NTNU – Trondheim
Norwegian University of
Science and Technology

Verification of a GIS-based system for identification of potential hydro power plant sites in Uganda

Florence Gimbo

Hydropower Development
Submission date: June 2015
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Norwegian University of Science and Technology
Department of Hydraulic and Environmental Engineering

Verification of a GIS-program for identification of potential hydro power sites in Uganda

6/10/2015

Norwegian University of Science and Technology
Florence Gimbo

A valley Gorge in Rwenzori-Uganda

THE NORWEGIAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY (NTNU)

Department of Hydraulic and Environmental Engineering

MSc Thesis

In

Hydropower Development

Candidate: **Florence Gimbo**

Topic: **Verification of a GIS-based system for identification of potential hydro power plant sites in Uganda**

1. Background

A GIS-based program system have been developed by PhD student Emmanuel Jjunju, with the purpose of identifying potential hydropower project sites in Uganda, based on topographic and hydrological maps and data. The purpose is to be able to assess the hydropower potential in a country and use these results in climate-change studies of hydropower.

This program system will first be used in Climate Change studies, where it is important to study climate change impacts not only on existing power plants, but also on all the potential sites that may exist and probably will be developed. If found reliable, it may also be used for resource mapping and simplifying the analysis of total hydropower potential in the country. Similar tools have been developed in for example Norway and USA, and have proved to be very useful. It is, however, important to investigate closely how reliable the results are, if it can find all potentially good sites, and if the computed capacity and generation are reasonable.

The method of verification should be done in three stages:

- Comparing results from the GIS analysis to existing (built) hydropower plants
- Comparing results to planned hydropower plants, where planning documents can be found

- Performing a reconnaissance study within one or several regions, comparing the results to those from the GIS program within the same region. Here, it is important to study how well the program system manage to find correct location of intakes and power plants, and how well it can evaluate the correct capacity, energy generation and economic parameters.

Finally, the results from all three type of studies should be summarized and compared, with an evaluation and recommendation about the quality of the program system, and if the results can be trusted. If possible, possible weak areas or typical errors should be pointed out, together with proposals for improvements.

2. Main questions for the thesis

The project will consist of the following topics (though not necessarily be limited to these):

- A brief description of the program system, data requirements, methods, results, limitations etc+
- Use the program system to identify all promising sites for hydropower plants in Uganda
- Use the program to compute capacity, generation and economic parameters for the identified sites
- Compare the results with data for existing and planned hydropower projects within the country
- Select one or more regions where you study in detail all the proposed location, the layout and capacity proposed by the program system, and evaluate how good the results are, compared to your own findings.
- Evaluation of the results
- A summary of how good the program system is performing
- Reporting and presentation

3. Supervision

Supervisor: **Professor Ånund Killingtveit**

Co-supervisor: **Emmanuel Jjunju, SWECO**

This specification for the thesis should be reviewed after about 6 weeks, and not later than 1/4. If needed, the text could then be modified, based on proposal from the candidate and discussions with the supervisor.

4. Report format

The report shall include a summary, offering the reader the background, the objective of the study and the main results. The thesis report shall be using NTNU's standard layout for Thesis work. Figures, tables, etc. shall be of good report quality. Table of contents, list of figures, list of tables, list of references and other relevant references shall be included. The complete manuscript should be compiled into a PDF file and submitted electronically to DAIM for registration, printing and archiving. Three hard copies, in addition to the students own copies, should be printed out and submitted. The entire thesis may be published on the Internet as full text publishing. All documents and data shall be written on a CD thereby producing a complete electronic documentation of the results from the project. This must be so complete that all computations can be reconstructed from the CD.

Finally, the candidate is requested to include a signed statement that the work presented is her own and that all significant outside input has been identified.

The thesis shall be submitted no later than Wednesday 10 June, 2015

Department of Hydraulic and Environmental Engineering, NTNU

……………………………………………………………………

Ånund Killingtveit

Professor

ACKNOWLEDGEMENT

The Lord Almighty has been my strength in this two years journey of hydropower knowledge acquisition, and I say thank you Lord for thus far you have brought me!

I would like to express my deepest appreciation to all those who helped me in one way or another to complete this report. A special gratitude goes to my Supervisor, professor Ånund killingtveit for your unreserved guidance at all times but also not forgetting the parental, emotional, financial and psychological support that you offered in my difficult times. I appreciate!

My gratitude goes to my second supervisor, Mr. Emmanuel Jjunju for the unreserved assistance that you provided at all times. I was not afraid of knocking at your door for help! You invested your time and effort in making sure that this task is successfully accomplished, May God bless you abundantly!

My family played a central role in encouraging, cheering, standing in my gap to take care of my child (Ethan) and above all, praying for me! Mummy and the team, your encouraging words always recounted in my mind and they acted as fuel for me to always do my best. Indeed, I cannot say thank you enough! My husband Mr. Okello Guido, thank you for the support and encouraging me to see that I finish my course!

To Robert and Sarah, thank you for giving me a home away from home. You have been the king and queen that the Lord prepared for me in this Land of Norway. Thank you once more!

Lastly but not least, Appreciations go to all my class mates the hydropower class of 2013/2015 for being such a lovely family. Working on different tasks but always willing to help each other. Thank you all!

I hereby acknowledge that the work presented in this thesis report is my own and that all other data sources have been acknowledged

………………………………………………………………..

Florence Gimbo
Department of Hydraulic and Environmental Engineering
Norwegian University of Science and Technology
Trondheim, 10th June 2015

DEDICATION

This Report is dedicated to my mother Mrs. Walusansa Magaret and the entire family who have been my constant source of inspiration. They have given me the drive and discipline to tackle any task with enthusiasm and determination. Without their love and support this project would not have been made possible.

ABSTRACT

Hydropower makes and is expected to continue to make a significant contribution to meeting the electricity demand in many countries. The information on hydropower potential in many places is often incomplete. A GIS based tool under development is expected to help in quickly identifying possible hydropower plant locations over a large area in a short time. This study is aimed at evaluating how well this GIS tool is able to estimate the hydropower potential from the runoff maps and terrain/elevation data. The study compares the generation (MW/GWH) computed by the GIS tool with existing studies of potential projects and new desk studies carried out under this study. From the study the results show that 85 percent of the projects identified by the GIS system were in an acceptable distance range of less than 3km from the existing and desk study projects. Projects in which the runoff used was similar gave capacities in the range of 1 to 4.4 times greater than what had already been studied but with a potential that is between 5 to 100 times more than what actually exists. The search area used in the GIS (a factor that controls the length of possible waterways and the number of hydropower stations possible within a given area) has influenced the number of sites that the system proposes along an individual stream and the head differences between what the GIS and existing/desk studies. Based on the results from this study, the GIS system is a good tool that can quickly give an indication of the hydropower potential for a given runoff condition. For, identifying hydropower sites for development, there has to be a post process in the choice of the best alternative among that which it suggests before the final decision is made.

ACRONYMS

GIS	Geographical Information System
MW	Mega watts
GWh	Giga watt hour
El	Elevation
MUSD	Monetary US Dollars
NPV	Net Present Value
B/C	Benefit cost ratio
DEM	Digital Elevation model

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1 INTRODUCTION

1.1 Background

Climate change and variability are the greatest threat to socio-economic development throughout the world (Kaggwa, 2009), this is also the greatest challenges of the 21st century(Ipcc, 2011). A study by (THOMAS E. DOWNING 1 & 4, 1997) indicates that increased temperatures and change in seasonal precipitation would lead to change in soil moisture; changes in river runoff and ground water recharge.

It is now commonly understood that most climate change damage will be felt in developing countries, with Africa being the continent of most concern(Stern, 2006).

Ugandan society will be shaped in part by the manner in which it chooses to pursue new domestic energy sources such as hydropower especially in the rural areas (Buchholz & Da Silva, 2010). At the moment, Uganda's Electricity needs are more than it's meager supply(Buchholz & Da Silva, 2010). According to (Kaijuka, 2007), sustainable development is fuelled by energy sector. However, she notes that the pace of rural electrification over most developing countries such as Uganda is low. (Cook, 2011)also notes the need for rural electrification as an important part of a country's infrastructure, though not usually given priority

Hydropower generation according to (Hamududu & Killingtveit, 2012) makes a substantial and dominant contribution to meeting today's world electricity demand. It is a key energy option for meeting growing energy demands in east Africa and for mitigating the impacts of climate change. Generally, access to credible renewable energy resource data remains a challenge and inhibits the scoping for new hydropower developments and the nature of climate impact studies(Hamududu & Killingtveit, 2012). However, its production is dependent on runoff that is also dependent on precipitation and yet the future climate is not known. This leaves a question of what the impact of global climate change will be on the future hydropower generation Potential. This then creates a need to evaluate the likely change in hydropower generation resulting from predicted changes in runoff as a result of climate change(Hamududu & Killingtveit, 2012).

A GIS-based program system have been developed by PhD student Emmanuel Jjunju, with the purpose of identifying potential hydropower project sites in Uganda, based on topographic and hydrological maps and data. The development of this tool was motivated by the need to conduct climate change impact studies on hydropower potential in the east African region where there are so few hydropower developments compared to existing potential. It is however, important to investigate closely how reliable the results are, if it can find all potentially good sites, and if the computed capacity and generation are reasonable.

1.2 Objectives of the Study

The main purpose of this current study was therefore to; investigate the reliability of the GIS program results in terms of Intake/site selection and Capacity, head and energy generation of hydropower.

The specific objectives included the following;

- To give a brief description of the program system, data requirements, methods, results, and limitations
- To use the program system to identify all promising sites for hydropower plants in Uganda
- To use the program to compute capacity, generation and economic parameters for the identified sites
- To compare the results with data for existing and planned hydropower projects within the country
- Carry out a desk study for some selected rivers and evaluate how good the GIS results are compared to the findings from the desk study.
- To evaluate the results and summarize how good the program system is performing
- To write a reporting and present the findings

1.3 Project Area

Uganda shown in *Figure **1**:**1*** is a landlocked state in Eastern Africa, west of Kenya and east of the Democratic Republic of the Congo; it has an area of 236,040 square kilometers and a total population of 34,856,813 million people with a growth rate estimate of 2.88% (2014 estimates). It is located between 1 00 N, 32 00 E.

It has a generally rainy tropical climate with two dry seasons (December to February, June to August); the terrain is mostly plateau with rim of mountains. The lowest elevation is Lake Albert which is 621 m and the highest point is the Margherita Peak on Mount Stanley (Rwenzori) which is 5,110 m.

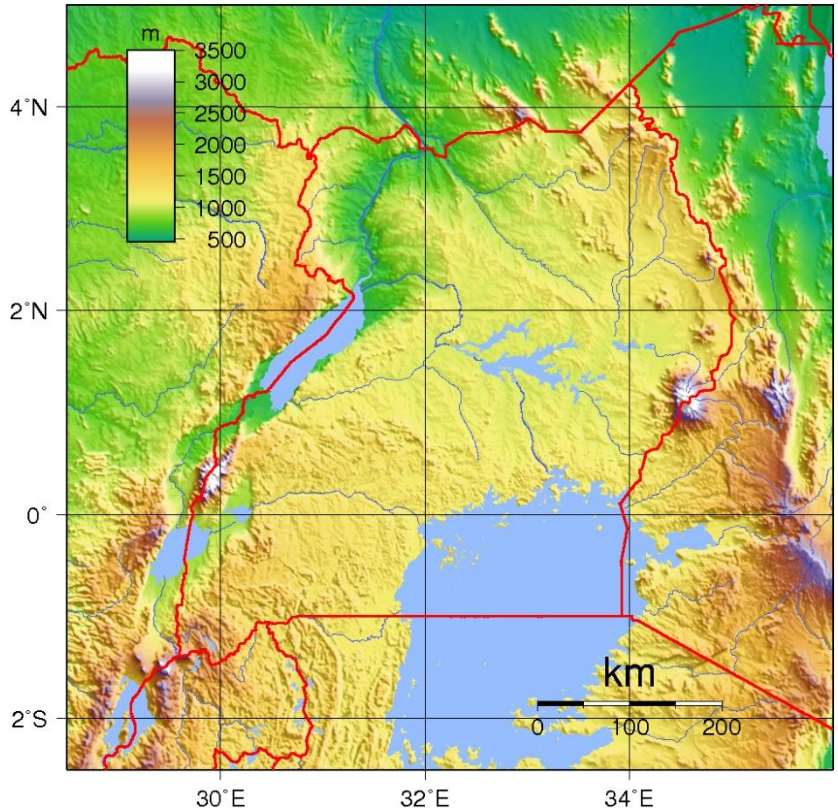

Figure 1:1: A map of Uganda and it's terrain

(Source http://en.wikipedia.org/wiki/Outline_of_Uganda#/media/File:Uganda_Topography.png)

1.4 Scope of the study

The study was limited to Uganda as a country. The major hydropower characteristics considered for purposes of comparison are intake locations, Head, Capacity and Generation. *Figure **1**:**2*** shows the location of the project areas;

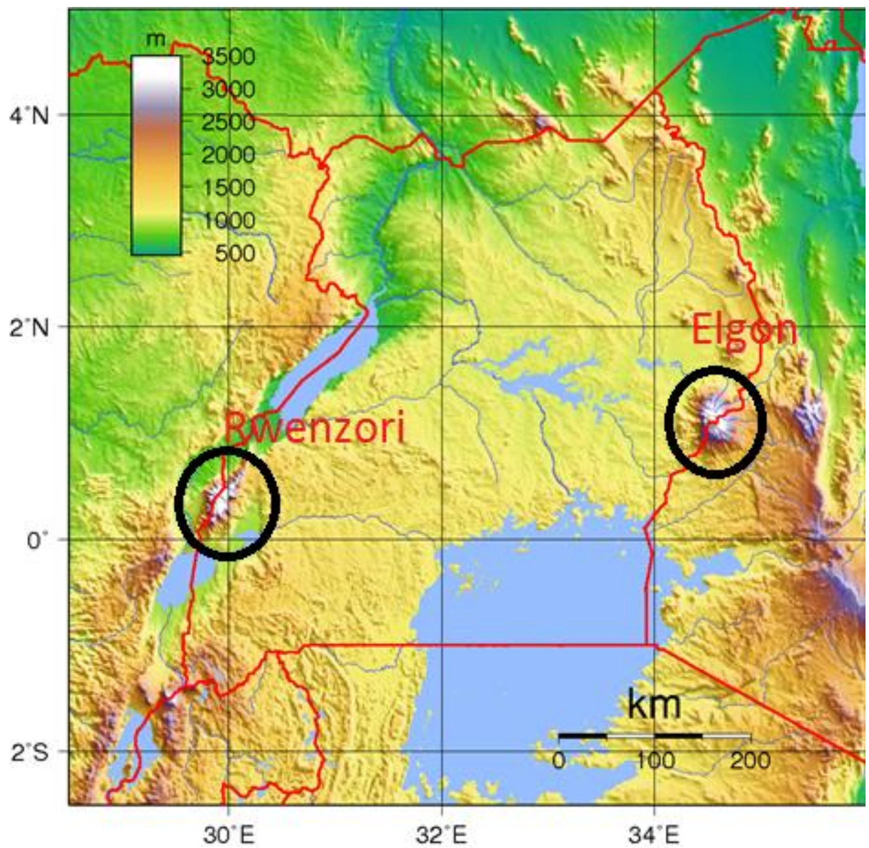

Figure 1:2: Location of Rwenzori and Elgon Regions in Uganda

1.4.1 GIS Program

The GIS Program was run for the entire country of Uganda, but for purposes of this assessment, only selected regions of Rwenzori and Elgon mountains will be discussed

1.4.2 Existing Projects

Due to difficulties in obtaining information (feasibility study reports); only two existing projects were reviewed. These include Bugoye Hydropower Site and Mpanga Hydropower Sites

1.4.3 Desk Study

The desk study was carried out for two regions, the Rwenzori Mountains in Western Uganda and the Elgon Mountains in Eastern Uganda. These were chosen because of their mountainous terrains characterized with their high hydropower potential/

*Figure **1**:**3*** and *Figure **1**:**4*** Shows images of The Elgon Mountain and the Rwenzori Mountain Respectively;

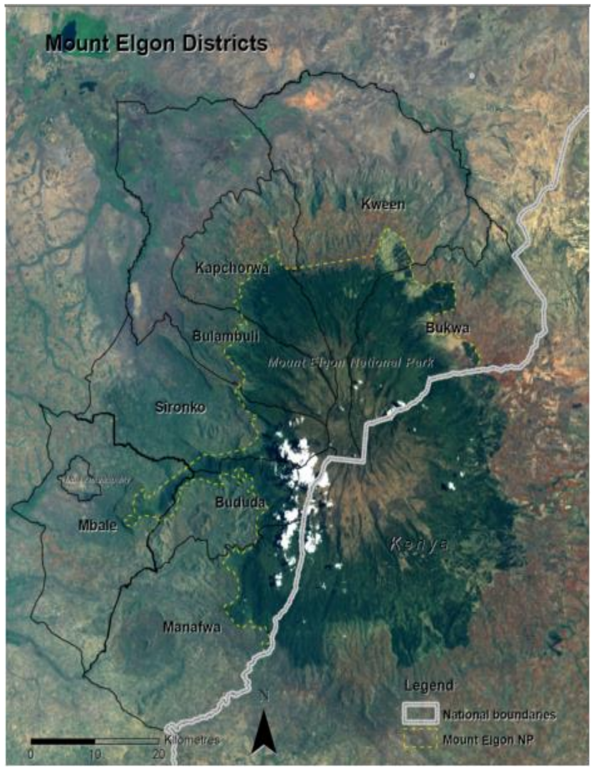

Figure 1:3: Elgon Mountains

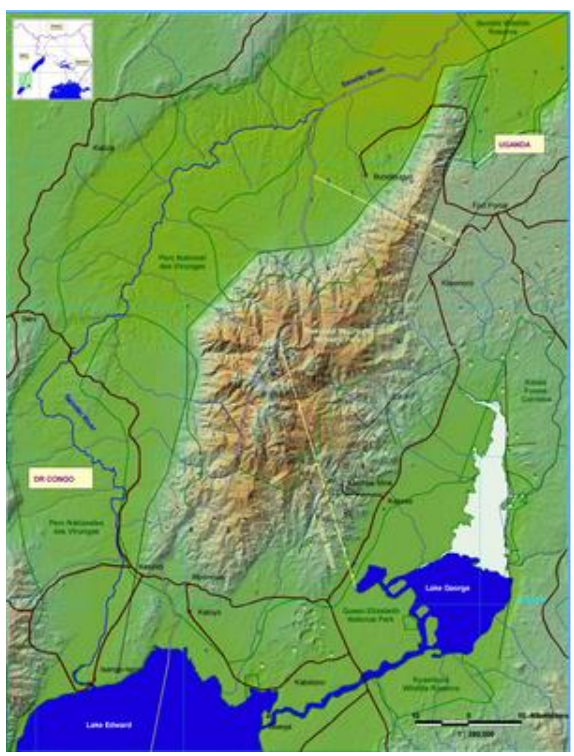

Figure 1:4: Rwenzori Mountains

1.5 Report Structure

This report is structured to include the following chapters;

The introduction part that presents the back ground of this study and the study questions. It gives a brief description of the project area and why it was chosen, the physical and study limits of this project work are also presented in this chapter.

Part two presents the approaches and or methods that were used to answer the objective questions. Approaches to data collection, review of existing projects, the procedure followed during the desk study is as well presented in this part of the report. The main components used to compare the findings are also presented here.

Chapter three describes the GIS program, its data requirements, the assumptions made in the program, the methods of computation and the limitations associated with the program.

Chapter four presents the findings from the existing projects. I.e. Mpanga and Bugoye Hydropower projects

Chapter five presents the desk study in detail. Chapter six presents the results and their discussion in relation to the GIS findings.

Finally, chapter seven has the limitations, conclusions and recommendations.

2 APPROACH AND METHODOLOGY

2.1 Introduction

This chapter outlines the research methodology of this study. The approach of the verification was done in the following stages:

- Data collection
- Field visits to the Rwenzori region in Uganda to verify the existence of some river
- Carrying out a Desk study on the selected regions of Rwenzori and Elgon
- Reviewing Literature of the existing studied projects
- Running the GIS program system to obtain results
- Comparing results from the GIS analysis to existing/planned hydropower plants
- Comparing the Desk study results to those from the GIS program within the same region
- Finally, Summarizing the results from all the three study types, comparing them and giving comments about the quality of the GIS program system

2.2 Data Collection

Data were collected during the summer holiday of 2014. Institutions responsible with custody of the necessary data in Uganda were requested in writing. Hydrologic data was obtained from the Ministry of Water and Environment in Uganda. *Table **2**:**1*** shows the gauging stations that were obtained and consequently used to scale runoff for catchments that were not gauged.

Table 2:1: Gauging Stations and their location

Number	Latitude	Longitude	Elevation (meters)	Area (sq. km)	Name
82212	0:56:13 N	34: 9:28 E	1100.2	494.2	R. Manafwa at Mbale - Tororo Road
82240	1:14:10 N	34:15:25 E	1118.0	265	R. Sironko at Mbale - Moroto Road
82242	1:20: 0 N	34:18: 0 E	0.0	136	R. Muyembe at Mbale - Moroto Road
82243	1:22:58 N	34:18:52 E	1081.0	92	R. Sipi at Mbale - Moroto Road
82244	1:30: 0 N	34:27: 0 E	0.0	70	R. Atari at Mbale - Moroto Road
84212	0:38:37 N	30:23:36 E		401	R. Mpanga at Kampala - Fort Portal Road
84215	0: 6: 2 N	30:27:44 E	1151.0	4670	R. Mpanga at Fort Portal - Ibanda Road
84222	0:16: 0 N	30: 7: 0 E	0.0	256	R. Mubuku at Fort Portal - Kasese Road
84227	0: 7:22 S	30: 6:24 E	1028.0	660	R. Chambura at Kichwamba
84228	0: 7:24 S	29:50:34 E	930.0	507	R. Nyamugasani at Katwe - Zaire Road
84267	0:41: 0 S	29:48: 0 E	0.0	1746	R. Mitano at Kanungu - Rwensama Road

Their relative location on the map of Uganda is also shown in *Figure **2**:**1*** below and the estimated long term average flow values presented in the hydrograph in *Figure **2**:**2***;

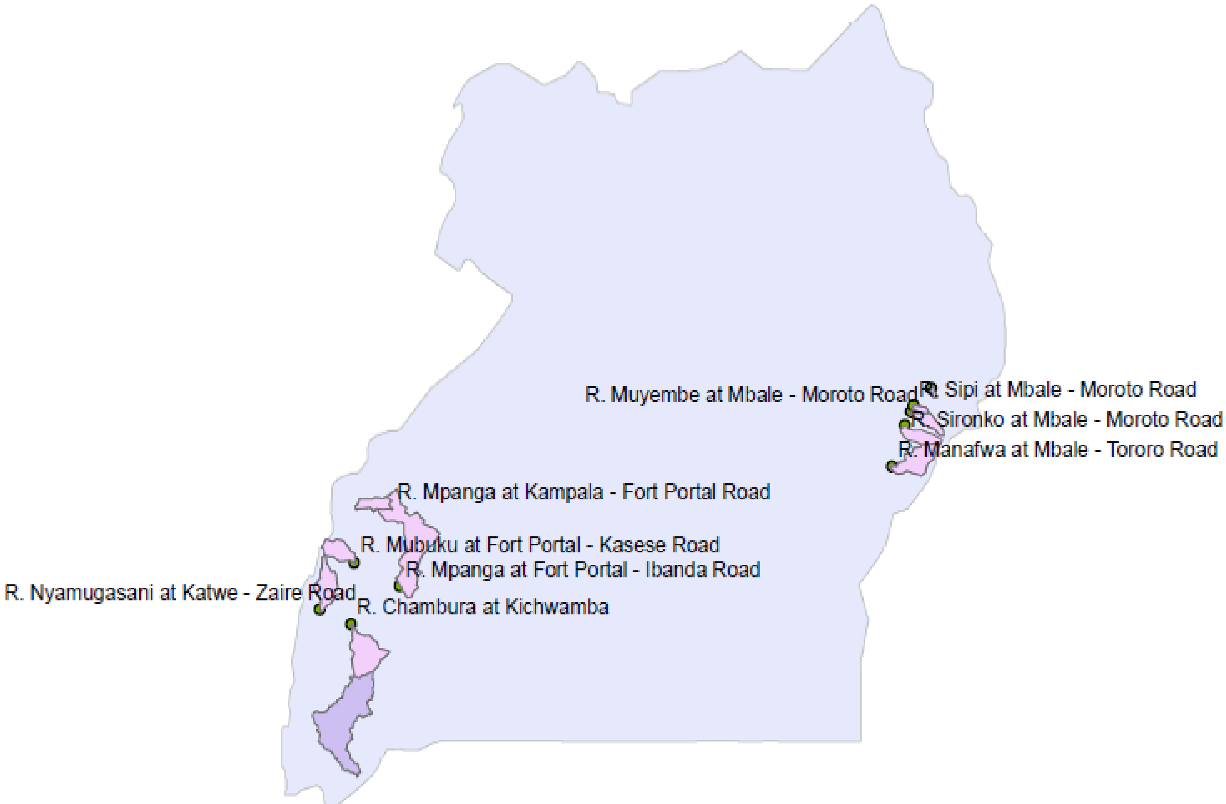

Figure 2:1: A map showing the location of gauging stations in Uganda

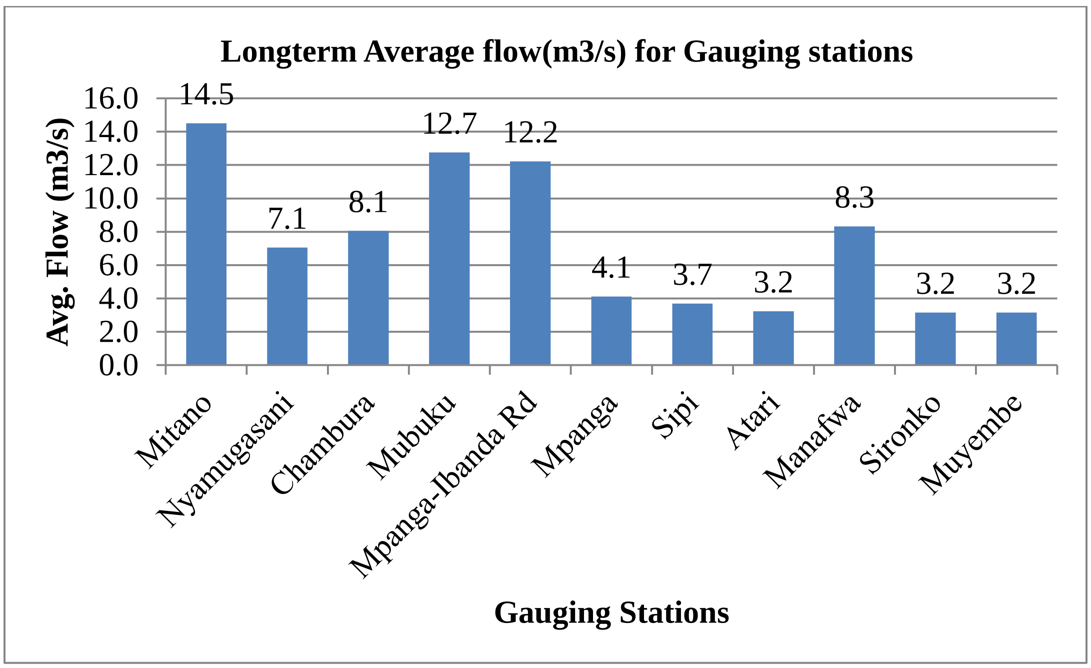

Figure 2:2: Long term average flow for the Gauging Station

Topographic survey maps were obtained from the Ministry of Lands and Surveys in Uganda. Existing and planned hydropower sites in Uganda were obtained from the website below developed by both the Electricity Regulatory Authority and Ministry of Energy in Uganda. http://www.energy-gis.ug/webmap.html. and http://geoiq.grida.no/maps/1545. The sites were compiled into a data base that was used for comparison purposes.

Digital elevation models of 90 m were down loaded from SRTM 90 m Digital Elevation Database v4.1 on internet whose link is as below http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1. And the background maps showing the river networks in Uganda were necessary in order to make reference to while identifying the generated rivers from the GIS system. These were obtained from the link below;http://hydrosheds.cr.usgs.gov/datadownload.php?reqdata=15rivs.

2.3 Field Visit

In July, a total 10 rivers were visited in the Rwenzori region in western Uganda. These included; Mbuzi, Wassa, Mukimiri, Kazingo, Nyabuswa, Dunga, Igassa Upper, Igassa Lower, Peripa and kibaate.

All the sampled rivers were found to be existing though the intake locations could not be accessed. *Figure **2:3*** show some of the rivers visited

Figure 2:3: Some of the Rivers visited in the Rwenzori Region in Western Uganda

2.4 Review of Existing Studies

Literature (feasibility study report) for already studied projects (Bugoye Hydropower Plant) was obtained from Newplan Consulting Engineers and Planners in Uganda. Another Feasibility study report for Mpanga Small Hydropower Project was obtained from Emmanuel Jjunju who is my second supervisor. These two reports were reviewed and the findings compared with those from the GIS program.

2.5 Running of the GIS Model

The program uses a preset grid size within which the search is made. For this study, two alternatives were used. The first search area was a grid of 10 km^2 and the second search area being a grid of 5 km^2. Using the two search resolutions, the GIS Program was run for the entire country and the map showing the identified intake points presented. The system locates both the power house and the intake points.

2.6 Desk Study

This section presents the procedures followed and activities carried out during the desk study.

2.6.1 Obtaining longitudinal profiles

First, this was manually done by recording distance and contour elevations at points where contours cross the river using a sheet of paper, a ruler and a pencil. The data was entered in an excel sheet and then a profile graph of contour elevation versus distance along the stream was plotted. However, the process was slow and to help improve speed, the same river profile graphs were generated in ArcGIS and the data plotted on the same graph with that obtained by hand. To compare and verify the results from the ArcGIS process *Figure **2:4*** illustrates the river profiles from the two processes drawn on the same graph. This verification process was carried out for a number of rivers. See river profiles in appendix A

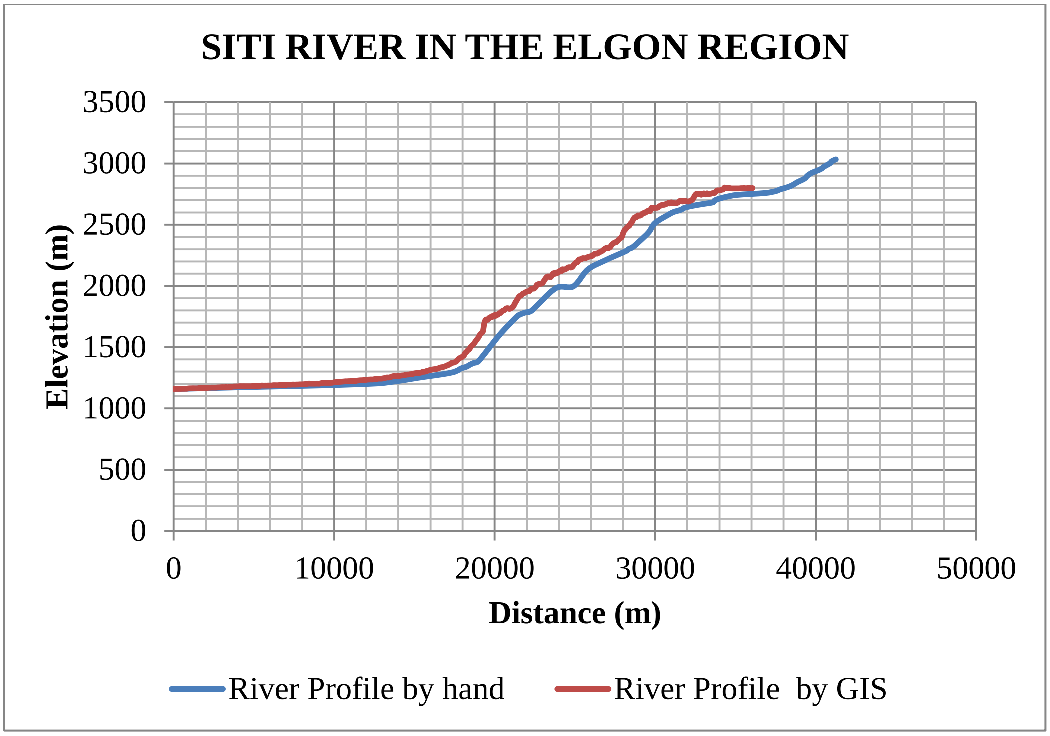

Figure 2:4: ArcGIS and Manual River Profile Graphs for Siti River

Upon comparison as seen from *Figure **2:4***, the two methods were matching as long as the start points on the river had been the same. Based on the above findings, ArcGIS was used to generate river profiles for the preceding streams. **Appendix b** presents the procedure followed in ArcGIS to obtain river profile

Profile sections were important to locate interesting intake points for hydropower. Features considered for site selection at this level included observation of sudden drops in elevation which meant availability of head for power production. See *Figure **2:6*** and *Figure **2:6*** for the possible intake points that were identified for River Nsonge and River Sisi with the corresponding catchments area in Km^2 plotted at each possible intake points

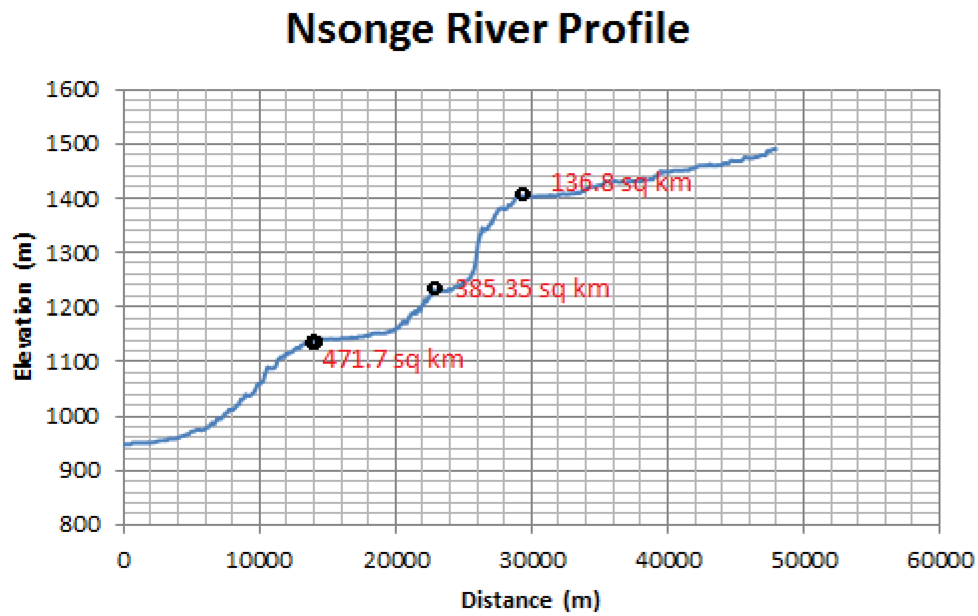

Figure 2:5: Showing the Possible intake on River Nsonge in Rwenzori Region

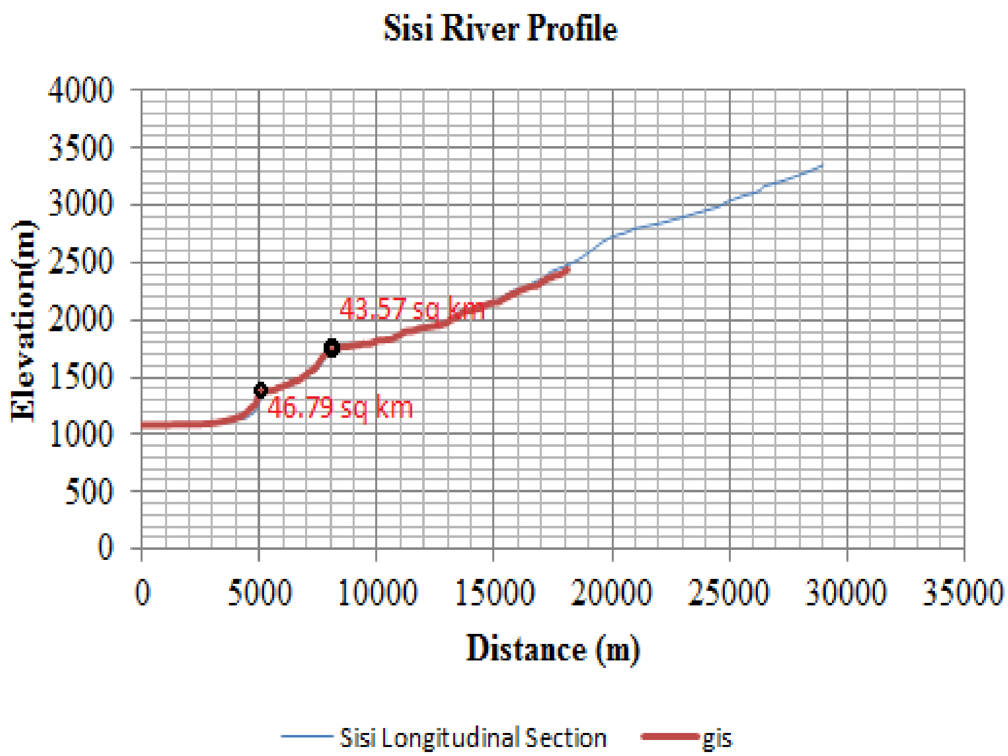

Figure 2:6: Showing the Possible intakes on River Sisi in the Elgon Region

However, the choice of the optimum intake location was a function of the catchment area upstream. Decisions of the optimum intake points were based on maximum power alone with no economic evaluation of whether the projects is viable or not.

2.6.2 Catchment Areas

Determination of catchment areas for the possible intake points was carried out following the procedures below;

First, the manual approach of tracing watersheds for possible intake points along the river on paper map was done by following ridges and ensuring no intersection with water streams. For each river, the points with sudden drop in head on the river profile were chosen as watershed outlets (possible intake points to the power plant). From the outlet point, the watershed was delineated. After delineating the catchments, the areas were then determined manually using a planimeter shown in *Figure **2**:**7***. By marking a start point at the intake point and tracing the catchment divide from the start until you come back to the same point, the catchment area in square kilometers could then be directly read and recorded from the digital planimeter. This process was done for a number of catchments in the Elgon region.

Figure 2:7: A Planimeter

Later, ArcGIS program was also used to delineate catchments at those selected possible intake points using the procedure presented in **Appendix c**. The results from the two methods were compared and found to give similar results as seen in *Table **2**:**2*** and in *Figure **2**:**8***.

Table 2:2: Comparison of Catchment Areas from GIS and Planimeter

River Name	Elevation	Head(m)	Planimeter Catch area(sq km)	GIS Catch Areas(sq km)
Manafwa	1380	120	43.7	40.9
Sironko	2000	900	102.4	100.9
Simu	1320	220	106.1	103.5

River Name	Elevation	Head(m)	Planimeter Catch area(sq km)	GIS Catch Areas(sq km)
Sipi	1240	140	75.8	76.6
Cheptui	1200	100	42.1	44.4
Chesebere	1600	500	28.0	29.0
Atari	2400	1300	54.9	48.3
Muyembe	1320	240	120.5	122.6
Ngenge	2120	1600	28.7	25.5
Kere	2000	800	20.1	21.7
Siti	1750	550	132.0	130.2
Ririma	1900	500	38.2	42.0

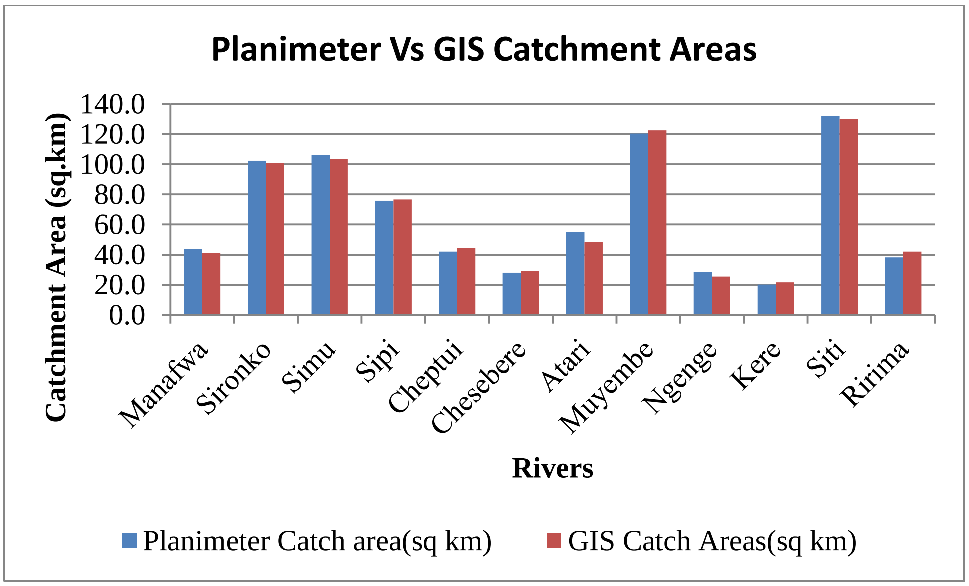

Figure 2:8: Comparison of Catchment Areas from GIS and Planimeter

Since the results from the two methods were similar, the preceding catchment areas were determined using GIS method.

2.6.3 Specific Runoff/Area Scaling

Most catchments under study did not have installed gauging stations for runoff; there was therefore need for scaling to estimate runoff of the ungauged catchments.

Information about specific runoff was so scanty; the only available specific runoff data for Uganda was the specific runoff map in *Figure* ***2:9*** that was developed basing on data between 1950 and 1967. However, there was need to crosscheck the reliability of this map by comparing with estimations from the runoff data obtained for this study.

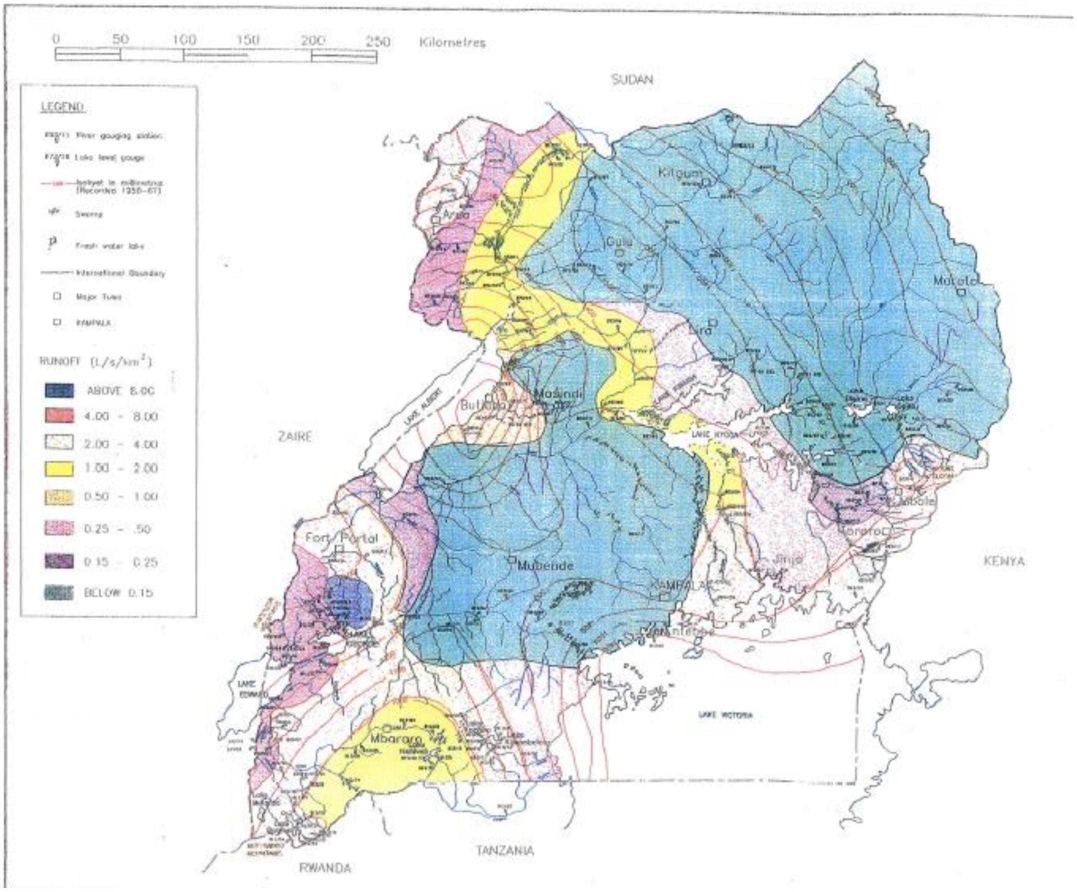

Figure 2:9: A specific Runoff Map for Uganda (Source: Kennedy and Donkin, 1997)

Using equation 1, a simple calculation of the specific runoff values were made based on the average annual flow values and the catchment areas of the gauging station. The same values were also estimated from the map. *Table **2:3*** compares the results of specific runoff obtained from calculation with those read from the map.

$$SR = \left(Q(m3/s) * 1000\right) / A(sq.km) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Table 2:3: Comparison of Specific Runoff from calculation and from Map

Gauging Station	By Calculation	Map Range	From Map
Sipi	40.06	>8	8
Atari	46.12	>8	8
Manafwa	16.84	0.25 - 0.5	0.38
Sironko	11.89	0.25 - 0.5	0.38
Muyembe	23.16	>8	8
Mitano	8.3	2.0 - 4.0	3

Gauging Station	By Calculation	Map Range	From Map
Nyamugasani	13.9	0.25 - 0.5	0.38
Chambura	12.2	2.0 - 4.0	3
Mubuku	49.8	>8	8
Mpanga - Ibanda	2.6	2.0 - 4.0	3
Mpanga	10.3	2.0 - 4.0	3

The corresponding graph is also presented in *Figure **2:10*** below for better comparison

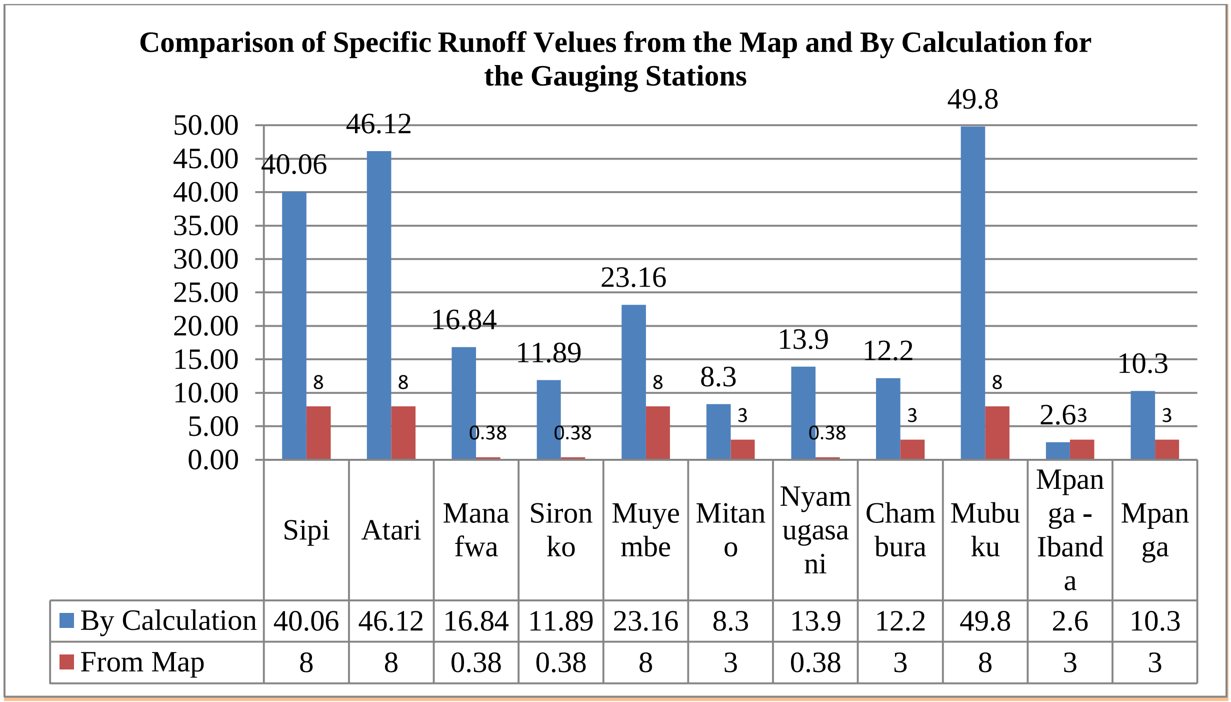

Figure 2:10: Comparison of Specific Runoff from Calculation and Estimation from Map

The runoff values as obtained by calculations were in the range of 44 to 3 times greater than the values read from the specific runoff map. This was with exception of only Mpanga – Ibanda road whose results were similar for all the two cases. Based on the comparison above, the runoff map was considered not reliable and was therefore not used for further studies.

A report that contained a number of gauging stations in the nile bansin, with their locations coordinates including their long term average flow values in m^3/s was found. This data was imported into ArcGIS and a runoff map shown in *Figure **2:11*** was created based on spatial interpolation of the points. Consequently, this is the runoff map that was used in this study. However, it is worth mentioning that the data may not be reliable since it is old and with the changing weather patterns, runoff changes are inevitable.

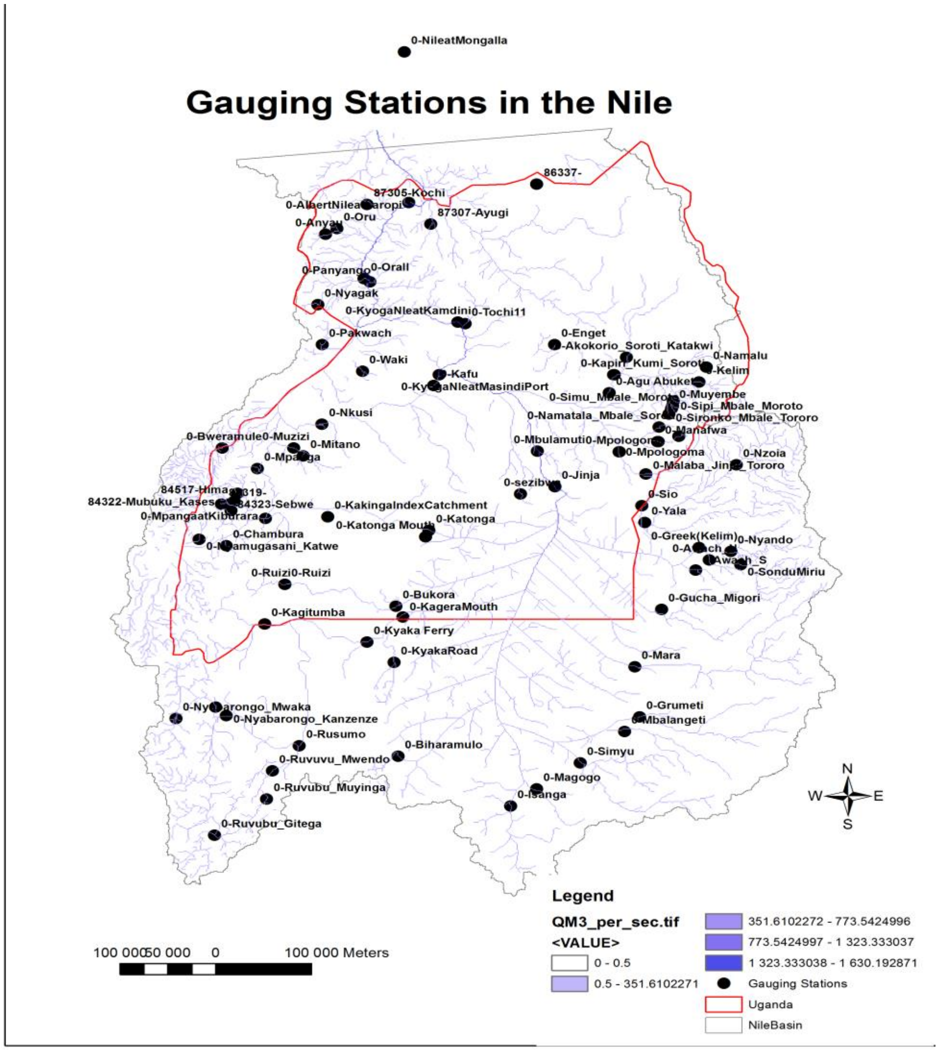

Figure 2:11: A runoff Map

*Table **2:4*** below shows a comparison between the average flow values for the gauging station in m3/s as determined by calculation and as determined from the developed from the map. This is also shown in *Figure **2:12*** for better comparison.

Table 2:4: Comparison of average flow in m3/s from the map and from calculation

Gauging Station	m^3/s By Calculation	m^3/s From Map
Sipi	3.67	3.74
Atari	3.23	3
Manafwa	8.32	7.95
Sironko	3.15	3.53
Muyembe	3.15	3.26
Mitano	14.5	12.97
Nyamugasani	7.18	10.72

Gauging Station	m^3/s By Calculation	m^3/s From Map
Chambura	8.05	8.08
Mubuku	12.75	12.81
Mpanga - Ibanda	12.23	17.02
Mpanga	4.12	4.49

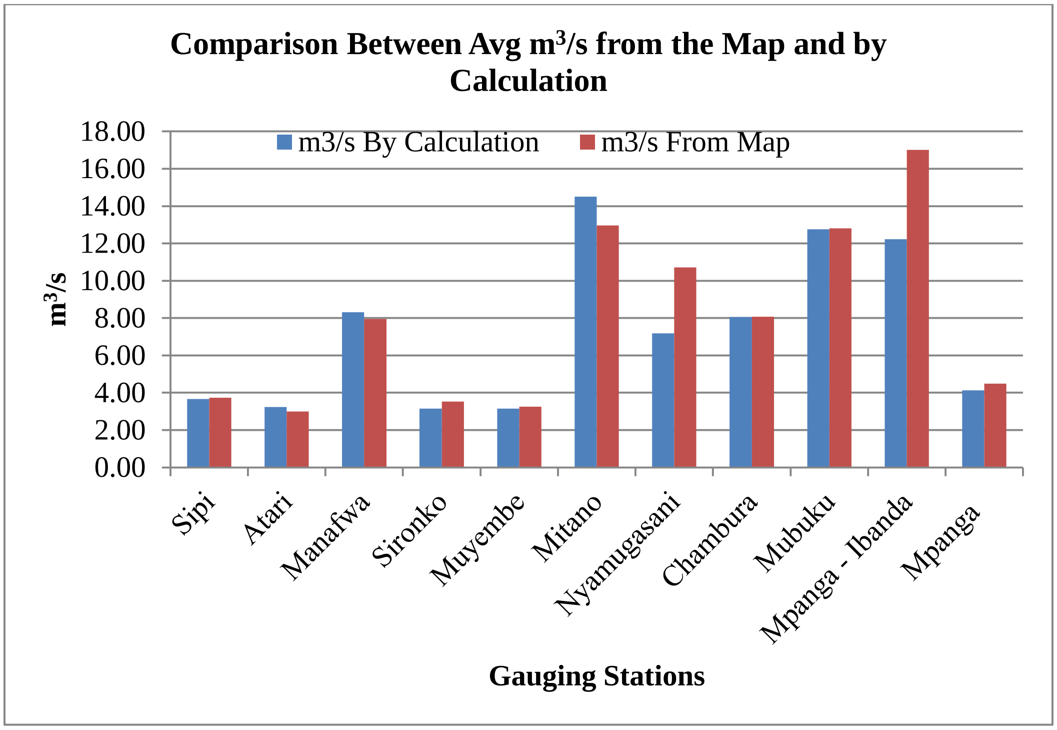

Figure 2:12: Comparison of average flows in m3/s from map and by calculation

A few gauges like for the case of Mpanga – Ibanda and Nyamugasani showed a great variation in the average flow values from the Map giving and exaggeration of 4,79 m^3/s and 3,54 m^3/s. The rest of the gauging stations were however, in close agreement. This runoff map was therefore based on to estimate the flow.

It worth noting that the spatial interpolation may however, give a great variation over space as the data based on to develop the map above were point values. An assumption was therefore made that there is a close relationship between flow and proximity of the catchments.

The Identified intake points were imported into this runoff map and the average flow value for each of the intake points recorded. For purposes of scaling, the scaling factor was estimated from equation 2

$$Q_2 = \left(\frac{A_2 * R_2}{A_1 * R_1} \right) * Q_1 \quad \text{.........................2}$$

This was then used to scale flow series for each of the study catchments. From these, the flow duration curves shown in appendix d. were developed and the 50% and 90% flow for each catchment recorded.

2.6.4 Hydrology of gauging stations

A number of government stations exist in the regions of Mt. Elgon and Mt. Rwenzori and these have been used to evaluate the runoff conditions for the ungauged catchments in the respective areas. *Table **2**:**5*** below shows the existing gauging stations with some major details about each.

Table 2:5: Existing Gauging Stations

Name	Latitude	Longitude	Elevation(m)	Area(sq.km)	Number	Region
R. Manafwa	00:56:13	34:09:28	1100.2	494.2	82212	Elgon
R. Sironko	01:14:10	34:15:25	1118	265	82240	Elgon
R. Muyembe	01:20:00	34:18:00	No data	136	82242	Elgon
R. Sipi	01:22:58	34:18:52	1081	92	82243	Elgon
R. Atari	01:30:00	34:27:00	No data	70	82244	Elgon
R. Mpanga (Kampala - Fort Portal Road)	00:38:37	30:23:36	No data	401	84212	Rwenzori
R. Mpanga (Fort Portal - Ibanda Road)	00:06:02	30:27:44	1151	4670	84215	Rwenzori
R. Mubuku	00:16:00	30:07:00	No data	256	84222	Rwenzori
R. Chambura	00:07:22	30:06:24	1028	660	84227	Rwenzori
R. Nyamugasani	00:07:24	29:50:34	930	507	84228	Rwenzori
R. Mitano	00:41:00	29:48:00	No data	1746	84267	Rwenzori

It should be noted that most of the areas of catchments under this current study are in the range not greater than 800 sq. Km. For this reason, the two gauging stations of R. Mpanga (Fort Portal - Ibanda Road) and R. Mitano were not used in the scaling since large area differences would result in a dampening effect for the smaller catchments. *Table **2**:**6*** shows the most relevant parameter obtained for each gauging stations. These have been determined based on only years with full record of data from the years of data obtained

Table 2:6: Relevant Parameters for each gauging Stations

Name	From	To	Area (sq. km)	Avg Flow (m3/s)	Specific Runoff (l/s/km2)	50 %	90 %
R. Manafwa	1949	2014	494.2	8.32	16.8	6.04	1.67
R. Sironko	1953	2013	265	3.15	11.9	2.83	0.57
R. Muyembe	1953	1999	136	3.15	23.2	2.35	0.13
R. Sipi	1953	2013	92	3.69	40.1	1.40	0.00

Name	From	To	Area (sq. km)	Avg Flow (m3/s)	Specific Runoff (l/s/km2)	50 %	90 %
R. Atari	1953	1979	70	3.23	46.1	2.17	0.31
R. Mpanga (Kampala - Fort Portal Road)	1956	2014	401	4.12	10.3	3.04	0.88
R. Mpanga (Fort Portal - Ibanda Road)	1966	2012	4670	12.23	2.6	8.63	2.81
R. Mubuku	1954	1971	256	12.75	49.8	11.39	6.78
R. Chambura	1954	2014	660	8.05	12.2	6.17	3.43
R. Nyamugasani	1954	2012	507	7.10	14.0	6.00	3.70
R. Mitano	1958	2014	1746	14.50	8.3	11.50	4.70

2.6.5 Design Discharge

Annual average discharge values were taken as the design flows. These values were calculated from years that had full record of flow.

*Figure **2:13*** and *Figure **2:14*** shows the flow duration curves for the gauging stations in Rwenzori and Elgon.

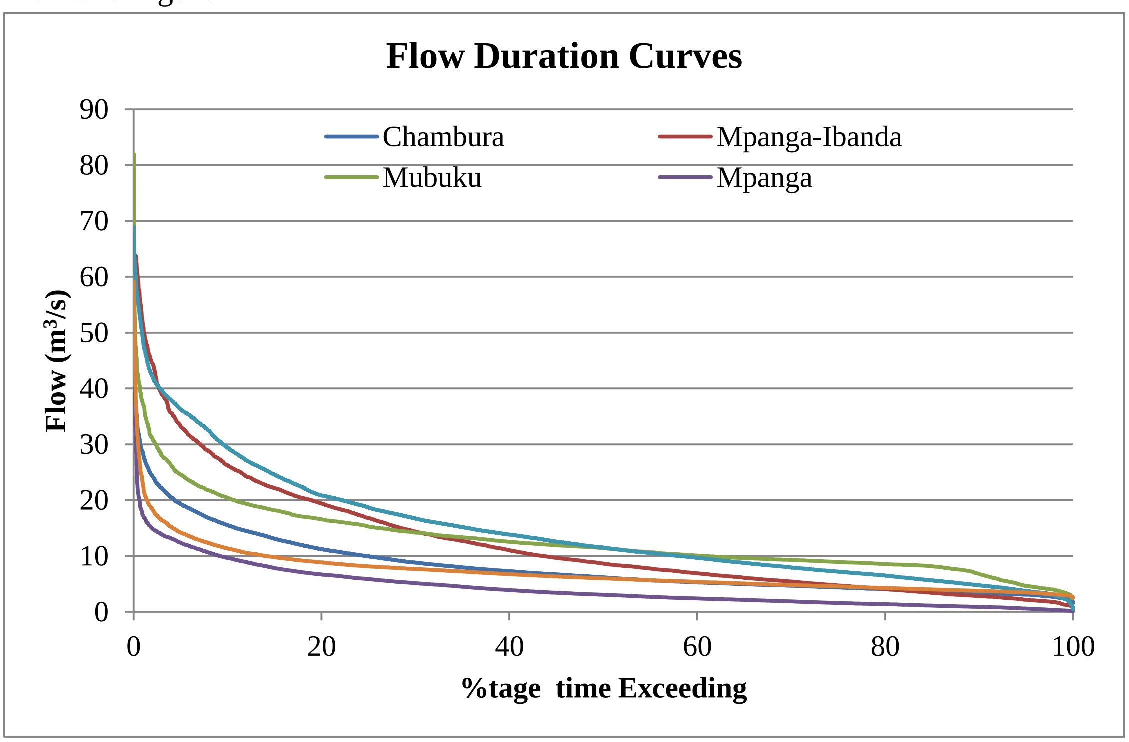

Figure 2:13: Flow Duration Curves for Gauges in the Rwenzori Region

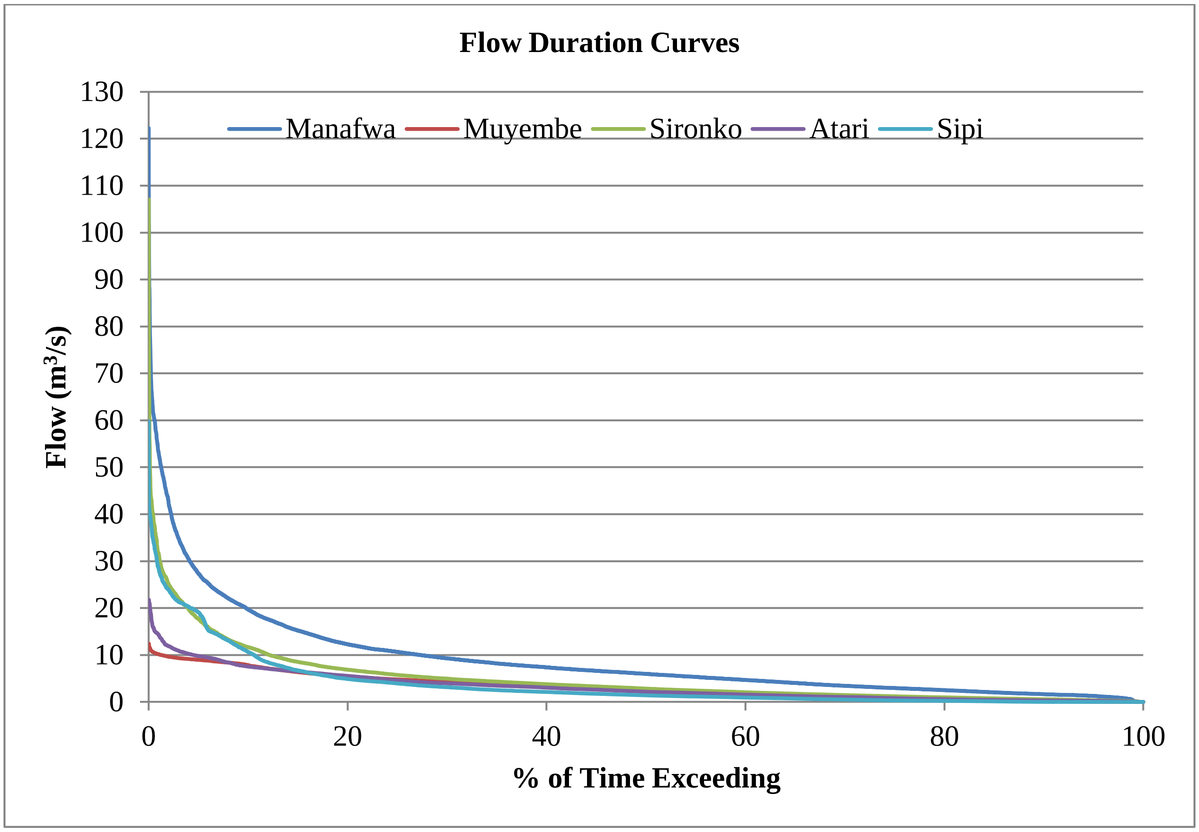

Figure 2:14: Flow Duration Curves for Gauges in the Elgon Region

2.6.6 Choice of Intake points

A number of potential intake points based on sudden head drop were identified on the profile graphs for each river. Corresponding catchment areas for each of the intake points was estimated and the resulting power outputs at each of the locations estimated based on the head and flow. The point with the highest values of power was then chosen as the intake point on that particular river.

*Table **2:7*** shows the power generations that was estimated for each possible intake. The results could then be plotted as in *Figure **2:16*** and *Figure **2:16*** to guide in the selection of optimum intake elevation.

Table 2:7: Power production at selected intakes on Nsonge and Kanyampara

River Name	Intake Elevation	Head	Catchment Area	Flow	Efficiency	gravity	KW	MW
Nsonge	1400	420	136.8	6.8	0.9	9.81	25266.6	25.3
Nsonge	1220	240	385.3	19.2	0.9	9.81	40657.1	40.7
Nsonge	1120	140	471.7	23.5	0.9	9.81	29030.0	29.0
Kanyampara	1600	520	5.0	0.1	0.9	9.81	322.4	0.3

River Name	Intake Elevation	Head	Catchment Area	Flow	Efficiency	gravity	KW	MW
Kanyampara	1400	320	26.5	0.4	0.9	9.81	1042.8	1.0
Kanyampara	1300	220	30.0	0.4	0.9	9.81	809.3	0.8

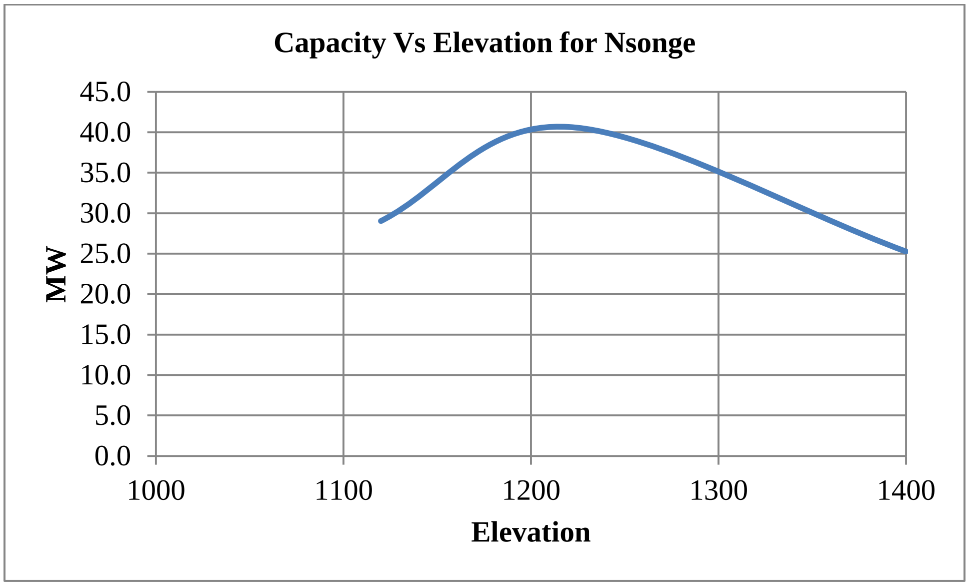

Figure 2:15: Intake Optimisation for Nsonge River

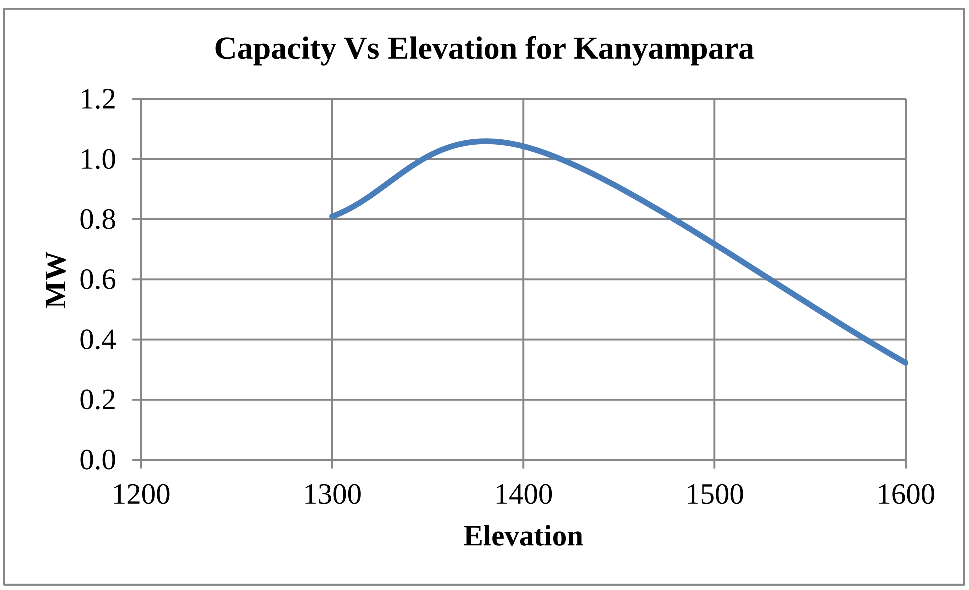

Figure 2:16: Intake Optimisation for Kanyampara River

2.6.7 Capacity and Energy Calculation

Power in MW was estimated for three different flow values using equation5.

$$P = (H * \ell * g * Q * \eta)/1000000 \ldots\ldots\ldots 5$$

Where
P = Power [MW]
η = Hydraulic and electromechanical efficiency [%]
g = Acceleration due to gravity [m/s²]
Q = Runoff [m³]
H=Head[m]
ρ=Density of water [1000kg/m³]

The energy generation was estimated based on the following expression

$$E = \frac{P * 24 * 365}{1000} \ldots\ldots\ldots\ldots\ldots 6$$

Where E is Energy in GWh/year and P is power in MW.

2.6.8 Economic Evaluation

The costs were estimated basing on the 2005 NVE base curves. *Table **2:8*** shows the major projects components were considered in the economic evaluation of the desk study projects.

Table 2:8: Project Components used in the cost calculations

S/No.	Component	Comment	Figure
1	Dam	Concrete gravity Dam of 8m height, and 20m width	2.2.2
2	Intake		2.3.1
3	Power House	A surface power house was assumed in all cases	2.4.1
4	Penstock Pipe	Penstock length assumed to be 20% of the total waterway length. GRP pipe material. Penstock diameter was estimated using D=(4*Q/Pi*v) where v was assumed to be 4m/s and Q is the discharge in m3/s.	2.5.1
5	Canal	Assumed to be 80% of the total waterway length. Also assumed between loose and rock.	2.5.2
6	Turbines	Turbine type was chosen based on the efficiency curves that are dependent on flow and head. The costs were based on the figures indicated	3.2.1 and 3.2.2
7	Gates	Assumed rolling gates	3.3.1
8	Trush rack	Considered a steel trash rack	3.4.1
9	Generator	Chosen based on power generation	4.2.1

S/N o.	Comp onent	Comment	Figure
10	Transf ormer		4.3.1a and 4.3.1b
11	Contro l Unit		4.4.1

Net present values were computed using the formulae below; $NPV = \frac{B_1 - C_1}{(1+r)^1} + \frac{B_2 - C_2}{(1+r)^2} + \ldots\ldots\ldots.. + \frac{B_n - C_n}{(1+r)^n}$ where;

B = Total benefits in a particular year

C = Total economic costs in a particular year

N = is number of years i.e. the projects' life time

R = is the discount rate

For the assessing the net present value of each project, the following assumptions were made;

- The project life time was 40years
- Unit price of power was 0.5 Nok/KWh
- Operation and maintenance costs were considered as 2% of the investment cost per year
- Interest rate was 7 %
- Construction period was taken as 4years with an investment distribution of 10%, 40%, 40% and 10% for each year respectively

2.7 Results and Discussion

Results from the two modes of evaluation were compared with those obtained from the GIS program using tables and figure such as maps and graphs. Maps show the relationship in terms of location of the intake points while graphs indicate the relationships/variations in magnitude of the findings from the two verifications modes in comparison to those obtained from the GIS program

3 GIS PROGRAM (Source: Emmanuel Jjunju)

This chapter presents information cited from **Emmanuel Jjunju's** ongoing work

3.1 Introduction

This program has been developed by Emmanuel Jjunju as part of his PHD work. The motivation roots from the need to study impacts of climate change on hydropower resources and the impact hydropower exploitation on the environment. According to the author, focusing on existing and already identified hydropower resource alone to study how climate change will affect it, would not give a clear picture of the possible potential in the study area (east Africa) where it is believe that much of the hydropower potential has not been tapped yet. By estimating the theoretical potential, a satisfactory inference of how climate change is likely to affect the hydropower resource can be made.

3.2 Description and Data Requirements

This program uses ArcGIS software to evaluate the hydropower potential. It relies on gridded runoff maps and digital terrain or elevation model (DEM). In this study, the analysis was carried out by combining the ArcGIS software (ESRI.2009), the associated hydrology tool to run a top ArcGIS and the R statistical language(R Development core Team 2011). The analysis requires hydrologically correct digital elevation and terrain based data. In this case, 1km DEM resolution was chosen for the analysis because of the large data files that would be associated with smaller resolutions given the size of the study area.

The tool requires raster maps data sets with each pixel (grid) representing a discrete location. The following raster maps were required as inputs to the program;

- The runoff at each pixel (grid cell) in a river in m^3/s [CumRuoff]
- The elevation of the pixels (grid cells) [StreamZ]. A no-data value is given for pixels (grid cells) that are not on river streams. T
- The pixels (grid cells) that are within lakes [Lakes]. A value of 1 is given for each pixel (grid cell) falling on a lake while a no-data value is given for any other cell. This layer eliminates lake areas from the study.
- A factor for applying to the mean annual runoff during the computation of the Plant capacities.

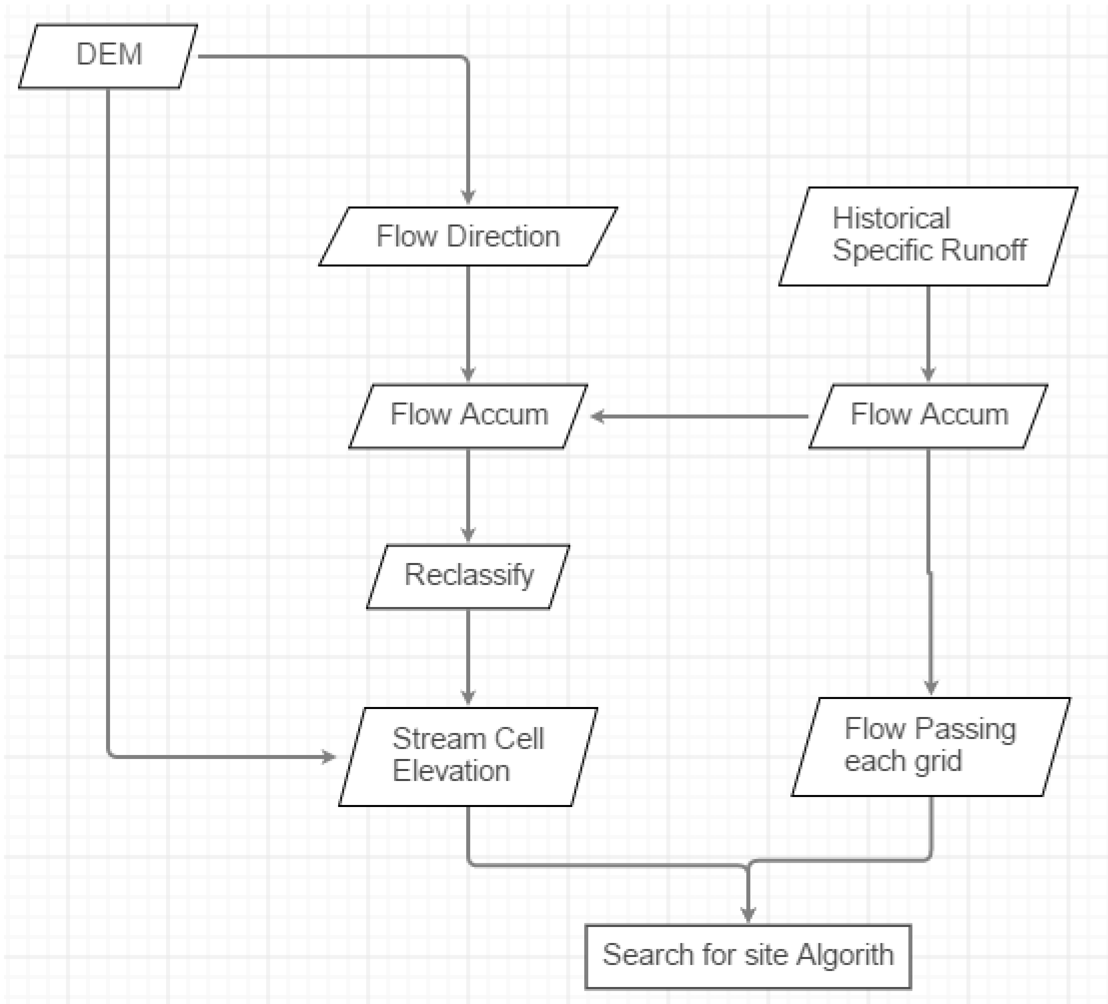

Figure 3:1: Data processing and mapping procedure (Source: Emmanuel Jjunju)

3.3 Methods of Hydropower Estimation

The hydropower potential is calculated using the formula of power; $P = (H * \ell * g * Q * \eta) / 1000000$.

Where

P = Power in MW

η = Efficiency as a %

g = Acceleration due to gravity in m/s^2

Q = Runoff in m^3

H=Head in m

ℓ =Density of water in kg/m^3

There are different contexts for estimating hydropower potential, i.e., theoretical, technical and economic hydropower potential.

Theoretical potential is the potential energy of all the water flowing in an area regardless of physical, technical and economic limits on usage. This refers to the assumption that from the highest to the lowest elevation all runoff is used for hydropower with no losses (Weiss and Faeh 1990).

The technical potential of hydropower is the energy capacity that is actually useable when technical, infrastructural, ecological and/or other conditions are taken into consideration but when economic limitations are ignored. This restricts the analysis within rivers and streams defined by a set threshold.

The economic potential of hydropower is the part of the technical potential that is economically exploitable after some economic analysis. A common criterion is the Net Present Value (NPV) and/or the Internal Rate of return (IRR) of all revenues and expenditures over a given time period. Factors such as investment costs, electricity prices, discount rates, the costs of alternative energy sources and the necessary and existing supply infrastructure are considered.

Hydrosearch in this program is limited to only the technical potential.

3.4 How it works

The algorithm (hydrosearch) used to search for hydropower sites is as explained before a variant of many similar approaches.

The following steps are followed in identifying the hydropower sites;

1. Each map (StreamZ, Lakes, and CumRunoff) is divided into large search areas specified by the user. During this study, we used 5 Km x 5 km and 10 km x 10 km search area areas. For a map with a resolution of 1 km, a sub-map of 10 km x 10 km contains 100 pixels (grid cells). An example showing a pixel (grid cell) is shown in *Figure **3:2***.
2. Each search area is independently analyzed. Each pixel in the ***StreamZ*** raster (that has a data value) is a considered a likely intake or powerhouse location. For each pixel, all lower lying pixels in the search area are considered likely power house locations. Using the runoff for the intake pixel, and the head difference between the intake pixel and the powerhouse pixels, an energy potential is calculated.
3. Since the runoff map gives the mean annual runoff, a factor is used to compute the hydropower potential. This factor is based on an external analysis of the shape of the flow duration curves. In this study, a default value of 2.5 was used.
4. For a given runoff and power, costs estimates for each possible site are calculated basing on the NVE cost curves. The current tool used data from 2005 curves. The study considered an interest rate of 15% and a project lifetime of 40 years. For each site a diversion weir of height 8 m and length ca. 20 m is used. The tool sizes the following components; Powerhouse, canals, penstock, turbines, and other electro mechanical equipment up to grid connection point. No technical economic optimization is included in the program.
5. After the computation is repeated for all cells within the search area, a criteria is employed to select the best configuration from each cell and afterwards the best configuration for each

search area. Choosing only one site in a search area avoids duplication and the size of it should be realistic so that it is unlikely to have more than one unique site within the grid.

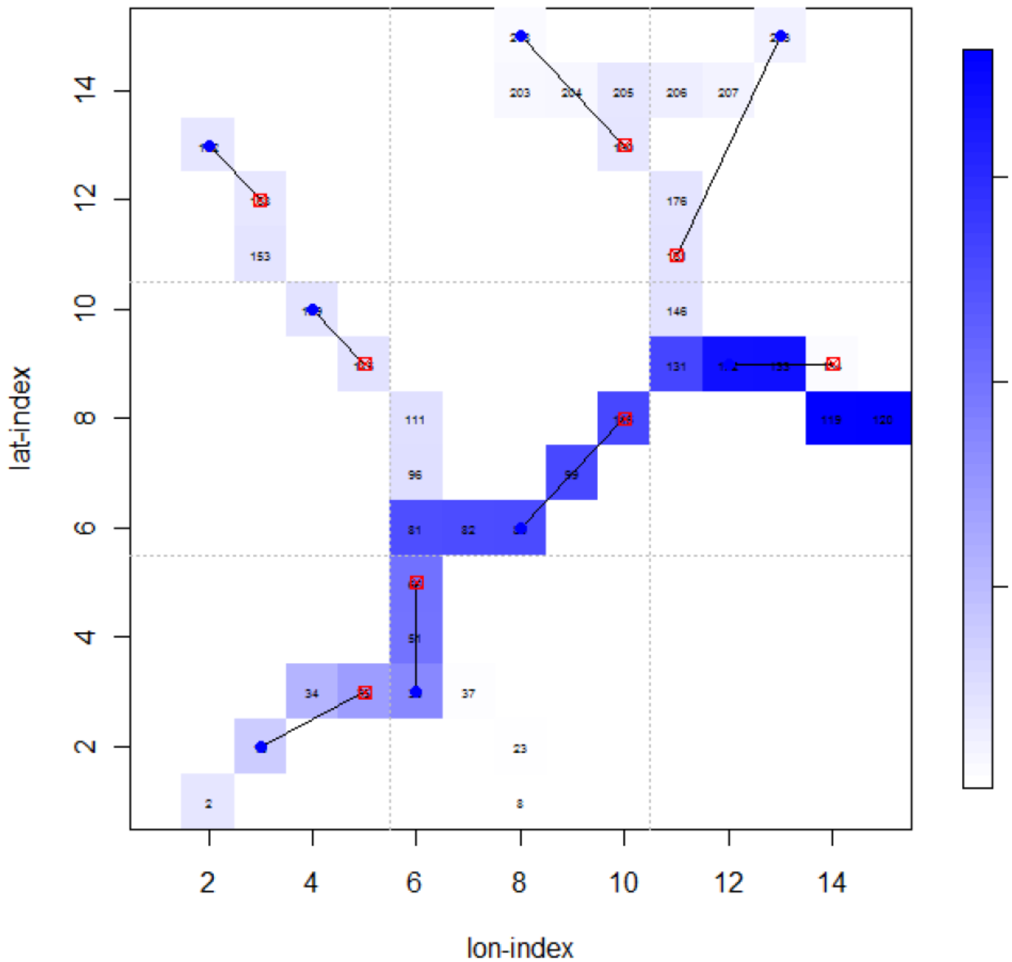

Figure 3:2: A search area showing stream grid cells and associated elevation values

The graduated blue color in the grid cells shows runoff. The blue do is the chosen intake for each sub grid while the red square is the powerhouse.

6. Only one-hydropower plant that has the maximum power output is chosen from each search area based on maximum energy. The size of the search area limits the possible length of waterways for a power plant. Depending on topography, the size of the search area chosen can be a factor in the size of the resulting power plants.
7. The results for all search areas are combines in a table showing all the key characteristics. A typical table for the area around Mt. Rwenzori in western Uganda is shown in *Figure **3**:**3***.

1961 -1990 (GRDC) runoff maps); Rwenzori (Uganda)

intk	ph	xin	yin	xph	yph	wayL	Qav	hd	mw	Gwh	NPV	MUS/MW	IDn
6320	6817	70	51	67	55	5003	7.962926	193	14.5	127	42.9	0.968	1
10016	10267	16	81	17	83	2236	155.905200	11	16.2	142	7.7	2.852	2
10594	10342	94	85	92	83	2834	17.356650	192	31.4	275	5.3	3.082	3
11671	11300	46	94	50	91	5028	1.289257	530	6.4	57	20.8	0.764	4
12220	11966	95	98	91	96	4474	3.467427	157	5.1	45	14.8	1.032	5
13069	12945	69	105	70	104	1414	14.979680	42	5.9	52	16.3	1.126	6
12821	12825	71	103	75	103	4000	15.088840	79	11.2	99	31.4	1.094	7
13692	13194	67	110	69	106	4474	11.250490	142	15.0	132	43.3	1.036	8
14176	14304	51	114	54	115	3188	1.605770	405	6.1	54	20.0	0.737	9
14309	14185	59	115	60	114	1416	7.175490	88	5.9	53	17.9	0.930	10
14186	13940	61	114	65	112	4479	8.576225	251	20.3	178	56.6	1.098	11
14551	14430	51	117	55	116	4198	1.850486	794	13.8	122	46.7	0.661	12
14431	14433	56	116	58	116	2009	4.689930	199	8.8	77	28.1	0.797	13
14951	14455	76	120	80	116	5661	4.578136	234	10.1	89	30.8	0.906	14
16893	16894	18	136	19	136	1000	169.764300	16	25.6	225	30.7	2.301	15
20161	20287	36	162	37	163	1414	180.403400	14	23.8	209	25.5	2.398	16

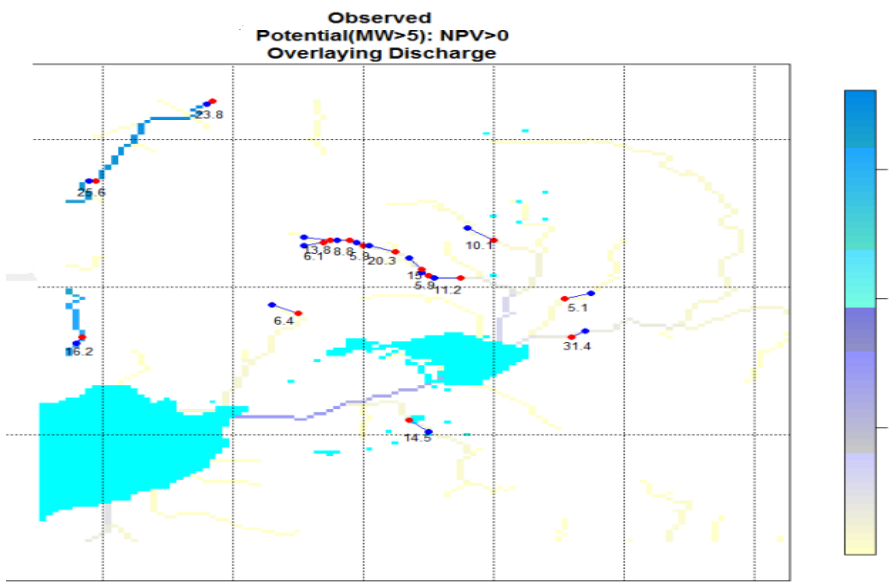

Figure 3:3: Typical results (Area around Mt. Ruwenzori Uganda)

3.5 Limitations of the program

The following are the limitations identified in the program;

The size of the search area limits the possible length of waterways for a power plant. Depending on topography, the size of the search area chosen can be a factor in the size of the resulting power plants. The choice of the search area may not be the one that gives the best results of the projects.

No technical economic optimization is included in the program as of now. Projects are chosen on the basis of maximum power output alone.

There is no internal analysis criteria to study the flow variation (flow duration curve) pattern over the year in order to choose the factor used in the calculation of capacity of energy. The constant factor of 2.5 that is applied to all projects may not be realistic for all cases.

The algorithm focuses on identifying small hydropower sites and the integrated simple economic analysis is valid for only small sites (i.e. used small cost base curves).

3.6 Results of the GIS program

The search for possible intake sites was made using two search areas, a 5km x5km and a 10km x 10km. The outcomes of the search were a plot of the possible intake points and the corresponding power houses. This section will present plots of possible intakes for the two search areas.

Typical hydrosearch results are as shown in ***Figure 3:4*** for a 5km x 5km and in ***Figure 3:5*** for a 10km x 10km search areas but a precise view is presented in appendix e.

The brown dots represent intake points. The sizes of the dots are relative to the power computed by the system for the respective sites.

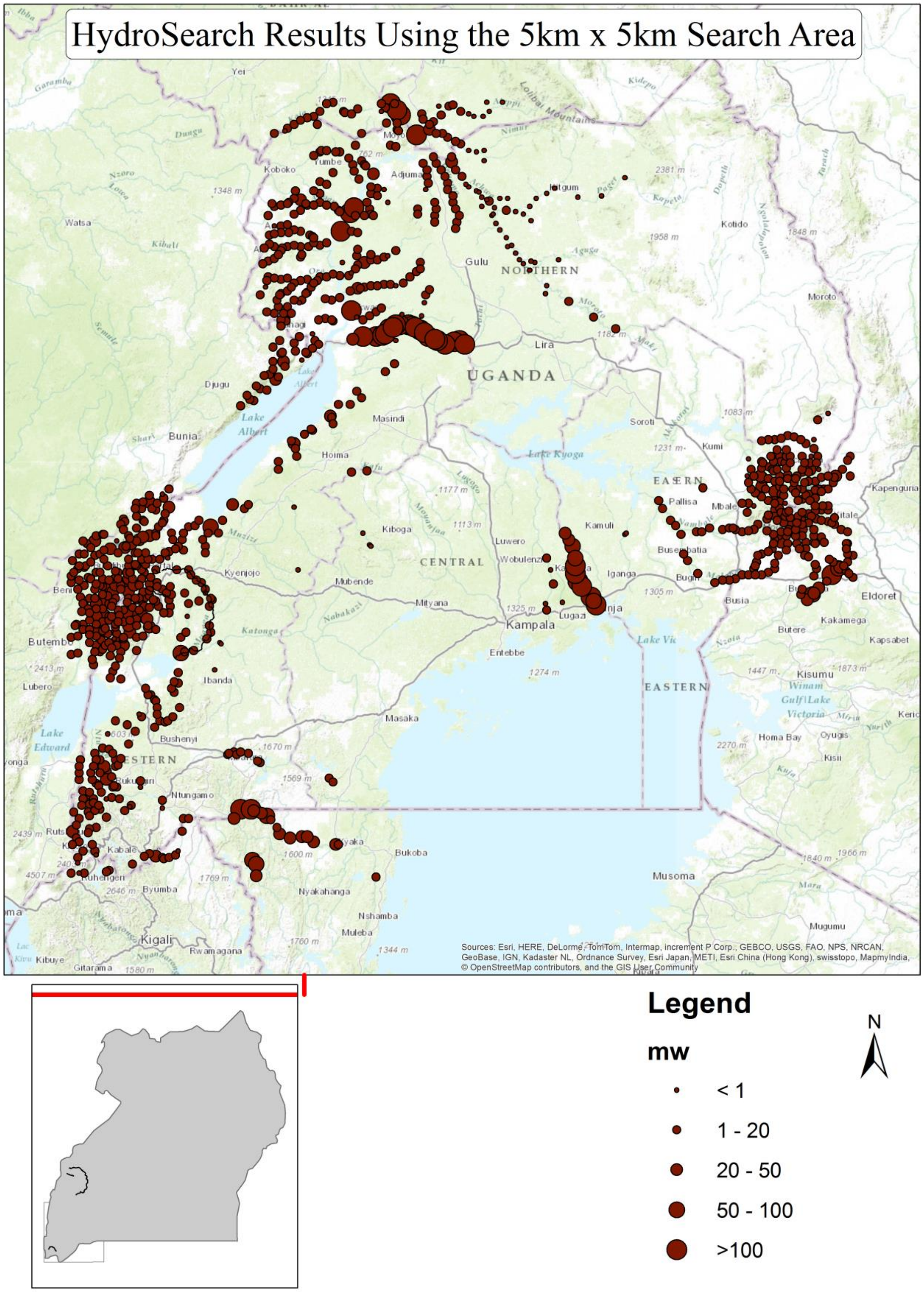

Figure 3:4: A map showing intake points for sites identified using the 5kmx5km search area

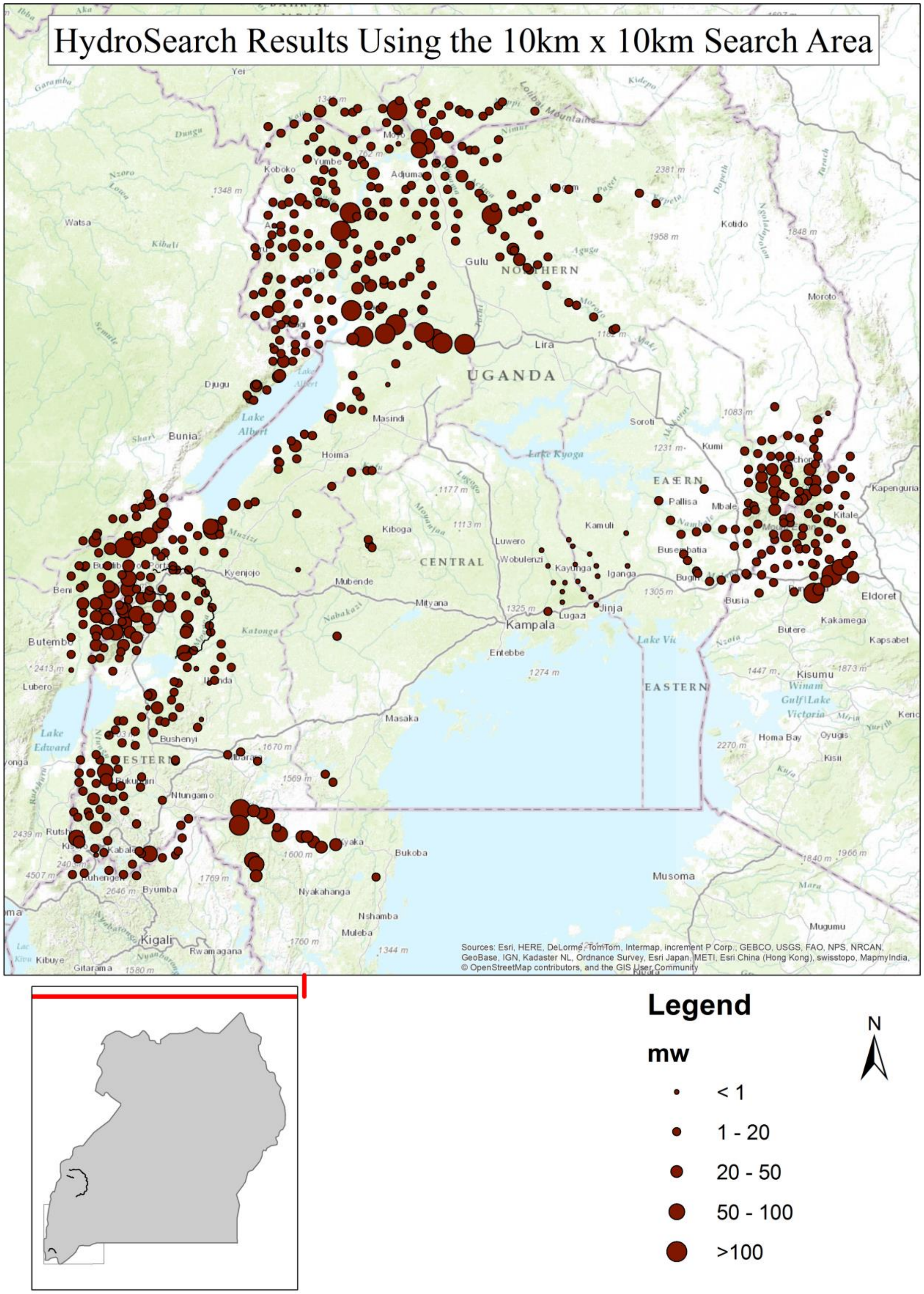

Figure 3:5: A map showing intake points for sites identified using the 10kmx10km search area

4 EXISTING PROJECTS

4.1 Introduction

Existing projects included both those projects that are under operation and those whose feasibility studies have been conducted already. Due to difficulties in acquiring documentation, only two study reports were obtained, which include Mpanga Small Hydropower Projects in the Rwenzori Regions of Uganda and Bugoye Hydropower Project also in the Rwenzori regions of Uganda. For purposes of this verification study, reference will be made to only those two documents.

4.2 Mpanga Small Hydropower Project

Mpanga River has its waters from the northern part of the Rwenzori Mountains. It discharges into the northeastern end of Lake George. The proposed project intends to use the hydraulic potential of the river with an approximate head of 142.5 m between coordinates Latitude 0 04 44 – 0 04 00 N and Longitudes 30 19 30 – 30 19 15 E and flow of 16cumecs.

The run off river project will generates 18 MW to feed approximately 68 Gwh of energy generated annually to the national grid.

4.2.1 Project Details

The following are the suggested sizes and specifications of the major details of Mpanga Small Hydropower project.

- A 9m high flow diversion weir, an elaborate intake with a trash cleaning, spillway and intake gate
- 1800m long reinforced concrete headrace canal, a reinforced concrete fore bay
- A mild steel penstock feeding the water from the intake to the power house
- Electromechanical plants shall consist of 3 horizontal shaft Francis turbines each of 6.19MW
- A mandatory discharge of 100 Liters /second

The project Location and project layout is given in *Figure **4:1*** below

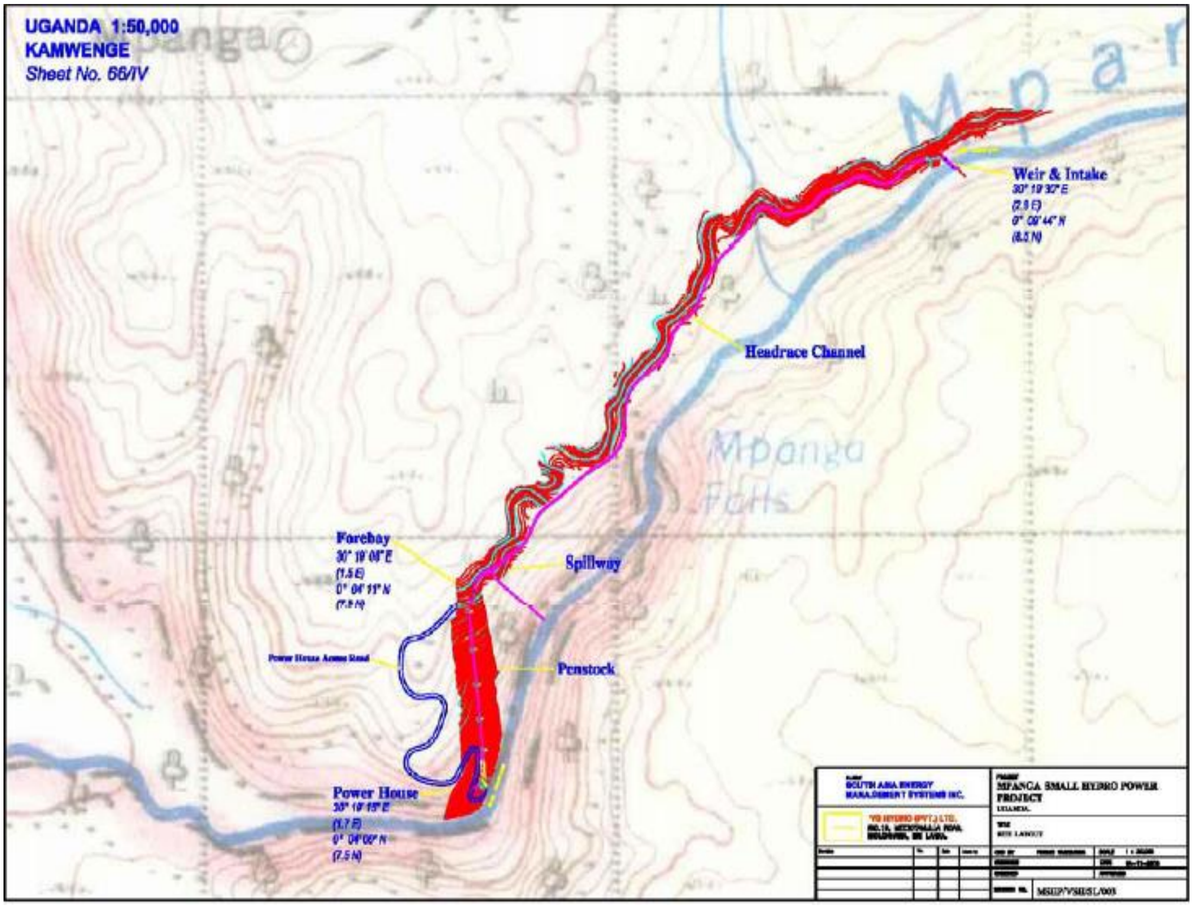

Figure 4:1: Layout of Mpanga SHP (source: Feasibility Report)

The river has a catchment area of 4760 km^2 up to the proposed intake. It has an annual average of 12.02 m^3/s and a standard deviation of 5.31 m^3/s, which ensures minimum flow variation in the river. From the flow duration curve derived from the source data, it is worth noting that the river will have 2.35m^3/s available for 95% of the time, which shall result in high plant utilization.

The main project technical parameters is shown in the *Figure **4:2*** below

	Parameter	Units	Data
1.	Power Net Capacity	MW	18
2.	Gross Annual Output	MWh	74,000
3.	Average Plant Lifetime	Years	50
4.	Operating Time	Hours	8,760
5.	Turbines	Type	Horizontal Shaft Francis
	+ Number	No.	3
	+ Net Head	m	131
	+ Capacity	kW	6,190
6.	Generator	Type	Horizontal Synchronous
	+ Number	No.	3
	+ Rated Capacity	kW	7,000
	+ Rated Voltage	V	6,300
7.	Design Flow	m^3/s	16
8.	Weir	Type	Gravity, with Ogee Profile
	+ Length	m	52
	+ Height	m	9
9.	Headrace Channel	Type	Reinforced Concrete on Ground
	+ Length	m	1,800
	+ Width	mm	3,400
	+ Wall Height	mm	1,900
10.	Forebay	Type	Reinforced Concrete Retaining Tank
	+ Length	m	25
	+ Width	m	8
	+ Height	m	8
11.	Penstock	Type	Milt Steel Helical Welded
	+ Number	No.	3 in Parallel
	+ Length	m	290
	+ Pipe Outer Diameter	mm	1,600 / 1,500 / 1,400

Figure 4:2: Main project Parameters for Mpanga Project (Source: feasibility Report)

4.2.2 Selection of Main project Parameters

Design Discharge was taken to be 1.2 times the average flow. In order to determine the optimum design flow for the project, a daily flow simulation into the turbine was carried using the flow series that was obtained by using the corrected daily flow Measurements of River Mpanga

4.3 Bugoye Hydropower Projects

The layout concept for Bugoye power Project shown in *Figure **4**:**3*** was based on studies carried out by SWECO during their site visit. The decision was made in consideration to the layout for the Mobuku III project that had been completed downstream of the Bugoye and the existing Mobuku I plant upstream of it.

Bugoye is located 5 km north of Mobuku at the road between Kasese, Fort portal, and Kabarole Districts. The intake dam collects water directly from the Mobuku I tailrace, and some water diverted from Isa River. An alternative headrace canal was constructed between the main river and the tailrace of Mobuku I to collect water from the spillway of Mobuku I to the intake of Bugoye in case of failure or a standstill at Mobuku I power station. In this way the, there is assurance of operation for Bugoye during all possible operation modes of Mobuku I plant.

Similarly, as the location of the intake for Bugoye is determined by the position of the outlet from Mobuku I, the position of the tailrace outlet for Bugoye was also determined by the location of the Mobuku III intake down stream of Bugoye.

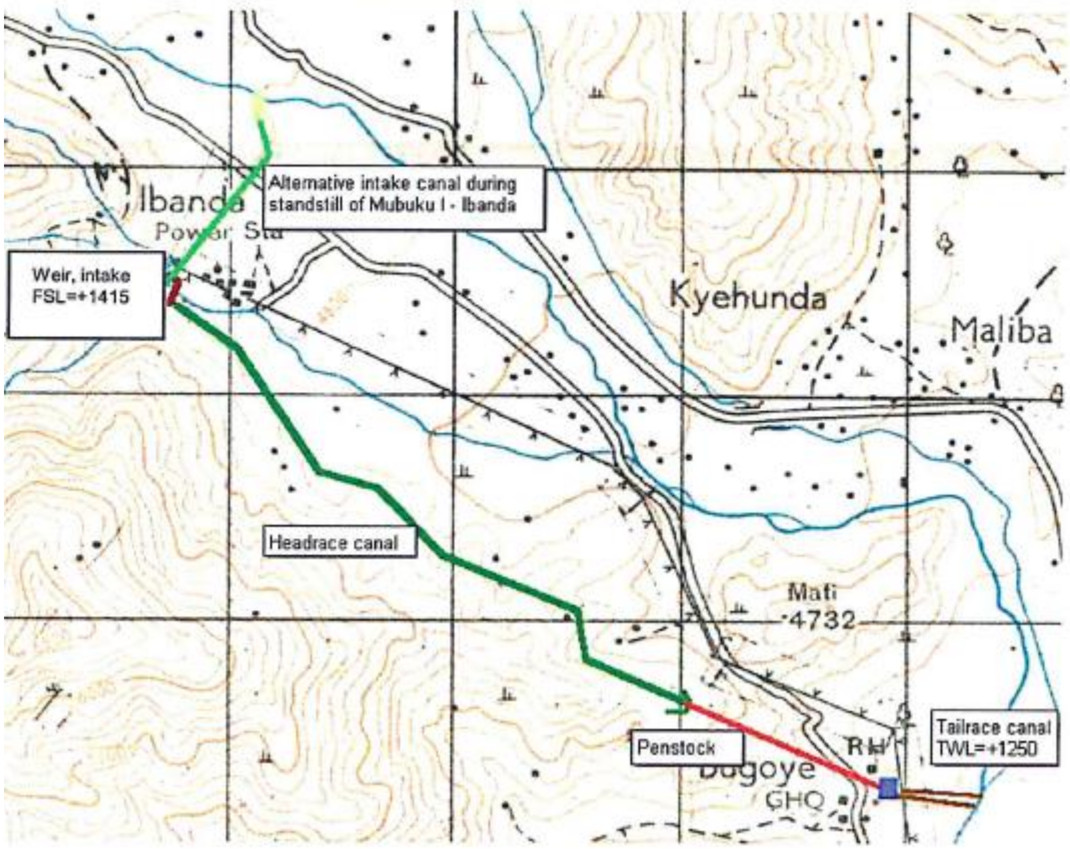

Figure 4:3: Bugoye General Layout (Source: Feasibility Report)

4.3.1 Project Details

The Project consists of a 10 m long weir located at El. +1415 in direct connection to the intake structure. A 1 km long alternative headrace canal between Mobuku River and the tailrace of Mobuku I is included to be used in cases when there is a standstill or failure at Mobuku I station.

It also consists of a 3250 m long almost horizontal and open headrace canal which follows the south western side of the river until it reaches a mountain ridge plateau suitable for the arrangement of an intake pond for the penstock.

A 1000 m long penstock with a diameter of 1.6 to 1.8 m down to the power house is located at approximately ground elevation 1255 m. The penstock is laid on piers established on rock with anchor blocks at vertical alignment changes.

A power house with two pelton turbines with a design flow of 2*4.4 =8.8 m^3/s is also included. Its 450 m long tailrace canal is excavated down to a tailrace water level of El. +1250

As access to the powerhouse, the existing Bugoye road was used and the powerhouse is located adjacent to the road. The proposed layout provides for a gross head of 166 m and a total capacity of 12.5 MW. The total Project cost was estimated at MUSD 24.9.

Some feasibility reports for the projects in the database could not be obtained

5 DESK STUDY

5.1 Introduction

A reconnaissance study was performed with in two selected regions which included Rwenzori in the western part of Uganda and Elgon in the eastern part of Uganda. This was intended to study how well the program system manages to find the correct location of intakes, and how well it can estimate the capacity, generation and economic parameters.

*Figure 5:1*and *Figure 5:2* Shows the catchments for each of river the rivers that was studied under this reconnaissance in the Elgon and Rwenzori regions respectively.

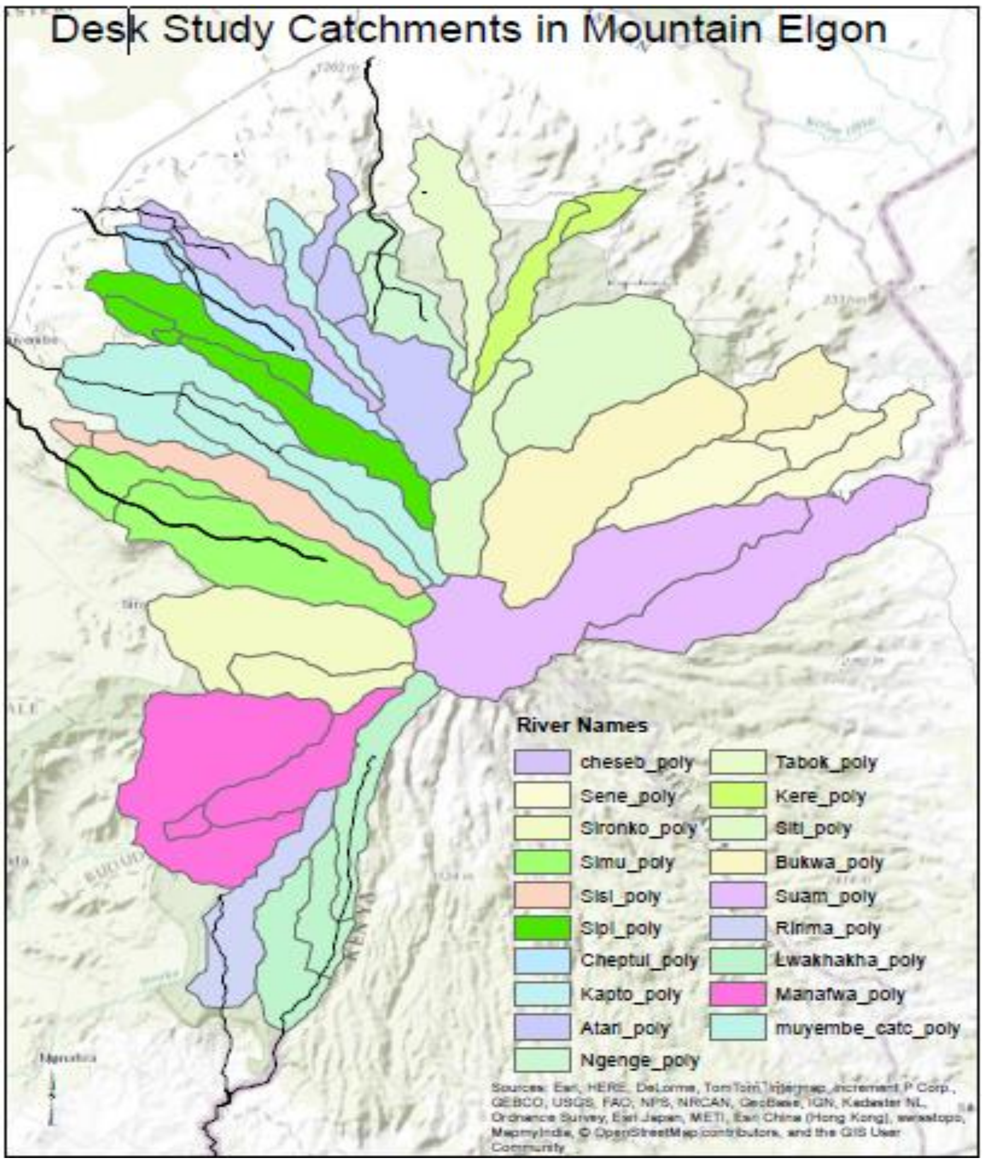

Figure 5:1: Study Catchments in the Elgon Region

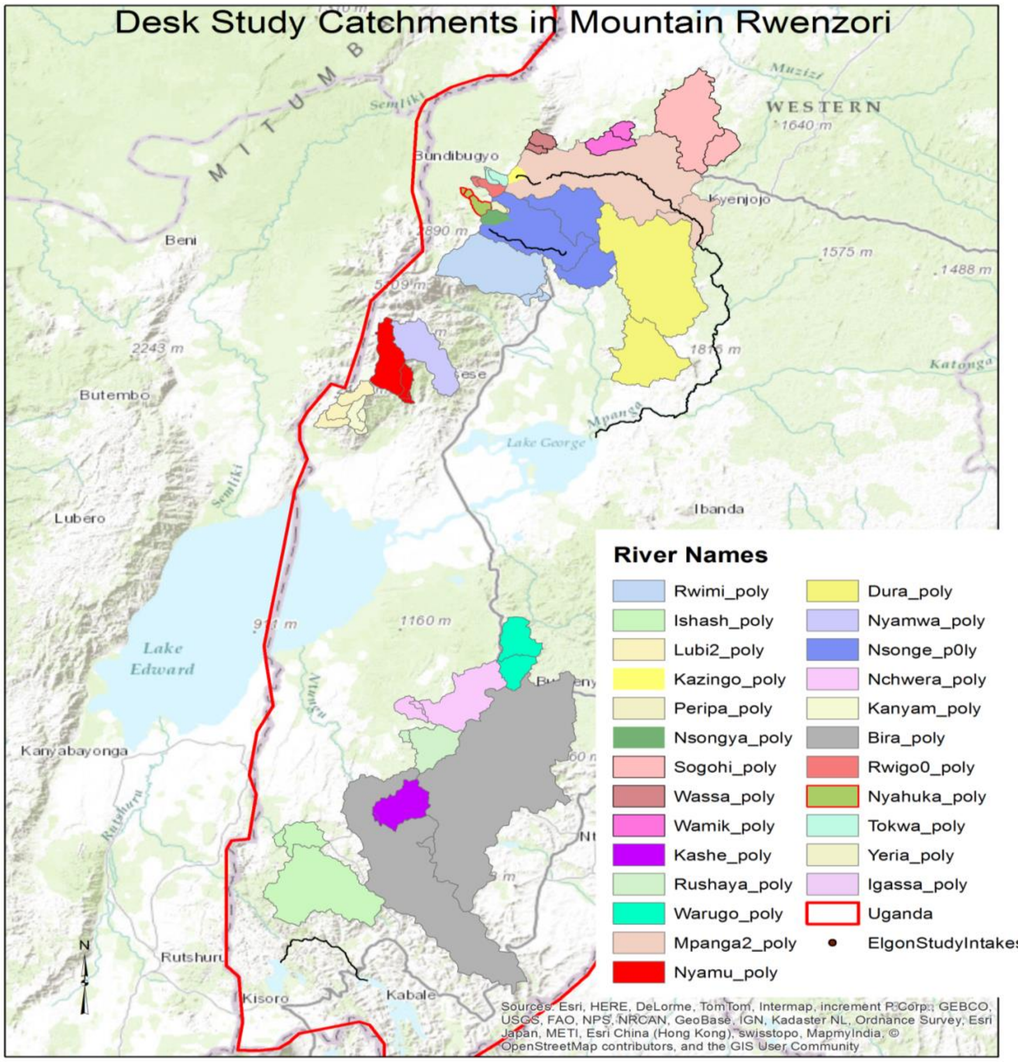

Figure 5:2: Study Catchments in the Rwenzori Region

5.2 River Profiles/Catchment Area

The river profiles and the corresponding catchments areas can be found in appendix f

5.3 Evaluating Water Resource

Below is figure k in which gauging stations that were used to scale off runoff to the catchments under study are plotted. *Figure 5:3* then tells us the gauging stations that were used to scale runoff for each river under study.

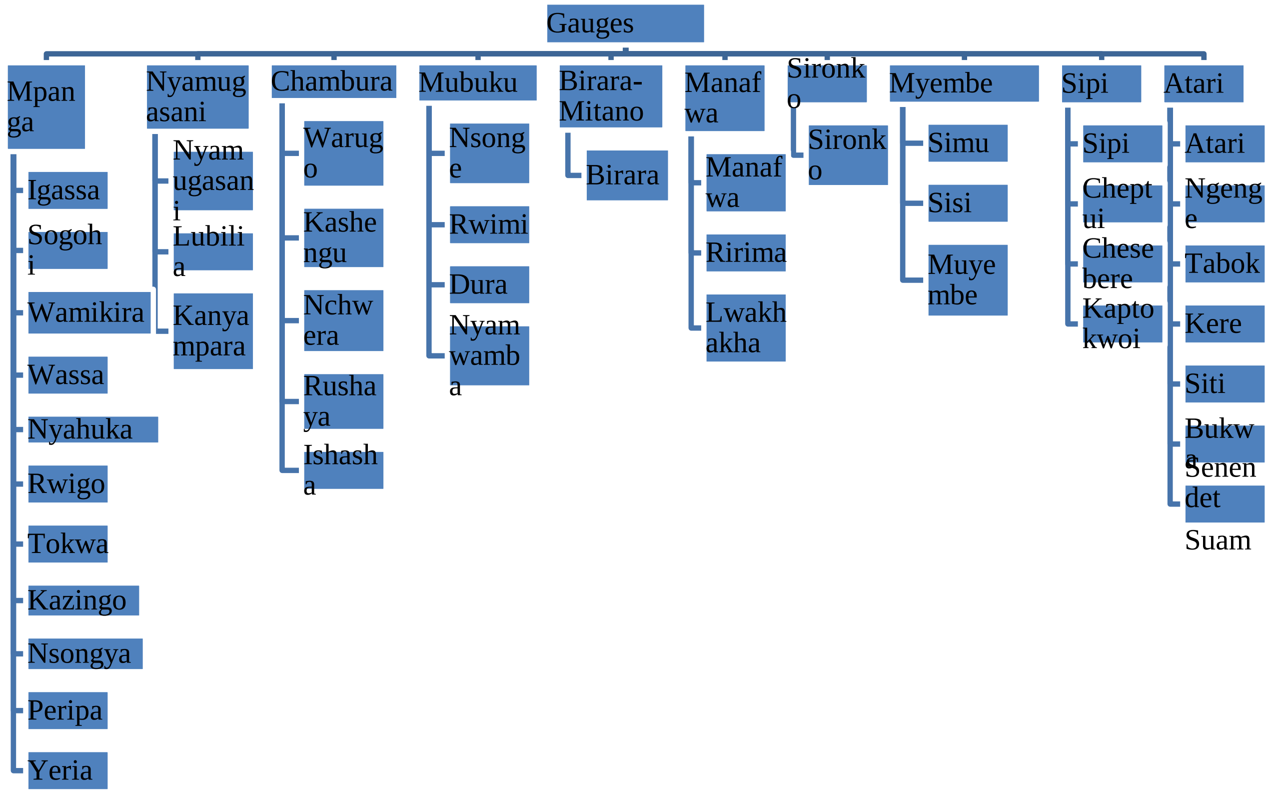

Figure 5:3: Gauging Stations used for Scaling to Catchments

The choice of gauging stations for scaling was based on three major factors of similarity in Area, Specific runoff and on the proximity of the catchments from one another. Equation 3 described under the methodology section was used to compute the runoff values. However, it is worth noting that only years with full record of data were considered in estimation of the annual average runoff. Figure p shows a hydrograph of the average annual runoff values for the gauging stations.

The average annual discharges were chosen as the design Discharge for estimating the productions with a maximum capacity of 2.5 times the average discharge, but also the flow available for both 50 % and 90 % of the year as seen from the Flow duration curve were investigated to understand what the effect would be if the flow volumes were less that the average flow volumes during the year. However, no environmental releases were considered in this study.

5.4 Intake Identification

From the river profiles generated for each river stretch, a number of promising intake points were chosen. The corresponding catchment areas upstream of each potential intake point identified were then determined using ArcGIS program.

Based on the flow value and gross head at each potential intake, the resulting power generation would then be estimated using equation 5 described in the methodology section.

A graph of generated power in MW against the elevation for each river was then plotted and the point with the highest values of power was then chosen as the optimum intake point on that particular river.

Two cases of Nsonge and Kanyampara rivers are presented here to illustrate the optimization process, this optimization process was done for all rivers under study in order to choose the best intake point.

*Table **5:1*** shows the power generations that were estimated for each possible intake, the results were then be plotted as in *Figure **5:4*** and *Figure **5:5*** to guide in the selection of optimum intake elevation.

Table 5:1: Power production at selected intakes

River Name	Intake Elevation	Head	Catchment Area	Flow	Efficiency	gravity	KW	MW
Nsonge	1400	420	136.8	6.8	0.9	9.81	25266.6	25.3
Nsonge	1220	240	385.3	19.2	0.9	9.81	40657.1	40.7
Nsonge	1120	140	471.7	23.5	0.9	9.81	29030.0	29.0
Kanyampara	1600	520	5.0	0.1	0.9	9.81	322.4	0.3
Kanyampara	1400	320	26.5	0.4	0.9	9.81	1042.8	1.0
Kanyampara	1300	220	30.0	0.4	0.9	9.81	809.3	0.8

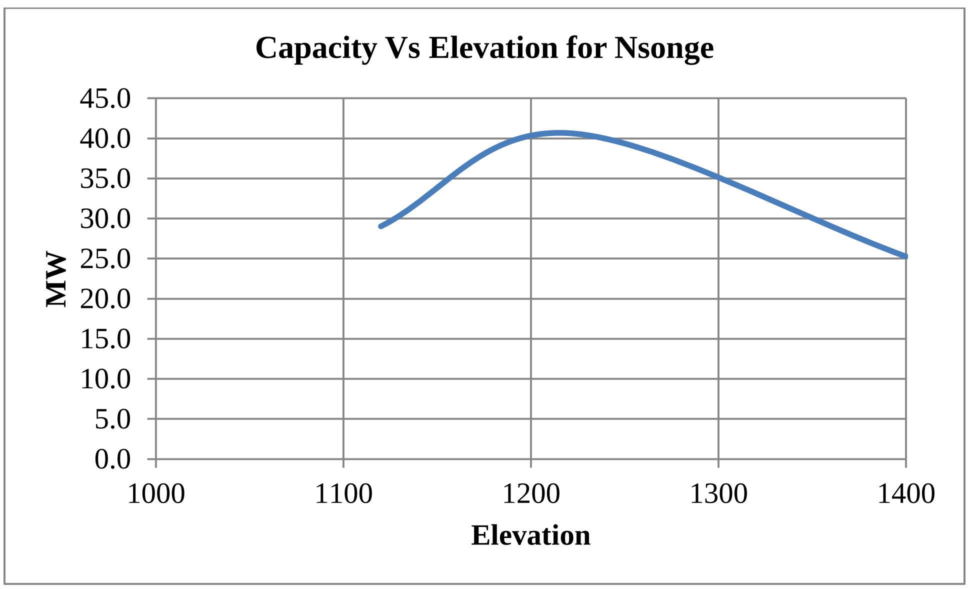

Figure 5:4: Intake optimization for Nsonge River

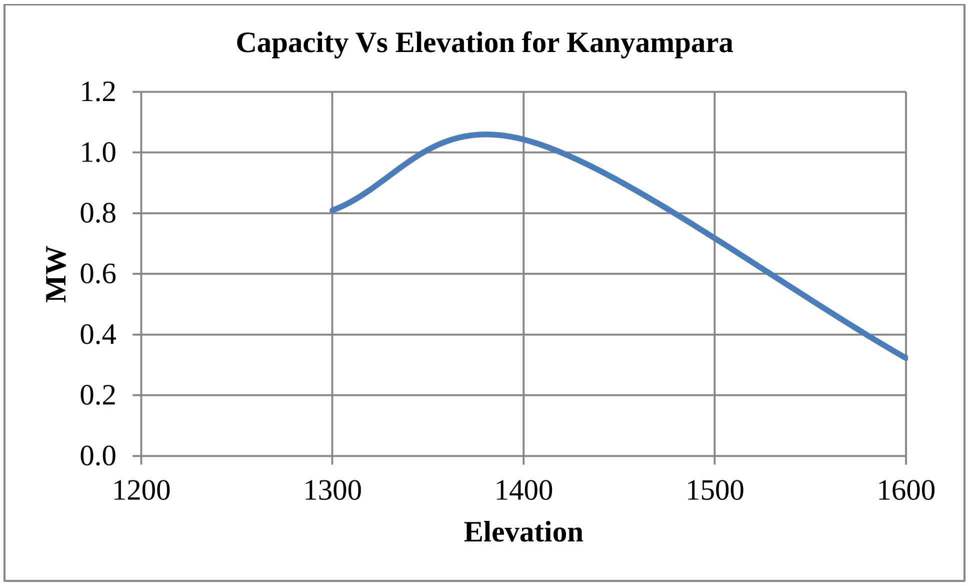

Figure 5:5: Intake optimization for Kanyampara River

Based on the optimization process above, *Figure **5:6*** and *Figure **5:7*** shows the plot of the optimum intake locations for the rivers under study in the Elgon and Rwenzori regions respectively. In both case, the blue dots represent the intake points identified from the study and the red squares represent the suggested power house locations.

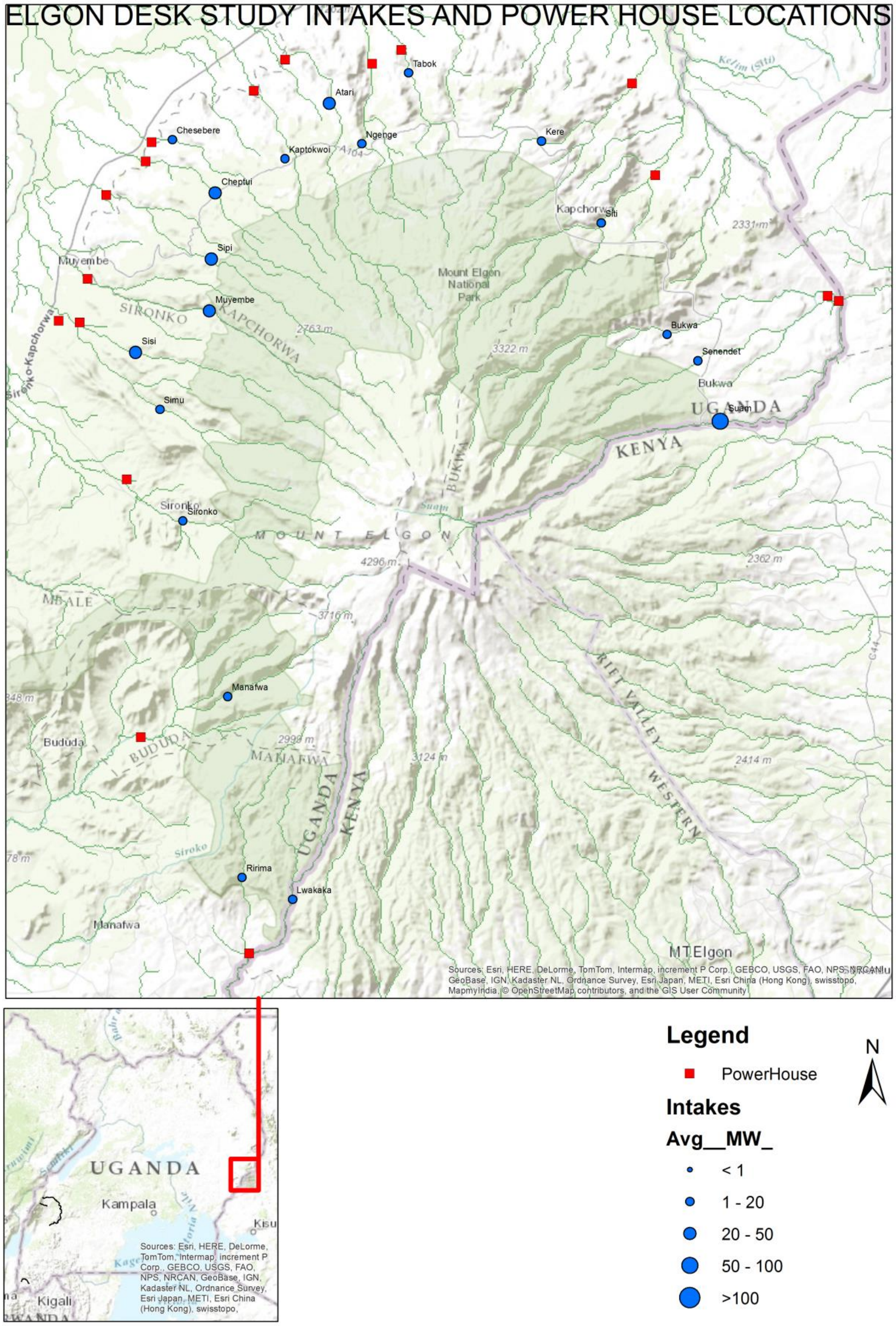

Figure 5:6: Intake Points for Elgon Desk Study

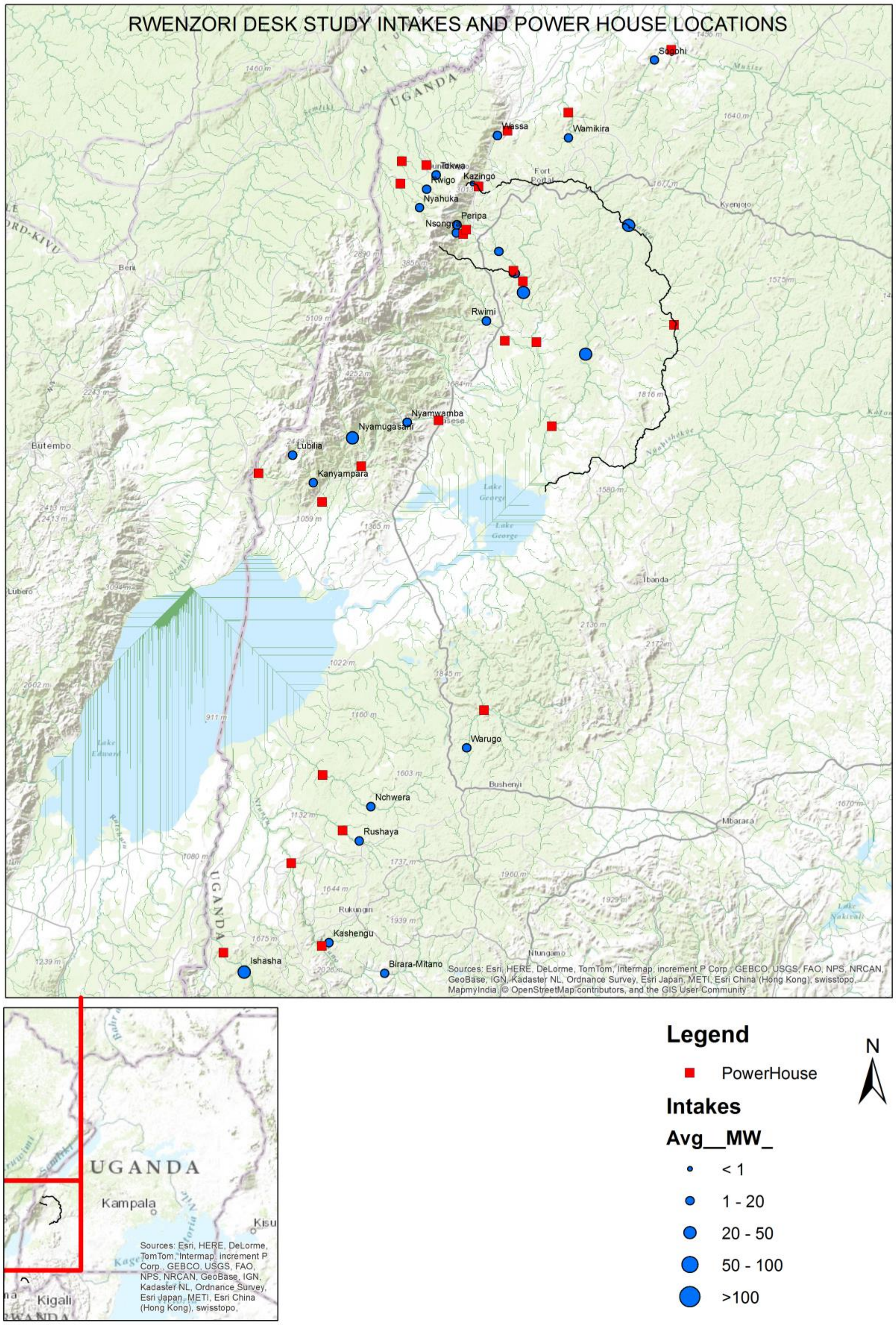

Figure 5:7: Intake points for Rwenzori Desk Study

5.5 Capacity computations

The computed generation estimates for the sites in the two regions are as presented in *Figure **5**:**8*** below. It show the generation capacities for three flow situations i.e. the average flow, flow available for 50% of the time and the flow available for 90% of the time. The case of Cheptui, Sisi, and Kaptokwoi all in the elgon region indicate no production at 90% of the time in the year because the rivers will almost be dry

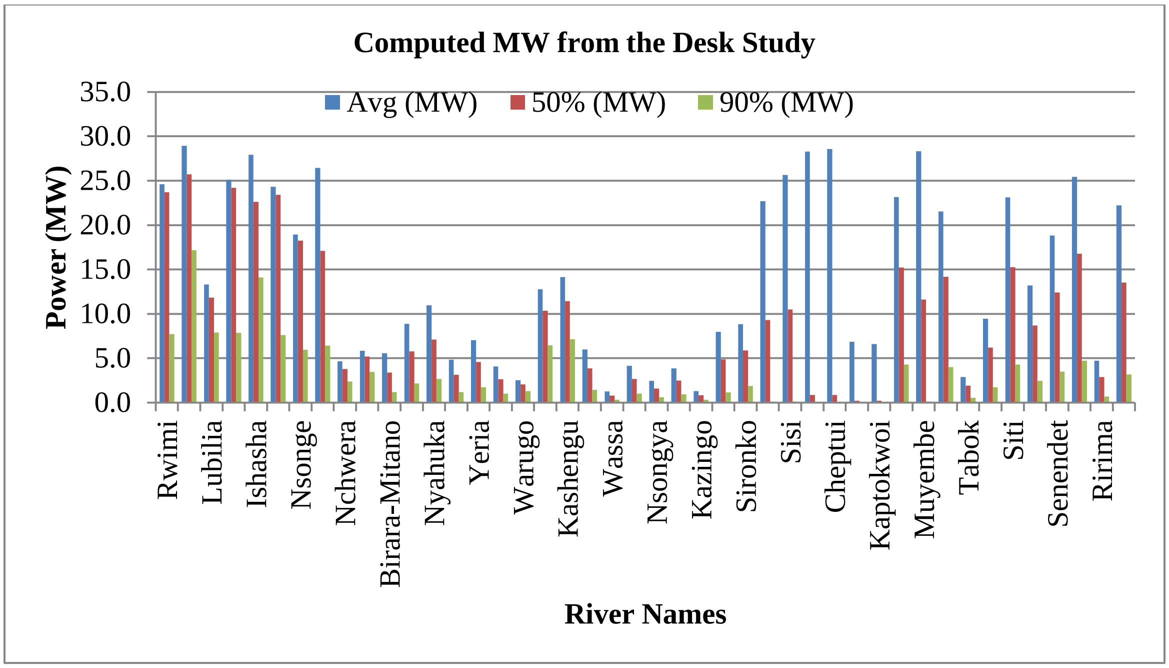

Figure 5:8: Calculated Capacity for Avg. flow, 50% flow and 90% flow

5.6 Cost computations

*Figure **5**:**9*** below represents the net present value and the benefit cost ratio estimates for each of the sites under desk study.

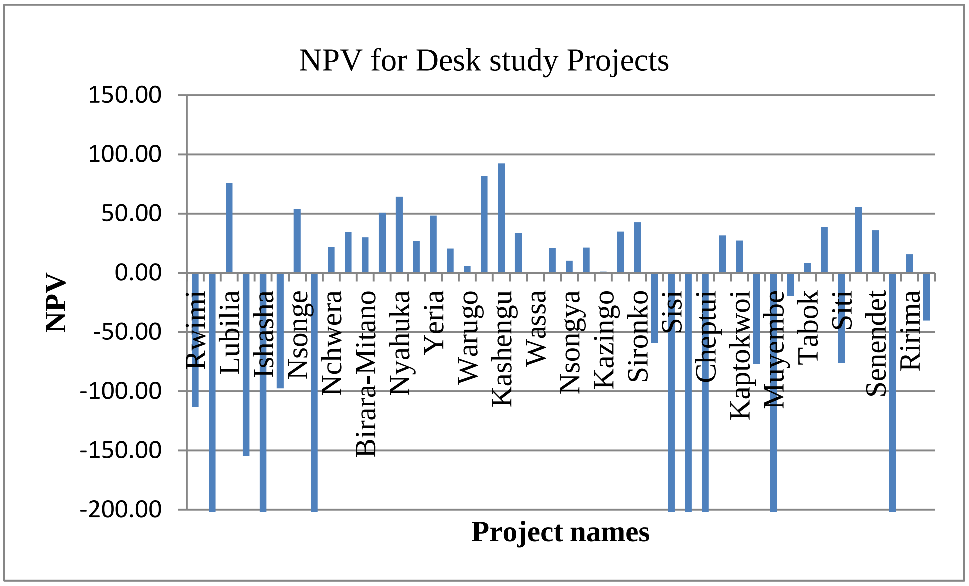

Figure 5:9: Representation of NPV and B/C Ratio for Desk study projects

6 RESULTS AND DISCUSSION

In an effort to evaluate the performance of the GIS system in computing the hydropower potential, a study was conducted by carrying out a literature review and doing a desk study in order to compare how well the GIS system computes the capacities, generation and identifies the intake points with the findings from the literature review and the desk study.

6.1 Capacity in MW

6.1.1 Capacity of GIS Program Vs Existing Projects

Figure ***6:1*** below shows the capacities in MW of the different existing project in relations to those obtained from the closet project identified by the GIS program. The site characteristics for each project are also presented in *Table 6:1* below.

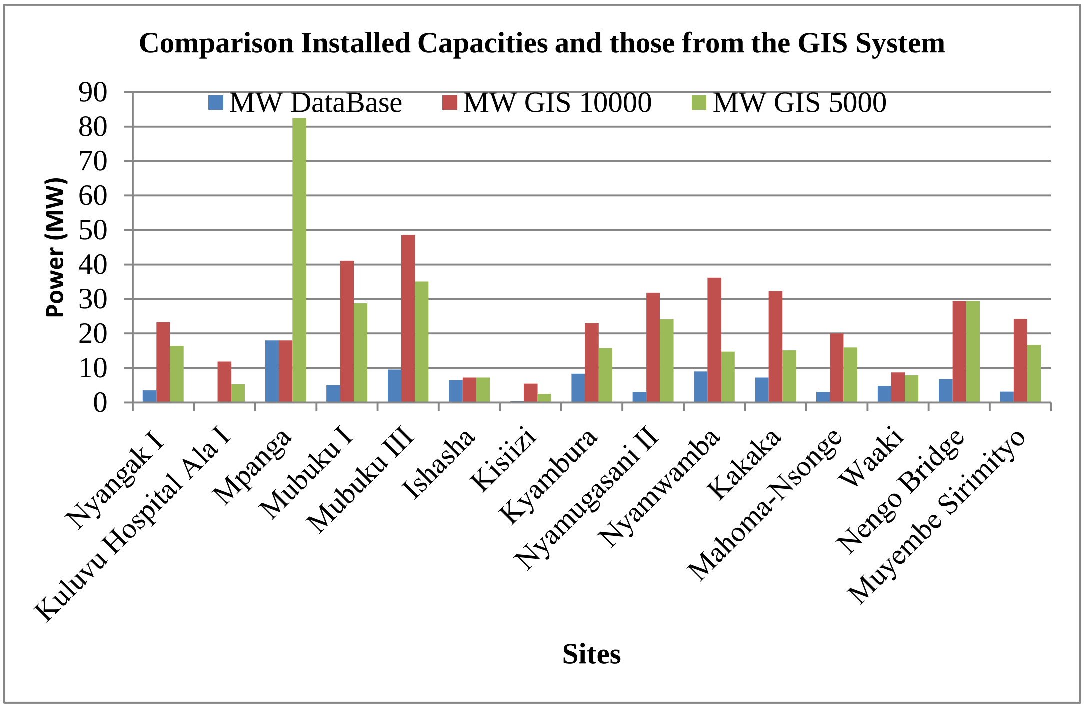

Figure 6:1: Comparison of Database and GIS MW

Table 6:1: Site characteristics for the Existing projects compared to the GIS System

	Flow (m^3/s)			Head (m)			Distance of GIS intake Location from Data Base Sites	
Site	**Data Base**	**GIS 5000**	**GIS 10000**	**Data Base**	**GIS 5000**	**GIS 10000**	**GIS 5000 (km)**	**GIS 10000 (Km)**
Nyangaki I	4.41	4.16	3.32	81	167	298	1.3	5.2
Kuluvu Hospital	0.16	2.84	2.84	80	79	176	3.1	3.1

	Flow (m^3/s)			Head (m)			Distance of GIS intake Location from Data Base Sites	
Site	**Data Base**	**GIS 5000**	**GIS 10000**	**Data Base**	**GIS 5000**	**GIS 10000**	**GIS 5000 (km)**	**GIS 10000 (Km)**
Mpanga	16.53	18.83	18.74	111	186	219	2.2	2.2
Mubuku I	No data	10.71	10.71	No data	114	163	0.1	0.1
Mubuku III	No data	12.81	12.81	No data	116	161	0.3	0.3
Ishasha	8.61	6.23	6.23	77	49	49	0.7	0.7
Kisiizi	No data	0.71	0.71	No data	147	324	2.4	2.4
Kyambura	6.94	8.03	7.94	122	83	123	2.6	2.6
Nyamugasani II	No data	4.25	4.25	No data	241	318	1.1	1.1
Nyamwamba	No data	3.63	3.63	No data	131	423	2.9	2.9
Kakaka	4.19	4.36	4.36	175	147	314	2.4	2.4
Mahoma - Nsonge	No data	6.3	6.28	No data	107	135	2.2	7
Waaki	4.47	2.73	2.74	114	122	136	4.9	4.9
Nengo Bridge	12.3	12.62	12.62	58	99	99	0.2	0.2
Muyembe Sirimityo	No data	2.29	3.08	No data	310	334	1.8	3.3

There is no clear trend in the relationship between the installed capacities and those computed by the GIS system. Taking a closer look to a few projects for example Nengo Bridge in which the flow values were not very different. GIS used 12.62 m^3/s with a head of 99m using both search areas, the data base used a flow of 12.3 m^3/s (may be not very different) but the head in this case was 41m less than that used by the GIS system which is an explanation to the 22.7 MW increase with the GIS capacity as compared to the data base capacity. In addition, the intake point identified by the GIS system in this case was 0.2 km upstream of the existing intake point. Again, could cause the differences in head. The data base does not indicate the location of its powerhouse to make sense of the head that was used

Another project that used quite similar flow values was the case of Kakaka. In this case, the database used 4.19 m^3/s while the GIS program used 4.36 m^3/s (a difference of only 0.17 m^3/s). A quick calculation from the formula; $p = (H * \ell * g * Q * \eta)/1000000$shows that the database considered 100% efficiency to come up with 7.2 MW while the GIS system used 90% efficiency.

Again, the average flow value was not multiplied by any factor to get the design discharge used to compute power. The GIS system used the design flow as 2.5 times the average flow and with the head of 147 m for the case of the 5 km x 5 km search area; the power generation was 15.1 MW. If similar design assumptions were used, then the 5 km x 5 km search area would yield less than 7.2 MW because the head was far less as compared to that of the database. Differences in principles of choosing the design discharge values and differences in efficiency values used are the explanation to the variation in the power obtained.

Looking at, Ishasha in which the data base used a design flow of 8.61m^3/s with head of 77 m records a capacity of 6.5 MW as compared to the computed capacity from the GIS system of 7.2 MW yet the GIS flow was 6.23 m^3/s (2.38 m^3/s less than the one used by the data base) and the head was 49 m (28 m less than the head used in the data base). In the ideal situation, the GIS system would be expected to yield less capacity as compared to the database if the same efficiency and design discharge is taken. This is because from $p = (H * \ell * g * Q * \eta)/1000000$, the higher the head and flow, the higher the power but in this case, low head and low flow produced high power as compared to the high head and high flow. It was not clear of the principles used by the database to determine the Q_{max} but the GIS system assumed Q_{max} of 2.5 times the average flow. This principle could explain the differences in the value of MW obtained from the two cases. In addition to the GIS intake is 0.7 km downstream of the existing intake the difference in intake locations could be an explanation to the difference in head which directly affects the power estimation.

It is worth noting that in this case, both the 5 km^2 and the 10 km^2 search area GIS system gave the same head of 49 m which suggests that maybe an increase in the search area may not affect the head in certain terrain but only cause an increase to the waterway length.

Another significant difference is the case for Kuluvu hospital Site were the data base records a very low capacity of 0.12 MW with a flow of 0.16 m^3/s and head of 80 m. The GIS system used the flow of 2.84 m^3/ s in both the two search criteria while the head was 79 m and 176 m for the two cases of 5 km^2 search area and 10 km^2 search area respectively. It is seen that the capacity differences between the 5 km^2 and the data base was likely due to the difference in the hydrology used (2.68 m^3/ s greater than that used in the data base). For the case of 10 km^2, the search area increased the head to 176 m (97 m greater than that computed using 5 km^2 search area) and the search area could therefore be another reason for the discrepancies in the capacities. It was also not clear if the design flow was taken as the average or the 90% available flow during the year given the very small value for this particular project.

6.1.2 Capacity of GIS Program Vs Desk Study

An overview of the capacity in MW from the desk study as compared to the GIS system is presented in the *Figure **6:2*** below. It is worth noting that the desk study based on the same design principles of assuming the discharge capacity to be 2.5 times the average flow in addition to using the same runoff map. However, the GIS system used a 1km digital elevation model while the desk study used 90m digital elevation model.

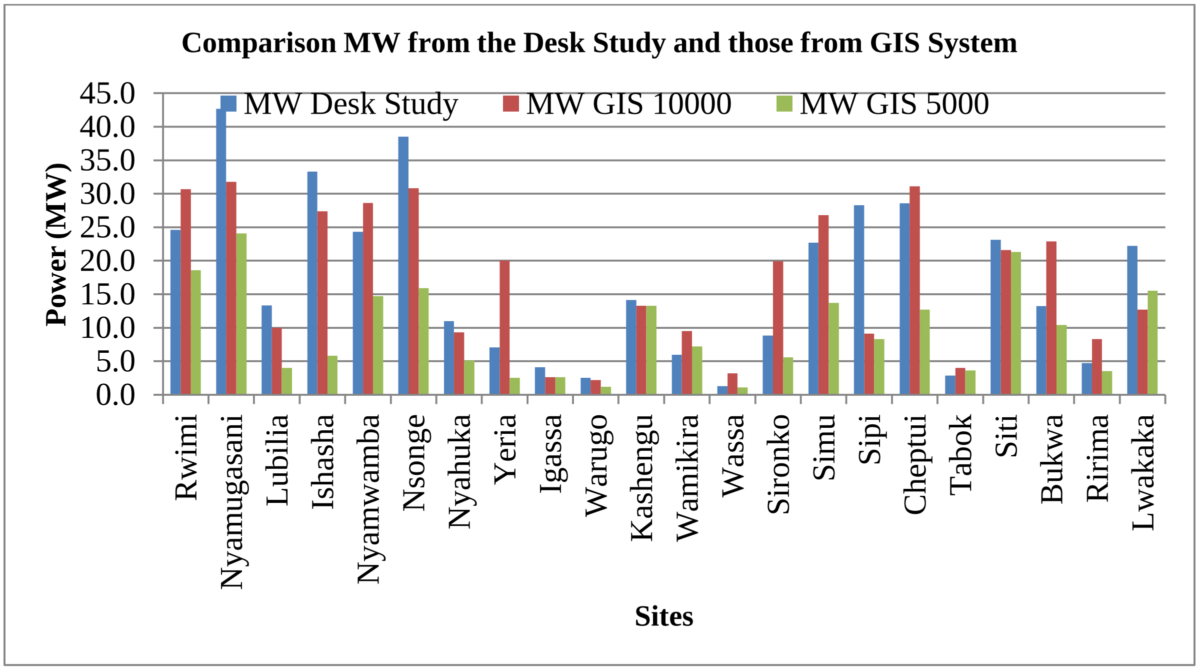

Figure 6:2: Comparison of Desk Study and GIS MW

The *Table 6:2* below presents the different site characteristics that could be the reason for the differences in the values.

Table 6:2: Site Characteristics for Desk Study as compared to GIS System

Site	Flow (m^3/s)			Head (m)			Distance of GIS intake Location from DeskStudy Sites	
	DeskStudy	GIS5000	GIS10000	DeskStudy	GIS5000	GIS10000	GIS 5000 (km)	GIS 10000 (Km)
Rwimi	6.19	5.34	5.34	180	148	244	2.3	2.3
Nyamugasani	4.6	4.25	4.25	420	241	318	2.83	2.89
Lubilia	0.79	0.81	0.67	760	210	629	1.4	0.3
Ishasha	4.44	5.55	5.34	340	73	218	0.42	3.87
Nyamwamba	5.51	4.78	4.78	200	131	254	0.6	0.6
Nsonge	7.27	6.3	6.6	240	107	198	1.14	3.15
Nyahuka	0.5	0.24	0.36	1000	904	1095	2.1	0.6
Yeria	3.19	2.7	6.28	100	40	135	2.1	2.5

Site	Flow (m^3/s)			Head (m)			Distance of GIS intake Location from DeskStudy Sites	
	DeskStudy	GIS5000	GIS10000	DeskStudy	GIS5000	GIS10000	GIS 5000 (km)	GIS 10000 (Km)
Igassa	2.06	2.4	2.41	90	45	45	0.1	0.1
Warugo	0.57	0.91	0.69	200	57	132	3.3	0.8
Kashengu	2.67	3.37	3.37	240	168	168	0.8	0.8
Wamikira	0.48	1.3	1.3	560	237	310	5.1	5.1
Wassa	0.57	0.2	0.35	100	206	398	3	0.9
Sironko	1.67	1.66	0.98	240	144	863	1.4	6
Simu	2.06	2.58	2.88	500	226	394	0.9	2.7
Sipi	1.36	2.51	2.51	940	141	153	7.3	7.3
Cheptui	1.85	1.41	1.41	700	381	936	2.5	2.5
Tabok	0.54	0.48	0.48	240	317	352	1.4	1.4
Siti	1.91	1.81	1.81	550	499	507	0.9	0.9
Bukwa	2.00	1.89	1.89	300	233	513	0.3	0.3
Ririma	0.43	0.49	0.49	500	301	714	0.5	0.5
Lwakaka	1.68	1.86	2.08	600	355	259	1.1	3.2

With the use of the same design criteria and runoff map, the computed capacities from the GIS system are significantly different from those obtained from the desk study but with no clear trend in the variation. In an attempt to verify what may be the cause for the discrepancy, examples of the projects studied will be discussed here.

A case in point is Lubilia where the desk study computed the capacity as 13.3 MW at an intake point whose average flow was 0.79 m^3/s and head of 760 m. Using the 5 km^2 search area, the GIS identified an intake at the same point implying the same flow but the head was 210 m leading to a capacity of 4 MW. In this case, the search area seems to have an effect on the head and hence differences in the capacity. A close intake (0.3 km upstream of the desk study point) identified using the 10 km^2 search area on the other hand yielded project with 10 MW at a head of 629 m and flow of 0.67 m^3/s. Differences in head and differences in the intake point played a role in the variation of the computed capacities

At a flow rate of 0.5 m^3/s and head of 1000 m, the desk study computed the capacity for Nyahuka as being 11MW. An intake point 0.6 km upstream which was identified using 10 km^2 search area with a head of 1095 m and a flow rate of 0.36 m^3/s lead to a capacity of 9.3 MW.

Again, the search area could have limited the choice of intake and head hence causing the differences in the computed capacities

6.1.3 Existing Capacity Vs GIS potential

The graph in *Figure **6**:**3*** below is a representation of the existing installed capacities for some projects and what the GIS program gives as the potential on the same rivers.

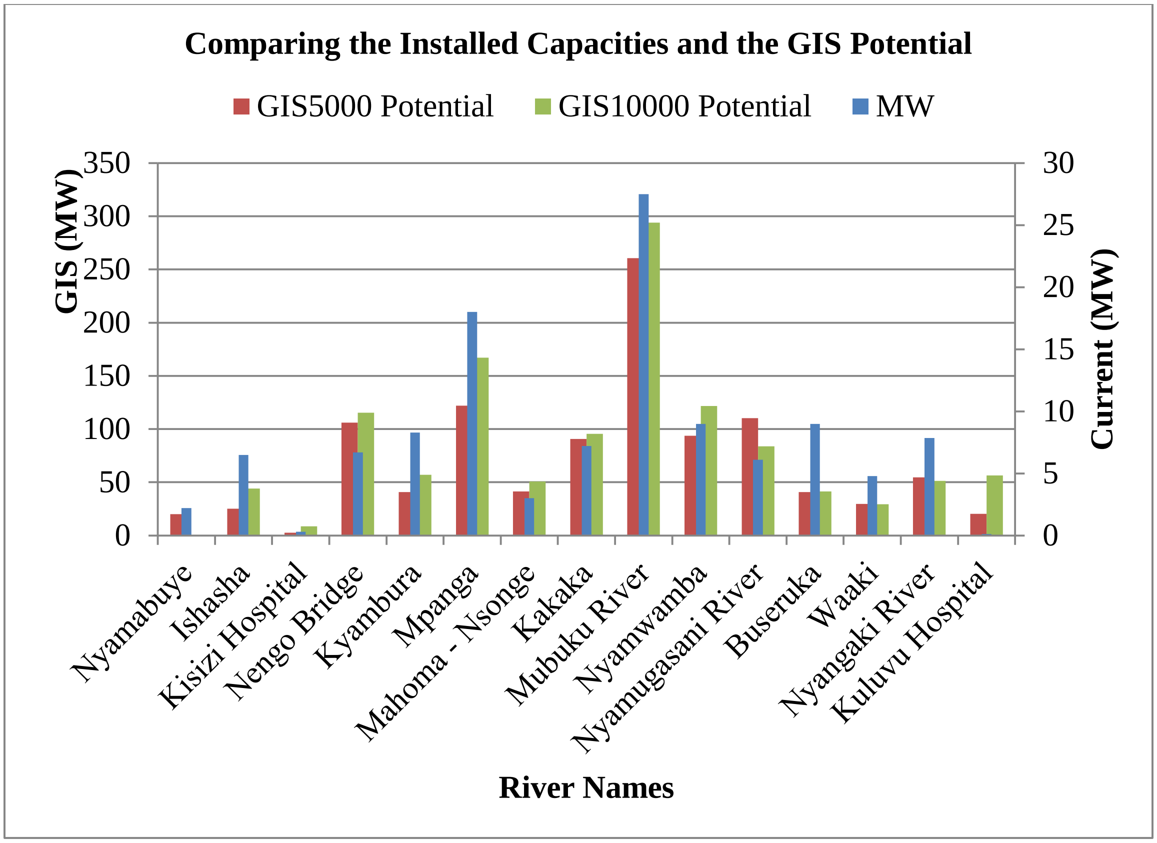

Figure 6:3: GIS Potential Capacities Vs Installed Capacities

*Table **6**:**3*** indicates the number of projects that the GIS system proposes along each of the selected rivers in comparison to what already exists.

Table 6:3: Number of Sites proposed by the GIS system on each River

River Name	Current		GIS5000 Potential		GIS10000 Potential	
	MW	No. of sites	MW	**No. of Sites**	MW	**No. of Sites**
Nyamabuye	2.2	1	20.1	1	0	0
Ishasha	6.5	1	25.06	4	44	3
Kisiizi Hospital	0.3	1	2.5	1	8.6	3
Nengo Bridge	6.7	1	106	5	115	5

River Name	Current		GIS5000 Potential		GIS10000 Potential	
	MW	No. of sites	MW	**No. of Sites**	MW	**No. of Sites**
Kyambura	8.3	1	40.9	7	57.1	5
Mpanga	18	1	121.9	11	167	11
Mahoma - Nsonge	3	1	41.4	4	50.8	2
Kakaka	7.2	1	90.8	7	95.5	3
Mubuku River	27.5	3	260.7	8	293.9	5
Nyamwamba	9	1	93.6	4	121.6	4
Nyamugasani River	6.1	2	110.3	5	83.8	2
Buseruka	9	1	40.7	4	41.5	3
Waaki	4.8	1	29.8	3	29.5	2
Nyangaki River	7.86	2	54.8	8	51.3	4
Kuluvu Hospital	0.12	1	20.3	3	56.5	3
Nile River	630		2409.4	11	0	0

The GIS indicates the hydropower potential that is in the range between 5 to 100 times more than the installed capacities. This could be explained by the greater number of sites that the GIS propose on each river as compared to what already exists (see *Table **6:3***). The number of sites is also dependent on the search area used by the GIS system with the 5 km^2 search area identifying more intakes but not necessarily giving a greater potential than the 10 km^2 search area. As argued out in the previous sections, the large differences in the potential and what exists is as a result of a number of factors such as differences in hydrology, design principles used in the two cases in terms of making the choice of the design discharge and efficiency. It worth noting that the GIS also includes sites in areas that may have restrictions for development in some cases and this too causes the disagreements in the generation capacities. A few cases like that of Nyamabuye, using the 10 km x 10 km did not locate any project on this river. This gives an indication that increase affects the choice of best projects. Another river within the same search area produced more power and therefore was chosen instead of the former identified using the 5 km x 5 km search area.

6.2 Intake Locations

6.2.1 Intakes of GIS program Vs Existing Projects

To be able to compare how well the GIS program chooses the intakes, the distances between the intakes of the already studied sites and the closest intake of the GIS were measured and presented in ***Figure 6:4*** and ***Figure 6:5*** below to give an indication of how far apart they are from the actuals. Note that the intakes of the studied projects are the starting points and the two GIS search criteria of 10 km^2 and 5 km^2 is compared based on them.

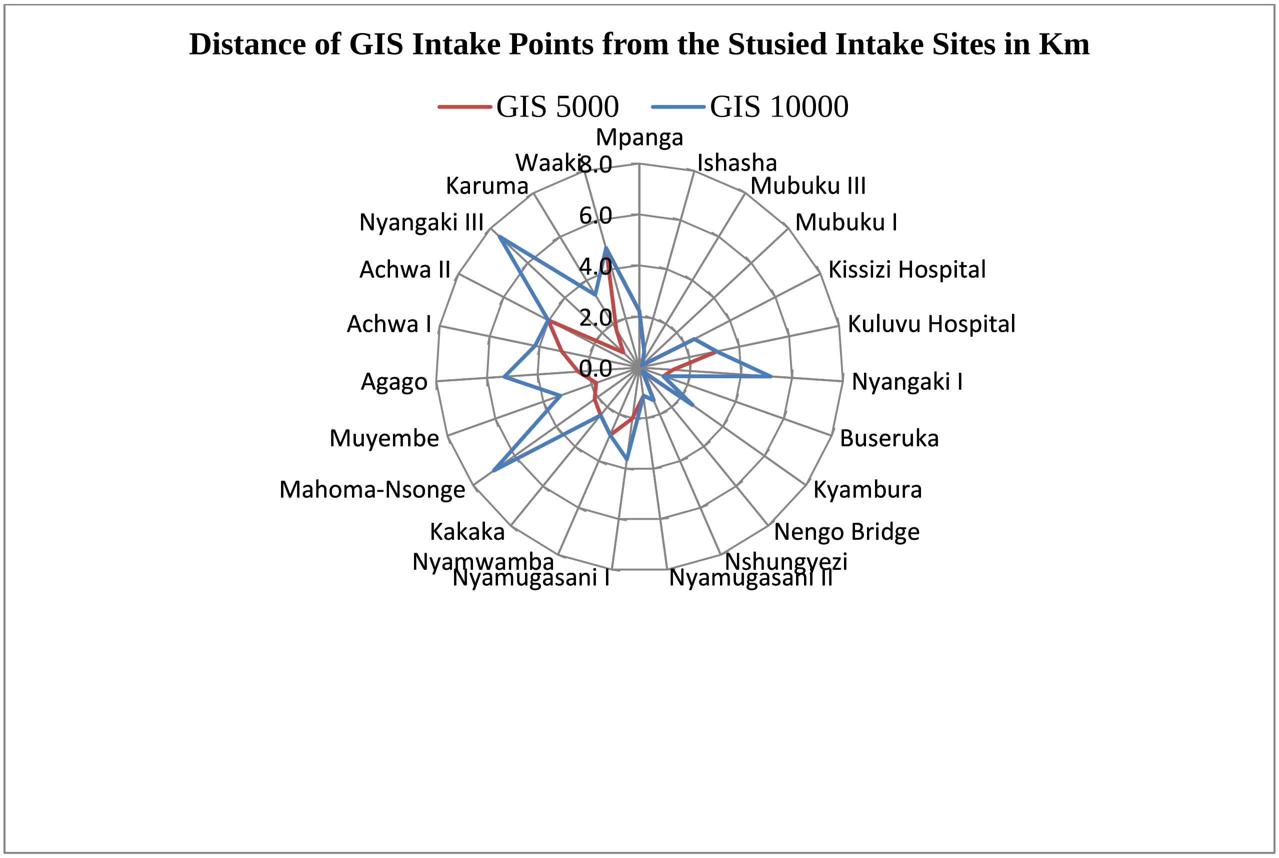

Figure 6:4: Distance of GIS intakes from the intakes of the existing projects

6.2.2 Intakes of GIS program Vs Desk Study Projects

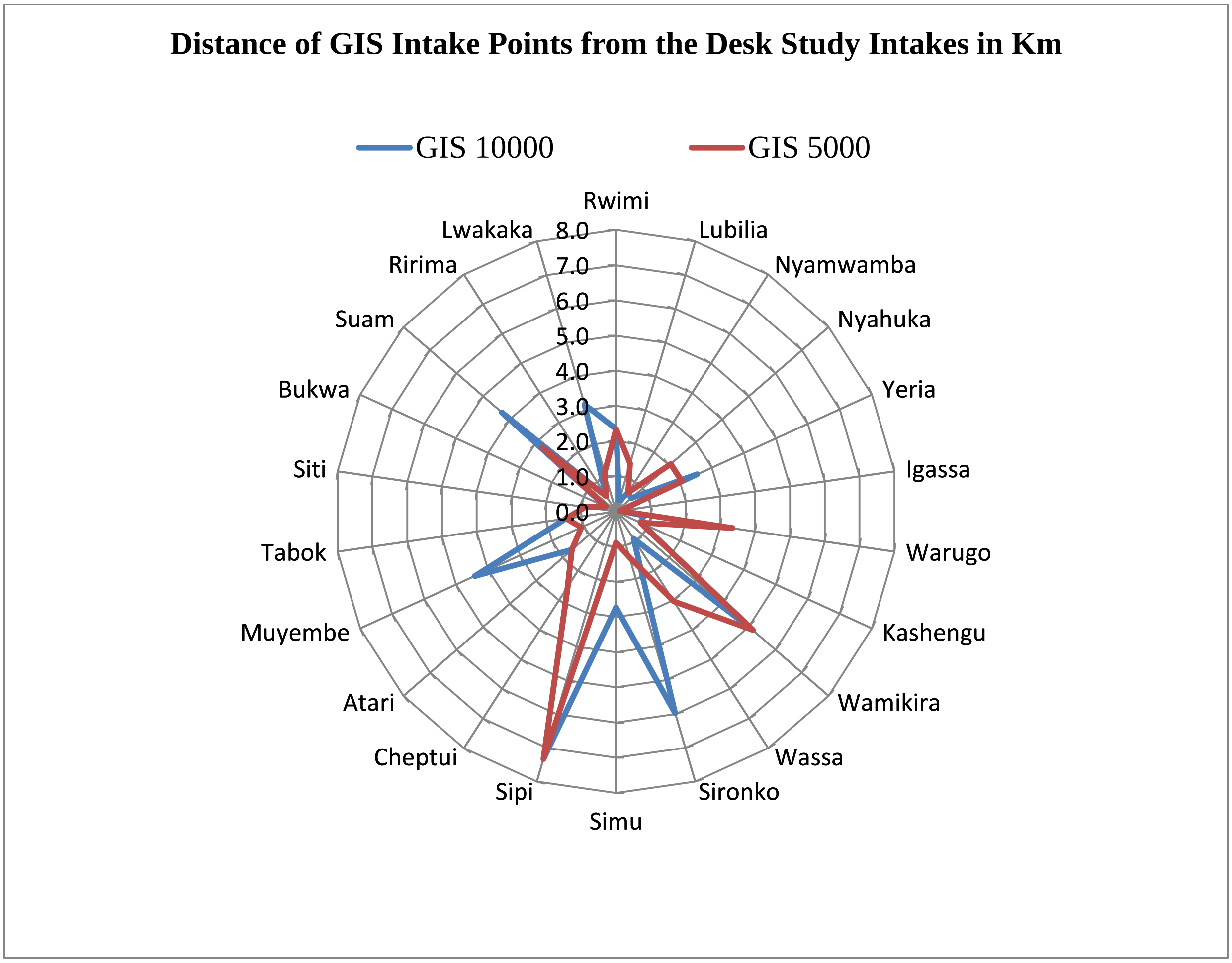

Figure 6:5: Distance of the GIS intakes from the intakes of the Desk study projects

Figure 6:6 shows the number of intakes identified by the GIS system as a percentage in relation the how far apart they are from the studied/existing intakes

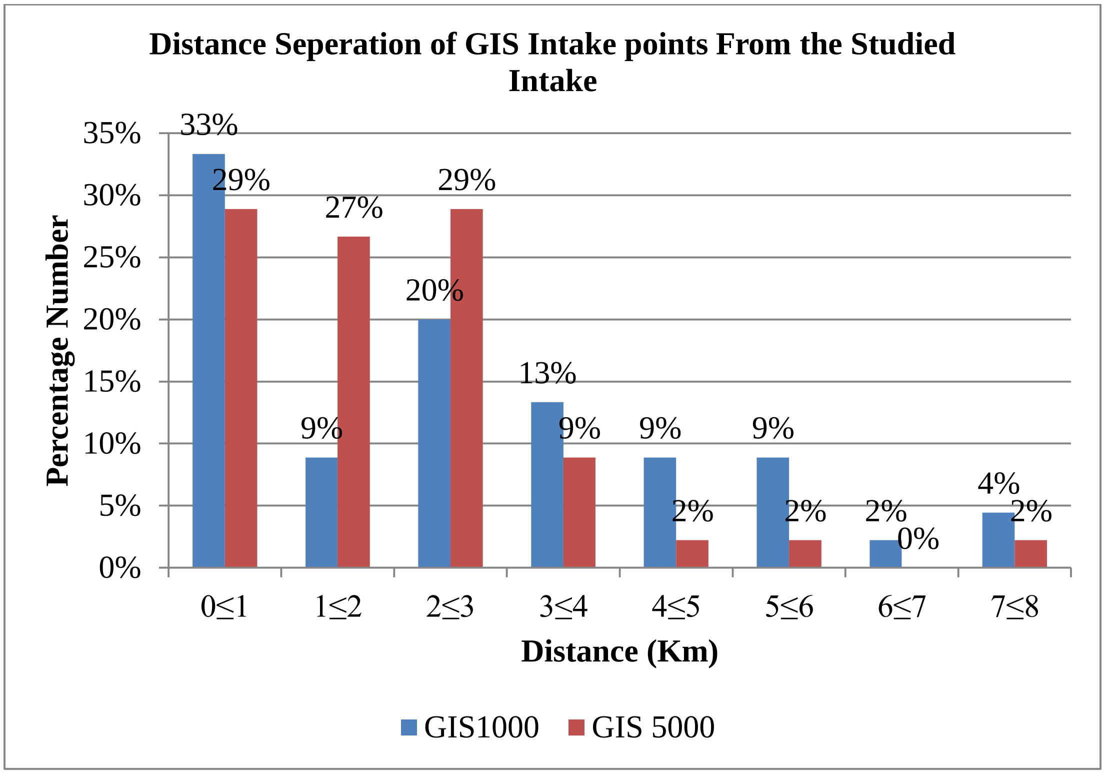

Figure 6:6: Percentage number of the GIS intakes in a given distance range

33% of the intakes identified using the 10 km^2 search area lied in the range of 0 to 1 km while 29% of those identified using the 5 km^2 search area. However, in the closest 3 km, the 5 km^2 search area gives a greater percentage of 85 as opposed to using the 10 km^2 which gives 62% total.

The closest of all intakes was the case of Mubuku I shown in *Figure **6:7*** using 5 Km^2 as the GIS search area 0.1 km away while the furthest of all was the case of Nyangaki I shown in *Figure **6:8*** using the 10 km^2 search area with 7.5 km a ways.

Figure 6:7: Mubuku Intake Points

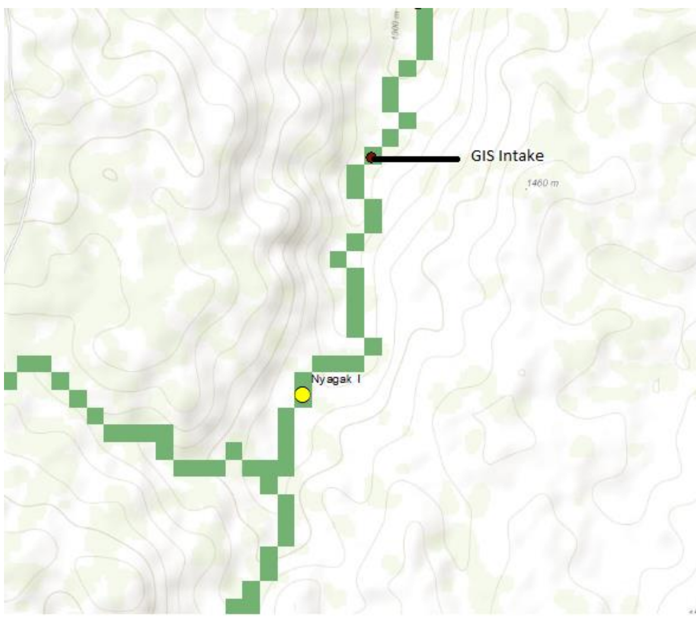

Figure 6:8: Nyangaki Intake Points

Again, the differences in the location of intakes seem to be as a result of the search criteria chosen by the GIS.

Whereas the choice of an intake from the desk studies was based on an maximum power but along the entire river section, i.e. optimization process in which all potential intake points along a stream were tested and the best alternative chosen, the choice of the intake sites by the GIS program was based also on maximum power production but within each grid area. The point that gives the maximum power within each grid is automatically taken as an intake point. The number of sites therefore, depends on the grid area that is decided into the program system.

6.3 Energy Generation

The Annual energy production in terms of GWh was assessed and the results presented in graphical formats below; please, note that there was limited data in relation to installed energy for the existing projects. For purposes of this study, The GWh for the data base projects have been estimated from the installed capacities using the assumption of 55% utilization factor as assumed in the GIS system.

6.3.1 Generation of GIS program Vs Studied Projects

Figure 6:9 below shows the comparison of annual GWh from the existing projects with those obtained by the GIS system.

This comparison will try to consider those projects that used quite similar runoff values for a better picture of how the GIS program estimates the energy generation in comparison with the existing records.

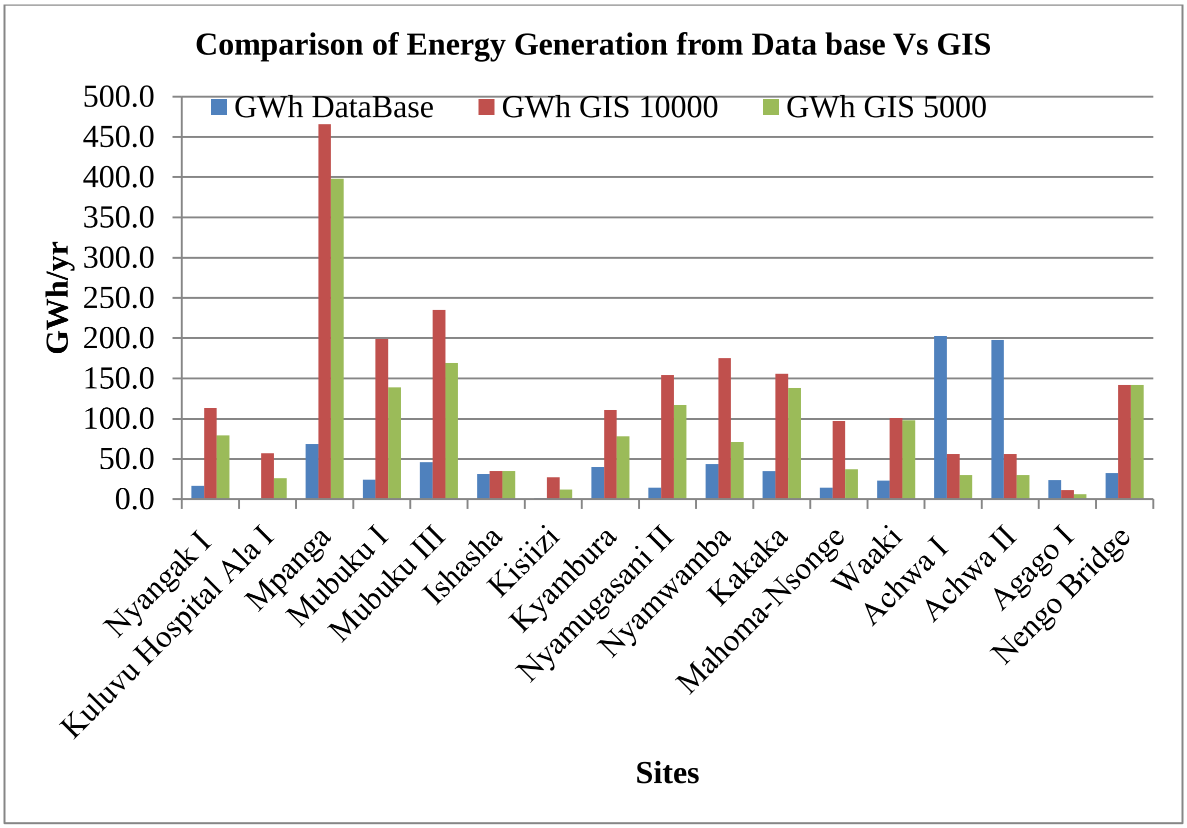

Figure 6:9: Comparison of Energy generation between GIS and the Existing projects

Drawing closer to Ishasha. Kakaka and Nengo Bridge. *Table **6:4*** below show the energy values for the three projects obtained from the database and the GIS.

Table 6:4: Energy for Ishasha, Kakaka, Nengo Bridge

Site Name	GWh DataBase	GWh GIS 10000	GWh GIS 5000
Ishasha	31.3	35	35.0
Kakaka	34.7	156.0	138
Nengo Bridge	32.3	142.0	142

The energy generation from the GIS system greatly varies from that estimated by the data base but a similar argument as that causing the variation in capacities could apply since the data base energy was computed directly from installed capacities.

In comparison to the existing projects, the greatest variation in terms of energy production was that of Kuluvu Hospital Site in which 10 km^2 search criteria was 98 times more than the energy as estimated from the database capacity while Ishasha gave similar generations in all cases with a GIS factor of 1.1 times greater than the values from the data base. For the case of Nengo Bridge, the GIS energy value exceeded by a factor of 4.4 times that of the data base

The differences in energy cropped from differences in the computed capacities which as discussed earlier is a result of differences in the choice of design discharge (either low flows or average), choice of the maximum design capacities (with or without a factor say 2.5 of the average flow), to differences in head. With no records of the actual energy production details, it therefore makes it difficult to draw conclusions comparing the two outcomes.

6.3.2 Generation of GIS program Vs Desk Study

*Figure **6:10*** below shows a plot of annual GWh computed for the desk study projects in comparison to those obtained by the GIS system. It is worth noting that the desk study considered 75 % utilization time for the sites in the Rwenzori region and 64% for the sites in the Elgon region while the GIS system assumed 55% utilization time for all projects. The GIS figures presented in this graph were therefore multiplied by factors of 1.4 and 1.2 for sites in Rwenzori and Elgon areas respectively for a better assessment.

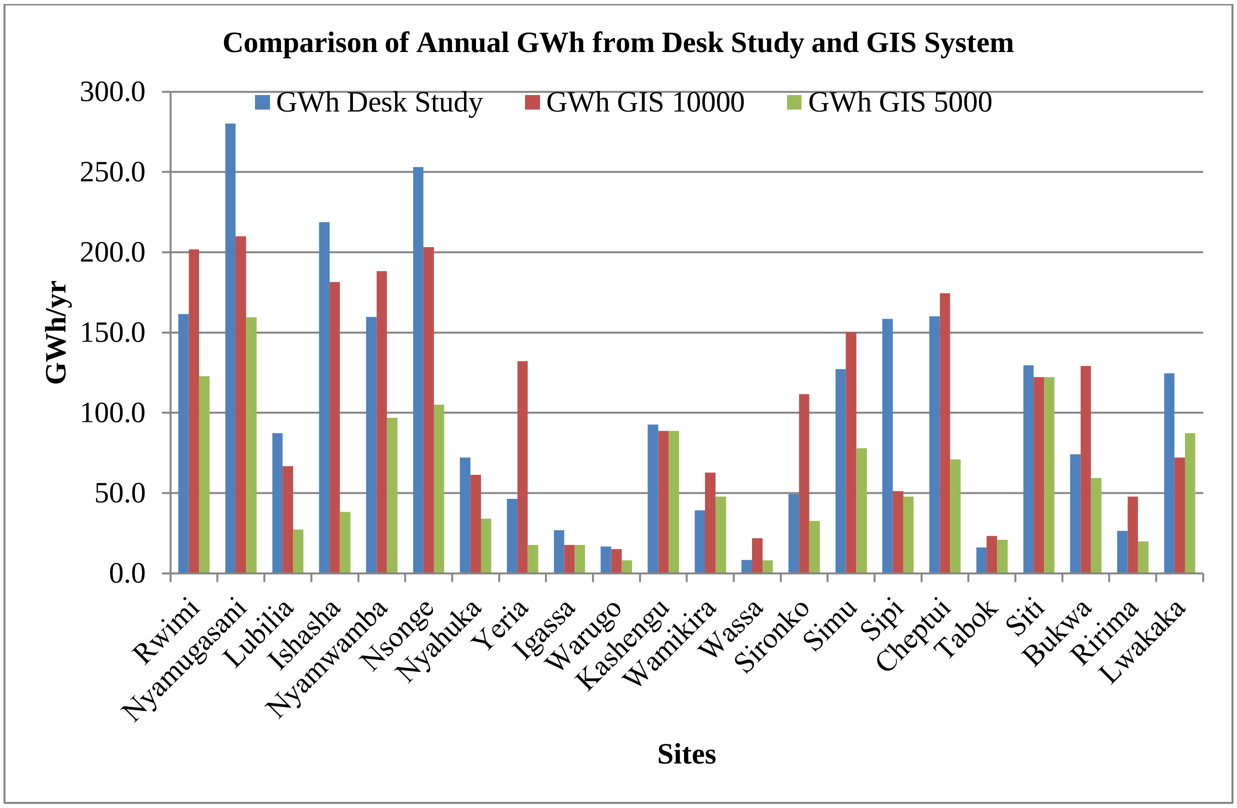

Figure 6:10: Comparison of Energy Generation between GIS and the Desk Study

The graph shows a variation in energy generation for all cases presented here. The trend is similar to the variation the capacity discussed under section 6.1.2 and the differences could be probably explained by the same factors. However, there seems to be a tendency of agreement for the two results whenever the flow values were close to one another. This there calls for a need to improve the hydrological data.

6.4 Head

6.4.1 Head of GIS Sites Vs Existing Projects

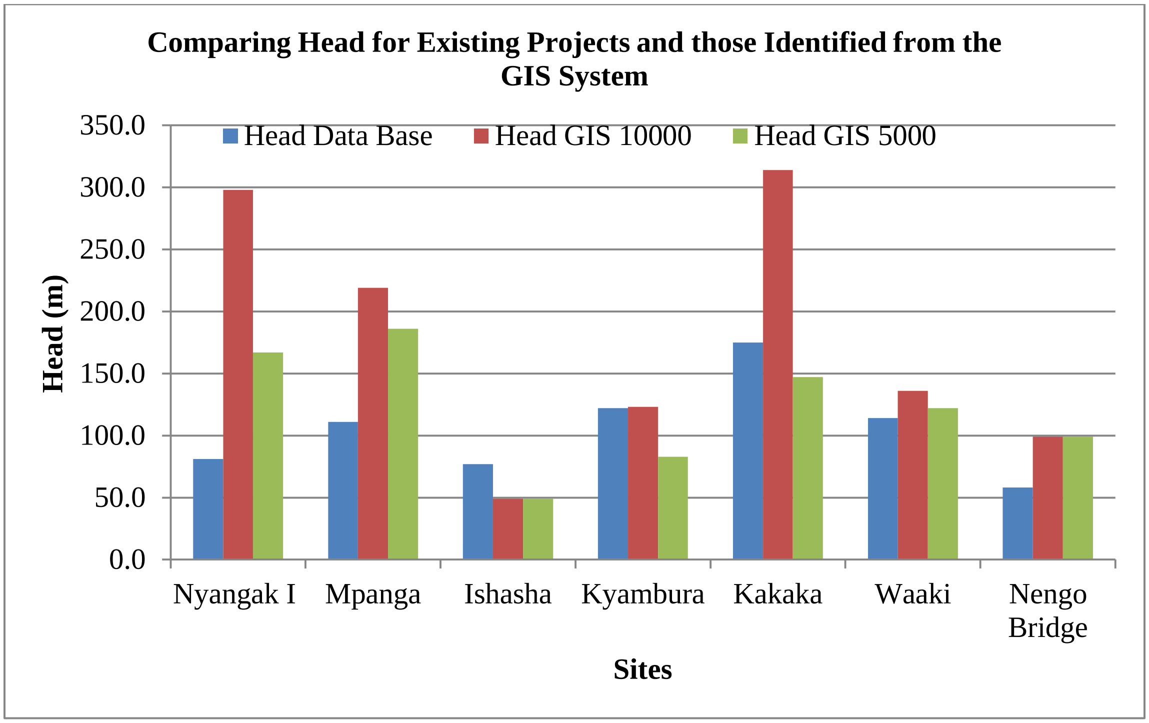

Figure 6:11: Comparison of Head between GIS and existing Projects

Head variations were in the range between 0 and 300 m. The variation magnitude as seen from the graph above was dependent on the GIS search area used. This case, the 10 km^2 search area always varied greatly as compared to the 5 km^2 search area. The bigger the search area, the higher the head. Adding an optimization algorithm instead of just choosing the intake with maximum power value would be of a benefit.

6.4.2 Head of GIS Program Vs Desk Study Projects

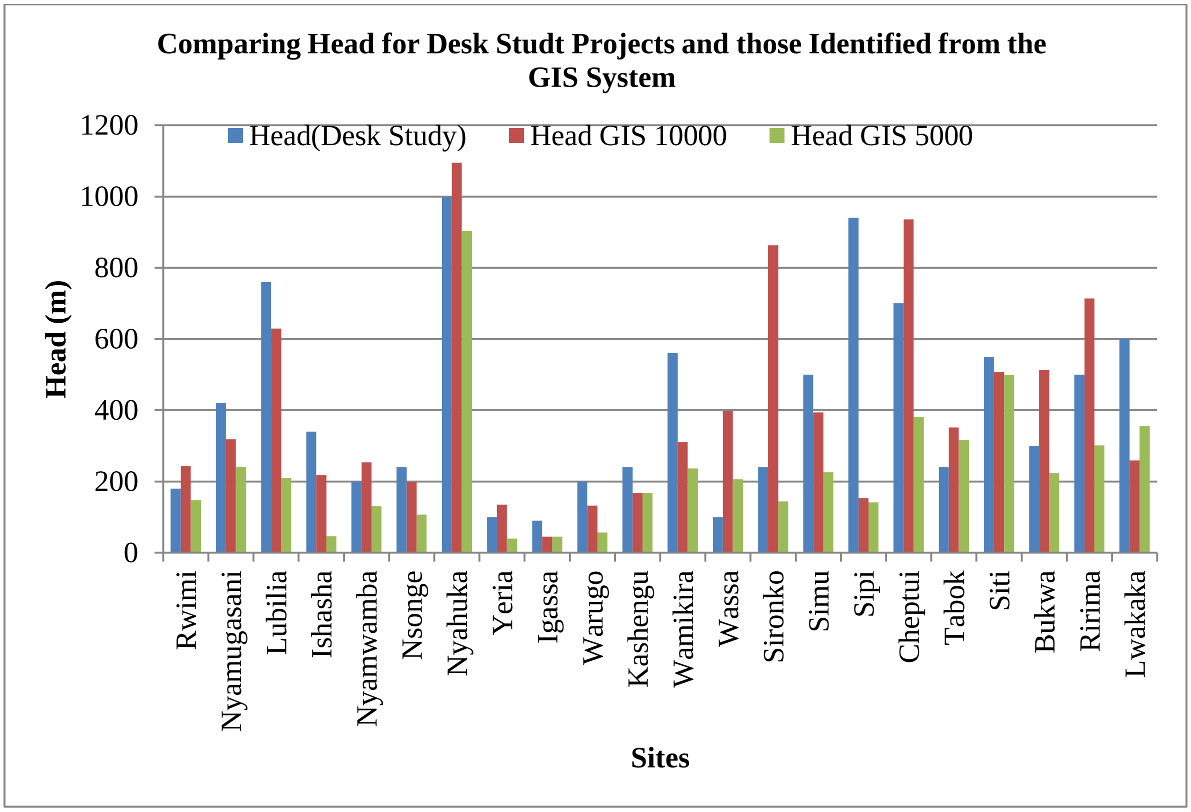

Figure 6:12: Comparison of Head between GIS and Desk study Projects

Similarly, there is no clear variation trend of the head. However, the differences could be attributed to the fact that the desk study intake choice based on an optimization criteria of all possible intakes along the river while the GIS optimization was within each search area. The GIS therefore ended up with several intakes depending on the search area used. I.e. the head and length of waterway was limited by the size of the search area.

6.5 Economic Parameters

Figure 6:13 below shows the comparison between NPV for the same projects as identified by the desk study, GIS 10 km^2 and GIS 5 km^2. Both methods assumed 15% interest rate, 5% operation and maintenance costs every year, and a project life time of 25 years

Both methods gave positive npv values of different magnitude except for the case of Atari, Siti and Lwakhakha where the desk study indicated a negative npv.

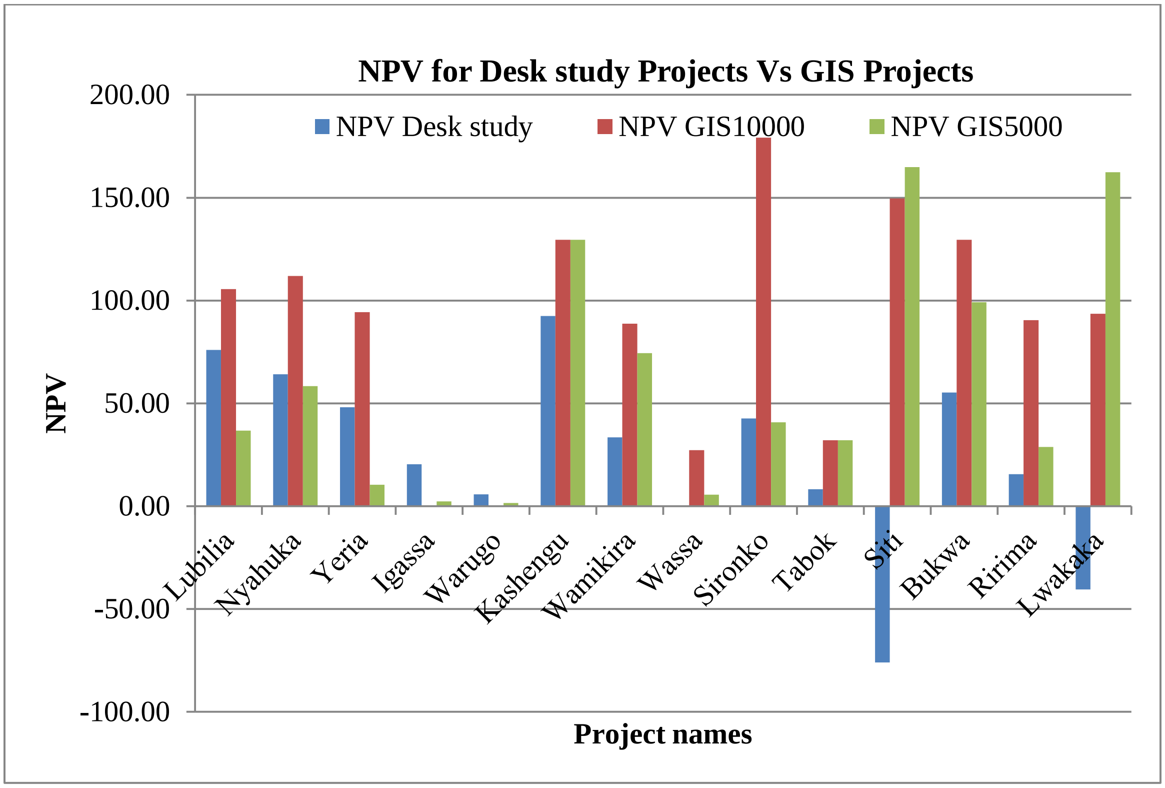

Figure 6:13: Comparison of Net Present Values

Table *Table 6:5* show the energy generation for the projects whose economic parameters are being compared

Table 6:5: Energy Generation for projects under economic comparison

River Names	Desk Study GWh	GIS 10000 GWh	GIS 5000 GWh
Lubilia	87.4	49	20
Nyahuka	72.1	45	25
Yeria	46.3	97	13
Igassa	26.9	13	13
Warugo	16.6	11	6
Kashengu	92.8	65	65
Wamikira	39.3	46	35
Wassa	8.3	16	6
Sironko	49.5	96	28
Tabok	16.1	20	18
Siti	129.7	105	105
Bukwa	74.1	111	51
Ririma	26.5	41	17
Lwakaka	124.7	62	75

The net present values for the Desk study projects are smaller in magnitude as compared to those obtained using the GIS system exept for Igassa and warugo. Generally, there is no clear trend in the variation because projects in which the desk study indicated a higher energy as compared to that estimated by the GIS like Lubilia are seen to show a lower NPV than what the GIS system estimates. The differences in project cost estimates could be the reason for the descrepancies with the desk study considering more project components during the cost estimates than the GIS system.

GIS determined npv in dollars and converted it to Norwegian Kroners using an exchange rate while the desk study worked directly in Norwegian Kroners, so the conversion from dollars to Norwegian kroners could be one of the reasons for the differences in findings. Also not forgetting the differences in generations which affect the benefits

7 LIMITATIONS, CONCLUSIONS AND RECOMMENDATIONS

Below are the limitations, conclusions and recommendations derived from the findings of this study.

7.1 Limitations

It is important to note the input data limitations in this research study. As previously stated, the most important limitation in this research is the inefficient hydrological data use. It was difficult to find a runoff map for Uganda that agreed with most of the runoff stations and as a result, there was need to develop one but there are uncertainties in the reliability of the developed map because Of the sparse station network that was used, the non-uniform length of data and other quality issues that could not be resolved during the study.

The flow records for the gauging stations used in the scaling process had a lot of gaps, as a result average flow values were estimated using only years with full data records for each gauging station. Elimination of some data periods would either overestimate or underestimate the annual average flow values that would directly impact on the findings.

Another yet important limitation was about the data base used in comparing the existing projects with the results from the GIS program. Some of the records for some projects such as flow, head were missing but for comparison purposes these had to be estimated using the available records. Also it was difficult to obtain all the feasibility reports about the existing projects to make reference to in the comparison. Only two reports could be found and they didn't cover all the projects.

7.2 Conclusions

The study aimed at verifying how well the GIS program identify the hydropower sites by comparing the choice of intake locations, computed capacity, energy generation and the computation of head. The main empirical findings are specific to particular chapter and were summarized within the respective chapters. This section will give a summary of the findings to give answers to the research questions.

The GIS program was able to identify potentially good hydropower sites close to all existing/studied projects. The capacities and energy generation were varying in magnitude but this could be explained by differences in the hydrology, utilization time and head of the sites.

Generally, the GIS program indicated a higher potential of hydropower for each river in comparison to what exists. The number of proposed sites was dependent on the search area set in the program. The smaller the search area, the more number of sites proposed by the GIS program but not necessarily giving higher potential than that identified using a bigger search area.

On average 74% of the GIS intakes identified were within a distance of 0 km to 3 km from the existing intake and intakes identified from the desk study.

The head sampled projects varied up to a magnitude of 300m. For some case, the studies proposed a higher head than what the GIS proposed and for other cases, the GIS head was greater than what the studied proposed. Generally, the 10 sq km search area of the GIS system always suggested a higher head than the 5sq km search area.

In spite of the differences in magnitude of the finding, it can be concluded that the GIS system can able identify potential hydropower sites subject to a detailed study to assess the potential and further decision making.

7.3 Recommendations to the GIS Program

The following are recommended;

- To consider running the GIS program with several search other search areas to establish the one that gives the best results for a particular topography.
- To run the program for a small catchment using a small DEM resolution say 90m to assess how well the program choses the intake point.
- To compute regional utilization factors that would be used in the calculation of energy generation for sites in particular regions of the country would help reduced the effect of a constant factor in all cases.
- To include an optimization algorithm in the GIS program that puts into consideration the economic feasibility of the projects as well in choosing the best instead of basing on just maximum power would be of an advantage.

7.4 Recommendations for further research

The following are recommended;

- The Hydrology should be verified and an up to date runoff map developed for use in the GIS program.
- Improve the hydrological data basis in the country

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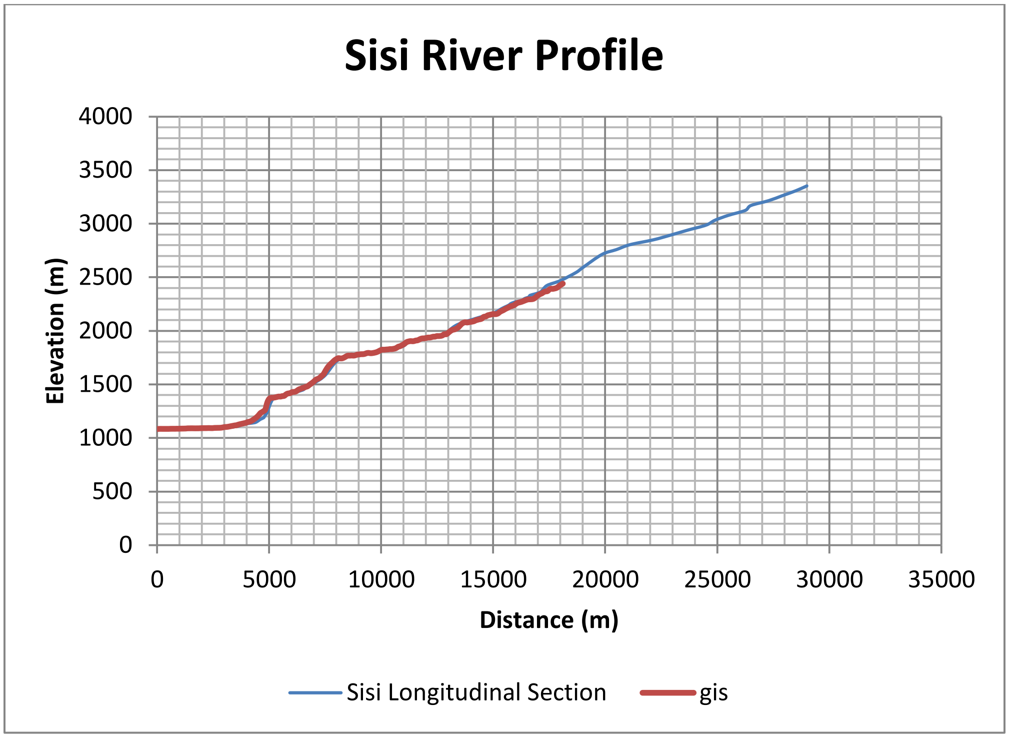
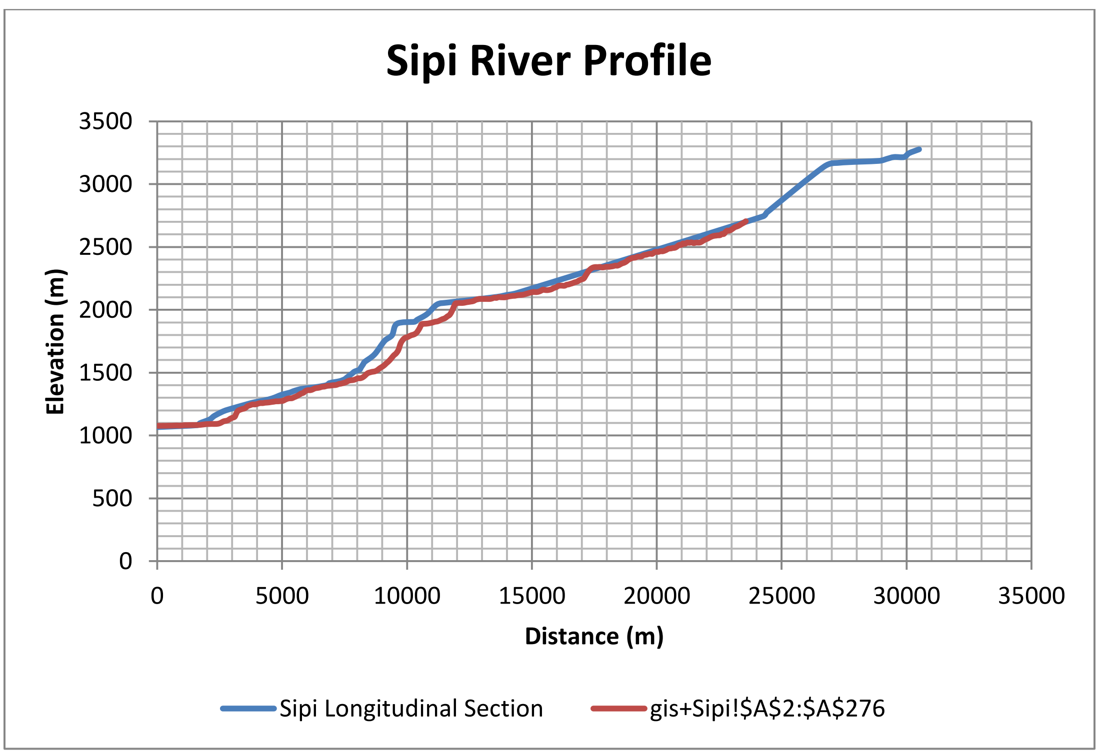
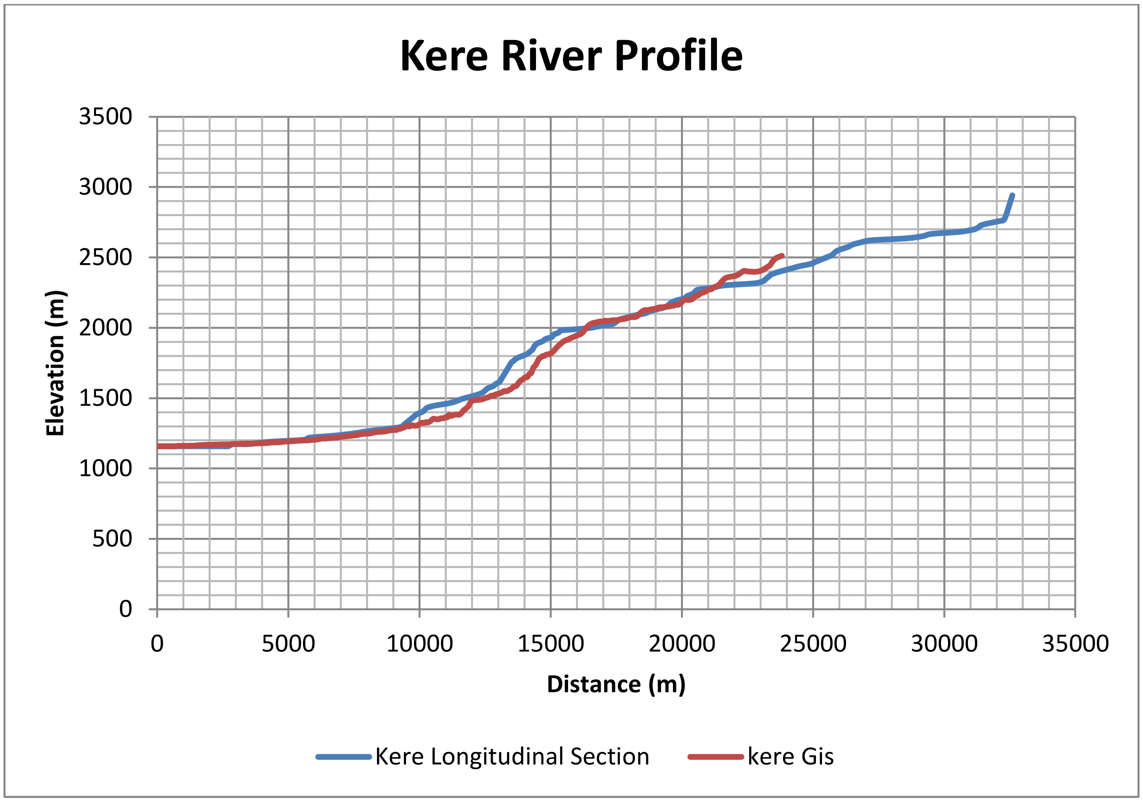
APPENDICES

Appendix A

GIS and hand river profiles plotted on the same graph



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Kere Longitudinal Section
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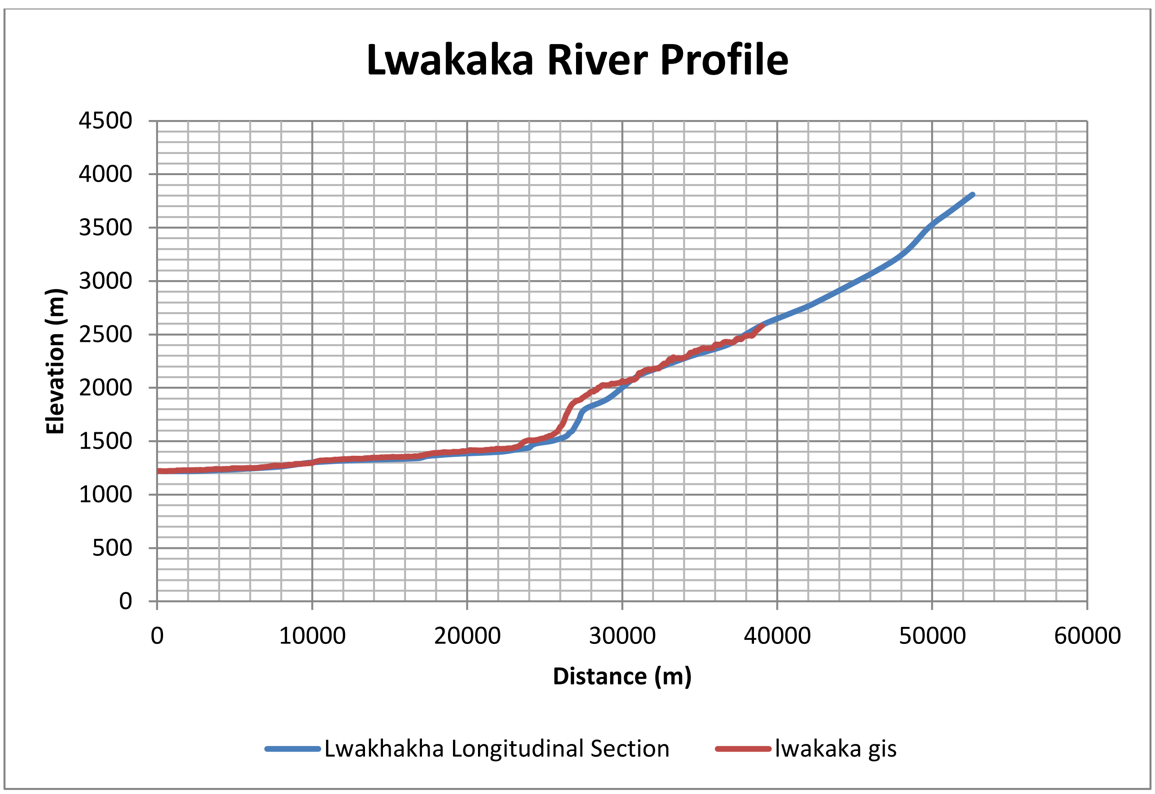
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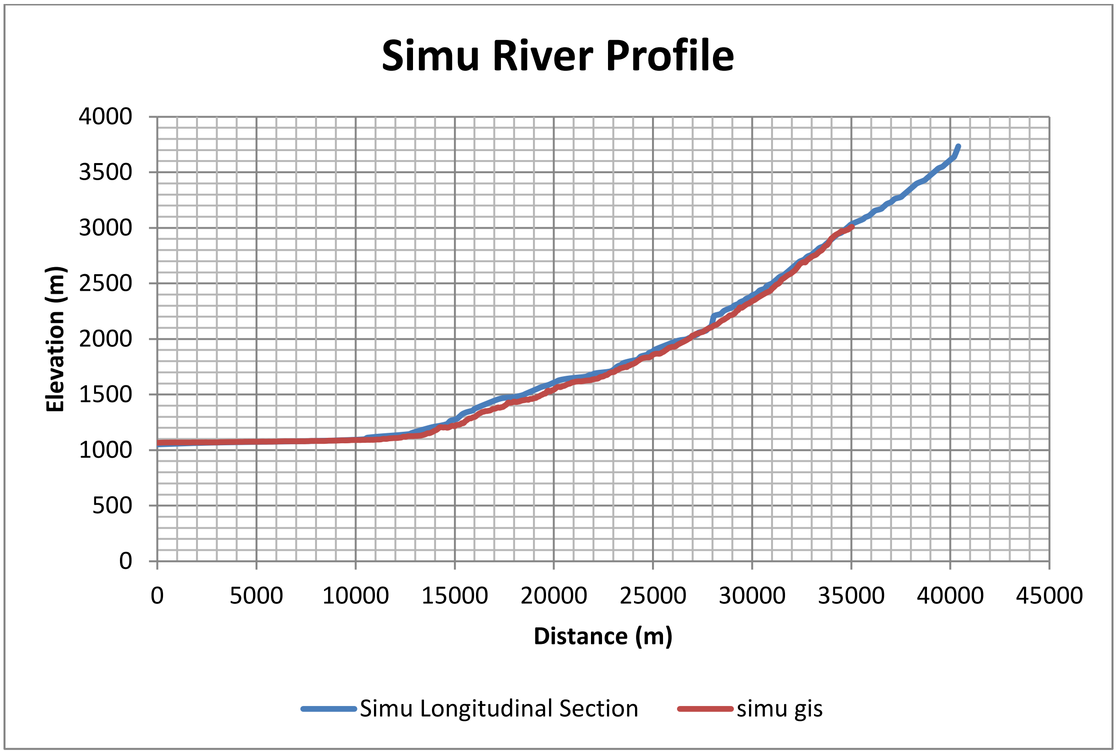
Distance (m)
Lwakhakha Longitudinal Section
lwakaka gis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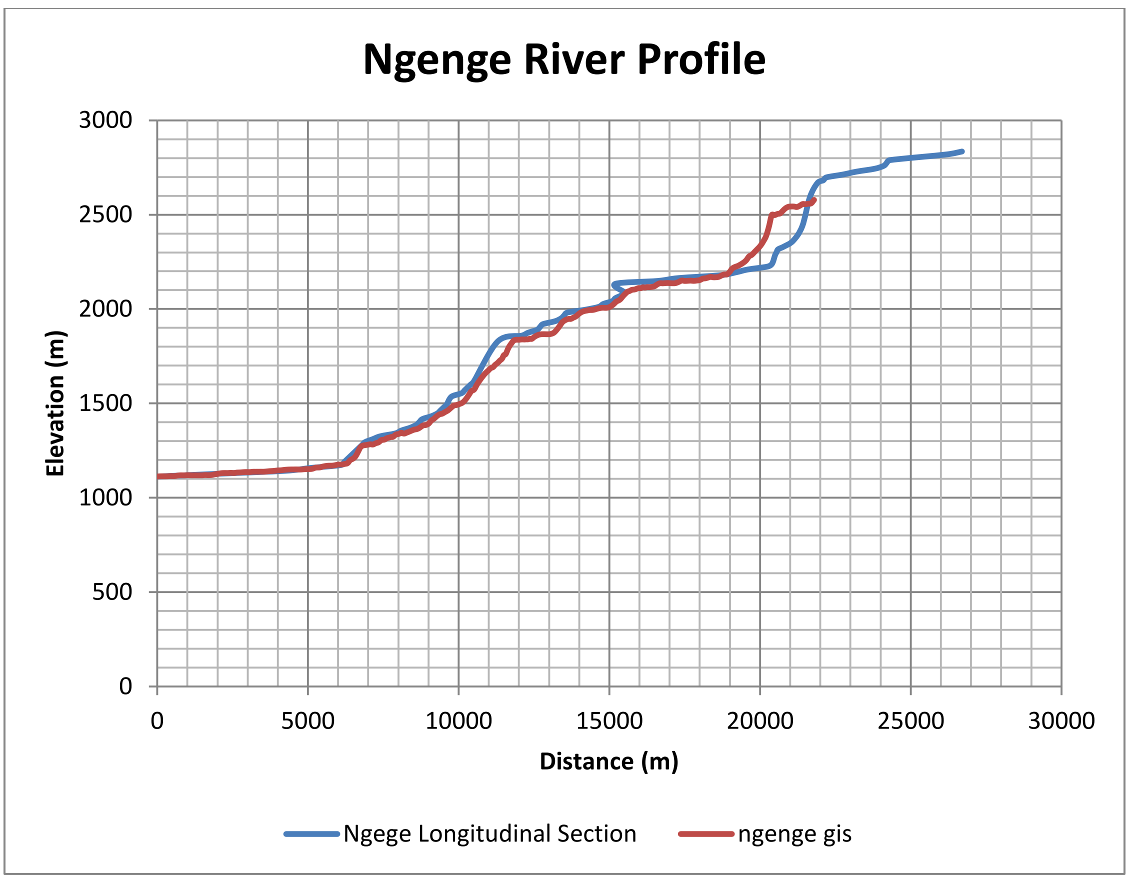
Distance (m)
Simu Longitudinal Section
simu gis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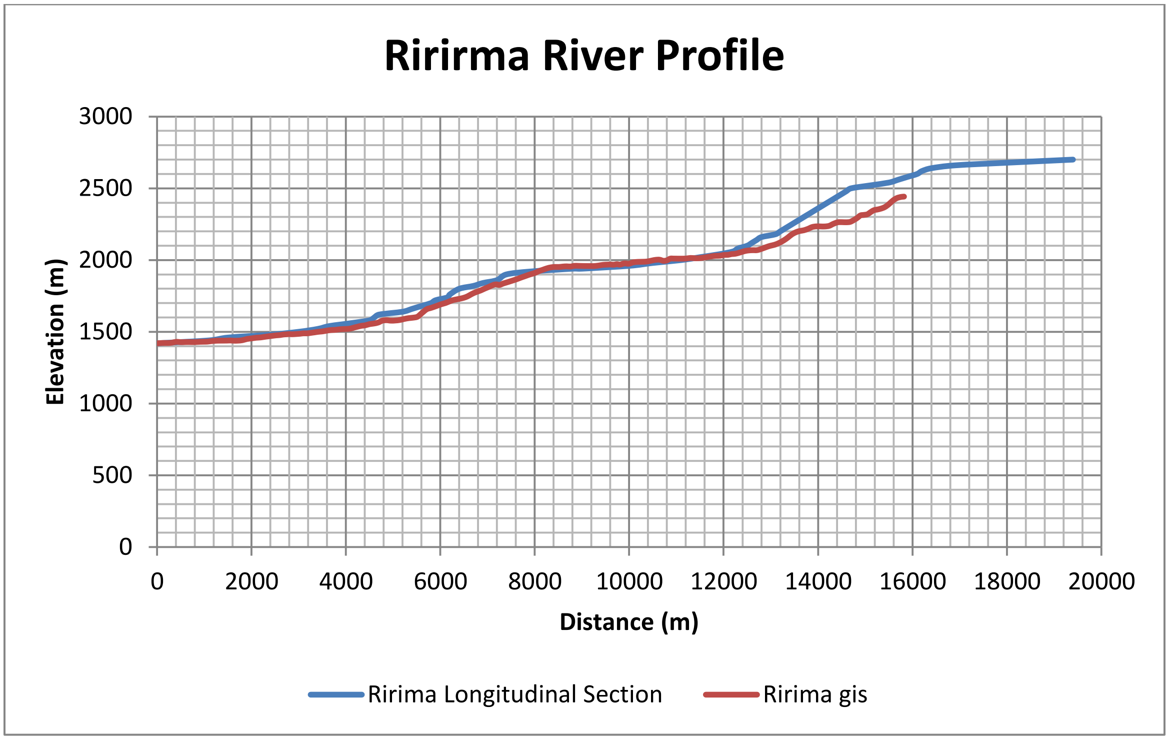
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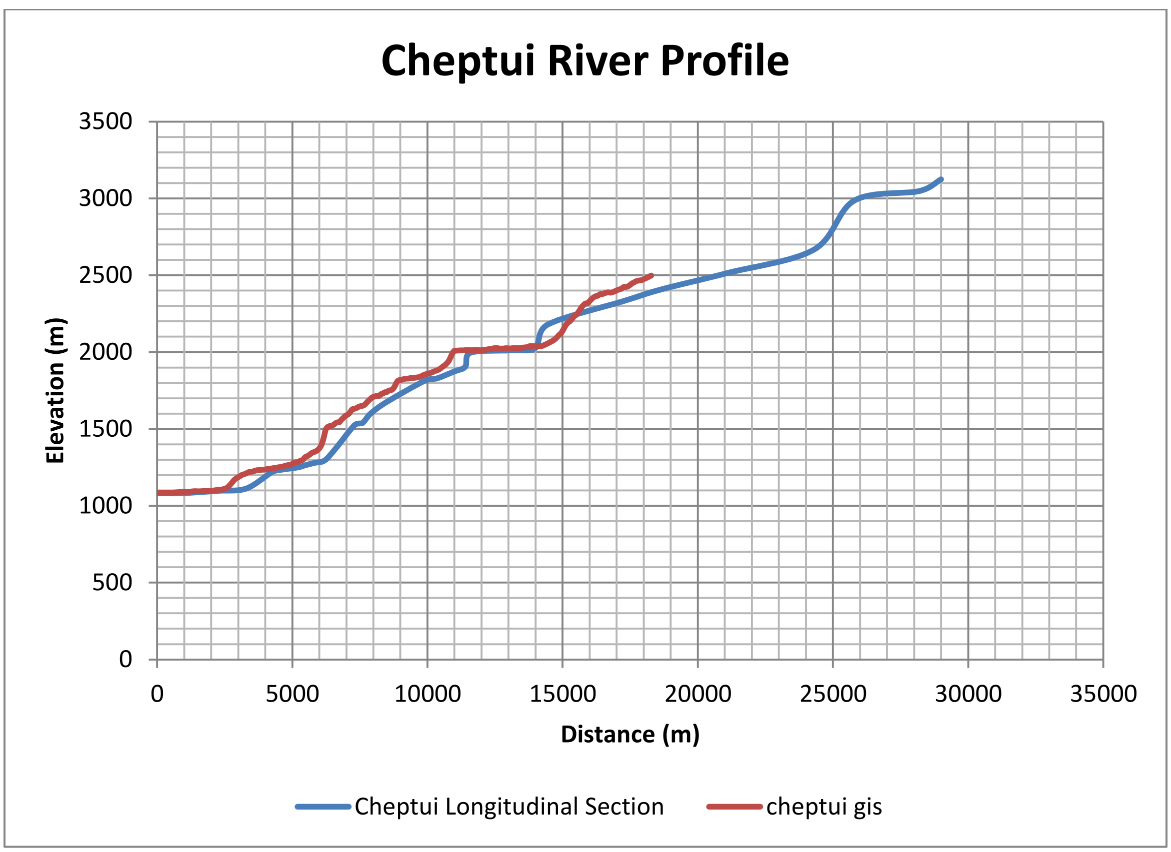
Ririma Longitudinal Section
Ririma gis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Cheptui Longitudinal Section
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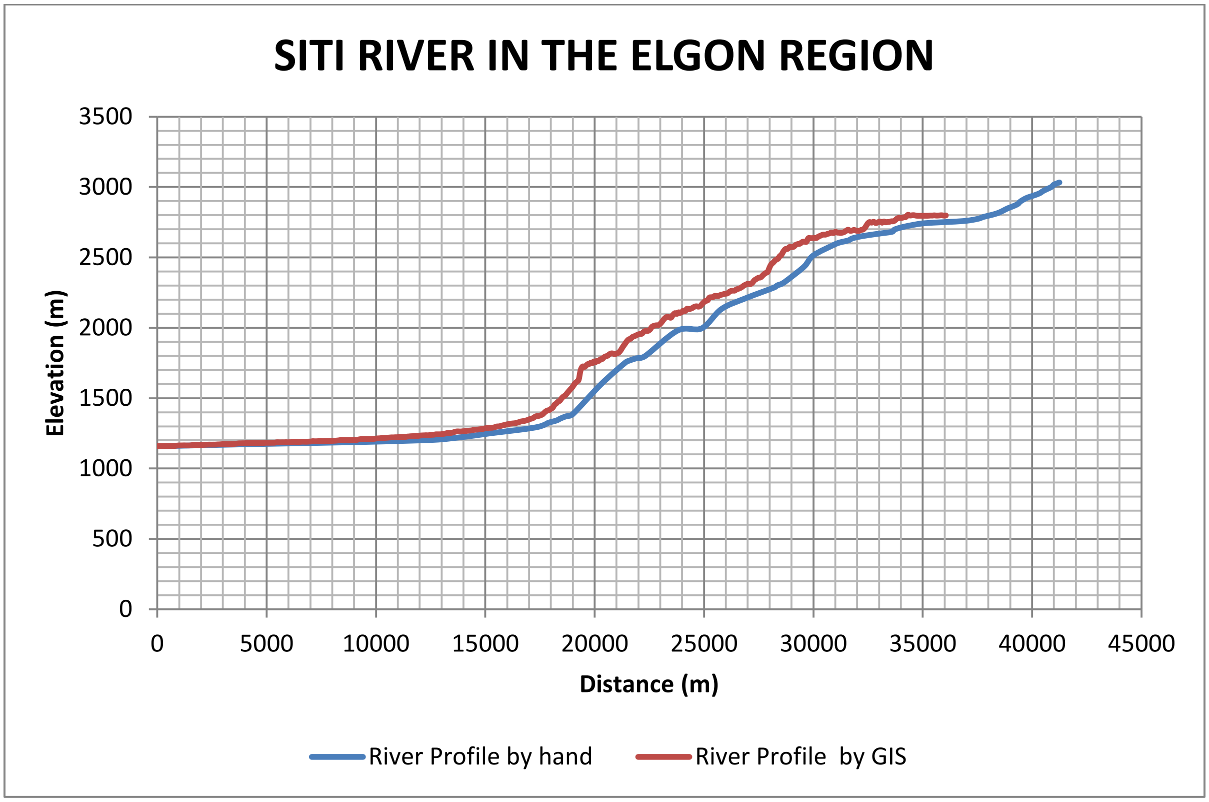
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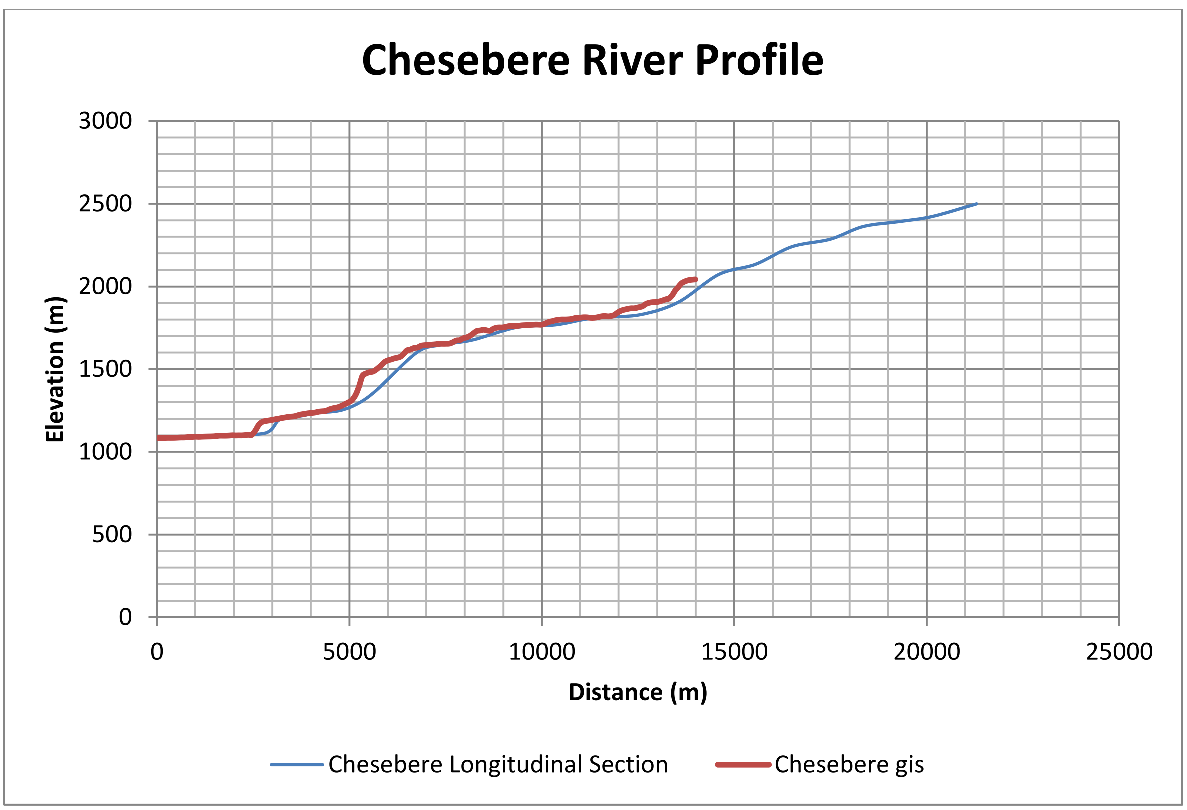
Distance (m)
River Profile by hand
River Profile by GIS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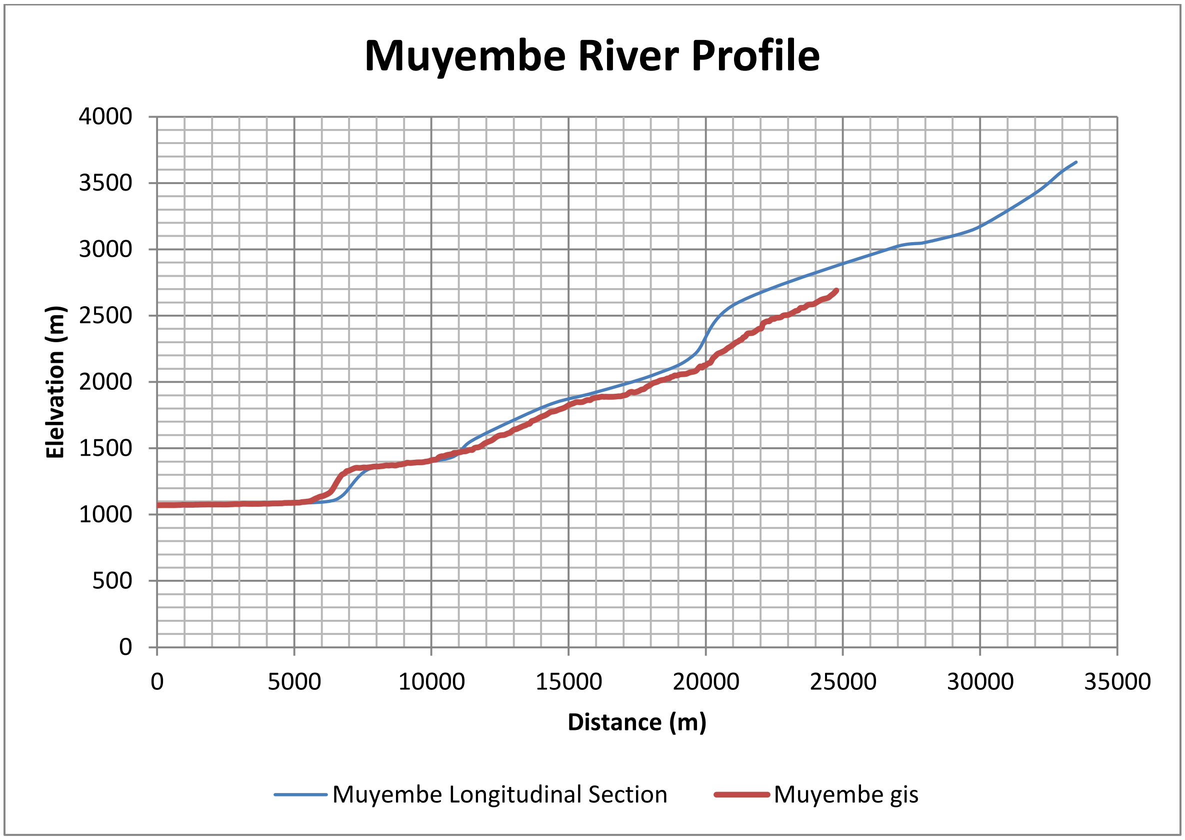
Chesebere gis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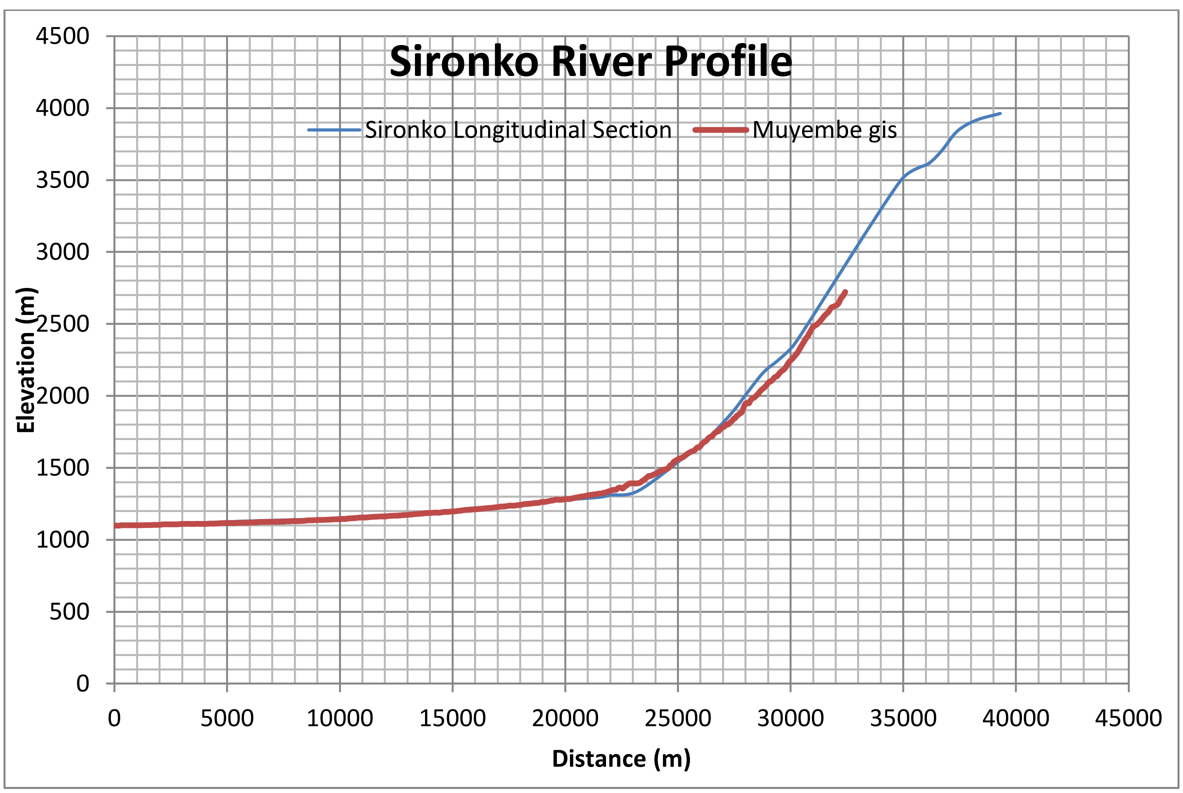
Distance (m)
Muyembe Longitudinal Section
Muyembe gis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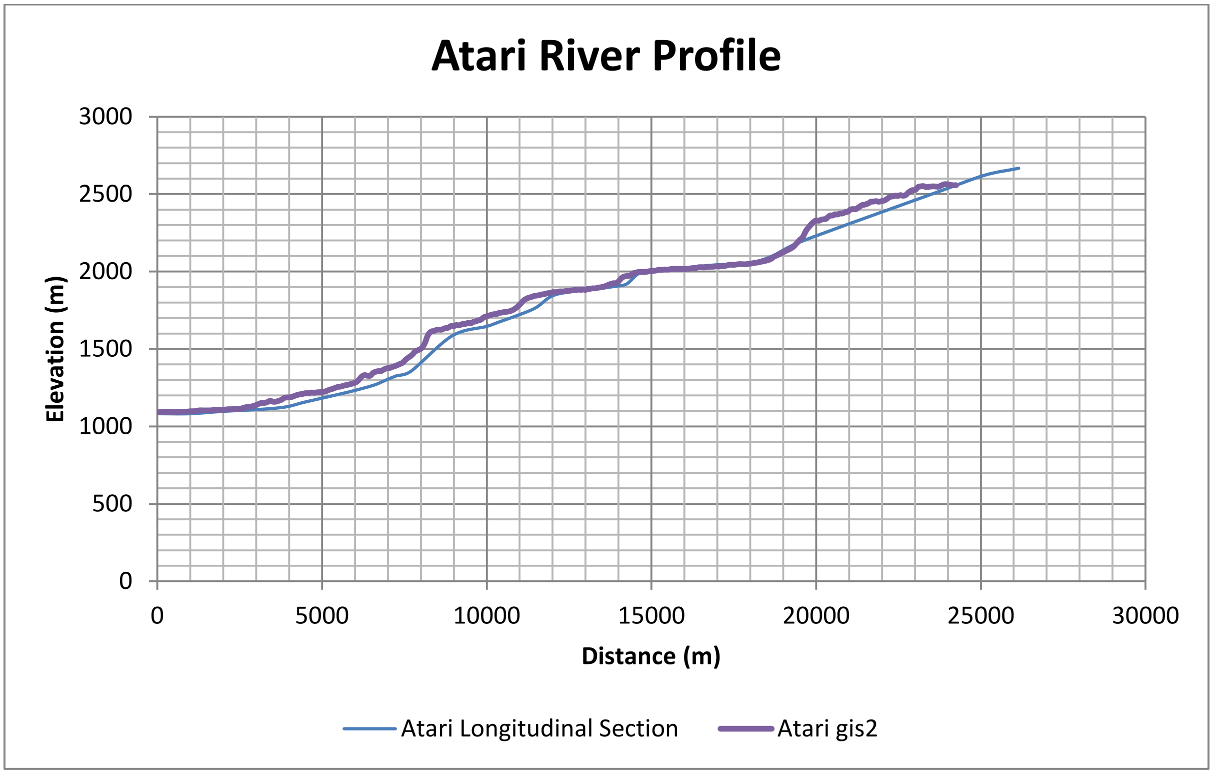
Atari River Profile
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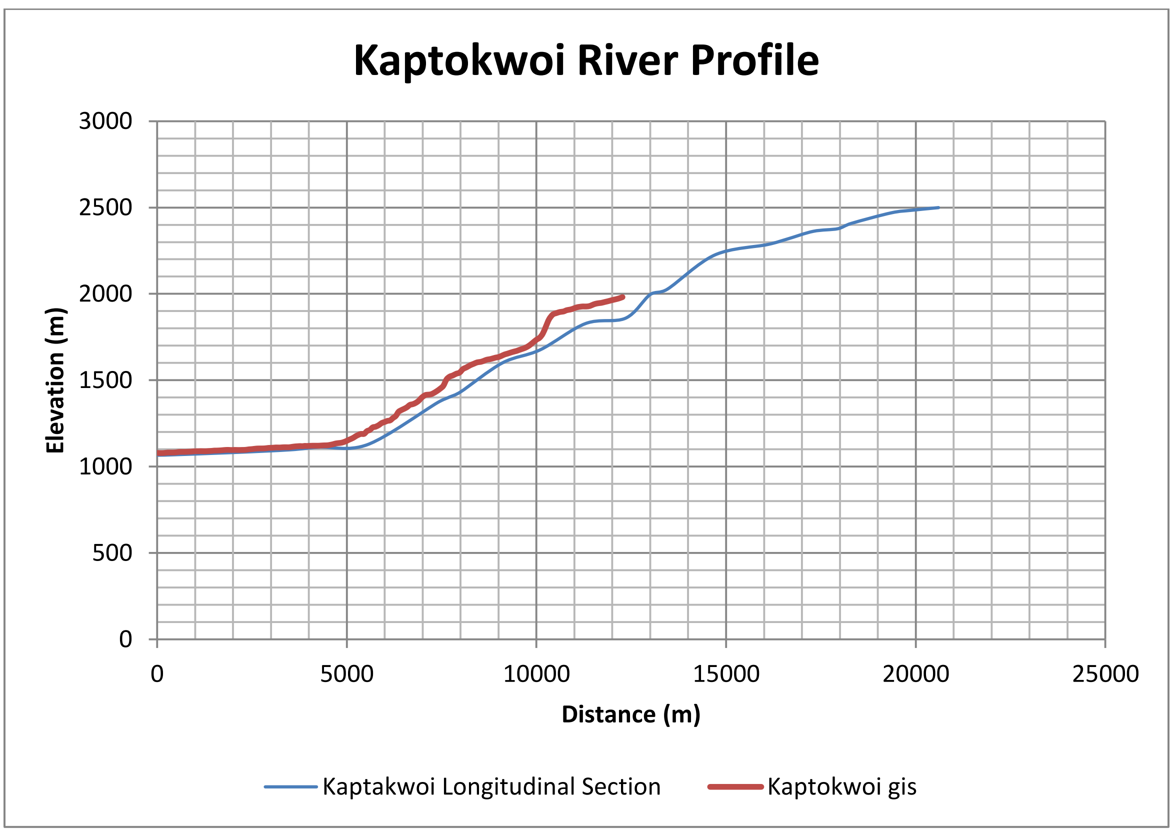
Atari Longitudinal Section
Atari gis2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Distance (m)
Kaptakwoi Longitudinal Section
Kaptokwoi gis

Appendix B

ArcGIS procedures for generating River profiles

Set up your working environment

90m digital elevation models were downloaded from internet. The DEM was added to ArcMap using the *Add data button*, the cell size (environment) was set through the Geoprocessing dialogue

c. Under *Raster Analysis Settings*, use the drop down arrow to set the *Cell Size* to the same as the DEM layer (or the EFDIR grid, if applicable). Click OK to accept the changes.

d. Enable the Spatial Analyst extension by accessing the *Customize* > *Extensions* menu and placing a check mark next to *Spatial Analyst*. Click *Close*.

e. Open the *ArcToolbox* window ( ) and expand the *Spatial Analysis Tools* > *Hydrology* toolbox.

f. Save your map document (*File* > *Save*) with a descriptive name.

Creating a depressionless DEM

The *Fill* tool in the *Hydrology* toolbox was used to remove any imperfections (sinks) in the digital elevation model. A ***sink*** is a cell that does not have a defined drainage value associated with it.

Drainage values indicate the direction that water will flow out of the cell, and are assigned when creating a flow direction grid for the landscape. The resulting drainage network depends on finding the 'flow path' of every cell in the grid, so it is important that the fill step be performed prior to creating a flow direction grid.

Double-click the ***Fill*** tool to open its dialog.

The *Input surface raster* was the DEM grid.

The *Output surface raster was*

The *Z limit was left* blank and clicked OK to run the tool.

Once the fill process was complete, a new grid was added to the data frame and could be viewed from the table of content. The original DEM was then remove the original DEM layer from the map by (*right-clicking on the layer* > *Remove*).

Creating Flow Direction

A flow direction grid assigns a value to each cell that indicates the direction of flow – that is, the direction that water will flow from that particular cell. This is an extremely important step in hydrological modelling, as the direction of flow will determine the ultimate destination of the water flowing across the surface of the landscape.

Flow direction grids were created using the *Flow Direction* tool.

Double-click the *Flow Direction* tool to open it.

The *Input surface raster* was set to the filled DEM.

The *Output flow direction raster* was once again defaulted to the working directory.

Click OK to run the tool. After the running process was complete, a new flow direction layer wasl added to the table of contents in the ArcMap.

Create flow accumulation

The *Flow Accumulation* tool calculates the flow into each cell by accumulating the cells that flow into each downslope cell. In other words, each cell's flow accumulation value is determined by calculating the number of upstream cells that flow into it.

Double-click the ***Flow Accumulation*** tool to open it.

The *Input flow direction raster* was set to the flow direction grid created in above.
The *Output accumulation raster* defaulted to the working directory, all other defaults were accepted and checked the Environment Settings to ensure that the *Raster Analysis* >
Cell Size property is set to the same as your filled DEM, and clicked OK to run the tool. After running was complete, the new flow accumulation raster was added to the ArcMap.

Creating a stream profile

Right click in an empty space on the upper window and turn on the 3D analyst. With the fill layer selected, click on interpolate line and the trace the stream from the starting point of interest to the end. At the end, double click to stop interpolation and the click on profile graph to view the river profile. This could then be exported to excel including the data its self.

Appendix C

ArcGIS procedures for delineating catchments

Create outlet (pour) points

The placement of pour points is an important step in watershed delineation. A pour point should exist within an area of high flow accumulation because it is used to calculate the total contributing water flow to that given point.

The following steps were used to create pour points;

Open the ArcCatalog window ( ). Right-click on the working directory and select *New* > *Shapefile*. Create a new point shapefile, give it a descriptive name and apply the appropriate projection information (the coordinate system should be the same as the DEM or Flow Direction Grid you will be using). Click OK. The new, empty point layer will be added to your map.

To add a pour point, open the *Editor* toolbar (*Customize* > *Toolbars* > *Editor*) and choose *Editor* >

Start Editing.

If necessary, in the *Start Editing* dialog, highlight the empty pour point layer and click OK. The *Create Features* window will open. Highlight the pour point shapefile and then move your cursor onto your map. Add a pour point by clicking in the centre of the high flow accumulation cell you have chosen as your outlet point. Try to place points in the centre of the cells.

If you are creating more than one watershed, add a pour point for each watershed then save your edits and exit the editing session. Open the attribute table for the layer by right-clicking the layer name and selecting *Open Attribute Table*. Click the *Table Options* icon ( ) and select *Add Field.* Stop editing and choose to save your edits.

Snap Pour Points

Select *Geoprocessing* > *Environments* and set the *Processing Extent* and *Raster Analysis* > *Cell Size* properties to the same as your flow accumulation grid

The *Snap Pour Point* tool accomplishes two things; it snaps the pour point(s) created or loaded in the previous step to the closest area of high flow accumulation, and it converts the pour points to the raster format needed for input to the *Watershed* tool.

Double-click the ***Snap Pour Point*** tool to open it. The *Input raster or feature pour point data* is the pour point layer.

The *Input accumulation raster* is your flow accumulation layer.

The *Output raster* was defaulted to the working directory.

The *Snap distance* is the specified distance (in map units) that the tool will use to search around your pour points for the cell of highest accumulated flow. The snap distance tool was run with a search radius of '0'.

Delineate Watersheds

Double-click the ***Watershed*** tool to open it (*ArcToolbox* > *Spatial Analysis Tools* > *Hydrology*).

The *Input flow direction raster* is the flow direction raster created in Step 3.

The *Input raster or feature pour point data* is the raster pour point output from the Snap Pour Points tool in Step 6.

And then Click OK to run the tool.

When complete, the new watershed raster(s) was added to your map.

Convert watershed raster to polygon

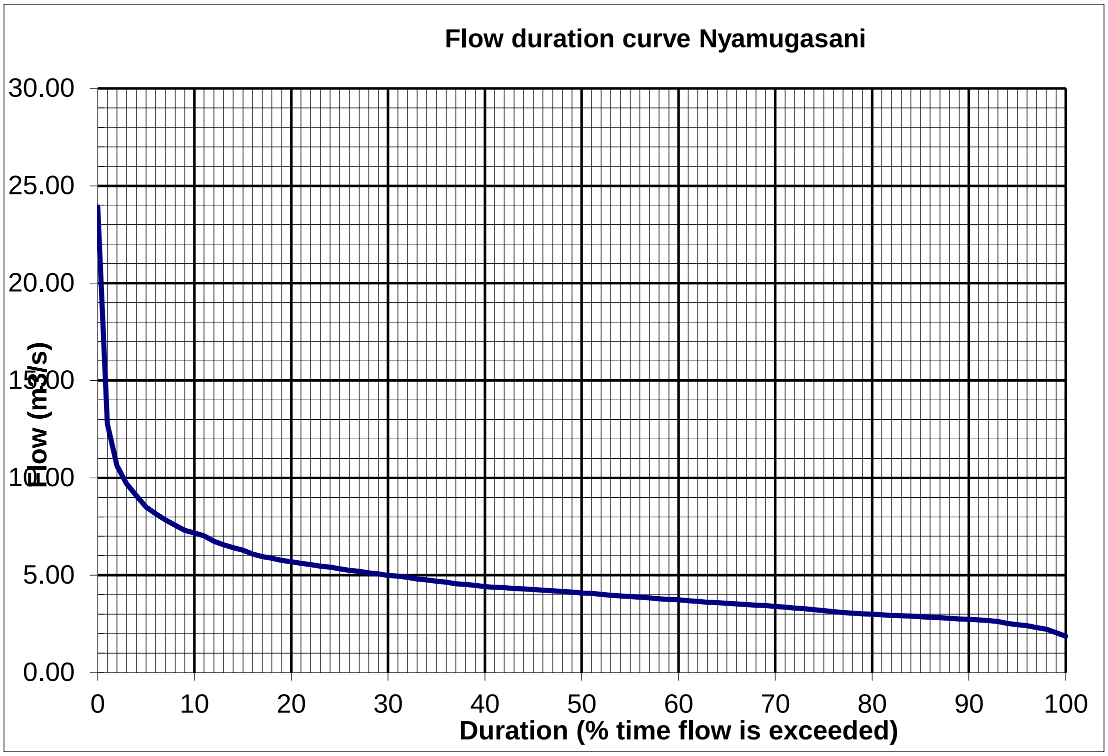
Converting the watershed raster to a polygon shapefile was necessary for area calculations
To do so i used the *Raster to Polygon* tool (*ArcToolbox > Conversion Tools > From Raster*)
Double-click the ***Raster to Polygon*** tool to open it.
The *Input raster* is the watershed raster file created in Step 7 above.
The *Output polygon features* defaulted to the working directory.
Leaving all other defaults and clicking OK to run the tool. The new polygon shapefile was added as a layer to your map.

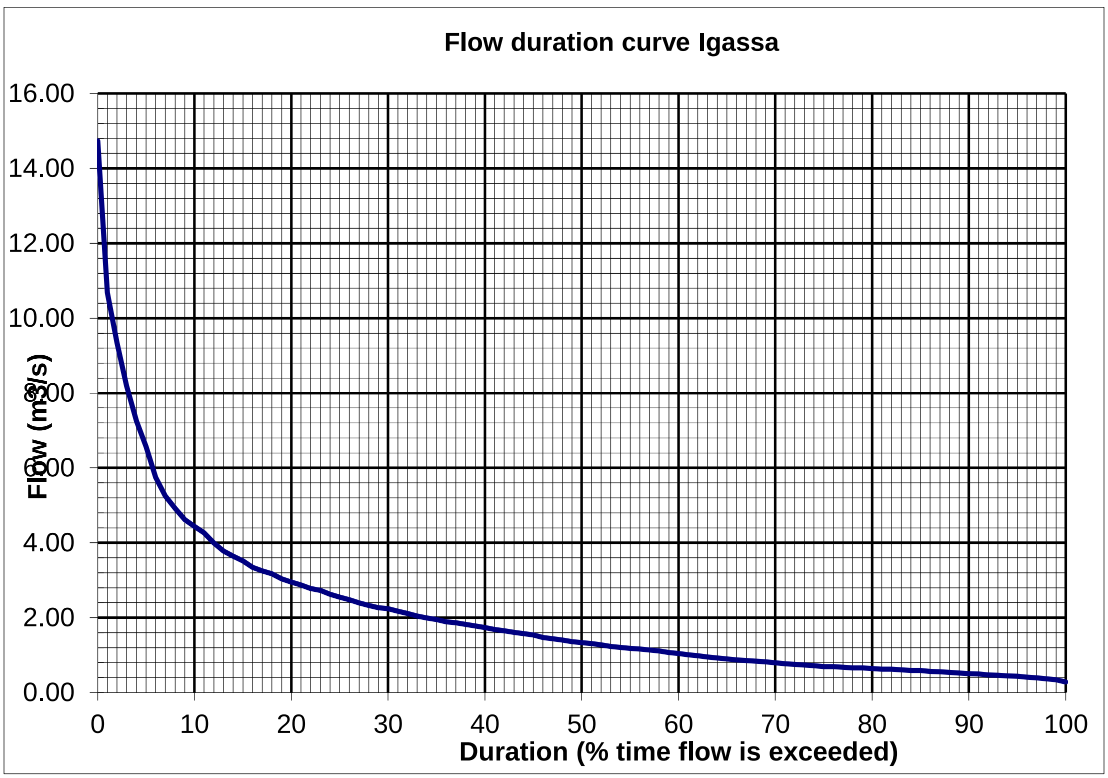
Calculating Areas of the catchments

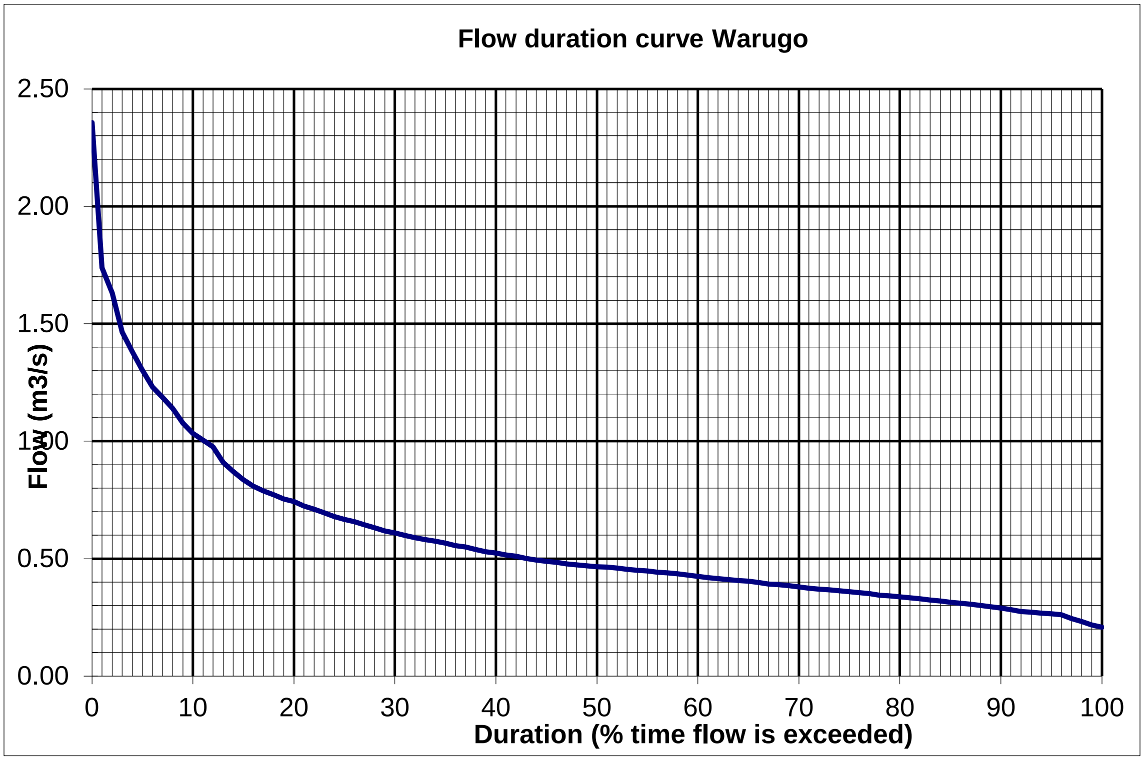
Right click on the layer file in the attribute table>Open attribute table>Add field which is area>float and then ok to add an empty area field in the attribute table. Select the area couloum and click calculate geometry then select sq kilometers and click ok. The area field is filled with area values for each catchment id in square kilometer.

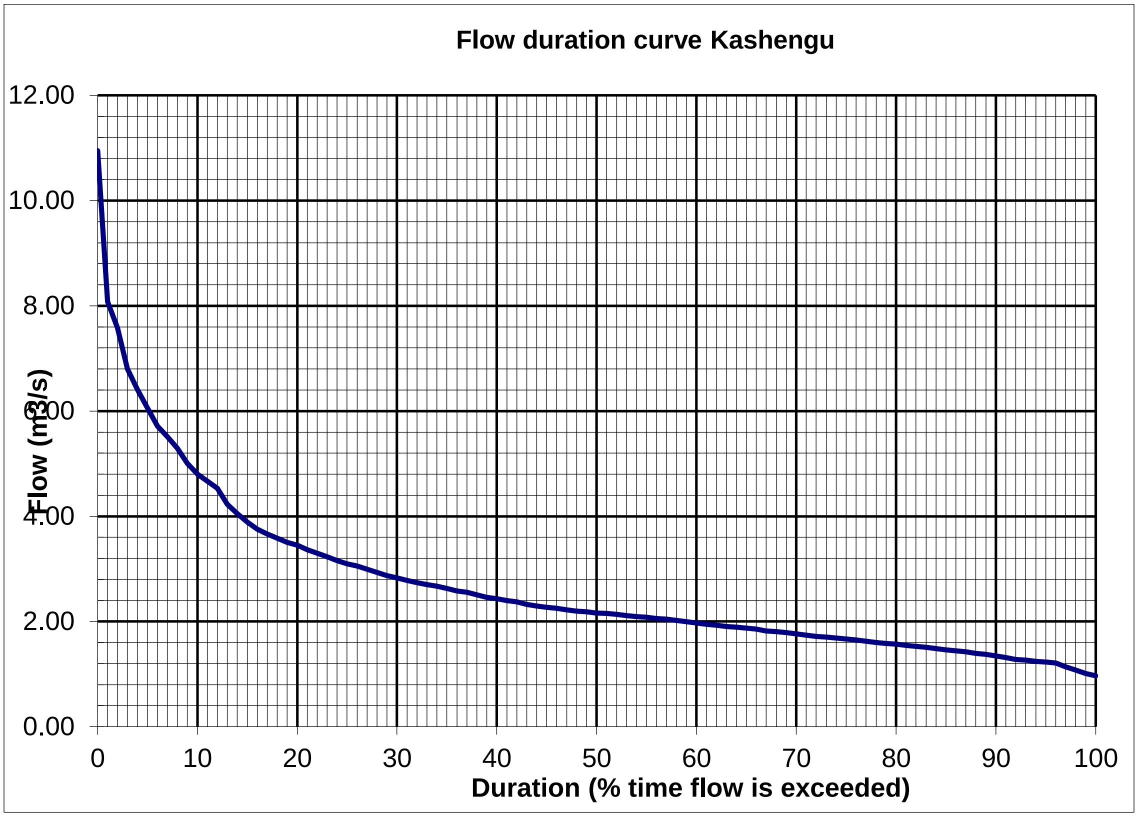
Appendix D

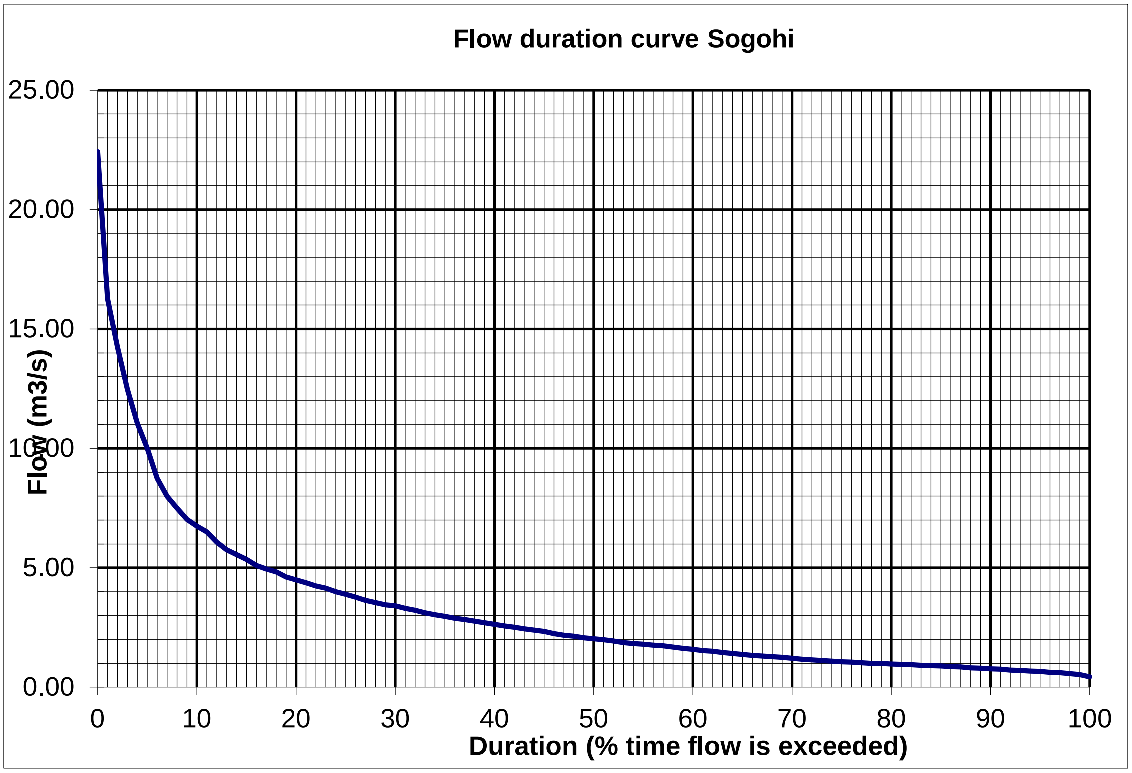
Flow duration curves for all desk study rivers

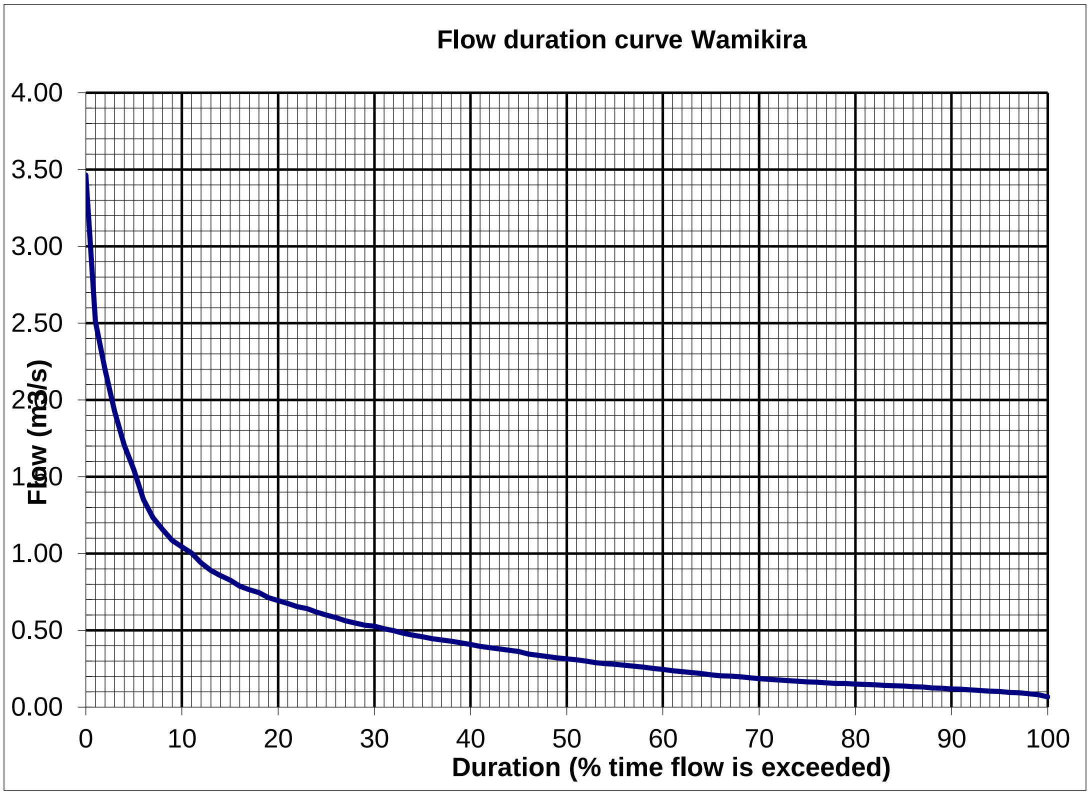


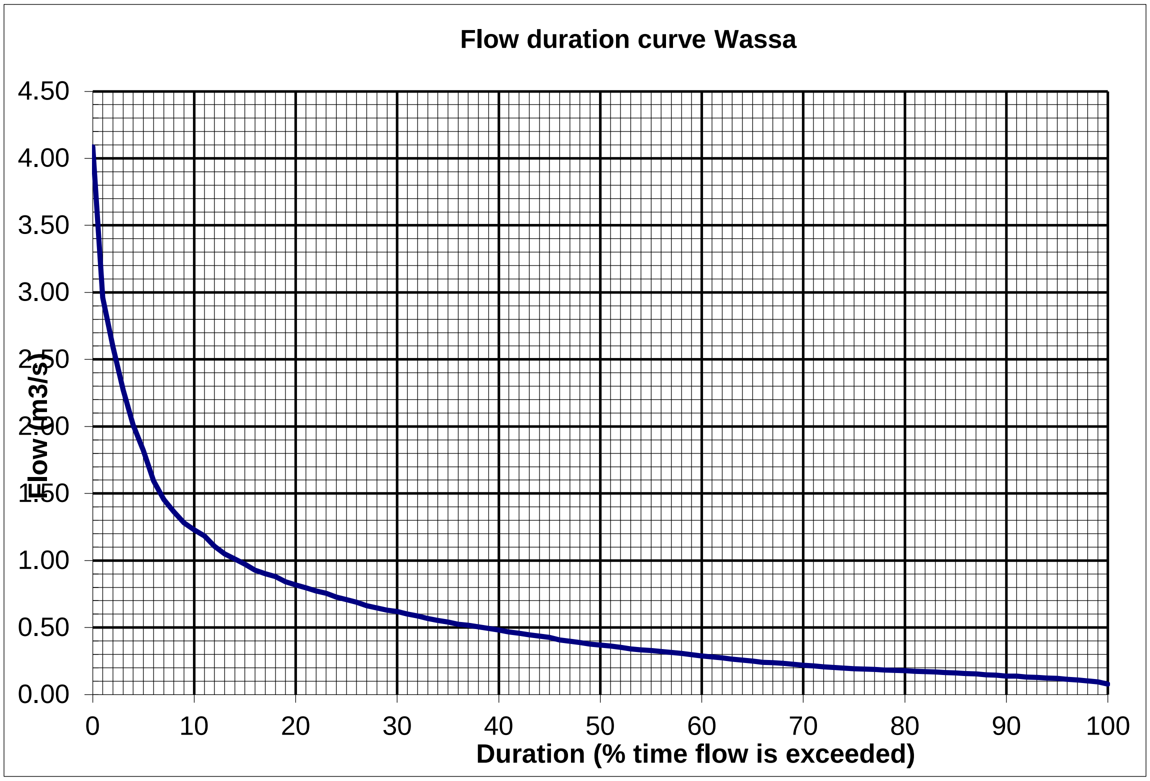


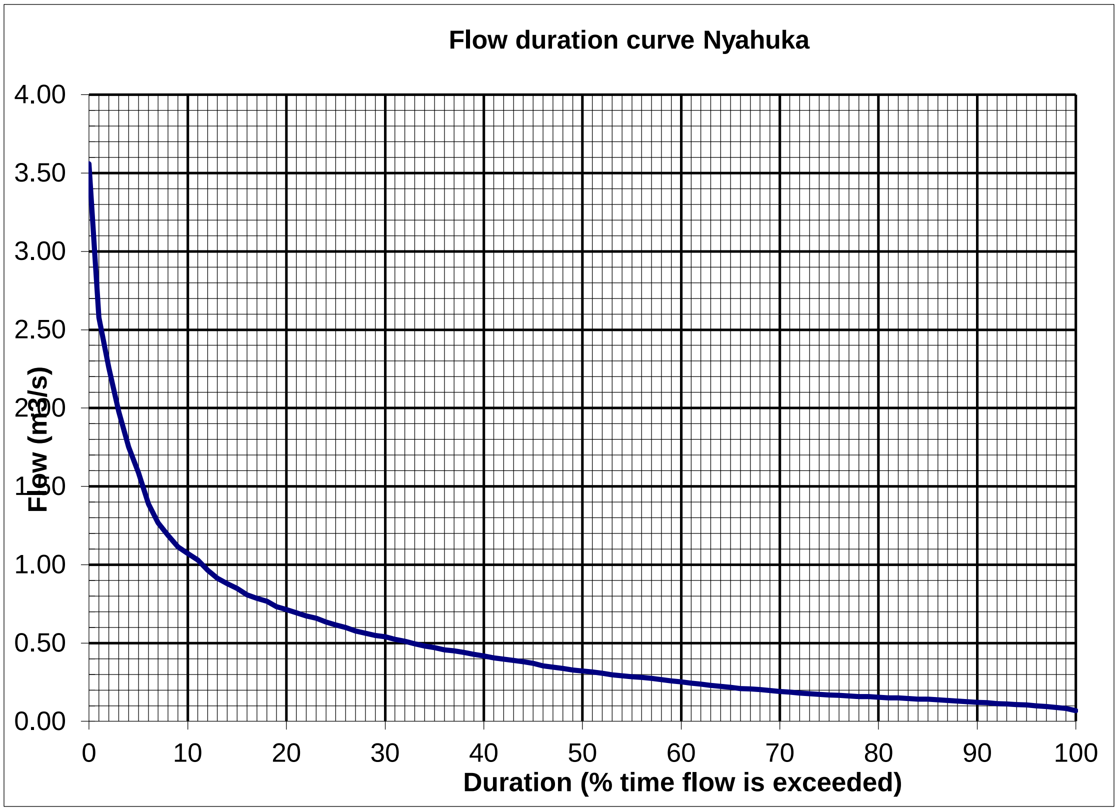

Flow duration curve Warugo
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

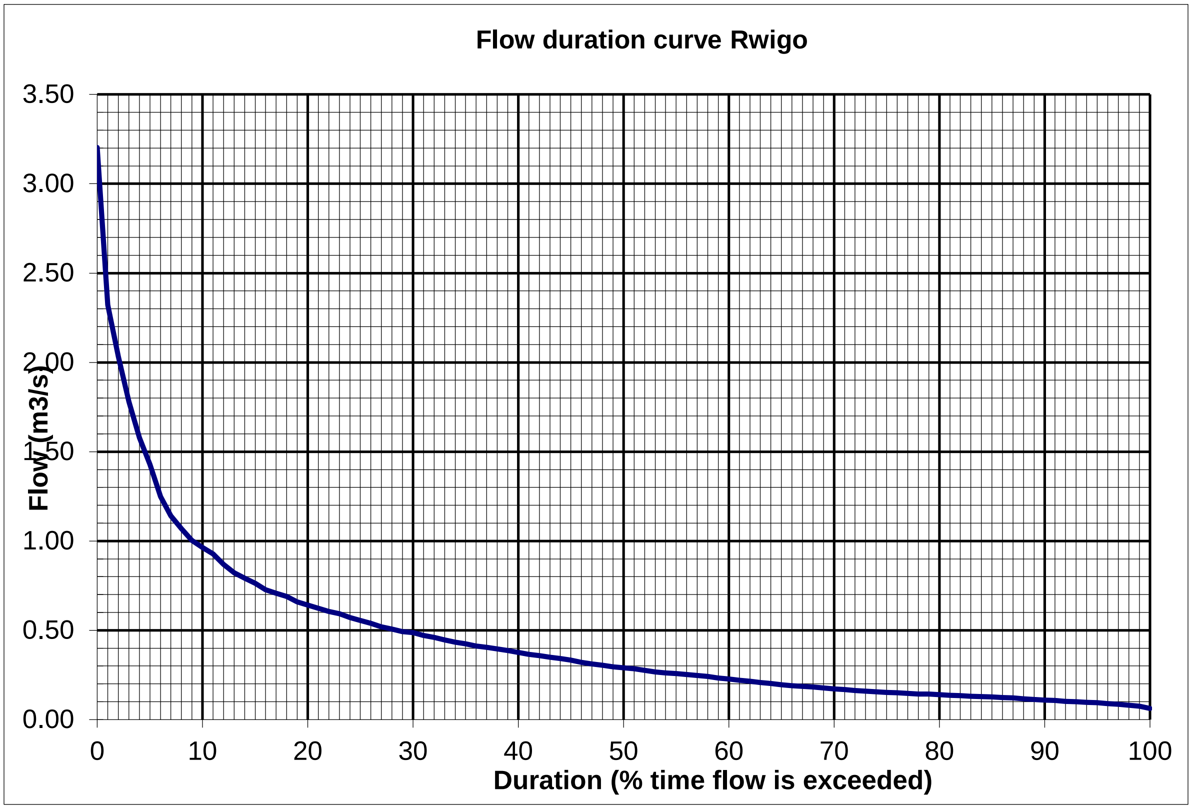

Flow duration curve Kashengu
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

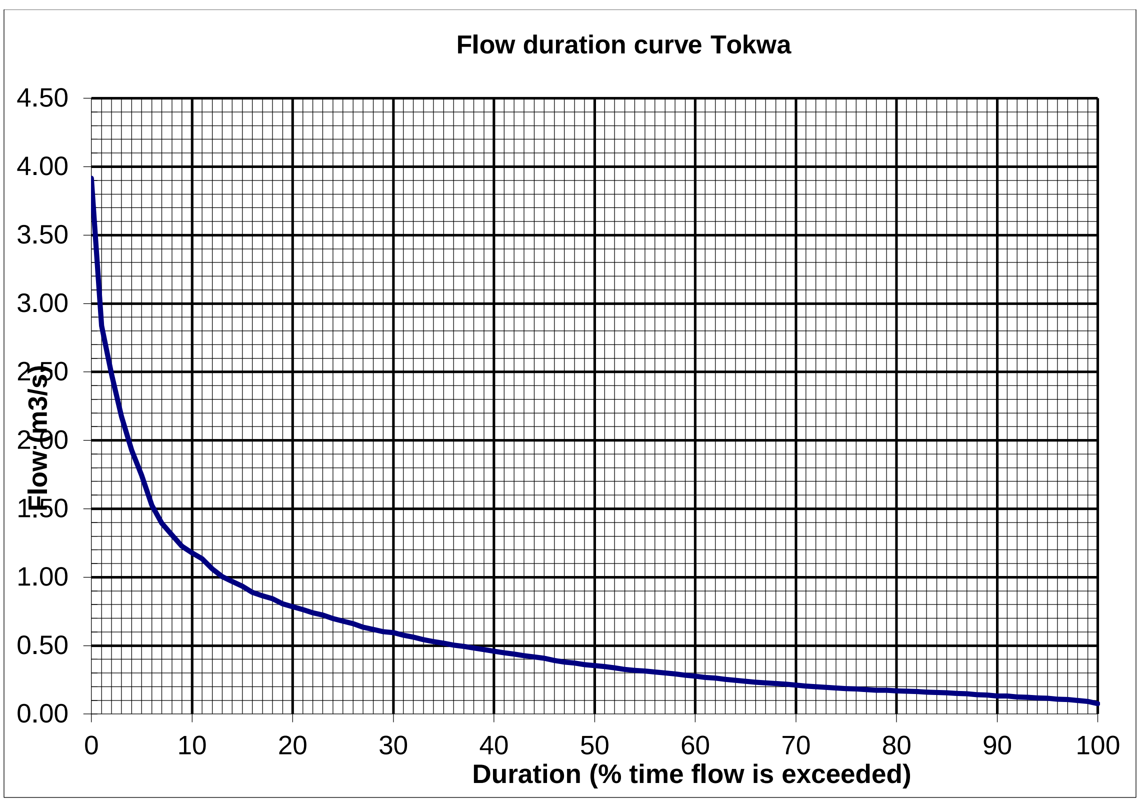

Flow duration curve Sogohi
25.00
20.00
15.00
10.00
5.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

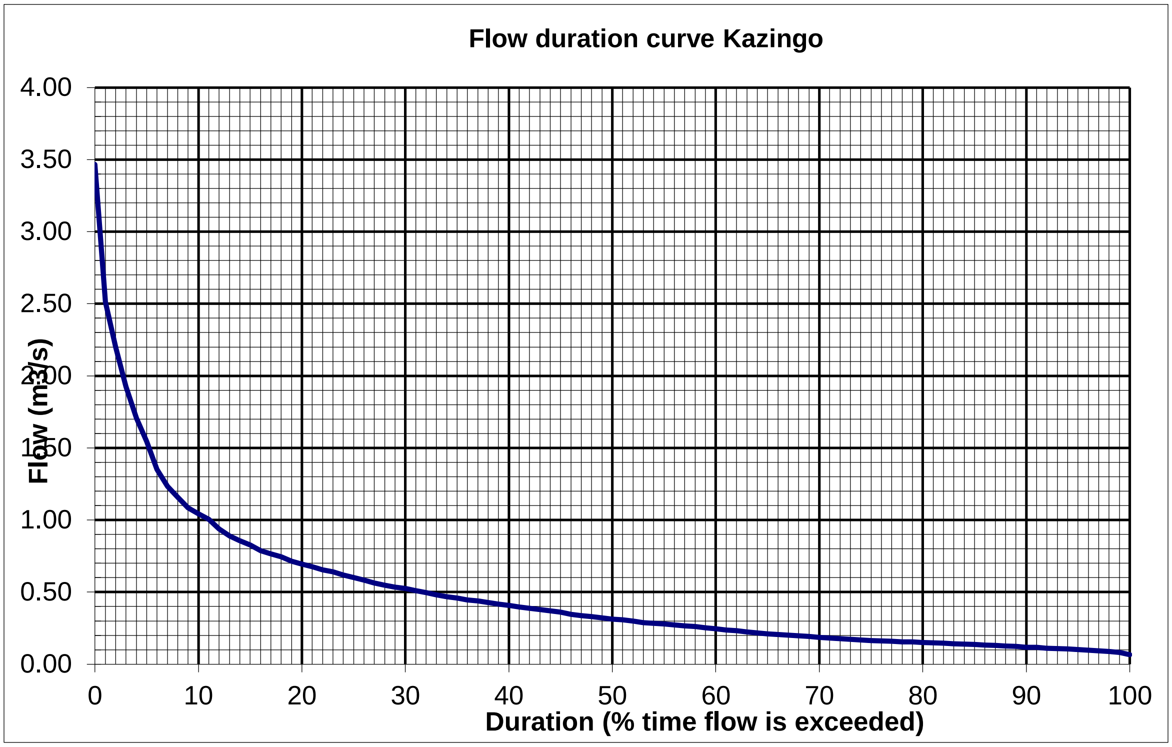

Flow duration curve Wamikira
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

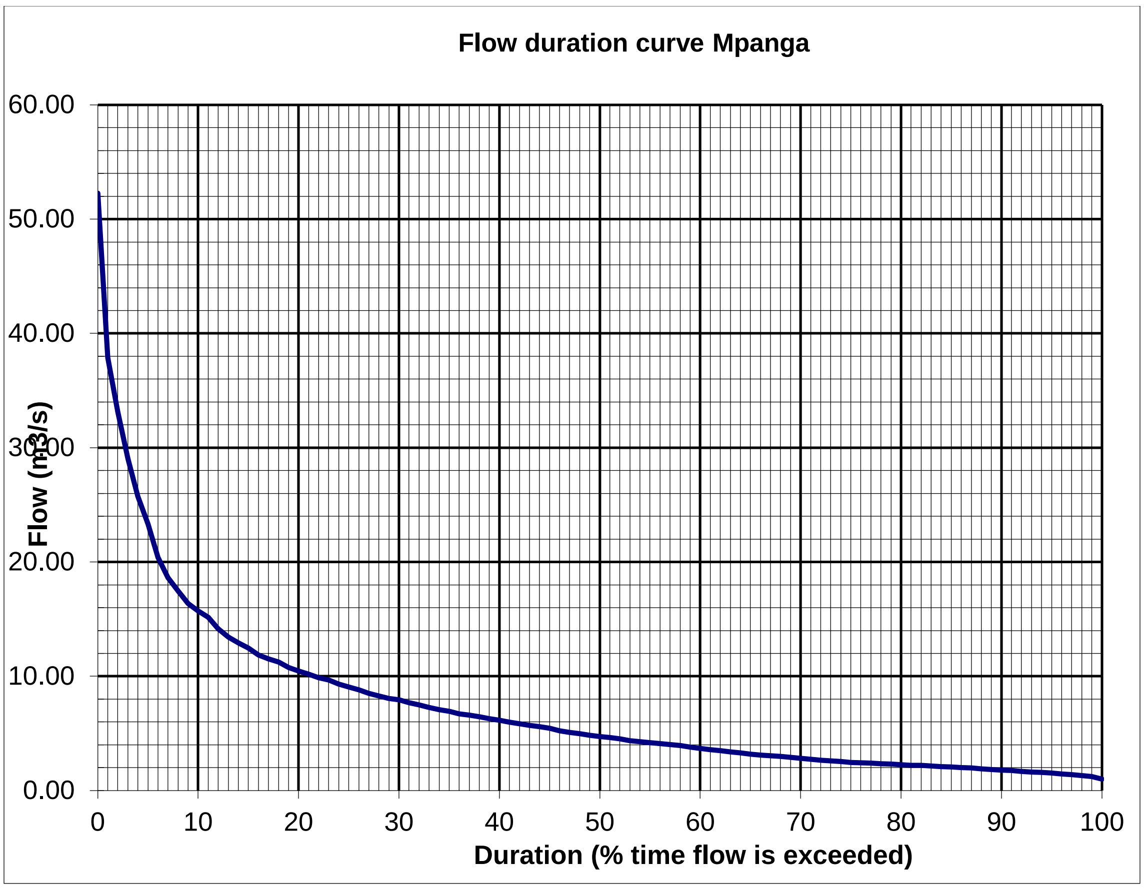

Flow duration curve Wassa
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

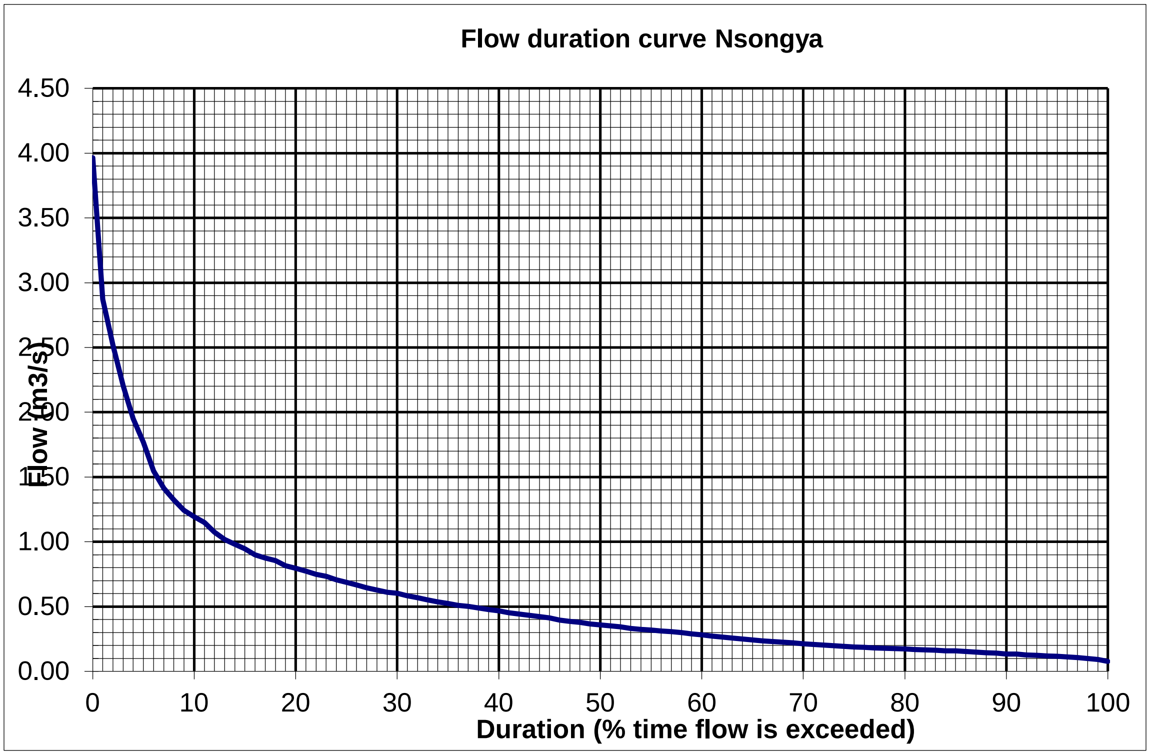

Flow duration curve Nyahuka
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

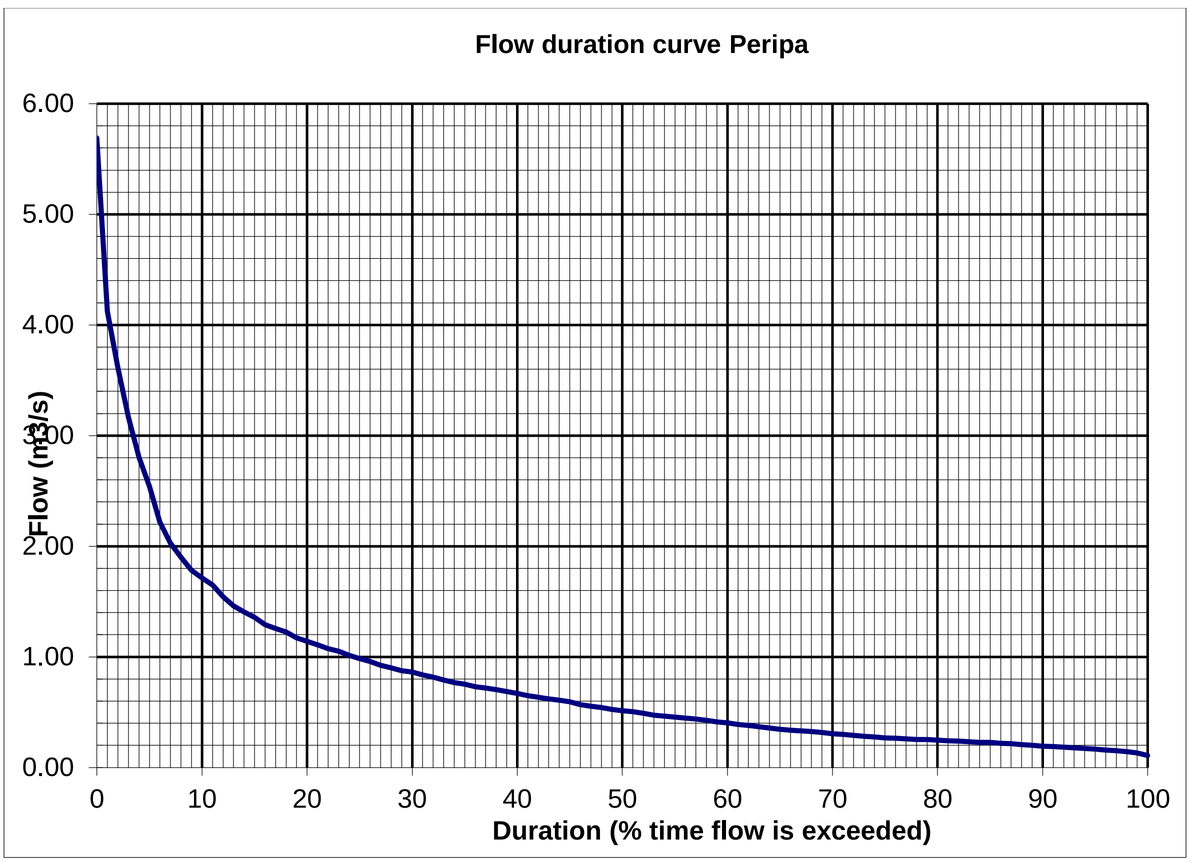

Flow duration curve Rwigo
Flow (m3/s)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

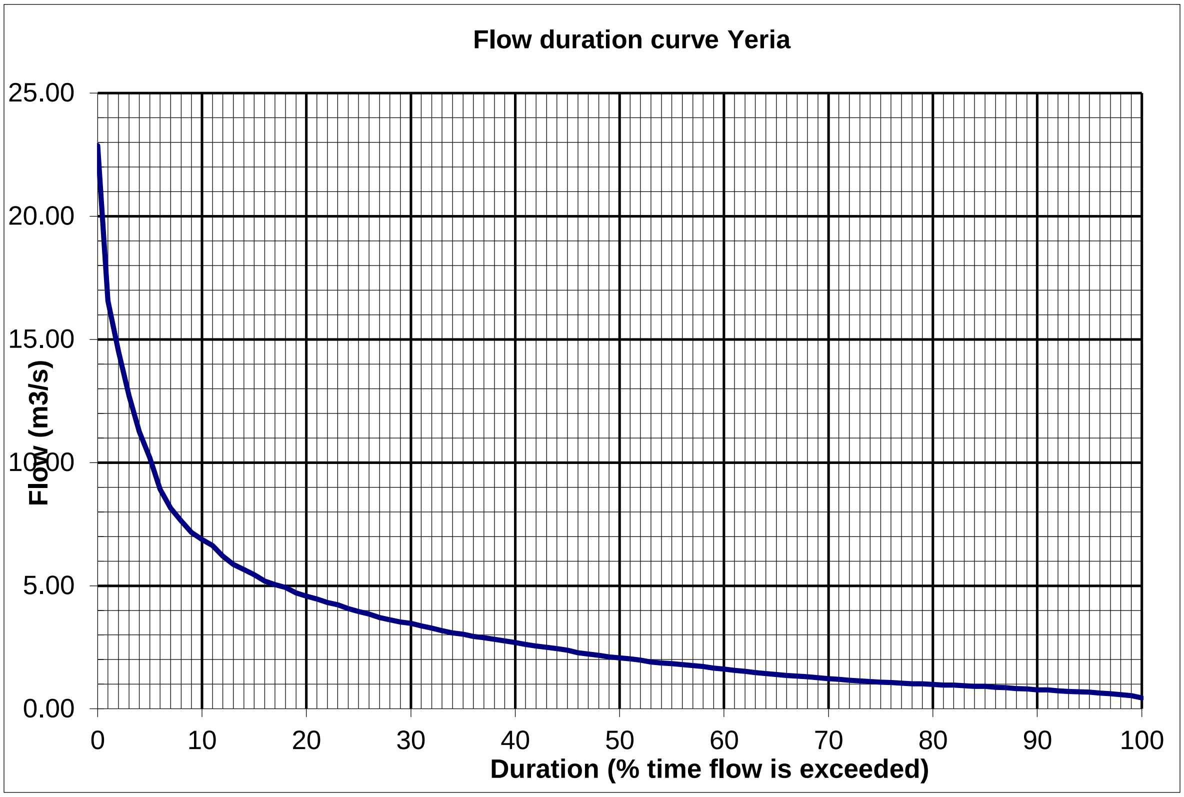

Flow duration curve Tokwa
Flow (m3/s)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

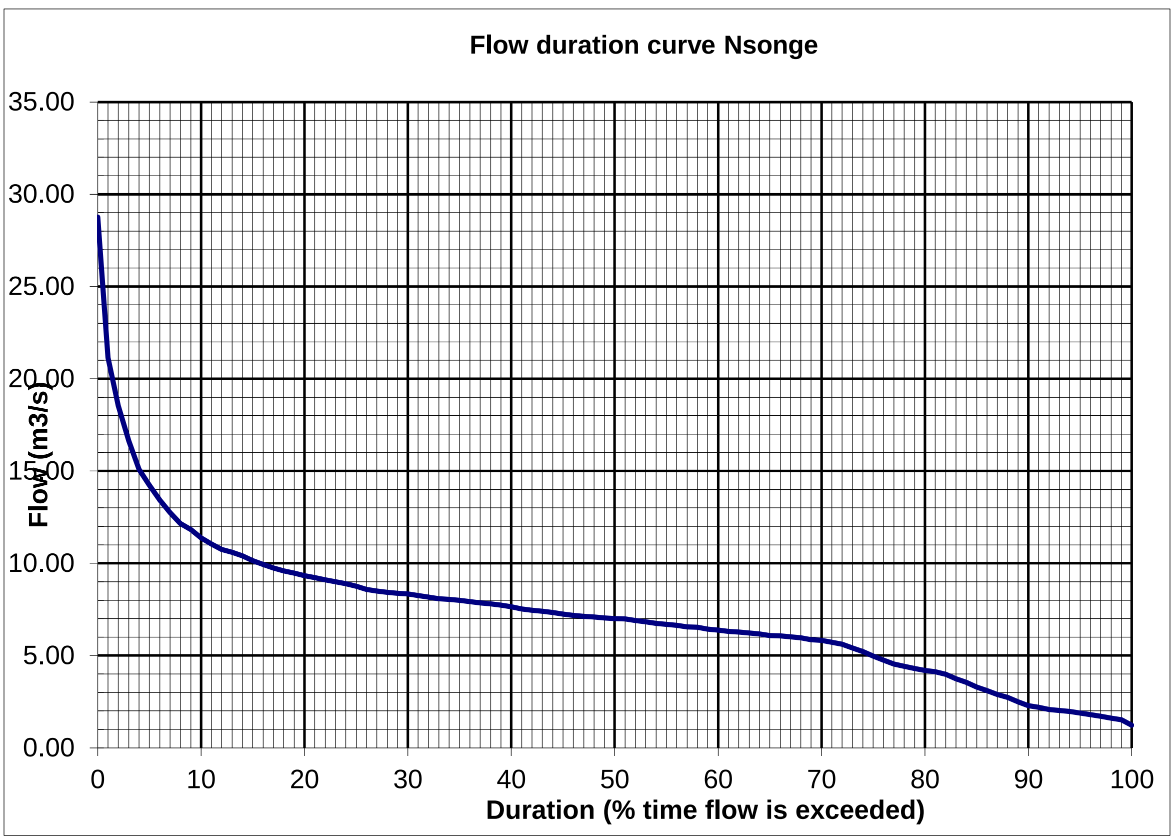

Flow duration curve Kazingo
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

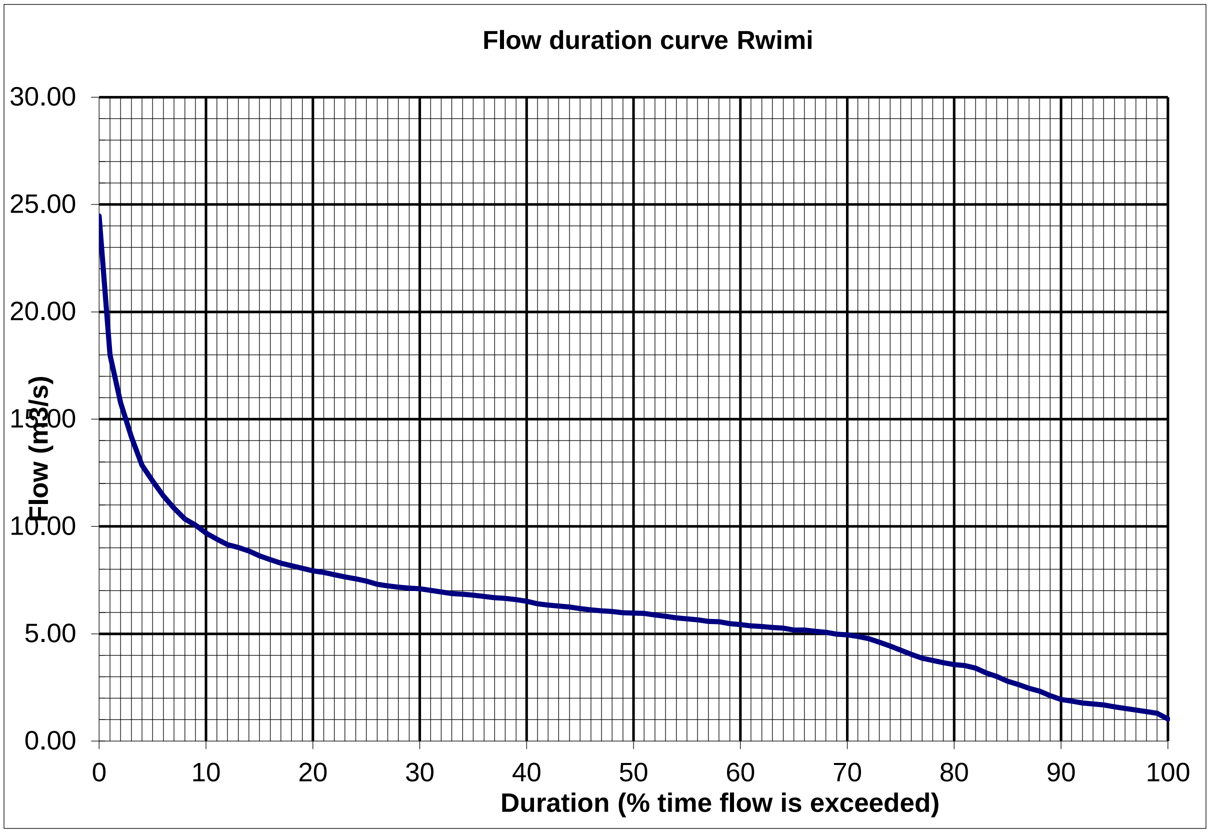

Flow duration curve Mpanga
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

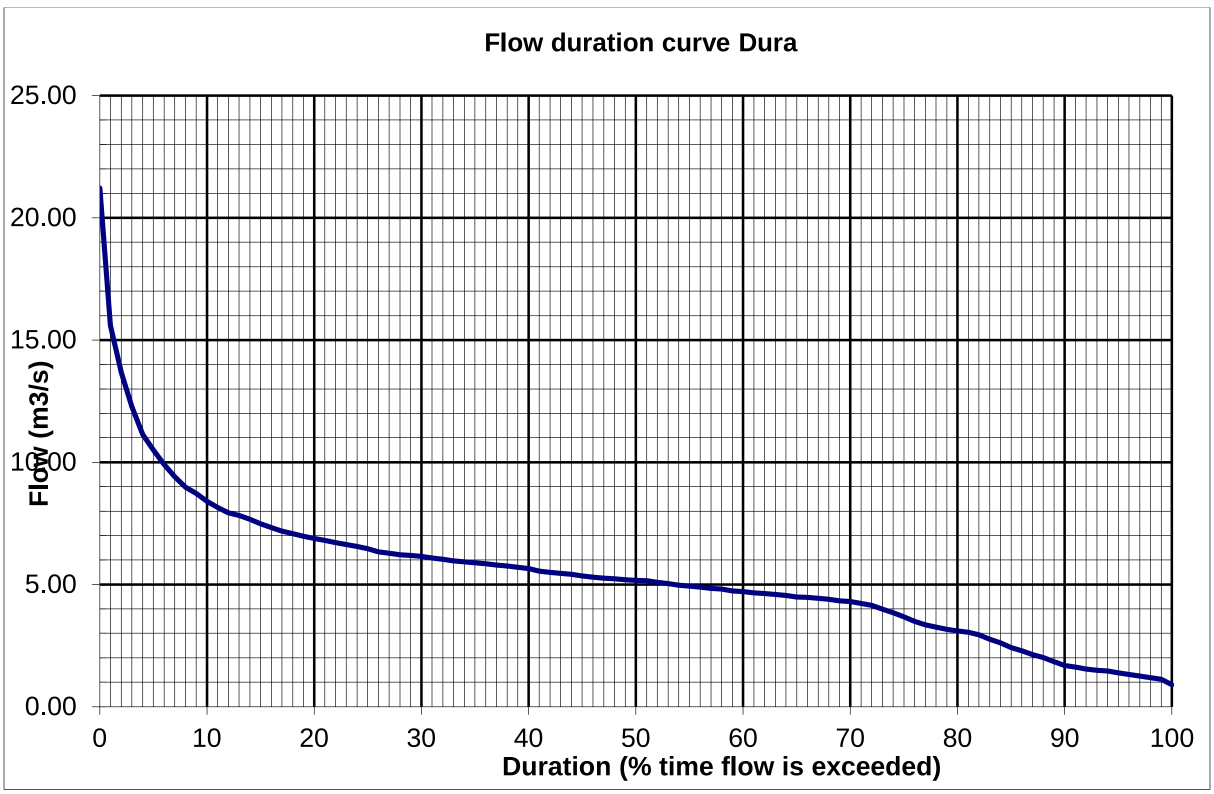

Flow duration curve Nsongya
Flow (m3/s)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

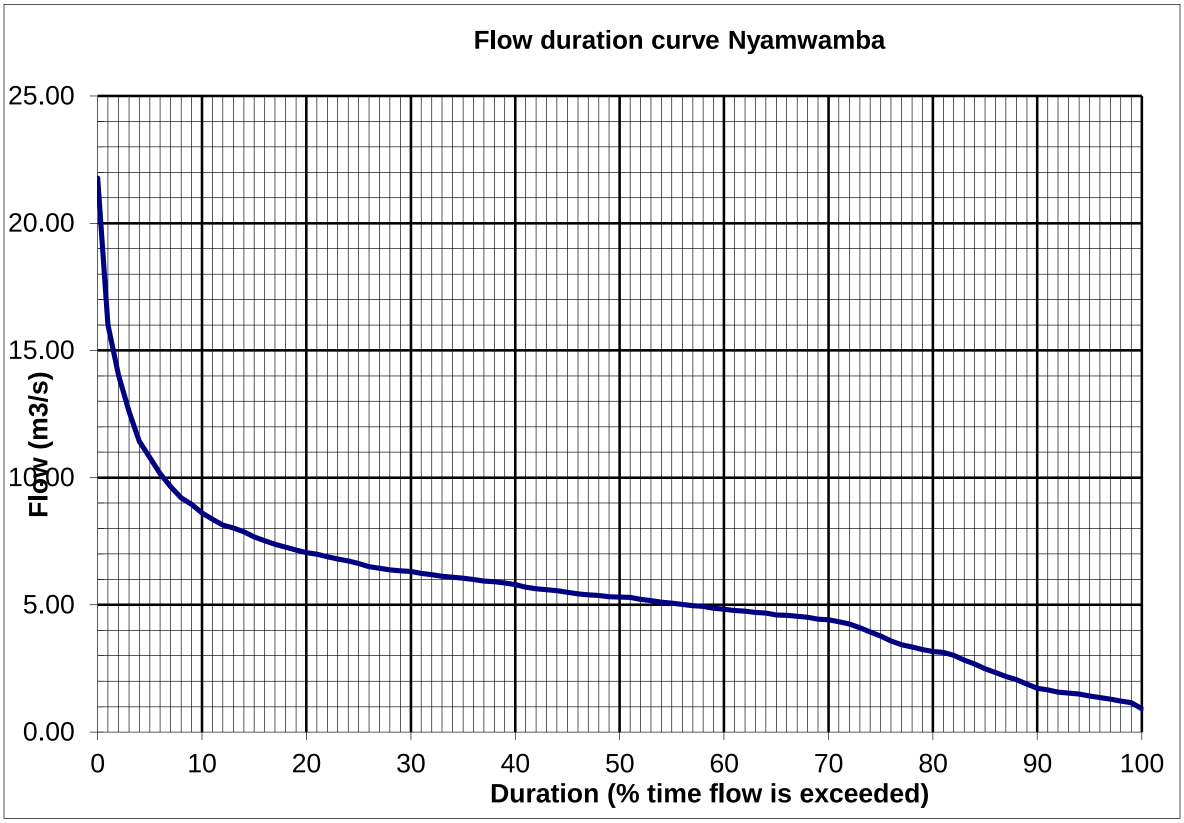

Flow duration curve Peripa
Flow (m3/s)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

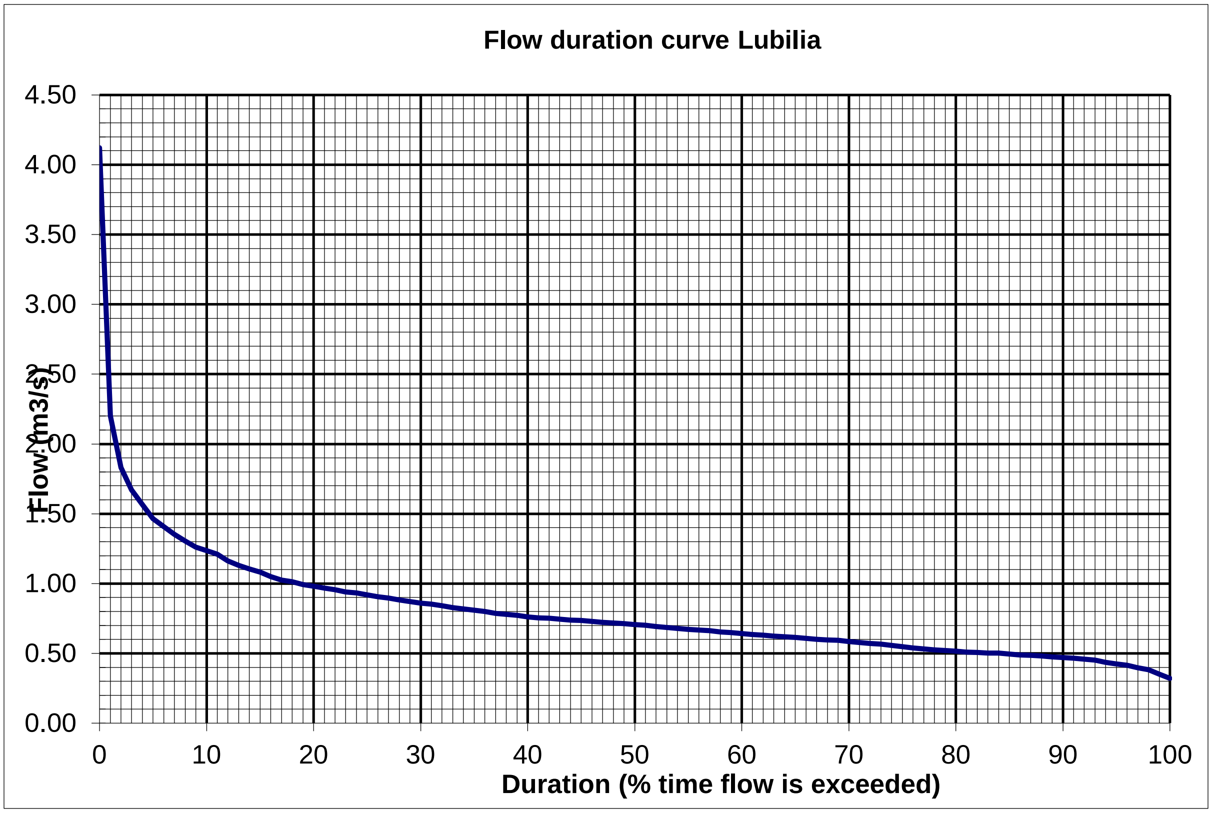

Flow duration curve Yeria
Flow (m3/s)
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

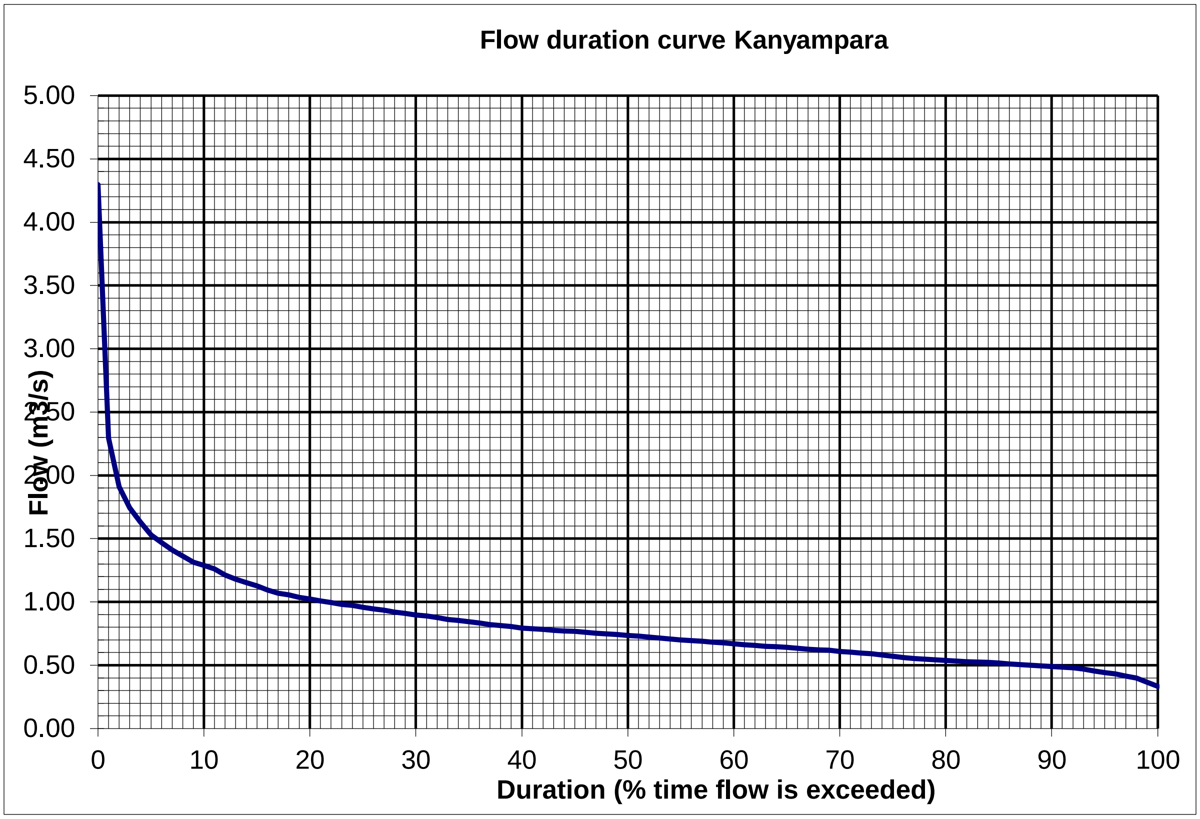

Flow duration curve Nsonge
Flow (m3/s)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

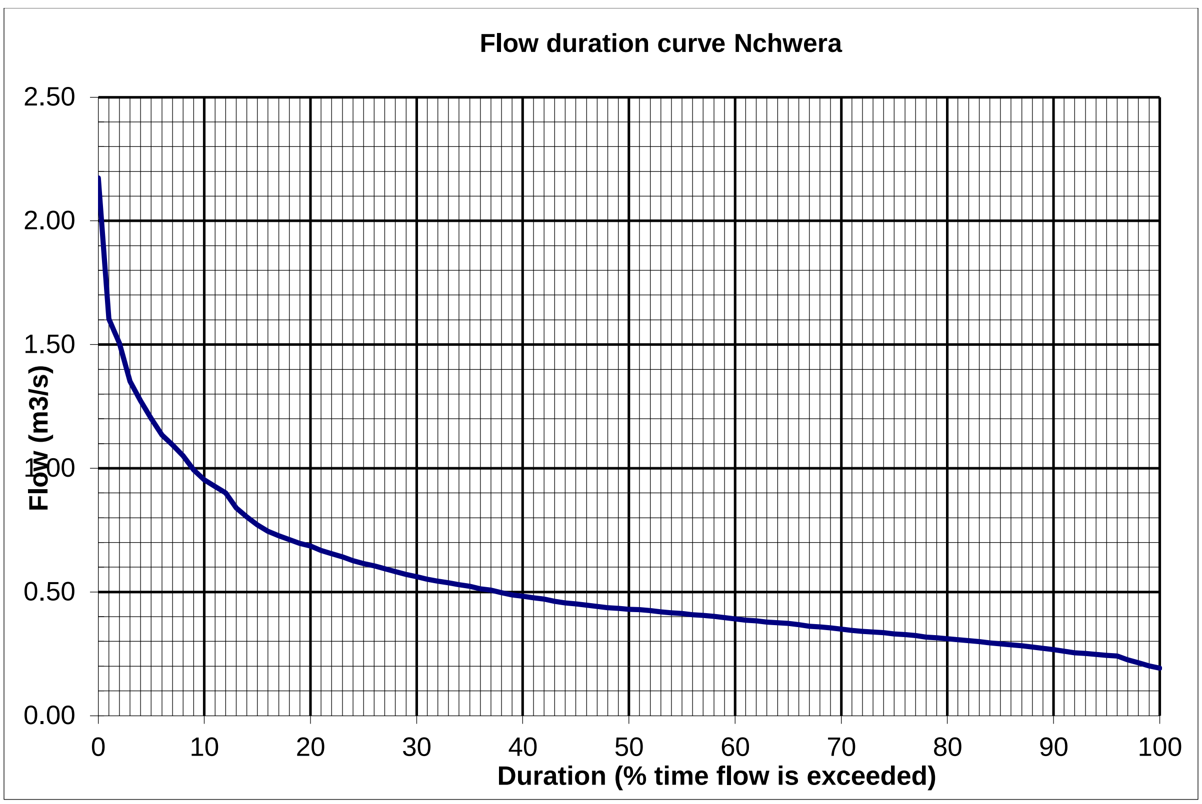

Flow duration curve Rwimi
Flow (m3/s)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

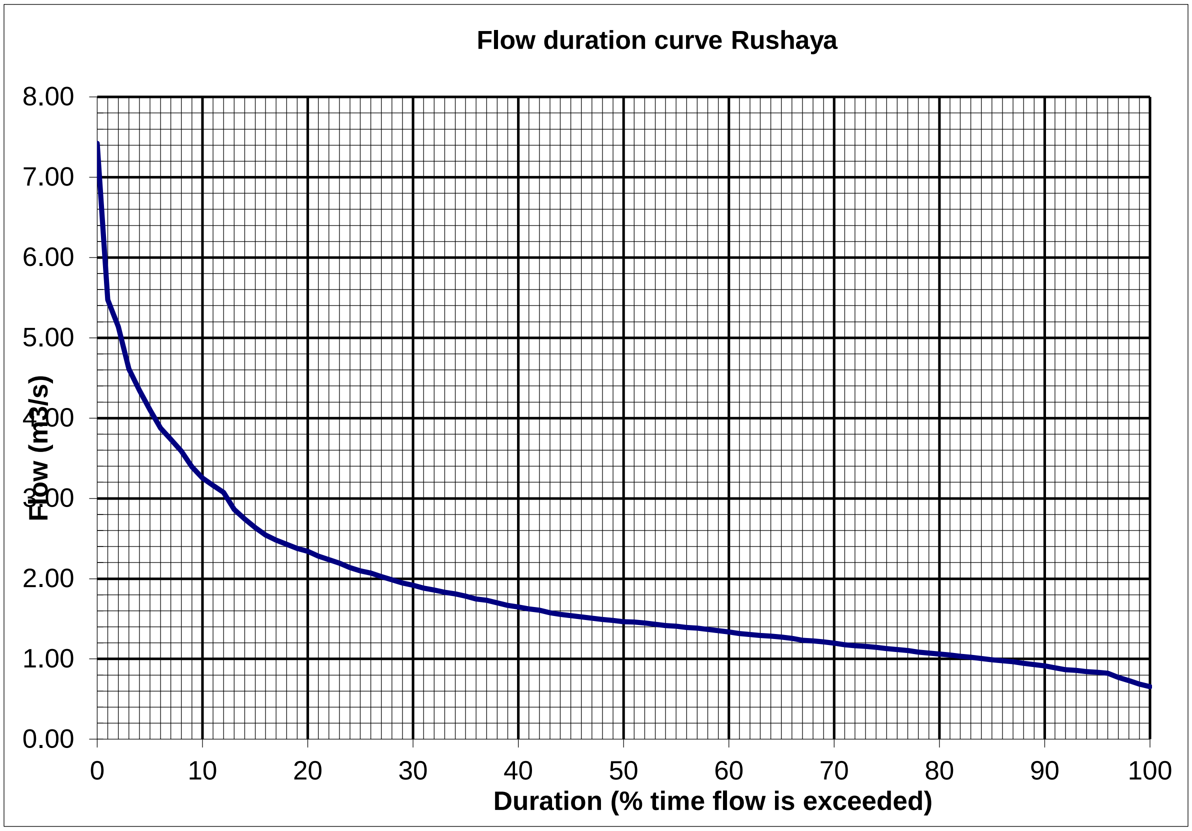

Flow duration curve Dura
Flow (m3/s)
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

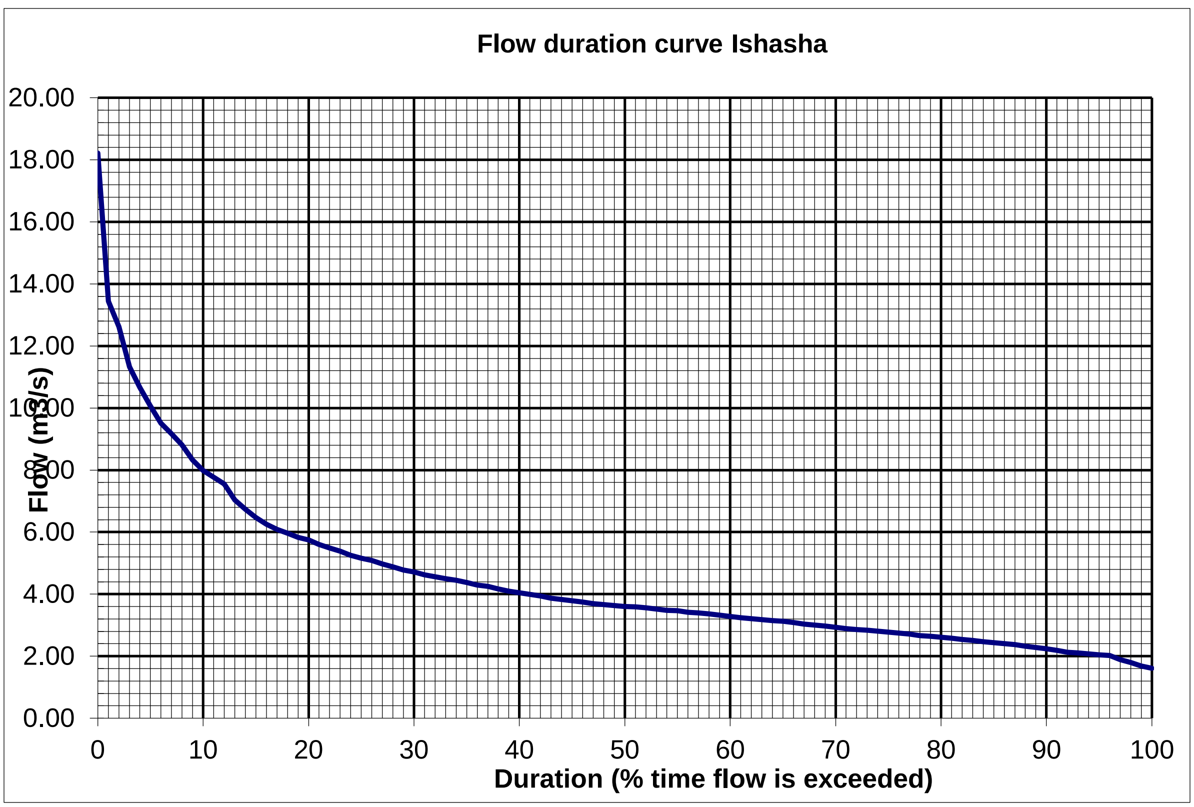

Flow duration curve Nyamwamba
Flow (m3/s)
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

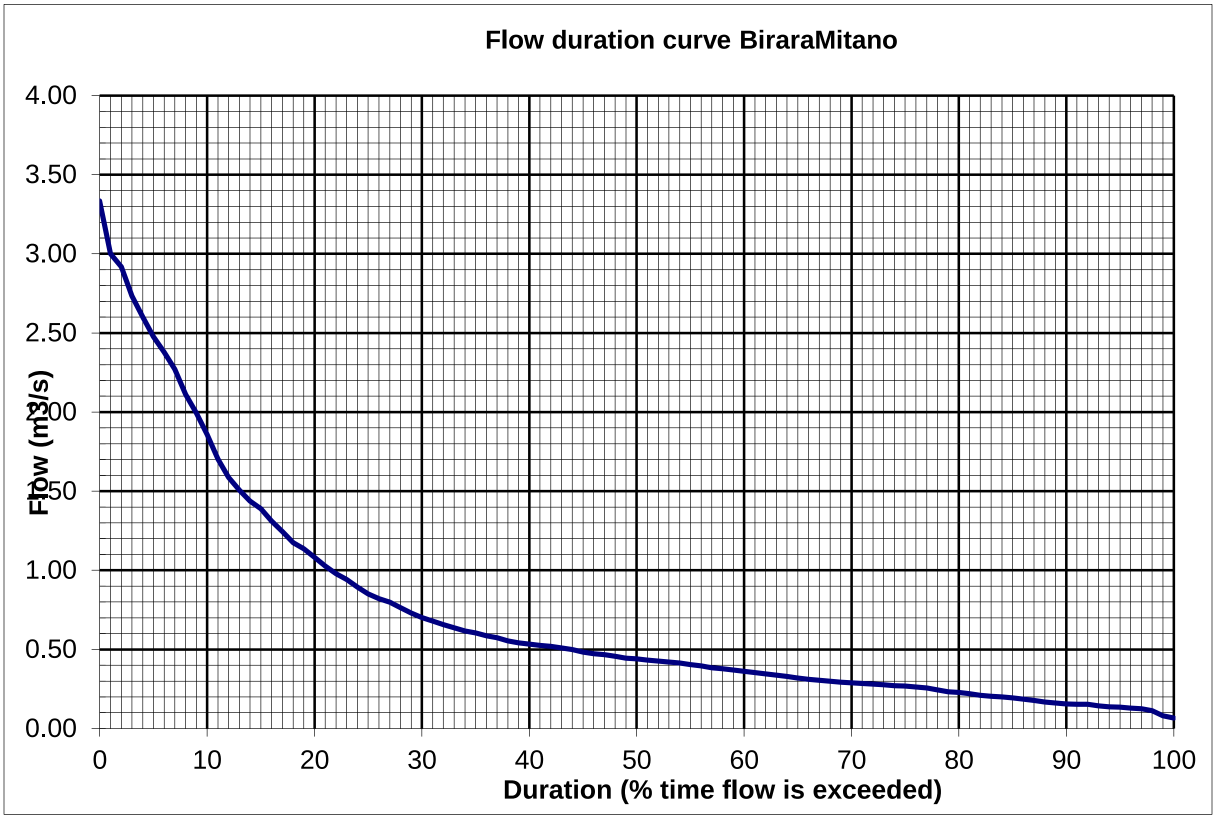

Flow duration curve Lubilia
Flow (m3/s)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

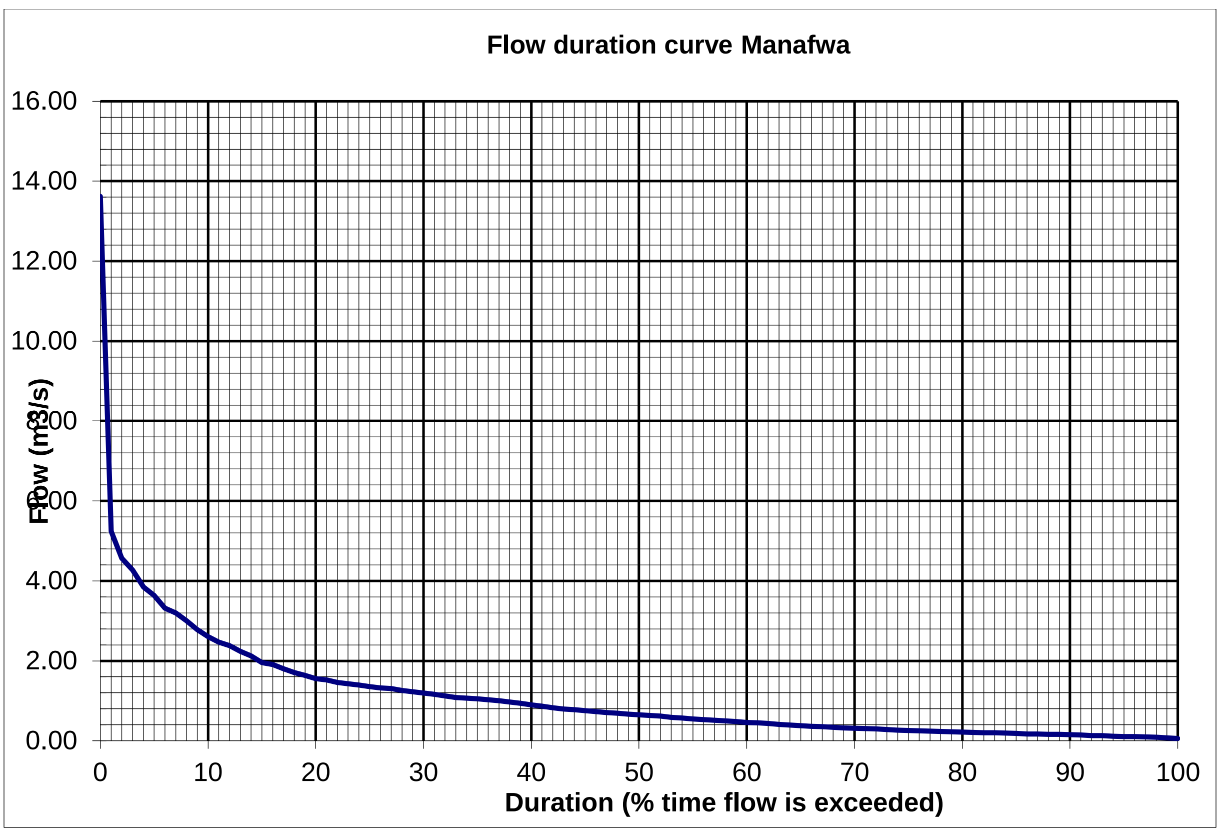

Flow duration curve Kanyampara
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

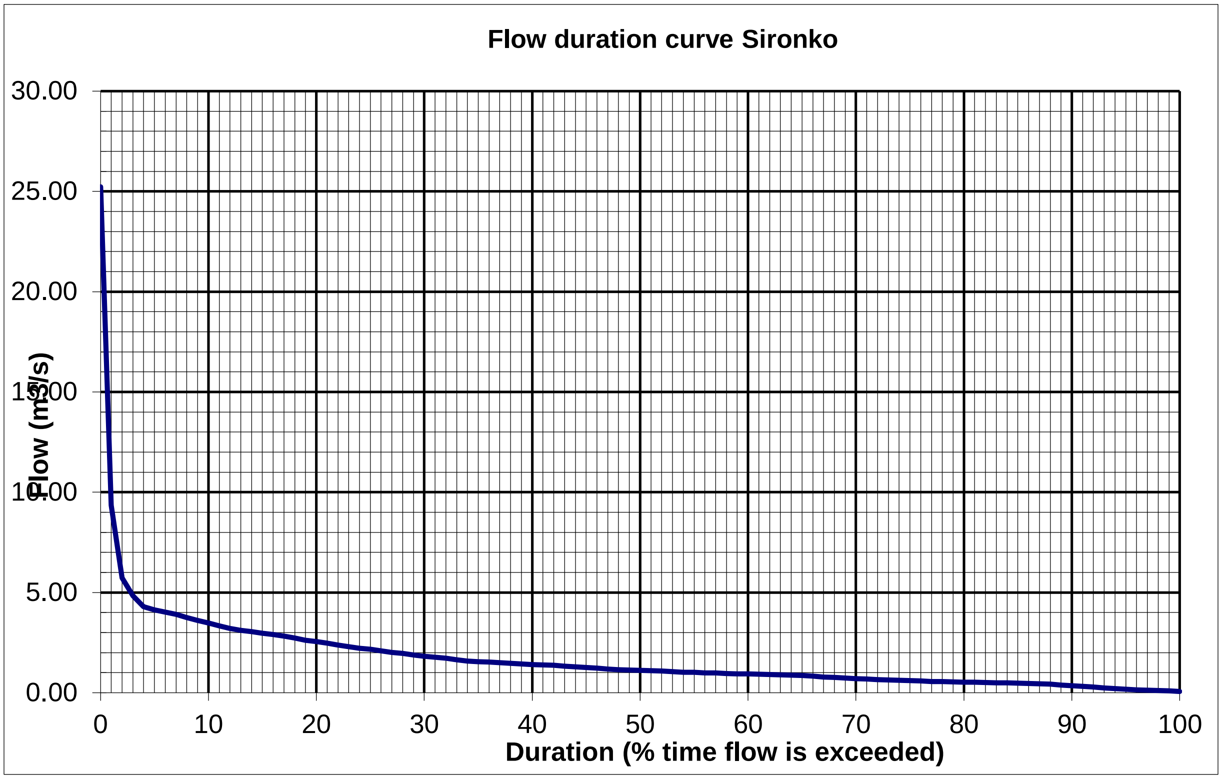

Flow duration curve Nchwera
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

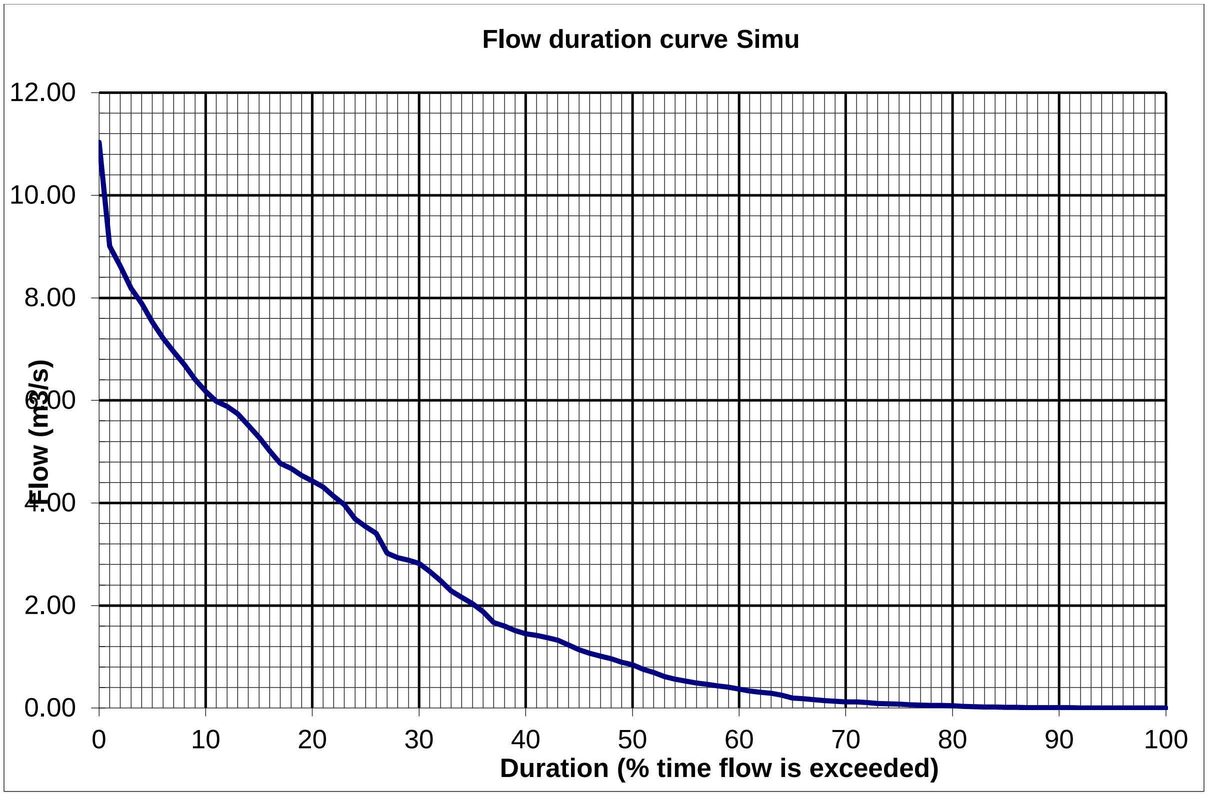

Flow duration curve Rushaya
Flow (m3/s)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

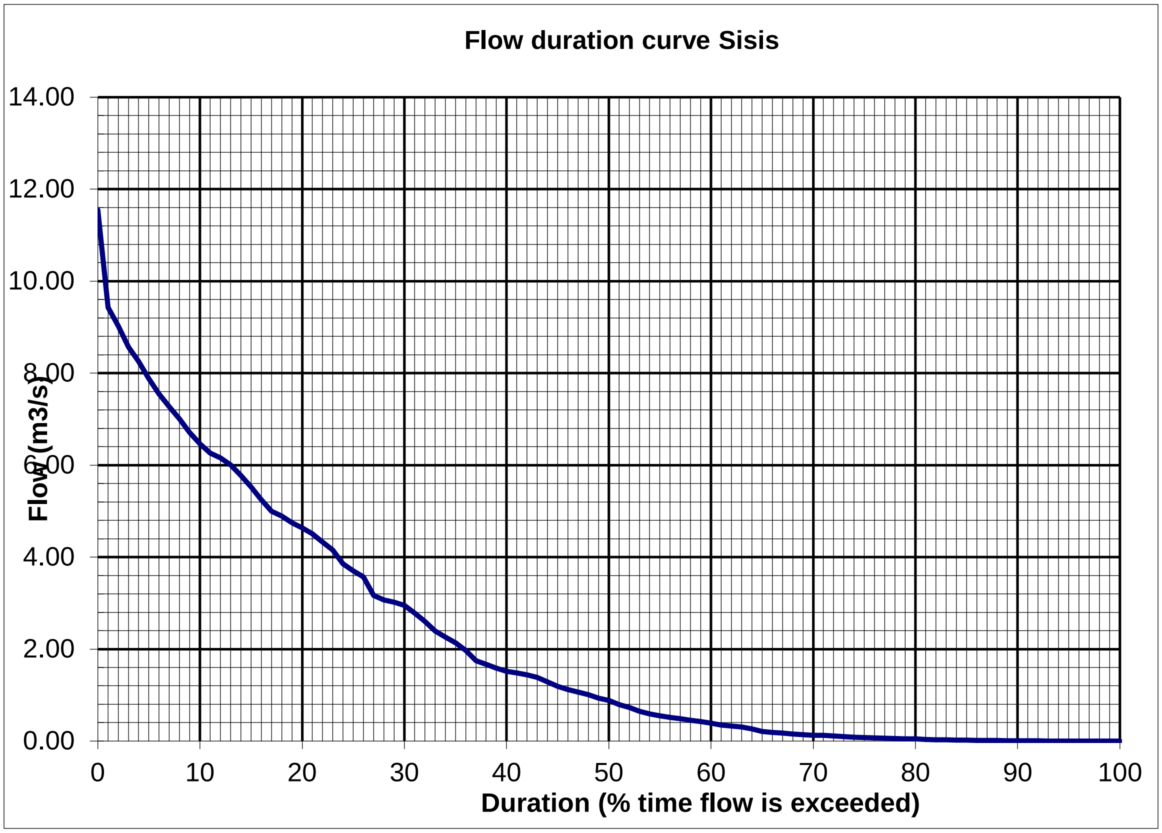

Flow duration curve Ishasha
Flow (m3/s)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

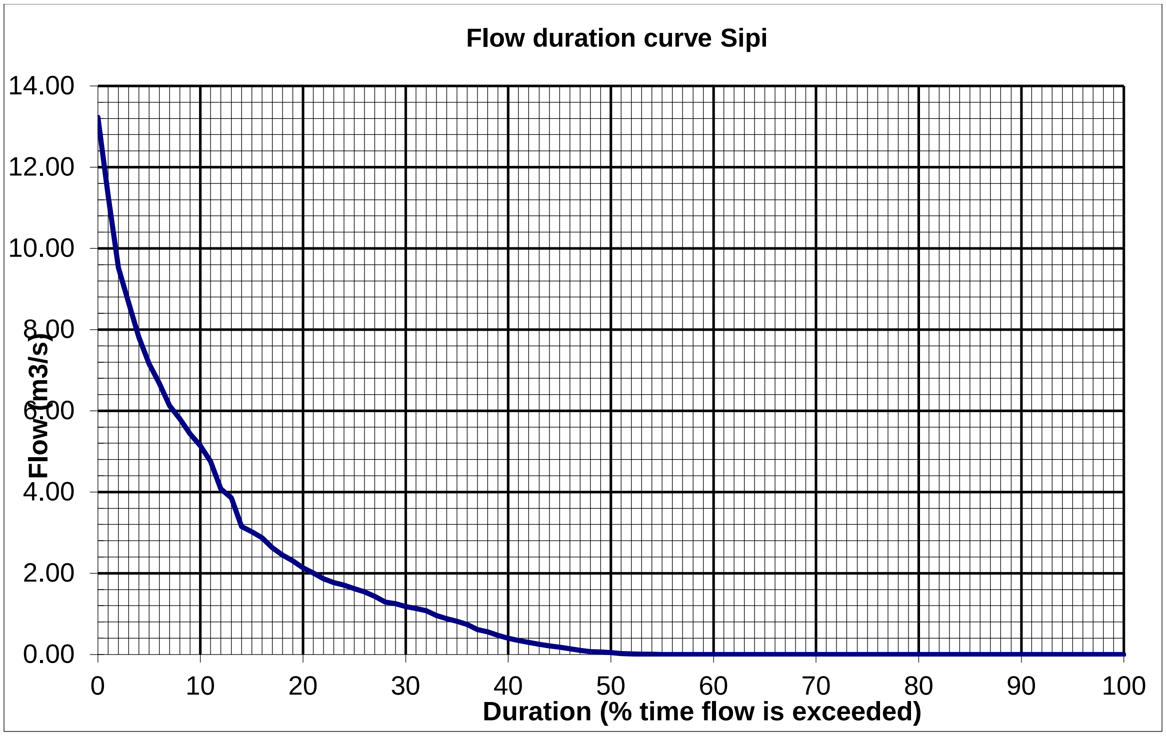

Flow duration curve BiraraMitano
Flow (m3/s)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

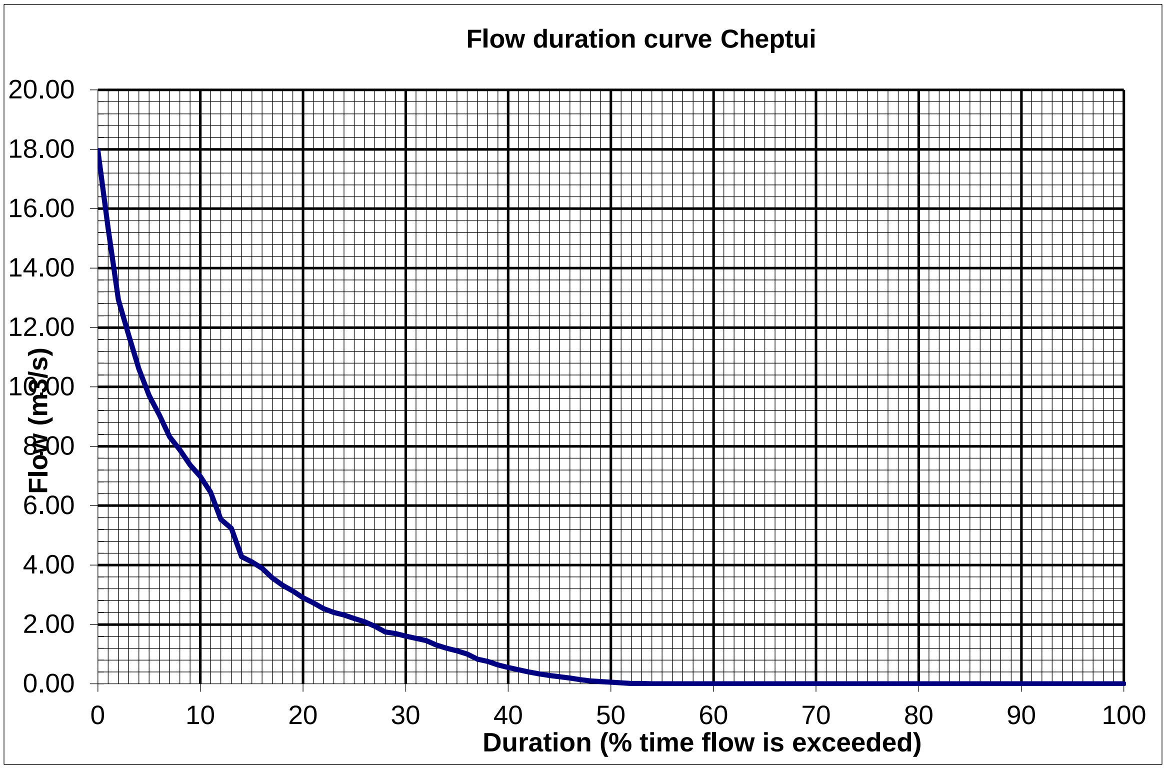

Flow duration curve Manafwa
Flow (m3/s)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

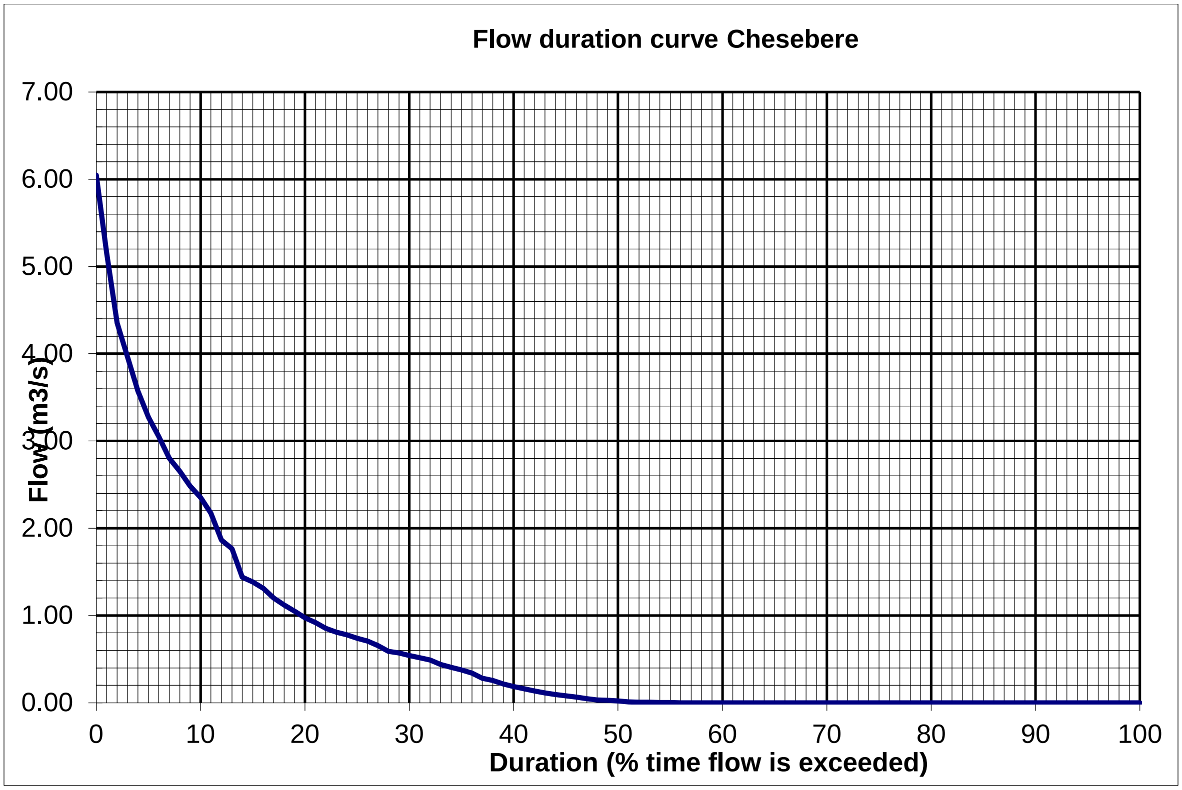

Flow duration curve Sironko
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

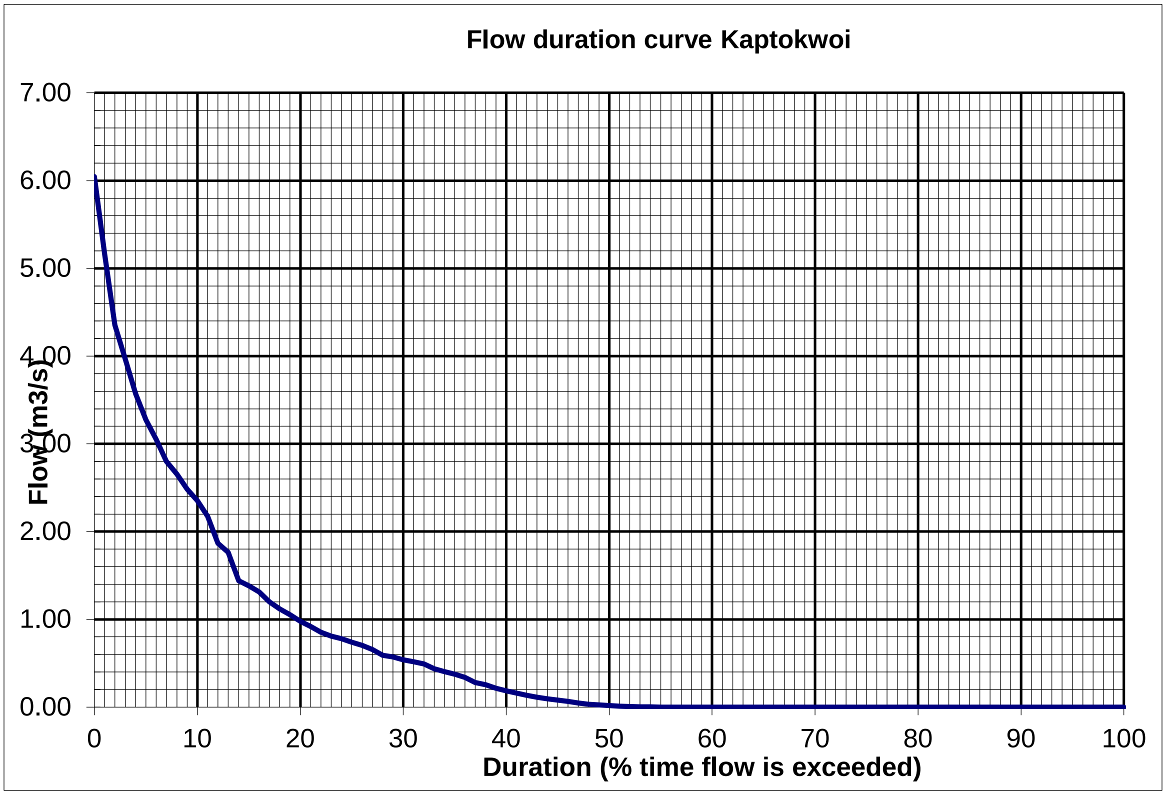

Flow duration curve Simu
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

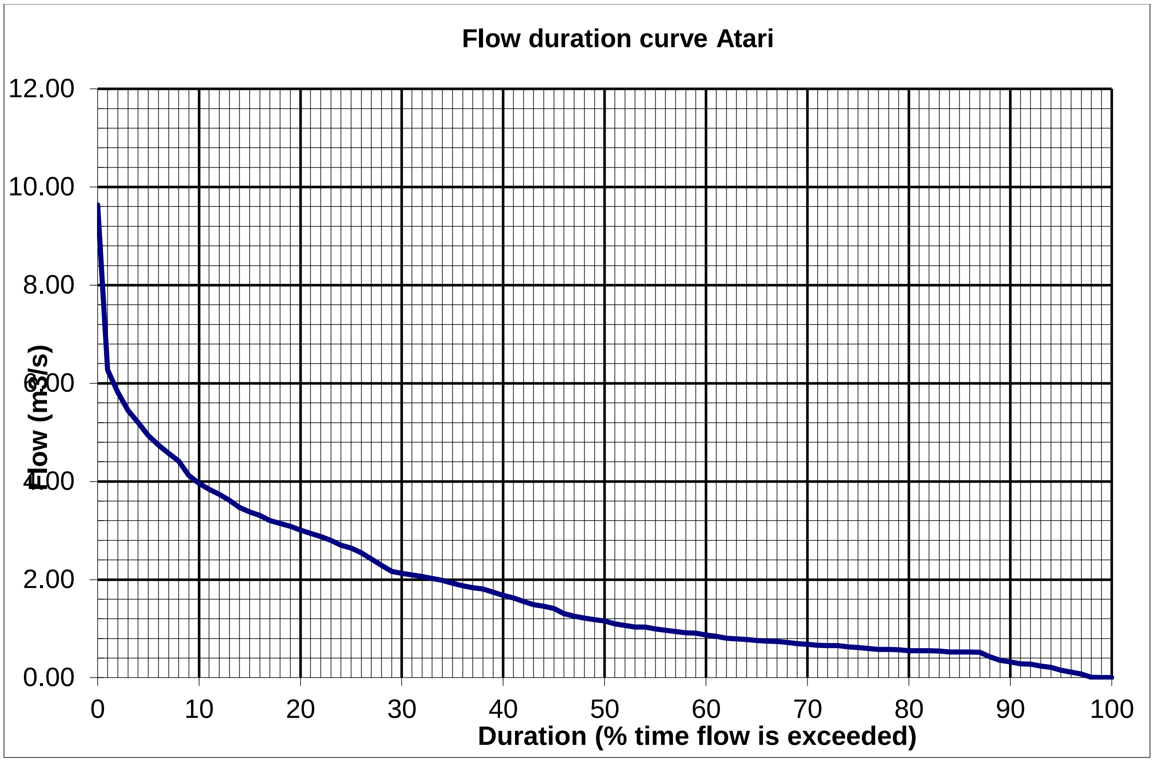

Flow duration curve Sisis
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

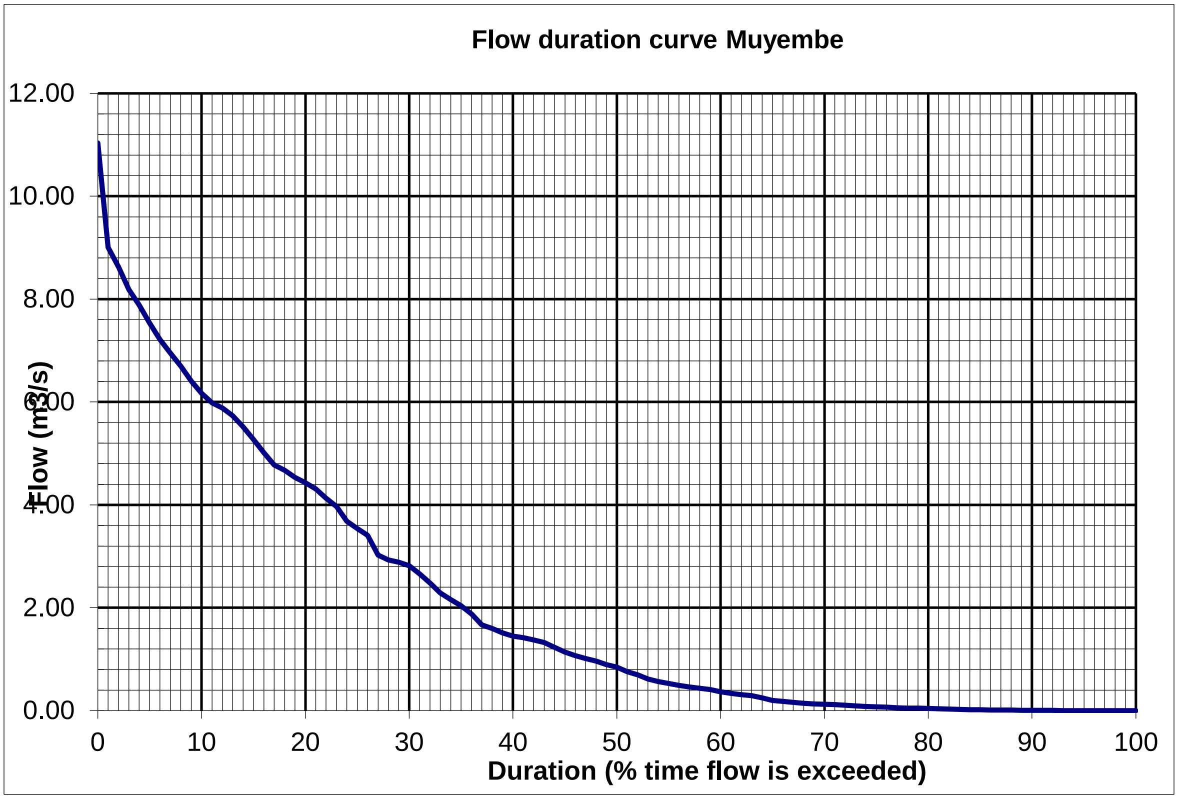

Flow duration curve Sipi
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

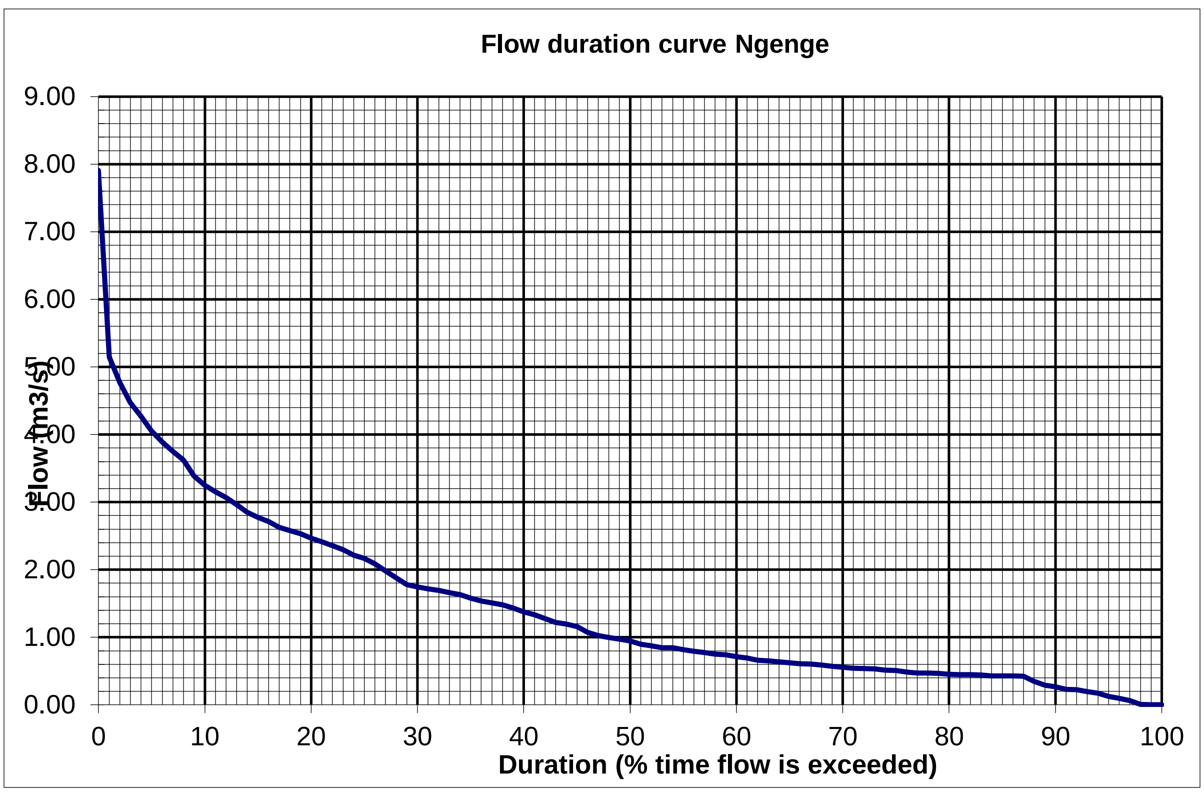

Flow duration curve Cheptui
Flow (m3/s)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

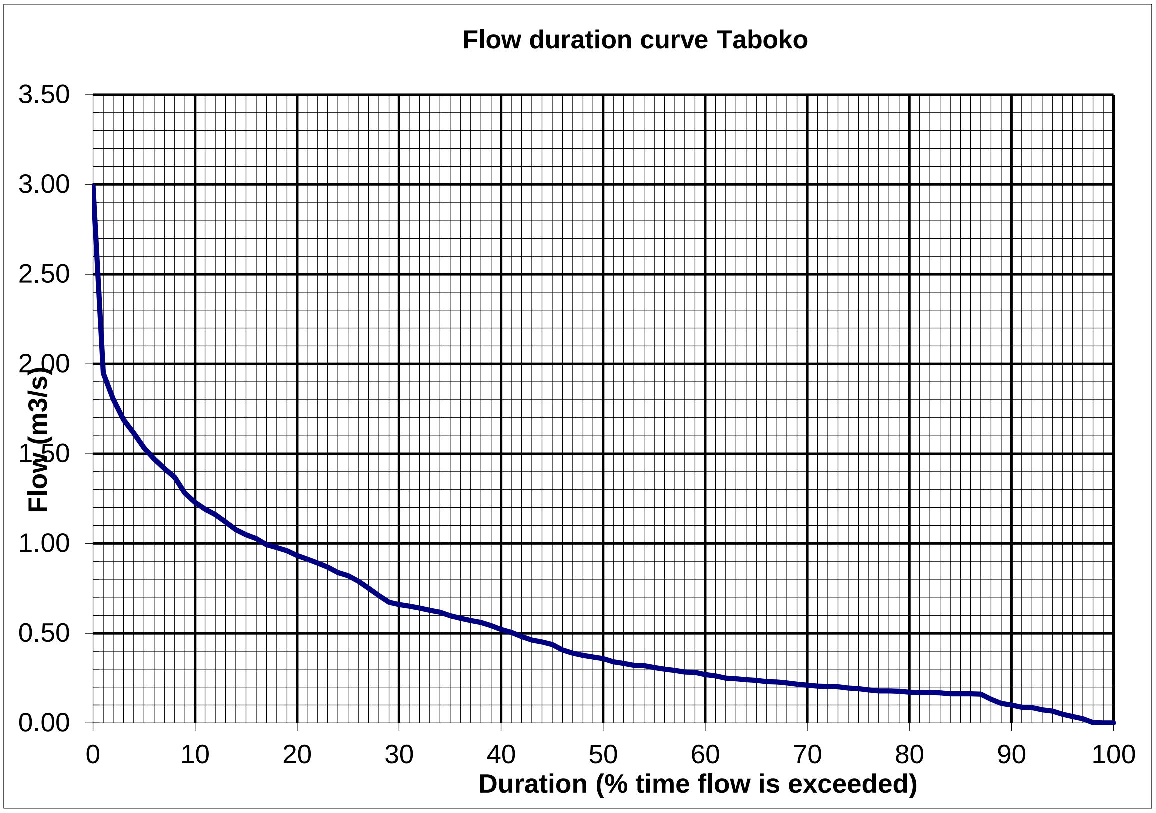

Flow duration curve Chesebere
Flow (m3/s)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

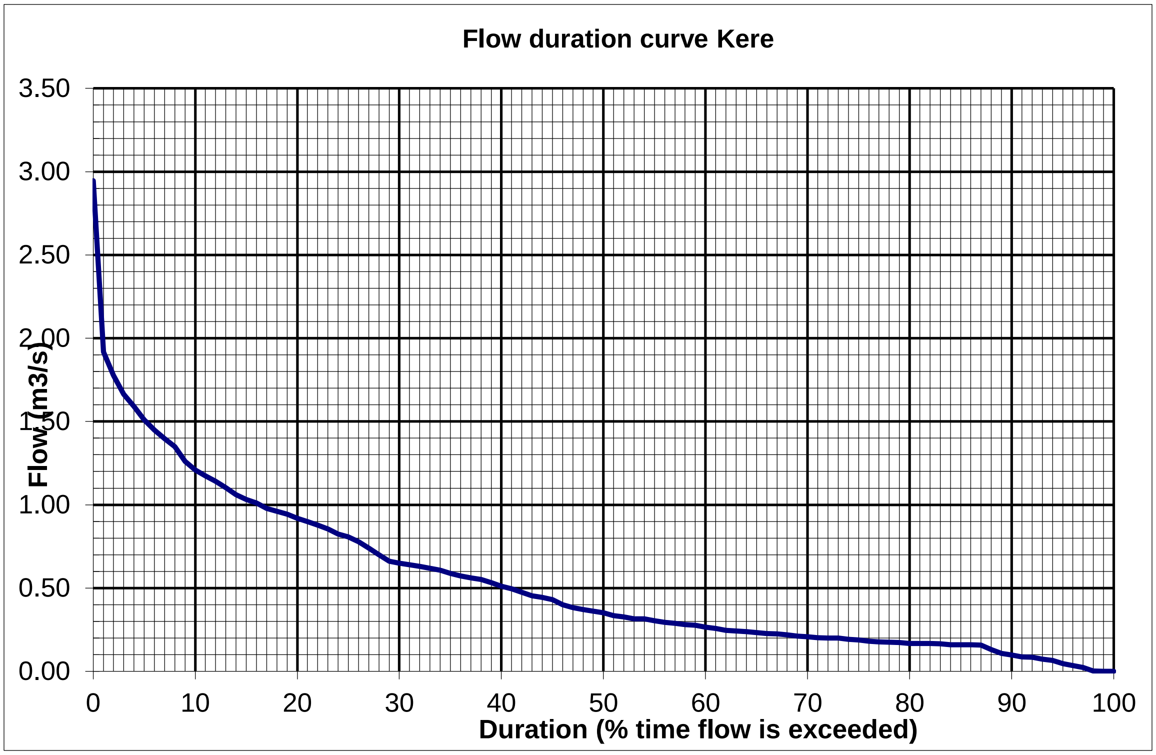

Flow duration curve Kaptokwoi
Flow (m3/s)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

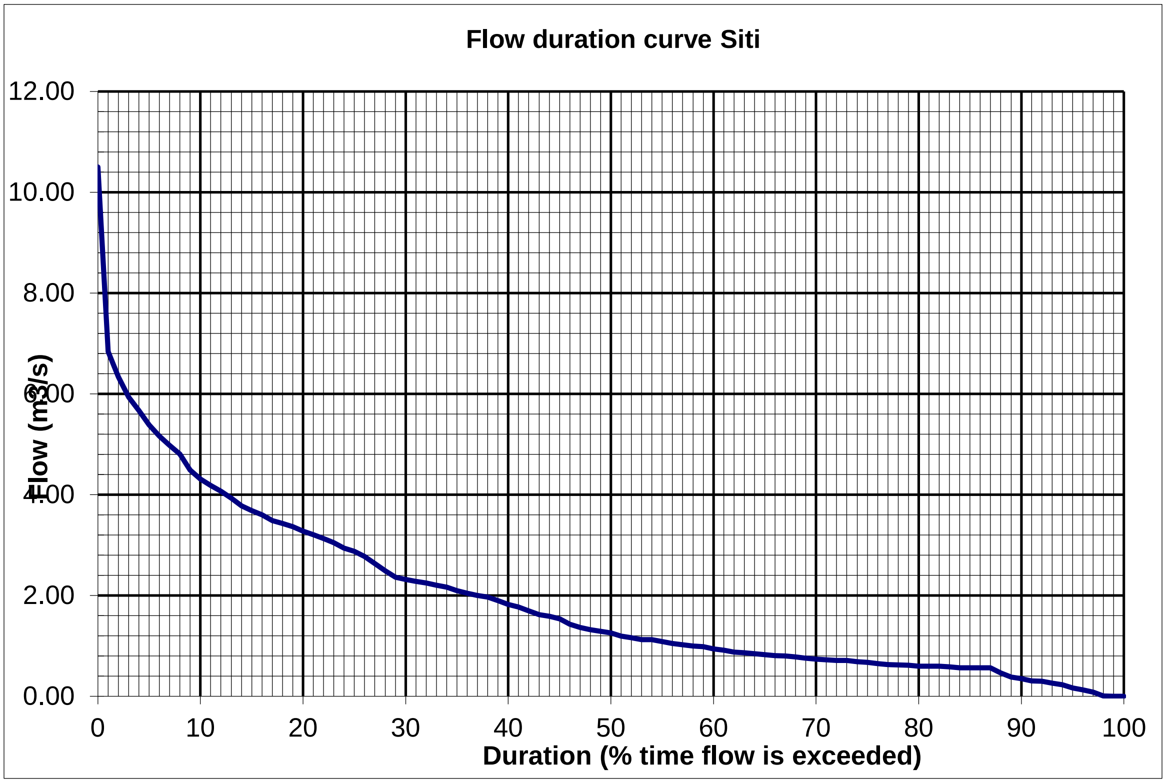

Flow duration curve Atari
Flow (m3/s)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

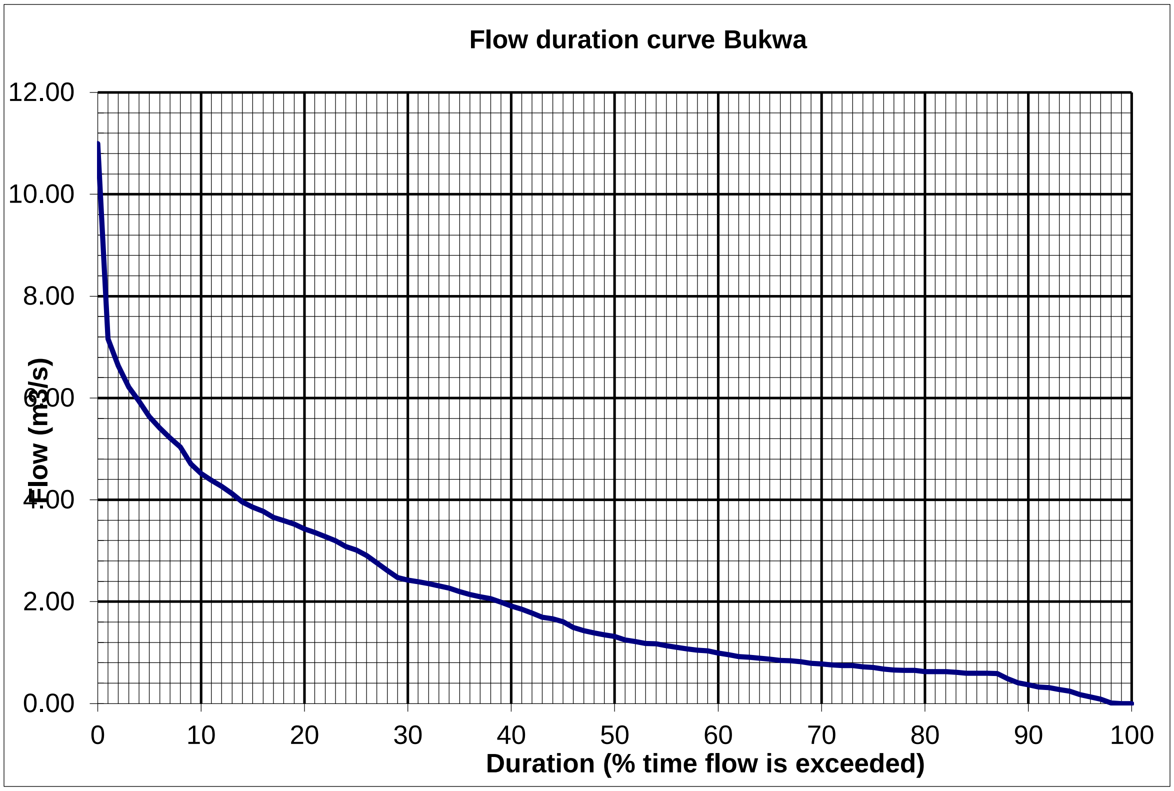

Flow duration curve Muyembe
Flow (m3/s)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

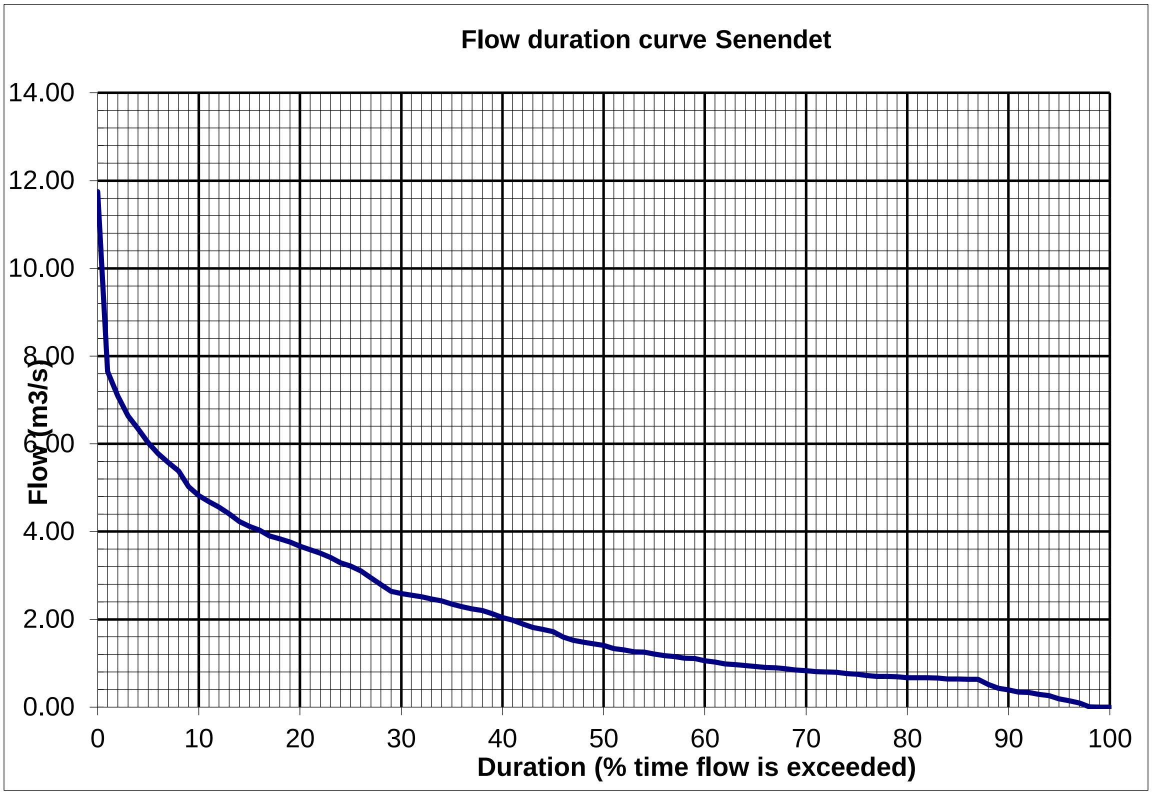

Flow duration curve Ngenge
Flow (m3/s)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

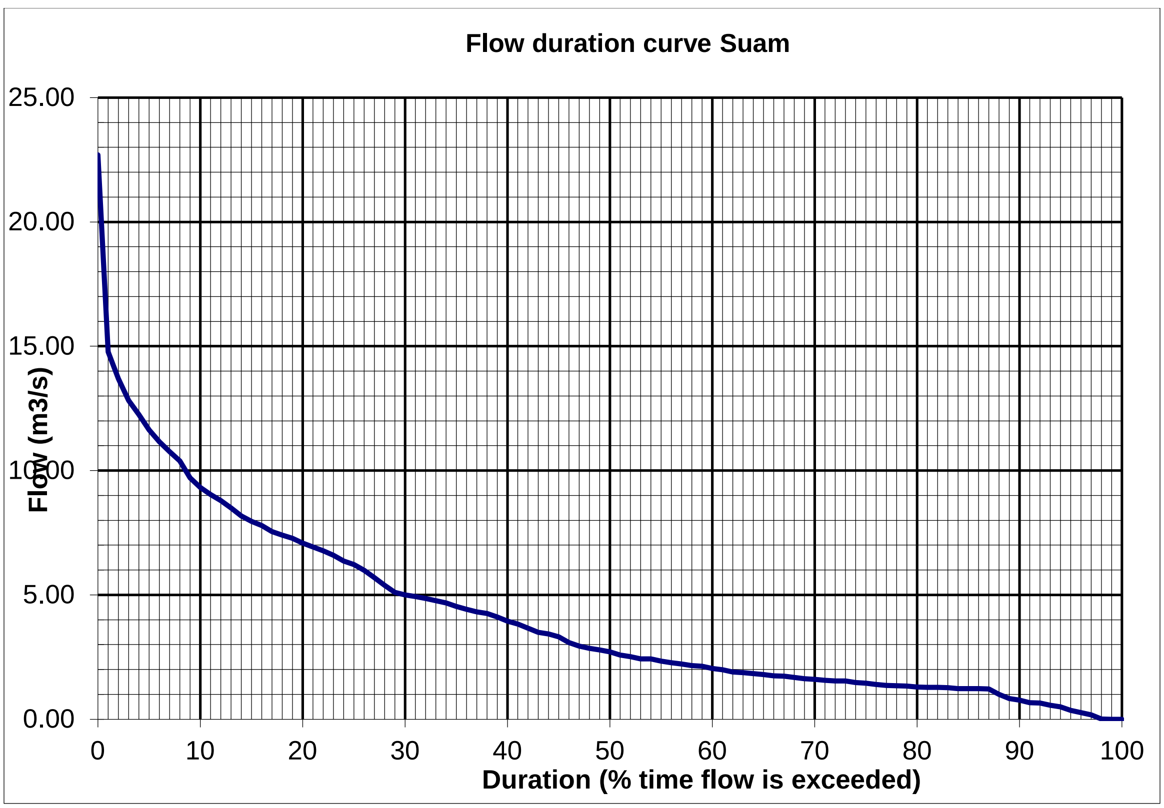

Flow duration curve Taboko
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

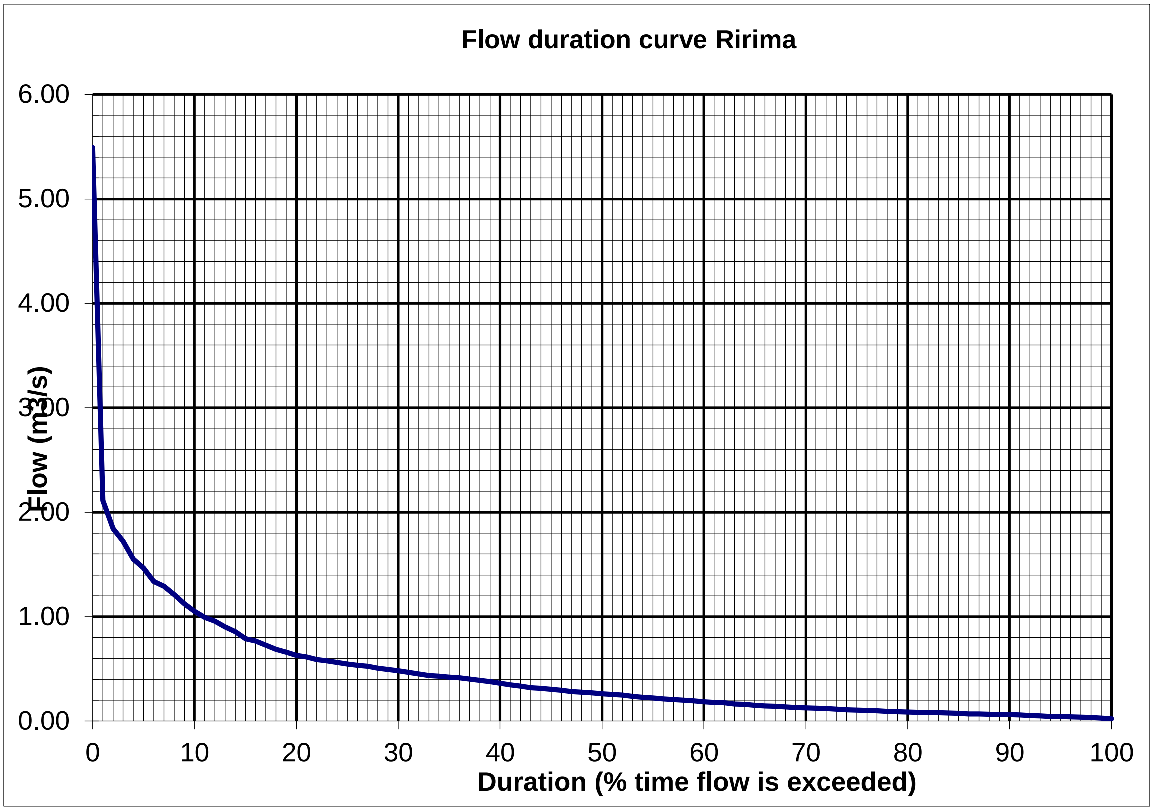

Flow duration curve Kere
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

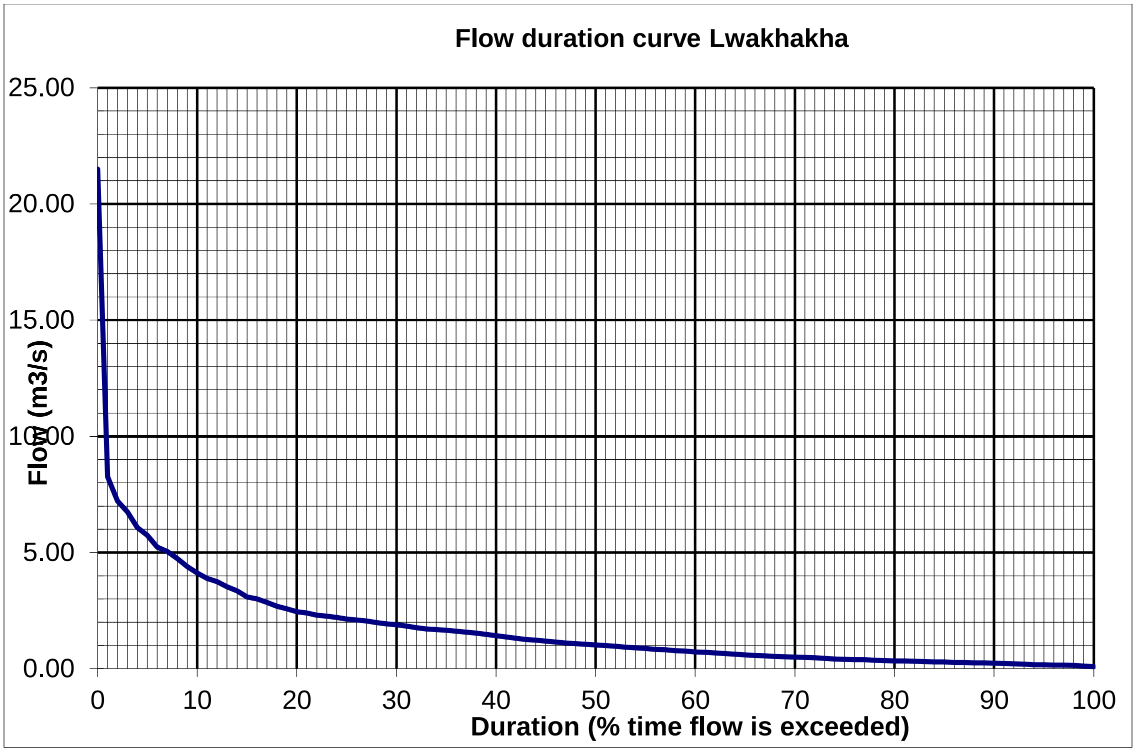

Flow duration curve Siti
Flow (m3/s)
Duration (% time flow is exceeded)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0
10
20
30
40
50
60
70
80
90
100


Flow duration curve Bukwa
Flow (m3/s)
Duration (% time flow is exceeded)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0
10
20
30
40
50
60
70
80
90
100


Flow duration curve Senendet
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

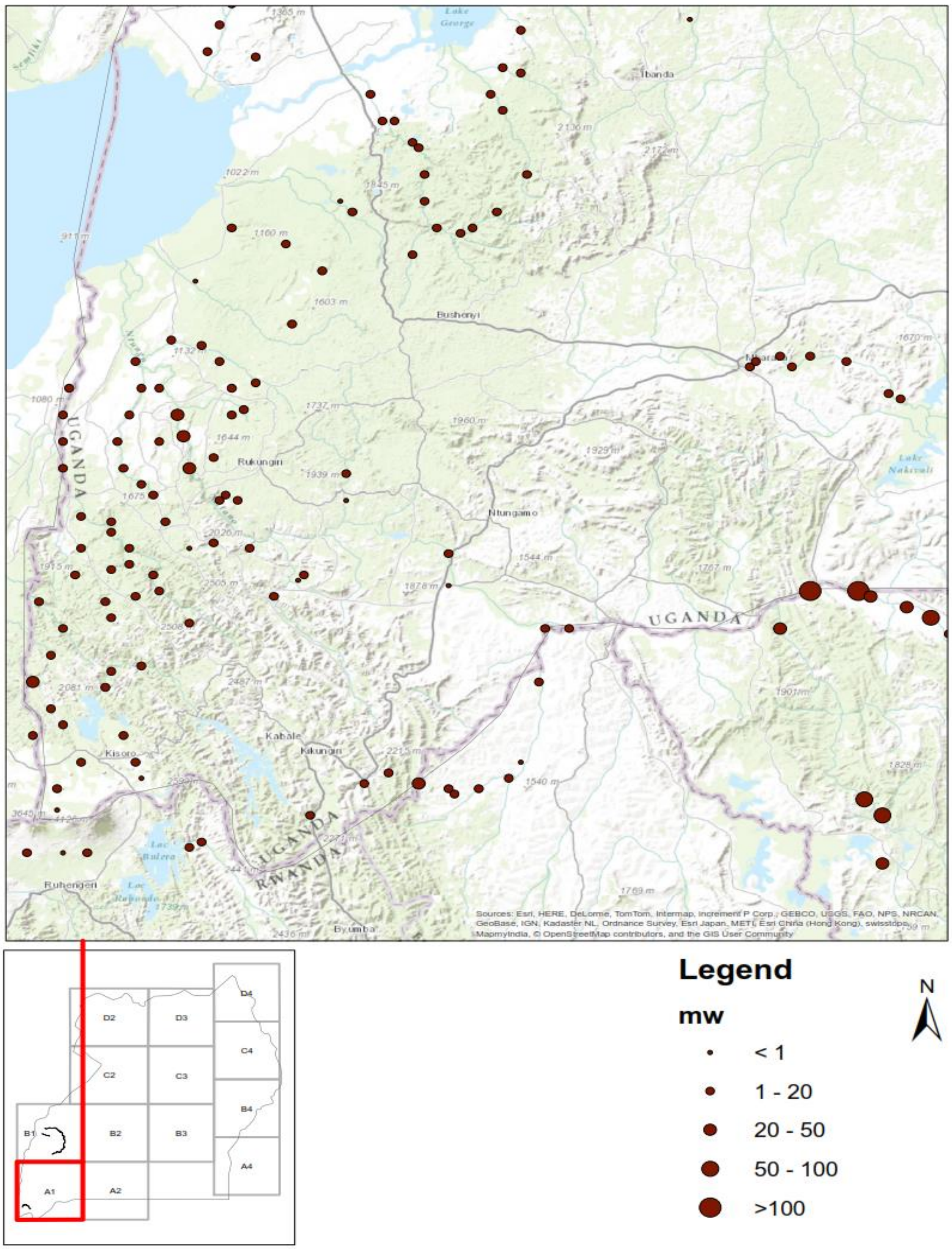

Flow duration curve Suam
25.00
20.00
15.00
10.00
5.00
0.00
Flow (m3/s)
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

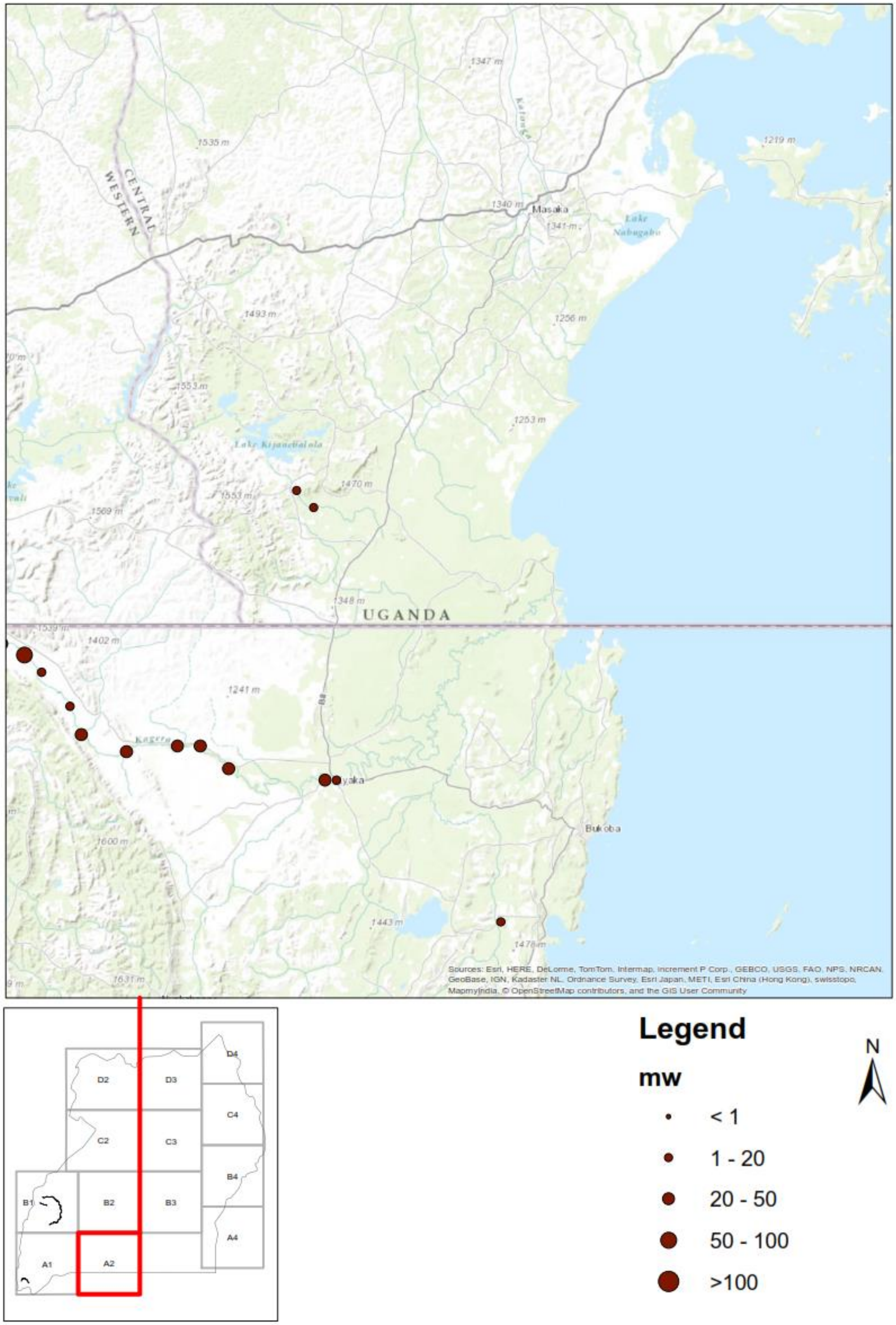

Flow duration curve Ririma
Flow (m3/s)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

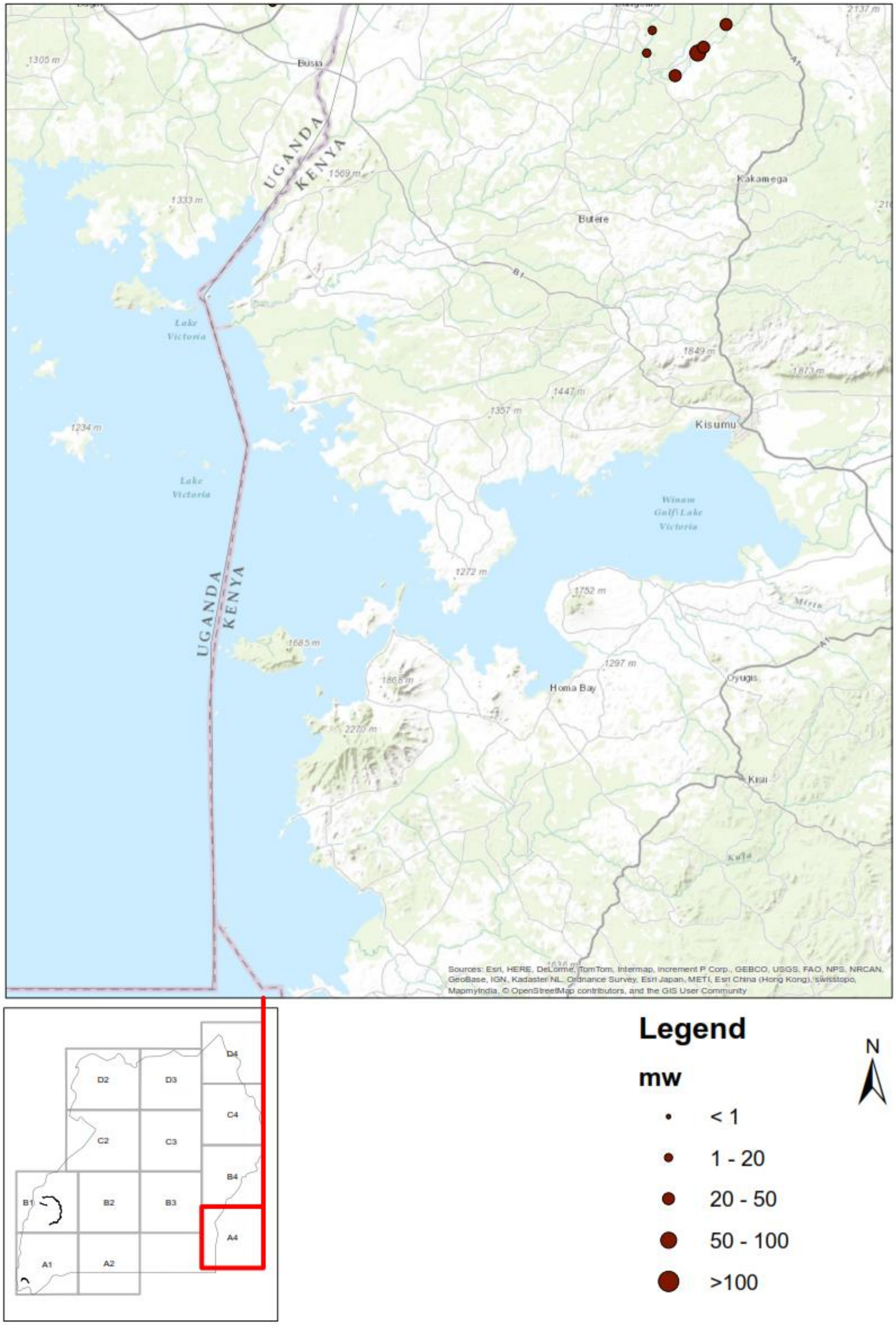

Flow duration curve Lwakhakha
Flow (m3/s)
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
100
Duration (% time flow is exceeded)

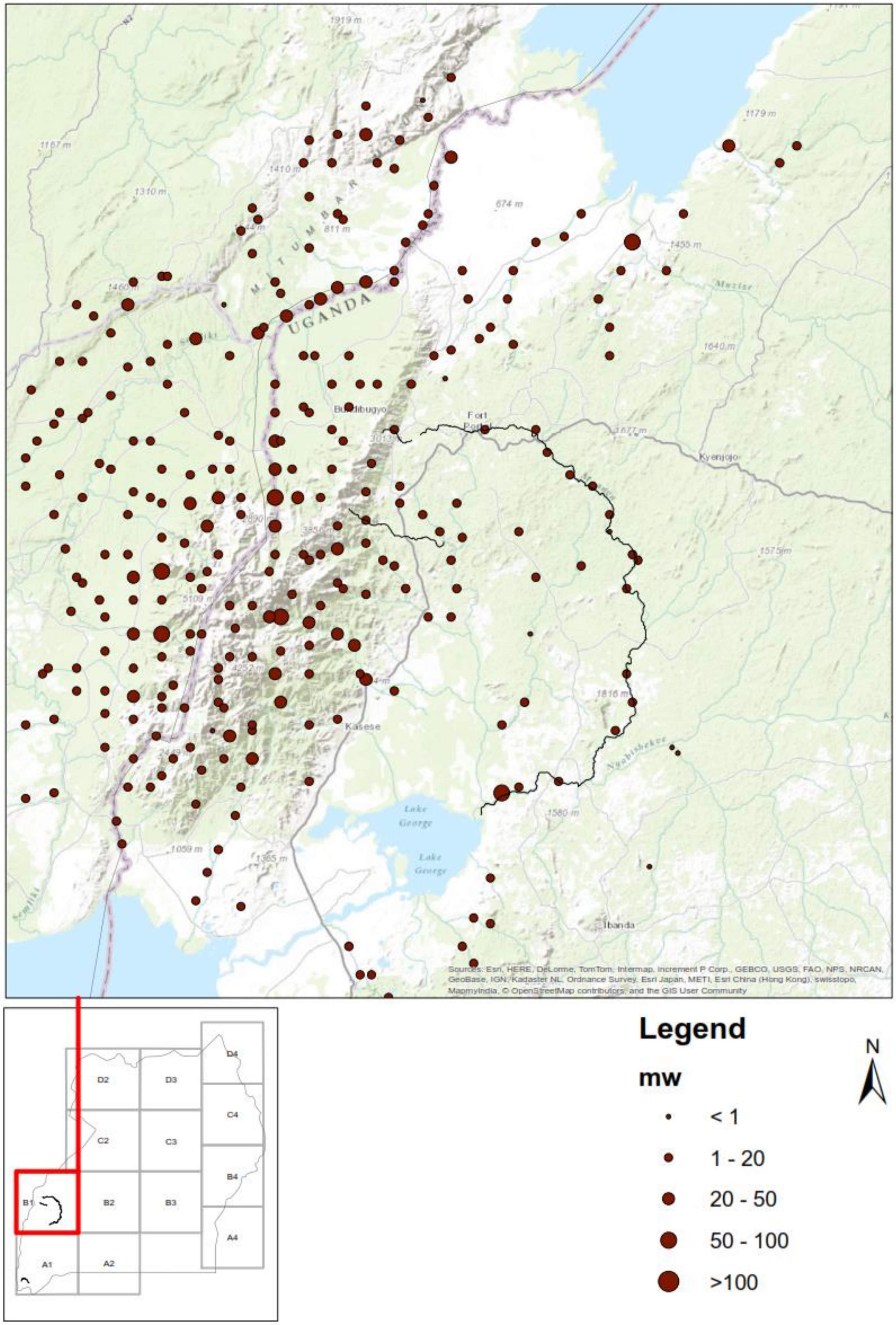
Appendix E

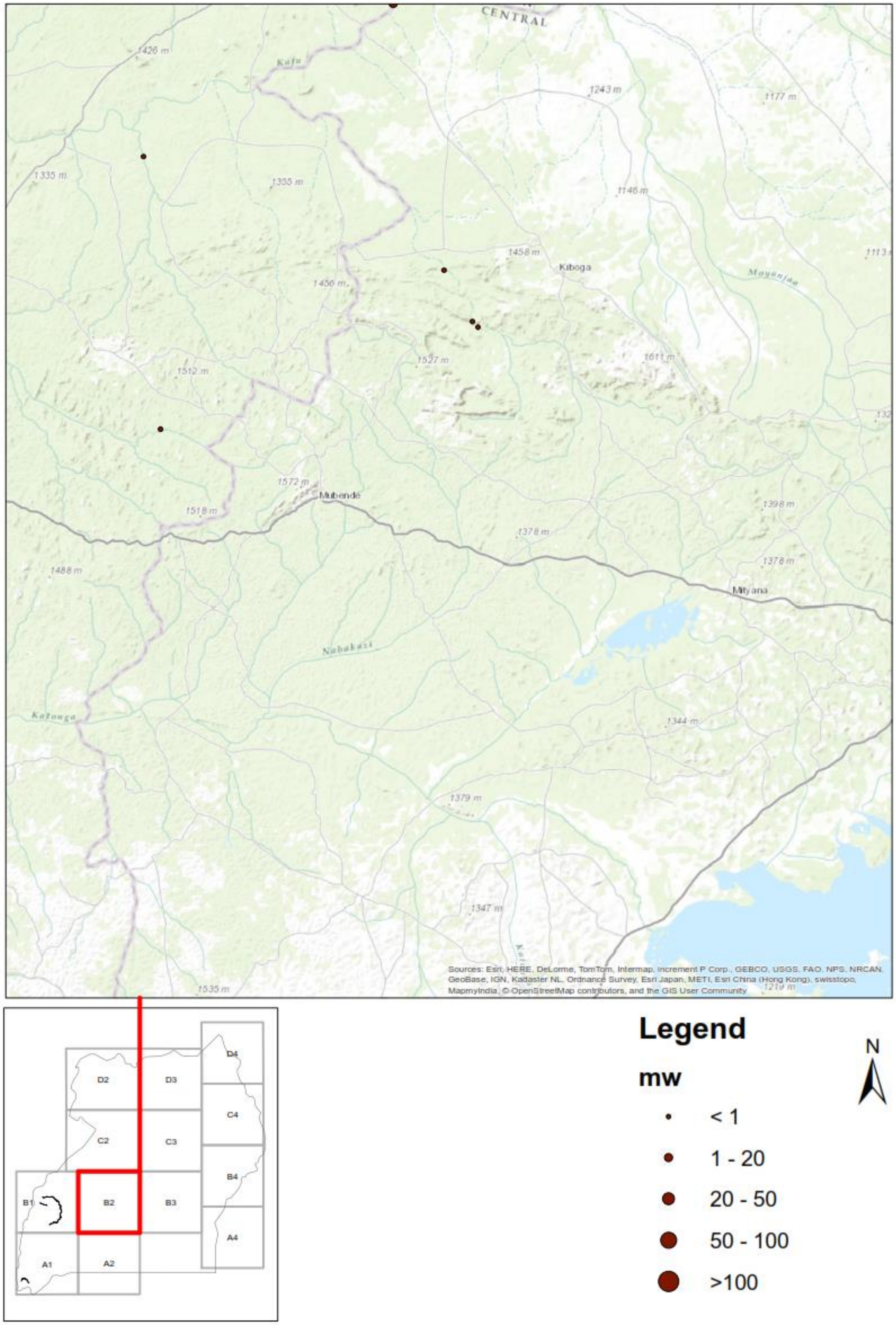
Hydro Search Results

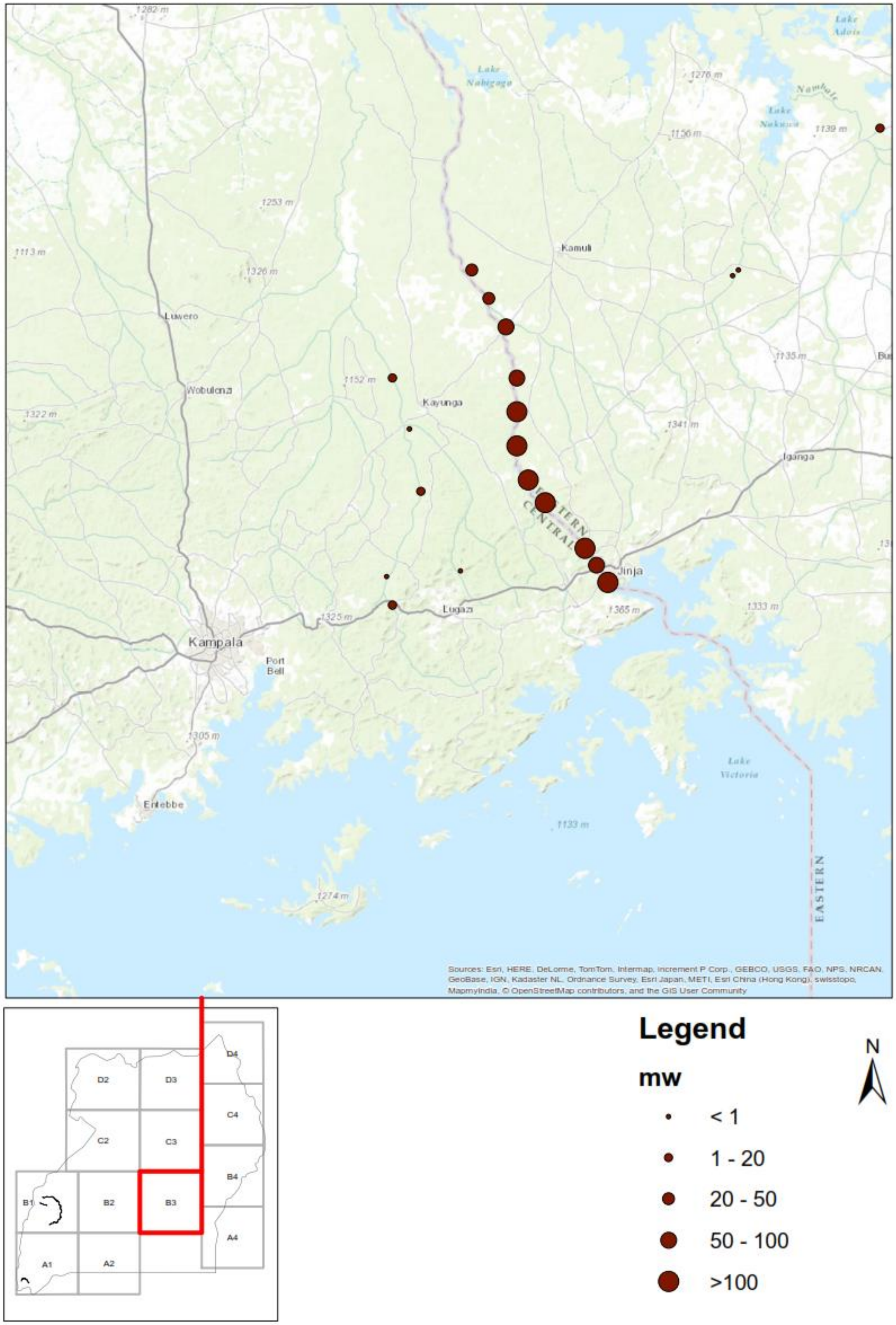


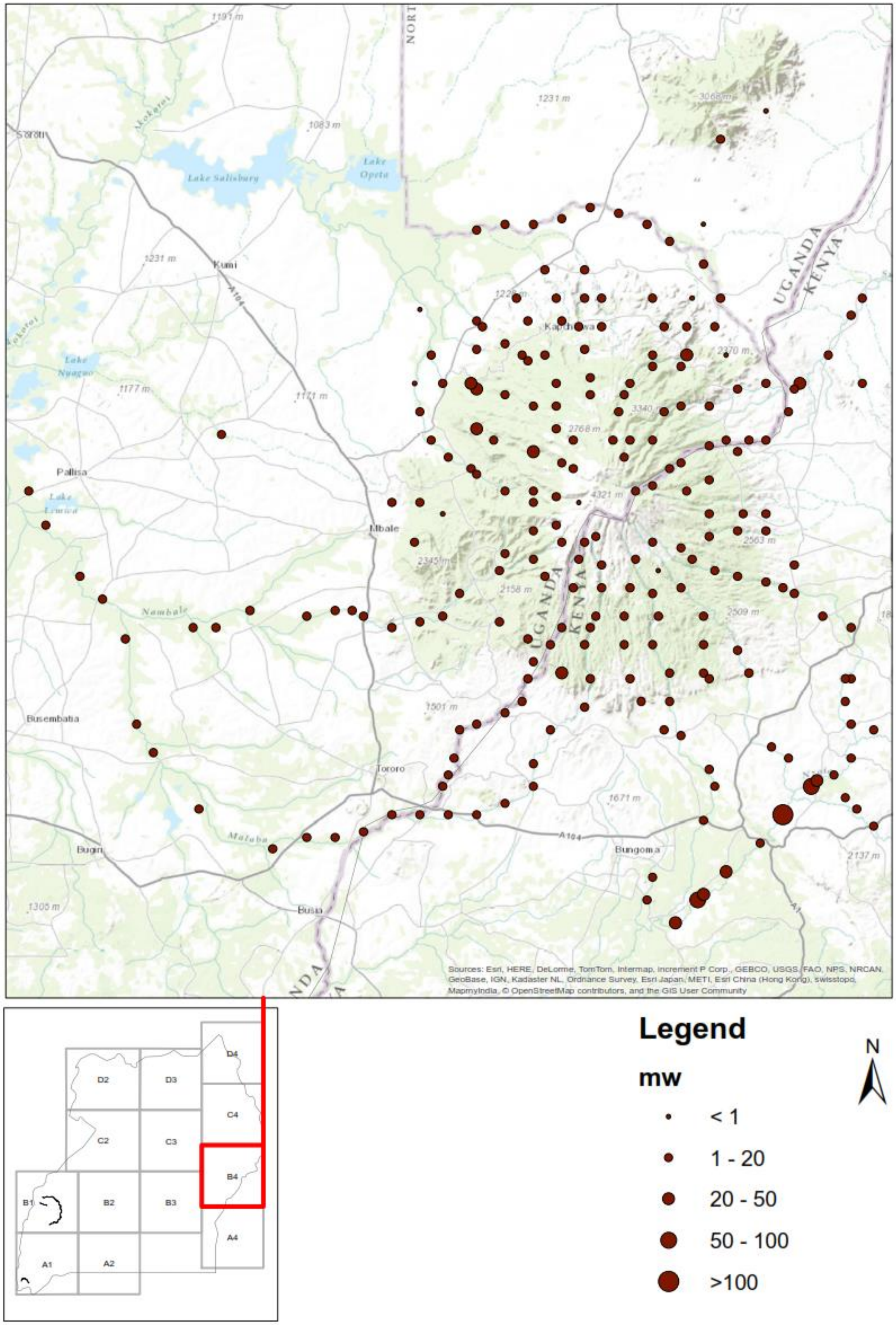

CENTRAL
WESTERN
Masaka
Lake Nabugabo
Lake Kijanebalola
UGANDA
Kagera
Bukoba
B8
1347 m
1535 m
1219 m
1340 m
1341 m
1493 m
1256 m
1553 m
1253 m
1470 m
1569 m
1348 m
1402 m
1241 m
1600 m
1443 m
1478 m
1631 m
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

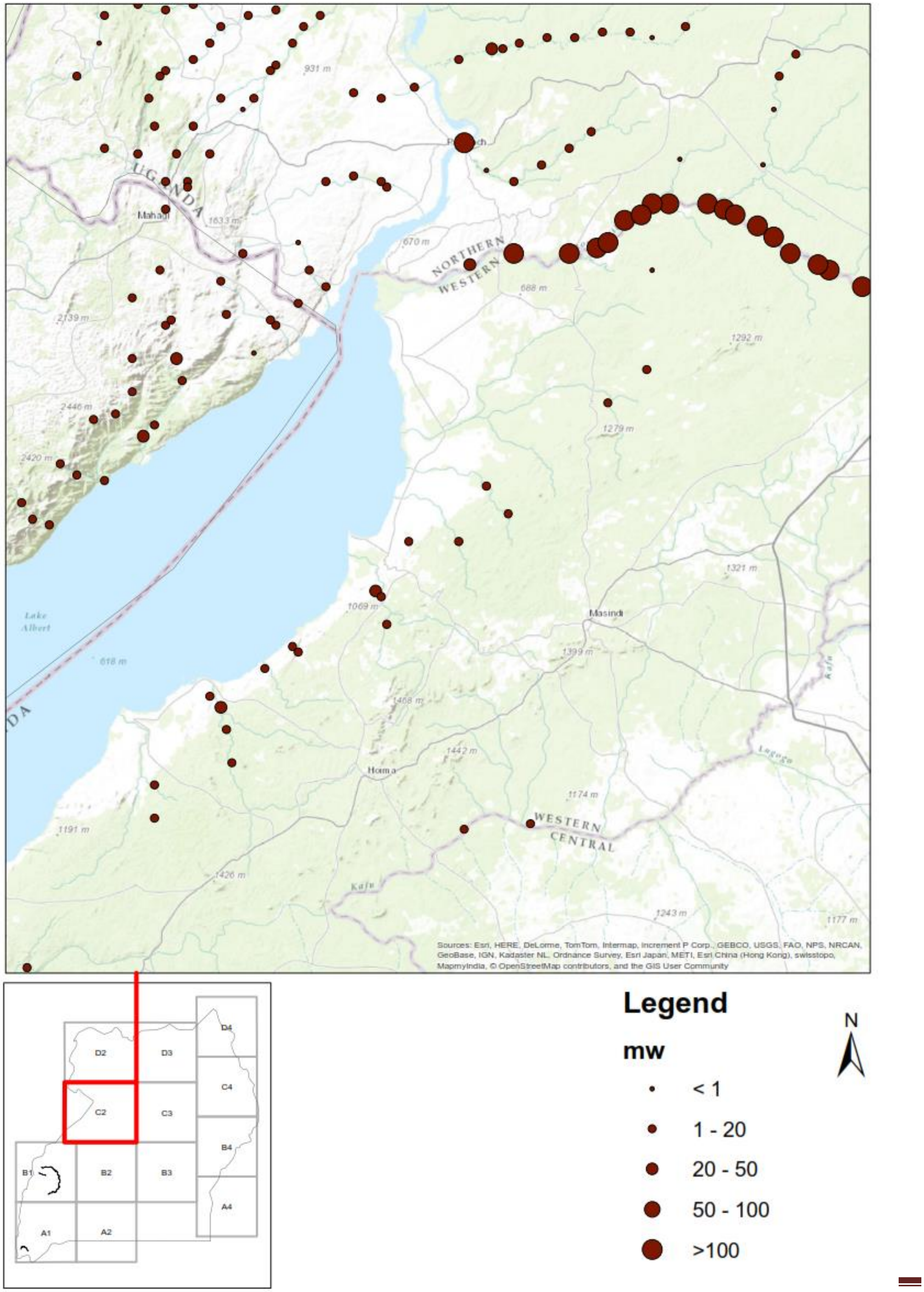

Busia
UGANDA
KENYA
1305 m
1333 m
1509 m
Kakamega
Butere
Lake Victoria
1849 m
1873 m
1447 m
1357 m
1234 m
Kisumu
Lake Victoria
Winam Gulf/Lake Victoria
1272 m
1752 m
UGANDA
KENYA
1685 m
1297 m
Homa Bay
Oyugis
2270 m
Kisii
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N


UGANDA
Fort Portal
Kasese
Kyenjojo
Ibanda
Lake George
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

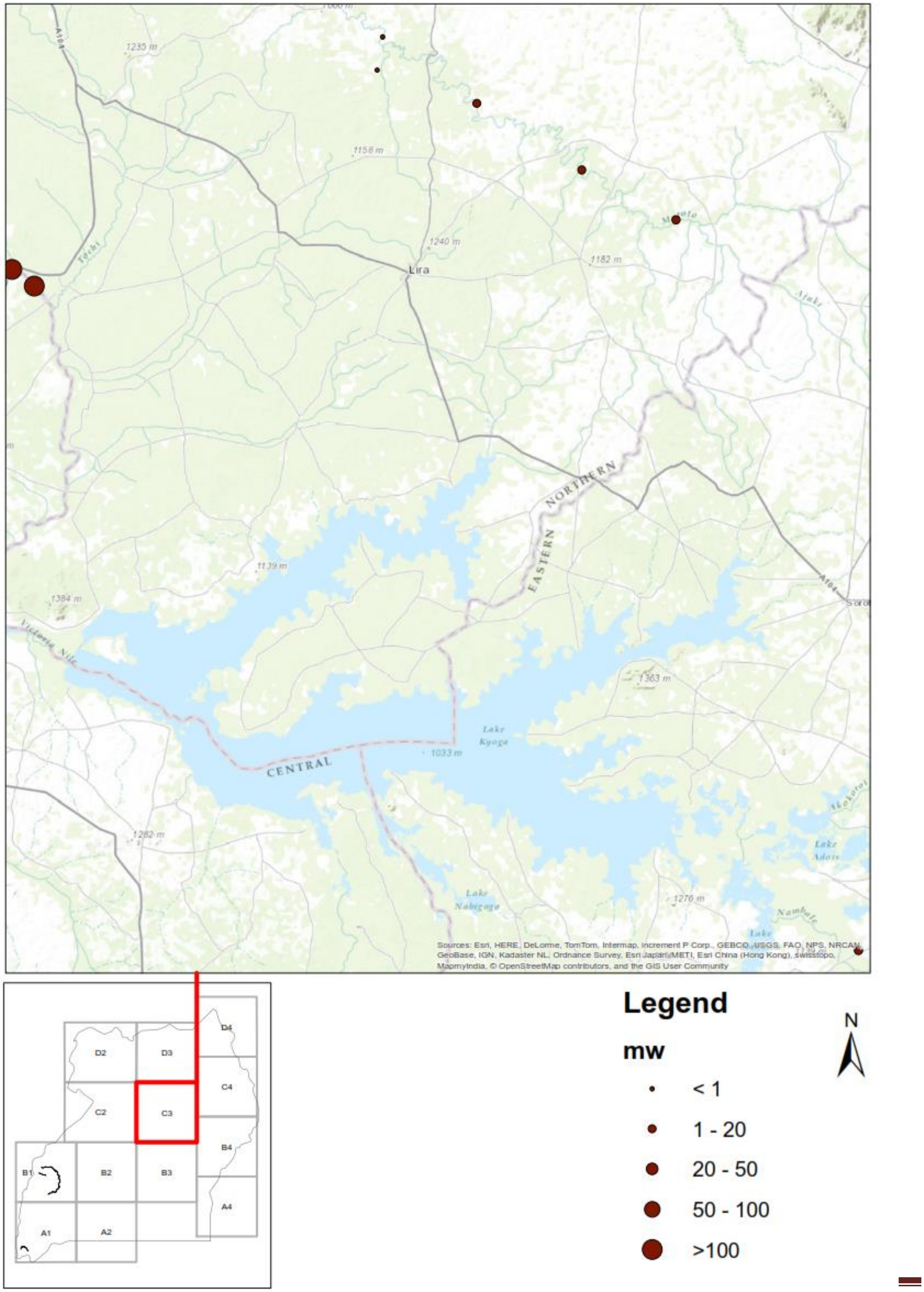

CENTRAL
Kafu
Kiboga
Mubende
Mityana
Nabakazi
Katonga
1426 m
1243 m
1177 m
1335 m
1355 m
1146 m
1458 m
1456 m
1527 m
1611 m
1512 m
1572 m
1518 m
1378 m
1398 m
1488 m
1344 m
1379 m
1347 m
1535 m
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

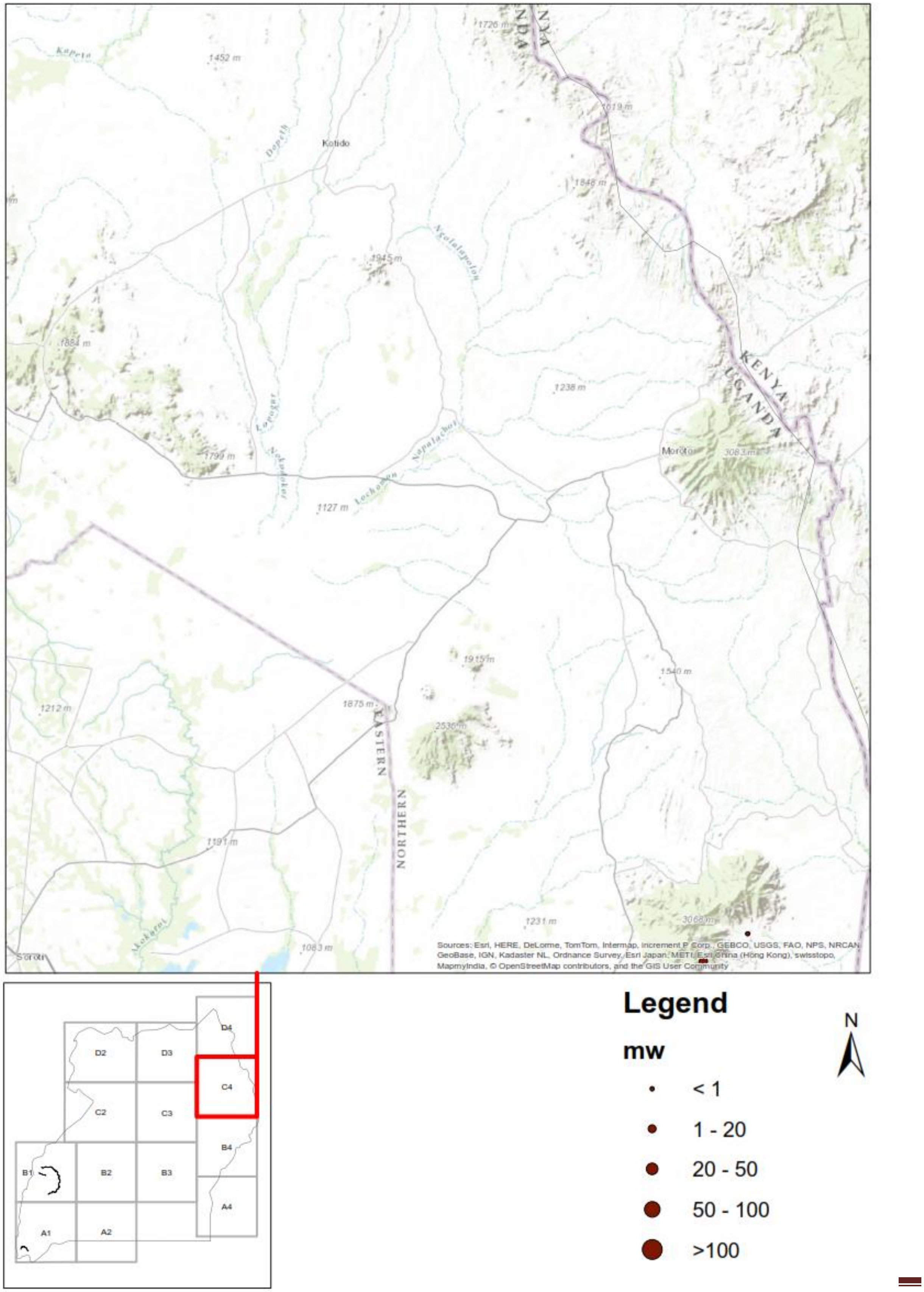

Kamuli
Luwero
Wobulenzi
Kayunga
Iganga
Jinja
Lugazi
Kampala
Port Bell
Entebbe
Lake Victoria
EASTERN
CENTRAL
1253 m
1113 m
1326 m
1152 m
1322 m
1341 m
1135 m
1156 m
1139 m
1276 m
1325 m
1365 m
1333 m
1305 m
1133 m
1274 m
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N


Soroti
Lake Salisbury
Lake Opeta
Kumi
Pallisa
Mbale
Tororo
Busia
Bungoma
Busembatia
Bugiri
UGANDA
KENYA
A104
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

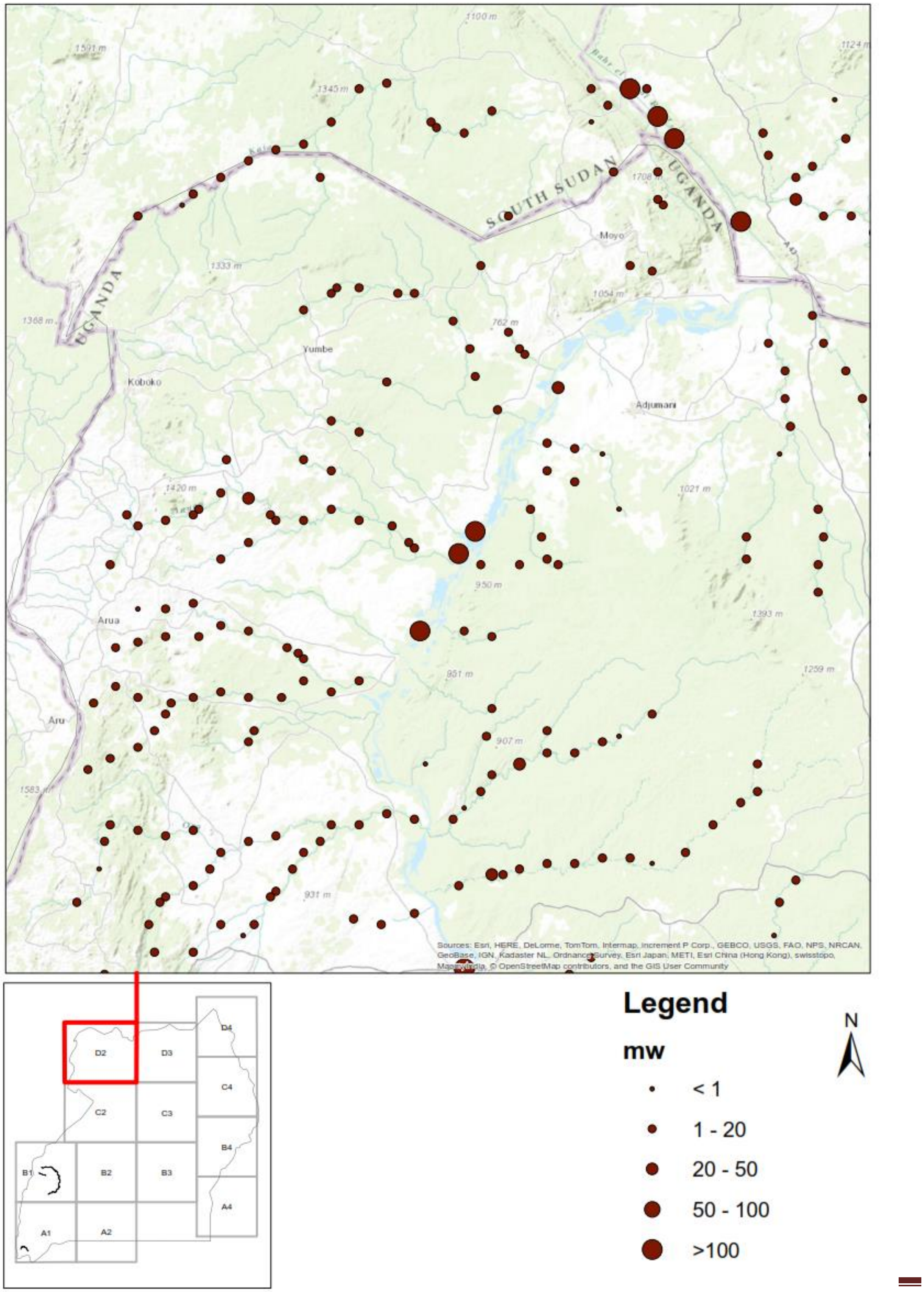


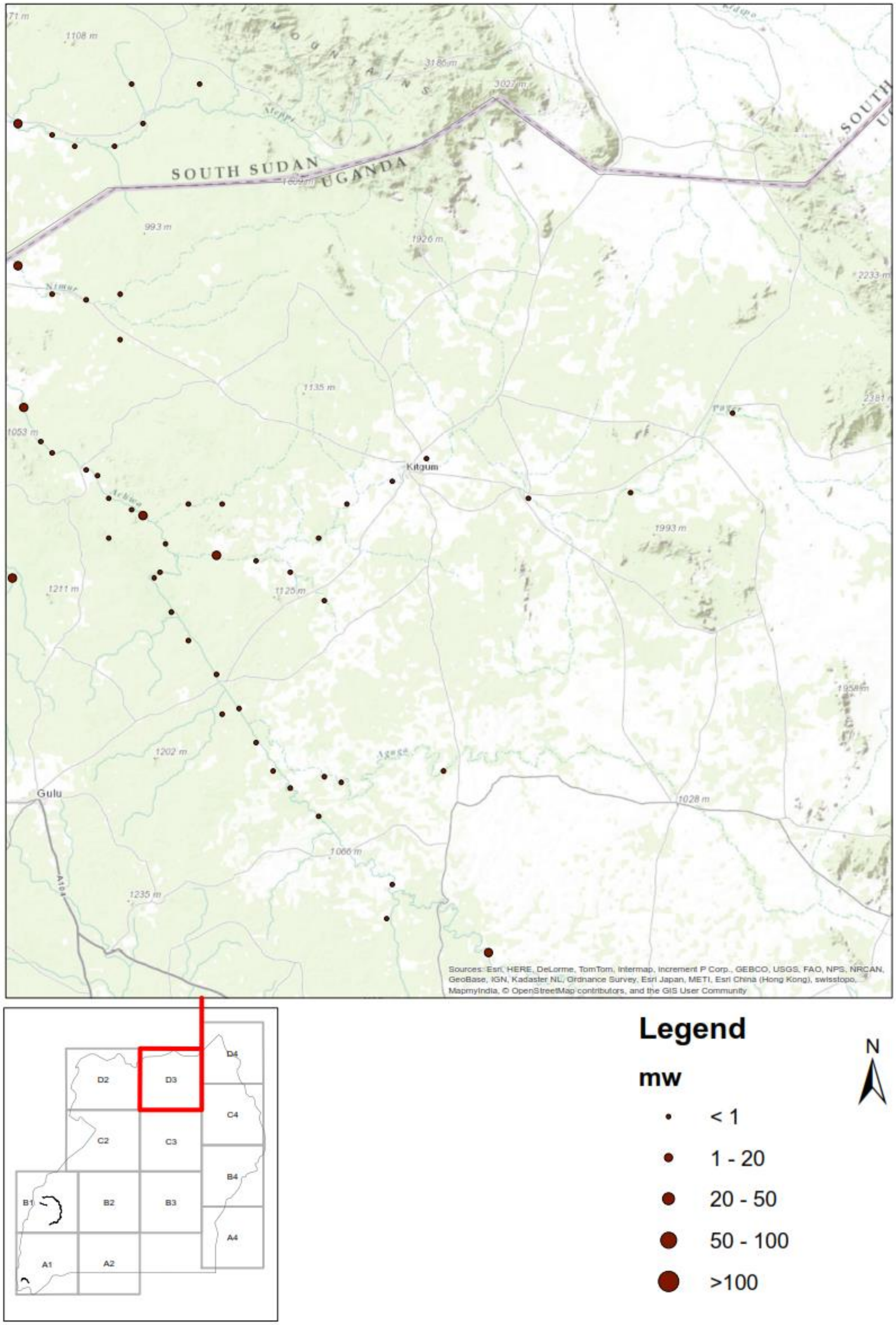
Mahagi
UGANDA
NORTHERN
WESTERN
Lake Albert
Masindi
Hoima
WESTERN
CENTRAL
Kafu
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

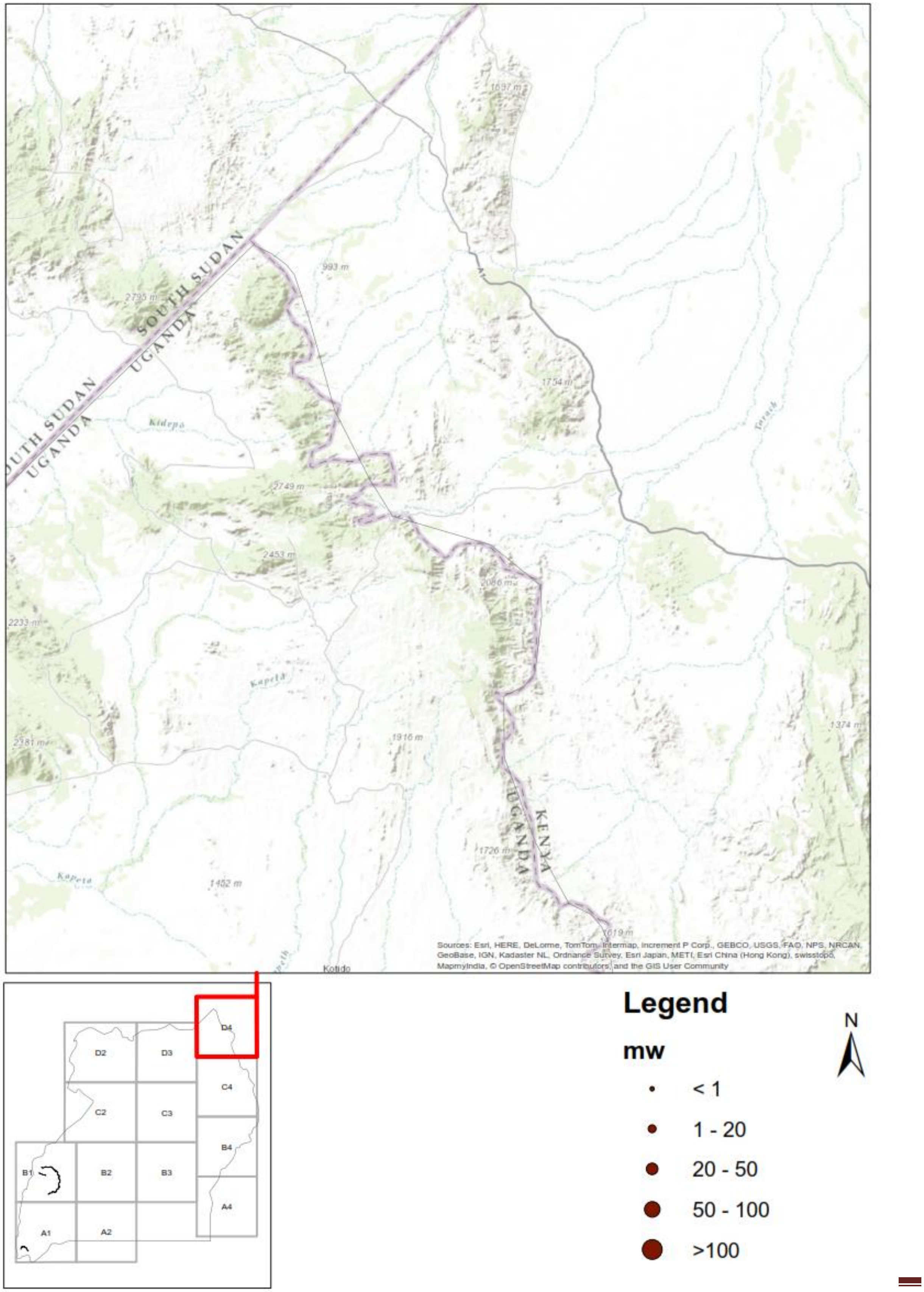

Lira
NORTHERN
EASTERN
CENTRAL
Lake Kyoga
1033 m
1139 m
1158 m
1240 m
1182 m
1235 m
1384 m
1363 m
1282 m
1276 m
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N



Kotido
Moroto
KENYA
UGANDA
EASTERN
NORTHERN
Soroti
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

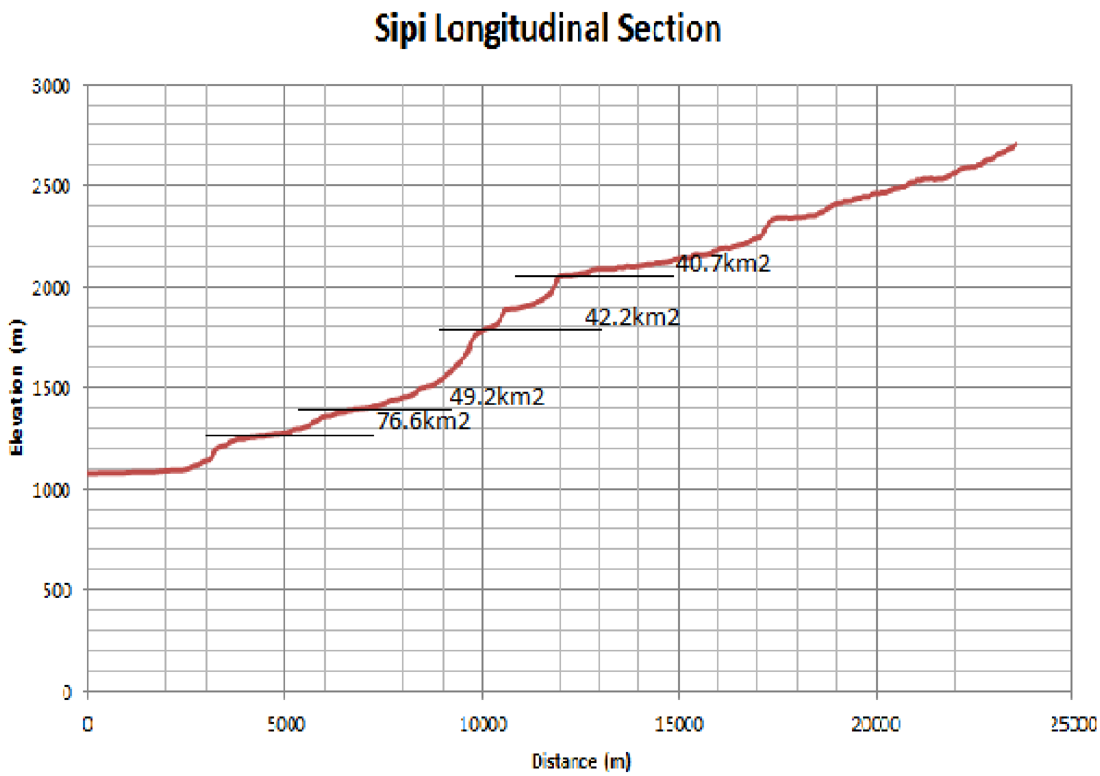

SOUTH SUDAN
UGANDA
UGANDA
Yumbe
Koboko
Moyo
Adjumani
Arua
Aru
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, Mapmyindia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

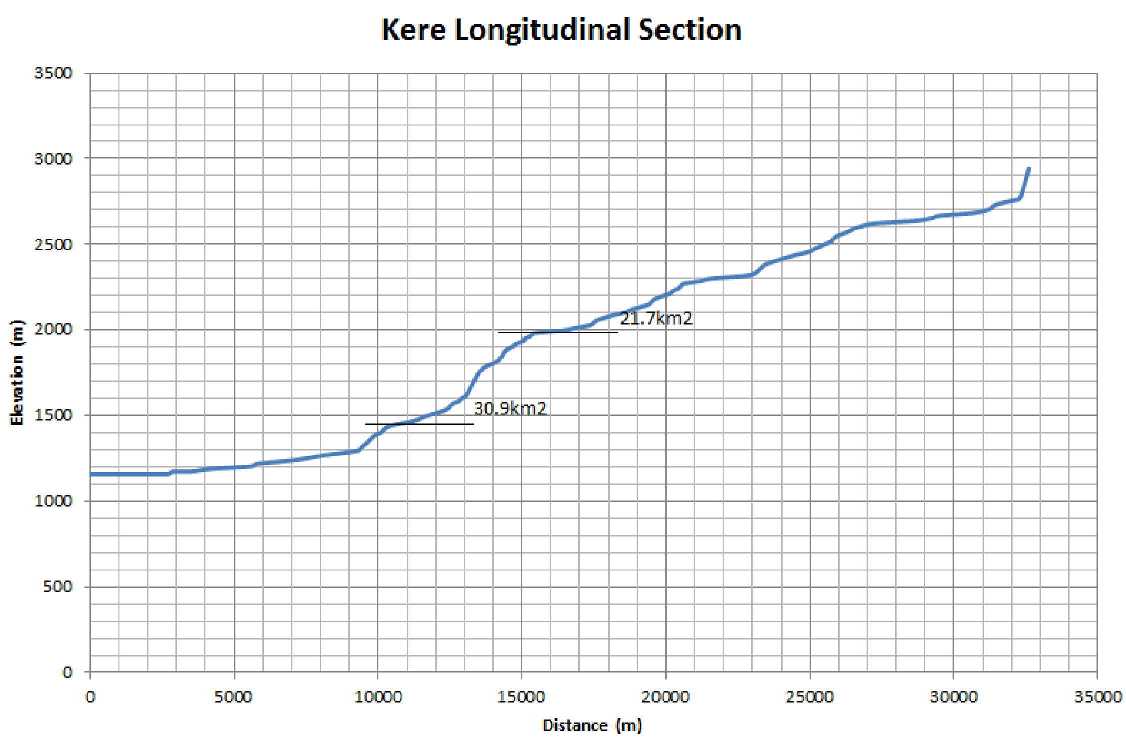

SOUTH SUDAN
UGANDA
Kitgum
Gulu
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

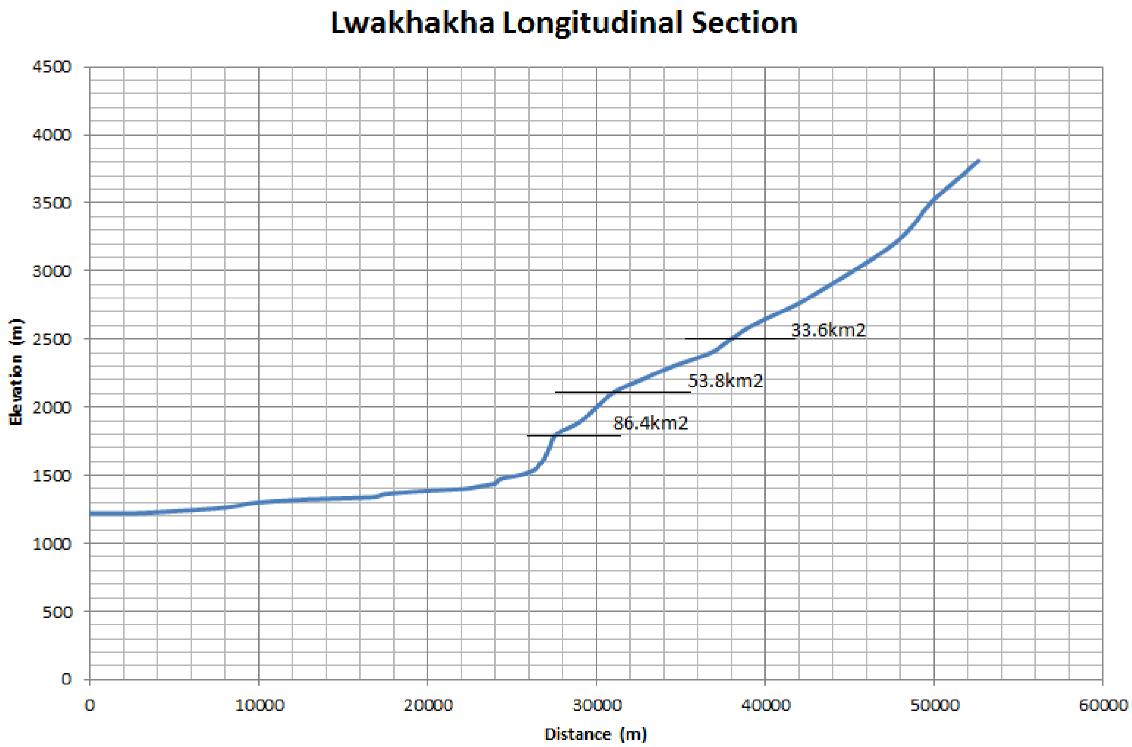

SOUTH SUDAN
UGANDA
KENYA
Kidepo
Kapeta
993 m
2795 m
1754 m
2749 m
2453 m
2086 m
2233 m
1916 m
1374 m
2381 m
1726 m
1452 m
1619 m
Kotido
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
D2
D3
D4
C2
C3
C4
B1
B2
B3
B4
A1
A2
A4
Legend
mw
< 1
1 - 20
20 - 50
50 - 100
>100
N

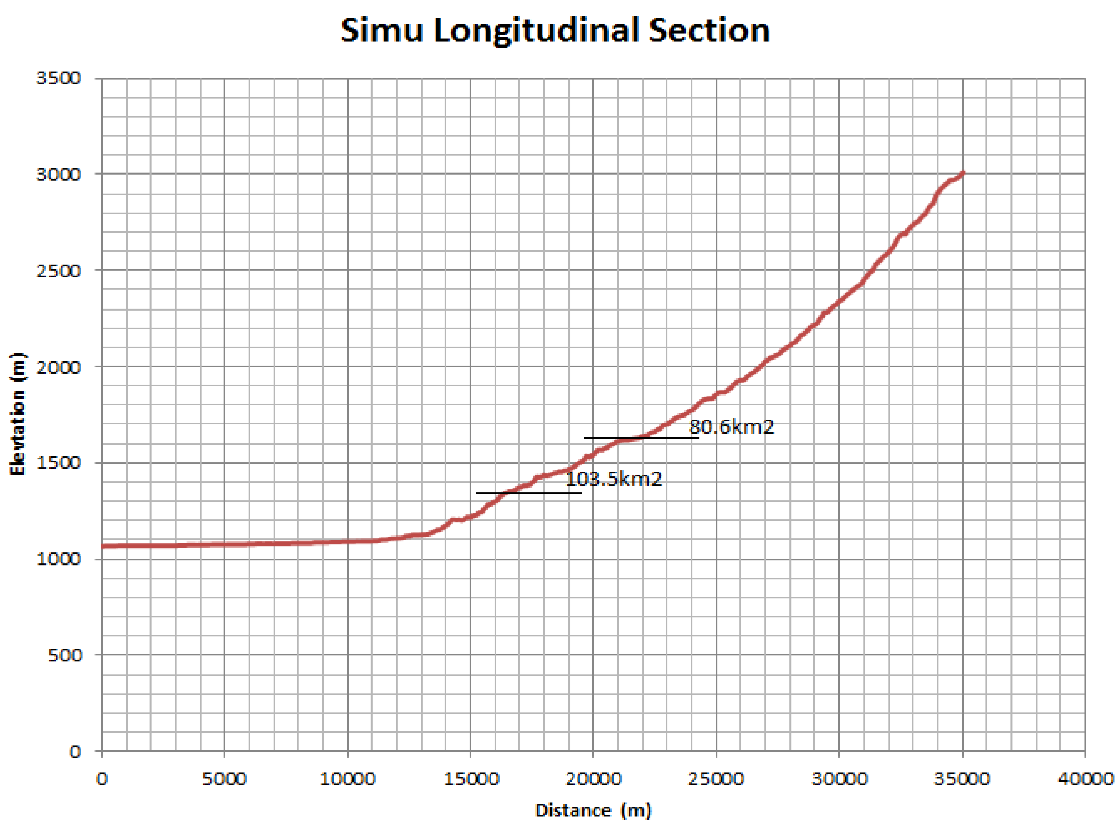
Appendix F

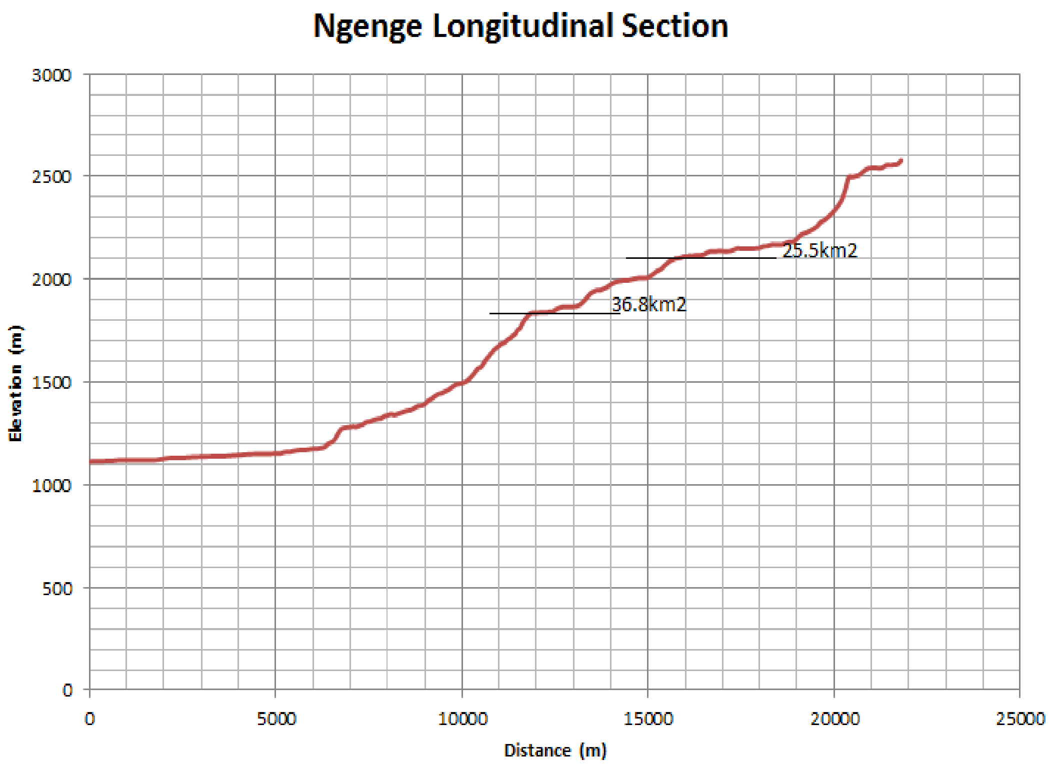
River Profiles with catchment area on each possible intake point that was studied

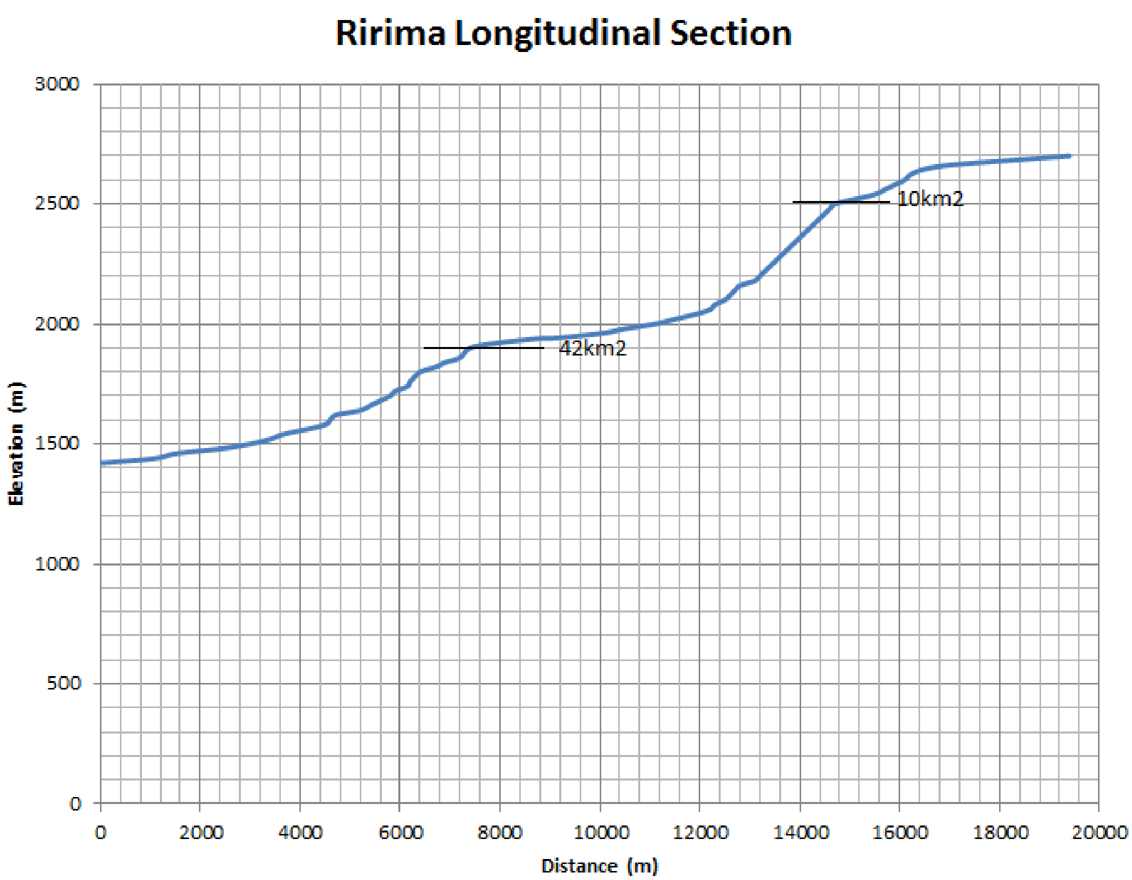


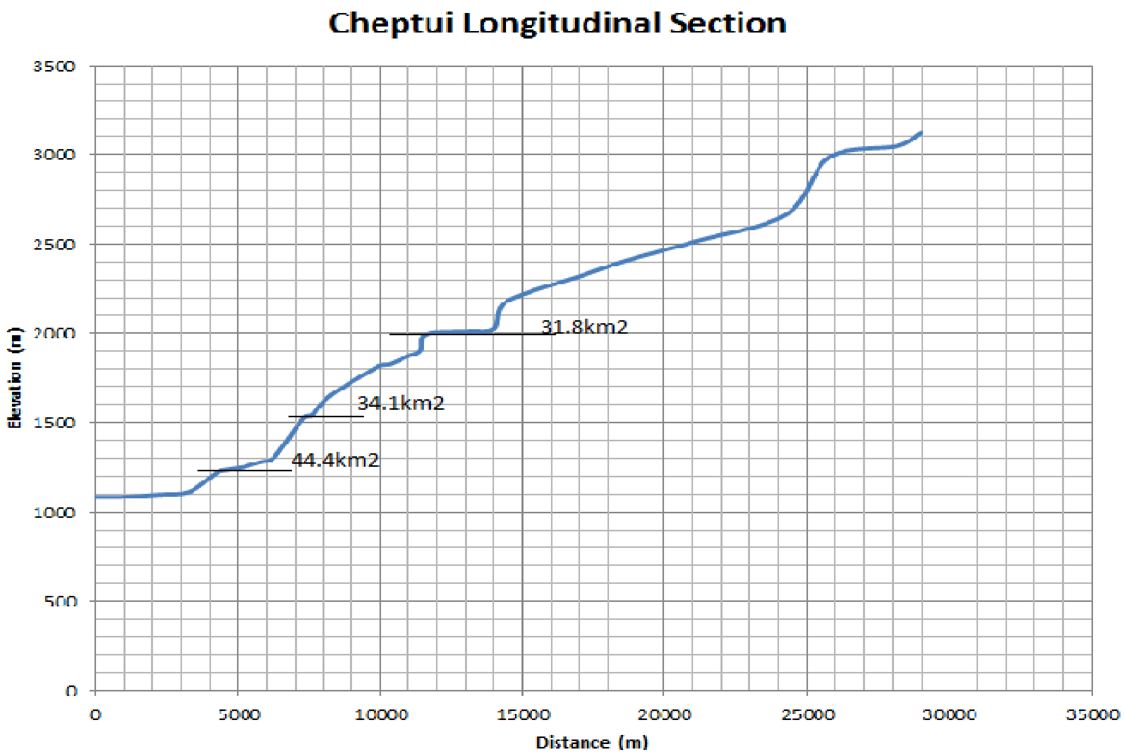


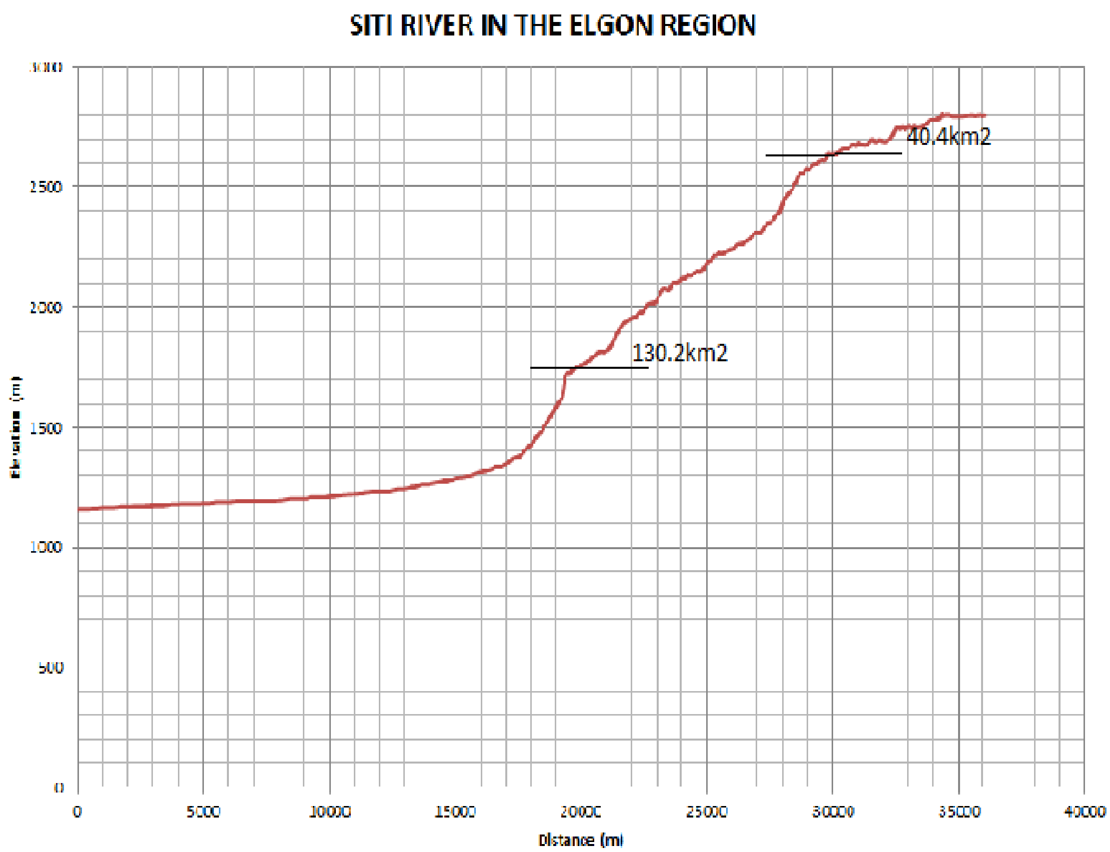

Lwakhakha Longitudinal Section
Elevation (m)
Distance (m)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
10000
20000
30000
40000
50000
60000
33.6km2
53.8km2
86.4km2

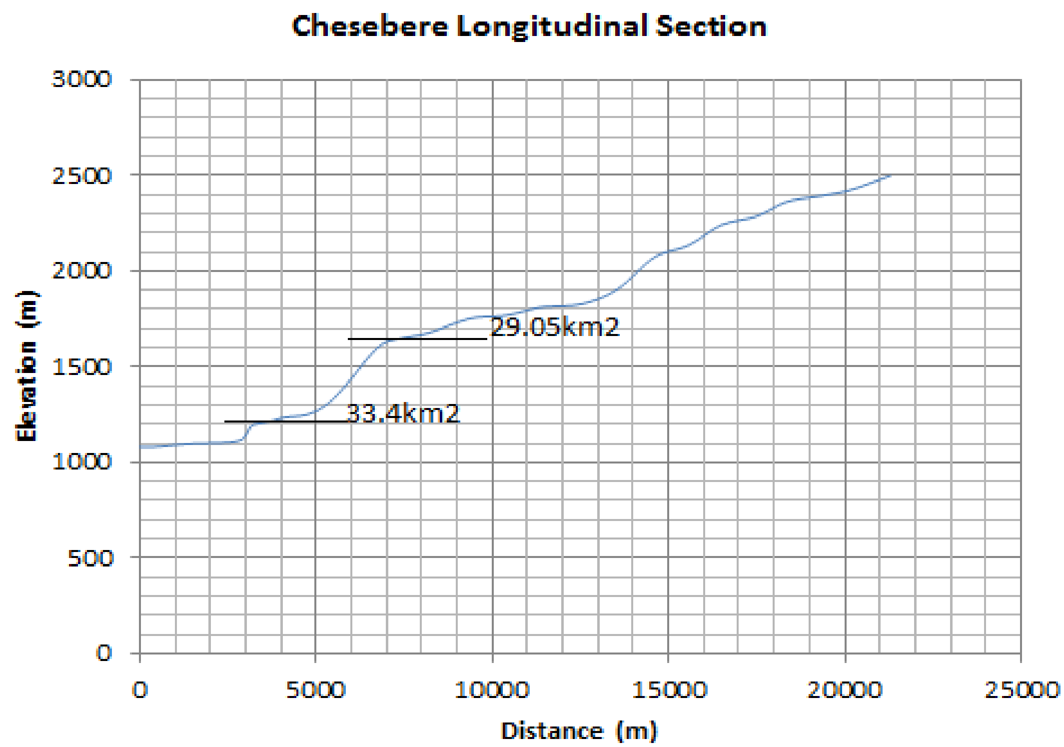

Simu Longitudinal Section
Elevtation (m)
Distance (m)
3500
3000
2500
2000
1500
1000
500
0
0
5000
10000
15000
20000
25000
30000
35000
40000
80.6km2
103.5km2

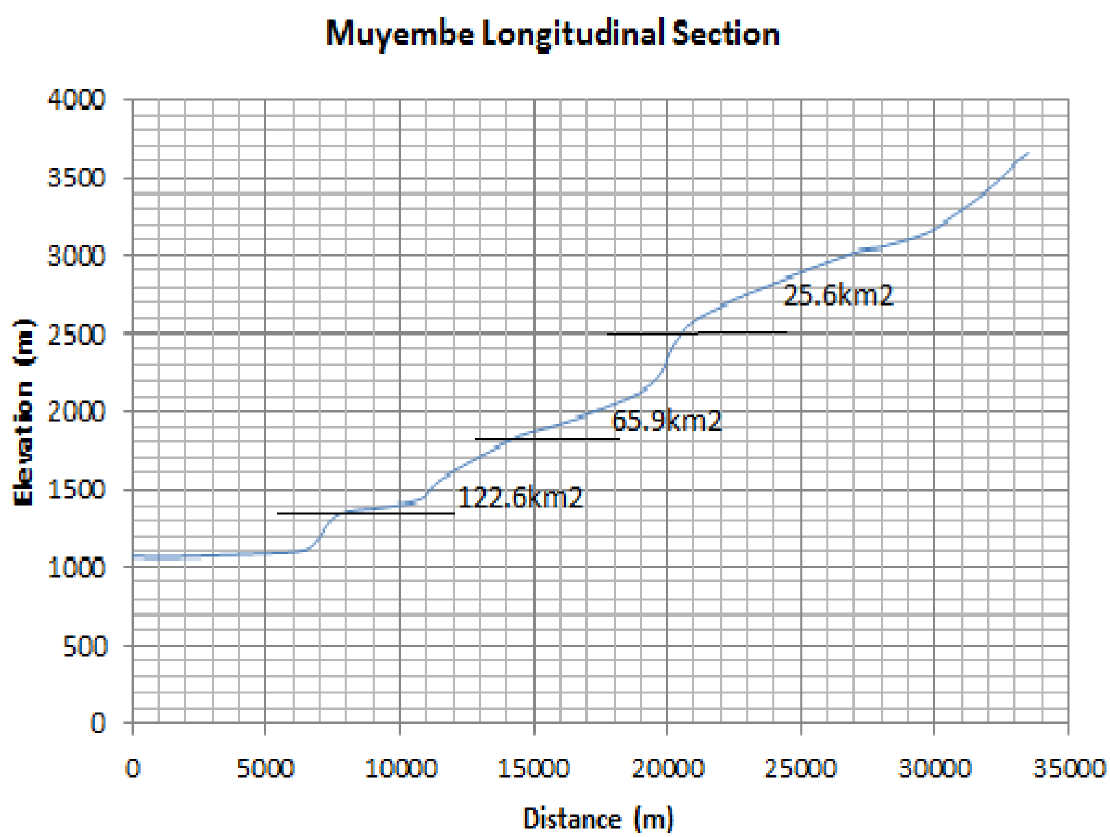

Ngenge Longitudinal Section
Elevation (m)
Distance (m)
3000
2500
2000
1500
1000
500
0
0
5000
10000
15000
20000
25000
25.5km2
36.8km2

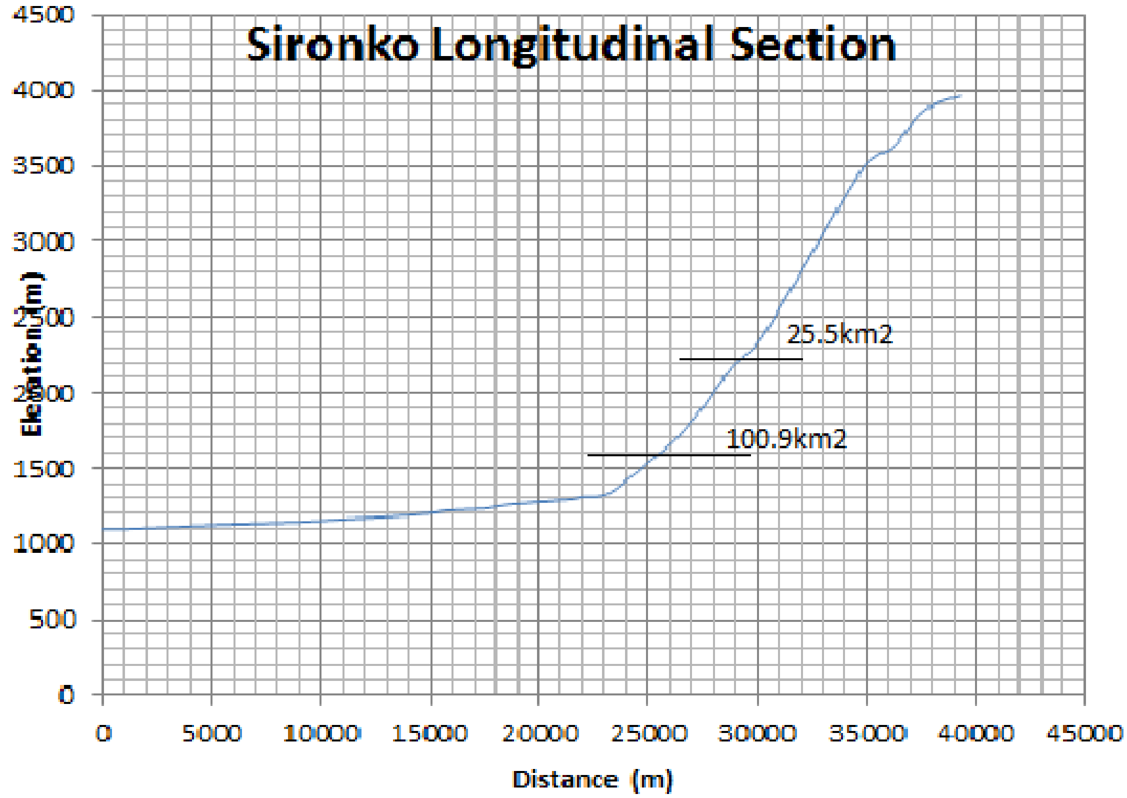

Ririma Longitudinal Section
Elevation (m)
Distance (m)
3000
2500
2000
1500
1000
500
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
10km2
42km2

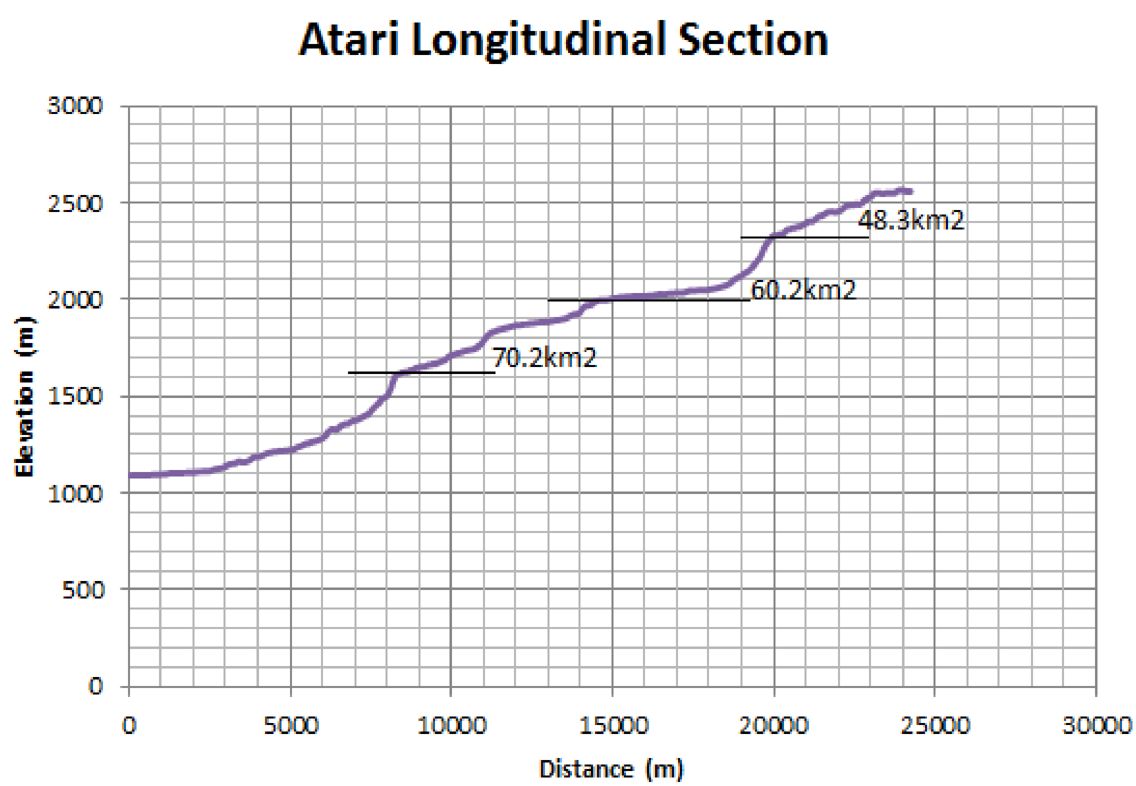

Cheptui Longitudinal Section
Elevation (m)
Distance (m)
0
500
1000
1500
2000
2500
3000
3500
5000
10000
15000
20000
25000
30000
35000
44.4km2
34.1km2
31.8km2

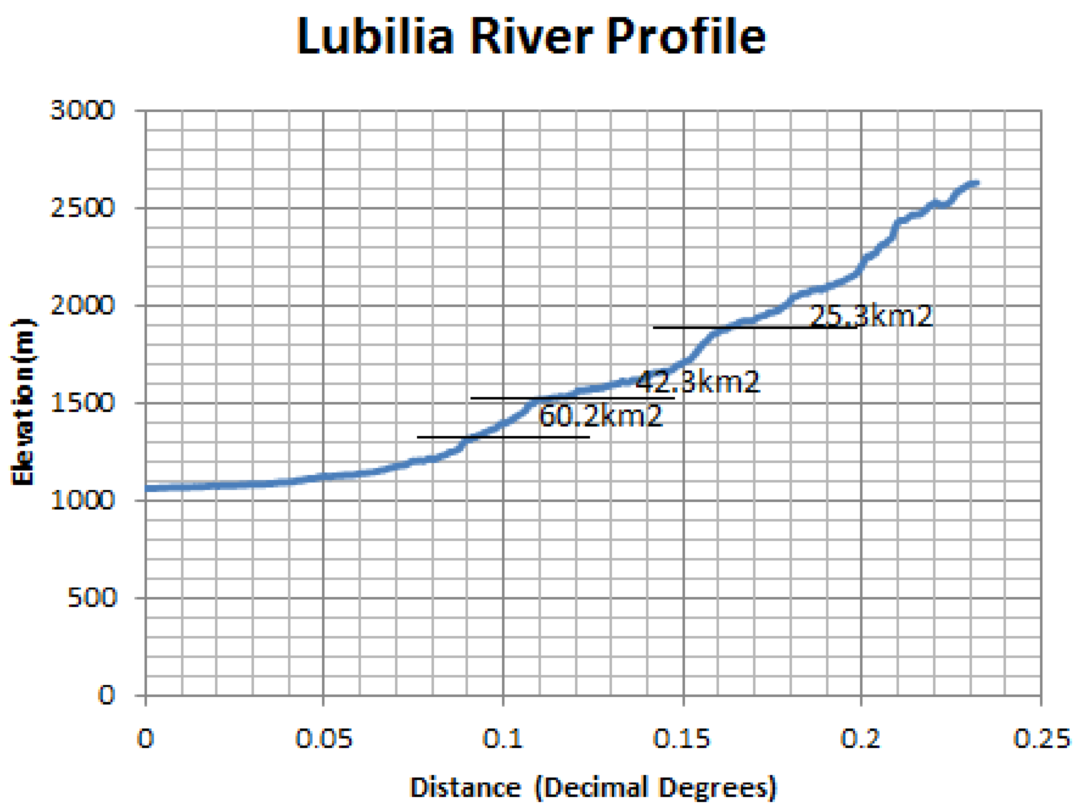

SITI RIVER IN THE ELGON REGION
Elevation (m)
Distance (m)
0
500
1000
1500
2000
2500
3000
5000
10000
15000
20000
25000
30000
35000
40000
130.2km2
40.4km2

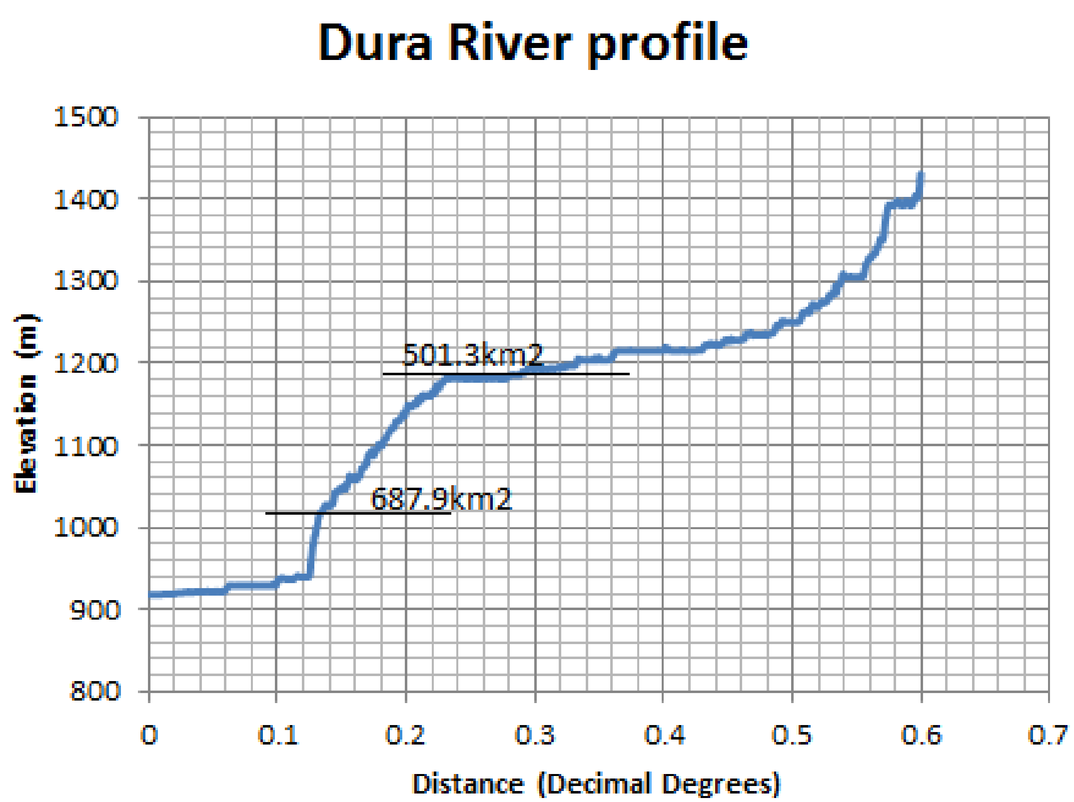

Chesebere Longitudinal Section
Elevation (m)
Distance (m)
29.05km2
33.4km2
3000
2500
2000
1500
1000
500
0
0
5000
10000
15000
20000
25000

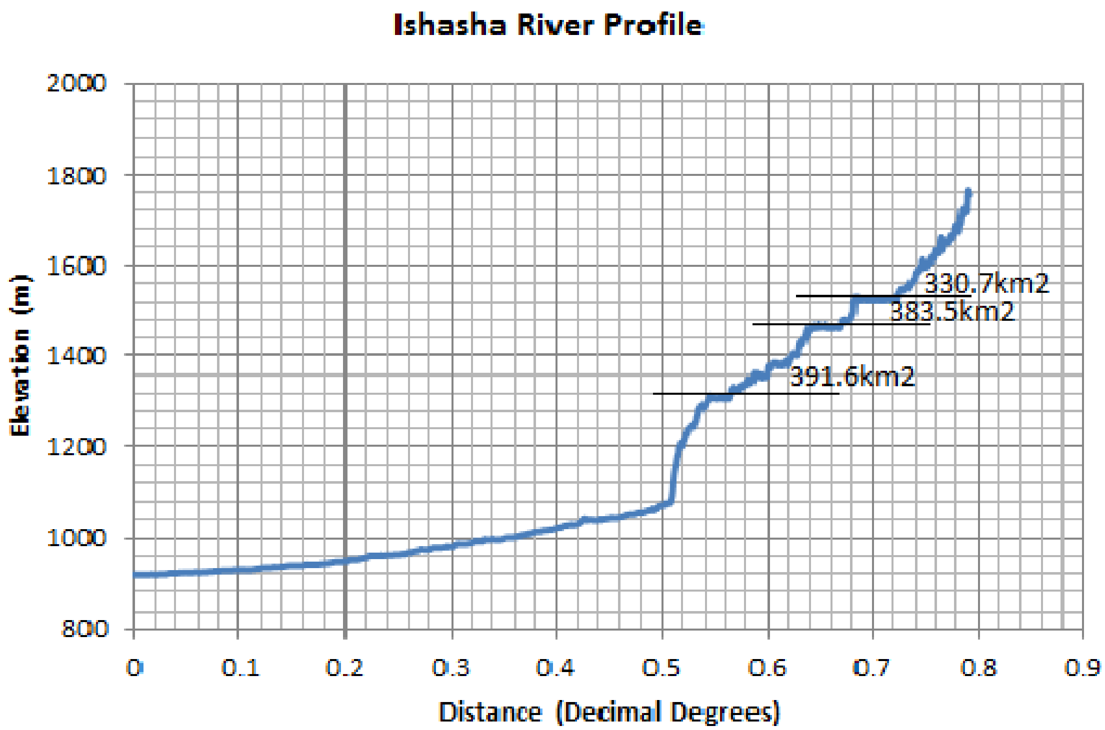

Muyembe Longitudinal Section
Elevation (m)
Distance (m)
25.6km2
65.9km2
122.6km2
4000
3500
3000
2500
2000
1500
1000
500
0
0
5000
10000
15000
20000
25000
30000
35000

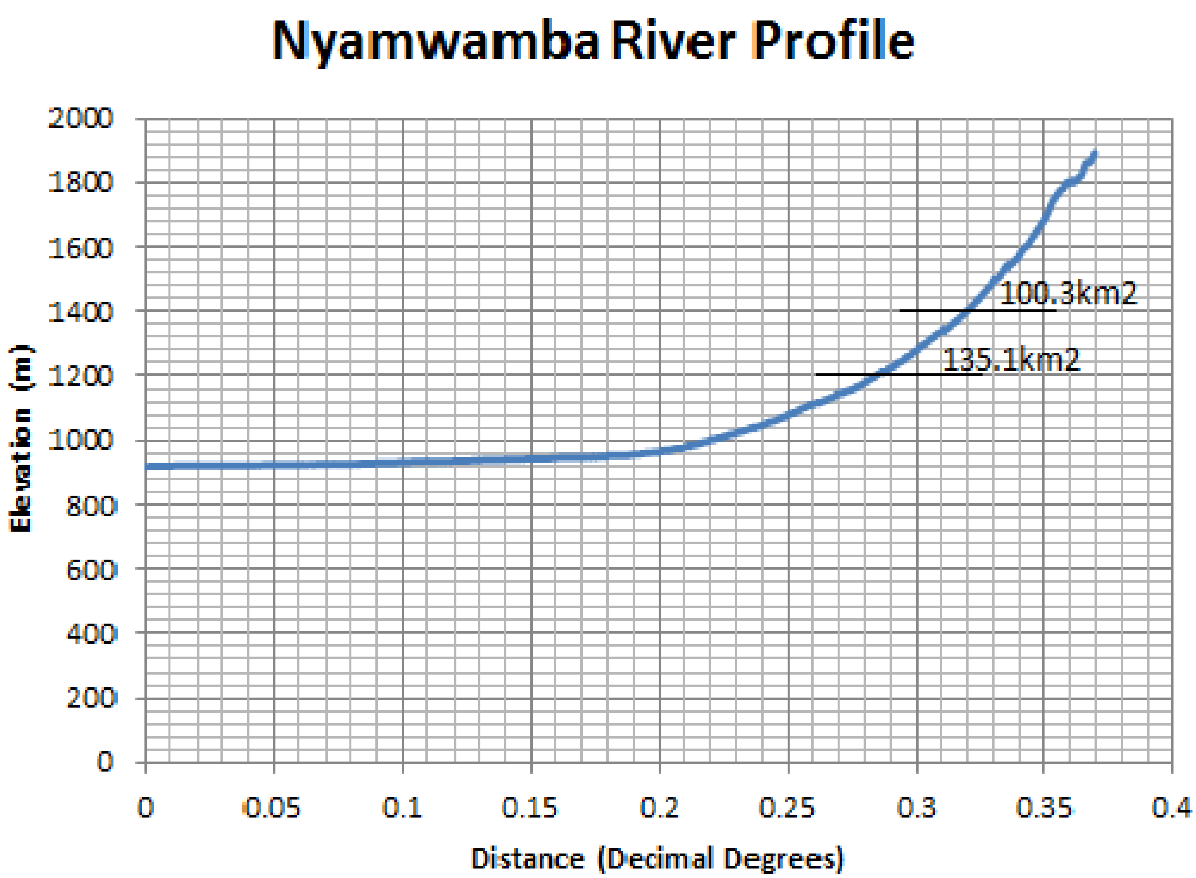

Sironko Longitudinal Section
25.5km2
100.9km2
Elevation (m)
Distance (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
5000
10000
15000
20000
25000
30000
35000
40000
45000

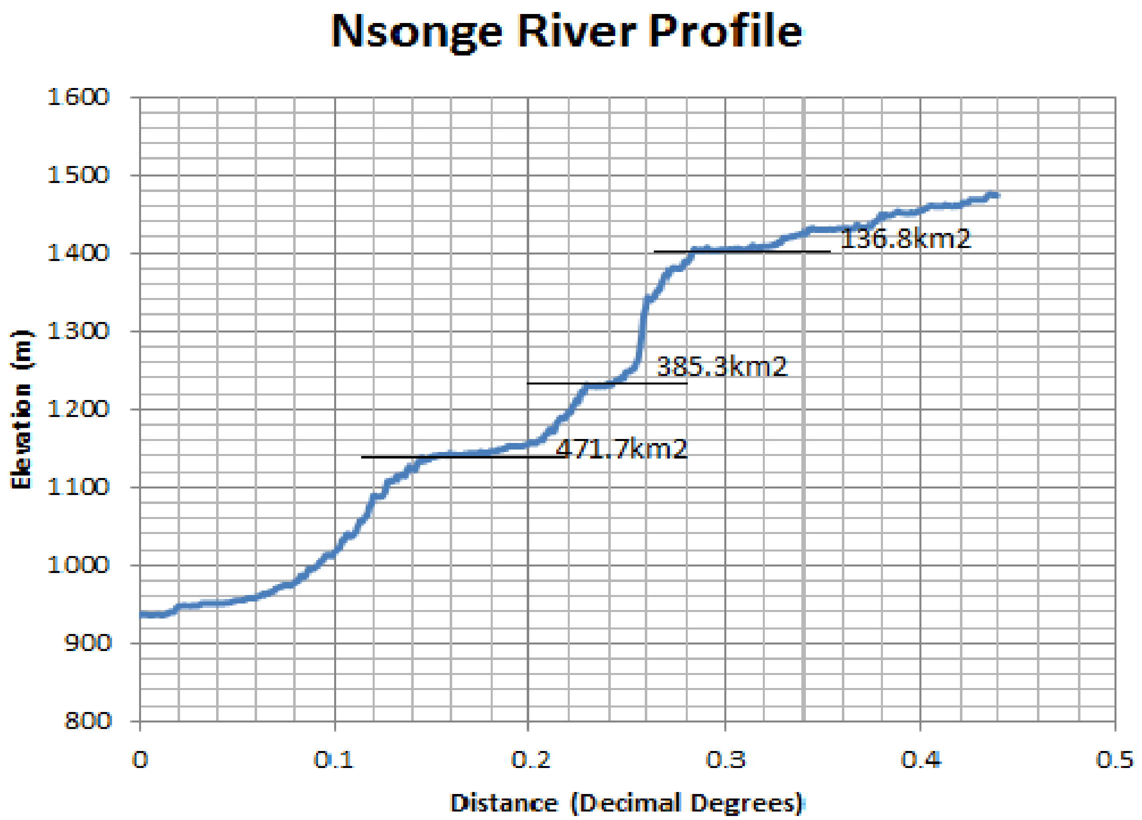

Atari Longitudinal Section
48.3km2
60.2km2
70.2km2
Elevation (m)
Distance (m)
0
500
1000
1500
2000
2500
3000
0
5000
10000
15000
20000
25000
30000

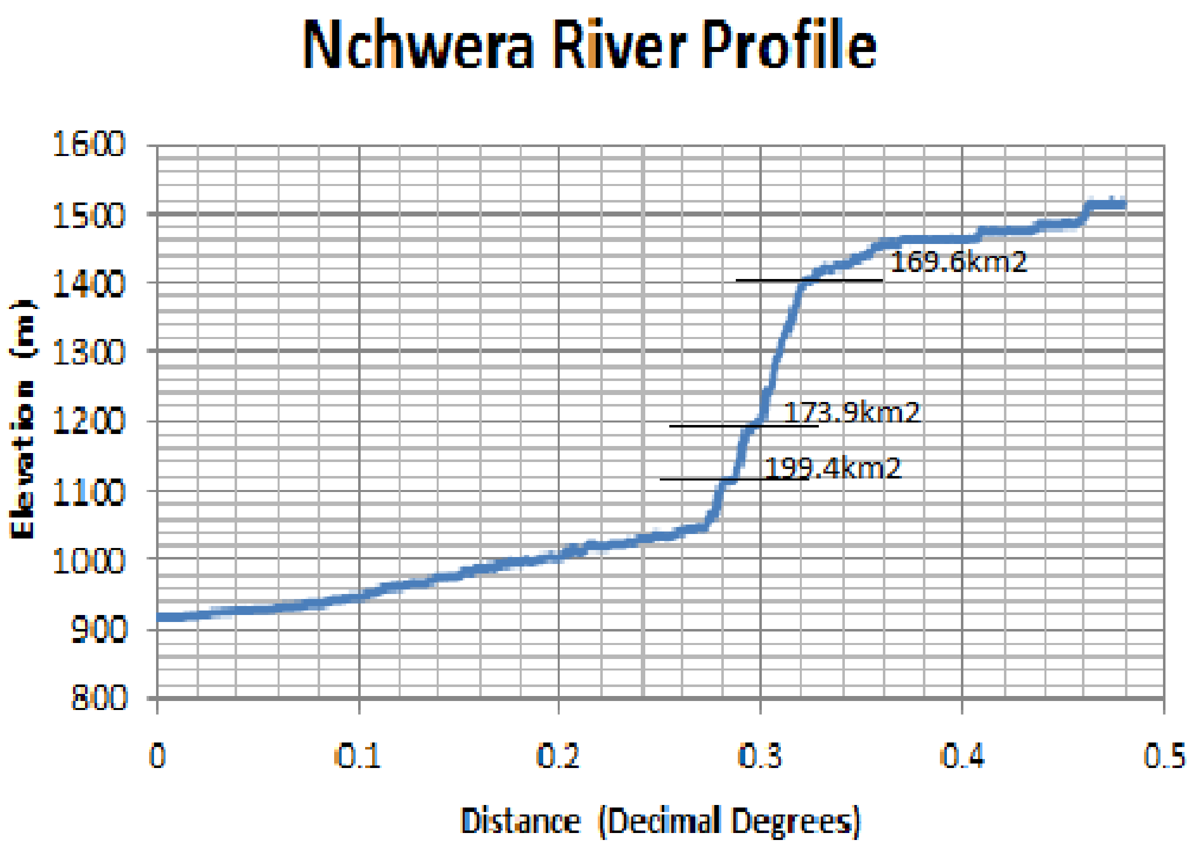

Lubilia River Profile
3000
2500
2000
1500
1000
500
0
Elevation(m)
25.3km2
42.3km2
60.2km2
0
0.05
0.1
0.15
0.2
0.25
Distance (Decimal Degrees)

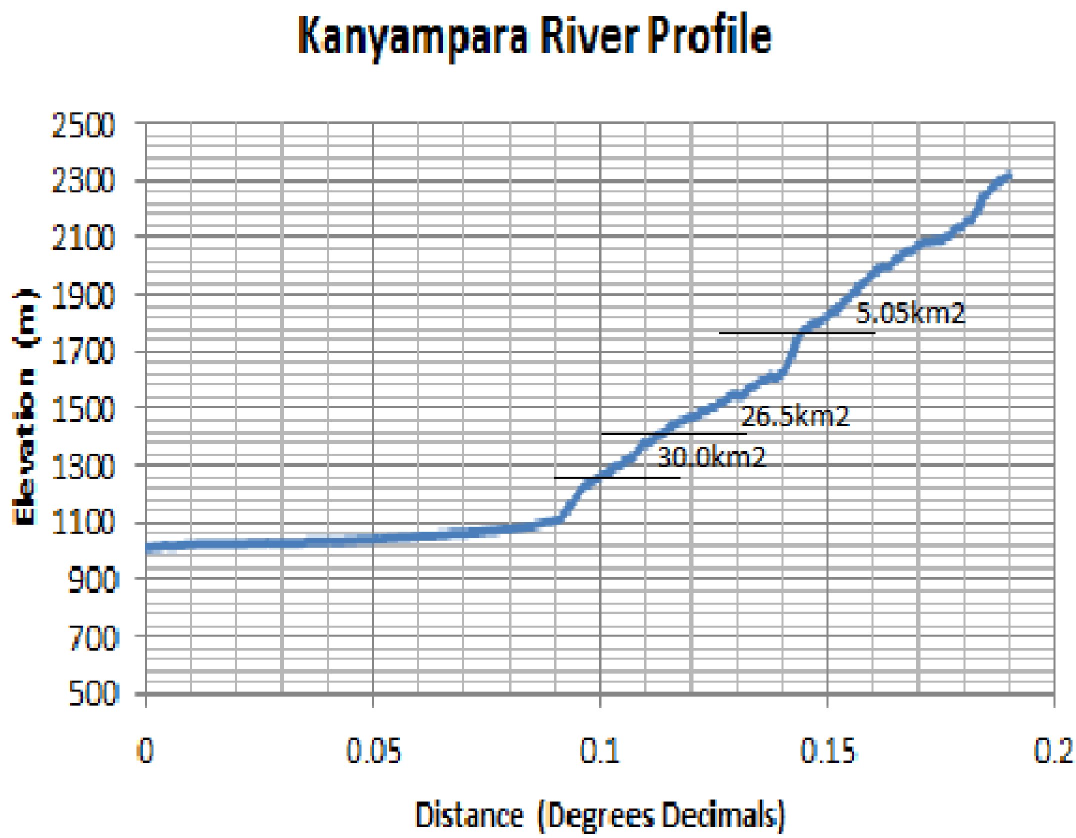

Dura River profile
1500
1400
1300
1200
1100
1000
900
800
Elevation (m)
501.3km2
687.9km2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Distance (Decimal Degrees)

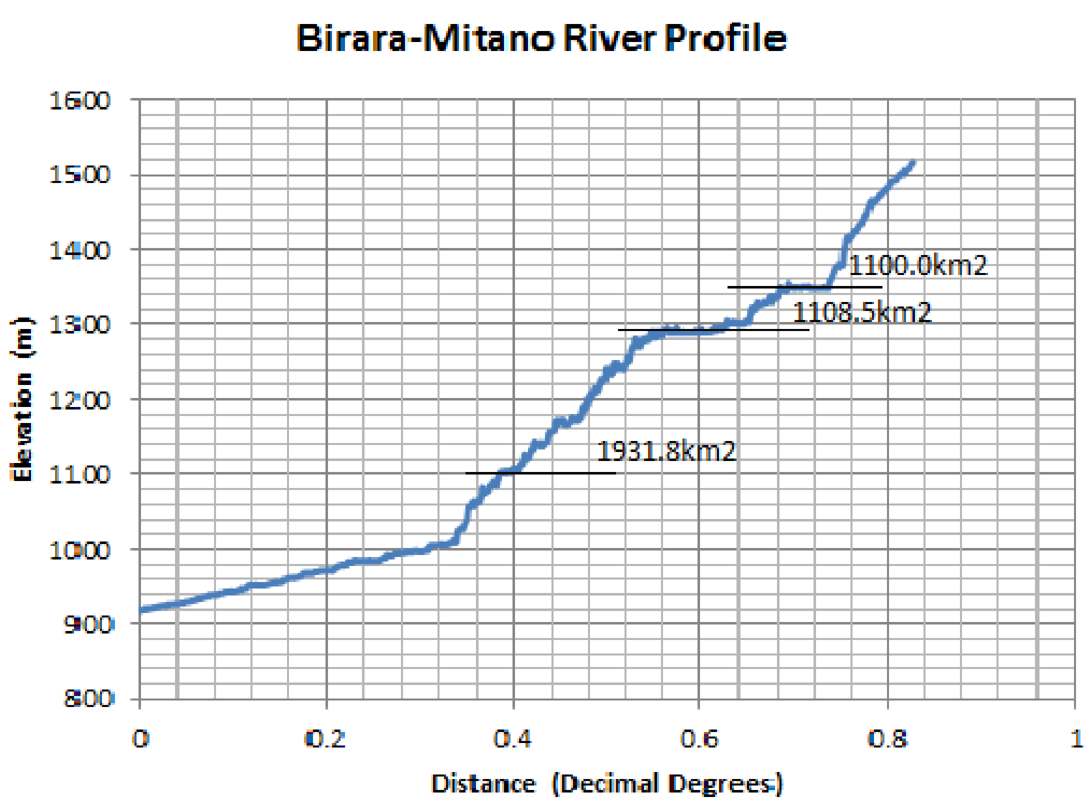

Ishasha River Profile
Elevation (m)
2000
1800
1600
1400
1200
1000
800
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Distance (Decimal Degrees)
330.7km2
383.5km2
391.6km2

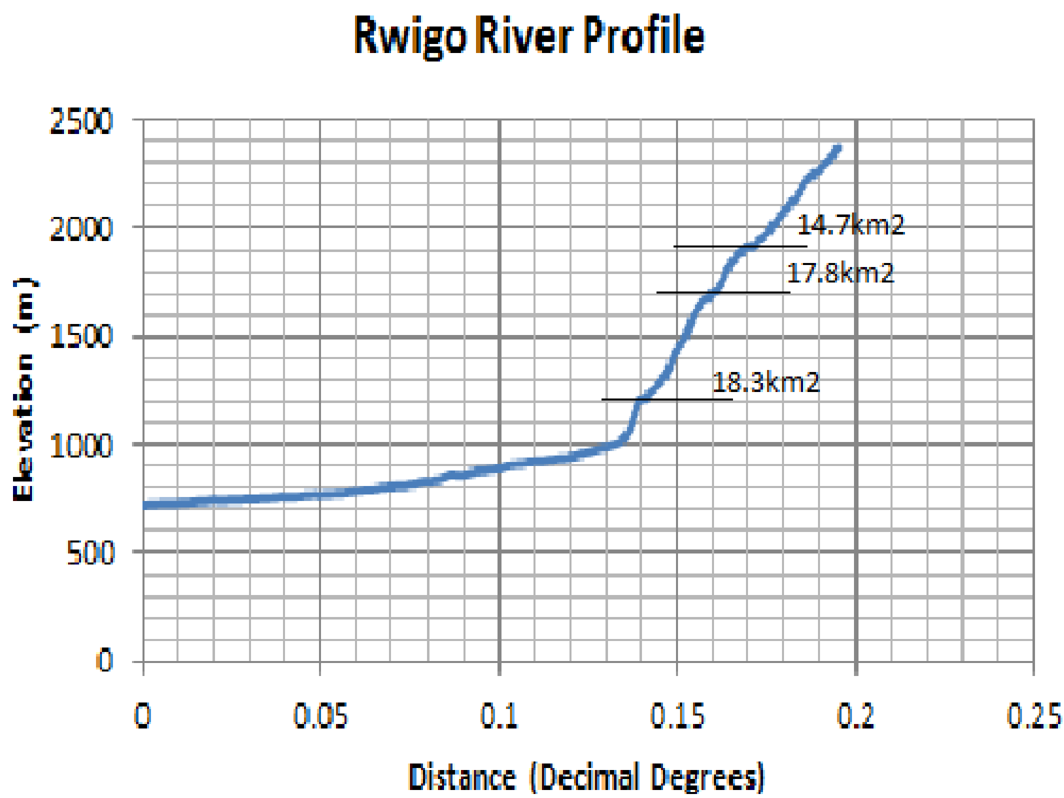

Nyamwamba River Profile
Elevation (m)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Distance (Decimal Degrees)
100.3km2
135.1km2

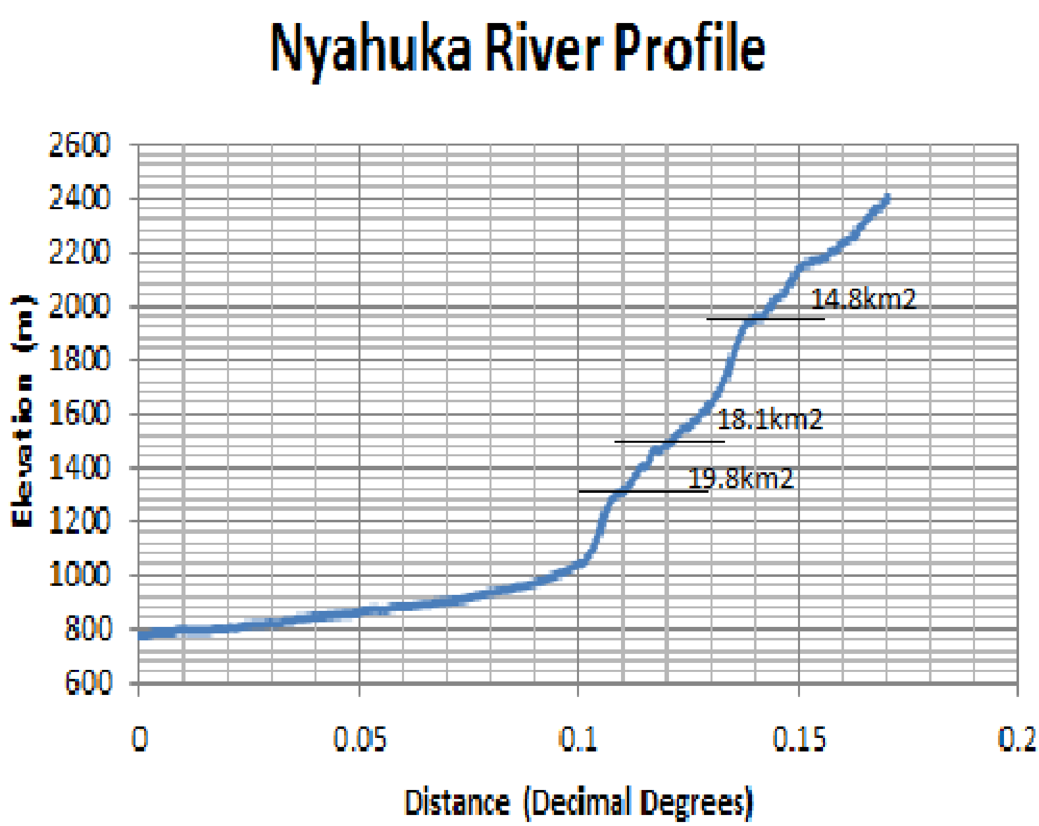

Nsonge River Profile
1600
1500
1400
1300
1200
1100
1000
900
800
Elevation (m)
136.8km2
385.3km2
471.7km2
0
0.1
0.2
0.3
0.4
0.5
Distance (Decimal Degrees)

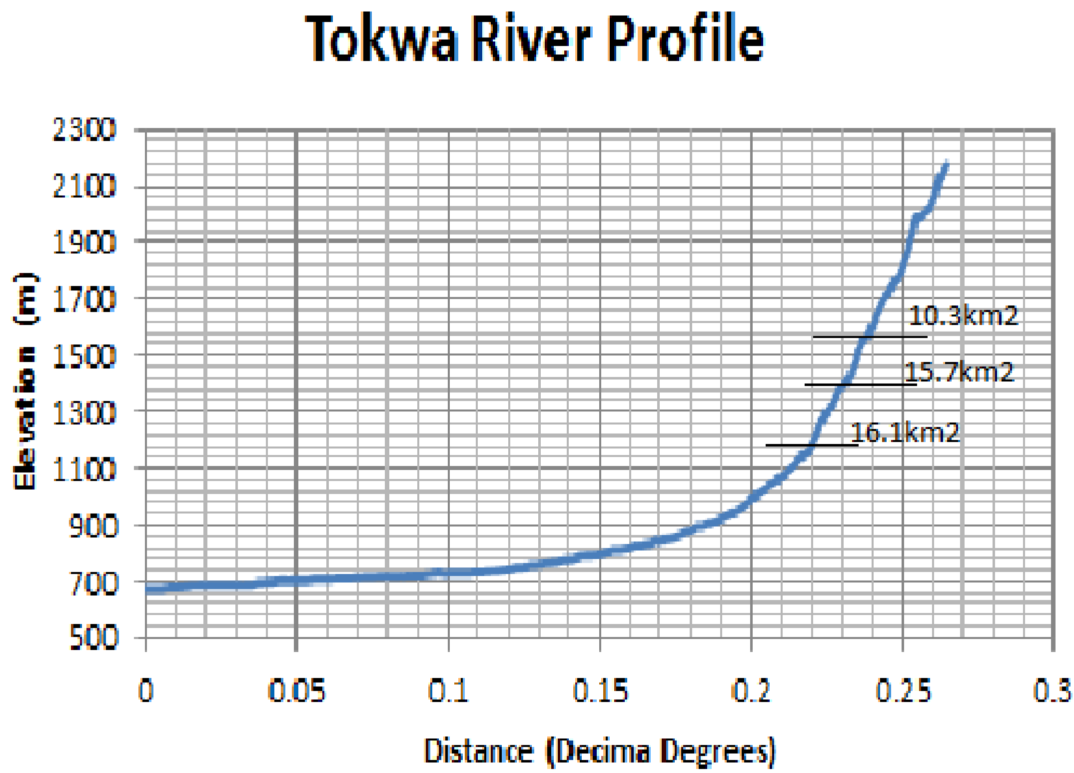

Nchwera River Profile
1600
1500
1400
1300
1200
1100
1000
900
800
Elevation (m)
169.6km2
173.9km2
199.4km2
0
0.1
0.2
0.3
0.4
0.5
Distance (Decimal Degrees)

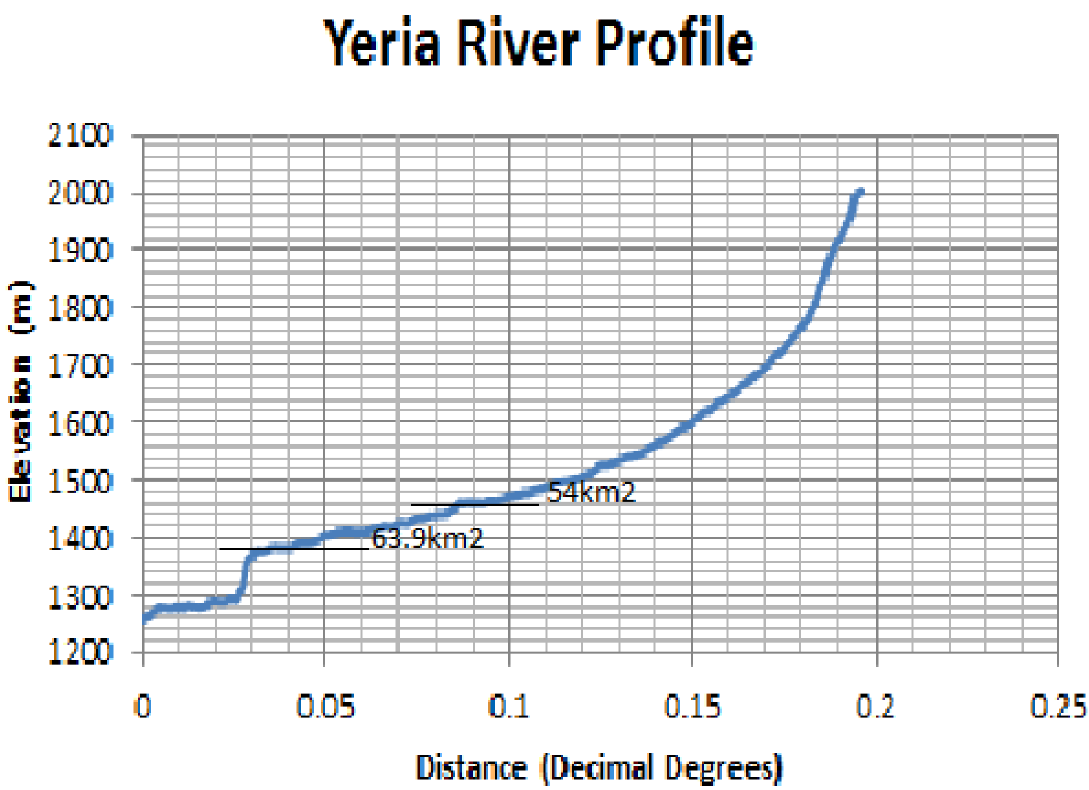

Kanyampara River Profile
Elevation (m)
2500
2300
2100
1900
1700
1500
1300
1100
900
700
500
5.05km2
26.5km2
30.0km2
0
0.05
0.1
0.15
0.2
Distance (Degrees Decimals)

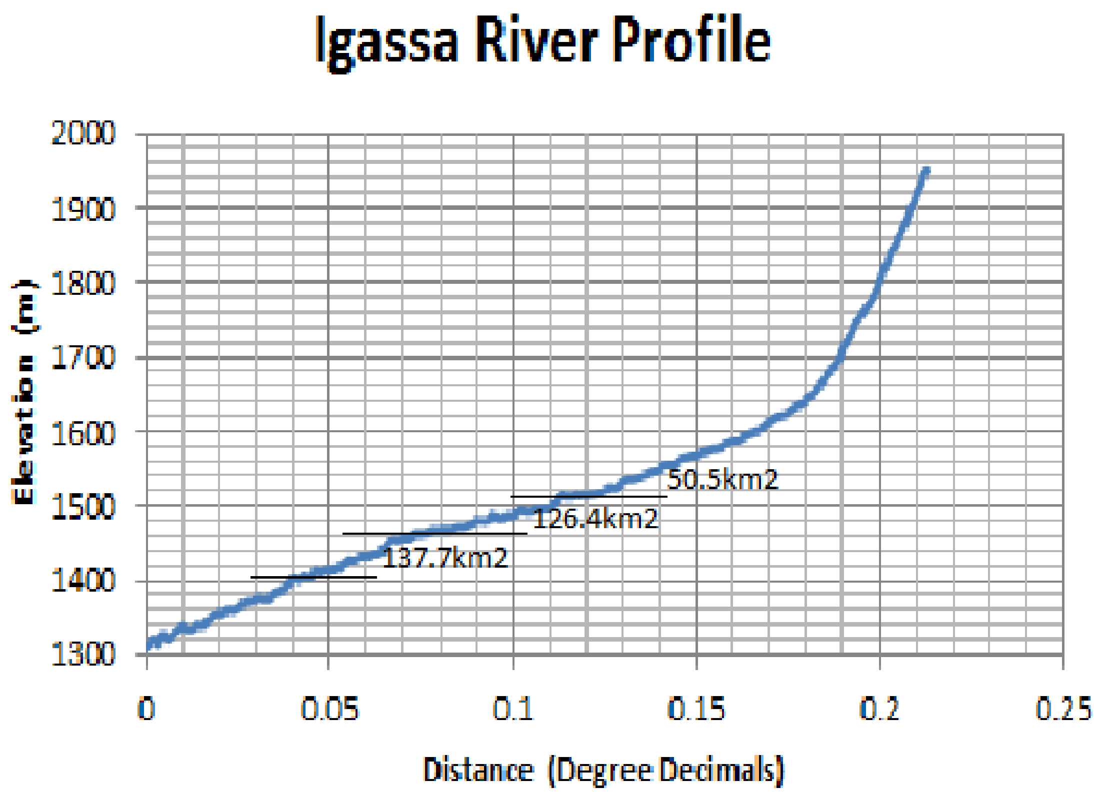

Birara-Mitano River Profile
Elevation (m)
1600
1500
1400
1300
1200
1100
1000
900
800
1100.0km2
1108.5km2
1931.8km2
0
0.2
0.4
0.6
0.8
1
Distance (Decimal Degrees)

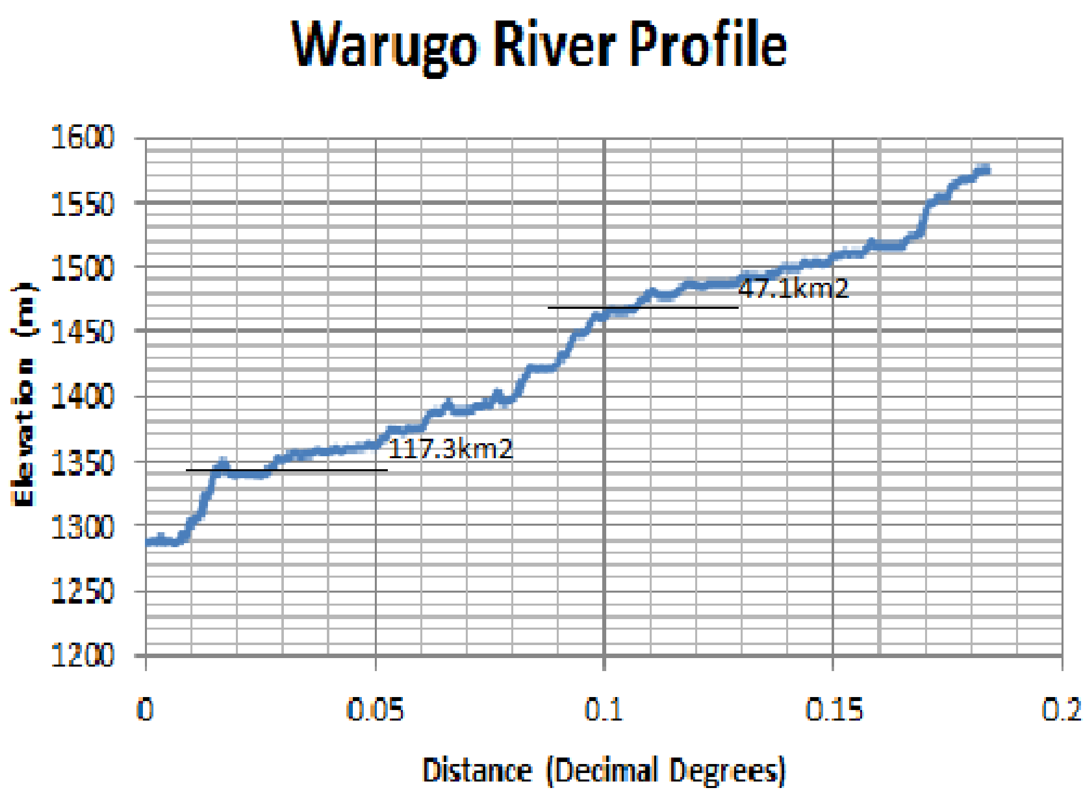

Rwigo River Profile
Elevation (m)
2500
2000
1500
1000
500
0
0
0.05
0.1
0.15
0.2
0.25
Distance (Decimal Degrees)
14.7km2
17.8km2
18.3km2

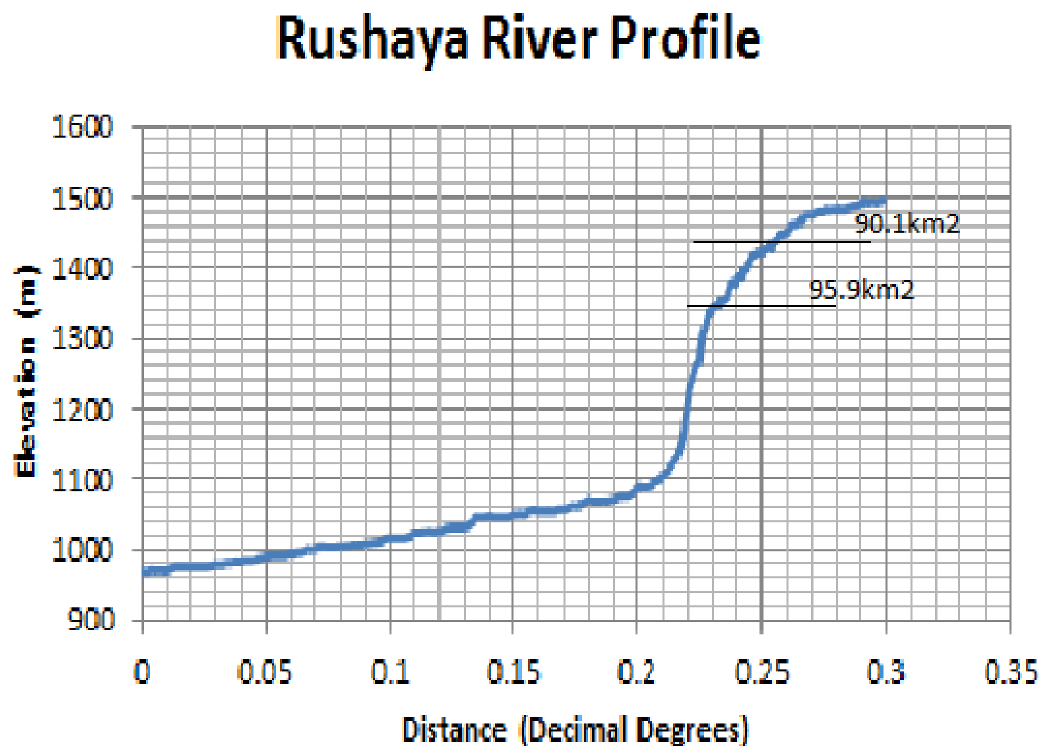

Nyahuka River Profile
Elevation (m)
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
0.05
0.1
0.15
0.2
Distance (Decimal Degrees)
14.8km2
18.1km2
19.8km2

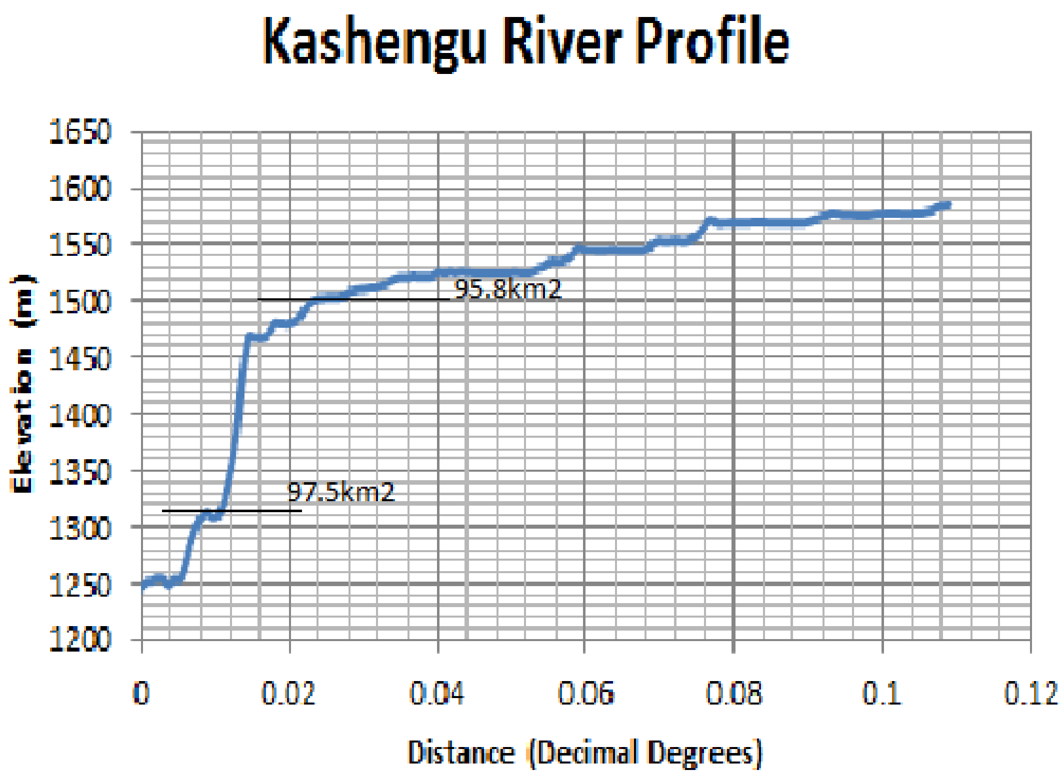

Tokwa River Profile
Elevation (m)
2300
2100
1900
1700
1500
1300
1100
900
700
500
10.3km2
15.7km2
16.1km2
0
0.05
0.1
0.15
0.2
0.25
0.3
Distance (Decima Degrees)

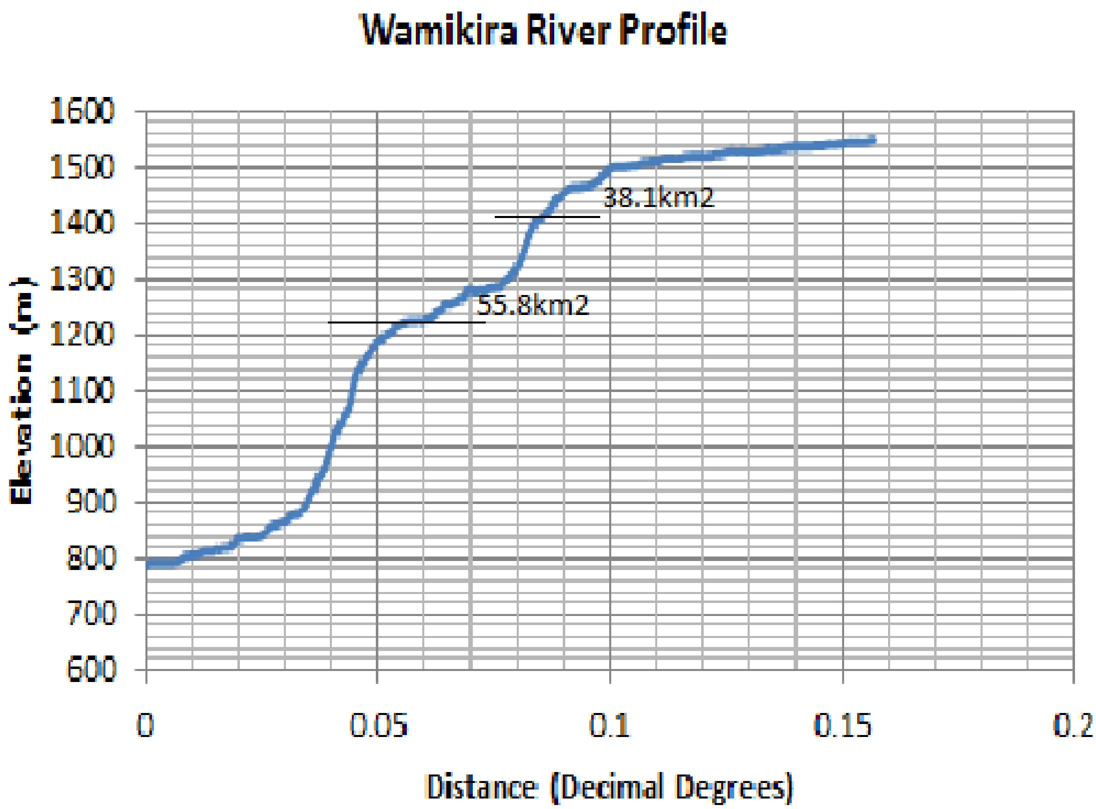

Yeria River Profile
Elevation (m)
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
54km2
63.9km2
0
0.05
0.1
0.15
0.2
0.25
Distance (Decimal Degrees)

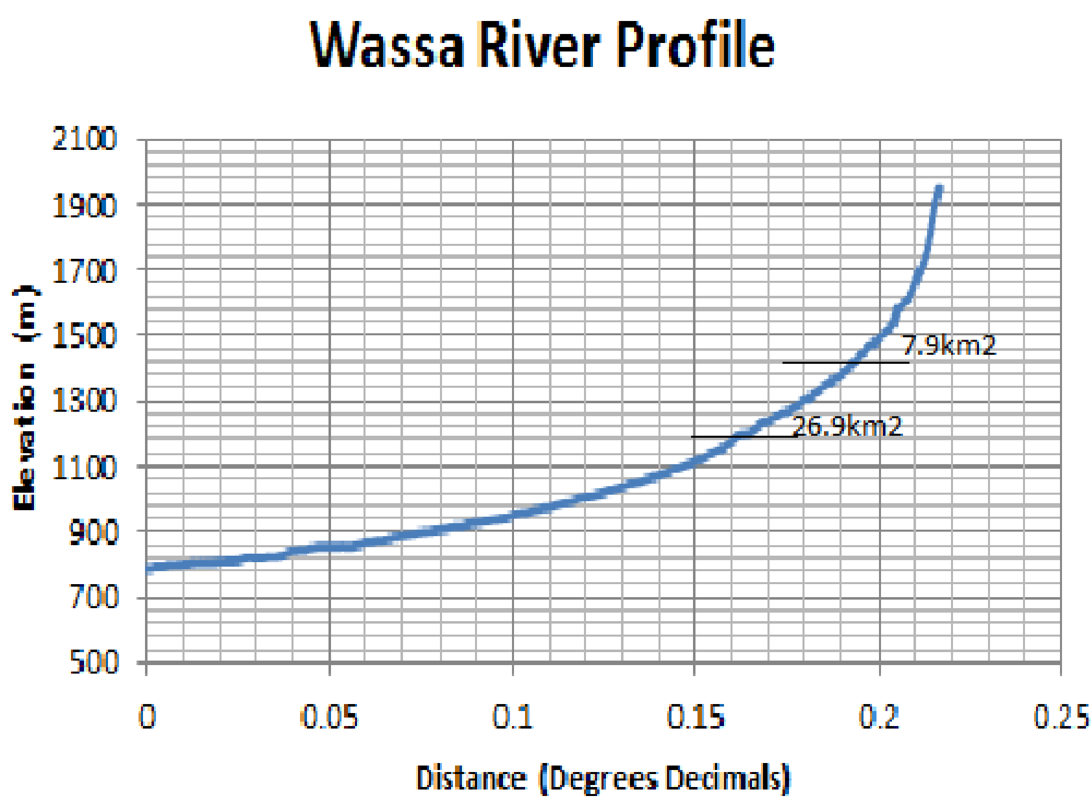

Igassa River Profile
Elevation (m)
2000
1900
1800
1700
1600
1500
1400
1300
50.5km2
126.4km2
137.7km2
0
0.05
0.1
0.15
0.2
0.25
Distance (Degree Decimals)

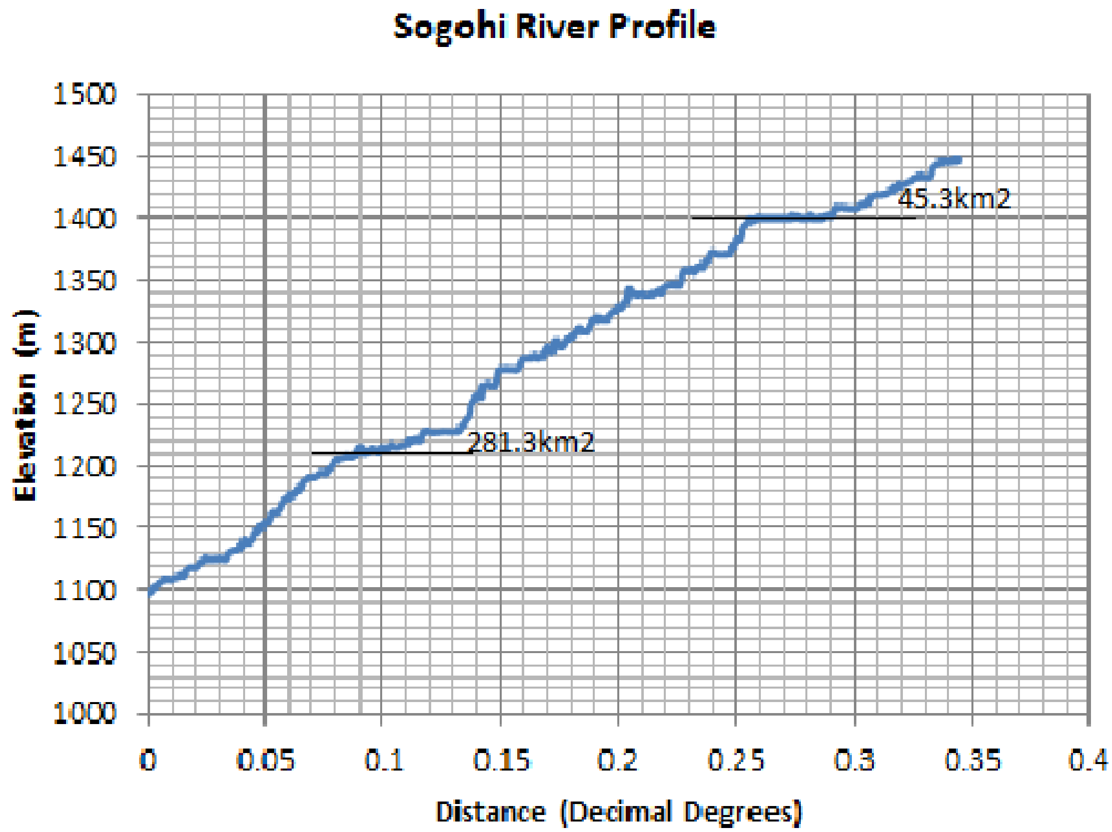

Warugo River Profile
Elevation (m)
1600
1550
1500
1450
1400
1350
1300
1250
1200
47.1km2
117.3km2
0
0.05
0.1
0.15
0.2
Distance (Decimal Degrees)

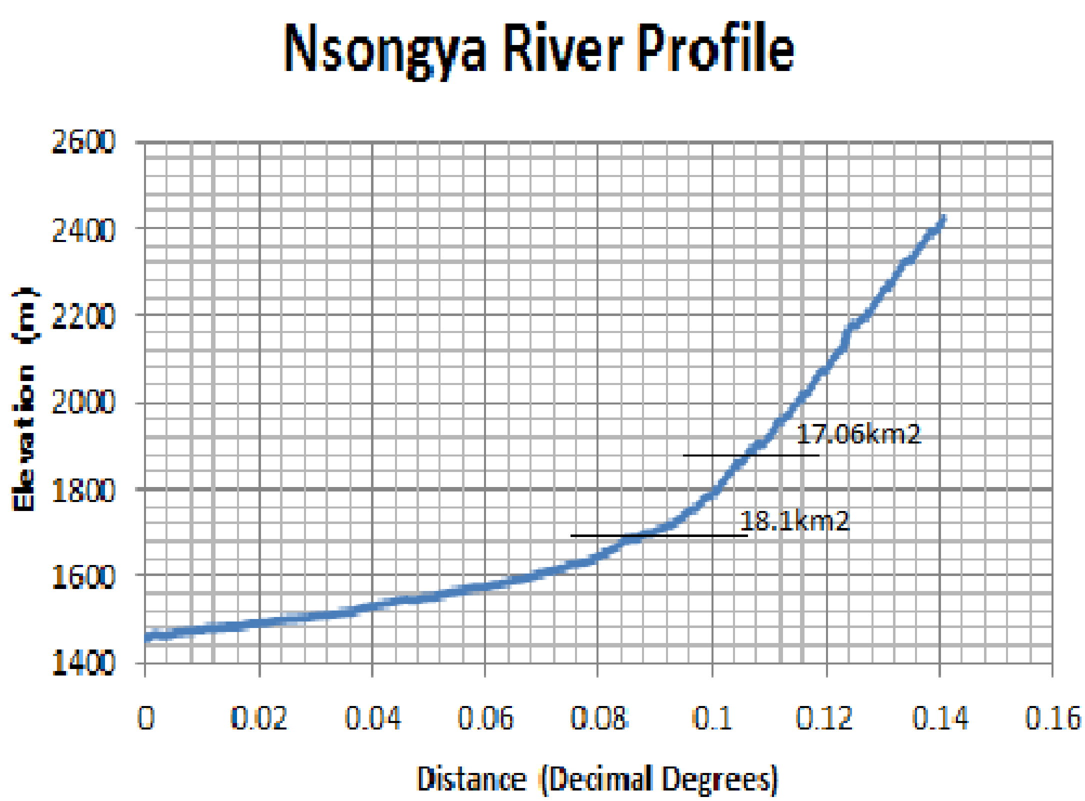

Rushaya River Profile
Elevation (m)
1600
1500
1400
1300
1200
1100
1000
900
90.1km2
95.9km2
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Distance (Decimal Degrees)

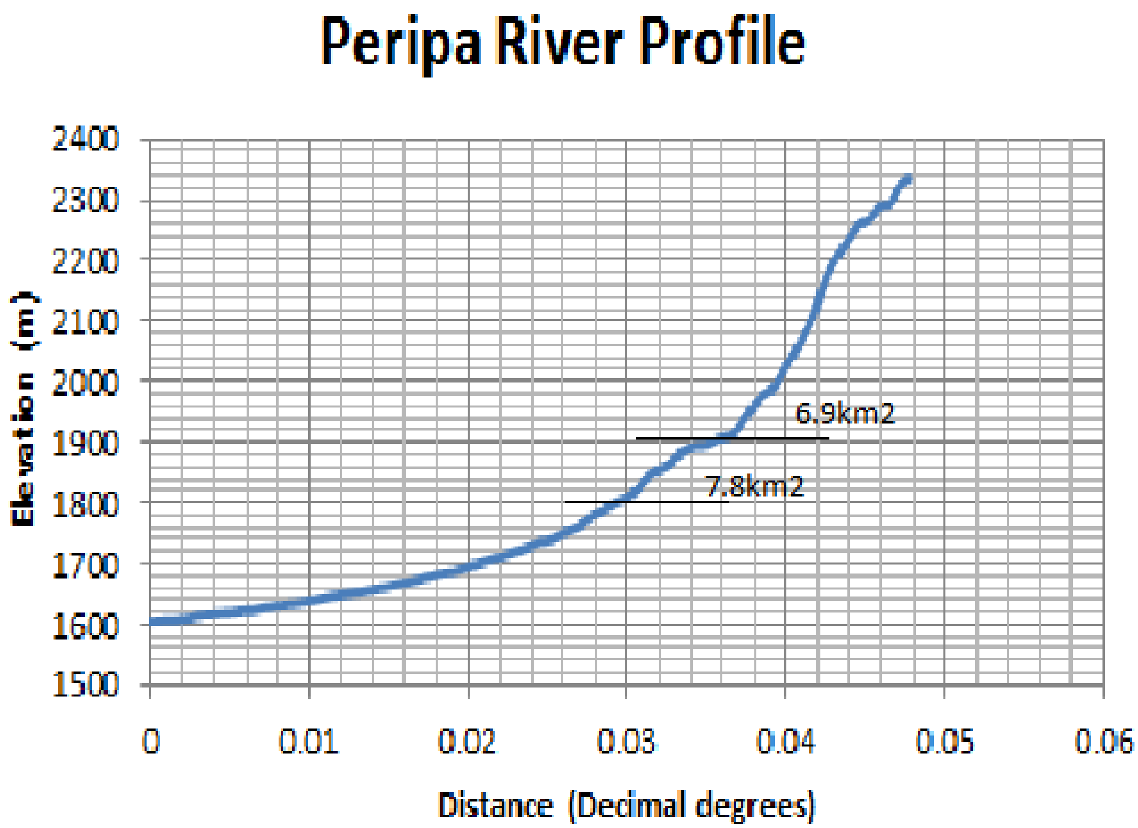

Kashengu River Profile
Elevation (m)
1650
1600
1550
1500
1450
1400
1350
1300
1250
1200
95.8km2
97.5km2
0
0.02
0.04
0.06
0.08
0.1
0.12
Distance (Decimal Degrees)

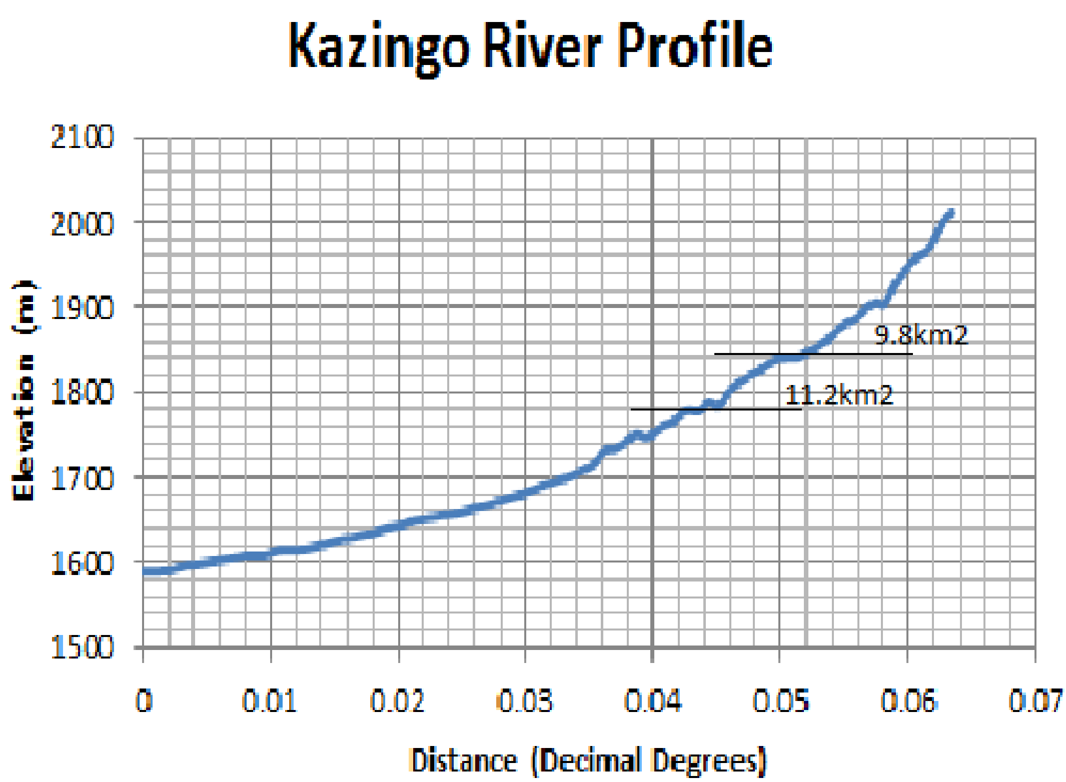

Wamikira River Profile
Elevation (m)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
38.1km2
55.8km2
0
0.05
0.1
0.15
0.2
Distance (Decimal Degrees)


Wassa River Profile
Elevation (m)
2100
1900
1700
1500
1300
1100
900
700
500
7.9km2
26.9km2
0
0.05
0.1
0.15
0.2
0.25
Distance (Degrees Decimals)


Sogohi River Profile
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
Elevation (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Distance (Decimal Degrees)
45.3km2
281.3km2


Nsongya River Profile
2600
2400
2200
2000
1800
1600
1400
Elevation (m)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
Distance (Decimal Degrees)
17.06km2
18.1km2


Peripa River Profile
Elevation (m)
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
6.9km2
7.8km2
0
0.01
0.02
0.03
0.04
0.05
0.06
Distance (Decimal degrees)


Kazingo River Profile
Elevation (m)
2100
2000
1900
1800
1700
1600
1500
9.8km2
11.2km2
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
Distance (Decimal Degrees)