Nile Basin Capacity Building Network

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Future Hydropower Scenarios Under the Influence of Climate Change for the Riparian Countries of Lake Victoria Basin

NBCBN-RE

Future Hydropower Scenarios Under the Influence of Climate Change for the Riparian Countries of Lake Victoria Basin

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NBCBN - BACKGROUND

Project Title

Knowledge Networks for the Nile Basin

Using the innovative potential of Knowledge Networks and CoP's in strengthening human and institutional research capacity in the Nile region.

Implementing Leading Institute

UNESCO-IHE Institute for Water Education, Delft, The Netherlands (UNESCO-IHE)

Partner Institutes

Ten selected Universities and Ministries of Water Resources from Nile Basin Countries.

Project Secretariat Office

Hydraulics Research Institute – Cairo - Egypt

Beneficiaries

Water Sector Professionals and Institutions in the Nile Basin Countries

Short Description

The idea of establishing a Knowledge Network in the Nile region emerged after encouraging experiences with the first Regional Training Centre on River Engineering in Cairo since 1996. In January 2002 more than 50 representatives from all ten Nile basin countries signed the Cairo Declaration at the end of a kick-off workshop was held in Cairo. This declaration in which the main principles of the network were laid down marked the official start of the Nile Basin Capacity Building Network in River Engineering (NBCBN-RE) as an open network of national and regional capacity building institutions and professional sector organizations.

NBCBN is represented in the Nile basin countries through its nine nodes existing in Egypt, Sudan, Ethiopia, Tanzania, Uganda, Kenya, Rwanda, Burundi and D. R. Congo. The network includes six research clusters working on different research themes namely: Hydropower, Environmental Aspects, GIS and Modelling, River Morphology, flood Management, and River structures.

The remarkable contribution and impact of the network on both local and regional levels in the basin countries created the opportunity for the network to continue its mission for a second phase. The second phase was launched in Cairo in 2007 under the initiative of; Knowledge Networks for the Nile Basin. New capacity building activities including knowledge sharing and dissemination tools specialised training courses and new collaborative research activities were initiated. The different new research modalities adopted by the network in its second phase include; (i) regional cluster research, (ii) integrated research, (iii) local action research and (iv) Multidisciplinary research.

By involving professionals, knowledge institutes and sector organisations from all Nile Basin countries, the network succeeded to create a solid passage from potential conflict to co-operation potential and confidence building between riparian states. More than 500 water professionals representing different disciplines of the water sector and coming from various governmental and private sector institutions selected to join NBCBN to enhance and build their capacities in order to be linked to the available career opportunities. In the last ten years the network succeeded to have both regional and international recognition, and to be the most successful and sustainable capacity building provider in the Nile Basin.

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FOREWORD

This report is one of the final outputs of the research activities under the second phase of the Nile Basin Capacity Building Network (NBCBN). The network was established with a main objective to build and strengthen the capacities of the Nile basin water professionals in the field of River Engineering. The first phase was officially launched in 2002. After this launch the network has become one of the most active groupings in generating and disseminating water related knowledge within the Nile region. At the moment it involves more than 500 water professionals who have teamed up in nine national networks (In-country network nodes) under the theme of "Knowledge Networks for the Nile Basin". The main platform for capacity building adopted by NBCBN is "Collaborative Research" on both regional and local levels. The main aim of collaborative research is to strengthen the individual research capabilities of water professionals through collaboration at cluster/group level on a well-defined specialized research theme within the field of River and Hydraulic Engineering.

This research project was developed under the "Integrated Research Modality". The main objective of research modality is to demonstrate the effectiveness of the network in implementing more integrated applied research that tackles real life problems in the field of river and hydraulic engineering by joining and integrating the experiences of researchers from three or more research clusters.

This report is considered a joint achievement through collaboration and sincere commitment of all the research teams involved with participation of water professionals from all the Nile Basin countries, the Research Coordinators and the Scientific Advisors. Consequently the NBCBN Network Secretariat and Management Team would like to thank all members who contributed to the implementation of these research projects and the development of these valuable outputs.

Special thanks are due to UNESCO-IHE Project Team and NBCBN-Secretariat office staff for their contribution and effort done in the follow up and development of the different research projects activities.

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EXECUTIVE SUMMARY

Hydropower is a major source of energy in the Lake Victoria basin (LVB) which is mainly due to the abundant hydro power potential. Despite this, the energy sector is still face with several challenges. Some of these include sustainable river flows for hydropower exploration, impact of climate change on the hydrology, increased abstraction due to population growth, and other competing water demands such as agriculture, industry, forestry and domestic use.

The energy sector experienced hydropower shortages during the 2007/2008 period. This was attributed to several factors including declining water levels at the different hydropower generation plants. Climate variability and change was also linked to the decline in hydropower production. However, the impacts of climate change on hydropower in the Riparian Countries of LVB are less known since they have never been studied. This research therefore aimed at exploring the impact of climate change on the future development and operation of hydropower schemes in Lake Victoria Basin (LVB). The hypothesis was to test whether climate change will have a significant impact on hydropower generation in LVB.

To achieve the objective of the study, hydrological models were built for two case studies in the LVB that is Kagera and Mara sub-basins, using the Soil Water Assessment Tool (SWAT). The results showed that model performance varies greatly for the two case studies. The results are highly dependent on several factors including the geophysical characteristics of the study areas (such as presence/absence of wetlands), quality and quantity of hydrometrical data available for calibration. The simulations showed that the performance of the SWAT model was better for the Mara basin compared to the Kagera. For both basins, simulated flow trends were well represented by the SWAT model.

The impact of climate change on hydropower was investigated by using “what if?” scenarios of climate change and then studying the changes resultant changes in hydropower potential due to changed hydrology. First, 3 potential hydropower sites were selected along each of the two rivers. The selected sites along River Kagera included Giteranyi, Rusumo and Kikagate while the selected sites along R. Mara included Kilgoris, Machove and Garonga. The “what if?” scenarios included changes in temperature and precipitation. Temperature was varied by +3^{o}C and -3^{o}C. Precipitation was varied by ±10%,±20% and ±30%. Combinations of temperature and rainfall variations gave 13 scenarios which 6 temperature increase scenarios, 6 temperature decrease scenarios and one baseline (no change scenario). The resulting changes in hydropower potential were then evaluated by comparing the hydropower potential under changed conditions with potential under baseline conditions.

Given the above results, the following recommendations are made

1. In order to improve the results of the hydrological model, alternative models should be tested on the basin. Examples of models that can be tried out include conceptual models like SACRAMENTAL, WASMOD, and HBV models. Alternatively, physically based models like MIKE Basin can be tried out.

2. Extension of the study to other rivers that have significant hydropower potential including Nzoia, Yala, Sio, etc. In addition, a similar investigation can be carried out for Victoria Nile where several large hydropower dams are planned.

3. The results of this study can be used to carry out a prefeasibility study for one or more of the identified sites to demonstrate their applicability in designing more robust hydropower projects taking into account the effect of climate change.

4. Within the framework of NBCBN-RE, EIA research cluster, a number of guidelines are being developed for carrying out Strategic Environmental Assessments (SEA). These guidelines can be tested on the identified hydropower sites.

5. A number of projects are planned in the area of water management by constructing reservoirs. These reservoirs will be used for purposes like municipal and industrial water supply, irrigation and livestock as well as flood control. The effect of climate change on the multi-purpose reservoirs should be investigated further.

6. Further investigation of the environmental effects of variation measures aimed at mitigating the effect of climate change and variability on the hydropower potential at the different sites. For example, increasing dam height may be one of the mitigation measures but this comes at a cost of inundating more land which will have significant environmental impacts.

ABBREVIATIONS & ACRONYMS

ALPHA_BF	Baseflow Alpha factor (days)
CH_K2	Channel effective hydraulic conductivity (mm/hr)
Ch_N2	Manning's "n" value for the tributary channels
CN2	Conservation Service runoff Curve Number (-)
DEM	Digital Elevation Model
EPCO	Plant uptake compensation factor
ESCO	Soil Evaporation Compensation factor (-)
FAO	Food and Agriculture Organization
GW_REVAP	Groundwater "revap" coefficient (-)
GWQMN	Threshold water depth in the shallow aquifer for flow (mm)
LVB	Lake Victoria Basin
NSE	Nash and Sutcliffe Coefficient of Efficiency
RCHRG_DP	Deep Aquifer percolation (-)
REVAPMN	Threshold water depth in the shallow aquifer for "revap"(mm)
SOL_AWC	Soil Available Water Capacity (mmH_20/mm soil)
SOL_BD	Moist bulk density (Mg/m^3 or g/cm^3)
SOL_K	Saturated hydraulic conductivity (mm/hr)
SRTM	Shuttle Radar Topography Mission
SUFI-2	Sequential Uncertainty Fitting Algorithm
SURLAG	Surface runoffs lag time (days)
SWAT	Soil and Water Assessment Tool
SWAT	Soil Water Assessment Tool
USDA	United States Department of Agriculture
USGS	United States Geological Surveys

1 BACKGROUND AND INTRODUCTION

1.1 Background

This research was sponsored by the Nile Basin Capacity Building Network for River Engineering (NBCBN-RE), under the Knowledge Networks for Nile Basin (KNNB) project. The project is one of the research projects identified during the kick –off workshop in Cairo in 2006. Because of the importance of hydropower in the Lake Victoria basin, the project was selected as one of those to be funded under the integrated research modality. The project has been implemented by the Environmental Aspects Research cluster with participation of Burundi, Kenya, Rwanda, Tanzania and Uganda.

1.2 Introduction

The area contributing to the flow in the Nile basin extends across 10 riparian countries. The Lake Victoria Basin (LVB), located in the upper reaches of the Nile basin, comprises of five countries (**Figure 1.1**): Kenya, Tanzania, Uganda, Burundi, and Rwanda. The basin to the lake covers 194,000 km^2 while the lake surface area covers approximately 68,800 km^2 (35% of the basin).

The lake is a valuable resource to several industries including water supply, fisheries, agro forestry, inland water transport, and hydropower. The basin has a high hydroelectric energy potential of 2000MW for Uganda, 100 MW for Rwanda, 1370 MW for Burundi, 4.7GW for Tanzania, 30,000 MW for Kenya. However, the hydropower potential is under exploited. Consequently the basin suffers from power shortages.

Figure 1.1: Coverage of the Lake Victoria Basin

With the growth in the basin economy and population, there is a rise in demand for water resources which is highly dependent on climate. It has been discovered that Climate Change is linked to the droughts which caused low water levels in rivers and lake systems resulting into low operating capacity of hydropower plants. The vulnerability of the hydro power industry to climate change however, has not fully been investigated using hydrological and climatological models due to data limitations as well as human and institutional capacity limitations.

2 ENERGY SITUATION IN THE LAKE VICTORIA BASIN

2.1 Introduction

This chapter presents the current energy production and demand levels in the different riparian countries in the Lake Victoria Basin including: Uganda, Tanzania, Kenya, Burundi, Rwanda. A summary of the different hydropower developments is given including the the small hydropower plants. An assessment of current and future projects is highlighted.

2.2 Current Energy production and demand

2.2.1 Uganda

The total energy production capacity of existing energy sources in Uganda as at May 2009 was 564 MW. The different energy sources include: Hydropower (68.23%), Thermal (26.93%), Imports (1.8%), Mini Hydro (2.6%), Off-grid (0.43%), whose components are expounded below.

Table 2-1: The different energy components. Source: Power Supply Situation in Uganda by Semitala Norbert presented at EREA, 1st General Assembly

Type	Project Name	Installed Capacity (MW)
Hydro	Nalubaale	180
	Kiira	200
Mini-Hydro	Kilembe Mines Limited	5
	Kasese Cobalt Company Limited	9.5
Thermal	Namanve (HFO	50
	Aggreko II (Kiira – Diesel plant)	50
	Aggreko III (Mutundwe)	50
Biomass Co-generation	Kakira	12
	Kinyara	5
Off-Grid Thermal Power	Nebbi	0.225
	Adjumani	0.306
	Arua	1.109
	Moroto	0.306
	Moyo	0.225

In April 2009, the peak demand in Uganda was 368 MW compared to the ‘firm’ production capacity of 305MW. Statistics reveal that there is a persistent shortage in electric supply which if coupled with the increase in demand causes a deficit. The deficit in electricity supply decreased by 20MW between 2006 and 2008. With only 15% of the existing hydropower potential utilised and the power demand growing as a rate of 8% per year, the demand continues to exceed the available supply.

Due to the variability in lake levels, the effective energy production for the hydropower complex (Kiira and Owen falls dam) lies at 305 MW. To enhance hydropower production, two new hydropower plants, one in Bujagali with a capacity of 250 MW and Karuma Falls with 700 MW are expected to go operational by the end of 2010.

Total number of the Ugandan population supplied with electricity in the 3rd quarter 2009 was 308,277 (1.2% of the total population) with 305,777 supplied by UMEME and 2,500 supplied by West Nile Rural Electrification Company (WENRECO). The population supplied by UMEME includes domestic, commercial, medium industrial, large industrial, street lights. (ERA Report).

Several other micro power projects are also being developed to provide limited power to communities in the neighbourhood such as Ishasha hydropower project (6.6MW), Sezzibwa micro hydro power station (0.1 MW) in Mukono district, Bwindi micro hydro project (0.064MW), Suam micro hydropower project (0.049 MW), and Ten pico hydro turbines (0.2 kW and 0.5kW).

2.2.2 Rwanda

The current electricity generation capacity is 69MW largely produced from hydropower and thermal sources. The planned extension of the generation capacity is 130MW by 2012 through investment in hydropower and other renewable sources like methane gas. The population with access to electricity will consequently increase from the current 6% to 16% (350,000).

Rwanda's primary energy balance stands at Electricity 3%, Biomass: 86%, Petroleum products 11%. With the available generation electricity capacity at 69 MW, Hydropower (home generated) accounts for 35%, Regional Hydropower – 15%, Thermal power (home) – 34%, Thermal power (rental) – 13% and Methal to power accounts for 3%.

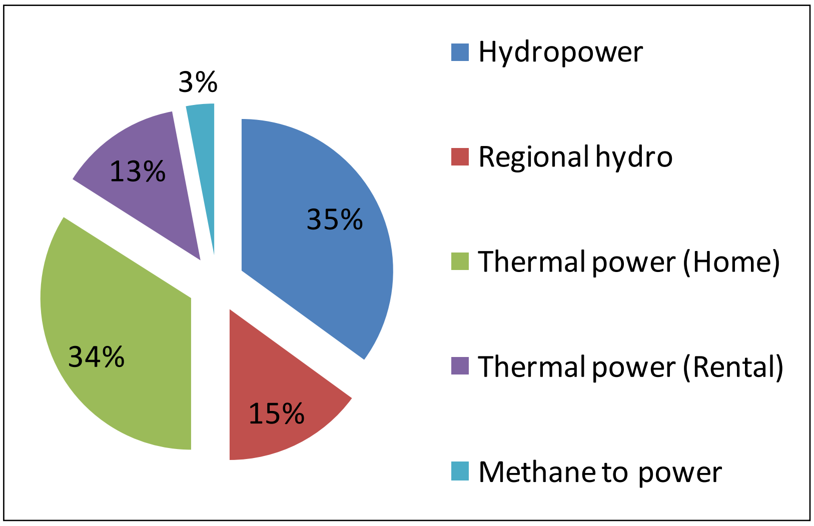


Figure 2.1 : Percentage contribution of different energy sources. Source: Ministry of Infrastructure, Rwanda.

Table 2-2: A breakdown of the specific energy sources is given below: (Source: Ministry of Infrastructure, Rwanda)

Category	Name	Installed Capacity (MW)	Available Capacity (MW)
Hydropower	Ntaruka	11.5	7.25
	Mukungwa	112	12

	Gihira	1.8	0.7
	Gisenyi	1.2	0
Regional Hydropower	Risizzi I	3.5	3.5
	Risizi II	12	8
Thermal Power	Jabana HFO	20.5	20.5
	Jabana Diesel	6.24	4.8
Rented Thermal Power	Gikondo Diesel	10	10
Solar Power	Kigali Solar	0.25	0.25
Methane gas	KP1	4.2	1.8
Total		85.3	69.10

The available capacity is 69MW leaving a deficit of 31MW. The average energy demand growth rate is 8% per annum. With the national electrification rate at 8% and a rural electrification rate at 1 %, Rwanda needs 100 MW to meet present demand and sustain its economic growth (*Kirai et al. 2009*).

2.2.3 Burundi

About 86% of Burundi's energy consumption is biomass, comprising of wood, charcoal and peat, 11% is imported petrol products, and 2% is electricity.

Burundi like other countries in the LVB faced an energy crisis which was linked to higher demand, drought and run down state of equipment. Burundi's energy demand growth rate is 4% and the total consumption estimated at 119,961 MWh. A comparison of the current power demand at 45MW and the installed capacity of 32 MW leaves an unfulfilled demand of 13 MW. The power deficit is currently 25MW during peak hours. To meet increasing power demand, two new hydro-facilities at a cost of $91 million are to be constructed.

Of the total population, 8.4 Million, 2% (31,454) have access to electricity of which 30,079 are in urban centres while 1,375 are in rural areas.

2.2.4 Tanzania

Total energy production in Tanzania is 1.88 billion KWh produced compared to 1.99 billion KWh consumed. (*Mizengo P, 2009*). Biomass fuels (for example wood-fuel) accounts for 90%, Petroleum 8%, electricity 1% and others 1% (includes coal and new and renewable energy sources). (*Kaale B. K., 2005*)

The total installed electricity generation capacity is 1219 MW, from which hydropower comprises 561 MW and thermal 658 MW. Only 2% of the rural population have access to electricity in contrast to 37% of the urban population - average only 10% of the country's population have access to electricity *(Kabaka and Gwang'ombe, 2007)*

The country generates only 595 MW of electricity against the peak electricity demand of 787MW (Kassana L. B, 2005). The growth rate is estimated as 7% per annum, at which rate demand is expected to rise to above 2500 KWh by 2025 (*Mizengo P, 2009*).

The net effective capacity of thermal generating plants in the country is 251 MW. Different thermal plants include: Ubungo gas turbines, Ubungo diesel plant, Independent Power Tanzania Ltd. (IPTL) plants, isolated remote diesel plants, Kiwira Coal Mine Company limited and Tanzania Wattle Ltd (Njombe).

2.2.5 Kenya

A total energy production of 1,115MW is installed. Hydropower accounts for 677MW, Oil based thermal - 407MW while imported power from Uganda accounts for 30MW. The hydropower contribution to electricity generation in Kenya is 78% while geothermal contributes 22% (*Karekezi, 2006*).

Five major stations in the Tana River basis supply the bulk of hydropower to Kenya. These are: Kindaruma (44MW), Gitaru (225MW), Kamburu (94.2MW), Masinga (40MW) and Kiambere (144MW). The Turkwel Gorge Hydroelectric station in the Turkana district has a capacity of 106 MW. There are also several small hydro stations including Mesco, Ndula, Wanjii, Tana, Gogo Falls and Selby Falls which have a combined generation output of 40MW.

The current effective electricity demand for Kenya is 923MW and the energy demand growth rate is 5% per annum. The peak demand was projected to grow to 1, 153MW by June (2008) against an effective generation capacity of 1,185MW, allowing for a reserve capacity margin of 3%.

The national consumption of electricity was projected to rise from 4.9 billion kilowatt hours in 2003/2004 to 5.1 billion in 2004/2005, and 6.9 billion kilowatt hours in 2009/2010 and to 11.8 billion in 20/9/2020. The hydroelectric potential is estimated to be 6,000 MW (30,000GWh per year).

In the long term, the installed capacity is projected to increase by 1342 MW between 2004 and 2018/2019 and will comprise of geothermal (503MW), hydro (220.6MW) and thermal (568.7MW) sources

2.3 Hydropower Production

2.3.1 Uganda

Currently two large hydropower plants are in operation including Nalubaale and Kiira dams. These were commissioned in 1954 and 2002 respectively. Nalubale has an installed capacity of 180MW while Kiira has 200MW. However, due to the prolonged drought and associated low water levels, the effective generation has currently reduced. The Current hydropower production in Uganda amounts to 308 MW produced by the hydroelectric complex: Nalubaale and Kiira dams.

2.3.2 Rwanda

The total electricity produced through hydropower is 27.3 MW from Ntaruka: 11.5MW, Mukungwa: 12.5 MW, Gihira: 1.8 MW and Gisenyi: 1.2 MW.

2.3.3 Burundi

Burundi relies heavily on hydro electric power. There are currently 15 small hydropower plants of up to 1 MW that are operational with a total capacity approximately 3 MW. The details are given in **Table 2-3**.

Table 2-3: Inventory of sites for small hydropower projects

S/N	Name of site	Name of river	Installed Capacity (MW)	Start year
1.	Gikonge	Mubarazi	0.850	1982
2.	Kayenzi	Kavuruga	0.350	1984
3.	Marangara	Ndurumu	0.240	1986
4.	Buhiga	Sanzu	0.072	1984
5.	Sanzu	Sanzu	0.024	1983
6.	Butezi	Sanzu	0.240	1990
7.	Ryarusera	Kagogo	0.020	1984
8.	Nyabikere	Nyabisi	0.139	1990
9.	Murobe	Rusumo	0.024	1987
10.	Mugera	Ruvyironza	0.030	1962
11.	Kiremba	Buyongwe	0.064	1981
12.	Teza	Nyabigondo	0.360	1971
13.	Kiganda	Mucece	0.044	1984
14.	Gisozi	Kayokwe	0.015	1983
15.	Burasira	Ruvubu	0.025	1961

2.3.4 Tanzania

Tanzania has a hydropower potential estimated at 4700 MW but the total installed generating power capacity is about 860 MW with 555 MW being hydro-based. Tanzania also imports electricity from Uganda (8 MW) and Zambia (5 MW).

Table 2-4: Existing hydropower projects in Tanzania. Source: Kaale B. K. (2005),'Baseline study on Biomass conservation in Tanzania' Ministry of Energy and mineral, Tanzania

Hydropower plant	Installed capacity(kW)	Effective capacity (kW)
Kidatu	204	204
Kihansi	180	180
Mtera	80	80
New Pangani Falls	68	66
Hale	21	17
Nyumba ya Mungu	8	8
TOTAL	561	555

2.3.5 Kenya

Five major stations in the Tana River basis supply the bulk of power to Kenya. They are: Kindaruma (44MW), Gitaru (225MW), Kamburu (94.2MW), Masinga (40MW) and Kiambere (144MW). The Turkwel Gorge Hydroelectric station in the Turkana district has a capacity of 106 MW. There are also several small hydro stations - Mesco, Ndula, Wanjii, Tana, Gogo Falls and Selby Falls which have a combined generation output of 40MW.

2.4 Hydropower developments in the Lake Victoria Basin

2.4.1 Uganda

A number of large hydropower potential sites available for Uganda include: Bujagali (250MW), Ayago North (304MW), Ayago South (234MW), Murchison (600MW), Kalagal (300MW), Isimba (87MW), Karuma (200MW), Bigumira (109 MW). Bujagali hydropower project is due to be completed in 2011.

Some of the small hydropower projects (defined as projects with an output capacity of 20MW) include: Nyagak (3.5 MW), Buseruka HEP Project (9 MW), Mpanga HEP Project (18 MW), Kikagati HEP Project (10 MW), Ishasha HEP Project (6.595 MW), Bugoye (13 MW), The WENRECO will complete work on Nyagak mini hydropower project in Nebbi in March 2010.

2.4.2 Rwanda

The hydro power plants that are under construction are listed in **Table 2-5**:

Table 2-5: Hydropower plants under construction

SN No.	Project title	Capacity	Progress
1.	Nyabarongo hydropower plant	27.5 MW	Commissioning is expected for 2013
2.	Rukarara hydropower plant	9.5 MW	Construction works are at 55% and commissioning expected to take place in the 1st quarter of 2010
3.	Eight (8) Micro Hydro Power Projects (MHPP)	Gashashi (200 KW), Janja (200 KW), Mukungwa-II (2.5 MW), Nyirabuhombohombo (500 KW), Nyabahanga (200 KW), Rugezi (2.2 MW), Nshilli-I (400 KW) and Ruhwa (200 KW).	The completion date has been set for end of June 2010
4.	Micro Hydropower under UNIDO	Nyamyotsi I (100KW), Nyamyotsi II (100KW), Mutobo (200KW) and Agatobwe (200KW)	The commissioning is expected beginning of 2010.
5.	Three (3) MHPP under the Belgian Technical Cooperation	Nkora, Cyimbili and Keya (Pfunda)	The commissioning is expected to take place

			before the end of 2010.
6.	Private Sector Partnership (PSP) Hydro project/GTZ	REPRO (105 kW) ENNY (250 kW) SOGEMR (400 kW)	The commissioning was expected by September 2009 for REPRO MHPP, by November 2009 for ENNY MHPP and by the first quarter of 2010 for SOGEMR MHPP.
7.	EPRER/IREAPPP Projects	Ntaruka A (2 MW, Nshili II (500 kW) & Rukarara II (2 MW)	Projects are under feasibility study

2.4.3 Burundi

The available hydropower potential is1370 MW and only 300 MW is seen as viable for economic exploitation. The annual production is 6000 GWh.

15 sites have been identified as small hydropower potential sites suitable for development. The combined capacity from these sources is expected to be 3MW.

Burundi is working on two hydro projects, due to be completed in early 2010, to add 15.85 MW to its national grid. Burundi plans another two hydropower dams on its border with Rwanda and the Democratic Republic of Congo for a total 410 MW by 2018 and an additional 60 MW project on its border with Tanzania due to start by 2016.

2.4.4 Tanzania

In 2005, a total of 85 small hydro sites countrywide with a total of 187 MW were identified (*Kabaka K. T. and Gwang'ombe F. 2007*). In an inventory study carried out by TANESCO, and financed by Ministry of Energy and Minerals focus was put on mini hydro potentials as a part of the Rural Electrification Master Plan study. In addition to other sources of electricity, five small hydropower potentials (**Table 2-6**) from the small hydro database were appraised during this study.

Table 2-6: Small Scale Hydro potentials appraised for Development in the Tanzania Rural Master Plan Study (2005)

Potential	Location	Cost
Pinyinyi Hydropower potential	Ngorongoro District, Arusha	5500
Nzovwe Hydropower Potential	Sumbawanga Rural District Rukwa	2700
Mulagarasi (Igamba Falls Stage II) potential	Kigoma Rural District	2900
Sunda falls Hydropower potential	Tunduru District, Ruvuma	2800
Nakatuta Hydropower potential	Lower Nakatuta, Songea Rural District	3500

2.4.5 Kenya

Hydropower contributes 70% of the electricity supply in Kenya. According to KENGEN (Kenya Generation Electricity Company), the potential sites are costly to develop. Therefore, KENGEN is looking to mainly expand the capacity of the existing stations for example:

Redevelopment of Tana Power Station: The feasibility and Environmental study are currently complete. It is expected the installed capacity will increase from 14.4 to 20MW. The estimated cost of the project is US$41 million.

Raising Masinga Reservoir: Project looks to increase the reservoir capacity so as to improve regulation of the cascade and increase energy production. The feasibility study was completed in 2007 and currently site investigations and the EIA are ongoing. Construction should begin in 2009. Estimated cost is US$12 million.

Kindaruma 3rd Unit Project: To increase the installed capacity by an additional unit of 20MW and refurbishment of the existing two. Tenders for the construction expected in June 2008 with commissioning of the 3rd unit in 2011. The estimated cost is US$20 million.

Kenya has other hydropower potential sites on River Nzoia shown in the table below

Table 2-7: Potential hydropower site in River Nzoia Basin

Project	Installed Capacity (MW)	Firm Capacity (GWh/yr)
Hemsted Bridge	60	297
Rongai	12	52
Lugari	15	62
Webuye falls	30	115
Anyika	25	95

2.5 Strategies for increasing the energy access

Currently less than 10% of the Ugandan population (24.2 Million) has access to electricity. 6% of the total population of Rwanda (9.7 Million) have access to electricity. Of the total population, 8.4 Million, 2% (31,454) have access to electricity of which 30,079 are in urban centres while 1375 are in rural areas. The total consumption is then estimated at 119,961 MWh. 14 % of the entire Tanzania population (40 Million people) have access to electricity (MEM 2010) and only 2% of the rural population have access to this vital power.

3 MODEL SETUP

3.1 Introduction

This chapter explicitly explains the hydrological model setup using SWAT. It includes a detailed study of the study area, SWAT conceptualisation, Data collection and processing, SWAT model setup and the results of the hydrological modelling.

3.2 Background

Lake Victoria Basin (LVB) is highly endowed with hydropower potential and in turn hydropower remains the highest contributor to the energy base for riparian countries. The high Hydro Electric Resource is due to its system of main rivers flowing into the Lake such as Mara, Kagera, Nyando, Sondu, Gurumeti, Migori, Simiyu etc. Despite the high hydropower generation capacity at the outlet of Lake Victoria, there is still a lot of unexploited potential of hydropower. However, the Hydro electric power (HEP) sector is faced many challenges including climate change, population growth, competing water demands from agriculture, industry, forestry and domestic use.

Due to the favourable conditions for agriculture, fishing, the LVB supports one of the densest rural populations of up to 1200 persons per square kilometre (*Hoekstra and Corbett, 1995*) with a growing rate of 3%. The total population is currently about 30 million and is projected to double over the next 50 years. The increased population puts a lot of pressure on the land and water resources (*Mulungu and Munishi, 2007*). Understanding the impacts of climate variability and change on the basin is crucial for Water Resource Management at both regional and national scale.

In 2007, most riparian countries experienced power shortages due to extended droughts in the region. Most media strongly affiliated this to climate change in the lake Victoria basin as reduced rainfall was thought to be the cause for the drastic changes in river flows and reservoir water levels. However, the impacts of climate change on hydropower in the Riparian Countries of LVB have so far not been studied and are unclear.

Against this background, the long term objective of this research is to contribute towards sustainable hydropower generation within the framework of sustainable socio-economic development in the Lake Victoria Basin. Specifically, the research explores the impact of climate change on the future development and operation of hydropower schemes in LVB. The hypothesis tested is whether climate change will have significant impact on hydropower generation in LVB.

To satisfy these objectives, the first task was to calibrate and validate hydrologic models of two catchments in Lake Victoria basin; Kagera and Mara. Hydrologic models were designed to mimic the catchment properties and characteristics using SWAT (Soil Water Assessment Tool) model.

3.3 Advantages of SWAT

Although the rainfall-runoff models are undoubtedly useful, modelling the relationship between rainfall and runoff can be complicated and time consuming as a result of the several variables and processes that are involved. Extensive input data and user expertise are necessary to integrate different factors when modelling runoff. The complexity of hydrological processes and basin characteristics lead to physically-based distributed models. Capturing and managing vast amount of spatially-distributed hydrological parameters and variables is now possible with the development of GIS technology tools. For this reason ArcSWAT was used for the study.

SWAT is a continuous time and spatially distributed watershed model, in which components such as hydrology, crop growth related processes and agricultural management practices are considered. The model is capable of simulating and capturing a high level of spatial details by allowing the watershed to be divided into a large number of sub-watersheds. The SWAT model is a long-term, continuous model for watershed simulation which operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields.

The Soil and Water Assessment Tool (SWAT) model is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the response to natural inputs as well as the manmade interventions on water and sediment yields. The model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. The major advantage of the SWAT model is that unlike the other conventional conceptual simulation models it does not require much calibration.

3.4 Study Area

3.4.1 Lake Victoria basin

Lake Victoria, located in the upper reaches of the Nile river basin, is the largest fresh water lake in Africa and the second largest in the world. It is the source of the White Nile and it also provides 14% of the total Nile flow. The basin has a surface area of 194,000 km2 and the lake surface is 68800 km2 (UNEP, 2006a). The lake has a mean depth of 40 m with a maximum depth of about 92 m (Spigel & Coulter, 1996).

The Lake Victoria Basin (LVB) is shared between Tanzania (44%), Kenya (22%), Uganda (16%), Rwanda (11%) and Burundi (7%). It comprises of 17 major river basins and the largest of which is the Kagera basin (*Howell et al, 1988*). The tributary inflow only accounts for 20% and rainfall accounts for 80%. LVB has a wide range of rainfall modulated by the altitude. Most of the basin is characterized as arid and semiarid with the mean annual rainfall in most areas is 1200 – 1600 mm. The mean annual evaporation over the lake is 1595mm.

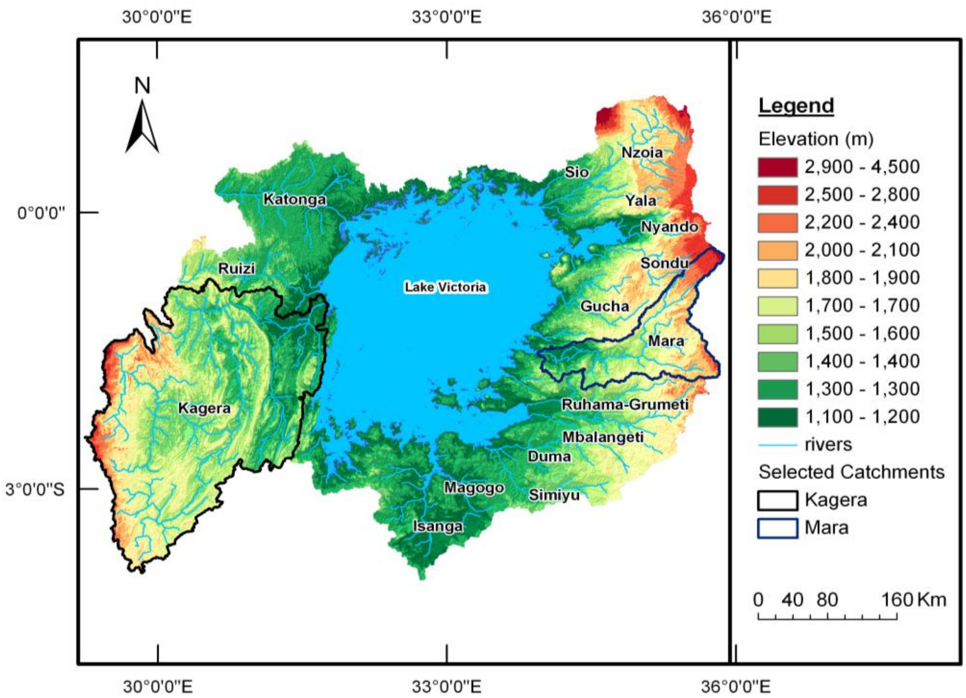


Figure 3.1: Extent of Lake Victoria basin

Lake Victoria lies at 0°30'N – 3°00'S and 31°39'E – 34°53E at an altitude of 1135 m above mean sea level. The northeastern part of the lake catchment is relatively steep and forested (**Figure 2.1**). The southeastern part of the basin is relatively flat and dry. In the southwest, the Kagera basin with its head waters in the mountains of Rwanda and Burundi drains about 60,000 km^2. The remaining 30,000 km^2 of the catchment in the northwest contributes little inflow to the lake (*Howell et al., 1988*).

3.4.2 Rainfall Variability in the LVB

The rainfall in Lake Victoria basin varies temporally and spatially across the basin as shown in (**Figure 3.2**). The diurnal, seasonal and inter-annual rainfall variability results from a complex interaction between the inter-tropical convergence zone (ITCZ), El Nino/Southern Oscillation (ENSO), Quasibiennial Oscillation (QBO), large-scale monsoonal winds, meso-scale circulations and extra-tropical weather systems (*Ogallo 1988; Mutai et al. 1998; Nicholson and Yin 2002*).

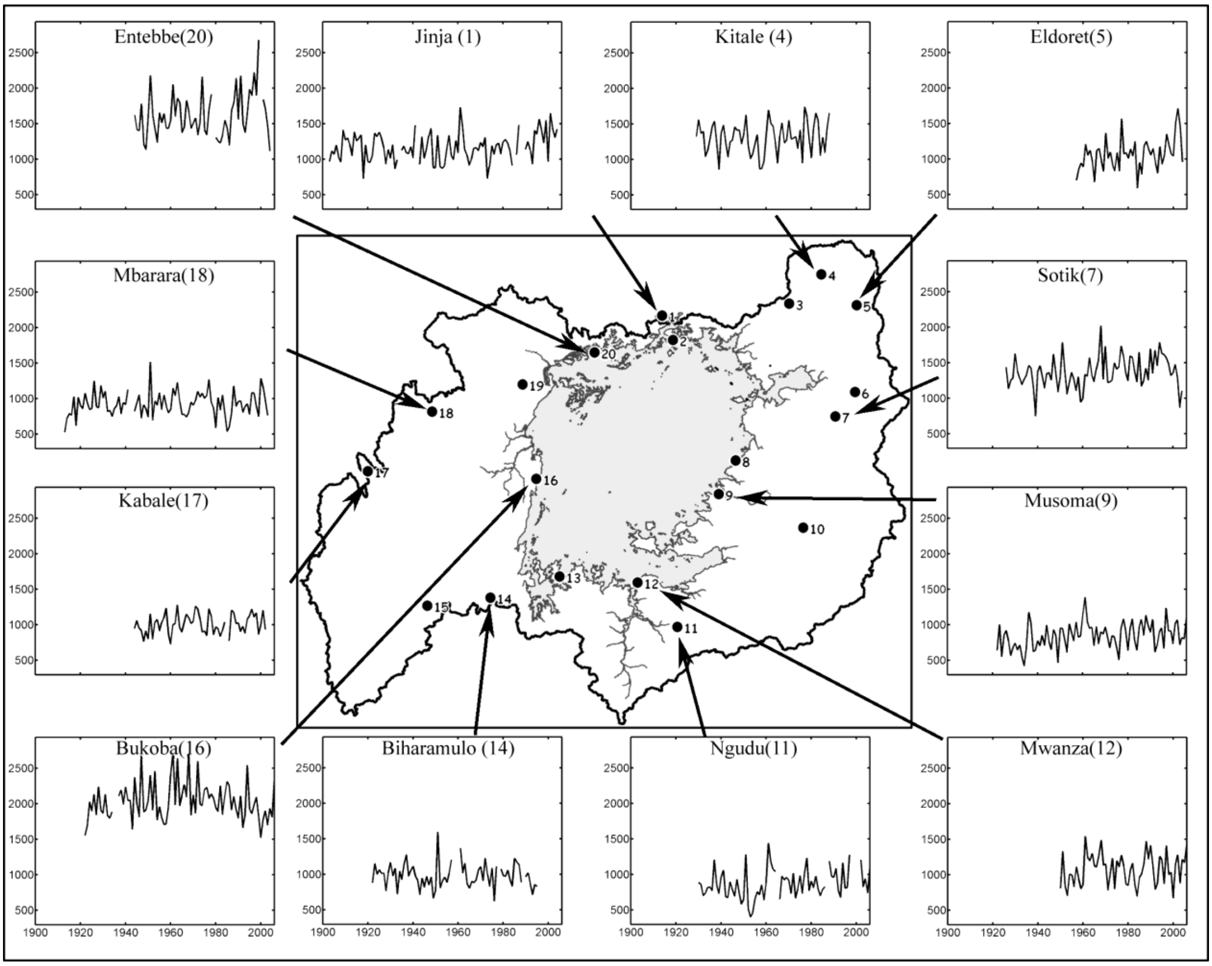


Figure 3.2: Annual rainfall series of selected study stations

Particularly, the seasonal climate patterns across the basin (**Figure 3.3**) follow the seasonal N–S movement of the ITCZ which lags the seasonal migration of the sun and results in a bimodal rainfall distribution; the March–May rainfall period (long rains) and the October– December rainfall period (short rains). The seasonal climate is also modified by the northeast (NE) and southeast (SE) monsoon winds (*Mukabana and Piekle 1996*).

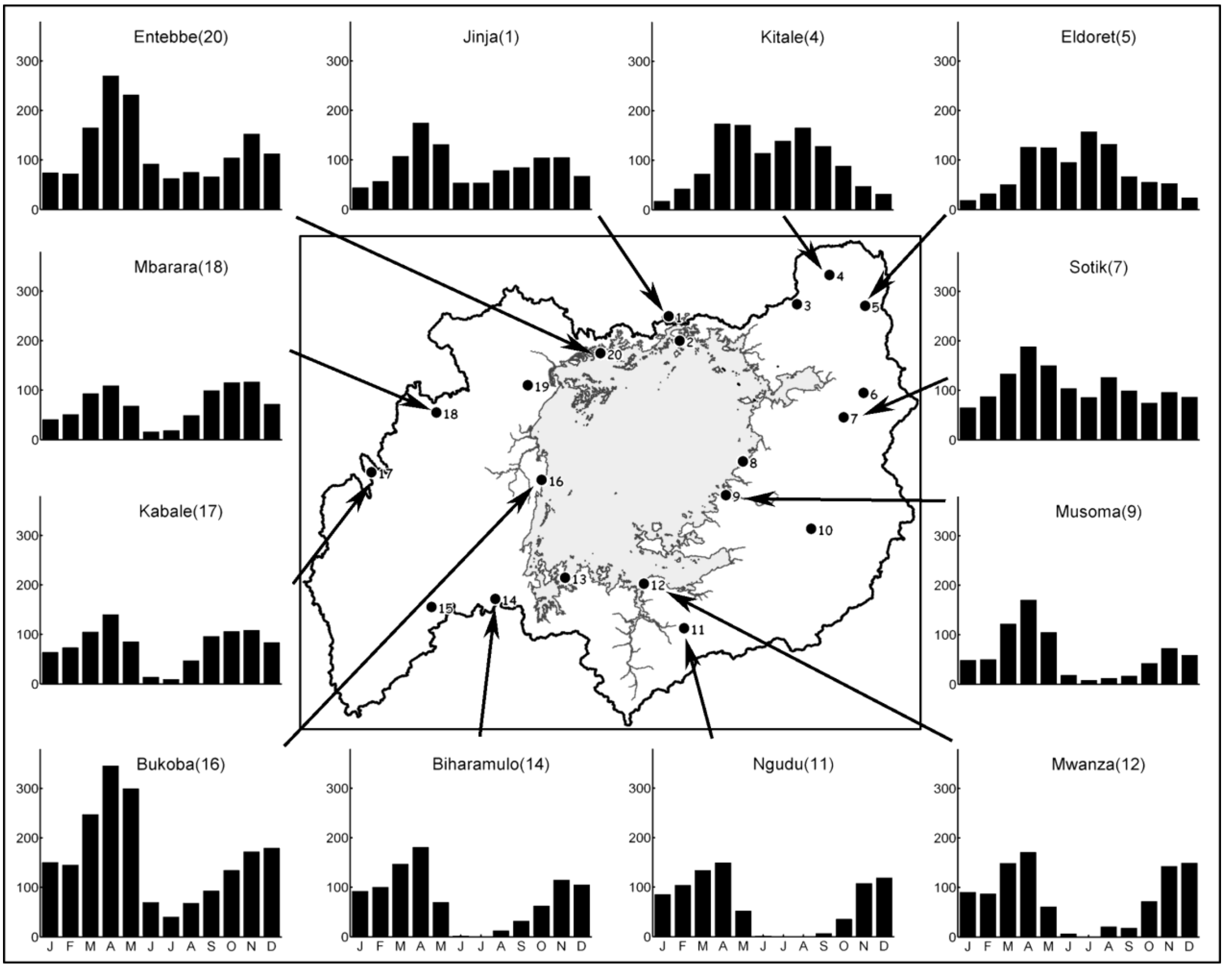


Figure 3.3: Long term median monthly rainfall for selected stations in the LVB

3.4.3 Mara

Mara is a transboundary catchment shared between Kenya and Tanzania with an areal coverage of 13,750 Km^2 of which 65% is located in Kenya and 35% is located in Tanzania (**Figure 3.4**). River Mara has a length of 395 Km. The Basin is located between 35.78° E and 0.43° S in southwest Kenya and 33.78° E and 1.48° S in northeast Tanzania. It is a part of the larger Lake Victoria basin which is a part of the upper catchments of the Nile basin.

The source of river Mara is the Napuiyapui swamp in the Mau Escarpment in the highlands of Kenya at an altitude of 2,932 m asl. The river drains into Lake Victoria through Mara bay at Musoma in Tanzania. The elevation at the outlet is 1,134 m. Mara catchment traverses the Maasai Mara and Serengeti National Parks. The basin highlands are at 2,915 m asl and the low lands are at 1,140 m asl at Lake Victoria.

In the basin, rainfall varies with altitude; mean annual rainfall ranges from 1,000 - 1,750 mm in the Mau Escarpment, 900- 1,000 mm in the middle rangelands to 700 – 850 mm in the lower Loita Hills and around Musoma. Rainfall seasons are bi-modal, falling between April and September, and between November-December.

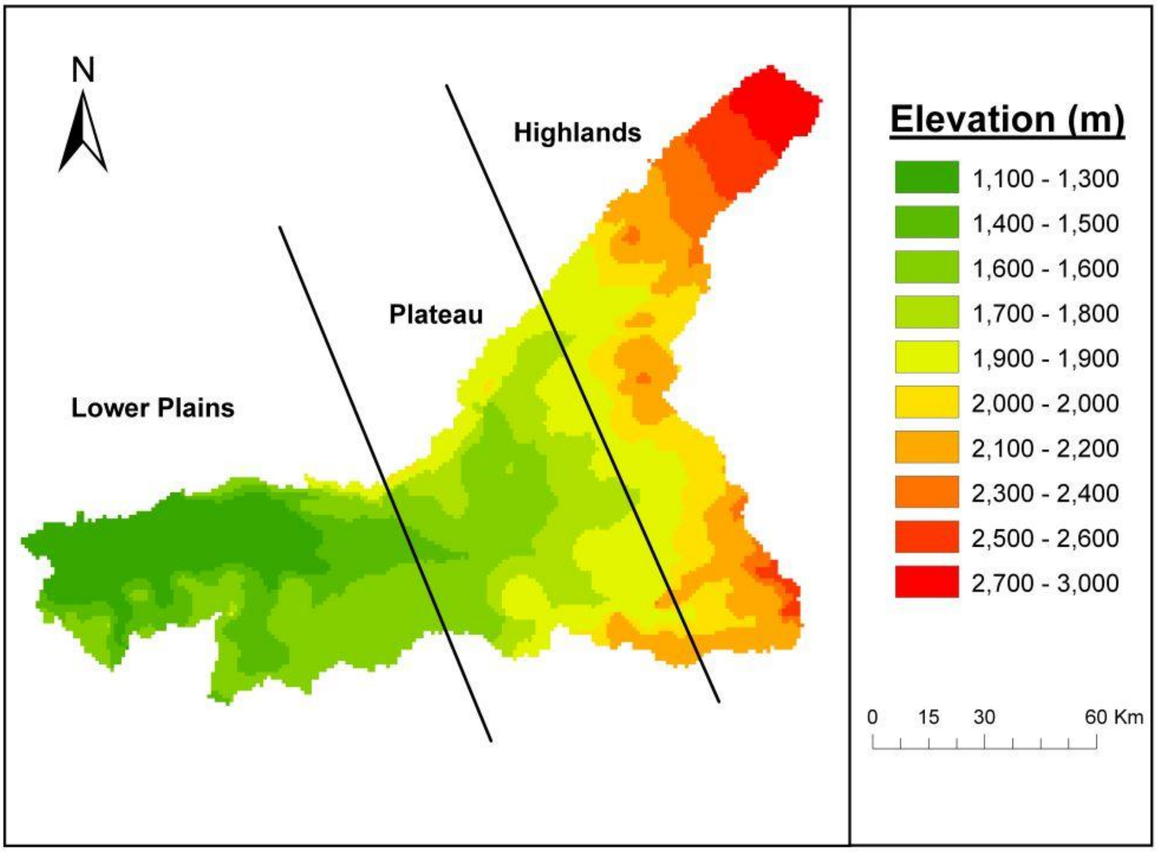


Figure 3.4: Mara Digital Elevation Map

Soil distribution in Mara catchment varies with elevation. The mountains have rich volcanic soils which are usually shallow but well-drained dark-brown volcanic types. On the hills and minor escarpments, soils are typically dark-reddish brown soils, shallow and excessively drained. The plateaus and high-level plains (including areas of Siria, Niarage Enkare and Narosura) have imperfectly drained gray-brown to dark dark-brown soils. Some deep, dark-grayish soils are mainly found on the plains of Kapkimolwa Shartuka, and Maasai Mara National Reserve. Along the floodplains of the Mara and Ol punyuta and Likirigi swamps lies clay soils that are moderately fertile (*Mutie et al., 2005*).

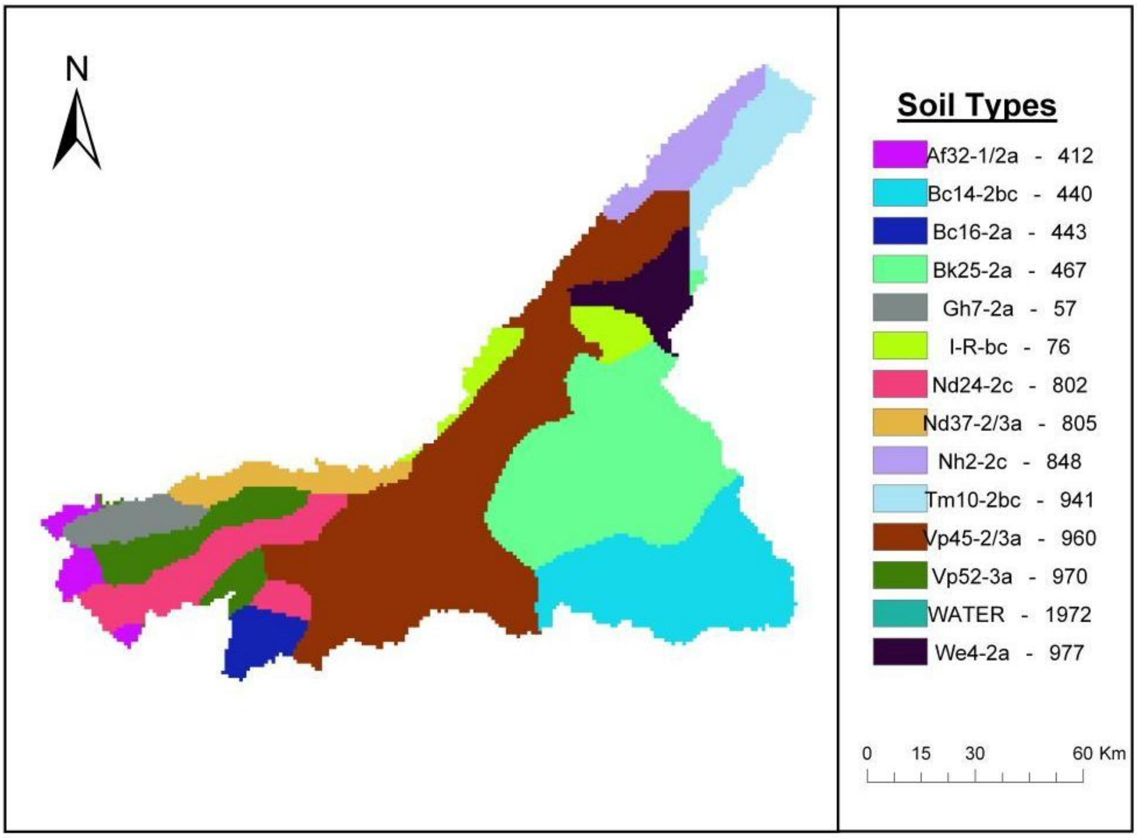


Figure 3.5: Soil classification in Mara catchment (ref FAO,…)

Preliminary analysis done by Bancy et al., (2005) using Landsat TM satellite data showed that in just 14 years between 1986 and 2000, agricultural land has increased by 55% through the combined encroachment of forests and savannah grasslands, which have in turn reduced by 23% and 24% respectively. The study also showed that the Mara basin has undergone significant changes in land cover over the last 50 years. Forests and savannah grasslands have been cleared and turned into land for agriculture, charcoal burning, overgrazing and expansion of agricultural activities (*Machiwa, 2002; Dwasi, 2002; IUCN, 2000*), while grazing resources have dwindled. For instance, the area under cultivation in the Amala subcatchment increased from less than 20% in 1960 (Olenguruone Settlement Scheme) to more than 51% in 1991. This is partly due to the rapid population growth, as a result of high rates of immigration. Between 1999-2002, the number of households increased by 13% in the upper basin reach.

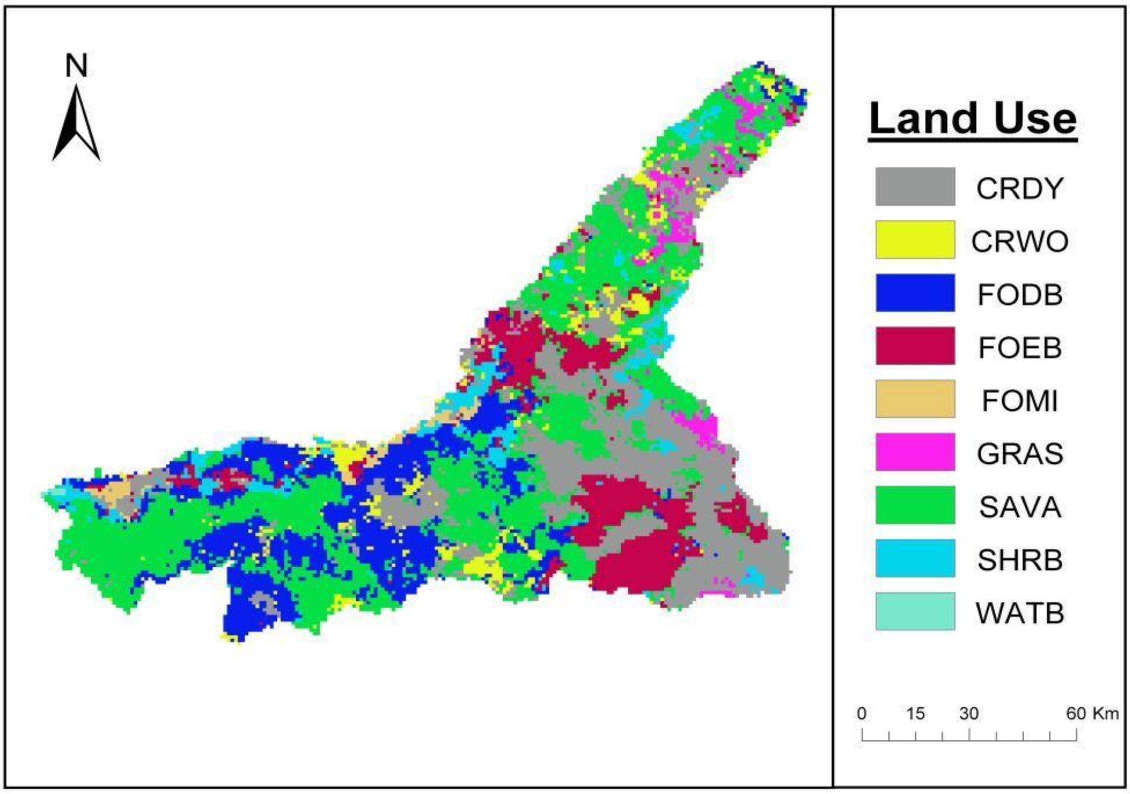


Figure 3.6: Land use classification in Mara catchment

3.4.4 Kagera

With 34% of the total annual tributary flow, Kagera is the largest river that drains into Lake Victoria. Its main tributaries are Ruvuvu and Nyabarongo. Kagera basin lies between latitude 1.00 and 2.45 degrees and longitude 30.25 and 32.40 degrees. It has a total area of 60,000 Km^2, of which 42,397 Km^2 is land and 17, 404 Km^2 is covered by lakes and swamps. The basin drains most of Rwanda, about half of Burundi and parts of Northwest Tanzania and south east Uganda with percentage coverage as shown in **Table 3-1**.

Table 3-1: Kagera Basin areal coverage in different countries

Country	Areal Coverage (Km^2)	% of total catchment
Burundi	13,060	22
Rwanda	20,550	34
Uganda	5,980	10
Tanzania	20,210	34

Kagera is diverse in topography, climatology and landforms. On average the basin has a general elevation of 1200 – 1600m but rises to above 2500m in the west, with peaks reaching 4500 m. The western part of the basin consists of a series of hills running along the North - South direction parallel to the Lakeshore. Much of the region is hilly in terrain with thick tropical vegetation including forests and open grasslands. The upper tributaries are generally steep but include flatter reaches where swamps where formed. The middle course of the river and its tributaries above Rusumo falls is convoluted.

The annual rainfall is less than 1000m over the eastern half of the basin but raises to over 1800 mm in the west where most of the runoff is generated. On average the basin receives 800mm - 2,000 mm of rainfall. The region experiences two rainfall seasons: March to May for the long rains fall (brought by the south-easterly monsoon) and October to December for the short rains (brought by north-easterly monsoon).

The runoff responds to the rainfall with the higher peak in May and the smaller peak in November. However, the river flows are attenuated by a number of lakes, and in particular by two sets of swamps and associated lakes above and below Rusumo Falls. The peak flow occurs in April in the upper tributaries, in May at Kigali and Rusumo falls but it's delayed to July at Kyaka Ferry on the lower Kagera. At this location the long-term mean runoff is relatively low at 136 mm compared with rainfall of 1170 mm.

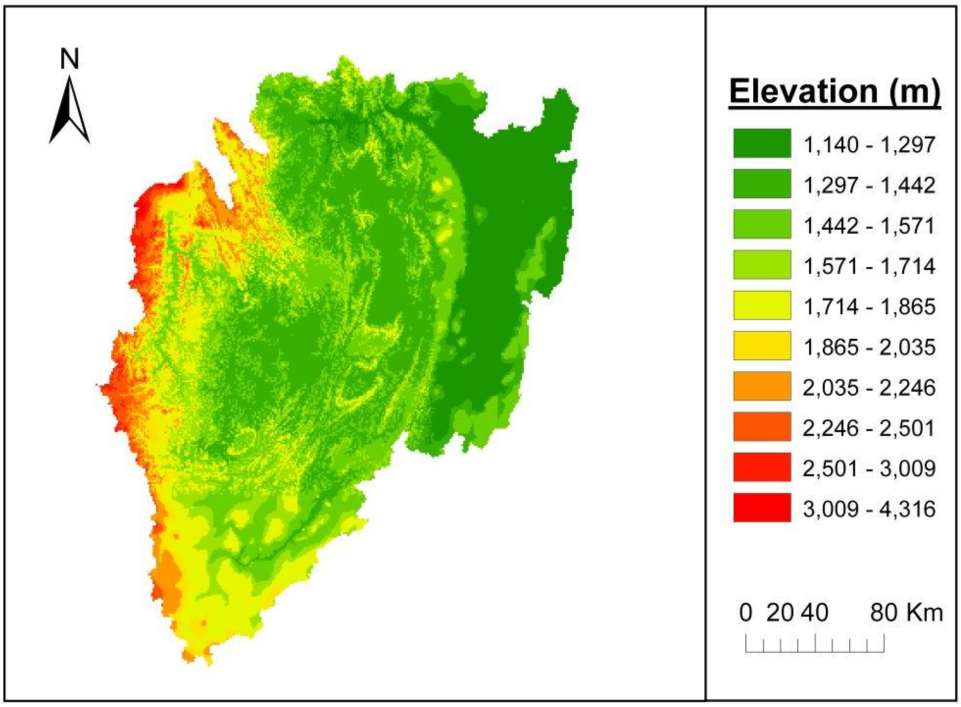


Figure 3.7: Kagera Digital Elevation Map

Kagera has shear rock cliffs, interlocking spars, deep valleys, waterfalls, escarpments and plateaus. Some areas are swampy with deposits of water washed pebbles and fertile upper soils from the hillsides. It has a variety of rocks including volcanic sedimentary and igneous.

The region is dominated by ferrasols characterized by strong acidity and very low-base saturation. The soils are generally low in phosphorus while the soils may have high iron and clay contents, in particular banana growing areas. Kagera region has reasonably fertile soils though high amounts of rainfall along and near the lakeshore coupled with poor soil management have led to serious soil erosion and soil exhaustion problems causing a need for the use of fertilizers.

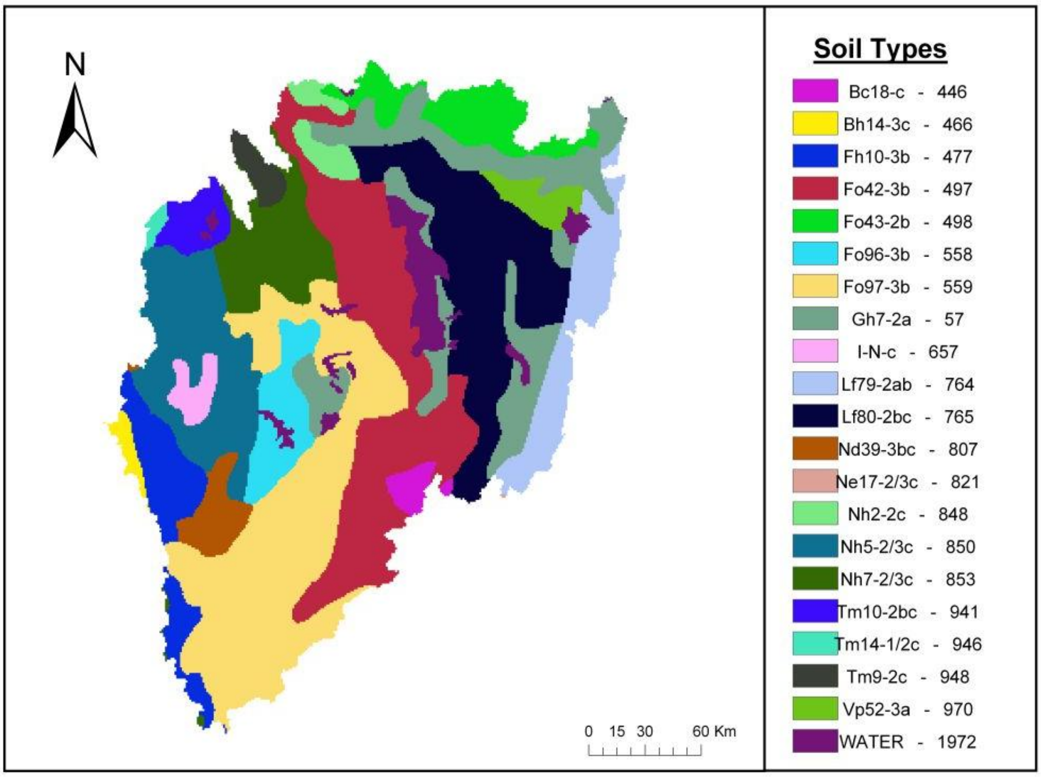


Figure 3.8: Kagera Soil classification

Although the west is partly forested, much of the basin has become intensively cultivated, resulting into erosion and river sediment load from the high rainfall areas.

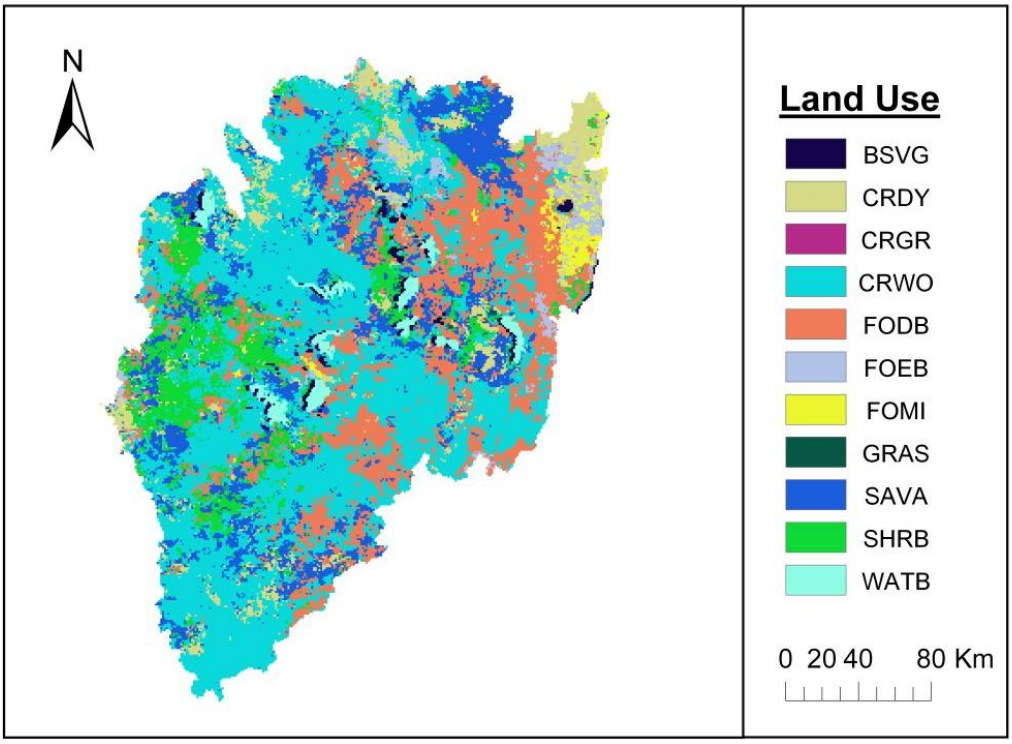


Figure 3.9: Kagera Land use classification

3.5 Modelling Framework

The main objective was to develop a hydrological model to simulate the catchment properties and flow characteristics. Specific objectives included: Setting up a hydrological model using ArcSWAT, model calibration and model validation using SWATCUP. The model calibration and validation is based on measured river discharges, and quantification of the uncertainty in model outputs using "Sequential Uncertainty Fitting Algorithm" (SUFI-2).

Two transboundary river basins were studied namely River Kagera and River Mara basins. The methodology for the entire project included data collection and analysis, analysis of power demand and production for the riparian countries, hydrological modeling, selection of climate scenarios, modeling of hydropower potential and analysis of future trends in hydropower production and demand.

ArcSWAT was used to setup the hydrologic model for the study catchments. ArcSWAT is a hydrological model (Soil and Water Assessment Tool) run under the ArcGIS environment. It is a watershed scale model developed by USDA Agricultural Research Service (Arnold et al., 1995). SWAT is a quasi−physically based, continuous in time, distributed model designed to simulate the catchment hydrology. It represents the hydrological cycle by interception, evapotranspiration, surface runoff, infiltration, soil percolation, lateral flow, groundwater flow, and channel routing processes (*Qi and Grunwald, 2005*). For this project, the model was developed to quantify the impact of climate change on hydropower production.

Surface runoff in SWAT is estimated by a modified Soil Conservation Service (SCS) curve number equation using daily precipitation data based on soil hydrologic group, land use/land cover characteristics and antecedent soil moisture. Potential evapotranspiration (PET) was simulated using the Hargreaves method (*Hargreaves et al., 1985*). Actual evapotranspiration (AET) was predicted based on the methodology developed by Ritchie (1972).

3.6 SWAT Conceptualisation

SWAT simulates the water balance based on the hydrologic cycle including evaporation, runoff, infiltration processes. The equations used in SWAT to simulate the hydrological process are discussed in the following sections.

3.6.1 Water Balance

$$SW_t = SW_0 + \sum_{i=0}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right)$$
……………………………………Equation 1

Where SW_t is the final water content (mm H_2O), SW_0 is the initial water content on day *i* (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day *i* (mm H_2O), E_a is the amount of evaporation on day *i* (mm H_2O), Q_{surf} is the amount of precipitation on day *i* (mm H_2O), W_{seep} is the amount of waters entering the vadose zone from the soil profile on day *i* (mm H_2O), Q_{gw} if the amount of return flow on the day *i* (mm H_2O).

3.6.2 Evaporation

The Penman-Monteith equation was used in this study. It combines the different processes that account for the energy needed to sustain evaporation, the strength of the mechanism required to remove the water vapour and aerodynamics and surface resistance terms. Equation 3 shows the penman-Monteith equation:

$$\lambda E = \frac{\Delta.(H_{net} - G) + \rho_{air}.c_p.[e_Z^o - e_Z]}{\Delta + \gamma.\left(1 + \frac{r_c}{r_a}\right)}$$ ……………………..………………………….. Equation 2

Where λE is the latent heat flux density (MJ m^{-2} d^{-1}), E is the depth rate evaporation (mm d-1), Δ is the slope of the saturation vapour pressure-temperature curve, *de/dT* (KPa °C^{-1}), H_{net} is the net radiation (MJ m^{-2} d^{-1}), G is the heat flux density to the ground ((MJ m^{-2} d^{-1}), ρ_{air} is the air density (Kg m^{-3}), c_p is the specific heat at constant pressure (MJ Kg^{-1} °C^{-1}), e_Z^o is the saturation vapor pressure of air at height z (Kpa), γ is the psychometric constant ((KPa °C^{-1}), r_c is the plant canopy resistance (s m^{-1}), r_a is the diffusion resistance of the air layer (aerodynamic resistance) (s m^{-1}).

3.6.3 Runoff

SWAT provides two methods for estimating the surface runoff: the SCS curve number procedure and the Green and Ampt method. Infiltration and surface runoff in this model was calculated using the SCS curve method. The input data required is the sub-daily precipitation data whose equation 3

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}$$ ………………………………………………………………. Equation 3

Where Q_{surf} is the accumulated runoff of rainfall excess (mm H_2O), R_{day} is the rainfall depth for the day (mm H_2O), I_a is the initial abstractions which includes surface storage, interception and infiltration prior to turnoff (mm H_2O), and S is the retention parameter (mm H_2O). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined in equation 4

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$ ………………………………..……………………………… Equation 4

Where CN is the curve number for the day. The initial I_a is commonly approximated as 0.2S.

3.7 Data Collection and Processing

The data utilised in this study was compiled from several sources. These included:

Digital elevation model (DEM): The 90m DEM was downloaded from the CGIAR -Consortium for spatial information, SRTM http://srtm.csi.cgiar.org/

Digital stream network (DSN): DSN-HYDRO1k: The USGS' HYDRO1k stream network database is derived from the flow accumulation layer for areas with an upstream drainage area greater than 1000 km2.

Soil map: FAO: Food and Agriculture Organization of the United Nations (FAO, 1995) provides almost 5000 soil types at a spatial resolution of 10 kilometres with soil properties for two layers (0-30 cm and 30-100 cm depth). Further soil properties (e.g. particle-size distribution, bulk density, organic carbon content, available water capacity, and saturated hydraulic conductivity) were obtained from Reynolds et al. (1999) or by using pedotransfer functions implemented in the model Rosetta

(http://www.ars.usda.gov/Services/docs.htm?docid=8953).

Landuse map: LANDUSE-GLCC: the USGS Global Land Cover Characterization (GLCC) database (http://edcsns17.cr.usgs.gov/glcc/glcc.html) has a spatial resolution of 1 kilometre and 24 classes of landuse representation. The parameterization of the landuse classes (e.g. leaf area index, maximum stomatal conductance, maximum root depth, optimal and minimum temperature for plant growth) is based on the available SWAT landuse classes and literature research.

Hydrometeorological data: precipitation, temperature, and flows. Most of the data were available for the study period 1960 to 1990. The available daily rainfall data varies in time and space and is not evenly distributed. For Kagera, 126 precipitation stations and 4 temperature stations were used. The daily discharge was available at the Rusumo station for the period 1971-1976. For Mara, data was available for 40 precipitation stations and 1 temperature station. The daily discharge was available at Mara mines station for the period 1971-1991. Most of the data was obtained from the riparian country databases. The rainfall and maximum and minimum temperature statistics are shown in the **Table 3-3** and **Table 3-2**.

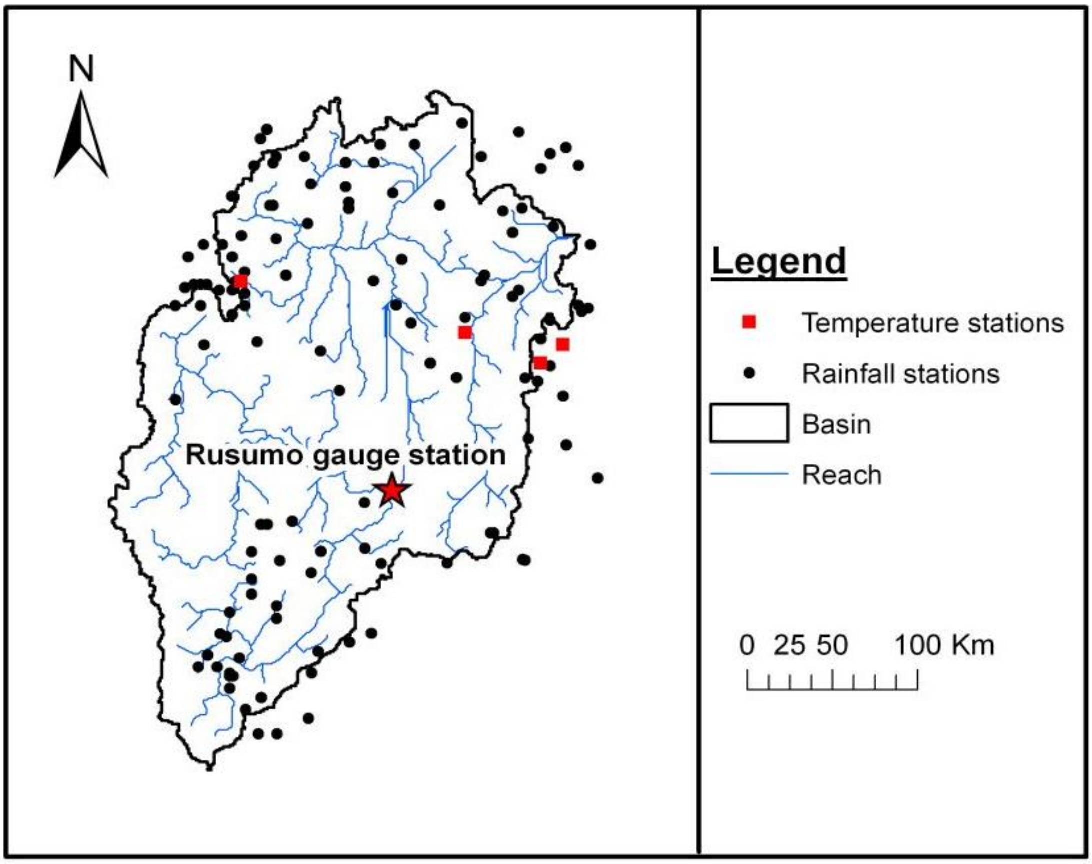


Figure 3.10: Data Availability for Kagera Case study

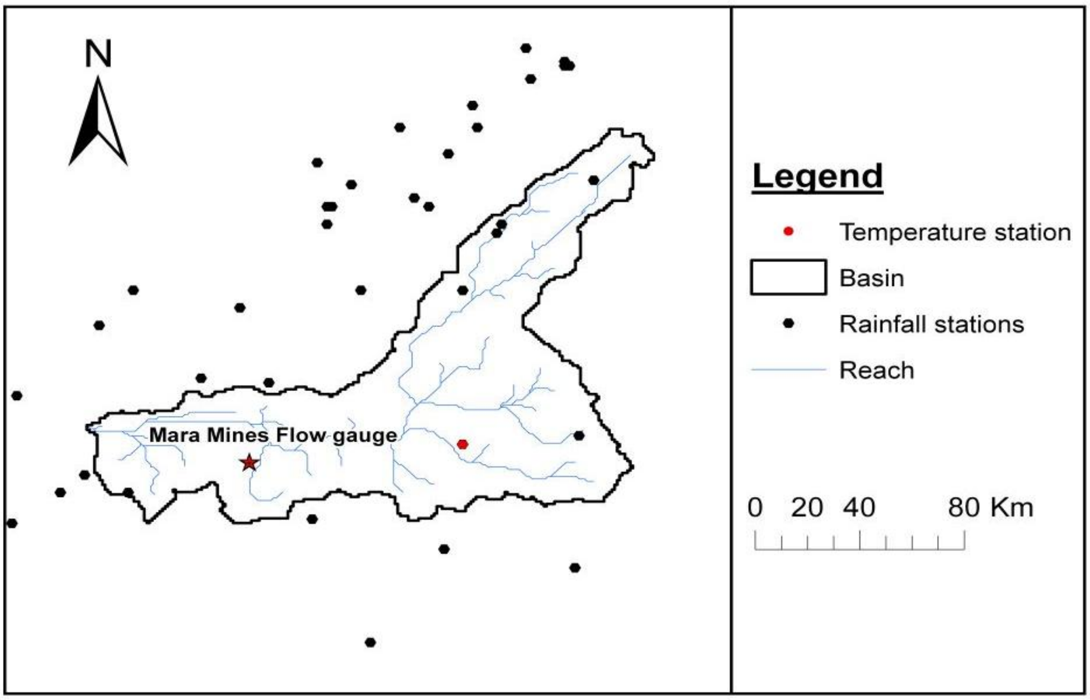


Figure 3.11: Data availability for Mara case study

Table 3-2: Temperature Statistics

	MARA		KAGERA	
	Min (°C)	Max (°C)	Min (°C)	Max (°C)
std dev	1.8	2.1	1.5	1.9
mean	13.9	27.6	13.8	24.8
skewness	-0.1	-0.1	-0.1	-0.5
max	22.7	39.7	19.2	32.7
min	5.7	17.8	7.5	16.2

Table 3-3: Rainfall Statistics

	MARA	KAGERA
std dev (mm)	8.3	8.0
mean (mm)	3.7	3.2
skewness	4.2	4.2
max (mm)	117.2	104.9
min (mm)	0.0	0.0

Rainfall data series used are longer (1960-present) for both catchments but Mara clearly has a poor distribution of rain gauges around the basin (5 gauges inside the basin). For this reason the raingauges close to the basin (8 additional gauges) where included in the study. This way, the raingauge distribution improved from 2,750 km^2/gauge to 1,058 km^2/gauge. SWAT simulations focused on the 1970s period because this represents the period covered by the hydromet survey which was an extensive data collection exercise within the LVB. Data (especially flow data) outside this period has been shown in many studies to have serious quality issues. In addition data outside the 1970s has lots of gaps which would require modelling to infill. Of course there has been many changes in the catchments since then (land use changes-especially deforestation, etc) which are bound to affect the flow characteristics. These changes are bound to affect the timing of the flow hydrograph but may not significantly affect the volumes received at a given cross section of the river, especially for longer time scales for example annual time scale. Depending on the type of hydropower plant, these fluctuations may not significantly affect the power production potential.

3.8 Data Quality Control

Rainfall stations were selected depending on data quality and length of available records. Only stations with over 80% available data were selected. For the missing climate data, synthetic daily data was computed using long-term mean monthly statistics. For all datasets available for modelling, simple data quality control tests were carried out. First, simple visual inspection of temporal rainfall variation was done followed by double mass plot curves to ascertain and verify non-homogeneity of the data. For stations with non-homogenous data two course of action were taken: (i) attempts were made to correct the data especially for regions were stations are sparsely distributed (ii) where there are nearby stations with good data to replace the station with non-homogenous data the entire station data was discarded.

3.9 SWAT Model Setup

Setting up a SWAT model involves different steps and processes described below.

3.9.1 Watershed Delineation

Using the automatic delineator, topographic maps were imported and hydrologically connected sub-basins delineated based on the Digital Elevation Model (DEM). Topographical reports were generated to provide sub basin/reach elevation/topography parameters.

3.9.2 HRU Analysis

Spatial parameterisation of the SWAT model is performed by dividing the watershed into sub-basins based on topography. These are further subdivided into a series of hydrologic response units (HRU) based on unique soil and land use characteristics. The definition of Hydrological Response Units (HRUs) is dependent on the land use, soil type and slope.

3.9.3 Definition of Weather data

For the defined watershed, weather data was added to the project using the defined projection of the project. This data included: rainfall, temperature, solar radiation, relative humidity data, and wind speed. A weather generator file had to be defined to stochastically infill the missing climate data for all climate stations in the SWAT project.

3.9.4 SWAT simulation (Model runs)

After the above three steps are accomplished, the SWAT model was run on a daily time step. Given a successful run the mode is ready for calibration and validation as explained in the following sections.

3.9.5 Model Sensitivity Analysis and Calibration

Using the inbuilt sensitivity analysis tool in SWAT (*Van Grienven, 2006*), the sensitivity analysis of the SWAT model parameters was carried out to identify the most influential parameters for flow simulation. Given the many parameters required by the SWAT model, an efficient calibration tool SWAT Calibration and Uncertainty Programs (SWATCUP, *Abbaspour et al., 2007*).

SWATCUP also allows for sensitivity analysis, in addition to calibration and validation. SWATCUP is a system analysis program with has several calibration/validation modules including: Generalized Likelihood

Uncertainty Estimation (GLUE) (*Beven and Binley, 1992*), Parameter Solution (ParaSol) (*Van Griensven and Meixner, 2006*), and a Monte Carlo Markov Chain (MCMC) (*Vrugt et al., 2003*).

In this study, the Sequential Uncertainty Fitting program, SUFI-2 (*Abbaspour et al., 2007*) was used for parameter optimization. SUFI-2 is a tool for sensitivity analysis, multi-site calibration and uncertainty analysis. It is capable of analyzing a large number of parameter sets, in addition to using multiple observation datasets. According to Yang et al. 2008, SUFI-2 needs the smallest number of model runs to achieve a similarly good calibration and prediction uncertainty results in comparison with the other four techniques.

A measure of model performance is given by 95% prediction uncertainty (95PPU) based on the 2.5% and 97.5% levels of the cumulative distribution. Model performance is also quantified by the P-factor and R-factor. The P-factor is the percentage of the data bracketed by the 95 PPU band whose maximum value is 100%. The R-factor is the average width of the band divided by the standard deviation of the corresponding measured variable. (*Abbaspour et al., 2007*). The selected sensitivity and calibration models used in the study are given in the appendices.

3.10 Results

3.10.1 Parameter Sensitivity

Given that the SWAT model has a number of parameters required for flow estimation, sensitivity analysis is normally required to establish the more sensitive parameters in simulating flows and other hydrological variables. The results of parameter sensitivity analysis using the SWAT inbuilt tool and the SWATCUP tools are summarised in the following tables. For calibration, the basin was distributed more depending on the dominant landuse types which are specific to Rusumo 1 and Rusumo 2.

Table 3-4: Results of sensitivity analysis for SWAT parameters.

Parameter Name	t-stat	P-Value
r__SOL_BD().sol (Rusumo 1)	-0.07	0.95
v__RCHRG_DP.gw (Rusumo 1)	0.07	0.95
v__GWQMN.gw (Rusumo 1)	-0.10	0.92
r__CN2.mgt (Rusumo 1)	0.35	0.72
v__SOL_AWC(1).sol (Rusumo 1)	-0.38	0.71
v__GW_REVAP.gw (Rusumo 1)	0.66	0.51
v__ESCO.hru (Rusumo 1)	0.95	0.34
v__EPCO.hru (Rusumo 1)	1.17	0.24
v__ALPHA_BF.gw (Rusumo 1)	1.44	0.15
v__GW_DELAY.gw (Rusumo 1)	-2.72	0.01
r__SOL_BD().sol (Rusumo 2)	-0.11	0.91
v__GWQMN.gw (Rusumo 2)	0.13	0.90
v__EPCO.hru (Rusumo 2)	-0.37	0.71
r__CN2.mgt (Rusumo 2)	3.68	0.00
v__SOL_AWC(1).sol (Rusumo 2)	0.53	0.60
v__ALPHA_BF.gw (Rusumo 2)	0.63	0.53
v__GW_REVAP.gw (Rusumo 2)	0.79	0.43
v__ESCO.hru (Rusumo 2)	1.32	0.19
v__RCHRG_DP.gw (Rusumo 2)	-2.18	0.03
v__GW_DELAY.gw (Rusumo 2)	-6.93	0.00

The lowest rank represents the most sensitive parameters, r –relative change used to calculate the parameter value and v – values used to calculate the parameter value.

3.10.2 Calibration

For an effective calibration exercise, observations (flows for this study) are required for a relatively long observation period. In this study, relatively short length observation data was available for calibration. For both case studies, the calibration period was 1972 -1973, using 1970-1971 as a warm-up period. For Mara, the Mara mines flow observations were used while for Kagera at Rusumo were used. Shorter periods were used for calibration (2 years for Mara and 5 years for Kagera). This was because SWAT simulations require a lot of time.

The calibration mainly focused on 10 most sensitive parameters (**Table 3-4**). Dotty plots were also analysed to explore the relative importance of parameter range estimation during the calibration exercise. This is helpful in determining the final calibrated parameter ranges for the model simulation.

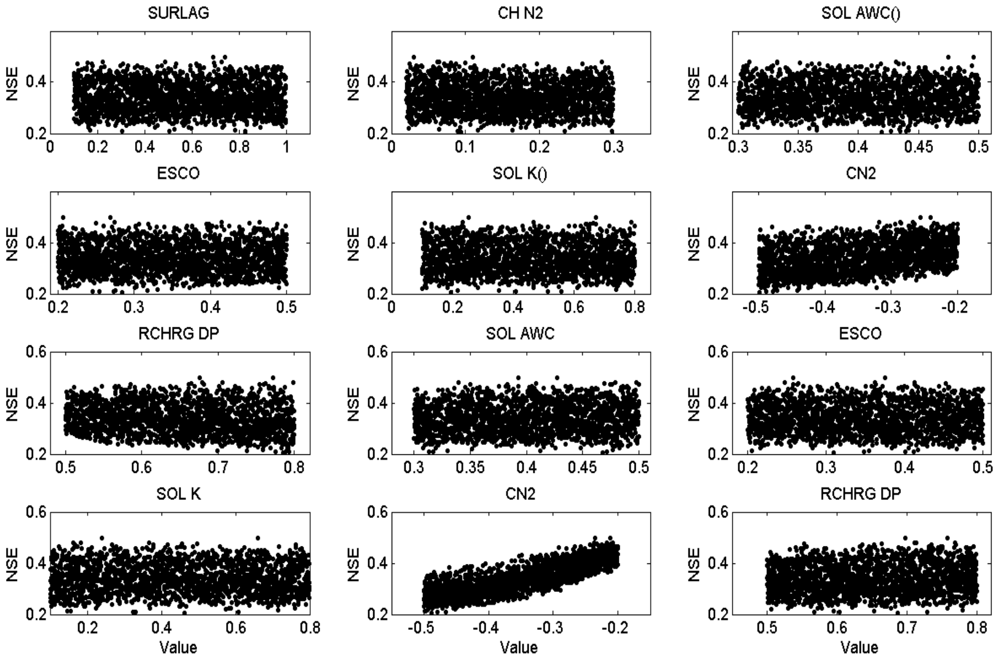


Figure 3.12: Dotty plots

The prediction uncertainty is estimated using the 95PPU plots. This is the 95% confidence interval of the simulated ensembles for a given number of model runs. For the different basins considered in this study, the simulation results are shown in **Figure 3.13** and **Figure 3.14**.

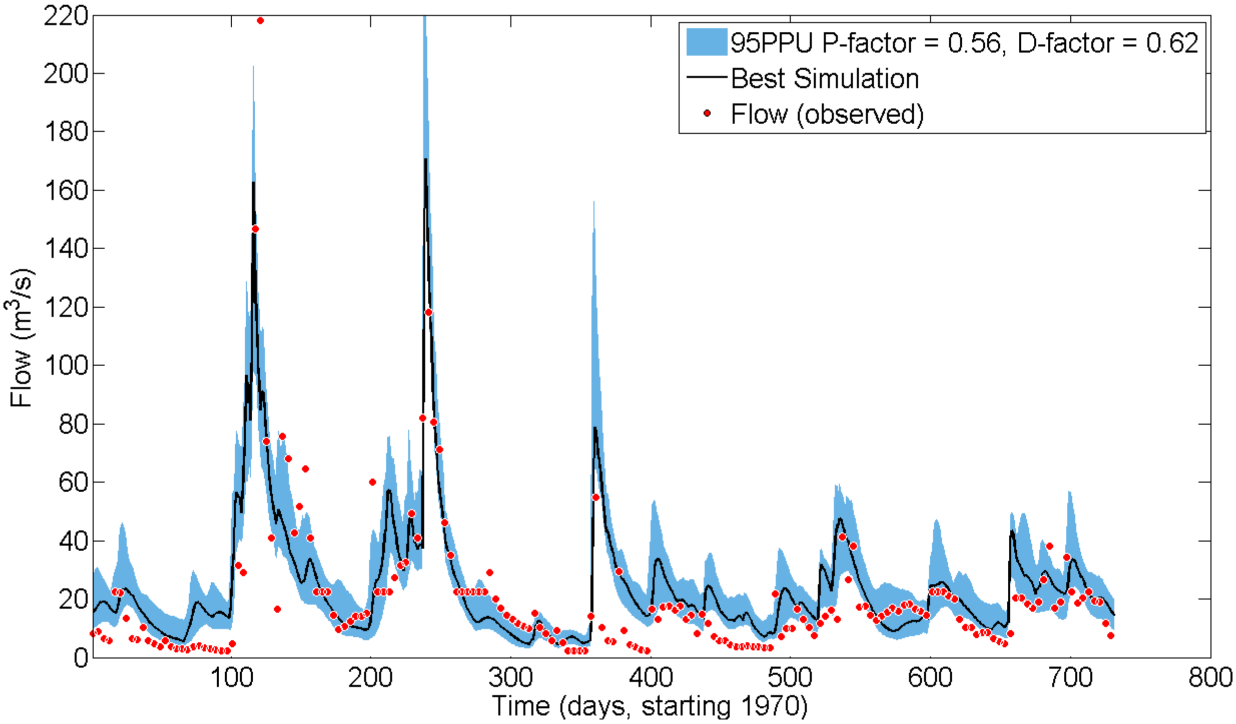


Figure 3.13: Calibration results for Mara mines station in Mara catchment

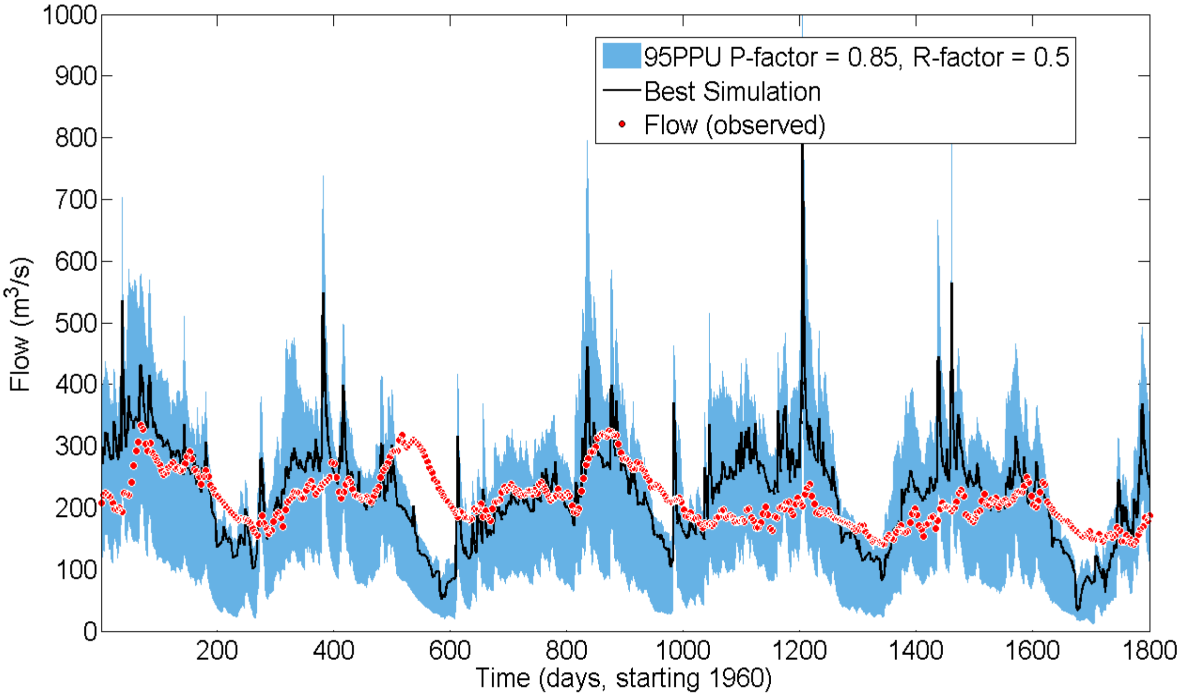


Figure 3.14: Calibration results for Rusumo station in Kagera catchment

3.10.3 Comments on the Calibration Performance

Model performance varies greatly for the two case studies. The Mara calibration results are seemingly better than the Kagera results. The Mara basin is a relatively flat and dry with low rainfall as compared to the undulating/mountainous Kagera basin. The use of global datasets, which were mainly available at a resolution greater than 90m presents obvious challenges in estimating basin topographical properties. The Kagera basin has numerous swamps and lakes which are not monitored. Therefore the water balance of these lakes and swamps cannot be well modelled in SWAT. For this reason, the Kagera results are relatively poor. Similar performance results for Kagera basin have been reported by Didier (2007). Additionally, the precipitation in Kagera is mainly orographic and Didier 2007 has shown that this is cannot be well presented using the available data sets.

The simulated trends for the two case studies are well represented by the models developed in this study. This gives confidence in the use of the models for studying the impact of climate change on hydropower in the two basins. The base flow sessions of the hydrographs are relatively well simulated in both case studies, while the peaks for Kagera are underestimulated. For both basins, the timing of the calibration hydrographs is consistent with the observations.

Table 3-5: Observed and Simulated flow Statistics

KAGERA		
	Observed flow (m^3/s)	Simulated flow (m^3/s)
std dev	42.8	76.1
mean	212.6	220.0
skewness	0.7	0.5
max	337.7	829.3
min	139.6	33.3

MARA		
	Observed flow (m^3/s)	Simulated flow (m^3/s)
std dev	30.1	20.5
mean	21.3	23.8
skewness	5.1	3.1
max	303.1	170.8
min	2.1	4.5

For Kagera basin, the observed flow data available at Rusumo is influenced by the proximity to the Falls and Rapids. This presents obvious challenges of the rating curve at this location, which may explain the less than satisfactory results during calibration.

4 SELECTION OF POTENTIAL SITES

4.1 Introduction

This chapter shows the criteria used to select the potential sites. In relation to the selected site, the physiology of the selected dams and their vicinity is given including the location on the river reach, and the reservoir extent and reach.

4.2 Selection of potential hydropower sites

Potential Hydropower sites were selected on the two rivers using a 30m DEM resampled to 10m. The criteria used to select the potential hydropower site in the two catchments included:

a) Existence of a steep river slope.

b) Presence of narrow valleys (Ridges)

c) A funnel shaped configuration upstream for the reservoir

The selected sites for both catchments are shown in the tables below and the details are further described in the subsequent chapters.

Table 4-1: Details for the selected hydropower sites in Kagera catchment

Site	Co-ordinates		Elevation (m asl)	Description
	x	y		
Giteranyi	249285	9889514	1222	Relatively steep and relatively wide
Rusumo	253988	9736974	1290	Steep and narrow
Kikagate	226110	9733466	1314	Steep and narrow

Table 4-2: Details for the selected hydropower sites in Mara catchment

Dam	Co-ordinates		Elevation (m asl)	Description
	x	y		
Kilgoris	740277	9876732	1654	Relatively steep and narrow
Machove	715338	9825120	1424	Gentle slope and wide width
Goronga	684410	9827016	1296	Realtively steep and narrow

4.3 Kagera

4.3.1 Location of selected sites

The map below shows the location of the selected hydropower potential sites in Kagera. The several reaches were considered along the main stream of the river.

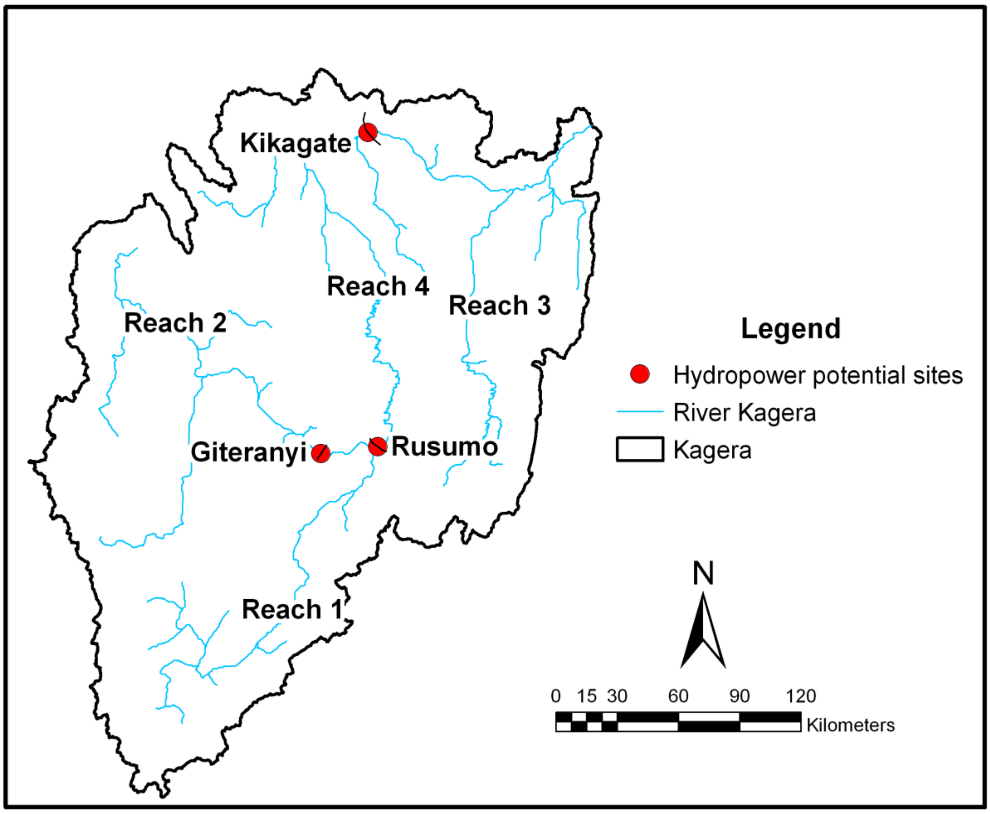
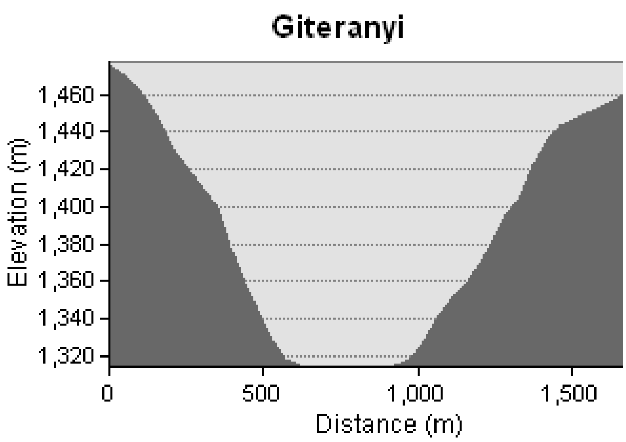


Figure 4.1: Location of hydropower potential sites in Kagera

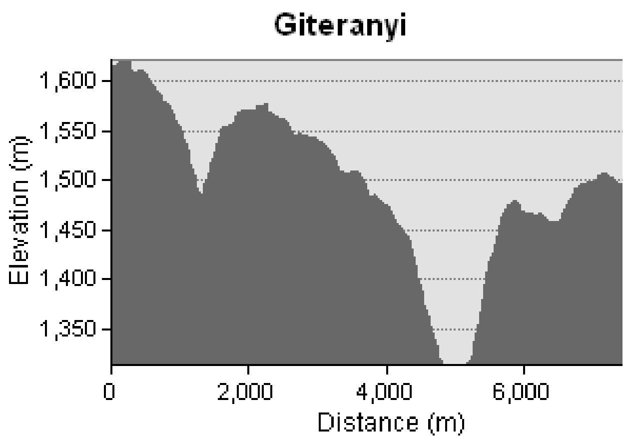
4.3.2 Giteranyi

The dam has a reservoir reach of 11.9Km and an extent of 25Km. The physiology of the selected dam is show in the figures below.

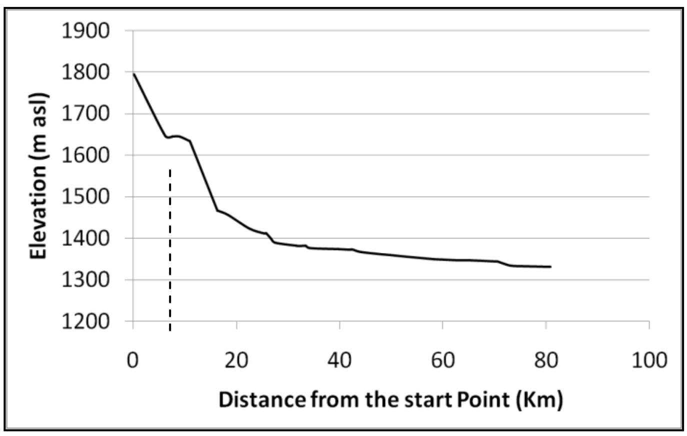
(a)



(b)



(c)



(d)

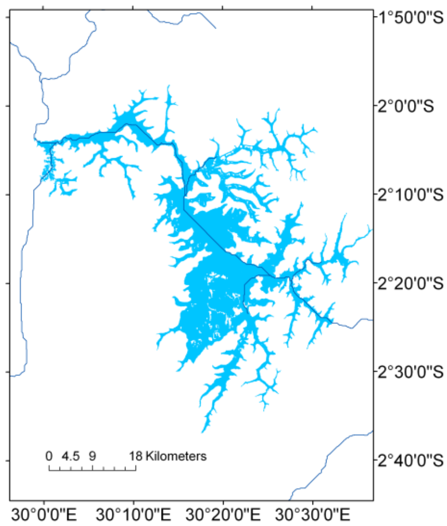
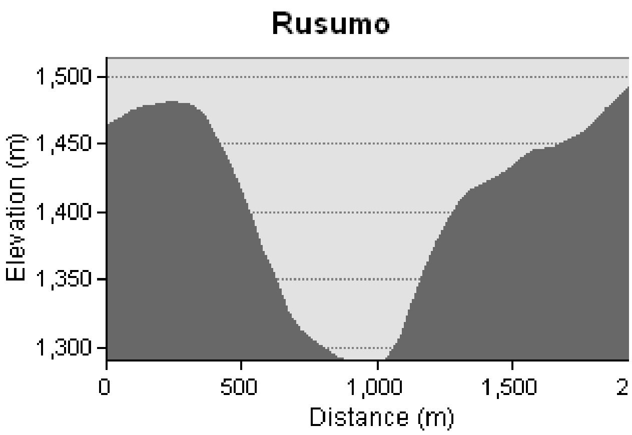


Figure 4.2: Details for the selected hydropower site at Giteranyi including (a) Dam physiology, (b) Dam Vicinity (c) Location at Reach 2 and (d) the reservoir extent.

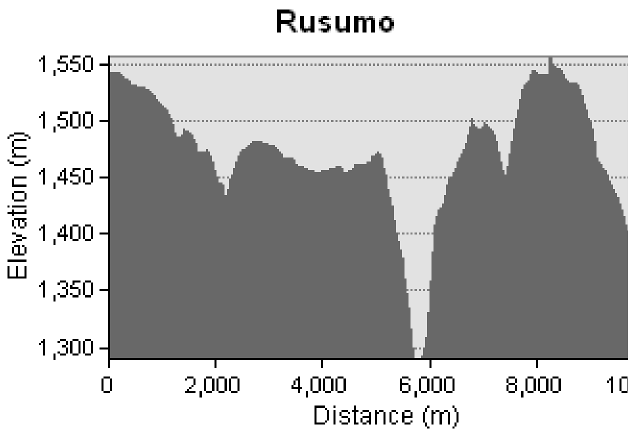
4.3.3 Rusumo

The reservoir reach is 5Km and the extent is 7 Km. The physiology of the selected dam is show in the figures below.

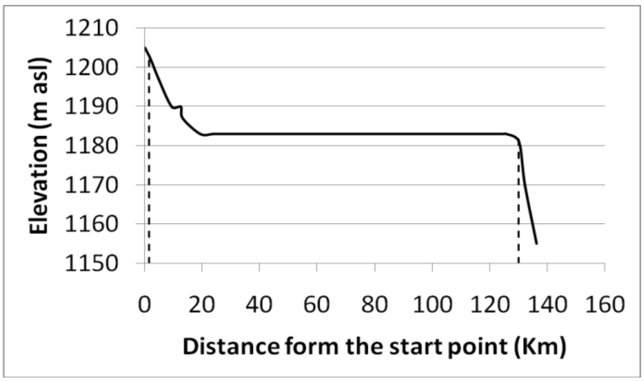
(a)



(b)



(c)



(d)

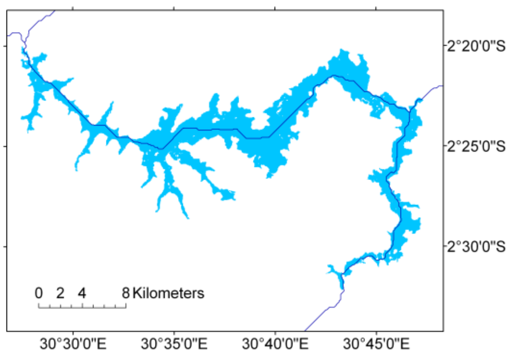


Figure 4.3: Details for the selected hydropower site at Rusumo including (a) Dam physiology, (b) Dam Vicinity(c) Location at reach 4 and (d) the reservoir extent.

4.3.4 Kikagate

The reservoir reach is 3.6 Km and the extent is 3.3 Km. The physiology of the selected dam is show in the figures below.

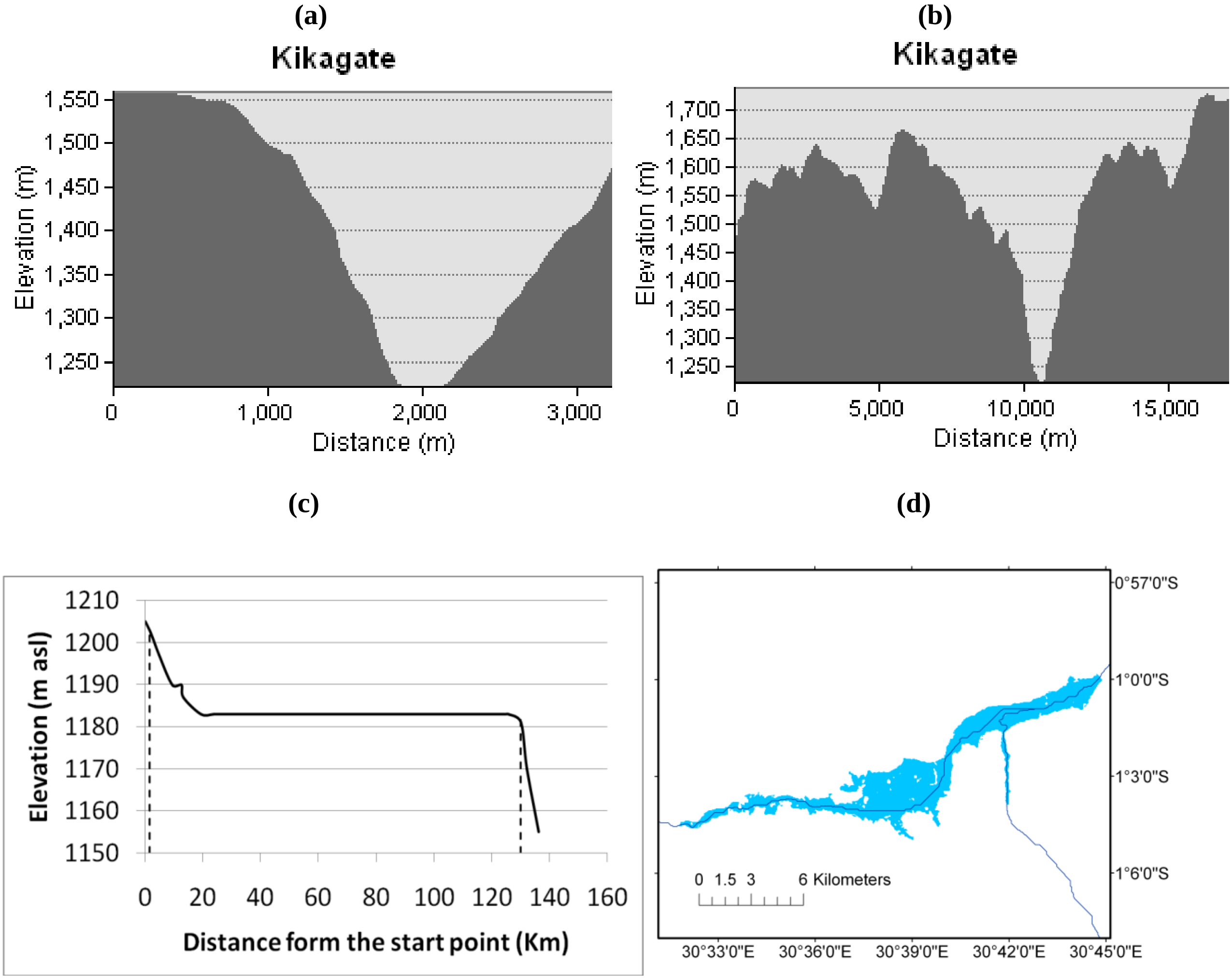


Figure 4.4: Details for the selected hydropower site at Kikagate including (a) Dam physiology, (b) Dam Vicinity (c) location at Reach 4 and (d) the reservoir extent.

4.3.5 Mara

4.3.5.1 Location of selected potential sites

Using the criteria, three potential hydropower sites were selected; locations are shown in **Figure 4.5** and the details are shown in subsequent sections.

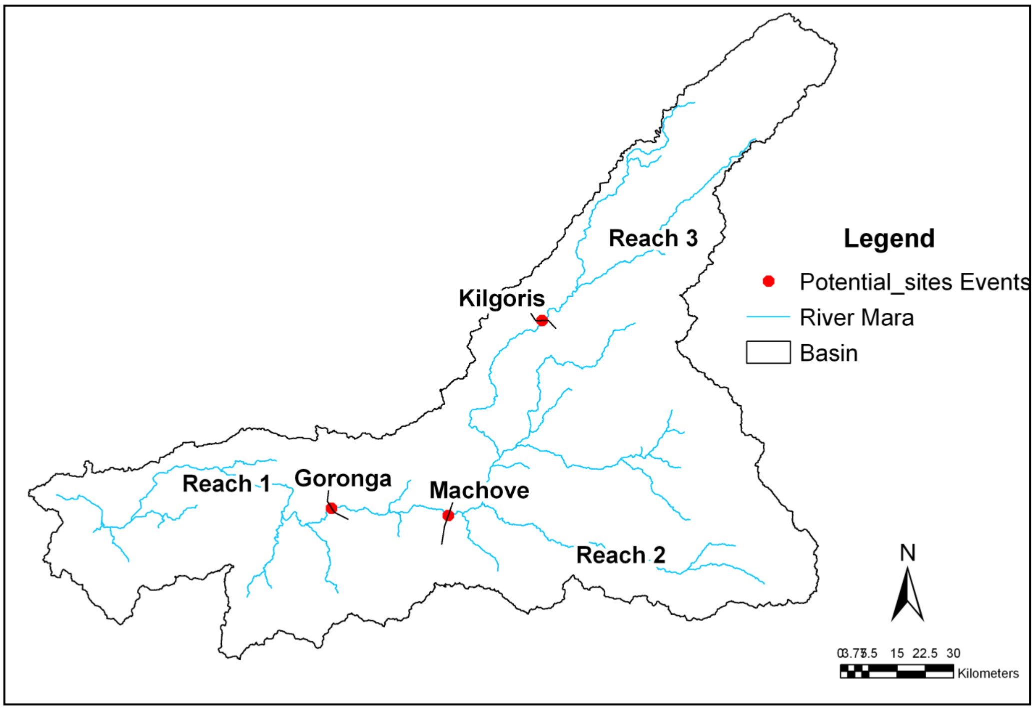


Figure 4.5 : Location of hydropower Potential sites in Mara Catchment

4.3.5.2 Kilgoris

The reservoir reach is 818 m and the extent is 7 Km. The physiology of the selected dam is show in the figures below.

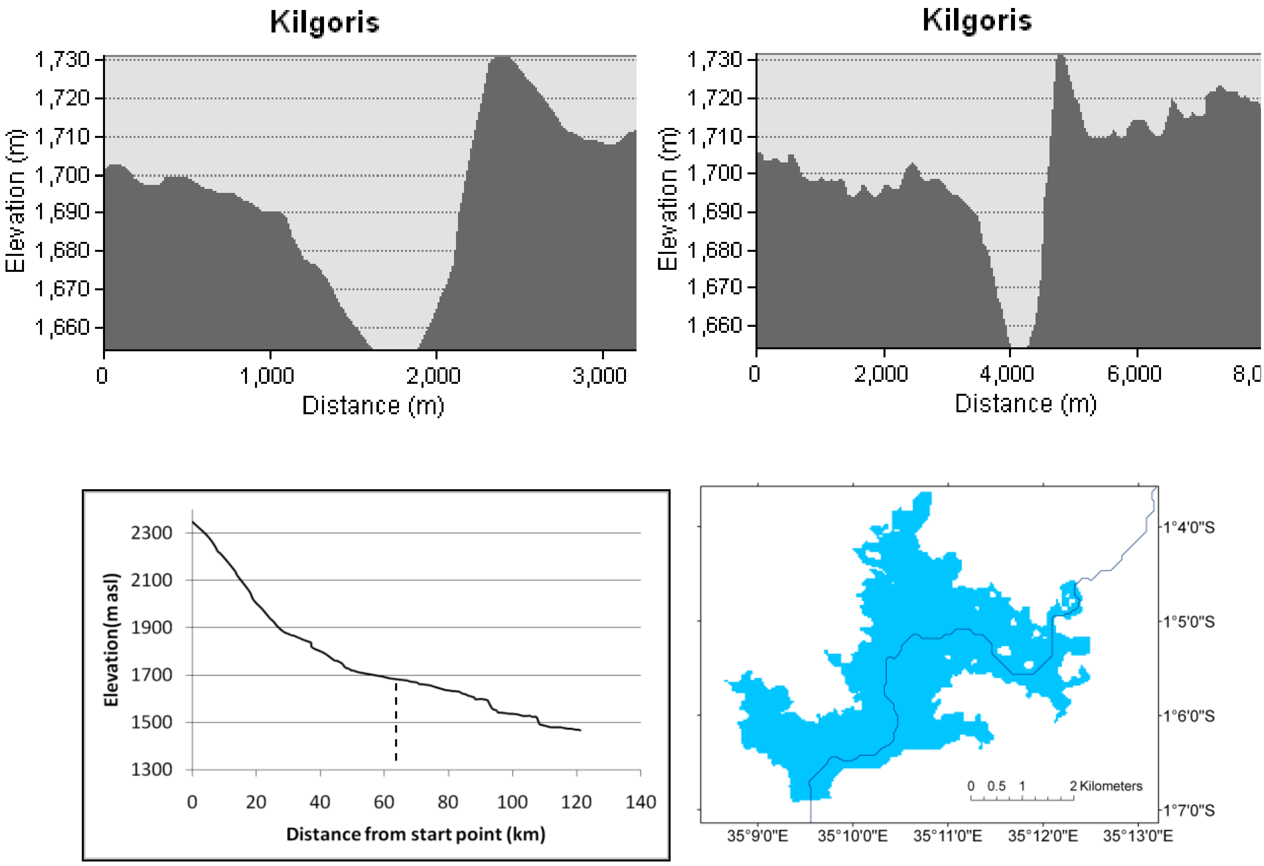


Figure 4.6: Details for the selected hydropower site at Kilgoris including (a) Dam physiology, (b) Dam Vicinity (c) location at Reach 3 and (d) the reservoir extent.

4.3.5.3 Machove

The reservoir reach is 261 m and the extent is 1.5 Km. The physiology of the selected dam is show in the figures below.

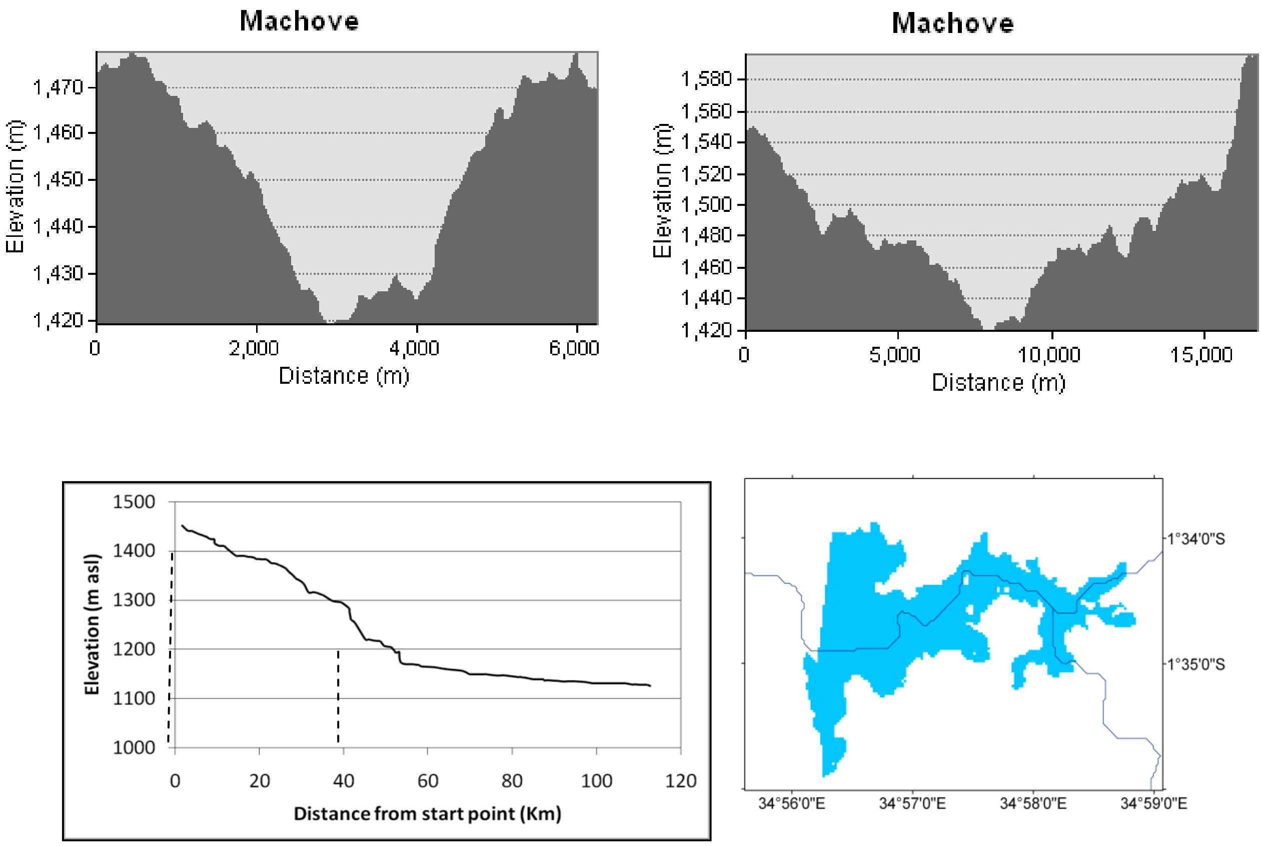


Figure 4.7: Details for the selected hydropower site at Kilgoris including (a) Dam physiology, (b) Dam Vicinity (c) location at Reach 1 and (d) the reservoir extent.

4.3.5.4 Goronga

The physiology of the selected dam is show in the figures below. The reservoir Reach is 9Km and the reservoir extent is 1.5 Km.

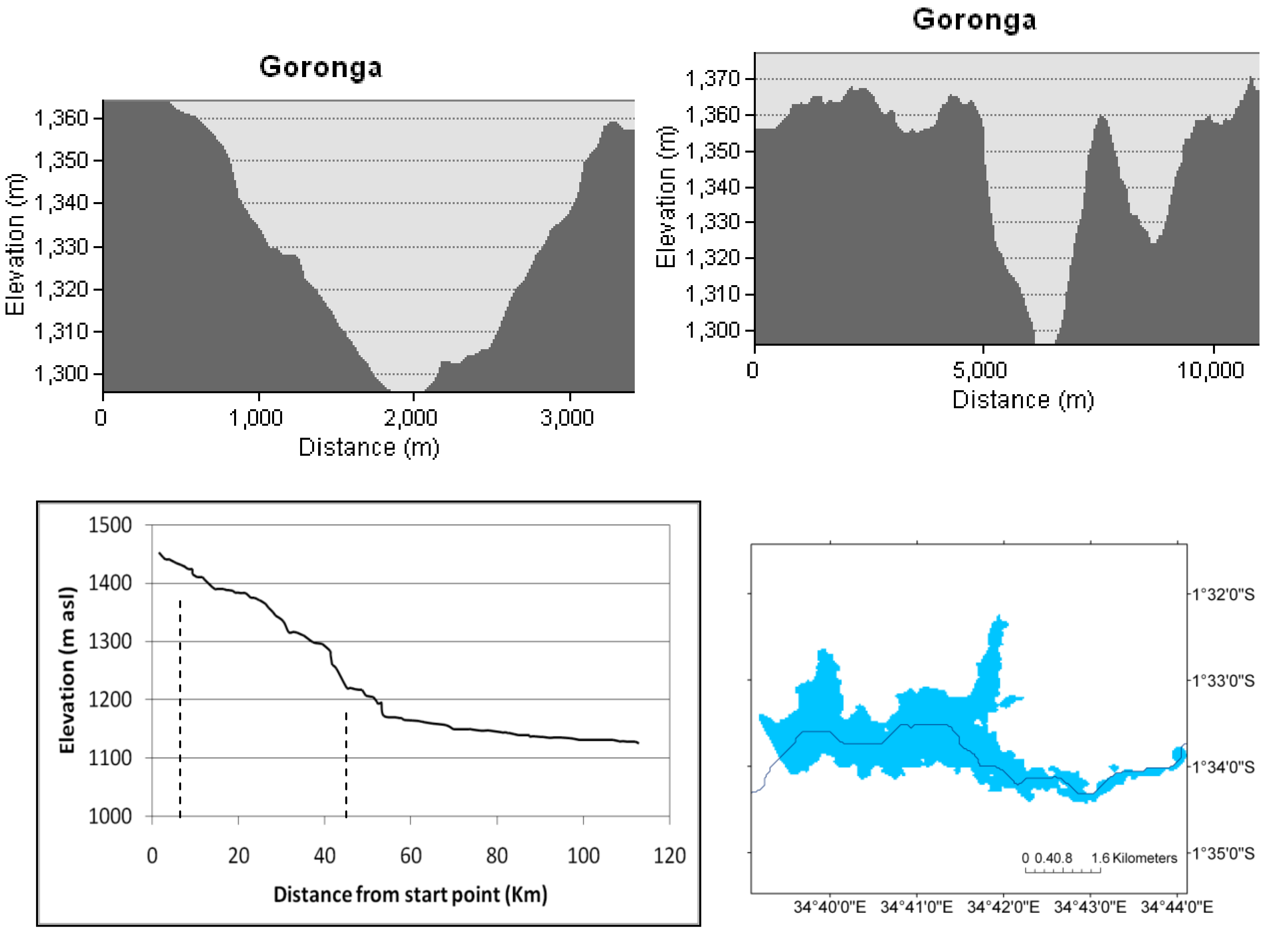


Figure 4.8: Details for the selected hydropower site at Goronga including (a) Dam physiology, (b) Dam Vicinity (c) location at Reach 1 and (d) the reservoir extent.

5 CLIMATE CHANGE MODELING FOR SELECTED HYDROPOWER SITES

5.1 Introduction

This chapter explains the selection of the "what-if" scenarios for analysis, the results from analysis of the flow variation in accordance to the what-if scenarios. The results anysis includes, the annual average statistics, total monthly flow volumes, resultant flow duration curves, and temporal monthly flow volume variations.

5.2 Preamble

The world is currently undergoing a major climate change, a fact attributed to the significantly growing levels of carbondioxide in the atmosphere (Mitchel 1961),….ref…IPCC). In turn renewable energy resources have been resorted to in order to minimize the production of carbondioxide. Particular emphasis has been put on hydropower because compared to other energy sources; hydropower is a cleaner option for energy generation in terms of carbondioxide release levels.

Hydropower is a source of electrical energy that is continually renewed and available in the runoff segment of the hydrological. It has been referred to by the Brundtland Commission as an economic activity that meets the needs of the present generation without jeopardizing the ability of the future generations to meet their needs. (World Commission on Environment and Development Report, 1987). It is essentially a non consumptive use as well as a non polluting one. The increased use of hydropower is therefore the key strategy for reducing the extent of climate change due to Green House Gas (GHG) emissions. However, hydropower is among the most vulnerable industries to changes in global and regional climate.

Additionally, there are several potential climate change adaptation and human well-being benefits from small or medium scale hydropower plants, since they can: serve as reservoirs for storing floodwater, provide electricity for irrigation in agriculture and local businesses, regulate low-flow season capacity, and thereby also prevent downstream salinity intrusion and enhance rural water access and availability.

The impact of climate change includes: change in timing of seasons, variation of length or magnitude and frequency of more extremes for floods and droughts, and return periods for a given event have become shorter. Traditionally, the principle that the hydrology will remain stationary and past conditions will remain the same for the future has been assumed in hydropower design and policies. With the knowledge of climate change scenarios, climate change should be accounted for, in order to avoid excessive costs or poor performance (Kundzewicz, 2007).

Studies have shown that over the 20th century, the rainfall in the Lake Victoria basin had a variation of upto 25% in rainfall (Kizza et al., 2009). During the El Niño years, Lake Victoria rainfall is expected on average to increase 15 - 25% (Janowiak 1988).

Previous studies have determined an increasing trend in minimum and maximum temperature over the majority of East Africa, with a few stations along Lake Victoria shoreline showing a decrease in minimum temperature. One possible consequence of changes in temperature would be an overall reduction in the availability of water resources for hydroelectric power.

5.3 Climate Change Scenarios

For different climate change studies, several scenario classifications are used. For example SRES classified the scenarios as:

- A1: globalization, emphasis on human wealth, globalised, intensive (market forces).
- A2: regionalization, emphasis on human wealth Regional, intensive (clash of civilizations).
- B1: globalization, emphasis on sustainability and equity globalised, extensive (sustainable development).
- B2: regionalization, emphasis on sustainability and equity
  Regional, extensive (mixed green bag).

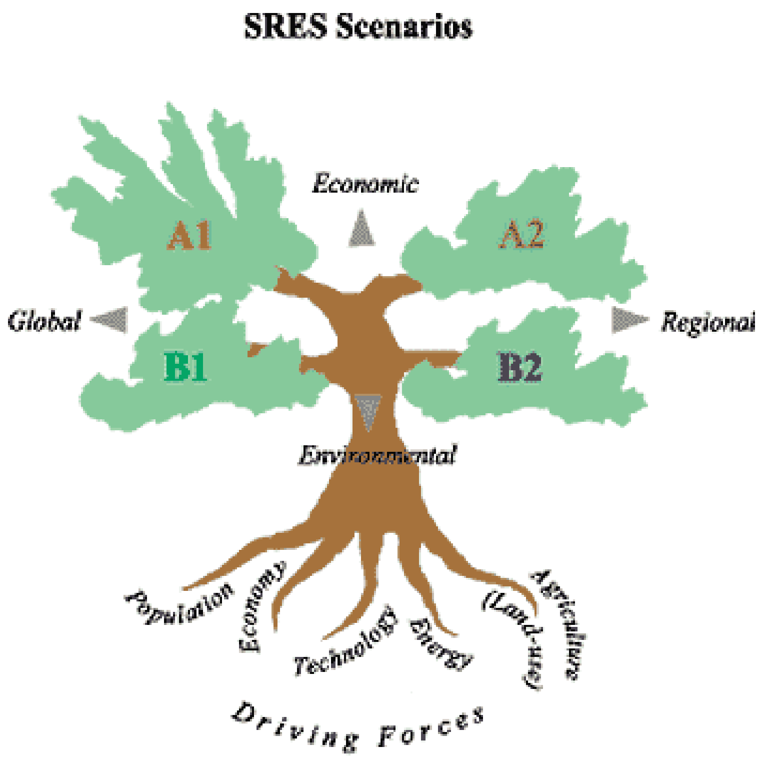


Figure 5.1 : Schematic Representation of the SRES scenarios

For this study, however, simple what-if scenarios were selected. These were selected on the basis that several trend studies have shown that as a region, the Lake Victoria basin has experienced 10 to 30% increase in rainfall over the past century (Kizza et al., 2009). Notwithstanding, results of assessments of trend for individual gauging stations vary considerably with some showing a positive trend while others show a negative trend. In accordance to the expected regional changes, as predicted by the IPCC and other previous studies, the "what if" scenarios were created to include both the increase and decrease rainfall variations as shown in **Table 5-1**. For temperature, only the temperature increase of 3^0C was considered in accordance to global warming. The 30 year (1961 - 1990) period was used as the baseline for this study.

Table 5-1 : Classification of climate change Scenarios

Rainfall / **Temperature**	-30%	-20%	-10%	Baseline	+10%	+20%	+30%
+3	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A

5.4 Results

5.4.1 Kagera (Temperature Increase = 3°C)

5.4.1.1 Annual Average Statistics

Table 5-2 : Annual Average values for potential sites in Kagera (Temperature increase of 3°C)

Scernario	Giteranyi (m^3) x 10^7	Rusumo (m^3) x 10^7	Kikagate (m^3) x 10^7
3A30B	615	1032	2306
3A20B	664	1133	2520
3A10B	715	1237	2724
Baseline	770	1341	2943
3A30A	820	1442	3155
3A20A	868	1556	3377
3A10A	907	1653	3598

5.4.1.2 Giteranyi

Table 5-3 : Total monthly flow volumes for Giteranyi (Temperature increase of 3°C)

Month	3A30B (m^3) x10^7	3A20B (m^3) x10^7	3A10B (m^3) x10^7	Baseline (m^3) x10^7	3A30A (m^3) x10^7	3A20A (m^3) x10^7	3A10A (m^3) x10^7
Jan	114.72	124.82	135.62	146.27	156.05	167.75	177.29
Feb	107.29	117.06	127.16	137.15	146.93	158.33	166.92
Mar	113.77	123.90	134.83	145.54	155.36	167.18	176.97
Apr	111.30	122.73	134.87	146.32	155.82	170.03	178.97
May	106.55	116.87	127.42	138.45	148.53	160.76	169.94
Jun	77.88	84.53	92.24	99.90	107.73	115.28	122.63
Jul	57.13	62.18	67.73	73.39	79.25	84.76	90.32
Aug	49.56	54.48	59.38	64.55	70.06	75.39	80.82
Sep	49.66	55.12	60.42	66.06	72.12	78.02	84.15
Oct	59.68	66.95	73.72	80.84	88.41	95.92	103.65
Nov	80.25	90.26	99.04	108.05	117.43	127.64	136.76
Dec	104.10	114.27	124.33	134.29	144.05	154.76	164.84

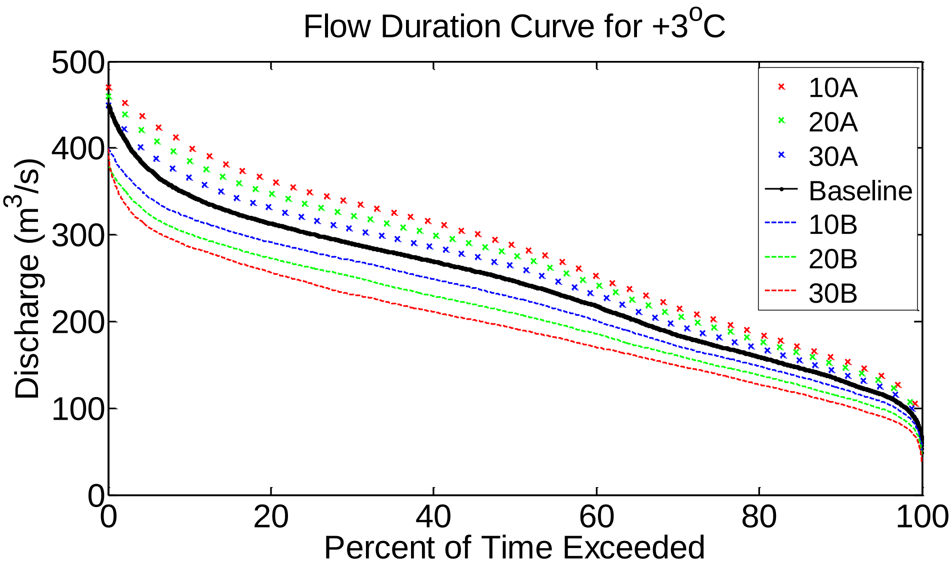


Figure 5.2 : Flow Duration Curve for Giteranyi

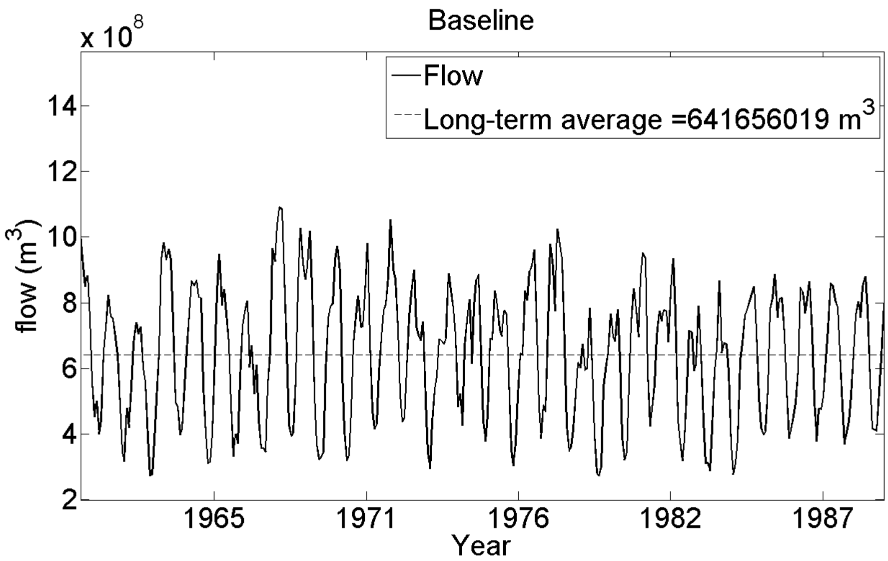


Figure 5.3 : Total flow volume variation for Giteranyi (Baseline)

5.4.1.3 Rusumo

Table 5-4 : Total monthly flow volumes for Rusumo (Temperature increase of 3°C)

Month	3A30B (m^3) x10^7	3A20B (m^3) x10^7	3A10B (m^3) x10^7	Baseline (m^3) x10^7	3A30A (m^3) x10^7	3A20A (m^3) x10^7	3A10A (m^3) x10^7
Jan	67.64	72.37	77.19	82.45	87.05	91.51	96.00
Feb	62.53	66.99	71.68	76.82	81.23	85.34	88.97
Mar	66.09	70.45	75.50	80.84	85.52	89.99	93.14
Apr	64.56	70.31	75.43	82.32	86.97	91.65	95.91
May	61.61	66.58	71.92	78.03	83.04	87.88	92.76
Jun	45.56	48.49	52.57	56.67	60.80	64.73	68.42
Jul	32.94	35.09	37.88	40.75	43.68	46.46	49.24
Aug	29.73	32.21	34.69	37.39	40.22	42.91	45.48
Sep	31.34	34.36	37.19	40.26	43.43	46.46	49.36
Oct	38.90	43.03	46.67	50.62	54.54	58.48	62.21
Nov	50.96	56.42	60.97	65.90	70.64	75.27	79.90
Dec	63.25	68.18	72.95	77.95	82.53	87.04	91.69

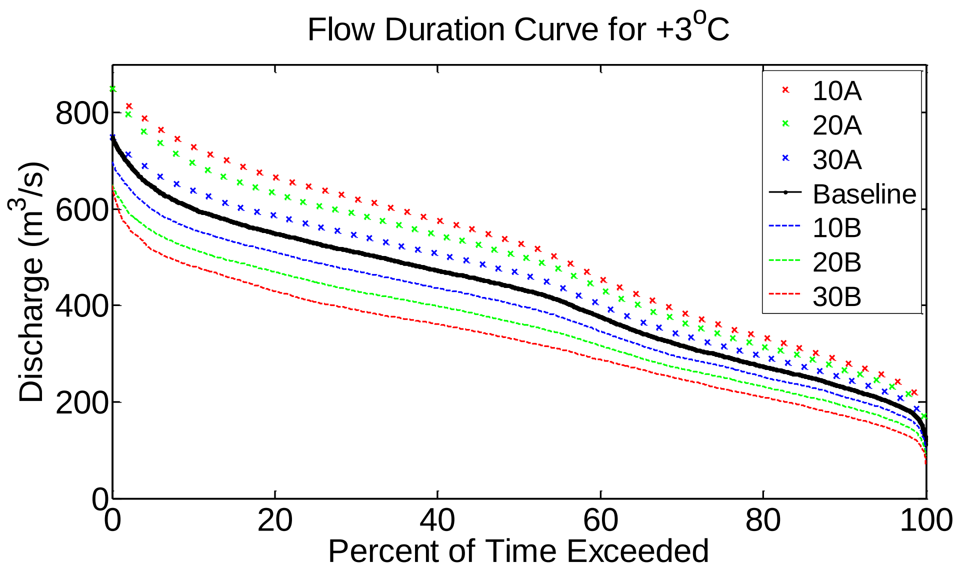


Figure 5.4 : Flow Duration Curve for Rusumo

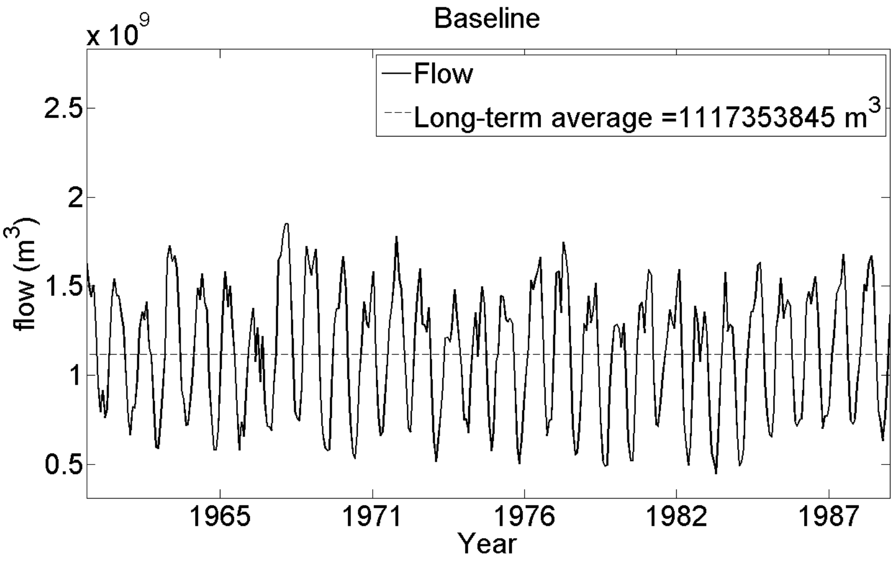


Figure 5.5: Total flow volume variation for Rusumo (Baseline)

5.4.1.4 Kikagate

Table 5-5: Total monthly flow volumes for Kikagate (Temperature increase of 3°C)

Month	3A30B (m^3) x10^7	3A20B (m^3) x10^7	3A10B (m^3) x10^7	Baseline (m^3) x10^7	3A30A (m^3) x10^7	3A20A (m^3) x10^7	3A10A (m^3) x10^7
Jan	247.92	268.16	288.51	309.25	329.89	351.10	372.19
Feb	218.92	237.35	255.69	274.20	292.85	312.01	331.55
Mar	237.39	258.15	278.71	299.77	320.68	342.19	364.16
Apr	255.62	282.70	303.00	331.04	352.51	380.60	405.64
May	230.29	253.41	275.27	298.85	321.28	344.96	368.45
Jun	162.64	177.12	192.03	207.48	223.23	238.24	252.99
Jul	110.63	120.72	131.10	141.86	153.05	163.46	173.99
Aug	98.06	107.16	116.04	125.69	136.07	146.04	156.19
Sep	120.04	132.14	144.03	156.70	170.20	183.32	196.85
Oct	159.33	175.53	191.19	207.33	224.17	240.77	257.85
Nov	211.37	232.73	252.69	273.34	293.96	315.33	337.07
Dec	253.35	275.20	295.58	317.08	337.53	359.18	380.93

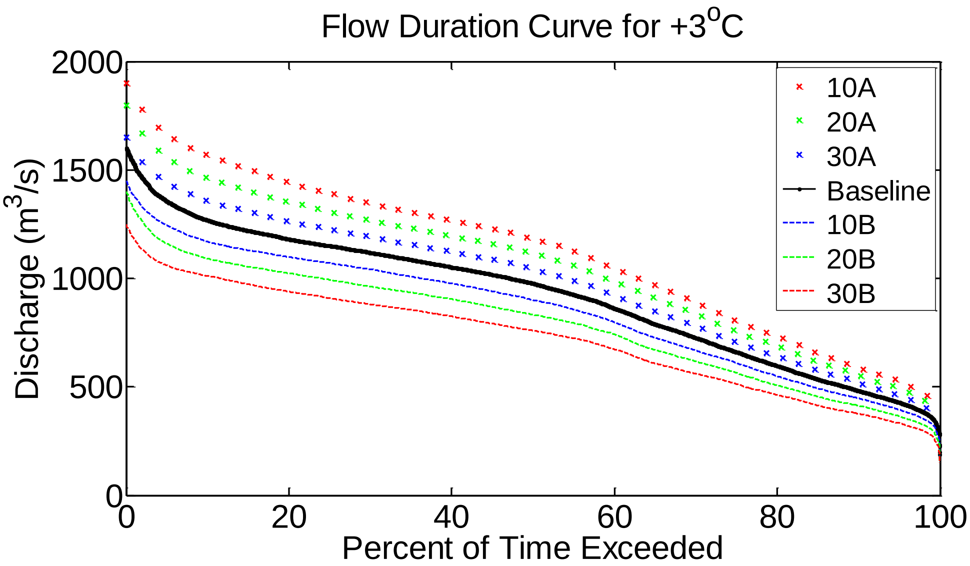


Figure 5.6: Flow Duration Curve for Kikagate

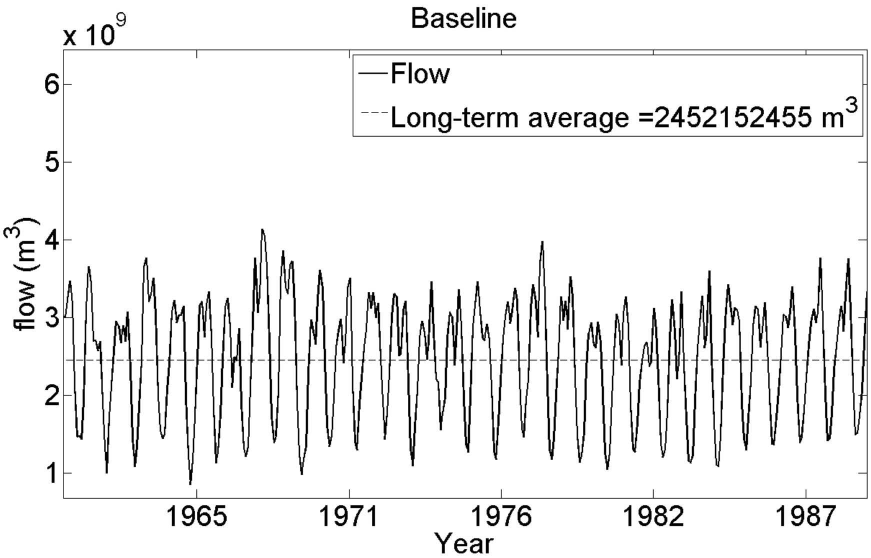


Figure 5.7: Total flow volume variation for Kikagate (Baseline)

5.4.2 Mara (Temperature Increase = 3°C)

5.4.2.1 Annual Average Statistics

Table 5-6: Annual Average values for temperature increase of 3°C for potential sites in Mara

Scernario	Goronga (m^3) x 10^7	Kilgoris (m^3) x 10^7	Machove (m^3) x 10^7
3A30B	62.49	15.31	15.31
3A20B	76.45	19.72	42.50
3A10B	92.89	25.17	25.17
Baseline	111.80	31.63	67.10
3A30A	132.56	38.99	82.22
3A20A	155.64	47.28	99.32
3A10A	180.82	56.47	118.27

5.4.2.2 Kilgoris

Table 5-7: Total monthly flow volumes for Kilgoris (Temperature increase of 3°C)

Month	3A30B (m^3) x10^7	3A20B (m^3) x10^7	3A10B (m^3) x10^7	Baseline (m^3) x10^7	3A30A (m^3) x10^7	3A20A (m^3) x10^7	3A10A (m^3) x10^7
Jan	0.79	1.03	1.34	1.71	2.13	2.60	3.12
Feb	0.62	0.84	1.13	1.47	1.87	2.33	2.84
Mar	0.92	1.27	1.72	2.26	2.87	3.56	4.33
Apr	2.40	3.27	4.34	5.61	7.05	8.64	10.38
May	2.56	3.19	3.97	4.86	5.88	7.03	8.30
Jun	1.29	1.64	2.06	2.56	3.11	3.73	4.41
Jul	1.14	1.42	1.77	2.19	2.66	3.19	3.79
Aug	1.08	1.34	1.67	2.07	2.55	3.09	3.70
Sep	1.10	1.35	1.66	2.02	2.45	2.94	3.50
Oct	1.05	1.33	1.66	2.04	2.47	2.96	3.50
Nov	1.26	1.58	1.99	2.49	3.05	3.70	4.41
Dec	1.11	1.45	1.87	2.35	2.89	3.50	4.18

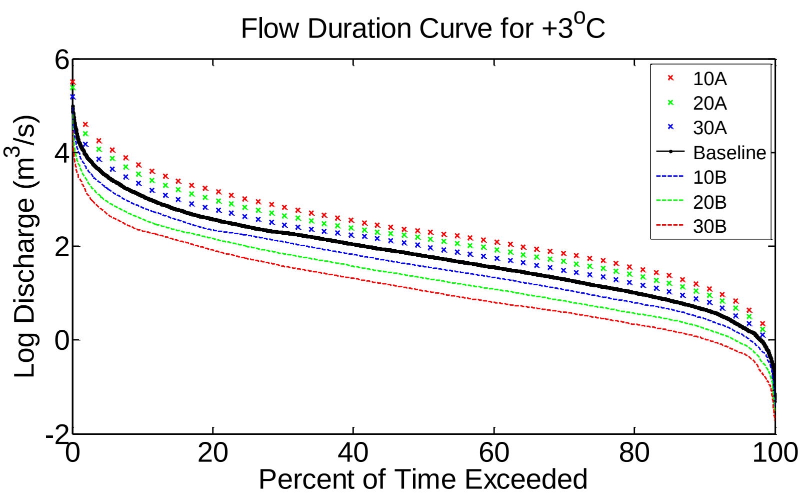


Figure 5.8: Flow Duration Curve for Kilgoris +3°C

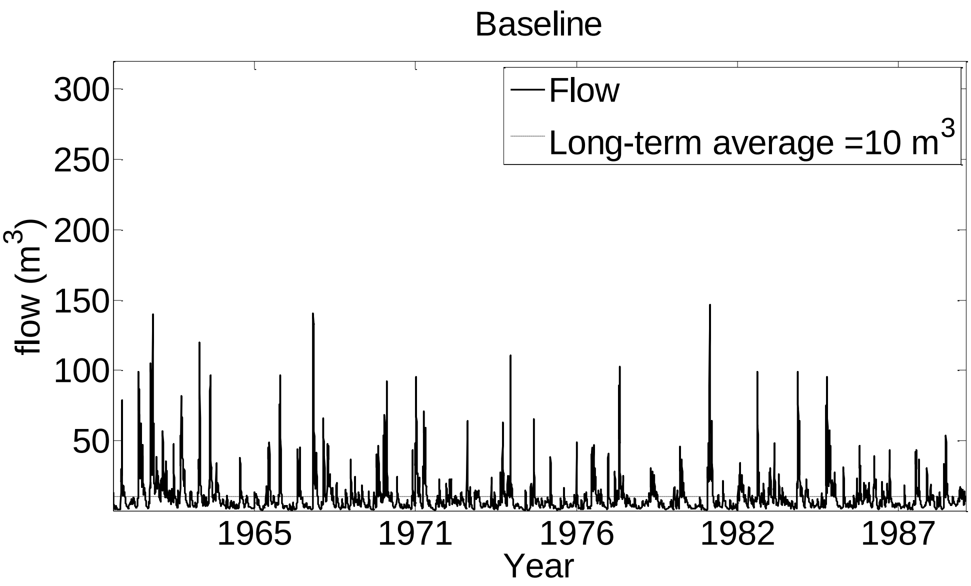


Figure 5.9 : Total flow volume variation for Kilgoris (Baseline)

5.4.2.3 Machove

Table 5-8 : Total monthly flow volumes for Machove (Temperature increase of 3°C)

Month	3A30B (m^3) x10^7	3A20B (m^3) x10^7	3A10B (m^3) x10^7	Baseline (m^3) x10^7	3A30A (m^3) x10^7	3A20A (m^3) x10^7	3A10A (m^3) x10^7
Jan	2.02	2.69	2.47	3.63	5.40	4.38	5.27
Feb	1.25	2.02	1.63	2.77	4.41	3.52	4.40
Mar	1.86	2.40	2.44	3.98	5.42	4.95	6.02
Apr	3.81	4.96	4.91	7.93	10.84	9.90	12.15
May	3.25	4.83	4.16	6.44	8.96	7.88	9.52
Jun	1.73	2.89	2.16	3.33	5.45	4.14	4.94
Jul	1.46	2.20	1.80	2.75	4.10	3.33	4.01
Aug	1.31	1.93	1.67	2.58	3.63	3.20	3.96
Sep	1.65	2.33	2.10	3.27	4.51	4.04	4.99
Oct	1.31	1.83	1.63	2.41	3.43	2.84	3.36
Nov	1.60	2.21	2.07	3.24	4.45	3.98	4.82
Dec	2.31	3.17	2.94	4.53	6.51	5.54	6.69

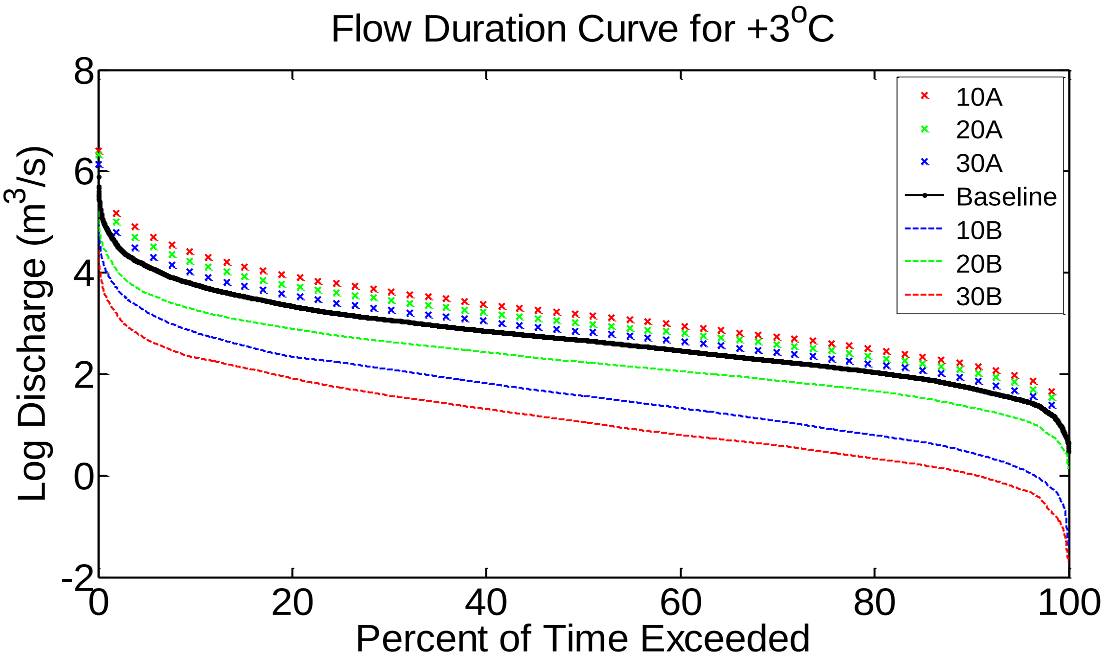


Figure 5.10: Flow Duration Curve for Machove +3°C

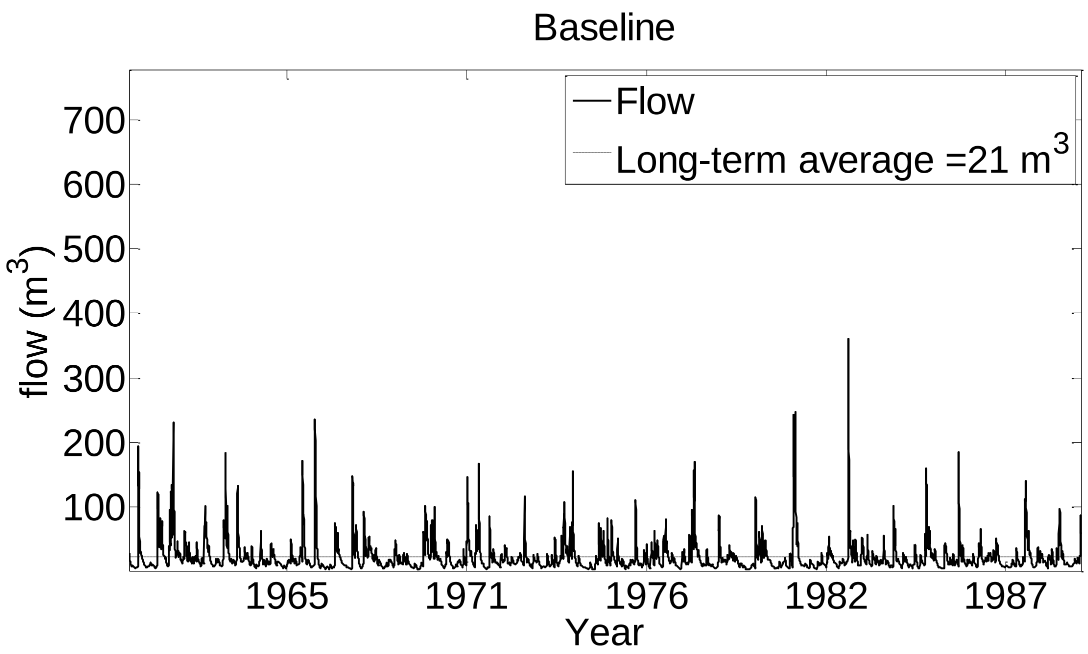


Figure 5.11: Total flow volume variation for Machove (Baseline)

5.4.2.4 Goronga

Table 5-9: Total monthly flow volumes for Goronga (Temperature increase of 3°C)

Month	3A30B (m^3) x10^7	3A20B (m^3) x10^7	3A10B (m^3) x10^7	Baseline (m^3) x10^7	3A30A (m^3) x10^7	3A20A (m^3) x10^7	3A10A (m^3) x10^7
Jan	5.47	6.65	8.03	6.50	11.36	13.30	15.42
Feb	4.23	5.22	6.40	5.00	9.30	10.99	12.85
Mar	4.90	6.15	7.66	6.50	11.41	13.61	16.01
Apr	8.58	10.85	13.60	12.04	20.34	24.28	28.60
May	8.57	10.35	12.40	10.55	17.23	20.03	23.09
Jun	5.75	6.85	8.11	6.06	11.09	12.80	14.64
Jul	4.24	5.03	5.93	4.63	7.98	9.16	10.46
Aug	3.53	4.21	5.02	3.88	7.01	8.19	9.49
Sep	3.70	4.55	5.54	4.43	7.91	9.30	10.83
Oct	3.46	4.21	5.06	3.83	7.03	8.12	9.36
Nov	4.38	5.35	6.53	5.64	9.49	11.25	13.18
Dec	6.11	7.51	9.15	7.62	13.04	15.30	17.78

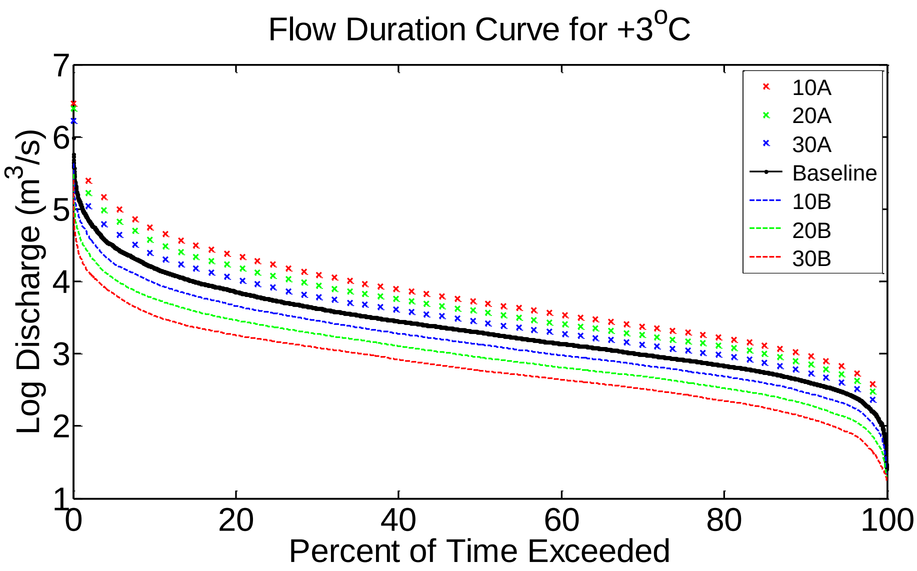


Figure 5.12: Baseline FDC for Goronga +3°C

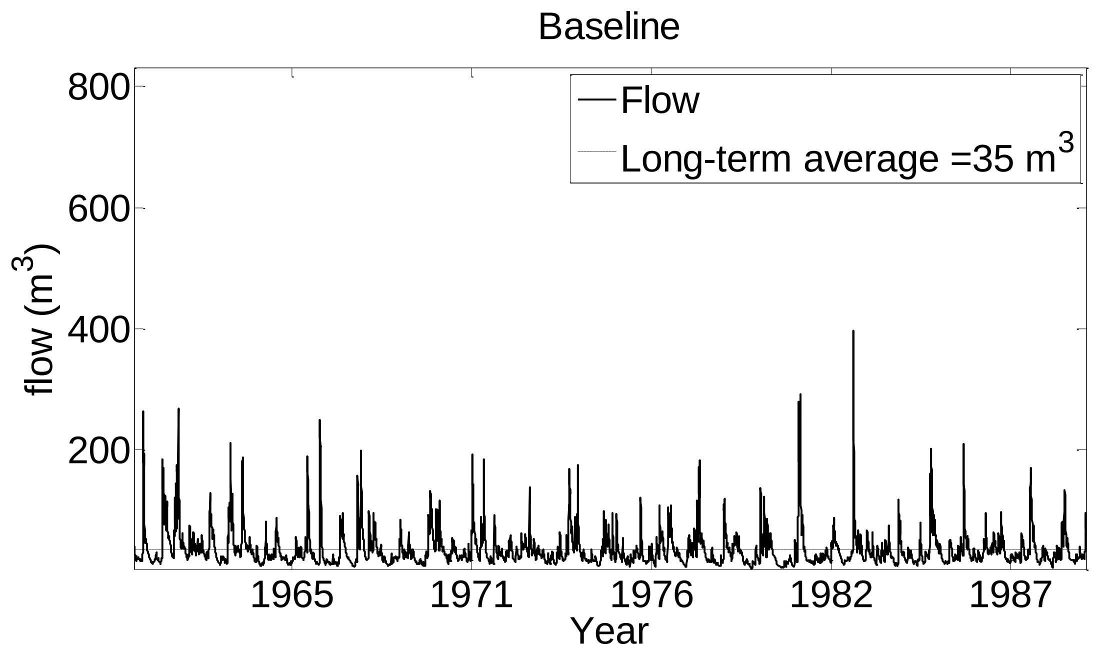


Figure 5.13: Total flow volume variation for Goronga (Baseline)

6 HYDROPOWER SIMULATION RESULTS

6.1 Introduction

This chapter presents the results of the assessment of the impact of climate change on simulated hydropower potential in each of the selected sites in the Kagera and Mara basins. For Kagera, the selected sites are Giteranyi, Rusumo and Kikagate while for Mara, the selected sites are Kilgoris, Machove and Goronga. Below are the steps used to carry out the assessment of the impacts of climate change on hydropower potential at each of the sites,

1. A sensitivity analysis was carried out to select the optimum dam height and turbine flow as a fraction of the long-term average river flow. The key variables for this were the variation of reservoir surface area and reservoir volume with top water elevation.
2. The resultant monthly energy production at the site for baseline conditions was estimated using the Energy equation (Equations 1 and 2).
3. The energy production for each of the climate change scenarios was estimated using the same energy equation.
4. The changes in energy production due to climate change were estimated by comparing the energy production under climate change with baseline conditions

The sections below give the results for each of the sites

6.2 Estimation of hydropower potential

Hydroelectric energy is developed by the transformation of the energy in the water from falling from a higher level to a lower level into mechanical energy on the turbine generator shaft and thence into electrical energy through the generator rotor and stator.

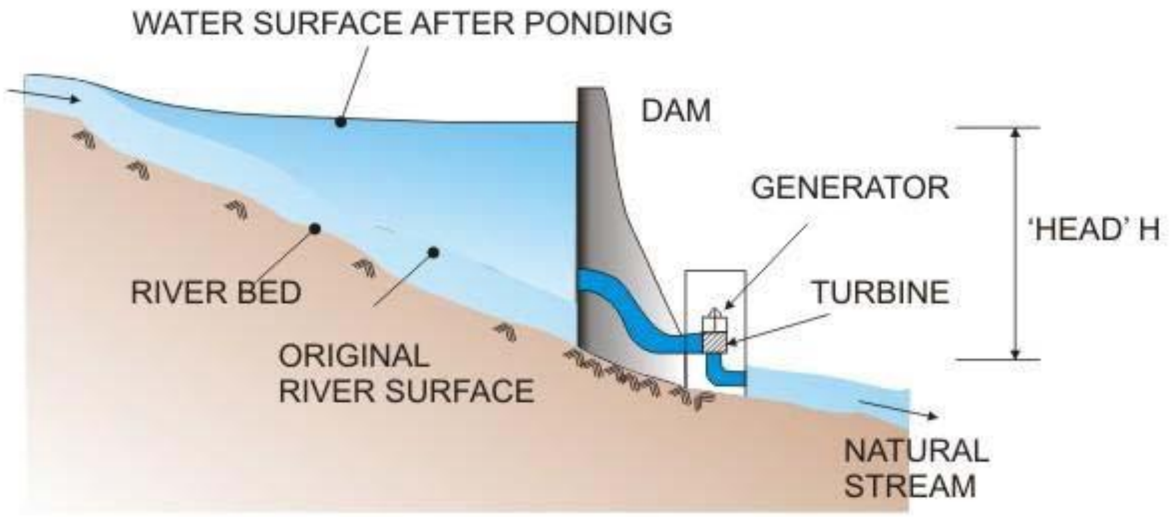


Figure 6.1: Set up of a Dam

To evaluate the power of the flowing water, a uniform steady flow between two cross sections is assumed with H (meters) as difference in water surface elevation between two sections for a flow of Q (m3/s), the power (P) can be expressed in [Nm/s] as

$$P = \gamma Q\left(H + \frac{V_1^2 - V_2^2}{2g} \right)$$

Where:

V_1 *and* V_2 *are mean velocities in the two cross sections.*

Neglecting the usually slight difference in kinetic energy and assuming a value of γ as 9810 Nm/s, the theoretical power can be calculate as

$P = 9810\ Qhe$ [Nm/s] …………………………...…………………………….Equation 5

The power potential of a site in kW is calculated as:

$P = 9.81\ Qhe$ …………………………………………..……………………. Equation 6

Where:

Q = discharge in m^3/s

h = net head in meters

e = efficiency of the plant

The above expression gives the theoretical power of the selected river stretch at a specified discharge. The amount of electricity produced at a potential site not only depends upon the magnitude and regime of the stream flow and the available head or flow fall but also the six of the available storage capacity, the length of the water ways, operating limitations imposed in the interests of other users and very importantly upon efficiency of the machines.

6.3 Kagera

6.3.1 Giteranyi

The relations for elevation Vs. Area and elevation Vs. Volume were initially developed and the equations are as shown below and the graphs shown in subsequent figures:

Elevation Vs. Area: $Elev = 1.296 \times 10^{-25} Area^3 - 1.407 \times 10^{-16} Area^2 + 5.917 \times 10^{-8} Area + 1320$

Elevation Vs. Volume: $Elev = 2.15 \times 10^{-25} Vol^3 - 2.659 \times 10^{-16} Vol^2 + 1.06 \times 10^{-8} Vol + 1319$

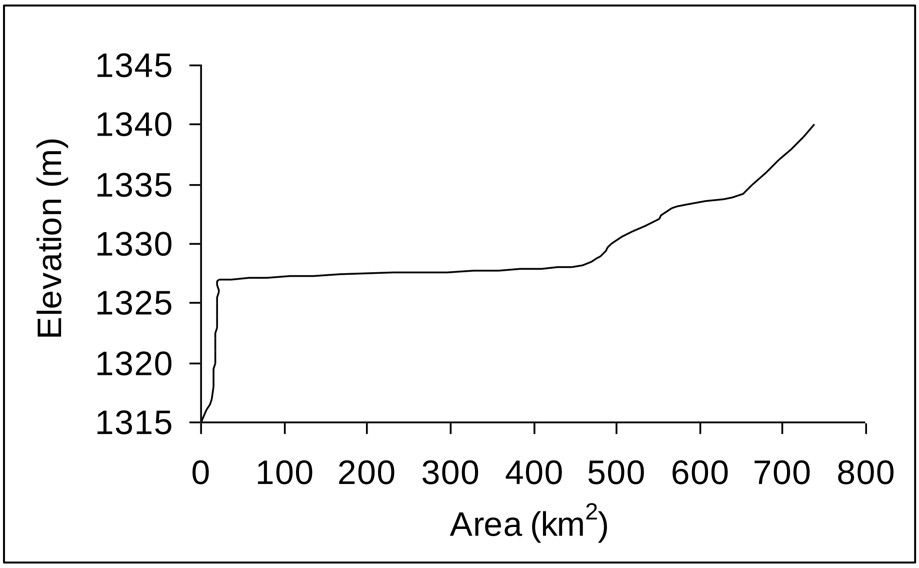


Figure 6.2: Height – Area relation for Giteranyi

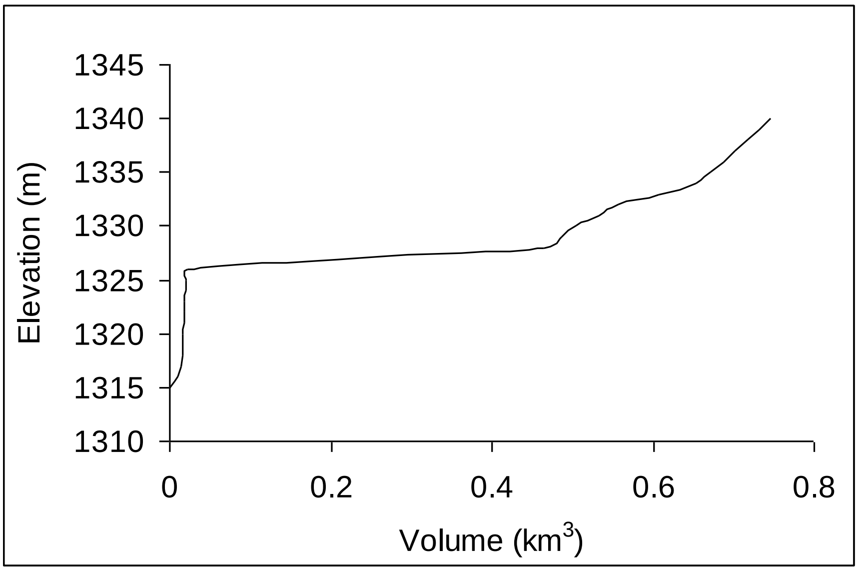


Figure 6.3: Height volume relation for Giteranyi

The dam designed at this location is of height 35m and flow fraction of 0.99 of the average river flow.

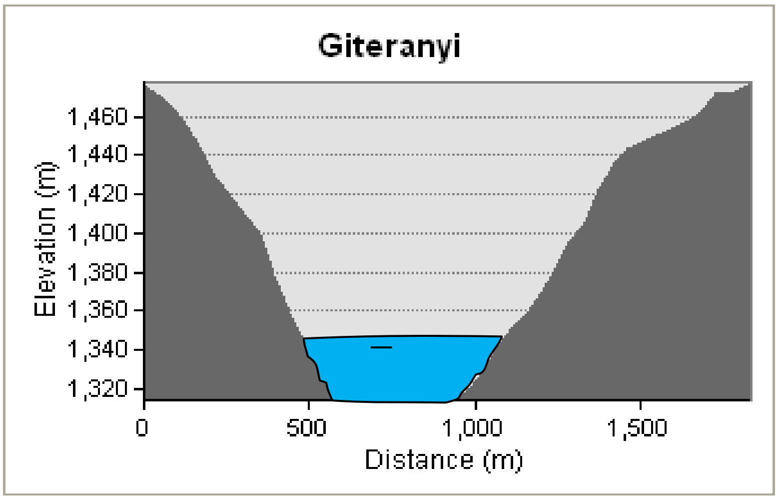


Figure 6.4: Dam Design at Giteranyi

The temporal variation of power production and elevation for the baseline period of 1960-1989 for Giteranyi is as shown in **Figure 6.5**. The lowest water level that can be used to produce power this location, is 1345m.

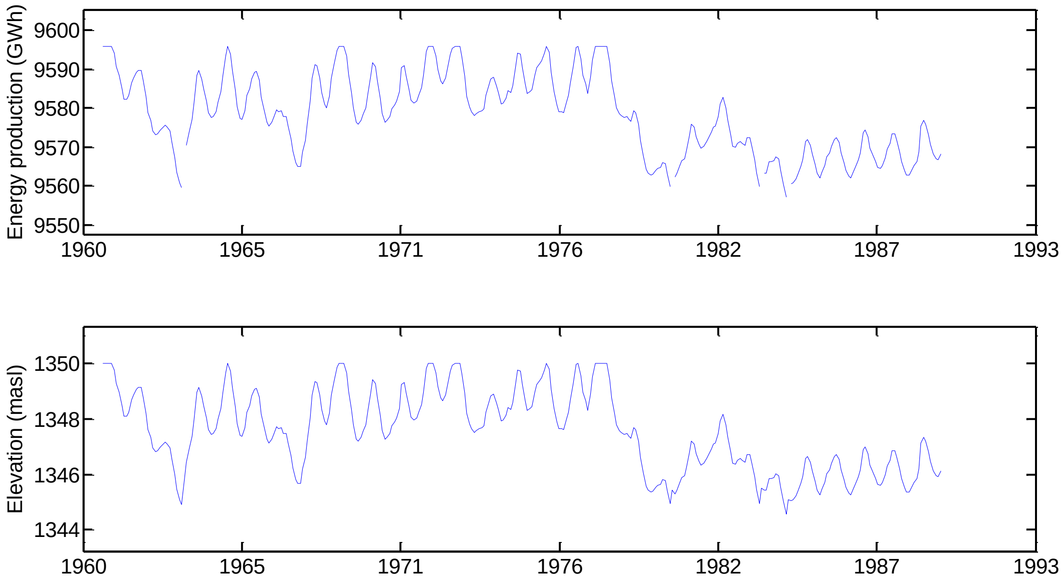


Figure 6.5: Temporal variation of Energy production and Elevation (Baseline) at Giteranyi

The annual temporal variation of energy production for different scenarios with a temperature increase of 3°C is as shown in Figure 6.6.

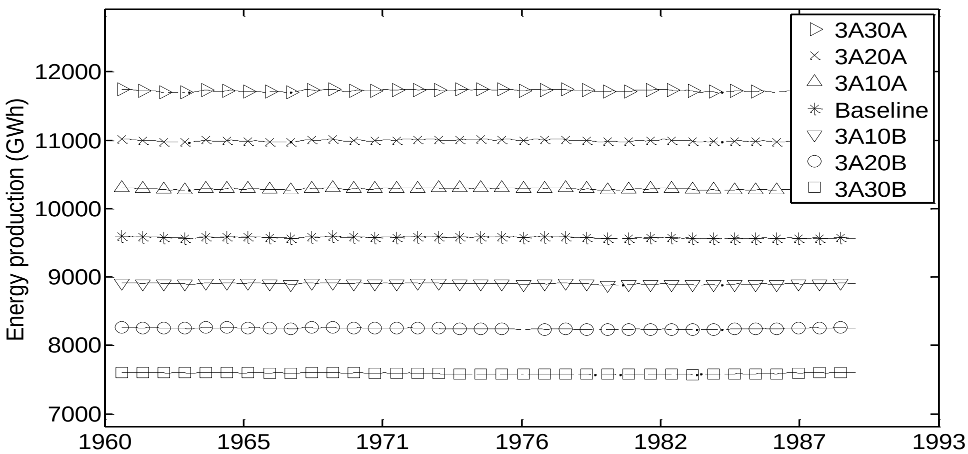


Figure 6.6 : Energy production variation for different climate scenarios with a temperature increase of -3°C at Giteranyi

The mean monthly variation of power production for different scenarios for a temperature increase of 3°C is shown in **Table 6-1**. An increase in rainfall volumes relates to an increase in power production due to increase in flow volumes.

Table 6-1 : Mean monthly energy variation (GWh) for Temperature increase of 3^{o}C at Giteranyi

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
January	7591.48	8248.52	8902.84	9577.73	10286.95	10992.59	11724.24
February	7592.31	8249.16	8903.94	9578.99	10288.29	10994.01	11725.63
March	7593.11	8250.46	8905.58	9580.62	10289.96	10995.58	11727.24
April	7593.85	8251.80	8907.82	9583.07	10292.63	10998.48	11730.26
May	7594.33	8252.51	8909.10	9584.49	10294.05	11001.13	11732.95
June	7593.68	8251.62	8908.10	9583.34	10292.77	10998.76	11730.14
July	7591.78	8249.26	8905.27	9580.12	10289.06	10994.51	11725.24
August	7591.49	8248.03	8903.01	9576.65	10285.89	10992.74	11723.07
September	7589.65	8246.08	8900.55	9575.08	10282.76	10987.17	11717.03
October	7589.62	8246.11	8899.77	9573.08	10282.18	10986.92	11718.97
November	7588.89	8245.21	8899.62	9573.51	10281.59	10987.74	11719.53
December	7591.43	8246.18	8900.74	9574.82	10283.89	10989.09	11720.67

The average and total annual energy production at Giteranyi for different scenarios for an increase in temperature of 3^{o}C is shown in Table 6-2. Results show a percentage change of -21%, -14%, -7%, 7%, 15% and 22% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively. The consequent reliability for the different scenarios is shown in Table 6-3.

Table 6-2 : Annual energy variation (GWh) for Temperature increase of 3^{o}C at Giteranyi

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Mean	7591.80	8248.75	8903.86	9578.46	10287.50	10993.23	11724.58
Total	91101.60	98984.95	106846.33	114941.51	123450.02	131918.71	140694.96

Table 6-3 : Reliability variation for Temperature increase of 3^{o}C at Giteranyi

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Reliability (%)	95.4	97.13	98.56	98.85	98.28	97.41	96.26

6.3.2 Rusumo

The relations for elevation Vs. Area and elevation Vs. Volume were developed and the equations are as shown below and the graphs shown in subsequent figures:

Elevation Vs. Area:

$$Elev = -4.688 \times 10^{-22} Area^4 + 9.934 \times 10^{-22} Area^3 - 7.006 \times 10^{-14} Area^2 + 1.84 \times 10^{-6} Area + 1299$$

Elevation Vs. Volume:

$$Elev = -4.206 \times 10^{-22} Vol^4 + 8.656 \times 10^{-22} Vol^3 - 6.021 \times 10^{-14} Vol^2 + 1.625 \times 10^{-6}\ Vol + 1299$$

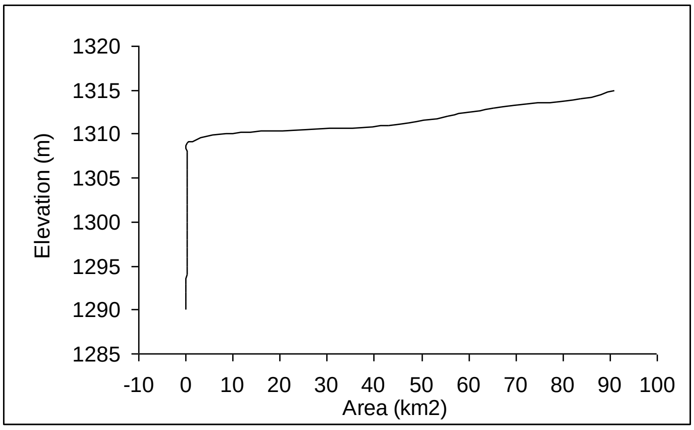


Figure 6.7 : Height – Area relation for Rusumo

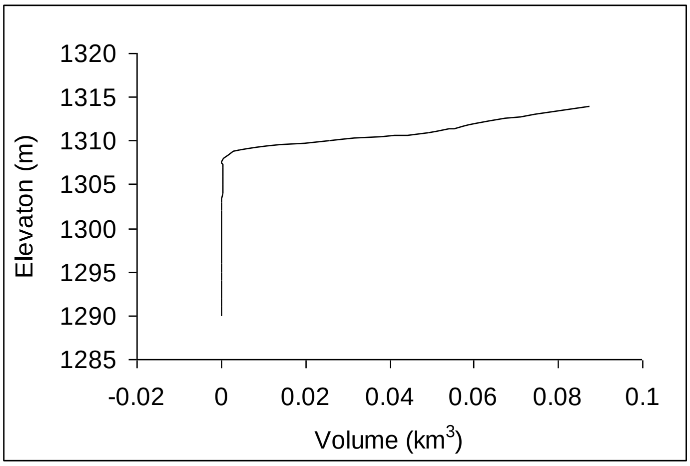


Figure 6.8 : Height – Volume relation for Rusumo

The dam designed at this location of height 35m and flow fraction of 0.99 of the average river flow.

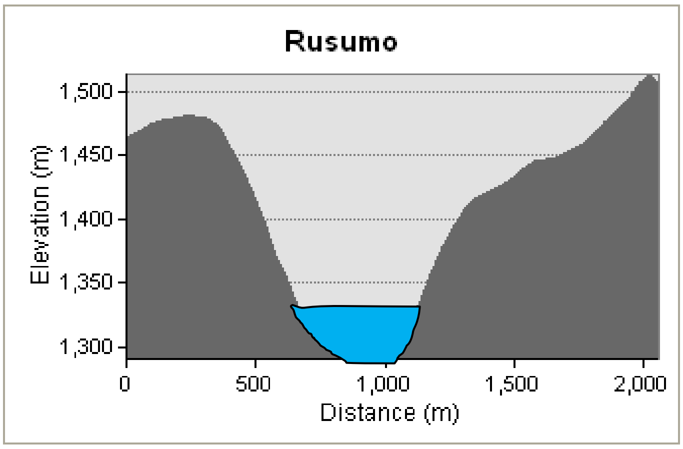


Figure 6.9: Dam Design at Rusumo

The temporal variation of power production and elevation for the baseline period of 1960-1989 for Rusumo is as shown in **Figure 6.10**. The lowest water level that can be used to produce power at this location is 1319m.

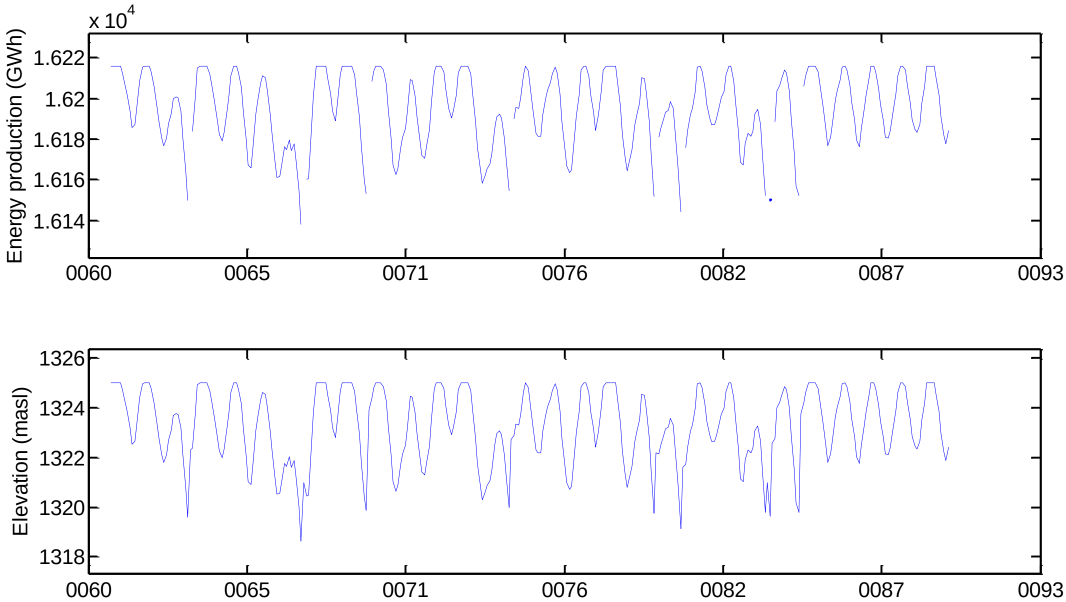


Figure 6.10: Temporal variation of Energy production and Elevation (Baseline) at Rusumo

The annual temporal variation of energy production for different scenarios with a temperature increase of 3^{o}C is as shown in Figure 6.11.

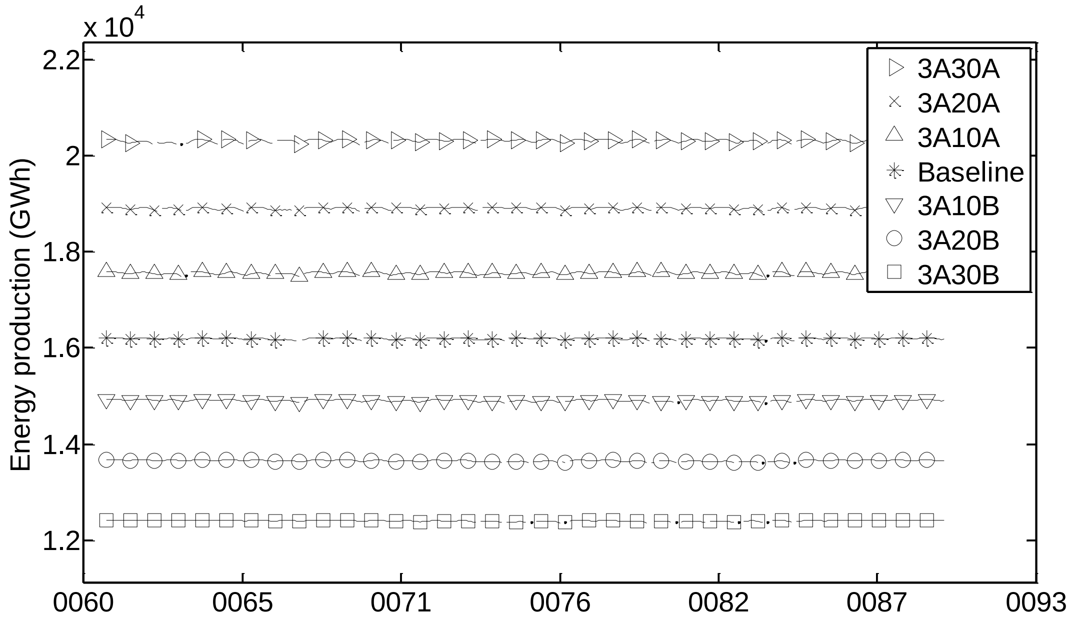


Figure 6.11: Temporal variation of Energy production for the climate change scenarios

The mean monthly variation of power production for different scenarios for a temperature increase of 3°C is shown in **Table 6-4**. An increase in rainfall volumes clearly translates into an increase in power production due to increase in flow volumes.

Table 6-4: Mean monthly energy variation (GWh) for Temperature increase of 3°C at Rusumo

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
January	12404.87	13651.14	14906.26	16195.59	17556.38	18911.07	20312.92
February	12407.09	13654.54	14910.41	16200.57	17561.32	18917.14	20319.99
March	12409.13	13657.80	14914.95	16205.26	17567.24	18923.69	20326.25
April	12411.10	13660.17	14918.32	16209.14	17572.34	18927.39	20330.04
May	12412.57	13661.97	14920.52	16211.05	17574.42	18928.13	20330.22
June	12410.95	13659.90	14918.19	16208.24	17570.99	18923.71	20324.76
July	12405.71	13653.61	14911.05	16199.99	17561.26	18914.87	20314.65
August	12401.34	13646.57	14901.23	16188.76	17548.06	18898.87	20295.57
September	12392.06	13641.03	14894.08	16180.22	17535.53	18885.53	20279.27
October	12398.32	13639.51	14887.83	16172.28	17529.26	18875.98	20269.00
November	12394.04	13636.96	14891.95	16175.22	17530.71	18879.89	20279.45
December	12400.14	13643.16	14897.85	16184.99	17543.66	18894.59	20298.00

The average and total annual energy production at Rusumo for different scenarios for an increase in temperature of 3°C is shown in Table 6-5. Results show a percentage change of -23%, -16%, -8%, 8%, 17% and 25% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively. The consequent reliability for the different scenarios is shown in Table 6-6.

Table 6-5: Annual energy variation (GWh) for Temperature increase of 3°C at Rusumo

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Mean	12403.94	13650.53	14906.05	16194.28	17554.26	18906.74	20306.68
Total	148847.32	163806.37	178872.65	194331.31	210651.16	226880.87	243680.14

Table 6-6: Reliability variation for Temperature increase of 3°C at Rusumo

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Reliability (%)	95.4	96.55	97.41	97.41	97.41	96.84	95.98

6.3.3 Kikagate

The relations for elevation Vs. Area and elevation Vs. volume were developed and the equations are as shown below and the graphs shown in subsequent figures:

Elevation Vs. Area:

$$Elev = 5.948\times10^{-22} Area^3 - 4.505\times10^{-14} Area^2 + 1.645\times10^{-6} Area + 1255$$

Elevation Vs. Volume:

$$Elev = 7.179\times10^{-22} Vol^3 - 5.176\times10^{-14} Vol^2 + 1.747\times10^{-6} Vol + 1255$$

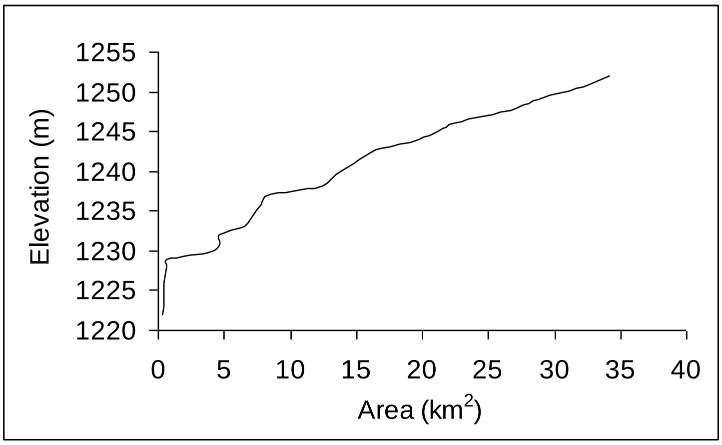


Figure 6.12: Height – Area Relation for Kikagate

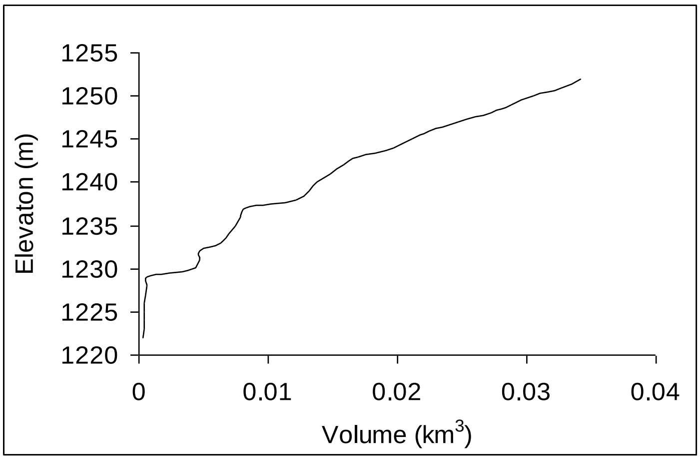


Figure 6.13: Height – Volume Relation for Kikagate

The dam designed at this location of height 40m and flow fraction of 0.6 of the average river flow.

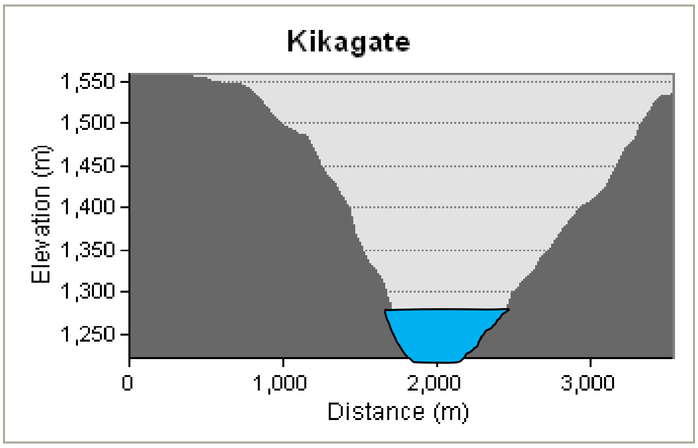


Figure 6.14: Dam design at Kikagate

The temporal variation of power production and elevation for the baseline period of 1960-1989 for Kikagate is as shown in Figure 6.15.

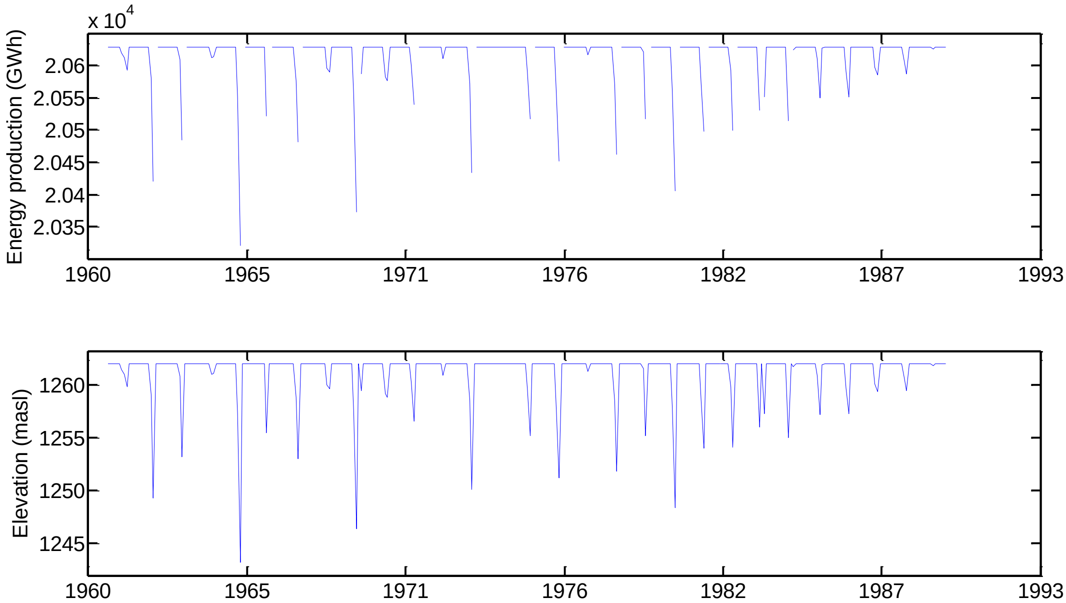


Figure 6.15: Temporal variation of Energy production and Elevation (Baseline)

The annual temporal variation of energy production for different scenarios with a temperature increase of 3°C is as shown in Figure 6.16.

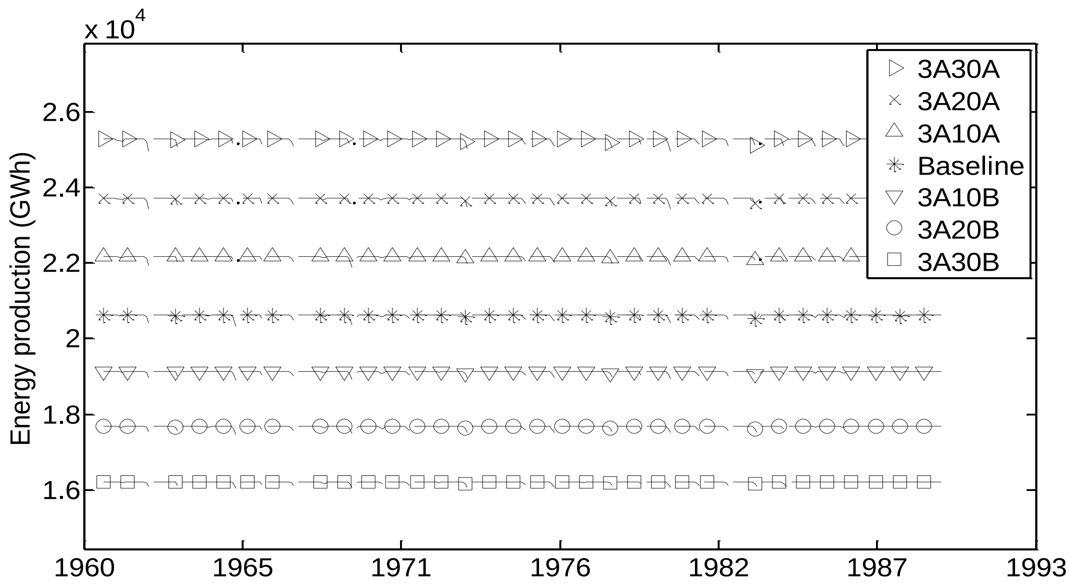


Figure 6.16: Temporal variation of Energy production and Elevation (Baseline)

The mean monthly variation of power production for different scenarios for a temperature increase of 3°C is shown in **Table 6-7**. An increase in rainfall volumes clearly translates into an increase in power production due to increase in flow volumes.

Table 6-7: Mean monthly energy variation (GWh) for Temperature increase of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
January	16221.99	17680.31	19139.83	20627.80	22180.82	23710.79	25278.20
February	16221.99	17680.31	19139.83	20627.80	22180.82	23710.79	25278.20
March	16221.99	17680.31	19139.83	20627.80	22180.82	23710.79	25278.20
April	16221.99	17680.31	19139.83	20627.80	22180.82	23710.79	25278.20
May	16221.99	17680.31	19139.83	20627.80	22180.82	23710.79	25278.20
June	16221.99	17680.31	19139.83	20627.80	22180.82	23710.79	25278.20
July	16201.14	17656.21	19111.94	20595.50	22143.33	23666.52	25226.01
August	16157.03	17605.02	19055.64	20535.97	22076.00	23590.21	25150.94
September	16205.37	17662.39	19130.77	20616.08	22167.13	23694.89	25253.28
October	16220.73	17679.02	19138.63	20626.60	22179.65	23709.71	25277.17
November	16221.99	17680.31	19139.83	20627.80	22180.82	23710.79	25278.20
December	16221.99	17680.31	19139.83	20627.80	22180.82	23710.79	25278.20

The average and total annual energy production at Kikagate for different scenarios for a increase in temperature of 3°C is shown in **Table 6-8**. Results show a percentage change of -23%, -16%, -8%, 8%, 17% and 25% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively. The consequent reliability for the different scenarios is shown in **Table 6-9**.

Table 6-8: Annual energy variation (GWh) for Temperature increase of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Mean	16213.347	17670.427	19129.638	20616.382	22167.721	23695.635	25261.083
Total	194560.16	212045.12	229555.65	247396.58	266012.65	284347.62	303132.99

Table 6-9: Reliability variation for Temperature increase of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Reliability (%)	94.83	95.11	95.11	95.11	94.25	93.68	93.39

6.4 Mara

6.4.1 Kilgoris

The dam designed at this location of height 25m and flow fraction of 0.3 of the average river flow. The relations for elevation Vs. Area and elevation Vs. Volume were developed and the equations are as shown below and the graphs shown in subsequent figures:

Elevation Vs. Area:

$$Elev = 7.18\times10^{-21} Area^3 - 2.292\times10^{-13} Area^2 + 2.962\times10^{-6} Area + 1655$$

Elevation Vs. Volume:

$$Elev = 3.645\times10^{-23} Vol^3 - 7.623\times10^{-15} Vol^2 + 5.551\times10^{-7} x + 1657$$

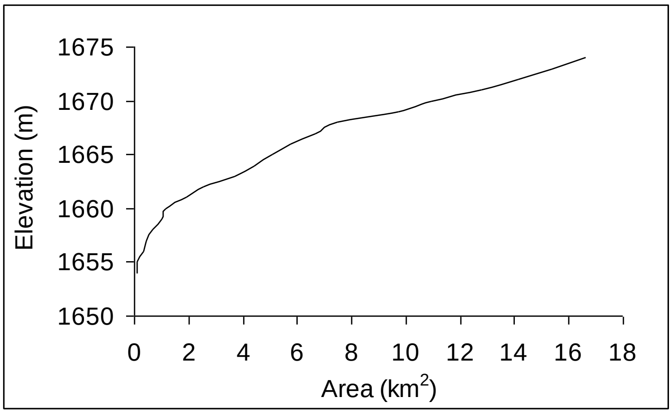


Figure 6.17 : Height – Area Relation for Kilgoris.

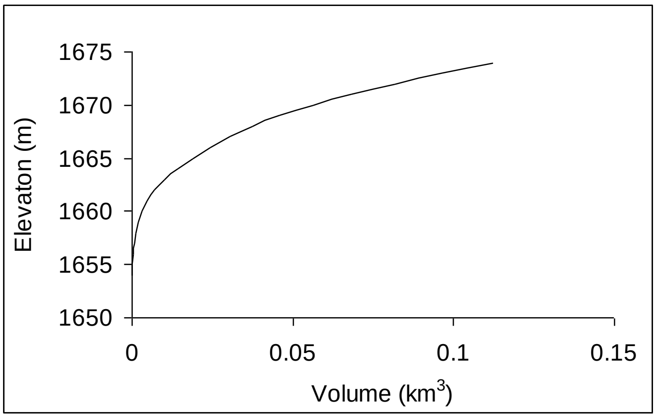


Figure 6.18 : Height -Volume relation for Kilgoris.

The temporal variation of power production and elevation for the baseline period of 1960-1989 for Kilgoris is as shown in Figure 6.19.

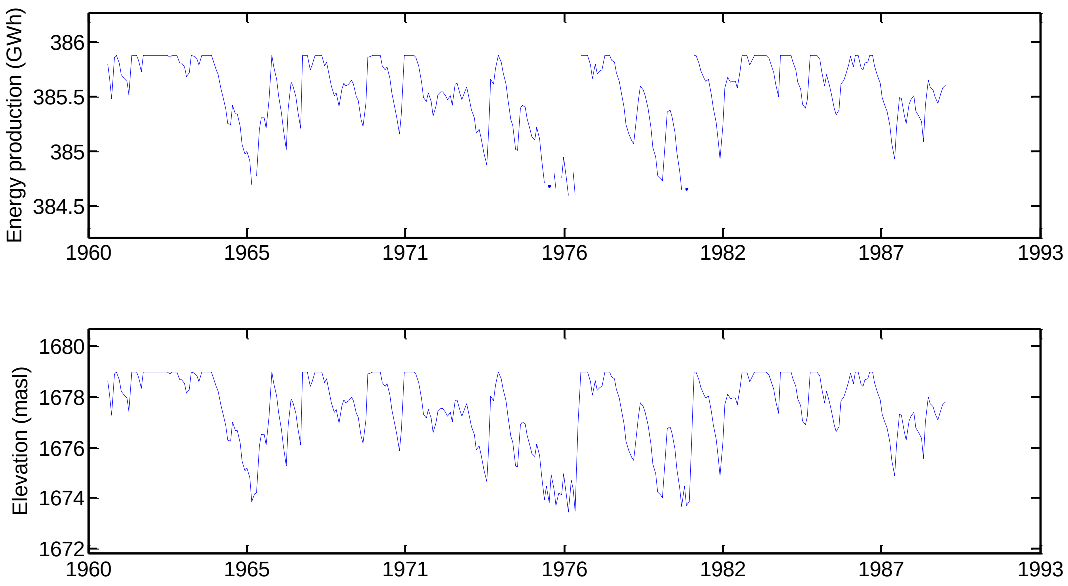


Figure 6.19: Temporal variation of Energy production and Elevation (Baseline)

The annual temporal variation of energy production for different scenarios with a temperature increase of 3°C is as shown in Figure 6.20.

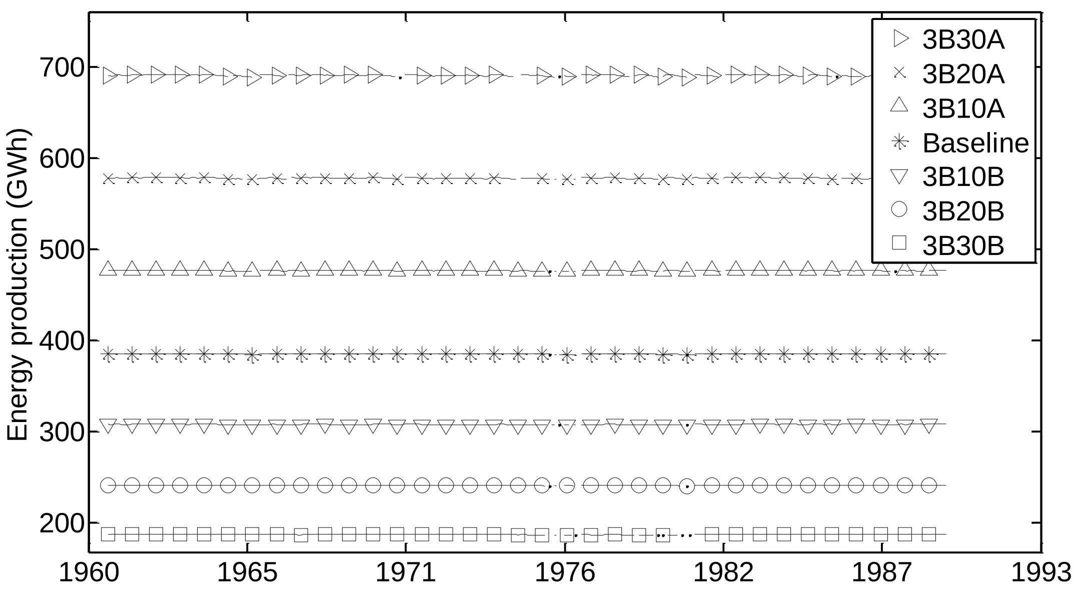


Figure 6.20: Temporal variation of Energy production and Elevation (Baseline)

The mean monthly variation of power production for different scenarios for a temperature increase of 3°C is shown in Table 6-10.

Table 6-10: Mean monthly energy variation (GWh) for Temperature increase of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
January	186.59	240.34	306.80	385.43	474.95	575.88	687.69
February	186.60	240.34	306.76	385.40	474.94	575.86	687.86
March	186.60	240.34	306.75	385.37	474.91	575.81	687.87
April	186.62	240.40	306.90	385.56	475.29	576.39	688.59
May	186.64	240.44	306.92	385.69	475.45	576.58	688.67
June	186.63	240.42	306.92	385.67	475.41	576.53	688.62
July	186.63	240.43	306.93	385.63	475.34	576.41	688.54
August	186.61	240.40	306.88	385.63	475.33	576.38	688.34
September	186.62	240.41	306.90	385.56	475.21	576.21	688.21
October	186.62	240.38	306.85	385.52	475.14	576.18	688.07
November	186.63	240.39	306.84	385.50	475.10	576.06	687.97
December	186.60	240.38	306.83	385.47	475.00	575.95	687.73

The average and total annual energy production at Kilgoris for different scenarios for an increase in temperature of 3^{o}C is shown in Table 6-11. Results show a percentage change of -52%, -38%, -20%, 23%, 49% and 78% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively. The consequent reliability for the different scenarios is shown in Table 6-12.

Table 6-11: Annual energy variation (GWh) for Temperature increase of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Mean	186.62	240.39	306.86	385.54	475.17	576.19	688.18
Total	2239.39	2884.69	3682.27	4626.43	5702.06	6914.24	8258.16

Table 6-12: Reliability variation for Temperature decrease of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Reliability (%)	95.69	97.13	97.7	97.41	96.26	94.54	91.95

6.4.2 Machove

The dam designed at this location of height 20m and flow fraction of 0.18 of the average river flow. The relations for elevation Vs. Area and elevation Vs. Volume were developed and the equations are as shown below and the graphs shown in subsequent figures:

Elevation Vs. Area:

$$Elev = 6.2 \times 10^{-20} Area^3 - 8.929 \times^{-13} Area^2 + 5.924 \times 10^{-6} Area + 1421$$

Elevation Vs. Volume:

$$Elev = 4.636 \times 10^{-20} Vol^3 - 7.848 \times 10^{-13} Vol^2 + 5.961 \times 10^{-6} Vol + 1420$$

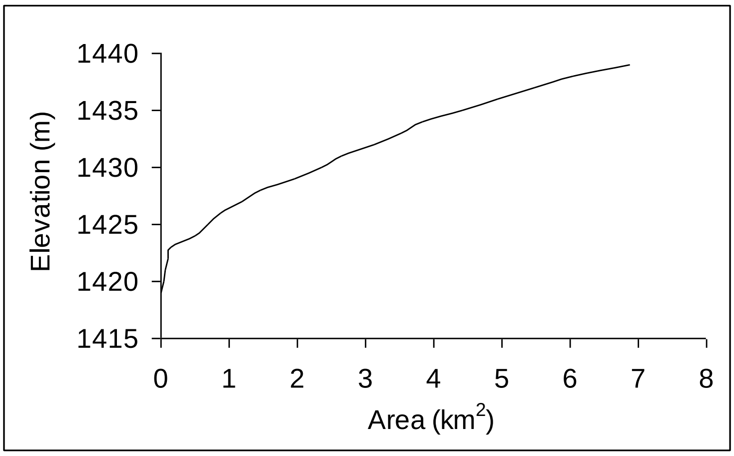


Figure 6.21 : Height – Area Relation for Machove

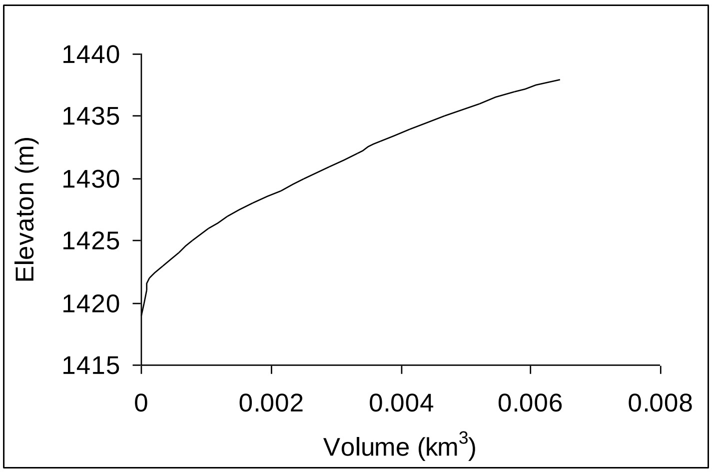


Figure 6.22 : Height – Volume relation for Machove

The temporal variation of power production and elevation for the baseline period of 1960-1989 for Machove is as shown in **Figure 6.23**.

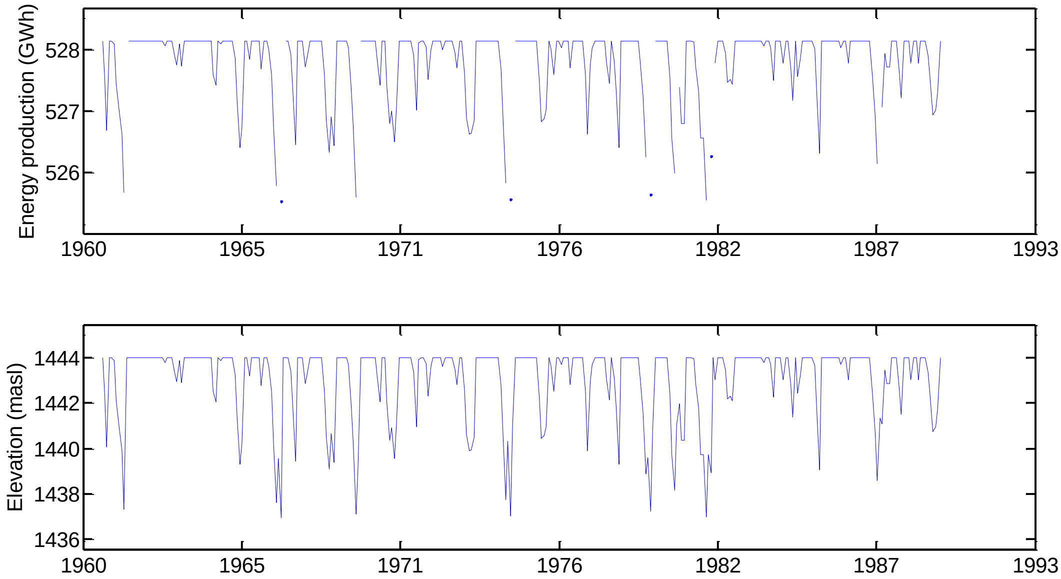


Figure 6.23: Temporal variation of Energy production and Elevation (Baseline)

The annual temporal variation of energy production for different scenarios with a temperature increase of 3°C is as shown in Figure 6.24

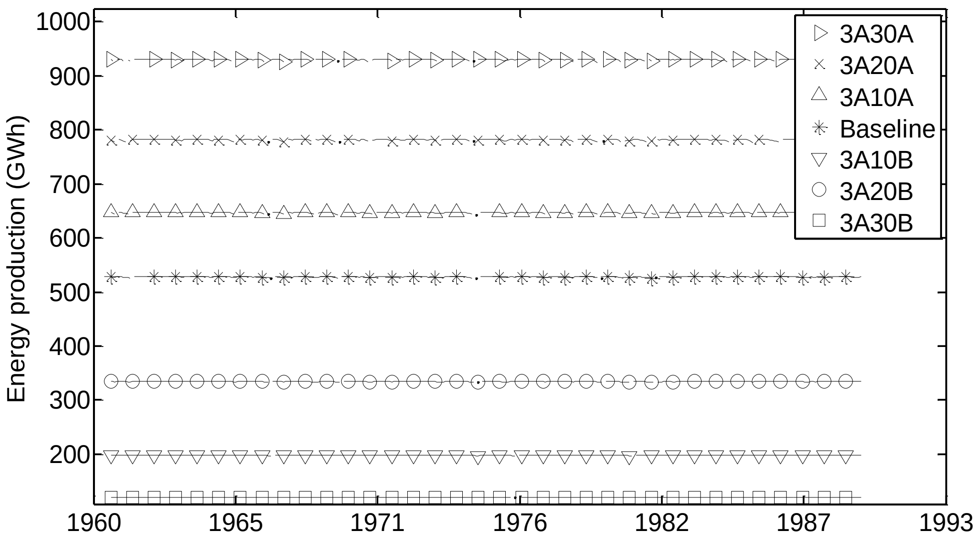


Figure 6.24: Temporal variation of Energy production and Elevation (Baseline)

The mean monthly variation of power production for different scenarios for a temperature increase of 3°C is shown in **Table 6-13**.

Table 6-13: Mean monthly energy variation (GWh) for Temperature increase of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
January	120.38	334.34	197.88	527.77	646.63	781.22	930.35
February	120.36	334.37	197.84	527.83	646.54	781.24	930.45
March	120.35	334.36	197.85	527.81	646.72	781.15	930.26
April	120.39	334.47	198.01	528.05	646.91	781.51	930.65
May	120.42	334.50	198.05	528.08	646.97	781.60	930.78
June	120.43	334.52	198.05	528.11	646.99	781.57	930.66
July	120.44	334.48	198.03	527.95	646.70	781.10	929.94
August	120.42	334.40	198.01	527.77	646.41	780.63	929.36
September	120.42	334.34	198.01	527.56	646.07	780.22	929.16
October	120.41	334.25	197.97	527.26	645.89	780.08	928.97
November	120.40	334.19	197.96	527.49	646.17	780.35	929.48
December	120.39	334.27	197.92	527.71	646.42	781.06	930.11

The average and total annual energy production at Machove for different scenarios for an increase in temperature of 3^{o}C is shown in **Table 6-14**. Results show a percentage change of -77%, -36%, -62%, 23%, 48% and 76% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively. The consequent reliability for the different scenarios is shown in **Table 6-15**.

Table 6-14: Annual energy variation (GWh) for Temperature decrease of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Mean	120.4005	334.3737	197.9653	527.7837	646.5352	780.9767	930.0145
Total	1444.8064	4012.485	2375.5837	6333.4049	7758.4221	9371.7201	11160.1738

Table 6-15: Reliability variation for Temperature decrease of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Reliability (%)	99.43	97.99	99.14	96.55	93.39	92.24	91.09

6.4.3 Goronga

The dam designed at this location of height 20m and flow fraction of 0.2 of the average river flow. The relations for elevation Vs. Area and elevation Vs. Volume were developed and the equations are as shown below and the graphs shown in subsequent figures:

Elevation Vs. Area:

$$Elev = -1.239 \times 10^{-21} Area^3 - 8.772 \times 10^{-14} Area^2 + 3.131 \times 10^{-6} Area + 1294$$

Elevation Vs. Volume:

$$Elev = -1.996 \times 10^{-21} Vol^3 - 7.188 \times 10^{-14} Vol^2 + 3.0331 \times 10^{-6} Vol + 1295$$

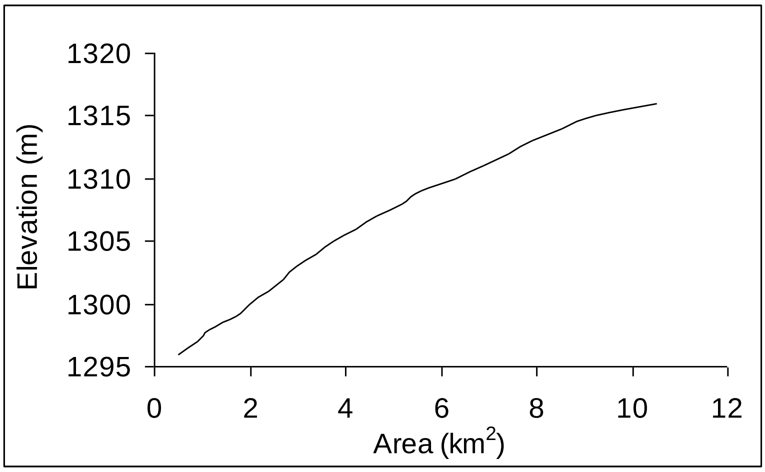


Figure 6.25 : Height – Area relation for Goronga

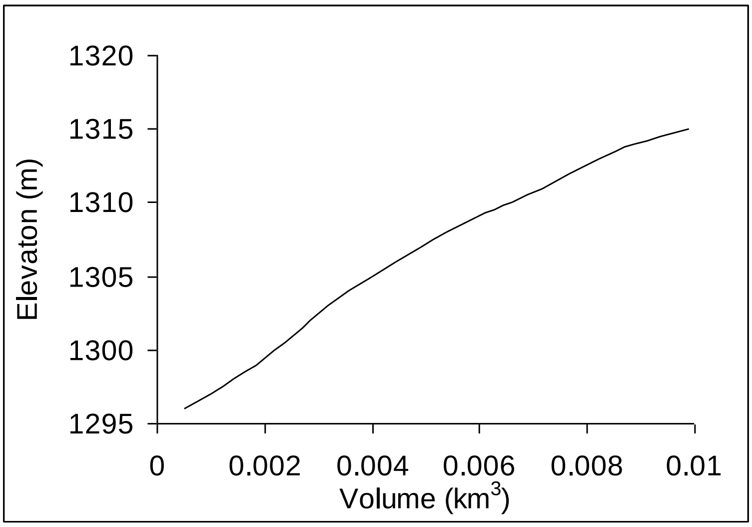


Figure 6.26: Height – Volume relation for Goronga

The temporal variation of power production and elevation for the baseline period of 1960-1989 for Goronga is as shown in Figure 6.27.

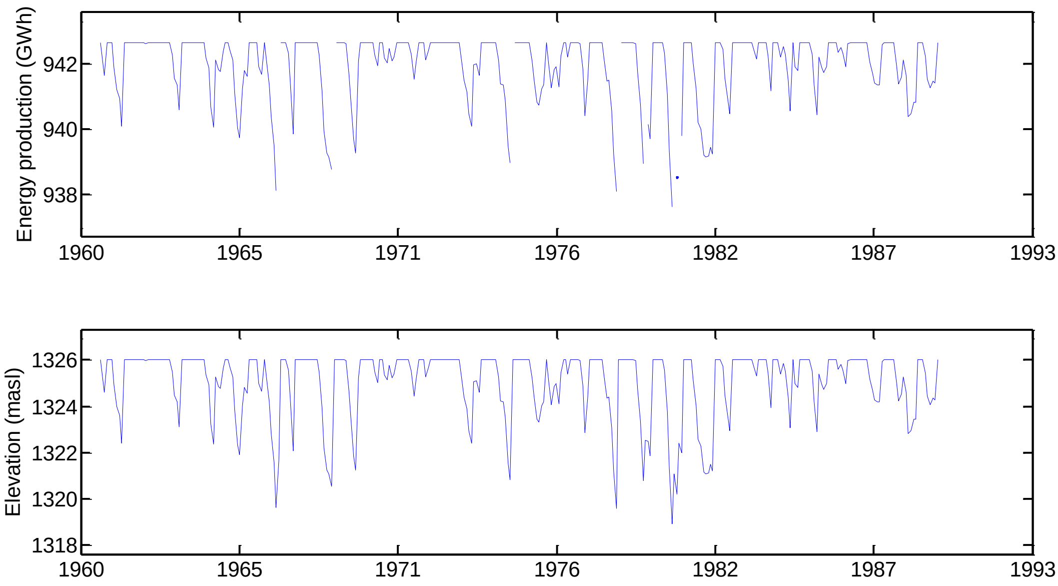


Figure 6.27: Temporal variation of Energy production and Elevation (Baseline)

The annual temporal variation of energy production for different scenarios with a temperature increase of 3°C is as shown in Figure 6.28.

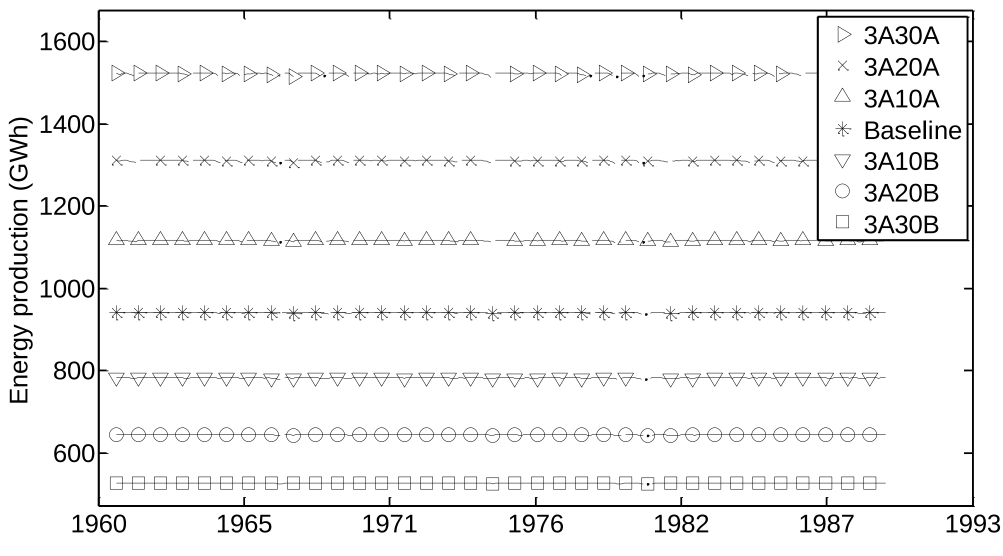


Figure 6.28: Temporal variation of Energy production and Elevation (Baseline)

The mean monthly variation of power production for different scenarios for a temperature increase of 3°C is shown in **Table 6-16**

Table 6-16: Mean monthly energy variation (GWh) for Temperature increase of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
January	526.60	644.16	782.71	941.84	1116.62	1311.25	1523.61
February	526.63	644.27	782.65	941.81	1116.85	1311.47	1523.23
March	526.59	644.22	782.68	942.11	1117.03	1311.52	1523.42
April	526.73	644.47	783.07	942.56	1117.54	1312.16	1524.38
May	526.81	644.53	783.12	942.59	1117.56	1312.20	1524.44
June	526.84	644.56	783.16	942.62	1117.58	1312.18	1524.33
July	526.81	644.49	783.01	942.36	1117.14	1311.49	1523.30
August	526.70	644.32	782.75	941.97	1116.56	1310.63	1522.08
September	526.60	644.16	782.49	941.56	1115.94	1309.72	1520.78
October	526.50	644.01	782.23	941.12	1115.39	1308.69	1520.68
November	526.46	643.96	782.29	941.35	1116.02	1309.82	1521.45
December	526.62	644.21	782.57	941.61	1116.61	1310.85	1523.00

The average and total annual energy production at Goronga for different scenarios for a decrease in temperature of 3^{o}C is shown in Table 6-17. Results show a percentage change of -44%, -31%, -16%, 19%, 39% and 62% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively. The consequent reliability for the different scenarios is shown in Table 6-18.

Table 6-17: Annual energy variation (GWh) for Temperature decrease of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Mean	526.6564	644.2802	782.7291	941.9596	1116.7367	1310.9986	1522.8928
Total	6319.877	7731.362	9392.7497	11303.515	13400.841	15731.983	18274.714

Table 6-18: Reliability variation for Temperature decrease of 3°C

	3A30B	3A20B	3A10B	Baseline	3A10A	3A20A	3A30A
Reliability (%)	99.43	98.85	98.85	97.99	96.26	94.25	92.82

7 CONCLUDING REMARKS

The main objective of this research was to explore the impact of climate change on the future development and operation of hydropower schemes in Lake Victoria Basin (LVB). The hypothesis was to test whether climate change will have a significant impact on hydropower generation in LVB. Two case catchments were studied namely Kagera and Mara. Hydrological modelling was carried out using the SWAT model. The impact of climate change on hydropower was explored by setting up simple "what-if" scenarios and estimating the resultant changes in hydropower at selected potential hydropower sites. The climate change scenarios included: (i) a +3^{o}C increase in temperature and (ii) variations in rainfall of ±30%, ±20%, ±10%.

The SWAT model performed well for Mara reproducing the mean and variability of flow with Nash-Sutcliffe values of up to 0.6. The Kagera model reproduced the mean flows well though variability was not well modelled. The reason of this might be extensive storage in swamps and lakes especially in the middle to lower parts of the basin which might not be well simulated by SWAT.

Below are specific conclusions about the modelling and the hydropower simulation:

1 For Kagera basin the proposed hydropower sites are Giteranyi, Rusumo and Kikagate for which initial analysis shows that the optimum dam heights are 35m, 35m and 40m respectively. The reservoir volumes at maximum dam level are 860, 50 and 70 Million m^3 respectively. The estimated annual hydro energy potentials under historical (baseline) flow conditions for each of the dam sites are 9578, 16194 and 20616 GWh respectively.

2 For Giteranyi site, the changes in flow for the different climate change scenarios are -20%, -14%,-7%,6%,13%,19% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -20%, -14%,-7%,7%,13%,19% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios respectively. The resultant changes in hydropower potential are -21%, -14%, -7%, 7%, 15% and 22% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -20%, -14%, -7%, 8%, 15% and 23% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios respectively.

3 For Rusumo site, the changes in flow for the different climate change scenarios are -23%, -15%, -8%, 8%, 16%, 23% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -23%, -15%, -8%, 8%, 16%, 24% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios respectively. The resultant changes in hydropower potential are -23%, -16%, -8%, 8%, 17% and 25% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively and -23%, -15%, -7%, 9%, 17% and 26% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios respectively.

4 For Kikagate site, the changes in flow for the different climate change scenarios are -22%, -14%, -7%, 7%, 15%, 22% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -21%, -14%, -7%, 8%, 15%, 23%for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios respectively. The resultant changes in hydropower potential are -23%, -16%, -8%, 8%, 17% and 25% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -20%, -14%, -7%, 8%, 15% and 23% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios respectively.

5 For Mara basin the proposed hydropower sites are Kilgoris, Machove and Goronga for which initial analysis shows that the best dam heights are 25, 20 and 25 m respectively. The reservoir volumes at maximum dam level are 23, 6 and 17 Million m^3 respectively. The estimated annual hydro energy potentials under historical flow conditions for each of the dam sites are 110, 111 and 164 GWh respectively.

6 For Kilgoris site, the changes in flow for the different climate change scenarios are -44%, -32%, -17%, 19%, 39%, 62% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -44%, -31%, -16%, 19%, 40%, 63% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios

respectively. The resultant changes in hydropower potential are -51%, -38%, -20%, 23%, 49% and 78% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -51%, -37%, -20%, 24%, 50% and 79% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios respectively .

7 For Machove site, the changes in flow for the different climate change scenarios are -77%, -37%, -62%, 23%, 48%, 76% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -50%, -36%, -19%, 23%, 49%, 77% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios respectively. The resultant changes in hydropower are -77%, -37%, -62%, 22%, 48% and 76% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -50%, -36%, -19%, 23%, 48% and 77% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively

8 For Goronga site, the changes in flow for the different climate change scenarios are -44%, -32%, -17%, 19%, 39%,62% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -44%, -31%, -16%, 19%, 40%, 63% for 3B30B, 3B20B, 3B10B, 3B30A, 3B30A scenarios. The resultant changes in hydropower potential are -44%, -31%, -16%, 19%, 39% and 62% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively, and -44%, -31%, -16%, 19%, 40% and 62% for 3A30B, 3A20B, 3A10B, 3A30A, 3A30A scenarios respectively.

8 RECOMMENDATIONS

This study gives a preliminary insight into the impact of climate change on hydropower potential in the Lake Victoria Basin. The study shows, that any changes in temperature and precipitation would have significant effects on the hydrology of the Lake basin and hence, would result in substantial changes on hydropower potential. Further exploration of this linkage should be carried out. In particular, the following are recommended.

1. In order to improve the results of the hydrological model, alternative models should be tested on the basin. Examples of models that can be tried out include conceptual models like SACRAMENTAL, WASMOD, and HBV models. Alternatively, physically based models like MIKE Basin can be tried out.

2. Extension of the study to other rivers that have significant hydropower potential including Nzoia, Yala, Sio, etc. In addition, a similar investigation can be carried out for Victoria Nile where several large hydropower dams are planned.

3. The results of this study can be used to carry out a prefeasibility study for one or more of the identified sites to demonstrate their applicability in designing more robust hydropower projects taking into account the effect of climate change.

4. Within the framework of NBCBN-RE, EIA research cluster, a number of guidelines are being developed for carrying out Strategic Environmental Assessments (SEA). These guidelines can be tested on the identified hydropower sites.

5. A number of projects are planned in the area of water management by constructing reservoirs. These reservoirs will be used for purposes like municipal and industrial water supply, irrigation and livestock as well as flood control. The effect of climate change on the multi-purpose reservoirs should be investigated further.

6. Further investigation of the environmental effects of variation measures aimed at mitigating the effect of climate change and variability on the hydropower potential at the different sites. For example, increasing dam height may be one of the mitigation measures but this comes at a cost of inundating more land which will have significant environmental impacts.

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Future Hydropower Scenarios Under the Influence of Climate Change for the Riparian Countries of Lake Victoria Basin

2010

Knowledge Networks for the Nile Basin

Hydropower is a major source of energy in the Lake Victoria basin (LVB) which is mainly due to the abundant hydro power potential. Despite this, the energy sector is still face with several challenges. Some of these include sustainable river flows for hydropower exploration, impact of climate change on the hydrology, increased abstraction due to population growth, and other competing water demands such as agriculture, industry, forestry and domestic use.The energy sector experienced hydropower shortages during the 2007/2008 period. This was attributed to several factors including declining water levels at the different hydropower generation plants. Climate variability and change was also linked to the decline in hydropower production. However, the impacts of climate change on hydropower in the Riparian Countries of LVB are less known since they have never been studied. This research therefore aimed at exploring the impact of climate change on the future development and operation of hydropower schemes in Lake Victoria Basin (LVB). The hypothesis was to test whether climate change will have a significant impact on hydropower generation in LVB.

To achieve the objective of the study, hydrological models were built for two case studies in the LVB that is Kagera and Mara sub-basins, using the Soil Water Assessment Tool (SWAT). The results showed that model performance varies greatly for the two case studies. The results are highly dependent on several factors including the geophysical characteristics of the study areas (such as presence/absence of wetlands), quality and quantity of hydrometrical data available for calibration. The simulations showed that the performance of the SWAT model was better for the Mara basin compared to the Kagera. For both basins, simulated flow trends were well represented by the SWAT model.

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