting represents the initial or incipient stages of a continental separation. As is also known, the rift system bifurcates around the Tanganyika Shield (now more often termed the Tanzania Craton) into a western and a eastern branch, with the western one terminating near Lake Eyasi, where there is an increase in seismicity.

There has been considerable debate concerning the exact tectonic configuration of the East African Rift System, including spreading rates, directions, geometry and amount of extension (Rosendahal et al., 1992). What remain clear, however, is that the rift system has developed through a NW - SE extension along the main branches (Fairhead and stuart, 1982; Daly et al., 1989).

The rift zones along the western branch are marked by narrow lakes floored by thick piles of fluvial, clastic sediment. The earthquake activity along this branch is very pronounced (Kebede and Kulhanek, 1991), whereas magmatism is restricted to a few small arches between the lakes. In contrast, rift zones along the eastern branch are largely filled with volcanic and volcanoclastic materials and magmatism is generally perceived to be an integral part of the rifting process.

The Tanganyika – Malawi rift zones are composed of half graben basins linked in complex ways by accommodation zones which generally trend obliquely to the rift axis, and sometimes obliquely to the NW – SE extension direction. Half grabens alternate polarities where the rift crosses Proterozoic dislocation sources. Sedimentary fill reaches at least 4-5 Km, and the sediments are mostly Cenozoic in age, but patches of permo-triassic sedimentary rocks are believed to occur within both rift zones.

Tectonic Setting of Uganda

The major structural features of Uganda includes Orogenic Fold Belts and shear zones within the Precambrian rocks, the processes of formation of the rift valleys and later volcanic centers and crustal warping during the Pleistocene that probably resulted in the formation of lake Victoria. Shear zones of varying dimensions occur in the Precambrian rocks at several locations; however, the Aswa Shear Zone is the most extensive following NW – SE trend for over 300 km through northern Uganda into southern Sudan. The rift valley extends along the western border with the

Democratic Republic of Congo and encompasses Lake Albert, Lake George, Lake Edwin and the Ruwenzori Mountain’s horst block. Sediment thickness of 1800 to 4000 m is estimated to be present within this rift valley.

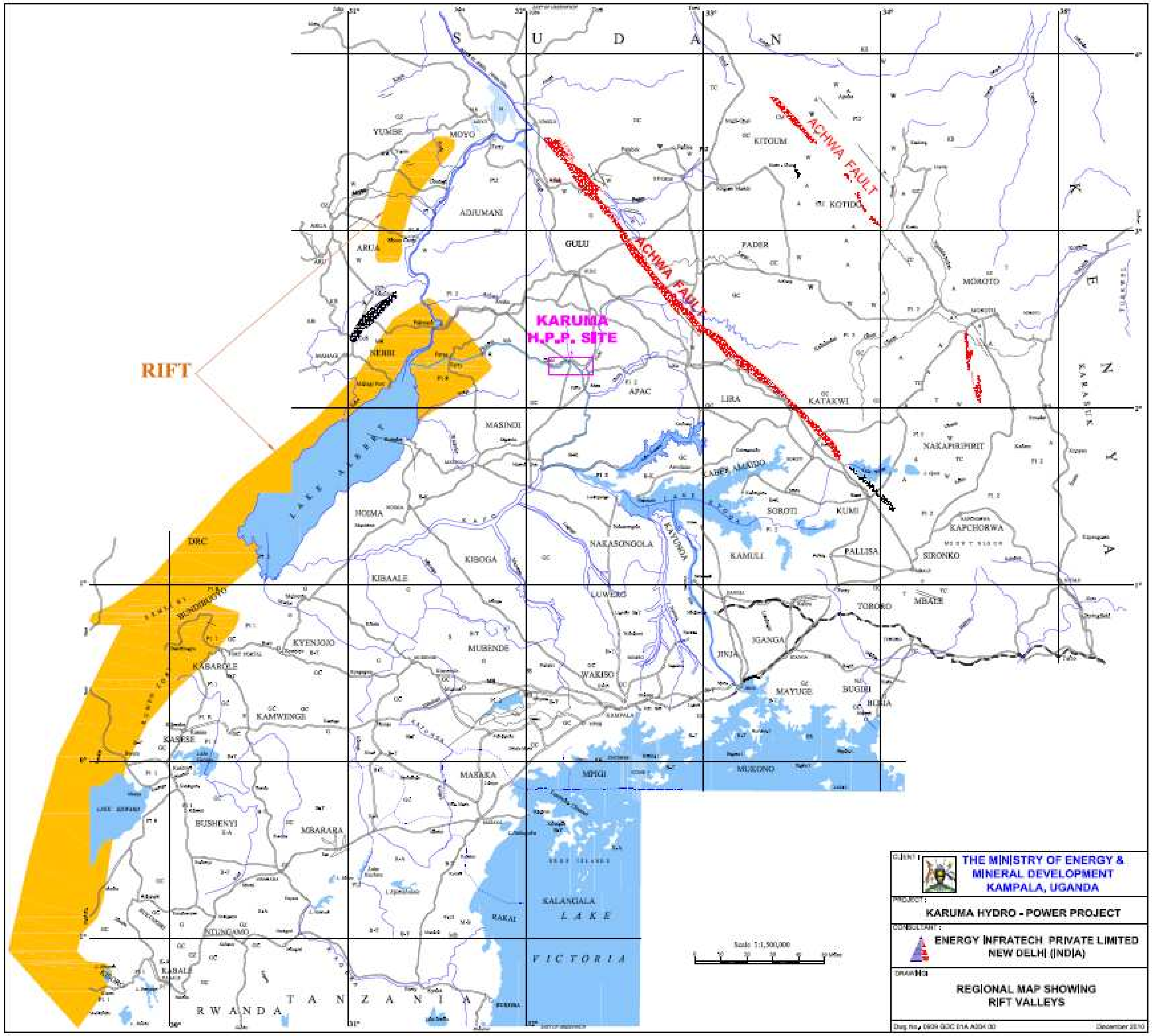


Figure 4.2: East African Rift System

4.2.4 Earthquakes in southeast Africa

The region encompassing south-eastern Africa is prone to a significant level of seismic hazard caused by the East African Rift system. Entire region is crossed by a tectonically active rift system. Kenya rift located to the east of Lake Victoria is almost devoid of the seismic activities, although micro seismic studies have shown that the rift floor is seismically active. Another high active region on the eastern branch is northern Tanzania. The western branch of the EARS, located to the west of Karuma Hydropower Project is more seismically active than the eastern branch. In the northern end, seismicity dies out abruptly in southern Sudan, as the rift valley abuts against the Aswa Shear Zone. The southern extension of the western Mozambique is the most seismically active part in south-eastern Africa.

The dynamics of rifting in the EARS region is illustrated by the distribution of seismic epicenters magnitudes and focal depths. The focal depth of the seismic activities in and around the Karuma Hydropower Project area reveal that seismicity is less frequent, of lower magnitude and shallower in the northern and eastern EARS sectors reflecting the prevalence of thin ductile lithosphere in the region of the Panafrican age East African Orogenic belt (EAO). In the west and south, greater epicenter densities, earthquake magnitudes and focal depths reflect the thicker and more brittle nature of the Paleo- and Mesoproterozoic Orogenic Belts within which the Western Rift is developing.

4.2.4.1 Seismicity around Project area

The Karuma HPP area is located north of the Western branch of the East Africa Rift System, within the Tanzanian Shield (carton). While the Shield separating the two branches of the rift system is of Precambrian origin, the rift system itself consists of asymmetrical basins bounded by alternate high angle normal faults or when unfaulted, monoclines, on the other side linked by comparatively high strain accumulation zones.

The project site is located within the Shield, but is only 50-100 km from the western rift and about 70 km south of the Aswa Fault Zone, thereby potentially affected by the major tectonic in the region. As per the project definition report prepared by M/S NORPAK Power Ltd, Uganda the project site in fact is reasonably close to the rift valley. The major earthquakes events occurred in Uganda are given in the **Table 4.1**

Table 4.1: List of Major Earthquakes in Uganda

Date of occurrence	Epicenter	Magnitude	Socio-economic losses
09 July 1912	Kitgum, close to Aswa Shear zone	6.7	Partial destruction of buildings in northern Uganda
02 October 1929	Toro, Western Rift	5.9	Change of water colour in hot springs, occurrence of landslides
18 March 1945	Sembabule (40 KM NORTH OF Masaka town) close to Katonga shear Zone	6.0	Entebbe seismograph put out of order, five persons died and destruction of some buildings
20 March 1966	Toro, Western rift	6.6	150 people died & over 1300 persons injured; loss of properties worth $ 1 million
07 September 1990	Lake Victoria, near Kampala	5.0	Destroyed semi-permanent buildings
09 October 1991	Butiaba Port, Lake Albert, Western Rift	5.3	Destroyed semi-permanent buildings
05 February 1994	Kisomoro, Toro, Western Rift	6.2	Eight people died, destruction of property worth $ 61 million

In order to evaluate to seismicity risks possibly involved in the design and construction of the Karuma Hydropower project, NORSAR, Norway, has performed a quantitative evaluations of the potential for future earthquakes which could be of relevance for the project. All available earthquake data for the Uganda region for events above 3.0 magnitudes recorded since 1965 were collected, and based on their magnitude; the area was divided in to two parts, viz., one for the Rift Zone (Area 1) and second for Shield area (Area 2).

The studies revealed that for the rift zone, an earthquake of 6 magnitude or larger can be expected in every 17 years, or 62 years for a larger area (100.0 Km2). The corresponding numbers for the Shield area, where the project site is located, are 191 and 776 yrs respectively. The earthquake occurrence statistics for the two areas is given in **Table 4.2.**

Table 4.2: - Earthquake occurrence statistics

Earthquake Magnitude	Return Period (Yrs)			
	Rift Zone (Area 1)		Shield Area (Area 2)	
	All Area 1	10,000 km²	All Area 2	10,000 km²
5	1.9	7	21	87
6	17	62	191	776

(After Project Definition report, NORPLAN 1999)

The NORSAR conclusion is that the earthquake hazard is not very high for this site. But it is still not negligible, and will depend on project characteristics. Thick overburden resulted by in situ chemical weathering of the bed rock is exposed in the major part of the project area. Topographically moderate relief, flat enough to prevent erosion and leaching of the products of chemical weathering, humid tropical to temperate climate and long period of tectonic stability of the area are the main factors to develop deep in situ soil profile.

4.2.4.2 Seismic Parameters

Site specific seismic studies have not been conducted for the Karuma Hydropower Project area. The "Hydropower Development Master Plan – Part 1(July 1996)' prepared by Kennedy and Donkin Power Limited shows that the horizontal seismic coefficients of 0.15g was considered for Owen Falls dam. Considering this, the horizontal seismic coefficients for this project has been considered as 0.18g. This is a 20% increase from the value considered for Owen falls Dam design. The vertical seismic design coefficient is considered as 2/3rd of the horizontal seismic design coefficient which works out to be 0.12g. However the detailed design seismic parameters for the project have to be worked out for the detail designing stage.

4.2.5 Soils

Soil map for the project area is acquired from Makerare University. Geometric correction is carried out for the same and is superimposed with project components. Soil classes within the study area of Karuma HPP are given in **Table 4.3** and **Figure 4.3**. More than 50 % of study area is under Petric Plinthosols followed by Gleysols (12.73%) and Acric Ferralsols (11.97%). The descriptions of the soil classes is presented in **Table 4.3**

PETRIC PLINTHOSOLS (Acric): Shallow reddish brown or grey sandy loams and loams over laterites, often formed from basement complex granites and gneisses or from lake deposits derived from basement complex granites and gneisses. Examples are soils in the BURULI CATENA and LWAMPANGA SERIES mapping units. This soil is Vulnerable to erosion.

ARENOSOLS: Greyish and yellowish brown sands, formed from Pleistocene beach deposits derived from basement complex rocks. Examples are soils in the LAROPI SERIES and BUKORA, MULEMBO, LWAMPANGA SERIES mapping units. This soil is Vulnerable to erosion.

ACRIC FERRALSOLS: Shallow reddish brown or dark brown or black sandy loams or laterites, formed from basement complex gneisses and granites. Examples are soils in the ANAKA COMPLEX and KITONYA CATENA mapping units. This soil is Vulnerable to erosion.

GLEYSOLS: Dark brown or grey sandy loams and sandy clay loams often calcareous of river alluvium. Examples are soils in the KAKU SERIES and BUKORA SERIES mapping units. This soil is not Vulnerable to erosion.

HISTOSOLS: Peat or peaty sands and clays of papyrus residues and river alluvium. Examples are soils in PAPYRUS PEAT mapping units. This soil is not Vulnerable to erosion.

Table 4.3: Soil classification with 2 km study area of Karuma HPP

S. No.	Soil Class	Area (ha)	% Area
1	Petric Plinthosols	10547.60	50.05
2	Arenosols	1535.33	7.29
3	Acric Ferralsols	2521.82	11.97
4	Gleysols	2683.05	12.73
5	Histosols	423.47	2.01
6	Waterbody	3363.02	15.96
	Total	**21074.28**	**100.00**

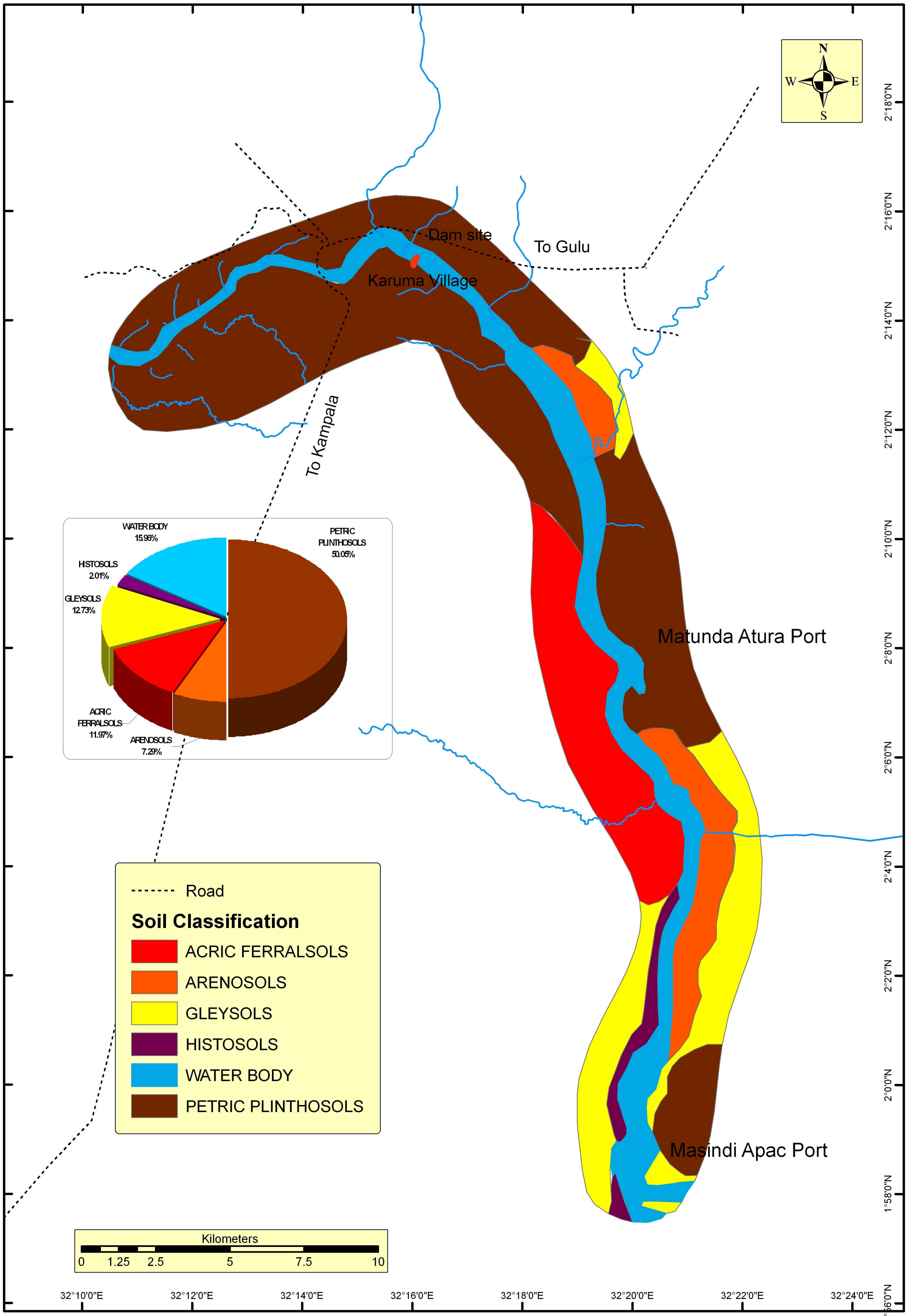


Figure 4.3: Soil Classes within the Study Area of Karuma HPP

4.2.6 Land use-Land Cover Classification

The main project area adjacent to diversion site is generally dominated by local farming activities and scattered low income settlements **(Figure 4.4).**

The land use land cover data has been procured from NFA(National Forest Authority) Kampala, Uganda. NFA has carried out Land use \ land cover classification using Landsat data of the year 1995. Land use describes how a patch of land is used (e.g. for agriculture, settlement, forest), where as land cover describes the material (such as vegetation, rocks or buildings) that are present on the surface. Further processing of data is done for the 2 km study area of Karuma HEP using ArcGIS software package. The land use pattern of the study area is outlined in **Table 4.4.**

Table 4.4: Land use \ Land cover within 2 km study area of Karuma HEP

S. No.	Land use/ Land Cover Class	Area (ha)	% Area
1	Subsistence Farmlands	8602.79	40.82
2	Grassland	224.68	1.07
3	Paparus Swamp	2606.77	12.37
4	Open Water	1994.57	9.46
5	Tropical High Forest	4141.43	19.65
6	Woodland	2137.89	10.14
7	Broadleaved Forest	673.07	3.19
8	Depleted Tropical Forest	665.88	3.16
9	Built Up Areas	27.20	0.13
	Total	**21074.28**	**100.00**

From the table, it is clear that most of the land with in 2 km study area is under subsistence farmland (more than 40%) where mostly crops like Tea, Banana, Coffee, Sugarcane, Kasava etc. are grown. Subsistence farmland is followed by tropical high forests (almost 20%) and Paparus swamp (more than 12%). Paparus swamp is mostly along the riverbank or in wetlands.


Figure 4.4: Cotton and Simsim farming next to the left bank of Kyoga Nile near the diversion site

But because of the protected nature of the bigger part of the project area i.e the Karuma wildlife reserve, the lower portion on the left side of the Kampala-Gulu/Arua highway is still more or less virgin and the land cover is dominated by pristine vegetation (**Figure 4.5**). However, the right side of the highway at Karuma is dominated by commercial structures (**Figure 4.6**) forming the Karuma township, a bigger part of which falls within the project zone of direct impact. Land use\ Land cover map for the 2 km stdy area is shown in (**Figure 4.7).**


Figure 4.5: Natural vegetation in Karuma Wildlife Reserve


Figure 4.6: Settlements structures and a commercial structure

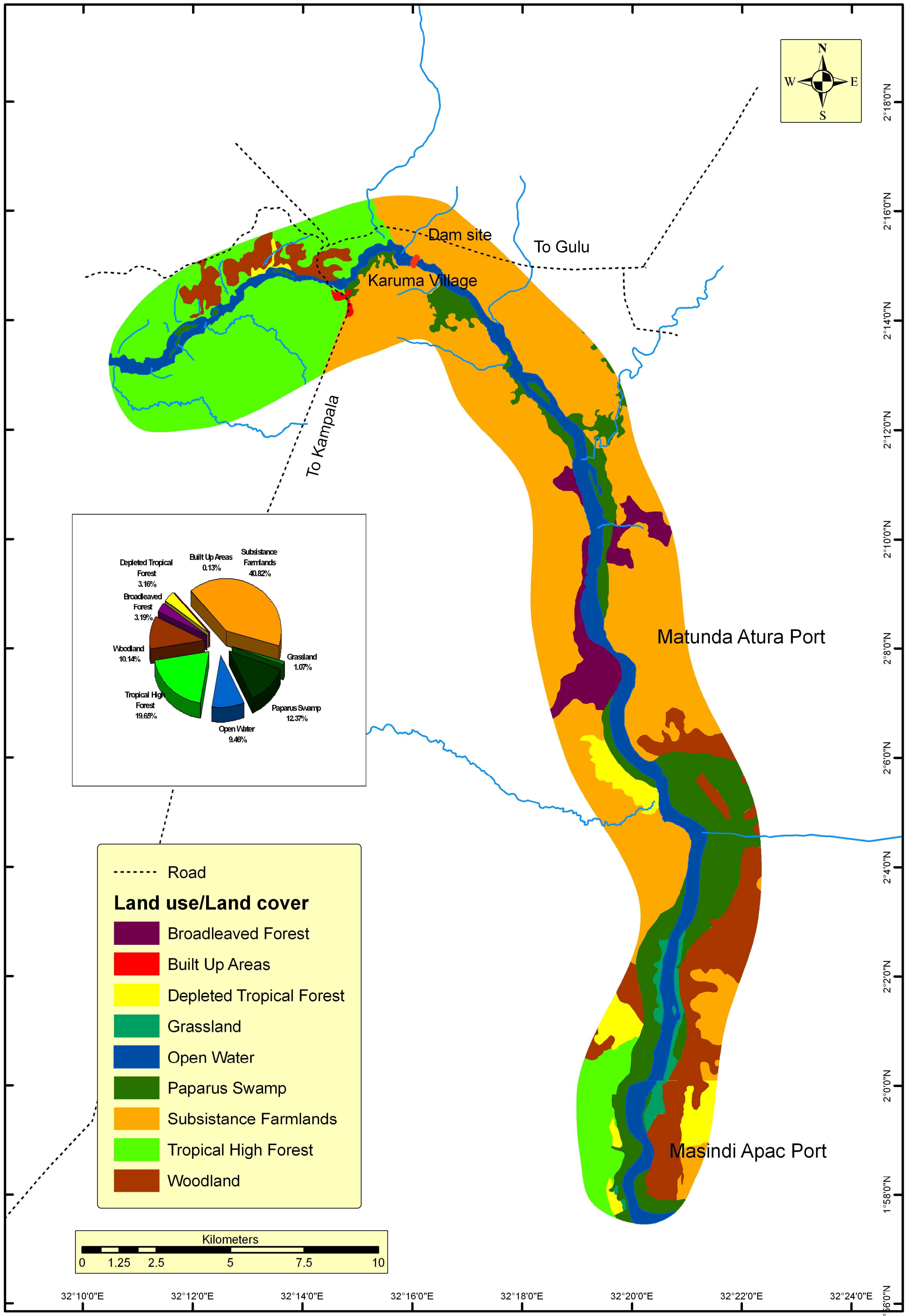
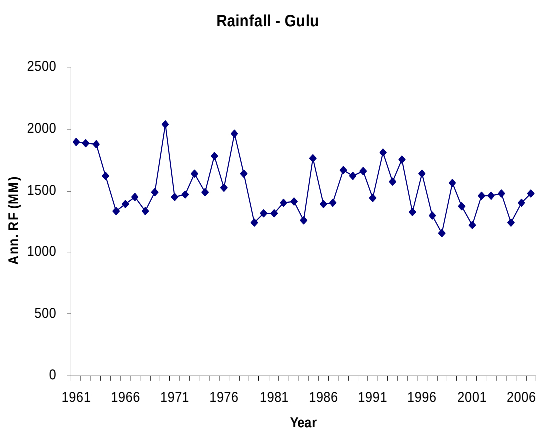


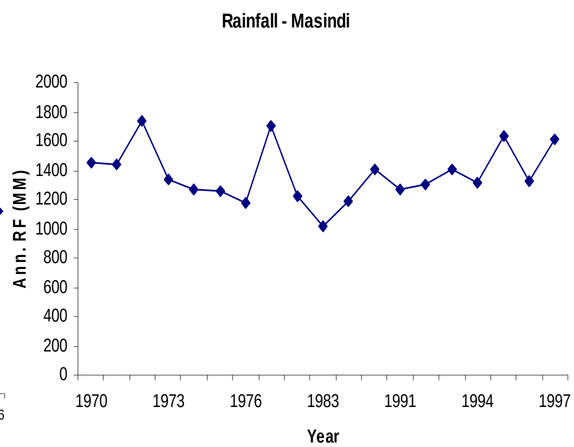
Figure 4.7: Landuse/ Land cover map of the Study Area of Karuma HPP

4.2.7 Climate

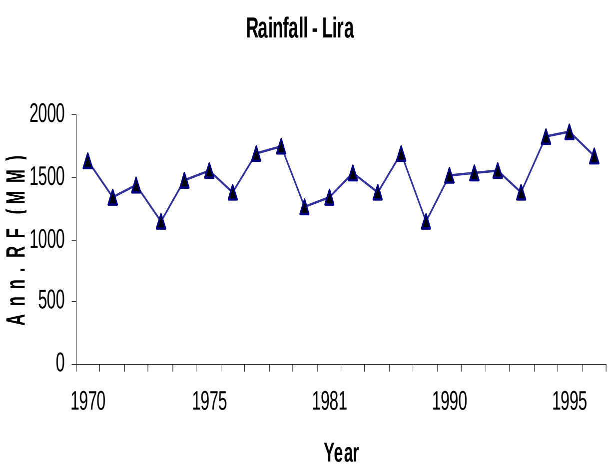
The climate of the project area is characterized by dry and wet seasons with rainfall distributed in two wet seasons, namely: March to June and August to November. Average annual rainfall received is 1500 mm. The project area has a bimodal rainfall pattern with a short dry spell in July and one long dry season from late November to early March. Mean monthly rainfall ranges from 14 mm in January to 230 mm in August. Micro-climate of the area is hot and humid with average relative humidity of 60%, mean maximum temperature of 29°C, mean minimum temperature of 22°C and wind speeds of 8 kph. Climatic data has been taken from the three meteorological station that are closest to the project site i.e Gulu, Lira and Masindi by assuming and anticipating that these neighbouring areas may have similar climatic conditions as around the project site which is presented in (**Figure 4.8 and Figure 4.9)**.



(a)

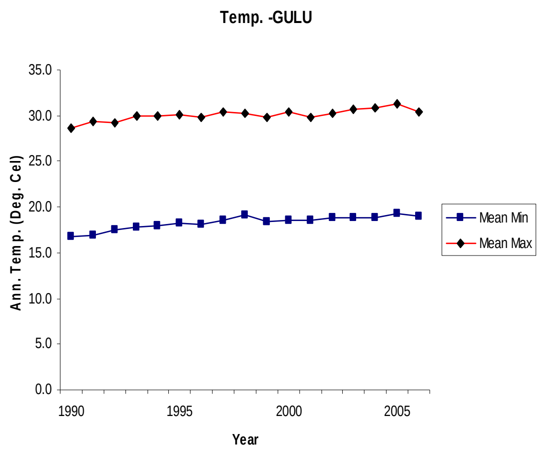


(b)

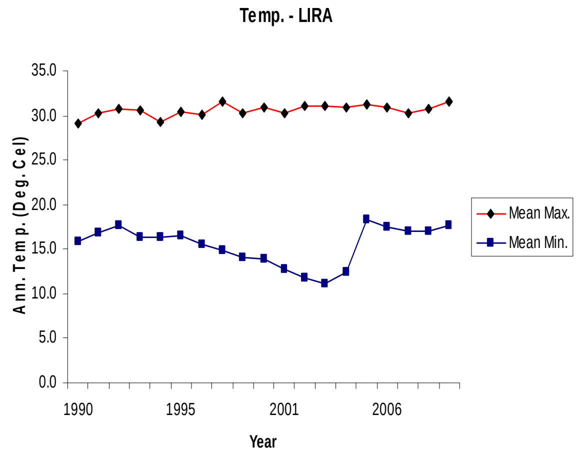


(c)

Figure 4.8: Annual Rain fall at (a) Gulu (b) Masindi (c) Lira near the project site



(a)



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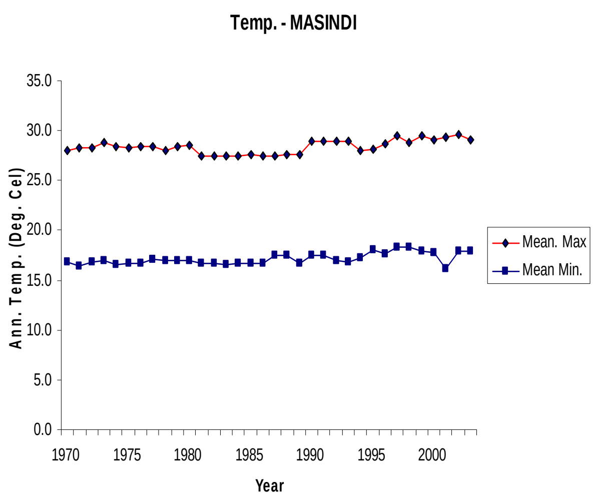

(c)

Figure 4.9: Annual Minimum and maximum temperature at (a) Gulu (b) Lira (c) Masindi

4.3 WATER

4.3.1 Catchment area

Total length of the River Nile from its source to the outfall in the Mediterranean Sea is 6,695 km and from Lake Victoria to the outfall is 5,584 km. The Catchment area of the entire Nile river basin is 2.9 million sq km. Within its basin there are five major lakes: Victoria, Kyoga, Albert, Edward & Tana. The Catchment area of River Kyoga Nile up to the Project site is about 346,000 sq km, of which the Catchment area up to Jinja, located downstream of Lake Victoria is 264,160 sq km **(Figure 4.10).**

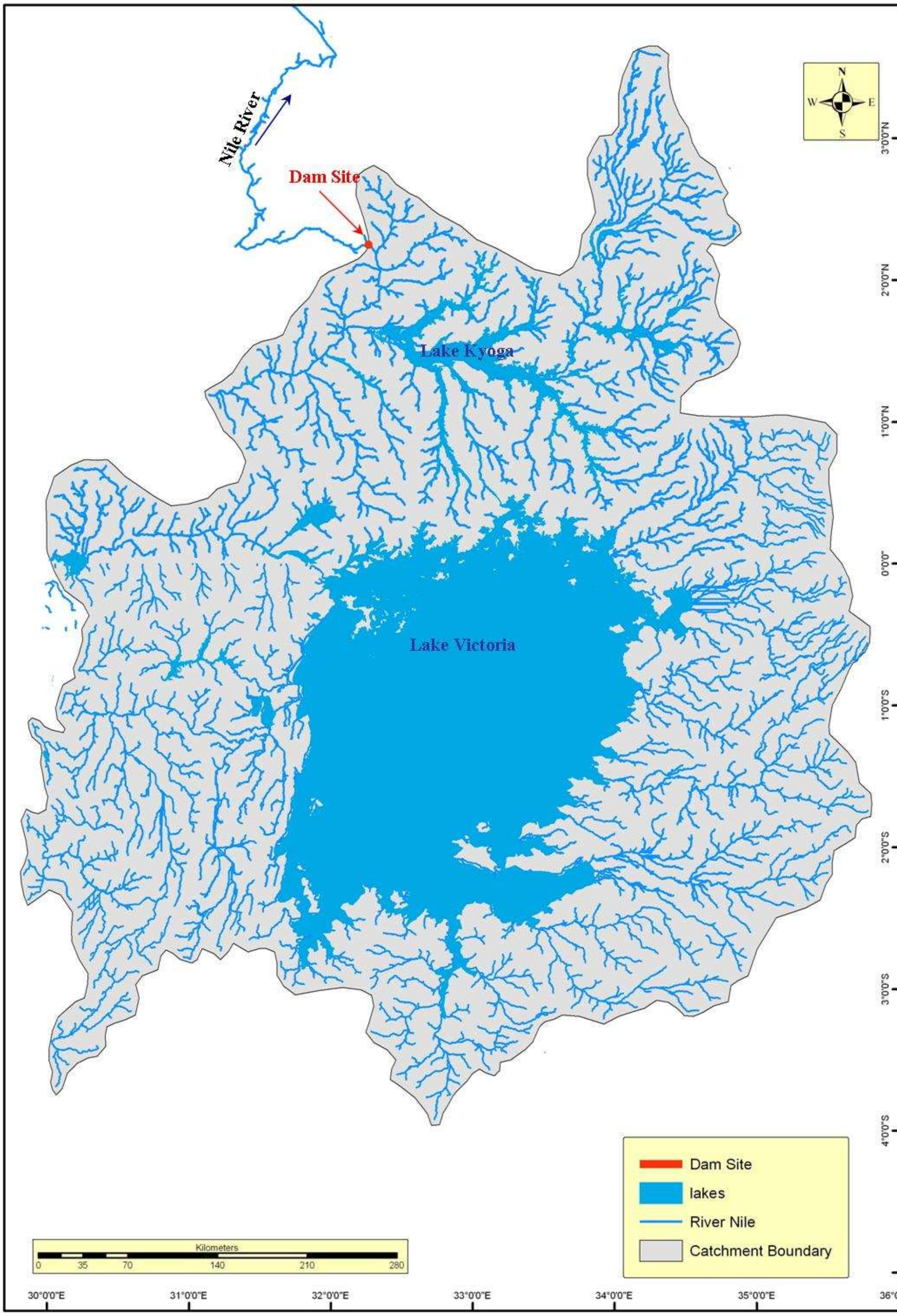

Figure 4.10: Drainage Pattern and Catchment Area of Nile River up to project site of Karuma HPP

4.3.2 Hydrology and Drainage

Uganda is a well-drained country, most part of the country lies in the watershed of the Nile River which takes its source from Lake Victoria (largest lake in Africa), in fact further south from one of the upper branches of the Kagera River of Burundi, which follows the Rwanda –Tanzania and Uganda – Tanzania borders in east central Africa and feeds Lake Victoria **(Figure 4.11).**

Figure 4.11: Main Rivers and Lakes of Uganda

4.3.2.1 Base Flow in the River Nile

The base flow in River Kyoga Nile at Karuma site is generally dominated by the outflows from Lake Victoria. Prior to the construction of Owen Falls dam in 1959, the outflows to Victoria Nile were controlled hydraulically by Ripon Falls acting as a natural weir and constriction. After the construction of Owen Falls Dam (known as Nalubaale Dam), the releases from the Lake Victoria are to be made as per the Agreed Curve, depending on Lake Victoria Levels. Based on an Agreement between Uganda and Egypt (1949 and 1953), an Agreed Curve was developed for the release of lake water to ensure that the pre – dam natural relationship between lake levels and outflows to Victoria Nile does not change, for details refer **Annexure 4.1**. Hence the base flows at Karuma dam site mainly depends upon Lake Victoria levels and releases as per Agreed Curves.

4.3.2.2 River Flow in the Project Site under Normal Conditions

The flows at Karuma dam site depend mainly on the Lake Victoria outflows at Jinja, contribution of intermediate catchment between Jinja and Lake Kyoga, outflows from Lake Kyoga and contribution of the catchment between Lake Kyoga and Karuma dam site. The Lake Victoria outflows arrive at the Lake Kyoga nearly unmodified, since minor tributaries join the river up to Lake Kyoga. Various studies have indicated that under normal dry condition, Lake Kyoga outflows at Masindi Port downstream of Lake Kyoga are slightly less than the outflows from Lake Victoria and the loss of river flows are 20 – 50 cumecs, depending on Lake Level. However, during wet periods, Lake Kyoga catchment adds water to the river flow and increase in river flow is 50 – 70 cumecs dependent on Lake Kyoga Level. The intermediate catchment area between Masindi Port and the project site is about 7,700 sq km. From various studies, it has been concluded that flow contribution from this area during dry periods is small and can be neglected. Hence the catchment area between Masindi Port and the project site doesn't contribute much to the flows of river Kyoga Nile.

4.3.2.3 River Flow in the Project Site under Flood Conditions

The catchment area of Lake Victoria being large, during flood conditions the flood peak upstream of Lake Victoria is moderated by the Lake. Due to increased flood inflows the Lake Victoria level rises and consequently the outflows at Jinja are increased as per the Agreed Curve. Further moderation of flood peaks takes place due to passage through Lake Kyoga. The impact of Lake Kyoga on the Victoria outflows is much more pronounced at seasonal scale. The passage through the lake attenuates and delays a peak by about 3 months from June to September. Between Masindi Port and Karuma falls several minor tributaries flow into the Kyoga Nile and which may contribute short duration floods at the Project site. The annual peaks of Kyoga Nile at Kamdini have been subjected to flood frequency analysis and design flood for Karuma dam has been estimated as 4657 cumecs.

4.3.3 Water Availability Study

The base flow in Victoria Nile & Kyoga Nile is completely dominated by the outflows from Lake Victoria, which are regulated as per the Agreed Curve, after the construction of Owen Falls Dam in 1959. Based on the available gauge and observed discharge data at various sites on the river up to Karuma Falls, a number of comprehensive studies have been carried out by experts to understand the hydrology of Nile basin and to develop a long term flow series (1896 to 2009) for Victoria Nile and Kyoga Nile for planning power projects in the basin. For planning the project, generally 30 to 40 years data is considered adequate, as it represents the hydrological cycle of good and bad years. However, it is better to base the planning studies on maximum possible length of reliable data **(Annexure 4.2)**.

4.3.3.1 Data Availability

Gauge and discharge data of River Victoria / Kyoga Nile at Jinja, Masindi Port and Kamdini and some other sites has been collected from the Directorate of Water Resources Management (DWRM), Uganda and also from the reports on the "Hydrology of River Nile' carried out by various eminent persons / organisations. Since Kamdini gauge and discharge site is located near the project site, the flow series at Kamdini after checking the consistency of data has been utilised for water availability studies. Daily discharges of River Kyoga Nile at Kamdini for the period 1950 to 2009 have been obtained from DWRM, Uganda. It is seen that during this period, there are some gaps in the data and data for the period 1981 – 1995 is not available. Continuous monthly discharge data for the period 1896 to 1995 is available in the Kennedy & Donkin's Report. Since the discharges received from WDD and those given in the report of Kennedy & Donkin are comparable, the discharges for the missing period have been obtained from the values given in the report of Kennedy & Donkin. Thus continuous long term monthly discharge series is prepared at Kamdini from 1896 – 2009 **(Annexure 4.2)**.

4.3.3.2 Analysis of Data

On examination of the data, it is seen that Lake Victoria level was relatively stable from 1900 to1961. From October 1961 to 1964, the lake level rose by about 2.4 m from 1133.8 m to 1136.2 m, perhaps due to high rainfall in the basin. After 1964 the lake levels generally followed a down trend, which was reversed several times in late 1970's, early 1990's and 1997, but the high Lake Victoria level continued till 2003. From October 2003 to August 2006, the lake levels dropped by about 1.5 m from 1134.7 m to 1133.2 m, perhaps due to drought conditions and also due to higher than Agreed Curve releases. Assuming that after the drought period of 2004 to 2006, good rainfall will occur in the coming years and due to the international obligations, the releases from Lake Victoria would be as per Agreed Curve, it is expected that the lake levels would continue to rise in the coming years.

Flow Duration Curves

As mentioned above, monthly flow series for the period 1896 to 2009 is available at Kamdini. Since the flow series is not homogeneous, as the discharges prior to 1961 are lower due to lower Victoria Lake levels, whereas from 1961 to 2003, the discharges are higher due to continuous high Victoria Lake levels. In view of this, Flow Duration Curves (FDC) for various sets of data lengths to include flows corresponding to low lake levels (prior to 1961), high lake levels (1962 to 2003) and combination of high and low lake levels (long term data) have been carried out. The flow duration curves for the following sets of data have been plotted: 1896 to 2009, representing the entire length of data, 1896 to 1961, representing the flows corresponding to low Victoria Lake levels 1962 to 2009, representing the flows corresponding to high Victoria Lake levels 1940 to 2000, representing observed flows at Kamdini, without extension of data and limiting the series till 2000, when the releases from Lake Victoria were generally as per Agreed Curve. 1940 to 2009, considering the entire observed flow series at Kamdini, without extended data for the period 1896 to 1939. 90 %, 75 % and 50 % dependable flows estimated from the flow duration curves are given below in **Table 4.5.**

Table 4.5: Summary of Dependable Flows observed at Kamdini near the project site

Period	**Dependable Flow (cumecs)**		
	90 %	**75 %**	**50 %**
1896-2009	463	579	803
1896-1961	418	498	605
1962-2009	891	1021	1180
1940-2000	523	682	1019
1940-2009	542	719	1043

As the flows of Lake Kyoga at Kamdini for the period 1912 to 1940 have been estimated based on straight line rating curve developed from limited discharge observations at Fajao from 1922 to 1932, the flows appear to be underestimated and may not be reliable. Similarly the flows for the period 1896 to 1911 have been estimated from correlation of concurrent Lake Victoria outflows and Lake Kyoga outflows for the period 1940 to 1977, which is also showing considerable scatter. Hence the estimated flows at Kamdini for the period 1896 to 1911 may also not be reliable. It is also seen that the outflows from Lake Victoria after 2000 are higher than the theoretical Agreed Curve releases. It is therefore; felt that considering the flow series for the period 1940 to 2000 would be ideal for project planning.

The flow duration curve using the monthly discharges of Kyoga Nile at Kamdini for the period 1940 – 2000 is given below in **Figure 4.12.**

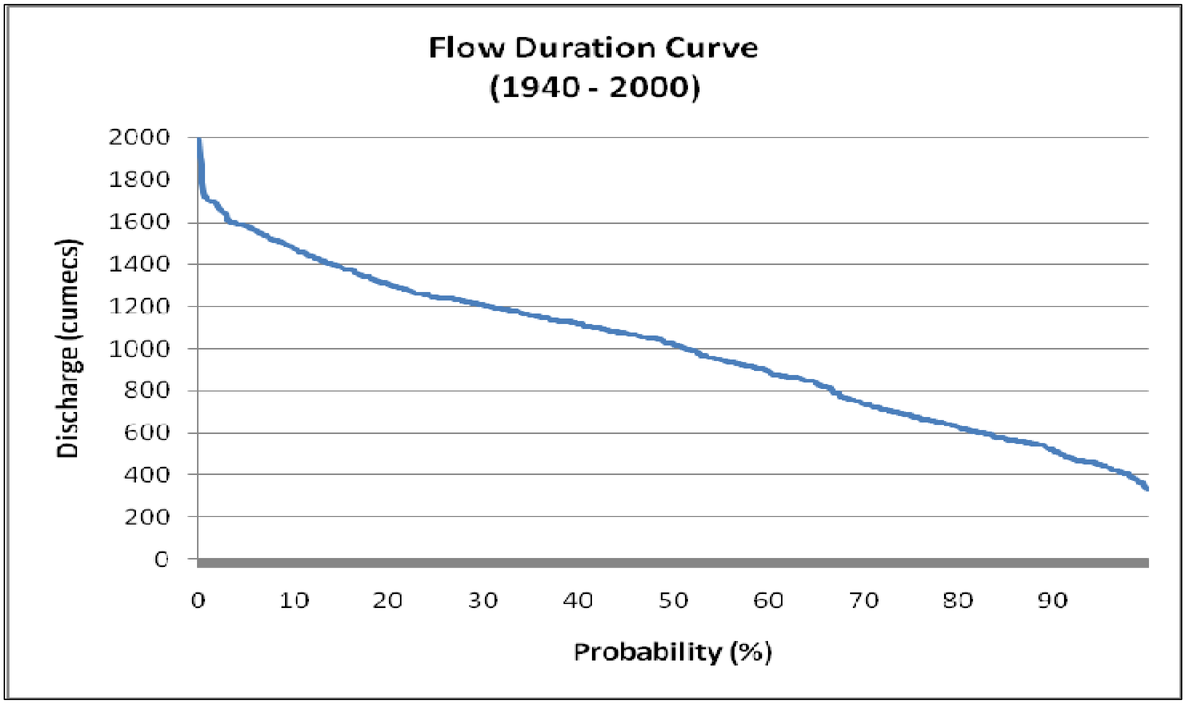

Figure 4.12: Flow duration curve for the Period 1940 - 2000

Dependability Studies

Annual flows for Karuma HPP for the period 1940 to 2000 have been arranged in descending order. Weibull’s method has been used for estimating the percentage dependability. From the analysis, it may be seen that 50 % dependable annual flows work out 32602 MCM, which correspond to the year 1975 respectively. The monthly discharges during the 50% dependable years of 1975 are given in **Table 4.6**. Monthly flows corresponding to 50% dependable year viz.1975 have been utilised for estimating the installed capacity for the project.

Table 4.6: Monthly Discharges for 50% Dependable Years (Cumecs)

% Dependability	**50%**
Month	**1975**
Jan	978
Feb	953
Mar	901
Apr	932
May	849
Jun	816
Jul	863
Aug	962
Sep	1091
Oct	1432
Nov	1392
Dec	1238
Mean Annual (Cumecs)	**1034**
Annual Yield (MCM)	**32602**

Sediment Flow

River Victoria Nile takes off from Lake Victoria and then flows through Lake Kyoga Nile, most of the sediment received up to Lake Kyoga is likely to get settled in the Lake. Hence the sediment contribution of river Nile at Karuma would mainly be from the catchment between Lake Kyoga and Karuma project site. Studies carried out by various organizations have indicated that contribution of flow to river Victoria Nile at Karuma beyond Lake Kyoga is insignificant and may be received during high flood period only. However, no sediment data downstream of Lake Kyoga has been collected. NORPAK have estimated average sediment rate of 8.7 mg/l at Masindi Port and 7.7 mg/l for river Tochi. Hence the average sediment inflow at Karuma may also be insignificant.

4.4 AIR QUALITY

There is no permanent environmental monitoring station in the study area; however site specific monitoring was conducted in June 2010 and sampling location map is presented in **Figure 4.13.** The sampling indicated that the air quality in the Project area was good during the period of evaluation. There are no industrial pollution sources in the vicinity of the Project, and apart from the highway traffic, the traffic density in the area is not high. Apart from the residential and commercial areas that are on the right side of the highway at Karuma Town, the area is generally not populated with a bigger chunk of the project lying in the protected and well vegetated KWR stretching on the left side of the Highway. Results of air quality monitoring are presented in **Table 4.7** and are based on Time Weighed Average (TWA). Exposure Standard – Time Weighted Average (TWA) is the average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week. **Table 4.8** given below indicates the permissible limits of the air pollutants.

Table 4.7: Air quality in Karuma Hydro Power Project study area

S.N.	Location	Location (Latitude)	Dust PM_{10} mg/m^3	CO ppm	SOx ppm	NOx Ppm
1.	Dam site	N 02^{o}15.197’ E032^{o}15.616’	0.10	BDL	BDL	BDL
2.	Power house site	N 02^{o}15.905’ E032^{o}15.698’	0.10	BDL	BDL	BDL
3.	Karuma village/center	N 02^{o}15.905’ E032^{o}15.698	0.15	2.0	BDL	BDL
4.	Karuma Bridge	N 02^{o}15.905’ E032^{o}15.698’	0.13	1.5	BDL	BDL
Standard as per NEMA, TWA			**10**	**9.0**	**0.15**	**0.10**

ppm: parts per million, *BDL: Below Detection Limit,*

NEMA = National Environmental Management Authority

TWA = Time weighed average

Table 4.8: Overview of indoor air & noise quality parameters in Uganda

Parameter	Recommended TWA Value Standard (NEMA)	Potential Health Risk
Carbon dioxide (CO_2)	9ppm	Headache, fatigue, dizziness, shortness of breath, inability to concentrate
Carbon monoxide (CO)	9ppm	Headache, fatigue, decreased alertness, nausea, rapid breathing.
Particulate matter(dust)	10mg/m^3	Allergies, throat irritation, irritation of the respiratory track.
Sulphur dioxide (SO_2)	0.15 ppm	Irritation to eyes and respiratory systems, aggravate respiratory diseases.
Nitrogen Dioxide (NO_2)	0.10 ppm	
Noise (dB)	85	Hearing loss, reduce productivity and contribute to discomfort and stress.

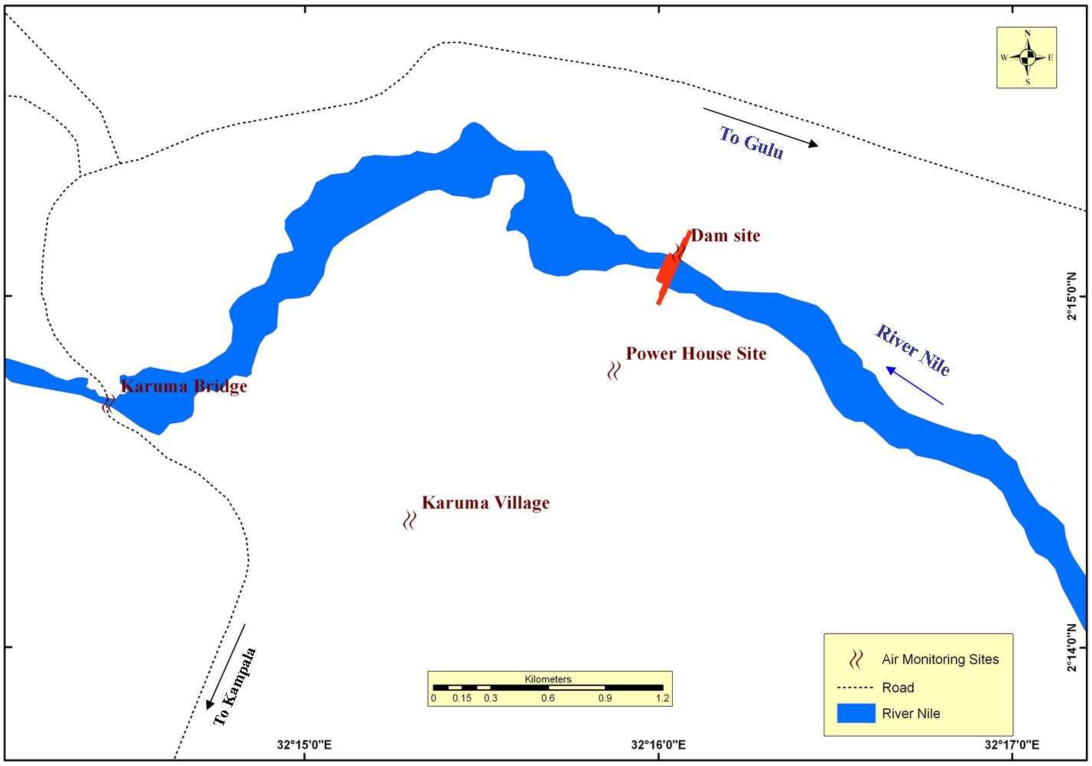

Figure 4.13: Air quality monitoring sites with in the study area of Karuma HPP

4.5 AMBIENT NOISE

Apart from the highways, at Karuma from the Kampala- Gulu and the other junctions to Arua and Lira, there are no permanent roads in the study area. There are some houses and commercial shops in the study area along the Highway (Karuma Village/center), Awoo and at Bedmot villages. Noise measurements were taken in June 2010 in the study area at the various locations. The data indicates low background noise levels. The noise measured results are given in **Table 4.9.** Highest level on noise was recorded on Main Dam and Power Intake area. **Table 4.10** and **Table 4.11** below indicate the maximum exposure to noise permitted in the workplace and maximum permissible limit of vibration respectively. **Figure 4.14** presents the sampling location map for the Noise quality assessment.

Table 4.9: Noise measurements in the study area (June 2010)

No	Project component site	Initial Noise levels in dBA (day time)	Initial Noise levels in dBA (night time)	Avg.
1	Main Dam and Power Intake area	68.2	56.4	62.3
2	Project Area - 1	33.8	28.2	31
3	Project Area - 2	36.4	30.6	33.5

4	Project Area - 3	44.7	34.9	39.8
5	Equipment Yard	40.2	32.8	36.5
6	Work shop area	45.4	37.2	41.3
7	Steel Yard	38.5	29.9	34.2
8	Fuel & Consumables area	33.1	25.6	29.35
9	Fabrication yard	53.4	47.4	50.4
10	Labour Camp	35.6	27.5	31.55
11	Office Colony	67.6	58.4	63
12	Permanent camp	67.4	58.8	63.1
13	Explosive Magazine area	67.7	54.4	61.05
14	Muck Disposal Area	34.4	26.7	30.55
15	Construction Facilities area	36.7	28.4	32.55
16	Karuma village/center	65.8	54.6	60.2
17	Bedmot	42.9	33.7	38.3
18	Karuma Bridge	62.9	54.5	58.7
Standard - 75 dBA for day and 65 dBA for night				

Table 4.10: Maximum exposure to noise permitted in the workplace in Uganda

Noise (dB(A)	Maximum exposure time in hours per employee and per working day
More than 87 but not more than 90	8
More 90 but not more than 92	6
More than 92 but not more than 95	4
More than 95 but not more than 97	3
More than 97 but not more than 100	2
More than 100 but not more than 102	1.5
More than 102 but not more than 105	1
More than 105 but not more than 110	0.5
More than 110 but not more than 115	0.25
More than 115 *	0.00

The National Environment (noise standards and control) Regulations, 2003.First Schedule, PartII.

* Exposure to continuous or intermittent noise louder than 115 dB(A) should not be permitted.

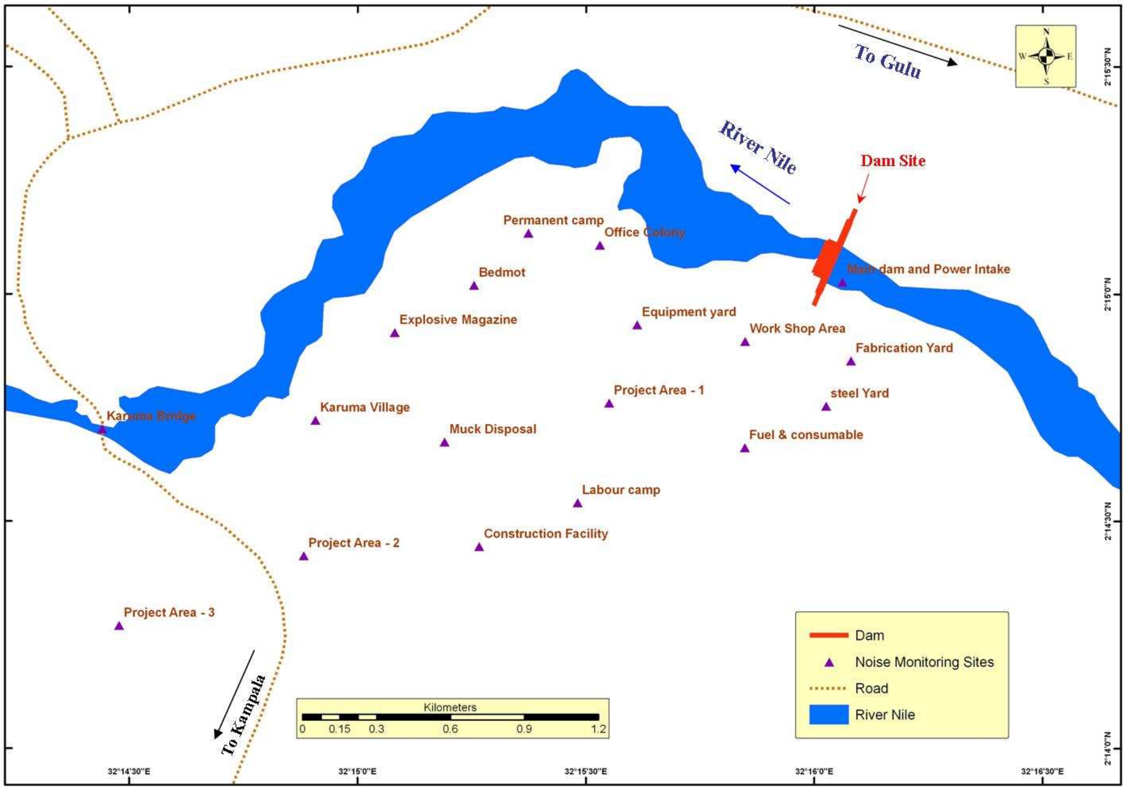

Figure 4.14: Noise quality monitoring sites within the study area of Karuma HPP

Table 4.11: Maximum permissible limit of vibration exposure to noise permitted in the workplace in Uganda

Geometric mean of octave band frequency, Hz	Octave band cut-off frequencies, Hz		Maximum permissible limits of velocity	
	lower	upper	Effective value, m/s	Pressure level of effective value, (db)
8	5.6	11.2	5.00 x10^{-2}	120
16	11.2	22.4	5.00 x10^{-2}	120
31.5	22.4	45	3.50 x10^{-2}	117
63	45	90	2.50 x10^{-2}	114
125	90	180	1.80x 10^{-2}	111
250	180	355	1.20 x 10^{-2}	108
500	355	710	0.90 x 10^{-2}	105
1000	710	1400	0.63 x 10^{-2}	102
2000	1400	2800	0.43 x 10^{-2}	99

Note: Octave is the interval between two sounds having a basic frequency ratio of two. The interval, in octaves, is the logarithm to the base two of the frequency ratio.

The differences in noise levels for various proposed allocation project site areas was due to various factors of which some include;

- Pending relocation area, residents that are to be affected by the project development
- Karuma river water falls mainly for the areas with noise levels exceeding 60 dB(A) and a few others depending on the closeness to such falls on the river. The nearer to the river, the higher the noise levels recorded and vice versa.
- Generator noise for an MTN base station(Mobile Service Provider) at about 200m away from the construction facilities area was noted as the main contributing agent (36.7dB(A))
- Vehicles along Gulu road as well as commercial businesses in the trading centre for proposed sites that are closer for example project area-2 of noise level 36.4dB(A).
- Other contributing factors were natural conditions such as insect and bird sounds as well as wind waves.

4.6 TRAFFIC DENSITY

The main traffic flowing through the project area is on the highway from Kampala to Gulu, Northern Uganda, which after crossing Karuma divides in two, one diversions goes to West Nile/Arua and the other to Lira. The roads to Arua and Lira, both on the North Bank are outside the project site, thus traffic measurements were only considered for the traffic around Karuma Town, taking into account that on the left of the highway at this point is a protected area, the Karuma Wildlife Reserve. **Table 4.12** and **Table 4.13** present the observed traffic flow on the Kampala -Gulu Highway in the project area.

Table 4.12: Traffic flow From Gulu to Kampala on Kampala -Gulu Highway

Vehicle	Time										
	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	Av.	**Total**
Saloon	2	6	3	3	2	9	6	15	8	4	6	**58**
Wagon	5	7	5	5	3	6	12	7	8	4	6	**61**
Omni bus	2	3	3	3	2	1	3	3	2	2	2	**23**
Bus	3	2	3	2	1	8	1	5	5	3	3	**32**
Trailer	0	1	1	1	0	3	0	2	4	3	1	**14**
Fuel Tanker	2	3	2	2	1	0	0	1	0	1	1	**12**
Lorry	6	6	6	6	8	4	7	9	4	2	6	**57**
Pick-up	3	4	3	4	3	2	1	3	3	3	3	**28**
Total	**21**	**30**	**25**	**26**	**20**	**33**	**30**	**45**	**34**	**22**	**29**	**285**

Table 4.13Traffic flow To Gulu from Kampala on Kampala -Gulu Highway

Vehicle	Time										
	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	Av.	**Total**
Saloon	1	2	2	2	2	9	10	8	5	7	5	**47**
Wagon	3	4	4	3	6	10	18	9	5	3	6	**65**
Omni bus	3	3	2	1	2	4	3	2	2	1	2	**23**
Bus	5	4	3	4	4	2	4	7	4	2	4	**39**
Trailer	3	2	1	2	0	1	4	2	2	3	2	**19**
Fuel Tanker	1	1	1	2	2	5	1	2	3	1	2	**20**
Lorry	4	5	6	4	4	4	4	5	6	3	4	**45**
Pick-up	5	4	3	6	2	5	4	2	4	3	4	**38**
Total	**25**	**23**	**22**	**24**	**22**	**40**	**48**	**37**	**31**	**23**	**30**	**295**

4.7 WATER QUALITY

4.7.1 Physical and chemical parameters

Population density along the river Nile in the study area is not very high and population in the vicinity of the project is mostly engaged in agriculture. Since there is no industrial unit in or around the proposed project area and also the fact that the inhabitants are still following their age-old methods of cultivation, there is no such source of water pollution in the area and the water quality is good apart from E. coli count at Kampala Beach and Opposite/Tunnel Outflow. All the other parameters recorded are actually far below the upper limits of national drinking water standards as per National Water and Sewerage Cooperation Uganda. Sampling is done on the Left and right bank of the river at six locations on both sides (**Figure 4.16**). The result of the water quality analysis is presented in **Table 4.14** and **Table 4.15** Values of the parameters recorded from both the shore did not reveal much difference and is more or less similar. A steady increase in oxygen concentration downstream is recorded along the left shore (1.4 - 7.8 mgL^{-1}) from Masindi Port to Tunnel-outflow. A similar range (1.8 - 7.2 mgL^{-1}) is recorded along the right bank from Apac to Chobe. The pH at all sites remained neutral ranging from 7.0 - 7.9 highly suitable for both drinking water and water for fish production. Both sites are associated with a bay-like enclave with many hippos and water covered with decomposing water hyacinth petioles **Figure 4.15**. Kampala Beach is popular with fish poachers as reported by the Uganda Wildlife Authority (UWA) rangers. The high population of hippos which defecate in the water most of the day and the decomposing water hyacinth explains the observed tendency to eutrophication and the suitability for fishing. Total phosphorus concentration shows a typical of mesotrophic conditions. The range could be useful bench mark for monitoring possible eutrophication.

Figure 4.15: Menacing hippos in a shallow water zone at Chobe Lodge (top); water hyacinth mat and weed petioles in a shallow bay (bottom) in the study area of the Karuma Hydropower Project on River Nile –June 2010

4.7.2 Biological parameters

4.7.2.1 E. coli

Only four sites (Apac/Masindi Port- Masindi Port/Apac, Atura/Mutunda and Nora/Awoo downstream) qualified the National Water and Sewerage Cooperation standard of zero colony forming units per 100 mL (**Table 4.14** and **Table 4.15**). The sites at Kampala Beach and Chobe Lodge recorded 3000 and 72 units, respectively. The high coliform counts at the two sites are possibly related to the detected presence of poachers at the restricted Kampala Beach a day or two before samples were collected; and to the large number of construction workers at Chobe Lodge during the sampling period.

4.7.2.2 BOD_5

During this survey, BOD_5 of the water ranged from 3 - 14 mgL^{-1} with both sides of the river bank showing uniformity. In most cases, the BOD_5 values for natural drinking water are supposed to be less than 1 mgL^{-1}.

4.7.3 Oil and grease

Oil and grease concentration at all sites ranged from 0 to 0.1 mg L^{-1} indicating so far no contamination.

Table 4.14: Water quality characteristics of water samples from the Left Bank of the river Kyoga Nile

Transects	Units	S1	S2	S3	S4	S5	S6	National Standard
Altitude	m	1039.0		1037.0		1003.0		NA
Dissolved Oxygen	mgL^{-1}	1.38	2.03	4.20	5.05	7.79	7.30	NS
pH		7.04	7.13	7.41	7.23	7.46	7.74	
Temperature	°C	27.2	28.4	28.7	27.6	27.8	28.4	NS
Electrical conductivity	μScm^{-1}	112.0	109.0	109.0	109.0	110.0	109.0	2500
Alkalinity (Total)	mgL^{-1}	38.0	36.0	38.0	34.0	50.0	54.0	500
Alkalinity (CO_3)	mgL^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	500
Hardness (Total) CO_3	mgL^{-1}	40.0	36.0	36.0	34.0	40.0	32.0	500
Calcium (Ca^{2+})	mgL^{-1}	8.0	8.0	7.2	8.0	10.4	9.6	75
Magnesium (Mg^{2+})	mgL^{-1}	4.8	3.8	4.3	3.4	5.6	1.9	50
Bicarbonate (HCO_3^-)	mgL^{-1}	38.0	36.0	38.0	34.0	50.0	54.0	500
Chloride (Cl^-)	mgL^{-1}	0.1	0.0	0.2	0.1	0.4	0.6	500
Fluoride (F^-)	mgL^{-1}	0.07	0.08	0.08	0.06	0.00	0.00	1.5
Sulphate (SO_4^{2-})	mgL^{-1}	1.0	0.0	0.0	0.0	4.0	4.0	200
Nitrate (NO_3^-)	mgL^{-1}	0.02	0.05	0.03	0.04	0.03	0.03	5.0
Ammonia (NH_3)	mgL^{-1}	0.14	0.13	0.09	0.20	0.23	0.20	2.0
Orthophosphate (PO_4)	mgL^{-1}	0.018	0.000	0.002	0.009	0.07	0.06	0.2
Phosphate (Total)	mgL^{-1}	0.071	0.080	0.079	0.077	0.09	0.08	NS
BOD_5 at 20°C	mgL^{-1}	6.0	9.0	7.0	4.0	3.0	4.0	NS
Oil and Grease	mgL^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	1.0
E-coli	CFU 100 ml^{-1}	0.0	2.0	8.0	12.0	3000.0	11.0	0.0

NS = Not specified **LS1: Masindi / Apac Port, LS2: Mutunda / Atura, LS3: Awoo / Nora Upstream of Weir, LS4: Awoo / Nora Downstream of Weir, LS5: Kampala Beach, LS6: Chobe Lodge**

Table 4.15: Water quality characteristics of water samples from the Right Bank of the river Kyoga Nile

Transects	Units	S1	S2	S3	S4	S5	S6	National Standard
Dissolved Oxygen	mgL^{-1}	1.82	1.6	4.66	5.12	7.22	7.20	NS
pH		7.32	7.14	7.45	7.24	7.54	7.78	
Temperature	°C	27.4	28.2	29.0	27.5	27.4	28.6	NS
Electrical conductivity	μScm^{-1}	106.0	107.0	107.0	107.0	118.0	107.0	2500
Alkalinity (Total)	mgL^{-1}	38.0	34.0	34.0	36.0	58.0	48.0	500
Alkalinity (CO_3)	mgL^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	500
Hardness (Total) CO_3	mgL^{-1}	38.0	38.0	36.0	36.0	36.0	44.0	500
Calcium (Ca^{2+})	mgL^{-1}	8.8	8.8	9.6	9.6	9.6	10.4	75
Magnesium (Mg^{2+})	mgL^{-1}	3.8	3.8	3.4	3.4	2.9	4.3	50
Bicarbonate (HCO_3^-)	mgL^{-1}	36.0	34.0	34.0	36.0	58.0	48.0	500
Chloride (Cl^-)	mgL^{-1}	0.1	0.1	0.1	0.1	0.6	1.0	500
Fluoride (F^-)	mgL^{-1}	0.1	0.07	0.05	0.08	0.00	0.00	1.5
Sulphate (SO_4^{2-})	mgL^{-1}	0.0	0.0	0.0	0.0	3.0	3.0	200
Nitrate (NO_3^-)	mgL^{-1}	0.03	0.03	0.03	0.04	0.02	0.03	5.0
Ammonia (NH_3)	mgL^{-1}	0.05	0.06	0.11	0.08	0.18	0.22	2.0
Orthophosphate (PO_4)	mgL^{-1}	0.001	0.011	0.000	0.011	0.06	0.06	0.2
Phosphate (Total)	mgL^{-1}	0.062	0.065	0.066	0.063	0.13	0.08	NS
BOD_5 at 20°C	mgL^{-1}	14.0	6.0	3.0	8.0	5.0	4.0	NS
Oil and Grease	mgL^{-1}	0.0	0.1	0.0	0.1	0.0	0.0	1.0
E-coli	$CFU100ml^{-1}$	0.0	0.0	0.0	18.0	16.0	72.0	0.0

NA = Not applicable; **RS1:Apac/Masindi Port, RS2: Atura/Mutunda, RS3: Nora /Awoo Upstream, RS4:Nora /Awoo Downstream, RS5:Opposite/Tunnel Outflow, RS6:Chobe Lodge**

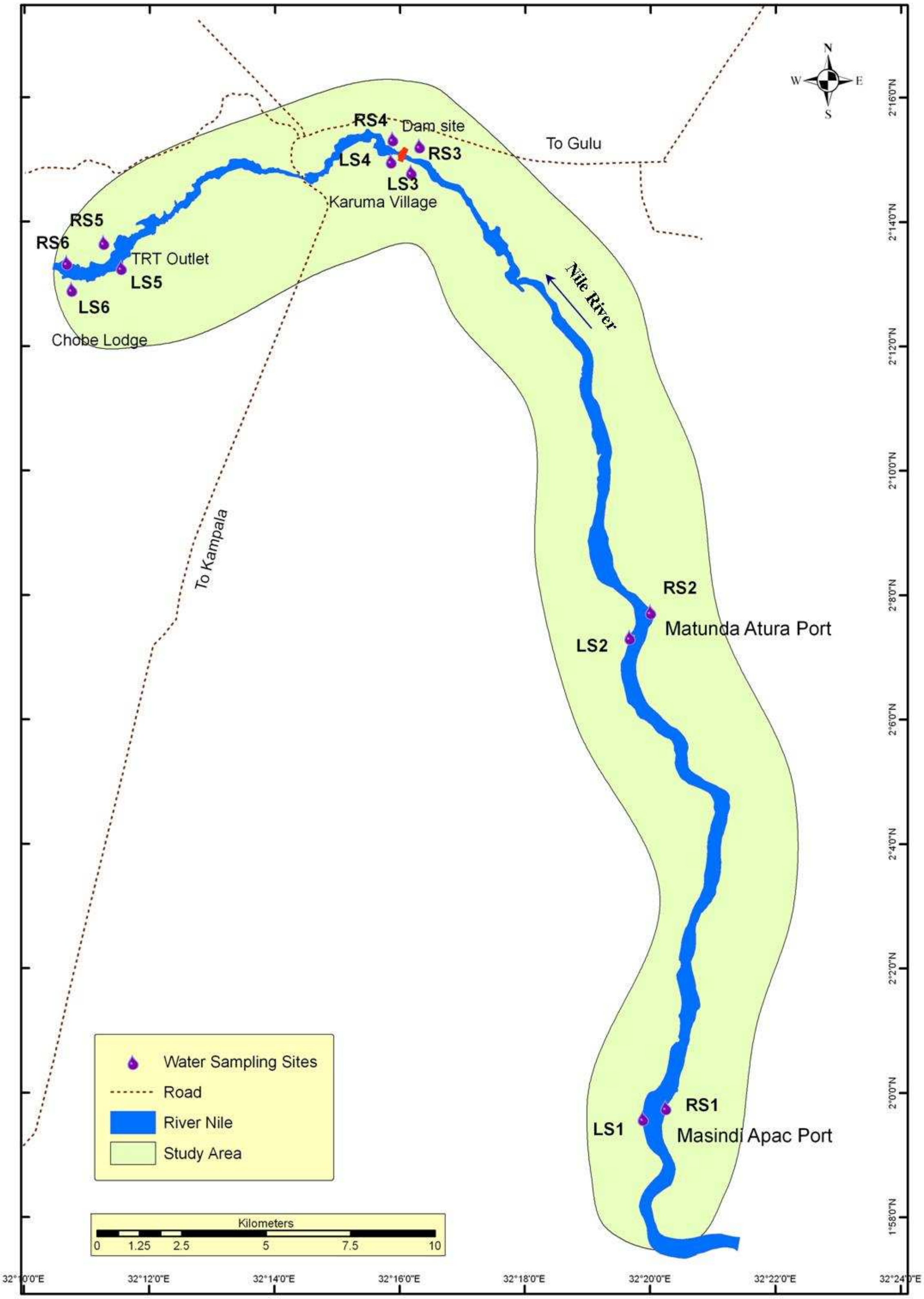

Figure 4.17: Water Quality sampling sites in the study area of Karuma HPP