ASSESSMENT OF SEDIMENTATION LEVEL USING REMOTE SENSING AND GIS IN KIIRA DAM, JINJA DISTRICT UGANDA

Report submitted to
Kampala International University in partial fulfillment
of the requirement for the award of the degree

of
Bachelor of Science
in Civil Engineering

by
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DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF ENGINEERING AND APPLIED SCIENCES
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DECLARATION

We hereby declare that this final year research project report is an absolute reflection of the work undertaken and has thereby never been presented for any award at any institution. We therefore submit in this final year research project report to the School of Engineering and Applied Sciences in partial fulfillment of the requirements for the award of the Degree of Bachelor of Science in Civil Engineering at Kampala International University.

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CERTIFICATION

I the undersign, do here by certify that I have read and forwarded for acceptance to Kampala International University, School of Engineering and Applied Science, department of Civil Engineering a research project report entitled "**Assessment of Sedimentation Level Using Remote Sensing and GIS in Kiira Dam, Jinja District Uganda**" in partial fulfillment of the requirement for the award of the degree of Bachelor of science in Civil Engineering.

Signed ……

Date ……

Dr. Lawal Tunji

(Supervisor)

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ABSTRACT

The Satellite Remote Sensing (SRS) method for assessment of reservoir sedimentation uses the fact that the water spread area of reservoir at reservoir boundaries keeps on increasing due to sedimentation. Remote Sensing technique gives directly the water spread area of the reservoir at a particular elevation on the date of pass of the satellite. This helps to estimate sedimentation over a period of time. This research project describes assessment of sedimentation carried out for the Kiira Reservoir using Remote Sensing satellite imageries. The area capacity curve of year the 2001, is used as a base for sedimentation assessment for the year 2010. The results of Remote Sensing survey for the period 2001 to 2010 are compared with the deposition pattern of Kiira Reservoir with the standard types of deposition pattern as per Area Reduction Method suggested by Borland and Miller. As per recent Remote Sensing survey of 2006 and 2010, it was observed that the original water spread area had increased to 4.82km^{2}and 4.96km^{2}respectively i.e. by approximately 3.549% in 9 years. Thus, there is a gradual reduction in the capacity of Kiira reservoir.

The validation process which involved collecting field data and incorporated with the remote sensing data gave an evidence of sedimentation in Kiira dam at the sample point locations as indicated the preceding chapters.

LIST OF ACRONYMS/ABBREVIATIONS

AHD	-	Aswan High Dam
DN	-	Digital Number
FCC	-	False Color Composite
FRL	-	Full Reservoir Level
GIS	-	Geographic Information System
IRS	-	Indian Remote Sensing
ISRO	-	Indian Space Research Organization
LISS	-	Linear Imaging Self-Scanning
MDDL	-	Minimum Draw Down Level
NB	-	Nile Basin
NDWI	-	Normalized Difference Water Index
NIR	-	Near Infrared
SRS	-	Satellite Remote Sensing
UNDP	-	United Nations Development Programme
UNEP	-	United Nations Environment Programme
WI	-	Water Index

CHAPTER ONE: INTRODUCTION

The ultimate destiny of all reservoirs is to be filled with sediment and the obvious consequence of sedimentation is the decrease of the live storage of the reservoir and hence its functions and life span (Linseleyet al.1992). The volume of sediment material in reservoirs depends on the quality of inflowing water, catchment quality, sediment load, reservoir geometry, projected operation and life among other things. A reservoir changes the dynamics of river flow by forcing the energy gradient to approach zero and results in loss of transport capacity of the river with the resulting deposition. Following this, information such as design life of the reservoir, reservoir capacity, reservoir yield, and sediment yield from the catchment is required so as to effectively manage reservoir sedimentation.

1.1 BACKGROUND

1.1.1 Studies carried out globally

Assessment of revised capacity of Shetrunji reservoir in Bhavnagar district of Gujarat which is a multipurpose medium project has been carried out using digital image analysis of remote sensing data. For the study, seven LISS III scenes of IRS 1D/P6 have been selected to cover the whole range of live storage. The normalized difference water index (NDWI), image rationing and slicing have been used to distinguish water pixels from rest of the pixels. The revised water spreads have been used to estimate revised capacity at different levels. From the study it has been observed that 120.66 M. cum of gross storage and 97.17 M. cum of live storage have been lost in last 42 years (1965 to 2007). The catchment area up to the dam site of the Shetrunji reservoir being 4317 km, the silting rate in common unit is computed to be 6.66ha-m/100 km/year. The present rate of siltation from 2000 to 2007 is 4.29 M. cum/year which is 65% more than the rate of siltation of 2.59 M. cum/year during the period from impoundment to 2000 according to J. Indian Water Resour. Soc. Vol. 29 No. 3, July, 2009.

1.1.2 Studies carried out in Uganda

The Nile River is the main source of water for the eleven countries that make up the Nile basin as shown in Figure 1. The climate and hydrology of the Nile Basin (NB) ranges from Equatorial in the White Nile headwaters to arid in the desert region of northern Sudan and Egypt. Thus, for much of its course, the Nile is an exotic river (Woodward, et al. 2007). Stretching over 35 degrees latitude of the north-eastern African quadrant, the Nile River basin represents one-third of the entire African continent. With an area of almost 3,176,543 km^2 extending over different geographical, topographical and climatological regions, the basin spans over ten African countries: Burundi, Democratic Republic of Congo (DRC), Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, S. Sudan, Tanzania and Uganda, (Fig. 1).

Catchment suffer severe land degradation and soil erosion due to extended dry seasons in some parts of the Basin, torrential rain and geological nature, bringing large quantities of sediment in the drainage systems (Abdelsalam, 2008). This leads to land degradation in the watershed and the upper lands, e.g. in Ethiopia Highlands in the east, and around upstream Lake Victoria in the south. At the same time, the sediment deposition in the reservoirs and irrigation systems downstream lead to serious reduction in reservoirs storage capacities and hence leading to hydropower generation problems, banks flooding and ultimately negatively impact on the socio-economic lives of the users, environment and ecosystem in general. The reduction of sediment supply in large alluvial systems due to sediment trapping in upstream reservoirs might lead to long-term impacts on the fluvial process.

One such example is the river channel downstream of the Aswan High Dam (AHD) on the Nile River, where river bed degradation and bank erosion occurred and serious shore erosion was observed at the river mouth area. In the case of the AHD, the aggregate storage capacity of Lake Nasser, which is twice as large as the annual runoff of the Nile River at the dam site, is sufficient to change both the flow regime and sediment supply to the river channels downstream of the AHD. Thus, the downstream section of the Nile is transformed into a system with a non-equilibrium sediment transport process. As a result, the annual peak discharge has been reduced

to less than a third of its original value, which caused navigation problems (Abdelbary 2004).

Dams and their reservoirs are constructed and operated for multipurpose including power generation, flood protection, drinking water, agricultural water supply, recreation, fishing, and others.



Figure 1: Map of the Nile Basin showing basin sources, the Nile course and the drainage network (Nile Basin Initiative, state of the River Nile Basin 2012).

Until now in the Nile Basin (NB) the common engineering practice has been to design and operate reservoirs to fill with sediment. With such an approach, the consequences of sedimentation and project abandonment are left to be taken care of by future generations. Therefore we need to develop ingenious solutions for integrated sediment and water management; unless we will lose the struggle to enhance the available water resources. Regardless of their purpose, all multipurpose dams trap sediment and inevitably lead to physical and ecological changes downstream of the reservoir site, as well as in the reservoir itself, and in some cases also upstream. Kondolf (1997) has described that, by changing flow regime and sediment load, dams can produce adjustments in alluvial channels, the nature of which depends upon the characteristics of the original and altered flow regimes and sediment loads.

1.2 Problem statement

Reservoir sedimentation affects the water storage capacity, erosion and cracking of the tips of turbine blades by water–borne sand and silt considerably reduces their generating efficiency and can require expensive repairs, floods on an event of a probable Maximum Flood (PMF) and due to lack of sedimentation data there was need to apply remote sensing and geographical information systems to assess the level of sedimentation in the dam.

1.3 Significance of the project

The result of the estimate in reduction of the current reservoir capacity helps to develop tools in collaboration with local and regional stakeholders, for the analysis and design of reservoirs to collaborate and ensure long-term sustainability of local water supplies to improve livelihoods.

1.4 Project objective

The main objective of the project was to assess sedimentation level using remote sensing and GIS in Kiira dam, Jinja district Uganda.

1.4.1 Specific objectives

i. To apply remote sensing and GIS for the purpose of delineating the watershed/catchment in which Kiira Dam belongs to.
ii. To obtain, analyze and process multi-temporal satellite images of Kiira Dam
iii. To process digital images for delineation of water and land boundary
iv. To determine the water spread area of Kiira Dam as a result of sediment deposition.
v. To validate the remote sensing data by ground trothing.

1.5 Scope of the project

The research project involved the use of Satellite Remote Sensing (SRS) and Geographical Information Systems (GIS) to estimate reservoir sedimentation in Kiira dam in Jinja district, Uganda.

This research project was be carried out with in a time frame of eight (8) months.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Different scholars have defined the concept of sedimentation worldwide and in general, sedimentation is defined as the deposition by settling of a suspended material due to gravity. In other words, sedimentation is a result of sediments which are defined as particulate matter that can be transported by fluid flow and eventually are deposited as a layer of solid particles on the bed or bottom of water body such as reservoirs (Wikipedia Free Encyclopedia, 2008).

A Geographical Information System (GIS) can be used to model bathymetry and the spatial distribution of sediments (Evans et al., 2002; Heimann, 1995). The use of Remote Sensing technique to estimate suspended sediment has been reported by several investigators (Solomonson, 1973; Bartoluci et al., 1977; Holeyer, 1978; Khoram, 1981). Smith et al. (1980) determined siltation in the Aswan High Dam Reservoir by comparing reflectance values in the green and red portions of the spectrum. Research findings indicate that siltation during the flood period was largely confined to the main river channel of the reservoir and large embayments. Areas of extensive siltation were identified and the amounts of deposition were determined through ground surveys. This information was used to predict the distribution of silt deposits in the reservoir. Rao et al. (1985) used a visual interpretation technique on large scale imagery of Landsat-MSS to estimate the water-spread area at different levels to evaluate the capacity of the reservoir and concluded that the results are comparable with hydrographic survey observations and similar to the curves obtained from the conventional methods. A digital technique in which density slicing of Landsat-MSS Near-infrared (NIR) data was performed for extracting the water-spread area and correlated computed reservoir capacity based on the surface area obtained using cone formulae. Goel& Jain (1996) earned out a reservoir sedimentation study using the density-slicing approach for water-spread area extraction. The status of studies shows that there is lot of scope of the Remote Sensing approach for sedimentation assessment in the Western Ghats region, which has extensive areas that are prone to soil erosion. The assessment may

be performed on the basis of geomorphic analysis and modelling in combination with analysis of recent bathymetry to determine the historical pattern and rate of deposition (Gregory L.Morris,Jiahu Fan, December 2010).

The shape of the reservoir is defined by the depth to capacity relationship. The Borland and Miller method, also known as the Area-Reduction Method, was developed from resurvey data of 30 US reservoirs. The Empirical Area-Reduction Method has been developed with revisions by Lara and subsequent changes by Pemberton. Rooseboom and Annandale used field survey data for 11 large reservoirs in South Africa to compile asemi-empirical graph. Their new technique represents new empirical curves based on variation of wetted-perimeter through the reservoir length for predicting longitudinal sediment distribution pattern in reservoirs. Among the scientists who implemented the Rooseboom and Annandale method, Michalec and Tarnawski (2006) studied the possibility of application of this method. They showed that supplementary research works on additional parameters considering the reservoir shape is still required. Also, Mohammadzadeh and Heidarpour introduced a new empirical method for prediction of sediment distribution in reservoirs based on original area-capacity and depth-capacity data of reservoirs.

2.2 Impacts of Sedimentation in Reservoirs

Sedimentation is common to all reservoirs and it is widely recognized that each year up to 1 percent of the world's reservoir capacity is lost to sedimentation (Howard, 2000). Several case studies have been conducted in the field of reservoir sedimentation and they point to the fact that sedimentation actually reduces reservoir storage capacities. Ainworth (2005) compiled a report on the World Water Storage in Man Made Reservoirs based on several studies carried out by many authors.

According to Ainworth (2005), loss of storage due to sedimentation exacerbates the problem of providing enough storage for the rising population with its rising aspirations and standards. The report states that demand for additional storage is assumed to be 1.6% in 2000 falling to 1.2% in 2030. The analysis shows that South America, Africa

and Asia water storage demands would outstrip supply in the foreseeable future and the storage shortage is attributed to high sedimentation rates in these regions. In another study by Chao, (2004), observes that sedimentation problems are a matter of global concern as they include issues arising from erosion, desertification, sediment yield, transport and deposition in reservoirs and lakes. The study findings show that about 1% of the precious storage capacity of the world's reservoirs is annually lost due to river-related sedimentation with more floods and droughts induced and leading to deteriorated ecosystems as a result.

Halcrow, (2001), states that in many cases the rates of sedimentation calculated are dependent upon the accuracy not only of a recent survey but also of the original survey at the time of dam construction and on comparability of the two surveys. The author states further that there are a number of direct and indirect consequences of reservoir sedimentation on environment with the loss of water resources being the most obvious consequence.

According to Halcrow, (2001) there are both positive and negative impacts of reservoir sedimentation. The positive impacts include; generation of valuable wetland habitat with biological diversity, reduction of fine sediment discharge and hence improved water quality. Further, there is an opportunity for uses of sediment deposits in substitution of other peat based compost (manure) and finally the control on the use of reservoir catchments may significantly benefit the environment. However, negative impacts of reservoir sedimentation include;

- loss of reservoir water storage capacity,
- need for periodic operations of bottom outlet valves for safety reasons,
- need for restrictions on draw down of reservoirs through bottom outlet valves to prevent sediment being mobilized during storms, and
- Environmental impacts in remote areas due to removal and transport of sediment deposits.

2.3 Causes of Reservoir Sedimentation

The susceptibility of reservoir sedimentation depends on the sediment delivery of the watercourses, the retention characteristics of the reservoir and the manner in which the flow is delivered from the natural source to the reservoir (Halcrow, 2001). Hughes and Prosser (2003:12), stating that river erosion is the most uncertain of the sediment sources in terms of river budget modeling. According to the study, it is known that degradation of riparian vegetation and other impacts on the rivers have resulted in greatly increased rates of riverbank erosion, to the extent that this erosion process cannot be ignored as a sediment source in regional assessment.

Ainsworth, (2005) states that erosion of the land surface yields sediments which are transported downstream by rivers and eventually deposited in reservoirs while the rate of erosion depends on a complex interaction of:

- Climate - precipitation and runoff, temperature, wind speed and direction,
- Geotechnics – geology, volcanic and tectonic activity, soils,
- Topography – slope, catchment orientation, drainage basin area, drainage density,
- Vegetation cover, and
- Land use and human impact.

Topsoil and other light surface particles from a catchment are transported by rainwater from land to a reservoir where some of it settles to the floor of the reservoir as a layer of silt. Lindqvist, (2005); observed that a layer of silt that is only a few centimeters thick is good because it reduces seepage, but thicker layers of silt decrease the water storage capacity, reducing the period during which water can be drawn from a reservoir. Therefore, catchments without soil conservation and ponds or dams without

silt traps may result in dam reservoirs that cannot store any water after only a few years.

In Uganda most of the reservoirs (both big and small) are said to be silted up due to poor catchment management practices. It is reported that most of the reservoirs in the country are greatly degraded due to lack of maintenance and serious environmental degradation of the reservoir catchment. Reservoir sedimentation is attributed to issues of catchment degradation through deforestation, river bank cultivation, and overgrazing, poor farming practices such as lack of terraces set by farmers. Vandalism and lack of maintenance of sediment preventing structures such as silt traps and weirs are part of the factors contributing to problems of reservoir sedimentation (Uganda Government, 2004).

2.4 Impact of Change of Land Use on Erosion and Reservoir Sedimentation

Land use practices have important impacts on both the availability and quality water resources and the impacts can be both positive and negative. However, it is very difficult to arrive at universally valid statements about land use impacts on water resources because the impacts depend on a host of natural and socio-economic factors. The natural factors include; climate, topography and soil structure while the socio-economic factors include economic ability and awareness of the farmers, management practices, and the development of infrastructure such as roads (Kiersch, 2000). For example a change of land cover from lower to evapotranspiration values will lead to a decrease in annual stream flow and vice versa according to Bosch (1982).

According to UNEP (2005), Uganda generally continues to face environmental degradation due to high population density and high growth rate. Currently population of Uganda is estimated at 38 million with an overall population density of 190 persons per square kilometer and is one of the highest in Africa. Malawi is basically an agro based economy and use of traditional fuels particularly fuelwood and charcoal is so pervasive accounting for 90 percent by 2004.

However, a small proportion of the population (16 percent) has electricity within 100 meters of their dwelling. Due to the high population density and dependence on the land great pressure is put on the environment for more farmland and fuelwood and Malawi has one of the highest rates of annual deforestation in Africa, at 2.4 percent based on reports for 1990 and 2000. As a result a according to the report there is an increasing removal of natural land cover in most parts of the country hence affecting the hydrological regimes of most catchments.

Land use and stream management can also trigger erosion responses and the responses can be complex often resulting in accelerated rates of erosion and sometimes affecting stability of streams for decades. Queensland Government (2006) observes that the following activities contribute very significantly to soil erosion and consequently reservoir sedimentation:

- over clearing of catchments and stream bank vegetation
- poorly managed sand and gravel extraction
- stream straightening works

According to Queensland Government (2006) the activities listed above are some of the examples of poor land management practices which result in accelerated rates of bank erosion which eventually leads to reservoir sedimentation when the eroded material is deposited in the reservoirs. Further to these poor land management practices, soil erosion is also accelerated by factors such as stream bed lowering or infill, saturation of banks from off-stream sources, redirection and acceleration of flow around infrastructure, obstructions, debris or vegetation within the stream channel, removal of disturbance of protective vegetation from stream banks as a result of trees falling from banks or through poorly managed stock grazing, clearing or fire and excessive or inappropriate sand and gravel extraction.

Another major cause of land use change is due to resource scarcity which results in pressure on the production of resources. Natural population growth and division of land parcels, domestic life cycles that lead to changes in labour productivity on sensitive areas following excessive or inappropriate use, failure to restore or to

maintain protective works of environmental resources and heavy surplus extraction away from the land managers are some of the examples that may slowly lead to land use changes in many areas. However fast land use changes may occur due to; spontaneous migration, forced population displacement, refuges, decrease in land availability due to encroachment by other land uses such as natural reserves (Lambin E.F. et al., 2003).

Caldel et al in 1995 carried out a case study on Lake Malawi on how land use change in Malawi (southern Africa) has altered the water balance of the Lake Malawi levels. In the study a water balance modeling was carried out to determine the causes of the changes in the lake levels and to determine to what extent these changes in level might have been the result of land use changes. The study concluded that the most significant among other causes was the clearance of the dry deciduous miombo woodland for rainfed agriculture Caldel (1998). According to the findings of the study, without the decrease in forest cover predictions showed that the lake levels would have been almost 1 meter lower than what was actually observed on the onset of the Southern African drought of 1992.

2.5 Impact of Climate Change on Water Resources

Nangoma (2008) states that impacts of climate change have affected almost all development sectors in Uganda which include the water sector. According to the author, Malawi has experienced a number of adverse climatic hazards over the past 20 years and the most serious ones have been dry spells, seasonal droughts, intense rainfall, riverine floods and flash floods. As a result droughts and floods have been on the increase in frequency, intensity and magnitude for the last two decades thereby adversely impacting on food and water security, water quality and sustainable livelihoods of the most rural communities.

Land change use is also an indirect result of climate changes experienced in different parts of the world because communities tend to respond to climate change by adopting measures for survival by changing use the land resources as noted by Bie et al (2007). According to UNDP (2008), the map of Uganda shows the sub-national drought–related

disaster risk data upon which the global map is based and the country is vulnerable for a number of reasons:

- Under present and historical climate, Uganda experiences two rainy seasons and the climate change impacts which may be beginning to manifest, will decrease the length of the rainy season with increased rainfall intensity and flood risk.
- Uganda is a largely agricultural country, with 85% of the people living in rural areas and four fifth of export revenues coming from the agricultural sector.
- Climate models consistently report that Eastern Africa which includes Uganda will be very likely to dry significantly in the coming century while the rain that falls will come in increasingly concentrated bursts which are nor useful for agriculture and heightening flood risks
- Climate change through drought and flood has the potential to exacerbate soil erosion and this will further exacerbate ongoing land degradation pressures while also impacting water resources.

Historic rainfall records from the Department of Meteorological Services in Uganda show that the area surrounding Kiira area in Jinja has increasing rainfall intensities for the past decades and on average the rainfall amounts have changed from about 800 mm per annum to 830 mm per annum.

2.6 Techniques of Sediment Removal from Reservoirs

There are a number of practical means of removing sediments from reservoirs such as hydraulic methods by flushing as well as mechanical methods such as dredging, excavation and siphoning. Sediment removal methods depend on the reservoir characteristics and quality of the sediments and as such sediment may be removed from the shore or from a boat. Since some dredging techniques have a disadvantage in that they may increase turbidity and causing water quality problems, hydraulic

methods or mechanical excavation methods that usually require the reservoir level to be lowered or by-passed and emptied are more preferred (Brabben, 1988).

An example is given of Dashidaira Dam in Japan by Kashiwai (2002) which had a major inflow of sediment during 1995 but subsequent flushing resulted in the reduction of sediment volume stored in the reservoir by approximately 40%. Kashiwai (2002) outlines five methods used in Japan to mitigate sedimentation in reservoirs. The five methods are; sediment flushing, sediment bypassing, excavation and dredging, discharging turbid water and reservoir emptying. However, most of these methods may be very costly in other circumstances so proper assessment should be made before a particular method is applied.

The World Bank has made a contribution to promote conservation of water storage worldwide by concentrating on the specific issue of reservoir sedimentation and how it might be reduced or possibly eliminated. The concept of "reservoir life cycle management" was then developed and looked at the physical processes by which sediment could be removed on a regular basis from reservoirs. This resulted in the development of a simple mathematical model (RESCON) which enables decisions to be made on the financial and engineering viability of preserving storage (Ainsworth, 2005). Following this development, several ways of removing sediments from reservoirs were then considered by the World Bank:

- **Flushing**: A technique whereby the flow velocities in a reservoir are increased to such an extent that deposited sediments are remobilized and transported through low-level outlets in the reservoir.
- **Sluicing:**

  An operational technique by which a substantial portion of the incoming sediment load is passed through the reservoir before the sediment particles can settle. This is accomplished in most cases by operating the reservoir at a lower level during the flood season to maintain sufficient sediment transport capacity through the reservoir.

Mechanical removal:

Mechanical removal of deposited sediments from reservoirs takes place using conventional techniques, dry excavation or hydrosuction.

- **Dredging**:

It is the process of excavating deposited sediments from under water. Dredging is a highly specialized activity which is mostly used for clearing navigation channels in ports, rivers, and estuaries and reservoirs.

- **Dry excavation:**

Also known as trucking and requires the lowering of the reservoir during the dry season when the reduced river flow can be adequately controlled without interfering with the excavation works. The excavated sediment is transported for disposal using traditional earth equipment and the method is mostly suitable for small reservoirs because it attracts lower costs of excavation and disposal for small reservoirs compared to big reservoirs.

- **Hydrosuction**:

It is a variation of traditional dredging in that the hydraulic head available at the dam is used as the energy for dredging instead of pumps powered by electricity or fuel. As such where there is sufficient head available, the operation costs are substantially lower than those of traditional dredging.

2.7 Determination of Sediment Accumulation in Small Reservoirs

All reservoirs formed by dams on natural water courses are subject to some degree of sedimentation but the problem confronting the project planner is to estimate the rate of sedimentation and the period of time before the sediment will interfere with the useful functions of the reservoir. Provisions therefore should be made for sufficient sediment in the reservoir at the time of design so as not to impair the reservoir

functions during the useful life of the project or during the period of economic analysis (Strand, 1977).

Reservoir surveys are necessary to get more realistic data estimate regarding the rate of siltation and to provide reliable criteria for studying the implication of annual loss of storage over a definite period of time. Particular reference should be paid to the reduction of intended benefits in the form of irrigation potential, hydropower, flood absorption capacity and water supply for domestic and industrial uses among other uses and periodic reallocation of available storage for various pool levels Martinko et al. (2006). In addition reservoir surveys help in proper estimation of loss of storage designed at the planning stage besides evaluating the effectiveness of soil conservation measures carried out in the catchment area of river valley projects. Again, Martinko et al. (2006), state that since the major cause of change in storage capacity of reservoirs is sediment deposition a reservoir monitoring program can be put in place to periodically determine the following:

- storage depletion caused by sediment deposition since closure of reservoir,
- annual sediment yield rates,
- current location of sediment deposition,
- sediment densities,
- lateral and longitudinal distribution of deposited sediment, and
- Reservoir trap efficiencies.

Martinko et al. (2006), state that it is generally recommended to carry out survey of reservoirs periodically so that the quantities of sedimentation taking place can be assessed and timely remedial measures taken. Prior knowledge of total storage capacity of a given reservoir and the availability of data on determined volumes at a time, would provide enough prerequisites for the determination of sediment yield in a reservoir (Agarwal and Idiculla, 2006).

2.8 Development of Dams in Uganda

The history of dam development in Uganda dates back as far as early 1950s during which a number of small and medium-sized dams were built across the country for various purposes including hydro power generation, irrigation agriculture, fisheries, livestock watering and conservation. Reports from the Ministry show that over 10 small and medium size dams had been built across the country, mostly by government address events of droughts that hit the country (Uganda Government, 2004).

Of late the Uganda Government has embarked on an intensive development campaign to construct over 30 small dams all over the country with the Ministry in charge of Water and Environment taking a leading role. It is reported by officials in the Ministry that in mostly the existing small dams do not have design and sediment data available. The same applies to Kiira Dam which was initially built to generate hydro power for the country in-order to improve livelihoods. Worldwide dams are defined and classified differently depending on agreed standards in individual countries. However, in all countries a general description of a dam is that it is any structure capable of diverting or storing water (Sawunyama, 2005). Table 2.1 shows different classifications of dams based on height and capacity.

Table 1: Classification of Dams in some Countries

Organization/Country	Unit	Dam/ Reservoir Classification			
		Small	Medium	Large	Major
Malawi	$x10^6$ m^3	<1	1-5	5-20	≥20
	Height (m)	<8	8-15	15-30	≥30
Zimbabwe	$x10^6$ m^3	<1 $x10^6$	<1 $x10^6$-3 $x10^6$	3 $x10^6$-20 $x10^6$	≥20$x10^6$
	Height (m)	<8	8-15	15-30	≥30
South Africa	$x10^6$ m^3	-	-	-	-
	Height (m)	5-12	12-30	≥30	-
United States of America*	$x10^6$ m^3	<0.123	0.123-5	≥5	-
	Height (m)	≤6	6-12	≥12	-
World Bank*	$x10^6$ m^3	-	-	-	-
	Height (m)	<15	-	≥15-	-
World Commission on Dams*	$x10^6$ m^3	0.05-1	-	-	-
	Height (m)	<15	-	-	-

Adopted from PEM Consult (1999) and *Sawunyama (2005)

CHAPTER THREE: METHODOLOGY

This chapter contains the methods that were used to achieve the main objective of the research study.

3.1 Data used

3.1.1 Digital Elevation Model (DEM) Data

This data was downloaded from the National Map Seamless Server which is the United States Geographical Survey (USGS) website that is the global data explorer (www.gdex.cr.usgs.gov.) specifically for the project area.

3.1.2 Satellite Data

The multi-spectral data was obtained from www.earthexplorer.usgs.gov.Satellites for LISS-III Sensor available for the cloud free dates at different selected levels for the year 2001-10 were used for this study. The Kiira reservoir water spread was covered in one scene of Path-100.

3.1.3 Field Data

The field data was obtained using a rudimentary method and tools including a stone of mass 450g, 30m long string marked at one meter intervals, tape measure and a GPS device as shown in the figure 3 below. The sedimentation level at the selected sample points accessed by canoe then measured by lowering the tied string into the water until the stone touches the bed then depth read off at particular co-ordinates.

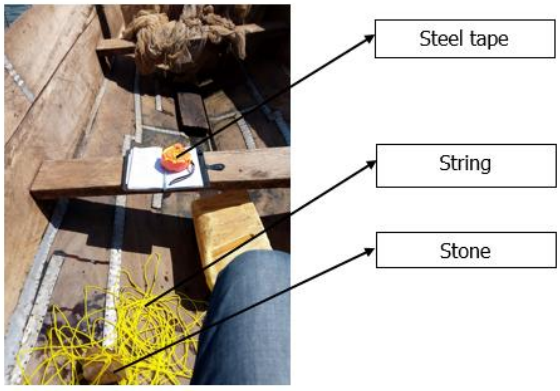

Figure 3: Tools used to collect the field data



Figure 2: Canoe from which the sample points were accessed

3.2 Delineating the watershed in which Kiira Dam belongs

The DEM obtained for the project area is digitally processed in the GIS environment. For this case Arc GIS 10.2software was used and the processes involved from Arc toolbox included; creating a fill to remove imperfections from the downloaded DEM, flow direction determined, flow accumulation, flow length, as well as stream order and snapping pour point then finally the watershed of project area delineated.

3.3 Analysis of Satellite Imageries

After comparing the availability of cloud free imageries for different date of pass vis-a-vis water level variation for different dates collected from the dam site, it was observed that there were very few imageries for one single water year during which there was maximum fluctuation in reservoir water levels. Therefore, the imageries for the period 2001-2010 were collected for cloud free dates in order to show variation from near FRL to MDDL. Cloud free imageries below MDDL were not available, hence the analysis of field data was restricted to live storage zone only.

The capacity estimation of Kiira Reservoir using Remote Sensing technique was carried out for the year 2010 in order to know deposition of sediment since 2001 in the reservoir.

The data was then imported in the Arc GIS v10.2. The Arc GIS software directly reads the raw imageries. On visual analysis, the pixels representing water-spread area (except at the periphery) of the reservoir were quite distinct and clear in the False Color Composite (FCC) image. The reservoir area and its surroundings (area of interest) were separated out from the full scenes from all the images. In present study, imagery of 28th January 2010 was considered as the base imagery.

3.4 Digital Image Processing for Delineation of Water and Land Boundary

For delineating the land and water pixels following method was adopted for a better accuracy.

3.4.1 Water Index (WI) Method

The water pixels are identified by taking band ratio of Green/Near Infrared. Since the maximum absorptance of Electromagnetic Radiation by water is in the Near Infrared

(NIR) spectral region, the DN value of water pixel in NIR band is appreciably less than the Digital Number (DN) values of Green spectral region, which is having high reflectance value. This ratio separates the water body from soil/vegetation quite distinctly.

— **Modified Normalized Difference Water Index (NDWI) Method**

The condition used to separate the water pixels from the other pixels is as follows:

$NDWI = (DN_G - DN_{NIR})/ (DN_G + DN_{NIR})$

"If NDWI is positive and if the DN value of NIR band is less than the DN value of Red band and the Green band (NIR< RED< GREEN), only then the pixel must be classified as water".

3.5 Corrections in Vector Contours and Masks

Water in tail channels of Kiira Reservoir appears as a part of reservoir in the imagery however, the elevation of the water surface in these river channels remains higher than the water surface elevation of the reservoir. This extended tail of main river channel and tributaries with higher water surface elevation were cut at the point of termination of reservoir water spread at corresponding levels taking help of base map (contour map). The longitudinal section of Main River and tributaries proved to be useful in order to decide cut-off points. Removal of extended tail is very much necessary as this could generate considerable errors in estimation of water-spread areas.

In the masks, isolated water pixels within and near the periphery of the reservoir, which show no hydraulic connectivity were removed. Similarly, water pixels downstream of reservoir were not a part of reservoir, hence were removed. The areas of islands present in the reservoir were deducted from the total water spread area from all the imageries.

3.6 Estimation of Cumulative Capacity

The reservoir capacity between two elevations of the reservoir was determined by water spread areas of corresponding satellite images of different dates of pass as processed using the method described in section 3.4.1.

3.7 Validation of the remote sensing data by ground trothing

The x, y and z data recorded from the process describe in section 3.1.3 was organized in an excel sheet and saved as type Excel 97-2003 Workbook. This sheet was then imported into the GIS environment to coincide with the already processed satellite image along with the stream order model of the catchment area in which Kiira dam belongs in order to establish the sample points thus validating.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Digital Elevation Model (DEM) Data

The DEM for the Kiira dam project area obtained as mentioned in section 3.1.1 is in the figure below.

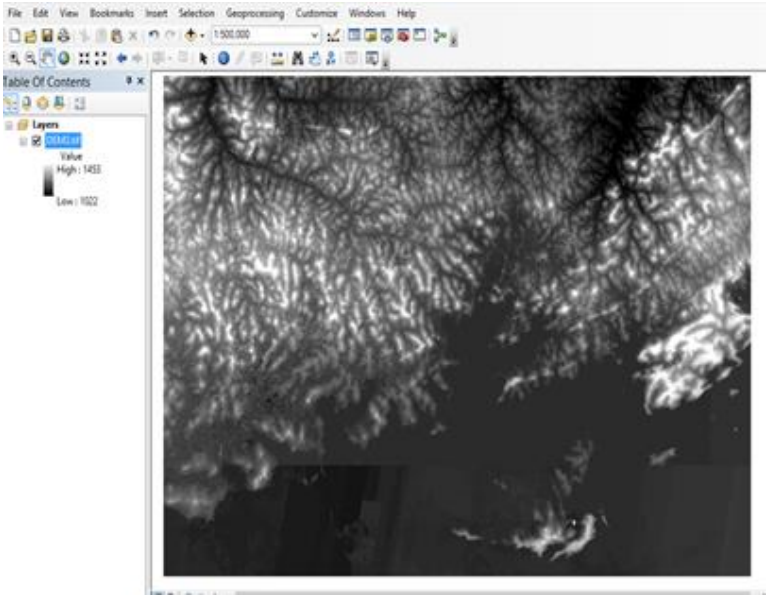

Figure 4: DEM for Kiira dam area

4.1.1 Watershed in which Kiira Dam belongs

Upon delineation of the watershed as described in section 3.2, a new watershed raster as shown in figure was added to the map document.



Figure 5: Delineated Watershed in which Kiira dam belongs

4.2 Satellite Data

The satellite images that were obtained are shown in the figures 6 and 7 for the year 2001 and 2010 as viewed from Arc map software.



Figure 6: Satellite image of Kiira watershed for 2001



Figure 7: Satellite image of Kiira watershed for 2010

4.3 Delineated Water and Land Boundary

After the images were analyzed as described in section 3.3 they were processed using the Normalized Difference Water Index (NDWI) method which is also elaborated in section 3.4 and thus gave rise to the model shown in figures 8 and 9 below.

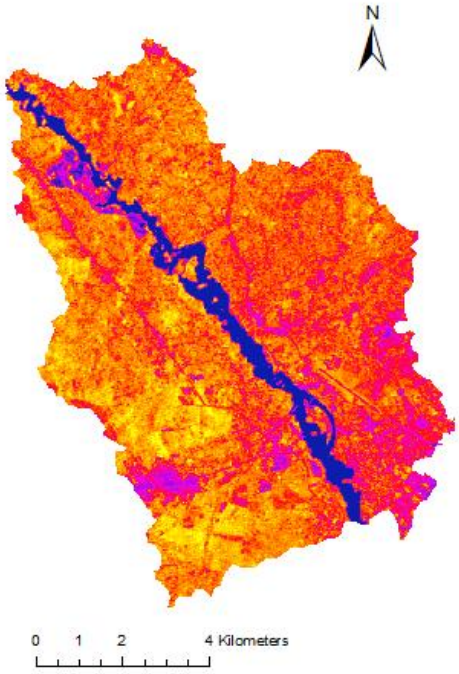

Figure 8: NDWI model for 2010

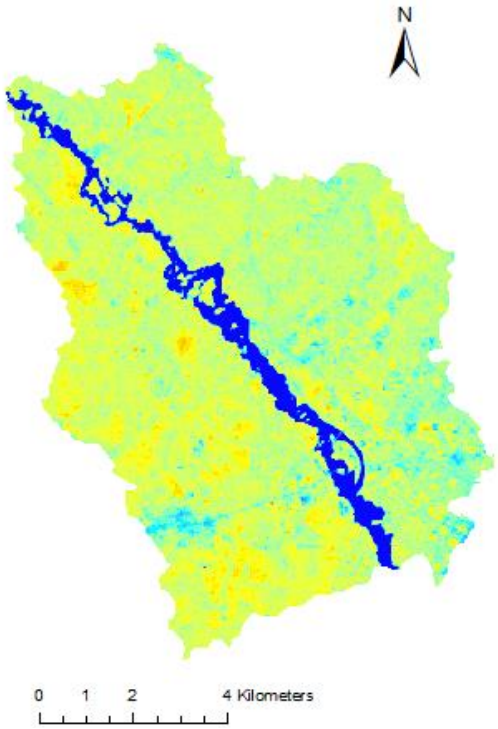

Figure 9: NDWI model for 2006

4.4 Estimation of Cumulative Capacity

After applying corrections, the actual water spread areas were obtained. The water spread areas of the reservoir extracted from imageries of 2001 to 2010 are shown as Figure 10 and 11 below. Estimated water spread areas for different dates (dates of satellite over pass) obtained by digital analysis of satellite data.

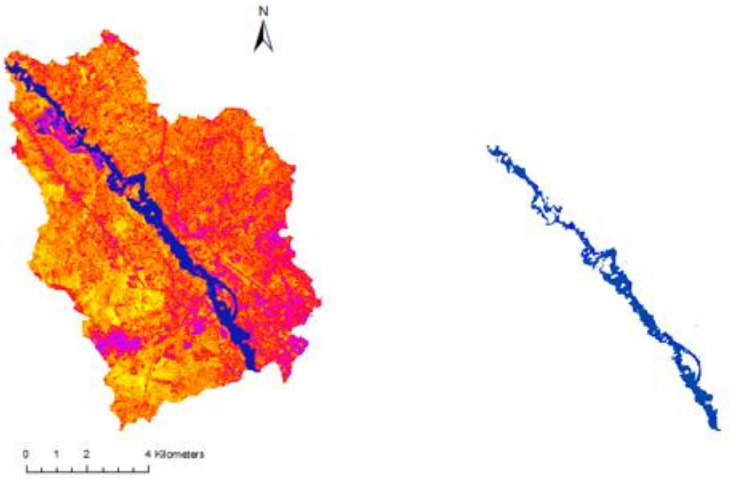

Figure 10: Date of Pass; 28th Jan 2010 Water Spread; 4.96km^2

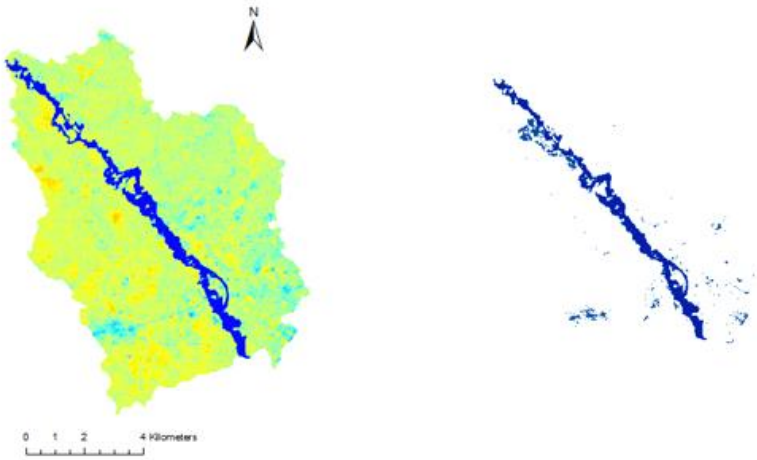

Figure 11: Date of Pass; 27th Nov 2001 Water Spread; 4.62km^2

The Water Spread Area - Year curve for the years 2010, 2006 as well as base year (2001) is shown as Figure 12. The shift in water spread curves as compared to original water spread curve represents the loss in capacity or sediment deposited at different levels in live storage zone. It was observed that the water spread area of the reservoir increased to 4.92km^2 from 4.62km^2 in 2001.

Table 2: Water Spread area in Kiira reservoir for different years

S/N	Date of Pass of Satellite	Water Spread Area(km^2)
1	27th Nov 2001	4.62
2	10th Feb 2006	4.82
3	28th Jan 2010	4.96

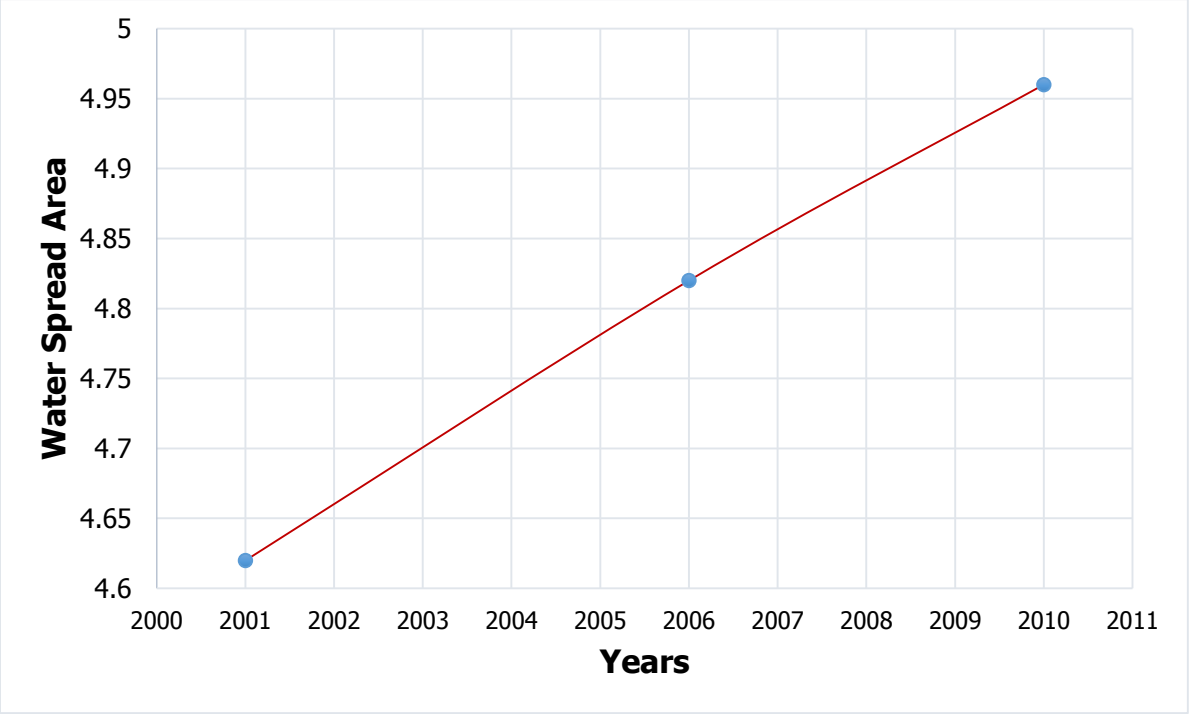

Figure 12: Water Spread Area - Year curve for Kiira Dam

4.5 Validation of the remote sensing data

This was done to check the concurrence of the remote sensing data with the field data. The x, y, z data obtained from the field as described from section 3.1.3 are as shown in table 3 below.

Table 3: Field sediment data from Kiira reservoir

Sample Point	[X]Latitude(DD)	[Y]Longitude(DD)	[Z]Depth(m)
A	0.4406044	33.1857838	10.5
B	0.4402992	33.1859489	5.7
C	0.4399632	33.1859031	9.7
D	0.4391596	33.1861573	17.3
E	0.4389169	33.186366	20
F	0.4378733	33.1879188	11.5
G	0.437308111	33.18805556	2.4

The seven sample point data in the table above were added into the Arc GIS environment which were found to lie within the spread water at the periphery of Kiira reservoir as shown in figure 13 below. The stream order in the Kiira catchment area flows towards the red color coded stream which is the main river which continues in the Northward direction to the outlet known as the pour point.

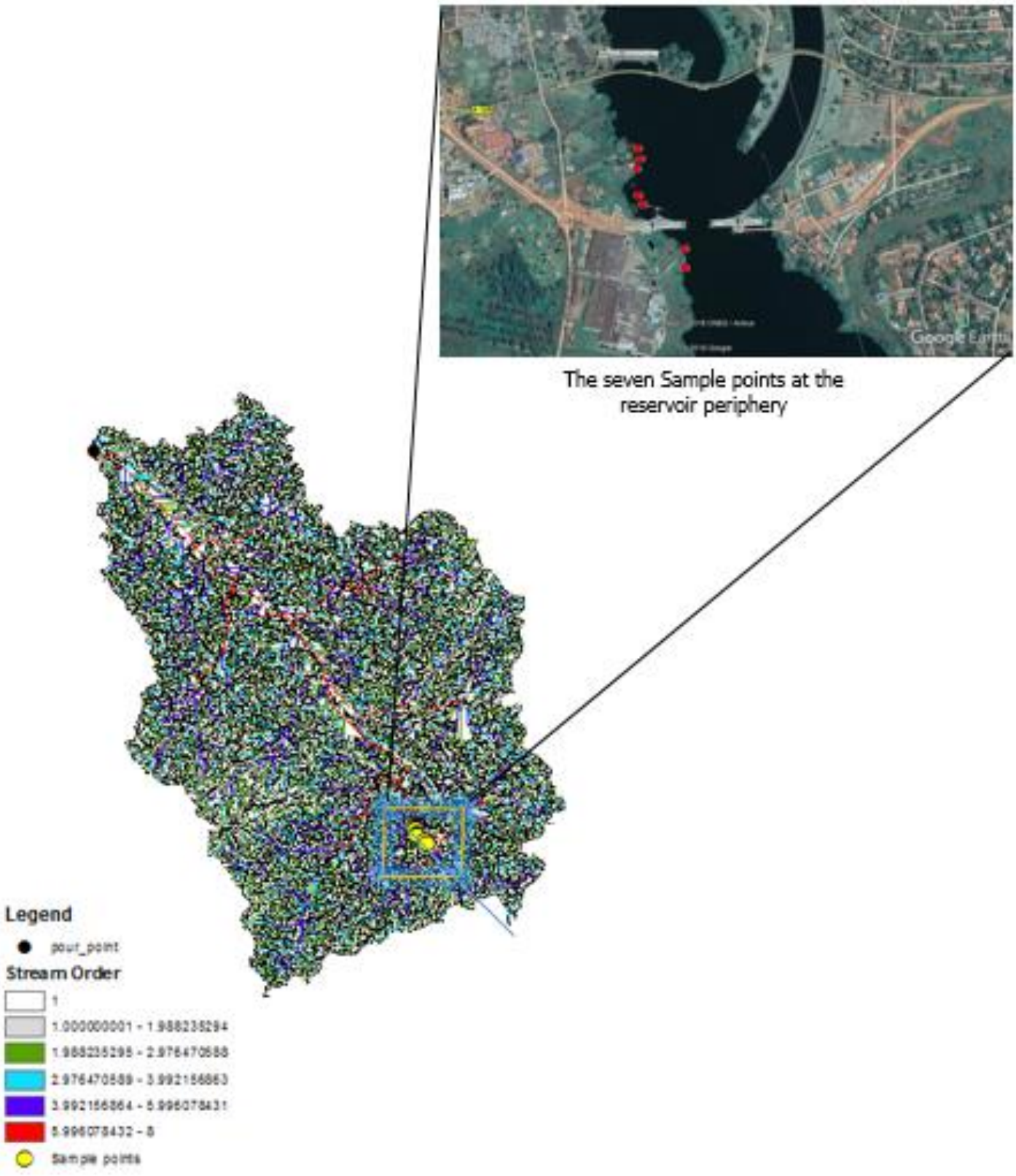

Figure 13: Stream order in which sediments move to the reservoir and the sample points from which sediment data was collected

The sample points G, C and B had low z values as seen in table 3 which showed more levels of sediment deposit due to interception by the edge rock barriers as shown in figure 14 below when they are washed following the stream order shown in figure 13 above from the remotest points of the watershed thus accumulating.

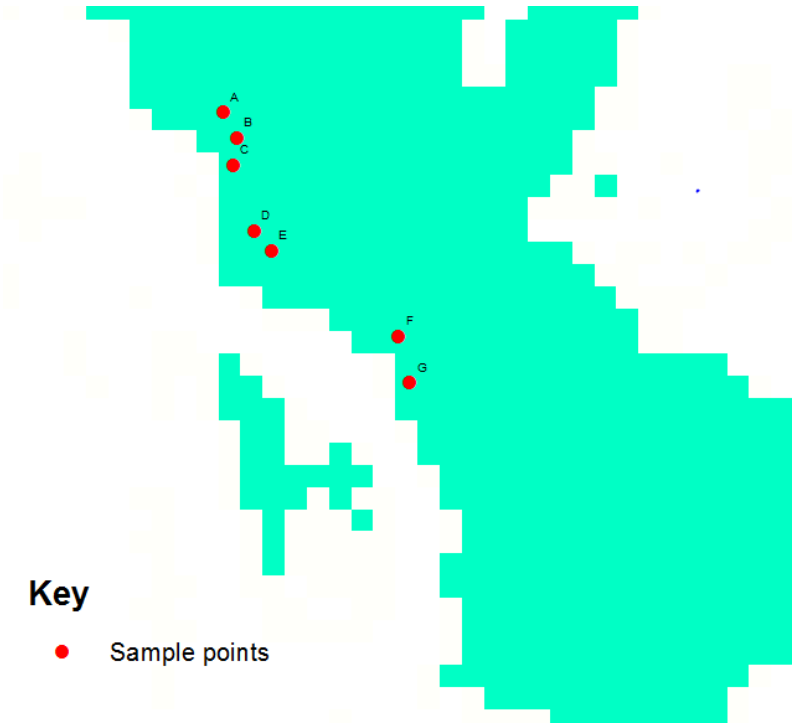

Figure 14: Labeled sample point from which sediment data was collected

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The water spread areas of Kiira reservoir for the year 2001 was4.62km^2. As per recent Remote Sensing survey of 2006 and 2010, it was observed that the original water spread area had increased to 4.82km^{2}and 4.96km^{2}respectively i.e. by approximately 3.549% in 9 years. Thus, there is a gradual reduction in the capacity of Kiira reservoir. The validation process which involved collecting field data and incorporated with the remote sensing data gave an evidence of sedimentation in Kiira dam at the sample point locations as indicated in the previous chapter.

5.2 Challenges

- Data of sedimentation in Kiira reservoir from Uganda Electricity Generation Company Limited (UEGCL) was unavailable.
- Water hyacinth and water waves occasionally distorted the collection sediment data which affected accuracy.
- Remote sensing data especially Landsat data were of a poor resolution.
- Using Arc Map software for executing the project objectives was challenging since it was a new experience.

5.3 Recommendations

A number of further inputs may need to be made for a more accurate research to fully benefit the community and the information therein to be used for sustainable development reservoir projects.

- The government should invest more into research as regards to sedimentation to avail data obtained to facilitate further research by university students.
- Local authorities should plan land use and developments around reservoirs to reduce generation of sediments which could be eroded into the reservoirs.
- The university should incorporate the teaching of software like ArcGIS among others into its curriculum to enrich students with the skills of modern development.

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