UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

Micro Hydro Potential Modelling - Integrating GIS into Energy Alternatives for Climate Change Mitigation

Gerald Cheruiyot Kipngeny Chelelgo F56/P/8731/05
BSc. Electrical & Electronic Engineering (UoN)

A thesis submitted in partial fulfilment for the Degree of Master of Science in Environmental & Biosystems Engineering at the Environmental & Biosystems Engineering Department in the University of Nairobi.

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DECLARATION

This research project is my original work and has not been presented for award of a degree in any other university or any other institution of higher learning for examination.

Sign.................................... **Date......................................**

Gerald Cheruiyot Chelelgo

F56/P/8731/05

This research report has been submitted for examination with our approval as the University Supervisors.

Sign.................................... **Date....................................**

Prof. Elijah K. Biamah,

Department of Environmental & Bio-Systems Engineering

Sign….................................. **Date....................................**

Dr. David N. Siriba,

Department of Geospatial and Space Technology

DEDICATION

I thank God for the blessing of precious family, friends, mentors and teachers who have prodded me along this walk and inspired my thoughts. I dedicate this work to God’s glory, to my wife Maryanne and three beautiful daughters, Tamara, Natalie, and Keilah; and to mankind that we may live sustainably and leave the world a better place for tomorrow’s generation.

Learning and innovation go hand in hand. The arrogance of success is to think that what you did yesterday will be sufficient for tomorrow. – *William Pollard*

ACKNOWLEDGEMENT

The completion of this study was made possible through supportive efforts from several individuals and institutions. I therefore extend my most sincere thanks to all those who contributed in these efforts.

This project could not have been produced without invaluable advice and critique from a number of generous people. Foremost are my supervisors, Prof. Elijah K. Biamah, and Dr. David N. Siriba, for the encouragement and guidance throughout the course of this research, which ensured that I came up with a quality piece of work. I extend my gratitude to the chairman of the Environmental & Biosystems Engineering department, my lecturers, faculty support staff and the Board of Postgraduate Students as well.

My appreciation also goes to my classmates, with whom I weathered through the storms, giving each other encouragement and valuable input.

Last but not least, my credits to the following institutions for assistance in field work as well as availing data necessary for the research; The Kenya Meteorological Department, Baringo Water Company, Rift Valley Water Service Board, WRMA, Survey of Kenya.

May God bless you all abundantly.

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LIST OF ABBREVIATIONS

ARD	Associates in Rural Development
CE	Circular Error
CGIAR	Consultative Group for International Agriculture Research
CIAT	International Centre for Tropical Agriculture
CIS	Consortium for Spatial Information
CDM	Clean Development Mechanism
CRA	Commission on Revenue Allocation
CRWR	Centre for Water Resources, University of Texas
DCW	Digital Chart of the World
DEM	Digital Elevation Model
DEPHA	Data Exchange Platform for the Horn of Africa
DTM	Digital Terrain Model
EMCA	Environment Management and Coordination Act, 1999
ERB	Kenya Electricity Regulatory Board
ESRI	Environmental System Research Institute
FAO	Food and Agricultural Organization
FEWS	Famine Early Warning System
GDP	Gross Domestic Product
GHG	Greenhouse gases
GIS	Geographic Information System
GISWR	GIS in Water Resources Consortium
GoK	Government of Kenya
GWh	Gigawatt hours
ILRI	International Livestock Research Institute
ITDG	Intermediate Technology Development Group (now Practical Action)
JNC	Jet Navigation Charts
KNBS	Kenya National Bureau of Statistics
KWh	Kilowatt Hours
LE	Linear Error

LEAP	Long-range Energy Alternatives Planning system
m.a.s.l.	Meters above Sea Level
MoE	Ministry of Energy
MSL	ean Sea Level (MSL)
MW	Megawatts
MWe	Megawatts, electric
NASA	National Aeronautics and Space Administration
ONC	Operational Navigation Charts
Ppm	Parts Per Million
SEI	Stockholm Environment Institute
SRTM	Shuttle Radar Topographic Mission
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USGS	United States Geological Survey
WGS	World Geodetic System
Yr	Year

ABSTRACT

This research focused on integrating GIS into energy alternatives for climate change mitigation by creating a GIS-based hydrologic model that can be used to identify sites that have significant potential for micro hydropower development within the River Perkerra catchment area. Hydropower is a clean and renewable energy source that remains largely untapped in the country and its development can be used to mitigate anthropogenic climate change by reducing reliance on fossil or bio-mass derived fuels. This research established the extent of this resource and whether the available sites with significant micro hydropower potential within the study area were amply copious to warrant further development. Currently, such identification is done physically using means that are menial, costly and significantly time consuming. A 90-metre resolution Digital Terrain Model (DTM) data obtained from the Shuttle Radar Topography Mission and various GIS tools were used to create a hydrologic framework which was used to identify potential sites along River Perkerra that suit any desired head requirement for the purposes of locating micro hydropower plants. The derived model demonstrated that it is possible to identify sites at discrete geographic locations along any stream drainage network using GIS. In addition, the model also provides a decision support system that integrates a powerful graphical user interface, spatial database management system and a generalized river basin network flow model for the purposes of exploiting and developing micro hydropower. With sufficient data on catchment discharge and use of higher resolution DTM, the model can be further enhanced to accurately obtain the total micro hydropower potential of River Perkerra whereby the potential of every stream segment would be aggregated.

CHAPTER 1: INTRODUCTION

1.1 Study Background

Kenya hopes to industrialize by 2030 (GoK, 2006). This would involve development of industries on an extensive scale and impact on the livelihood of its citizens. Industrialization has both negative and positive impacts of which the positive include economic growth and food security among others, whereas the negative include climate change which was first noticed as an impact of industrialization by Svante Arrhenious, a 19th century Swede scientist. Arrhenius, (1896).

Climate change is related to energy use and as such, it has been established that greenhouse gas emissions associated with energy use and generation are the key causes of anthropogenic climate change. Currently, CO_2 concentrations stand at 380 ppm and the global average temperature has risen by 0.6 $^{\circ}$C over the past 100 for which the effects are being noticed. With status quo prevailing, continued use of fossil fuels and destruction of bio-mass to satisfy the ever growing energy demand, the global average temperature is expected to rise by between 1.4 $^{\circ}$C and 5.8 $^{\circ}$C this century (Houghton et al., 2001).

Climate change is already having a large negative effect on the region's socio-economic development and this is likely to exacerbate hence the need to vigorously pursue technical and social mitigation strategies as well as promoting adaptation. If unchecked together with other factors including rapidly growing population, poor management of natural resources and limited use of technologies, climate variability or long-term climate change could worsen the poverty situation in Kenya. (Bergkamp et al, 2003).

Since factors related to energy use are the main contributors to climate variability, any technical intervention needs to focus more on greener sources of energy such as solar, geothermal and hydropower. Pico, micro and mini hydropower is one of the energy sources that can be harnessed in the Kenya but siting of the points for harnessing this energy poses a challenge. This research aimed at providing a means of using GIS to identify locations along river drainage networks that potentially meet the head (river drop) and river discharge requirements for siting micro hydropower plants to enable further evaluation and development to harness this clean energy source.

1.2 Problem statement

Climate change is an issue of global impact and concern which is driven mainly by anthropogenic causes. There is need to adopt cleaner energy and at the same time reduce demand for biomass energy that has driven destruction of forests which naturally act as carbon banks whilst sequestering atmospheric carbon dioxide, one of the major greenhouse gases (Pacala & Socolow, 2004).

Hydropower is one of the most common renewable energy resources abundantly available in regions that receive significant rainfall and provides itself as an alternative clean, low cost and well developed technology that can be adopted to avert energy scarcity, biomass destruction and advancement of climate change (Frey & Linke, 2002).

Geographic Information System (GIS) technology on the other hand is evolving and its use expected to steadily increase across a multitude of domains. GIS provides an efficient framework for geo-referencing information enabling expedited and accurate decision making based on location and innate relationships hence reducing the costs associated with extensive fieldwork and manual office work. The overall problem addressed by this study was that while the use of GIS has been commonplace in disciplines such as forestry, hydrology, environmental management, geology and mining, it has not been used extensively in the exploitation of renewable energy sources. (Renewables.com, 2015)

Despite the 3,000 MW estimate of untapped hydroelectric capacity of small, micro to pico-hydropower, part of which may be viable for community based electricity production, detailed resource assessments have only been done for a small number of hydroelectric power projects in all regions making it impossible for hydroelectric power projects to be included in the least-cost power development plan (GoK, 2004).

Currently, identification of suitable micro hydropower sites within river drainage networks is conducted through abstract and manual means that do not provide the entirety of crucial hydrologic information needed to support decision making. This process is menial, time consuming and costly hence in order to hasten and improve the process of locating and planning micro hydropower projects within a given river basin there are pertinent research questions such as:

Could GIS be used as a proactive planning tool that could lay ground for a quicker assessment of micro hydropower potential and identification of suitable sites where this source of renewable energy can be effectively exploited?

1.3 Research questions

This study was guided by the following focal research question:

Can GIS be used as a planning tool in the development of micro hydropower? And if so;

i. How can GIS provide information on river drainage networks to facilitate planning and development of micro hydropower?

ii. How can GIS be used to identify locations along river drainage networks that provide the highest head (river drop) for any given micro hydropower installation?

iii. How can GIS be used to accurately estimate micro hydropower energy potential of specific identified sites within a river drainage networks?

1.4 Research objectives

The overarching objective of this research study was to identify sites along the River Perkerra catchment within Baringo County, Kenya, that have significant potential for micro hydropower development by use of a GIS-based hydrologic model.

The specific objectives of this study were:

1. To determine the appetite for adoption of renewable by assessing energy use within the study area.

2. To delineate the River Perkerra watershed and its stream network from DTM data and ground-truthing the derived river network against that obtained from digitized maps.

3. The identify sites along the River Perkerra network with suitable head requirement and potential for micro hydropower development

4. To estimate the hydropower generation potential of selected sites along the gauged segments of River Perkerra.

1.5 Research hypothesis

i. GIS hydrologic modelling can be used to estimate the micro hydropower potential of renewable water energy resources in Kenya.

ii. Potential micro hydropower sites are numerous within the study area hence can contribute sufficient power for rural electrification.

iii. Aggregation of the derived stream segment potentials reflects the micro hydropower potential within the study area.

1.6 Scope and Limitations of the study

Integrating GIS into energy alternatives for climate change mitigation by micro hydropower potential modelling was done on a spatial and time domain using process models. The watershed and stream network layout was obtained from digital elevation models and mapped streams. Data which were not available were interpolated using focal statistics and re-sampling tools within the GIS application.

The Arc-Hydro time series component provides a means for storing spatially and temporally irregular measurements including stream flow and monitoring point measurements. It was difficult to acquire all stream flow and monitoring point data for the study area. Only water resources associated with natural water courses were assessed.

1.7 Significance of the study

This study was required to address the development of micro hydropower resources that would buttress efforts aimed at mitigating climate variability and change through the reduction of GHG emissions, increased sequestration of CO_2 by means of preservation of bio-mass, use of green energy and reducing dependence on fossil fuels.

Most rural populations are located off the grid and despite concerted efforts by the government through its agencies to rapidly extend electrical distribution networks to rural areas, getting access to the national grid is still costly and exigent to low income households. If the results of this study are implemented, rural populations can be empowered by access to a low cost and sustainable clean energy to promote development and drive commercial activities. As a result, more people would have opportunity to a wider range of economic activities such as to micro industry and agricultural processing. The issue of energy and poverty will also be addressed leading to less demand for wood based fuels and benefiting the environment due to the corresponding reduction in logging (Practical Action et al., 2014).

Micro hydropower installations are known to have a long running life requiring minimum capital investment once operational. In this sense, populations served by this sustainable energy source would benefit from reduced health hazards and energy costs associated with kerosene, charcoal and firewood. On a bigger scale, the Sessional Paper No. 4 of 2004 on Energy states that there exists hydroelectric potential in the category of small and micro hydropower which is projected to be about 3,000 MW. It further states of the government's intention of encouraging development of such projects by communities and investors alike on priority of those commanding high economic merit.

To facilitate the government and stakeholders in undertaking reconnaissance and feasibility studies to establish the available micro hydropower potential within any given river drainage network, GIS potential modelling can serve as a strategic and tactful approach.

Access to electric lighting and energy by rural communities would translate to increased academic performance by school going children due to;

i. Less time engaged in collecting firewood

ii. Reduction of respiratory illnesses

iii. Being able to study after dusk

iv. Improved access to information via television, radio and internet

In addition, occupational hazards associated with tin lamp fire accidents, smoke inhalation would virtually be eliminated if adoption and expansion of micro hydropower supplied electricity is encouraged.

1.8 Description of the study area

1.8.1 Geographic Location

The study was based in Perkerra river catchment which falls across the two counties of Baringo and Nakuru within Nakuru, Koibatek, Mogotio and Baringo districts. The latitudinal extent is 00° 05' 44" S - 00° 32' 41"N, the longitudinal extent 35° 31' 47" E - 36° 07' 52"E, the highest elevation 3,048 meters while the lowest elevation 965 meters above sea level.

River Perkerra catchment has an area of 1207 km^2 and drains into Lake Baringo whose drainage area is 6820 km^2. The entire catchment is characterised by very steep slopes on the hillsides and gentle slopes in the middle and lower reaches where the surface is bear with very little undergrowth (Onyando et al., 2005).

A large extent of the Perkerra catchment falls within Koibatek district while the Molo River headwaters are in Nakuru district. The lower reaches of the River Perkerra flows through Mogotio district while floodplain lies in Marigat district where the river empties its waters into Lake Baringo. River Perkerra river and its tributaries: Lelgel, Tigeri, Ravine, Narosura and Molo form the core hydrologic drainage network.

1.8.2 Vegetation and Wildlife

The vegetation within the study area varies from tropical alpine moorland with swamps, tussock and tufted grasses at the upper altitudes giving way to moist montane forests bearing species *Arundinaria alpina* (mountain bamboo), *Hagenia abyssinica* (African redwood), *Juniperus procera* (African pencil cedar), *Dombeya torrida* (Mukeu or Silipchet), *Podocarpus latifolius* (Podo), *Polyscias kikuyuensis* (Mutati or Mwachoniot), *Prunus Africana* (Red stinkwood), *Olea capensis* (East African Olive) and *Olea europaea ssp. Africana* (Brown Olive). This is an extension of the Mau complex known as the Lembus forest consisting of indigenous trees, glades of tufted and kikuyu grass and exotic pine and cypress plantations. There is a transition from the montane to intermediate forest containing *Croton macrostachyus*, *Warburgia ugandensis* (East African greenheart), *Tarchonanthus camphorates* (Wild sage wood), *Acokanthera schimperi* (Arrow-poison tree), *Euphorbia tirucalli* and *Acacia drepanolobium* (Whistling thorn). On the rift valley floor, the vegetation consists of low Acacia woodland, bush land and thicket.

A number of wild animals can be found within the study area ranging from buffalos, leopard, bongo, giant forest hog, and a variety of snakes, gazelles, hyena, wild dogs as well as occasional migratory herds of the African Elephant. Baringo County has 65,280.4 ha of gazetted forests. Established plantations cover an area of 13,940 ha while the rest is natural (Baringo County, 2014).

Environmental degradation is a challenge facing Baringo County and is driven by deforestation, livestock overstocking, uncontrolled charcoal burning, and invasive *Prosopis juliflora*, cultivation on deforested and steep slopes. If this remains unchecked, there would be continued loss of productive land and wildlife habitat, due to extensive soil erosion, flooding and desertification creep.

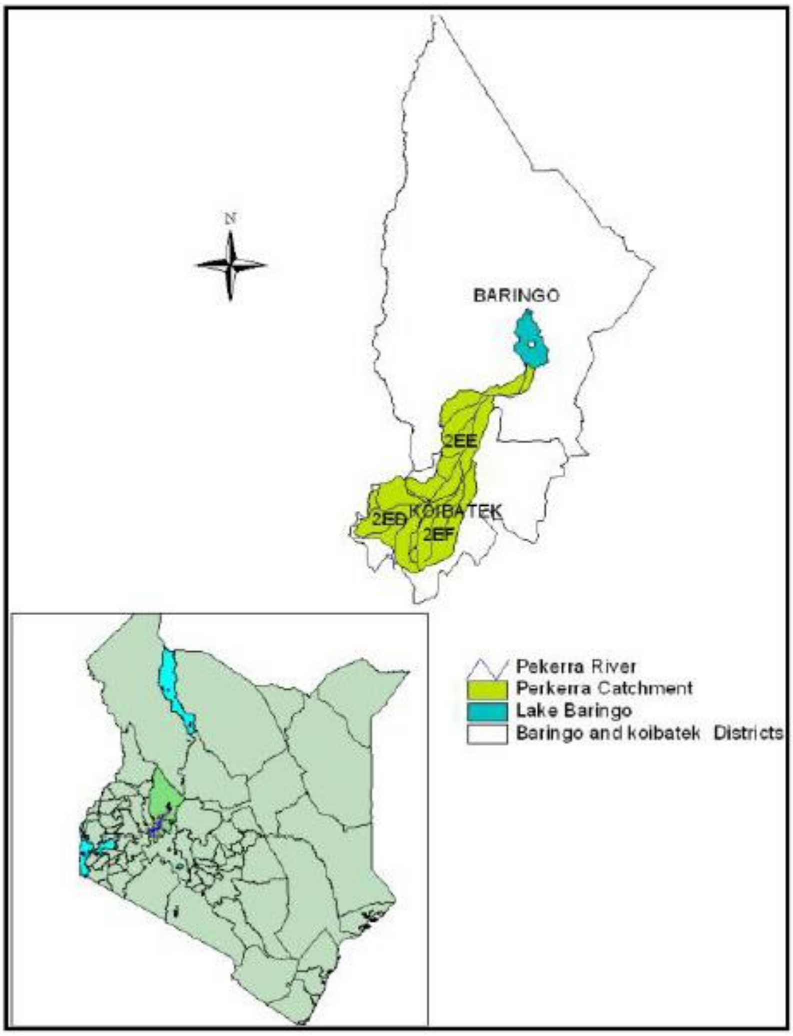

Figure 1.1: Perkerra River Catchment Area (Mugatsia, 2010).

1.8.3 Topography and Climate

Topographical features in the Baringo include valleys, plains, highlands and hills, lakes and the floor of the Great Rift Valley. These topographical features are an important tourist attraction and include the Kerio Valley, Lake Bogoria, Lake Baringo and Lake Kamnarok. The county straddles across the rift valley from the Laikipia plateau near Nyahururu transversely to the Mau ranges with the Tugen hills lifting up from the valley floor running north to south. The presence of these highland and the lowland features within the study area contribute immensely to the diverse climatic characteristics which can be categorized into the distinct agro ecological zones that can be defined as Upper Highland (UH), Lower Highland (LH), Upper Midland (UM), Lower Midland (LM) or Inner Lowland (IL). Figure 1.2 illustrates the distribution different AEZ within the study area.

The mean temperature ranges from below 10° C in the upper highland zones to above 25°C in the inner lowland zone around Lake Baringo (Refer to figure 1.2. while the average annual rainfall ranges from >1400 mm in the UH (1,2) and LH 2 AEZ to below 400 mm in the IL (6) AEZ bordering Turkana county. This is temperature variation. Table 1.1 gives a summary of the temperature and precipitation characteristics of the different AEZ while table 1.2 and 1.3 contain historical temperature and rainfall data for selected stations within the study area.

The precipitation and the topography within the study area sustain the expansive hydrologic network forming the River Perkerra catchment. The spread of average annual rainfall across the study area and trimodal distribution are illustrated on Figures 1.3 and 1.4.

There is Evidence of climate change have been observed through the increase in frequency and intensity of weather events such as drought, flooding, severe frost, high daytime temperatures and season variability leading to an escalation of waterborne diseases, expanded malaria zones and famine (Ogola et al., 2012; Ngaira, 2007; Trauth et al., 2007; Aloo, 2002).

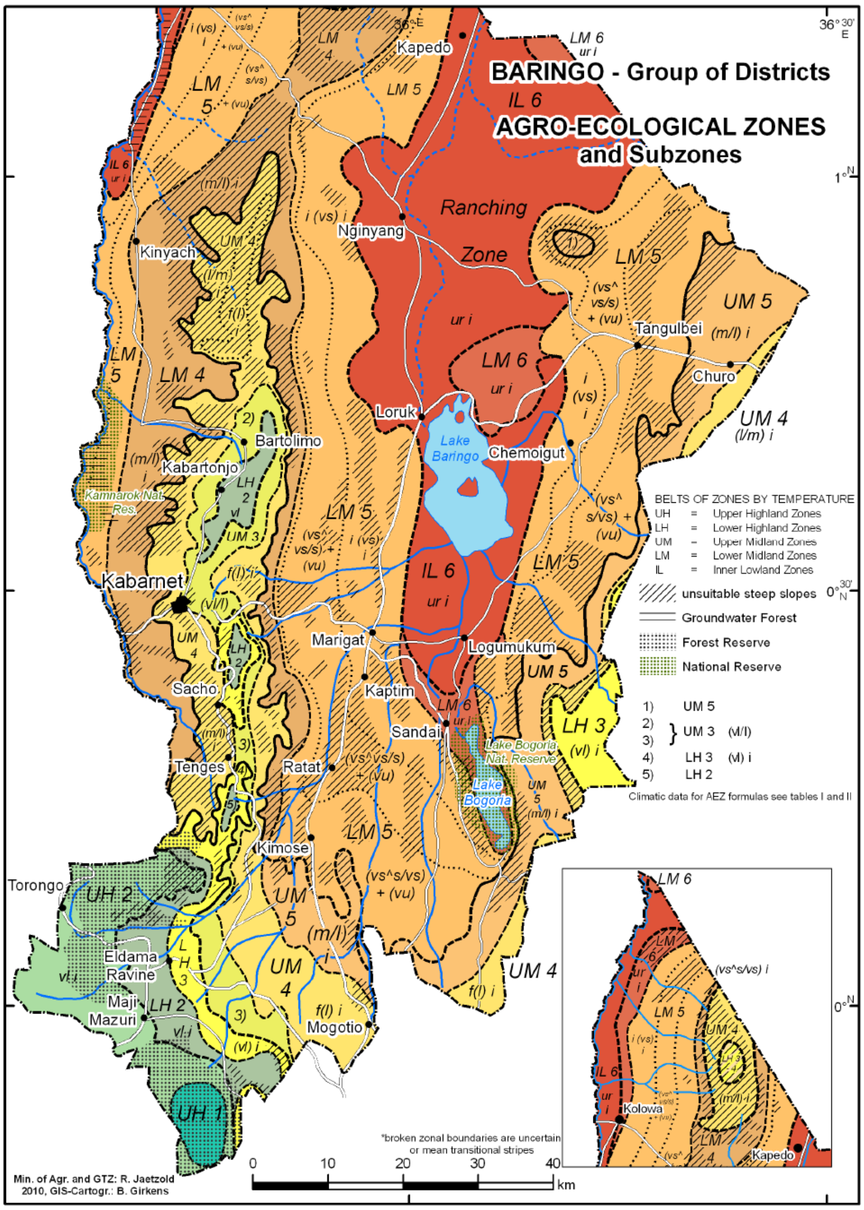

Figure 1.2: Agro-ecological Zones and sub Zones (Jaetzold et al., 2010).

Table 1.1: Climate in the Agro-Ecological Zones (Jaetzold et al., 2010).

Agro-Ecological Zone	**Altitude in m**	**Annual mean temp. in °C**	**Annual av. rainfall in mm**
UH 1 Sheep-Dairy Zone	Here Forest Reserve (very steep, cold and wet)		
UH 2 Wheat-Pyrethrum Zone	2 400-2 700	15.0-12.2	1 200-1 500
LH 2 Wheat/Maize-Pyrethrum Zone	2 100-2 400	17.0-15.0	1 200-1 450
LH 3 Wheat/Maize Barley Zone	1 960-2 400	18.0-15.0	900-1 300
UM 3 Marginal Coffee Zone	1 800->2 000	19.2-<18.0	1 000-1 400
UM 4 Maize-Sunflower Zone	1 550-1 950	21.0-18.1	850-1 400
UM 5 Livestock-Sorghum Zone	1 530-1 850	21.0-18.7	700-950
LM 4 Marginal Cotton Zone	1 060-1 550	23.8-21.0	800-1 200
LM 5 Lower Midland Livestock Millet Zone	1 030-1 550	24.0-21.0	700-980
IL 6 Lower Midland Ranching Zone	1 000-1 430	24.0-21.6	580-750
IL 6 Inner Lowland Ranching Zone	900->1000	24.0-25.0	300-750

Table 1.2: Temperature Data (Jaetzold et al., 2010).

No. And altitude	Name of Station	AEZ	Kind of records	Temperature in °C													Years of rec.
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
9035069	Equator	UH	Mean max	19.7	20.6	20.6	19.2	18.3	17.2	15.8	16.1	17.9	18.6	18.1	18.3	18.4	30
2,765 m	Met. St.	1-2	Mean	13.7	14.3	15.0	14.0	13.5	12.6	11.8	11.4	12.8	13.1	13.0	13.0	13.2	
	(operating		Mean min	7.7	7.9	8.3	8.8	8.6	8.0	7.8	7.7	7.6	7.6	7.9	7.7	8.0	
	to 1960)		Abs min	0.6	5.0	4.4	4.4	2.8	3.3	2.8	-1.1	3.3	3.3	3.9	1.7	-1.1	
9835007	Eldama	LH 3	Mean max	24.7	24.8	26.2	24.5	23.7	23.4	22.3	21.9	23.4	23.8	22.4	23.4	23.7	17
2,147 m	Ravine		Mean	16.4	16.8	17.6	17.2	16.5	16.1	15.5	15.2	15.7	16.0	15.8	15.7	16.2	
	Police		Mean min	8.2	8.8	9.1	9.9	9.4	8.9	8.7	8.6	8.0	8.3	9.2	8.0	8.8	
	Stat.		Abs min	2.8	2.8	4.4	5.6	4.4	3.3	2.2	3.3	3.3	3.3	3.3	2.8	2.2	
	(Operating																
	to 1932)																
8935163	Perkerra	IL 6	Mean max	33.2	33.7	33.6	32.6	32.4	32.0	30.3	31.0	33.1	32.9	31.3	31.4	32.3	12
1,065 m	Irrigation	- LM	Mean	24.7	25.3	25.7	25.3	24.8	24.1	23.7	23.5	24.4	24.8	24.2	23.9	24.5	
	Scheme,	5	Mean min	16.2	17.0	17.8	18.0	17.2	16.3	17.1	16.1	15.7	16.8	17.2	16.5	16.8	
	Marigat		Abs min	11.3	10.9	12.5	14.9	13.4	10.2	12.5	11.7	12.1	12.9	12.1	10.2	10.2	

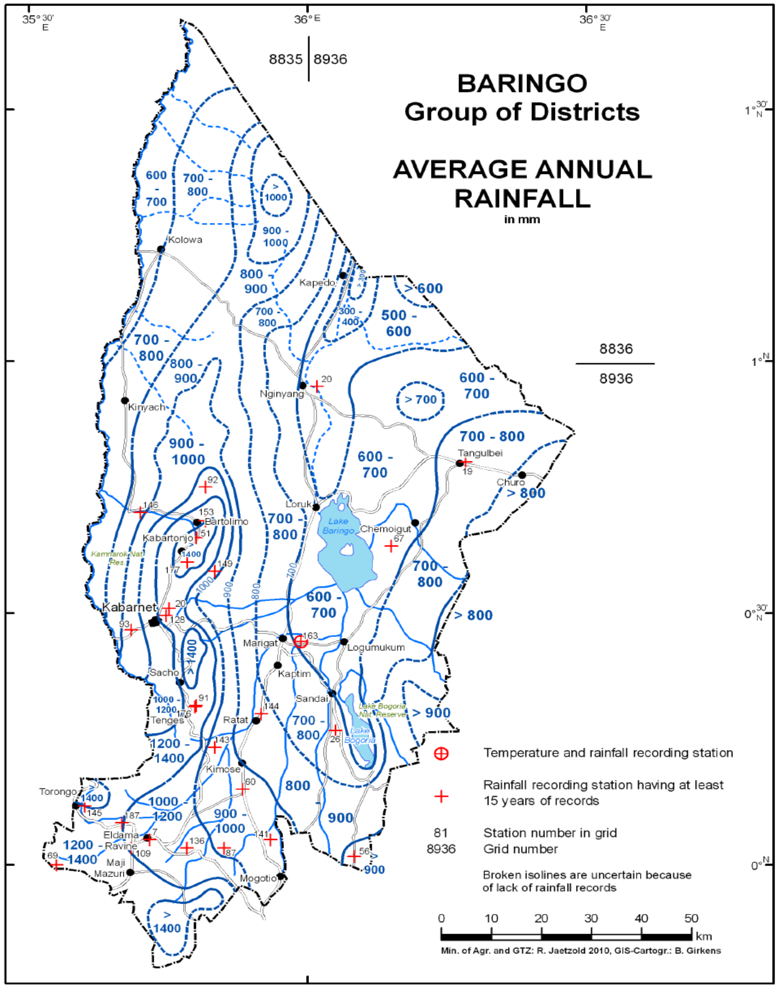

Figure 1.3: Average Annual Rainfall (Jaetzold et al., 2010).

Table 1.3: Average monthly rainfall distribution (Jaetzold et al., 2010).

Station Name	Station No.	Altitude m.a.s.l.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
D.O., Eldama Ravine	8935007	2194	32	43	81	167	142	94	122	128	78	73	92	52	1104
Emening Health Centre	8935060	1706	20	26	61	128	118	72	135	116	65	49	54	50	894
Esageri Kiptuim Aron Farm	8935087	1870	61	51	72	125	130	97	127	116	69	74	95	54	1071
Narasha Forest Station	8935109	2377	44	59	82	189	155	90	120	142	80	66	116	70	1213
Agric. Holding, Kibimoi	8935136	1968	52	62	99	177	123	90	116	123	74	73	111	65	1165
Cheberen Market	8935143	1476	24	33	70	137	119	84	113	127	55	58	74	48	942
Torongo Primary School	8935145	2600	52	48	96	229	155	98	141	172	87	97	106	82	1363
Chemususu	8935187	2360	33	41	79	201	143	107	145	141	85	76	99	41	1191
Equator C.D. Cullen	9035069	2762	36	46	77	164	136	111	157	193	105	53	73	54	1205
Ratat Intermediate School	8935144	1246	35	38	59	114	112	50	113	104	48	50	68	44	835
Perkerra Agric. Research Station	8935163	1148	28	25	50	87	74	55	90	83	35	35	48	29	639
Snake Farm, Lake Baringo	8936067	1050	23	33	44	91	73	66	94	93	32	31	61	27	668

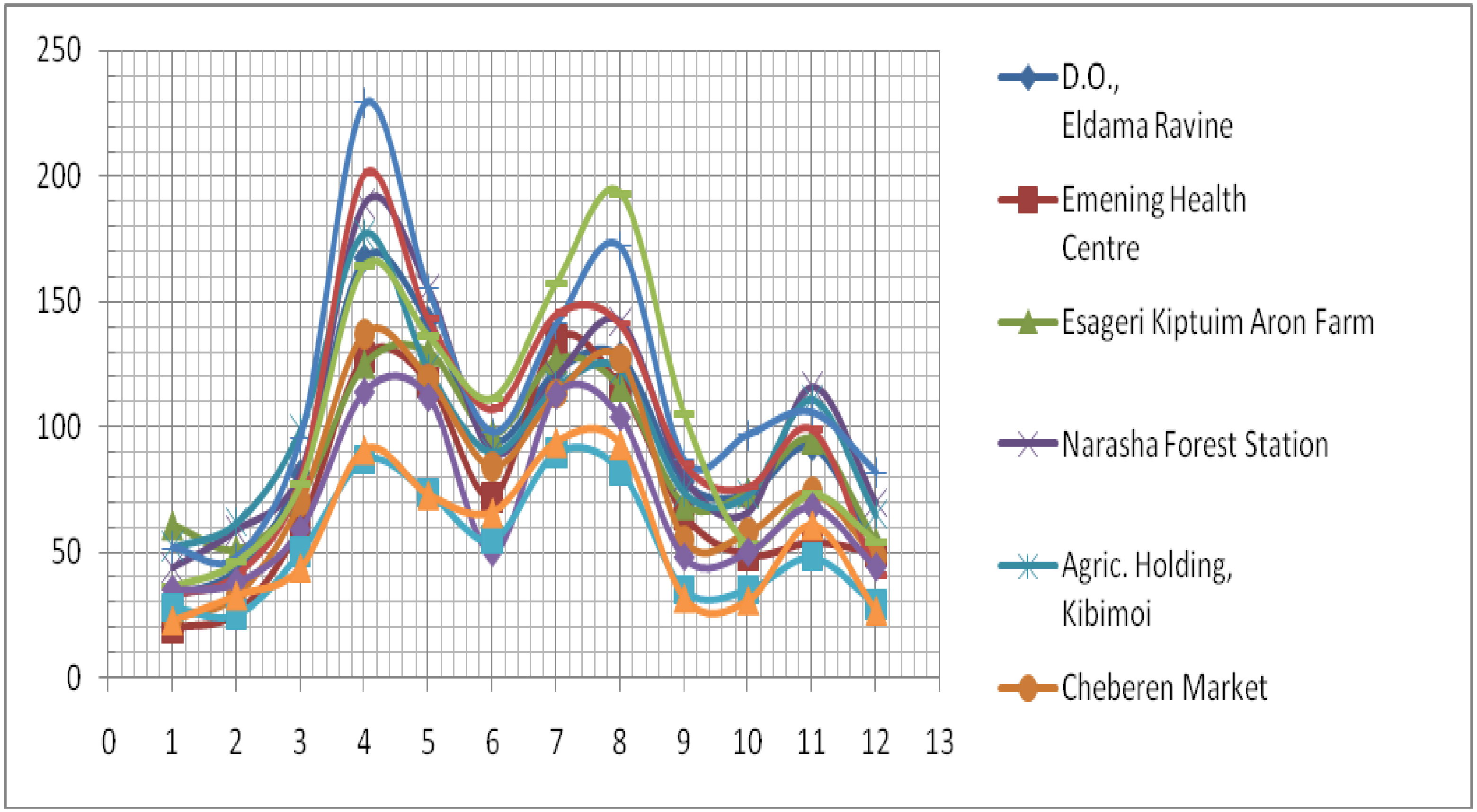

Figure 1.4: Tri-modal rainfall distribution (Rainfall data obtained from the Kenya Metrologic Department in 2005).

1.8.4 Administrative and political units

Figure 1.5 shows the 6 sub-counties Baringo County comprises of, namely Koibatek, Mogotio, Baringo Central, Marigat, Baringo North and East Pokot. These sub-counties are further divided into 30 wards (formerly divisions) and 116 locations as listed on Table 1.4 below.

Six electoral constituencies make up Baringo County namely, Eldama Ravine, Mogotio, Baringo South, Baringo Central, Baringo North and Tiaty having a total of 171,344 registered voters (Baringo County, 2014).

Table 1.4: Administrative Units in Baringo (Baringo County, 2014).

Sub-county	Area km²	Number of Wards / Divisions	Number of Locations	Number of Electoral Wards
Mogotio	1,314.6	5	24	3
Koibatek	1,002.5	4	16	6
Marigat	1,678.0	3	17	4
Baringo Central	799.9	4	21	5
Baringo North	1,703.5	4	14	5
East Pokot	4,516.8	6	24	7
Total	**11,015.3**	**26**	**116**	**30**

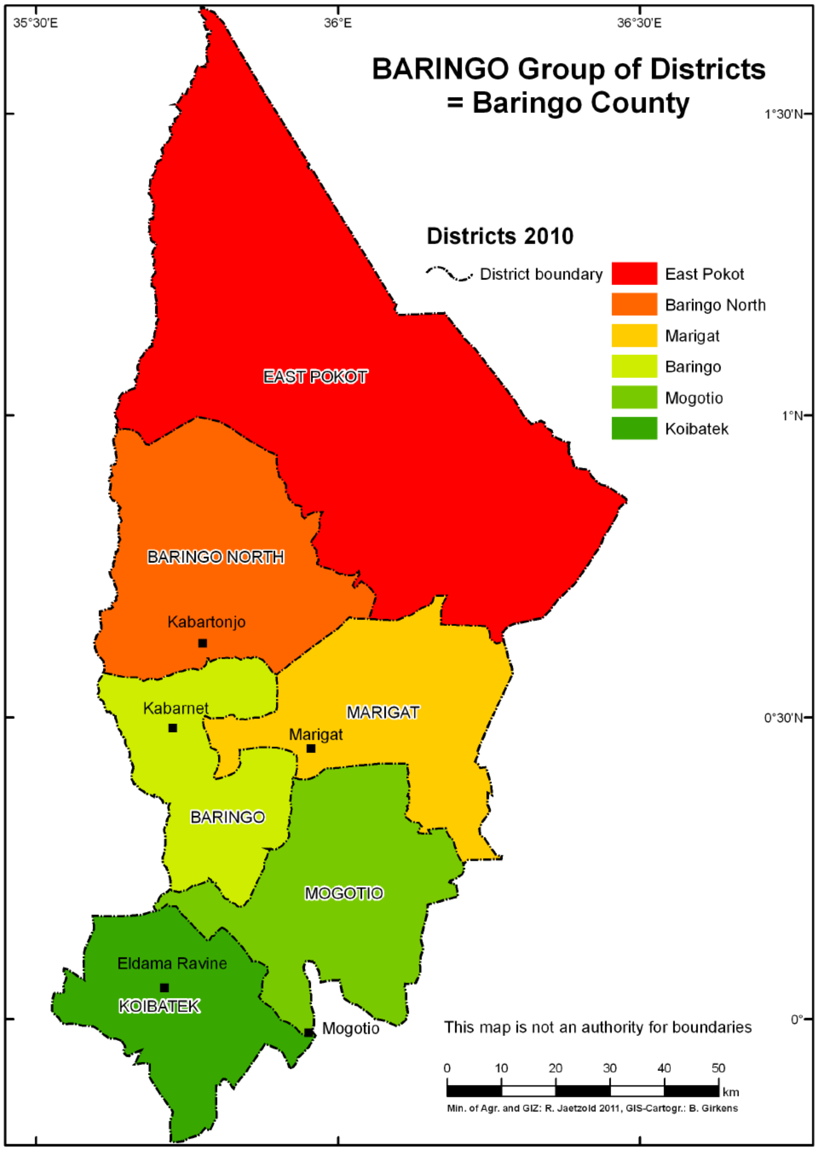

Figure 1.5: Baringo County (Jaetzold et al., 2010).

1.8.5 Demographics

According to the 2009 population and housing census, Baringo County has a population of 555,561 persons consisting of 279,081 males and 276,480 females. The county's inter-censal growth rate is 3.3% per annum which is above the national average of 3%. The population is projected to grow to 723,411 persons by 2017 (Baringo County, 2014).

The population density, poverty rate and share of urban population are indicated on Table 1.5.

Table 1.5: Demographics (CRA, 2011).

General Information (2009)	Baringo
Population	555,561
Surface area (km^2)	11,015
Density (people per km^2)	50
Poverty rate, based on KIHBS (%)	57.4
Share of urban population (%)	11

1.8.6 Urbanization and Socioeconomic information

The main administrative and urban centres in Baringo are Kabarnet and Eldama Ravine while there are several rapidly developing centres namely Timboroa, Maji Mazuri, Torongo, Mogotio, Marigat and Kabartonjo. A network of paved and drivable unpaved roads interconnects these centres. The extent of access to infrastructure is shown on Table 1.6 while Table 1.7 shows the urban population.

Table 1.6: Access to Infrastructure (CRA, 2011).

Access to Infrastructure	**Baringo**
Improved water (% households 2009)	35.1
Improved sanitation (% households 2009)	57
Electricity (% households 2009)	9.6
Paved roads (as % of total roads)	15.7
Good/fair roads (as % of total roads)	54.6

Table 1.7: Urban population (CRA, 2011).

Urban population in largest towns	**Baringo**
Kabarnet	25,346
Eldama Ravine	17,872
Marigat	6,661
Maji Mazuri	4,265
Mogotio	3,701
Timboroa	3,150

The major economic activities in Baringo district include agriculture, banking, tourism, horticulture, mining, commerce, industry and professional services. The industrial activities include timber sawmilling, milk processing, bakeries, grain handling and milling, mining, quarrying and abattoirs.

Small and medium scale businesses are situated in residential areas, centres and towns while quarrying is a rapidly expanding extractive industry within Arama, Kamasaba, Kamngoech, Simotwet, Metipso, Sinonin and Equator areas.

Health, education, banking and market facilities are widely available in the more populous and developed regions with all major centres connected to the electricity.

As at the year 2012, there were 656 primary and 125 secondary schools where enrolment was at 169,912 and 27,803 students respectively. Tertiary education is offered through youth polytechnics, private colleges and a university campus located in Baringo. Special needs and early childhood development centres also form part of the education system (Baringo County, 2014).

1.8.7 Agriculture

Higher elevations mostly have a modified tropical montane climate with volcanic soils that are generally well drained and fertile. In this zone lies the high potential for agriculture, forestry and dairy husbandry. As such, dairy and mixed farming is practice in the highlands while animal grazing and apiculture are practiced in the lowland areas.

The main crops grown in Baringo include cut flowers, wheat, potatoes, pyrethrum, maize, coffee, sisal, macadamia and fruits and are dependent on the agro ecological zone. At Perkerra irrigation Scheme in Marigat area near Lake Baringo, water from the River Perkerra is used to irrigate tracks of land on which fruits, vegetables and grains are grown. Commercial agriculture involving the production of cut flowers for the export market is expanding around Eldama Ravine. Table 1.8 illustrates the distribution of agricultural potential within Baringo.

Table 1.8: Baringo County Land Potential (KNBS, 2013)

Categories Of Agricultural Land ('000 Hectares)				
High Potential	**Medium Potential**	**Low Potential**	**Other Land**	**Total Land Area ('000 Hectares)**
166	84	751	62	1,063

1.8.8 Energy sources

The main source of energy in the Baringo at the moment is fuel-wood for cooking and kerosene for lighting. Though district's urban centres are fairly connected to the electric power grid, there are few *"last mile"* connections leading to prohibitive consumer connection costs.

The total electricity connections in Baringo stood at 10,400 with 2,346 connections made in the year 2010 – 2011 (Baringo County, 2014).

One of the objectives of this research would determine the percentage use of diverse energy sources.

CHAPTER 2: LITERATURE REVIEW

This chapter will review the past studies done in the development of GIS models and the hydropower technology.

2.1. Energy use in Kenya

Biomass and fossil fuels form the primary source of energy in Kenya mainly in the form of charcoal, firewood and petroleum while electric based energy serves the rest of the country's energy needs (GoK, 2004)

The Kamfor study, (2002) highlights the dominant role of biomass energy (80.5%), while petroleum products account for 18% and electricity only 1.4% while there has been increased adoption of renewable energy such as solar and wind power.

Because of the link between biomass and fossil fuel to climate change, there is need to develop clean energy systems to cater for conventional or commercial energy. This would reduce the demand for traditional energy forms which have significant potential in meeting energy requirements. These energy forms include wind, solar, hydropower, geo-thermal amongst others. Energy poverty through lack of access to electricity and dependence on solid biomass fuels for cooking and heating remains an enduring global problem (Sovacool & Drupady, 2012).

2.2. Policy framework for energy in Kenya

"Sessional Paper No. 4 on Energy", 2004 lays the policy framework upon which the government aims to provide cost-effective, affordable and adequate quality energy services to the domestic economy on a sustainable basis over the period 2004-2023. The overall national development objectives of the Government of Kenya are pegged on the condition that quality energy services are made available in a sustainable, cost effective and affordable manner to all sectors of the economy ranging from manufacturing, services, mining, and agriculture to households. (GoK, 2004)

By virtue of its versatility in application, electricity is crucial to Kenya's economic growth (GoK, 2004) and can be expected to bring tangible social and economic benefits to rural communities (UNDP, 2004).

To encourage the wider adoption and use of renewable energy technologies and thereby enhance their role in the country's energy supply matrix, the Kenyan government has set out to design incentive packages to promote private sector investments in renewable energy and other off-grid generation (GoK, 2004). A study by Kebede and others (2010) suggests that countries must diversify their energy sources and introduce energy-efficient devices and equipment at all levels of the economy to improve GDP growth rate and GDP per capita. The International Energy Agency (IEA) notes that, without new policy initiatives, use of fossil fuels will account for more than 90% of total primary energy demand globally in 2020 (IEA, 1998).

2.3. Challenges in the Kenya electrical energy sector

Since the initiation of rural electrification programme in 1973, the rate of penetration has been slow partly due to the high cost of network extension and the scattered nature of the human settlements in rural Kenya. In 2003, the average cost of supplying a rural consumer was about seven times the national per capita income in 2002 while rural electrification schemes also incurred higher operating costs per unit of electricity supplied (GoK, 2004). Renewable energy technologies offer a cost-competitive alternative to conventional energy sources in applications such as off-grid electrification of small hydropower (Martinot, & McDoom, 2000).

Many studies have linked respiratory diseases in developing countries to exposure to indoor air pollution from the combustion of biofuels (Ezzati, & Kammen, 2001;

Smith et al., 2000). Beyond mitigating climate change, micro hydropower generated electricity would also assist in reducing occupational health risks associated with use of biofuels.

2.4. Opportunity in Hydropower Technology

Major international studies indicate significant growth-potential for renewable energy, particularly in scenarios where environmental constraints are imposed, for example on CO2 emissions (IEA, 1998)). Since the early 1970s there has been proliferation of 'new' renewables than any other electricity supply technology. These technologies include but are not limited to small hydro, geothermal, solar PV, wind and biomass. (WEC, 1993)

The Millennium Goals set out at the 2002 World Summit on Sustainable Development highlighted a concern on the threat to livelihoods if access to sustainable energy is not addressed (UN, 2002). Currently, in excess of 2 billion individuals from rural population in developing countries have no access to reliable electricity supply (UNDP, 2004) which means a lot still needs to be done to achieve MDG targets.

The degree of biomass use in Kenya is enormous; the subsequent impacts through release of trapped carbon as GHG, reduced CO_2 sequestration and microclimatic changes associated with deforestation as well as occupational health hazards. Based on a comprehensive study on supply and demand for energy undertaken in the year 2000, the estimated demand for wood fuel and other biomass in Kenya stood at 34.3 million metric tonnes, comprising 15.1 million metric tonnes of fuel wood and 16.5 million metric tonnes of wood for charcoal. Only 17% of the households consuming fuel wood buy it, while the rest obtain their fuel wood supplies from various sources including own farms and the rangeland (Karekezi, 2002). The study revealed that approximately 89% of rural households use firewood compared to 7% in the urban areas, with a corresponding per capita consumption of 741 kg and 691 kg in the rural and urban areas respectively. On the other hand, 82% of the households in urban areas and 34% in rural areas rely on charcoal to meet their energy needs. The per capita consumptions of charcoal in urban and rural areas were 152 kg and 156 kg respectively, depicting a national consumption of 2.4 million metric tonnes per annum. These consumption patterns are consistent with the findings of a similar energy survey undertaken by the Ministry of Energy in 1980 (GoK, 2004)

Acker and Kammen (1996) argues that, sustainable adoption of renewable technologies require the elimination of capacity gaps at the local, national and global level. This activity would need to involve every stakeholder as each has a significant role to play in accelerating technology transfer, espousal of renewable energy initiatives. A Global Energy Fund paper by Martinot, and McDoom, (2000) further discusses in great detail, measures to overcome the barriers to the development of renewable energy

There is an opportunity for accelerated investment in generation from renewable sources such as wind, small hydro and biomass sources by leveraging on a Feed-in Tariff policy (FiT) established by the Ministry of Energy in 2008.

2.5. Decentralized energy generation

In many parts of Africa, rivers flow throughout the year and the objective is to harness their energy-generating potential (Singh, 2009). This is the case in Kenya where scaling down hydropower installations towards micro-hydro presents an opportunity to this end by creating the possibility of decentralized hydropower generation targeted towards meeting the energy need of communities at a localized level. These initiatives can then be maintained and owned by local community and regulated by the Electricity Regulatory Board.

It may be derived that such discrete community serving power grid networks would expand and get bridged to a point where one micro hydropower served power network may supply surplus power to another. Eventually as the grid networks expand further it would be possible to bridge them to the national grid providing a bottom up approach to rural electrification as well as giving Kenyans an opportunity to invest in their own development by supplying surplus energy off to the power grid to serve the national energy demand for some capital gain. In such a scenario the need to rely on fuel oil thermal generation to supply the grid at times of peak demand and drought would be eliminated.

2.6. Hydropower

Hydropower has been in use since ancient times from before 200 B.C. by the Greeks and Chinese where this form of energy was harnessed for basic tasks such as irrigation, grinding of grains into flour. (Spain, 2011; Yannopoulos et al., 2014 & Reynolds, 2002).

In terms of significance, Hydropower is amongst the key sources of renewable energy for electrical power production with a projected global potential of 14,370 TWh/year, of which 8,080 TWh/yr. is currently considered economically viable (Fraenkel, et al., 1991). Consequently rural populations in Africa including those located far away from the electricity distribution grid can hugely benefit from local small-scale hydropower projects (Klunne & Michael, 2010).

Electricity is a secondary energy source, obtained through conversion of primary sources of energy such as hydropower, thermal, wind or solar (Mirza, et al., 2008) as such; micro hydropower generation is an inexpensive compliment to solar and other renewable energy forms. The nature of hydropower makes its use possible beyond a single home and instead can provide electric power to a several homes.

Apart from being environmentally benign, having a long running life and maintenance easy, small-hydro has the advantage of being amongst cost-effective energy technologies that can be considered for rural electrification in developing countries while also augmenting power generation from large hydro schemes

Whereas reservoirs associated with large-hydro have considerable social and environmental impacts such as interrupted fish breeding, methane release into the atmosphere, water quality degradation, intensification of disease vector as well as reduced water availability downstream, small hydro is a cleaner substitute (Evans & Evans, 2009; Renöfält, et al., 2010).

Another benefit of micro hydropower is that water, which would otherwise cause soil loss on steep slopes, is directed through pipes and its force is used to produce energy rather than cause erosion.

To date, there is still no internationally agreed definition of small-hydro. Some school of thought applies the term small-hydro to collectively cover small, mini, micro and pico hydropower schemes. Conventionally, small-hydro refers to between 2.5 and 25 MW, mini-hydro typically refers to schemes below 2 MW, micro-hydro below 500 kW and pico-hydro below 10 kW. These are arbitrary demarcations though most principals cut across smaller and larger schemes (Paish, 2002).

Pepermans and others define small-hydro as ranging between 1–100 MW and micro-hydro between 25 kW–1 MW. Some authors define generation between 1 kW and 1 MW as dispersed generation (Pepermans, et al., 2005).

Table 2.1 outlines the categories of hydropower schemes based on power output from hydropower.

Table 2.9: Classification of hydropower by size (Singh, 2009).

Category	Output	Application
Large- hydro	More than 100 MW	Commonly fed to the national electricity grid
Medium-hydro	15 - 100 MW	Commonly fed to the national electricity grid
Small-hydro	1 - 15 MW	Larger standalone projects that provide power to a rural industries and also fed to the grid e.g. tea factories.
Mini-hydro	100 kW - 1 MW	Standalone projects that provide power to a rural industries and also fed to the grid e.g. tea factories.
Micro-hydro	5kW - 100 kW	Off-grid standalone projects that provide power to a small communities or rural industries in remote areas.
Pico-hydro	1Kw - 5kW	Stand alone

For the purposes of this research, micro hydropower referred to mini, micro and pico hydropower generation plants all generating less than 300 kW in line with the convention that micro-hydro refers to shaft or electrical power raising from 10 to 250 kW (Singh, 2009; Karekezi and Ranja, 1997).

2.7. Micro hydropower Technology

Figure 2.1 illustrates the design set up of a micro hydropower system, which typically involves diversion of water from a stream, by use of a weir into a canal feeding a forebay tank used to trap sediment and debris. A penstock connected to the forebay tank is used to deliver controlled water flow downhill by gravity to drive a turbine when expelled under pressure. The turbine is coupled to a generator where the mechanical energy is converted to electrical energy (Karekezi, et al.2009).

Micro hydropower systems are mostly "run of the river" systems, which allow the river flow to continue which is preferable from an environmental point of view, as seasonal river flow patterns downstream are not affected and there is no flooding of valleys upstream of the system (Harvey, 1993).

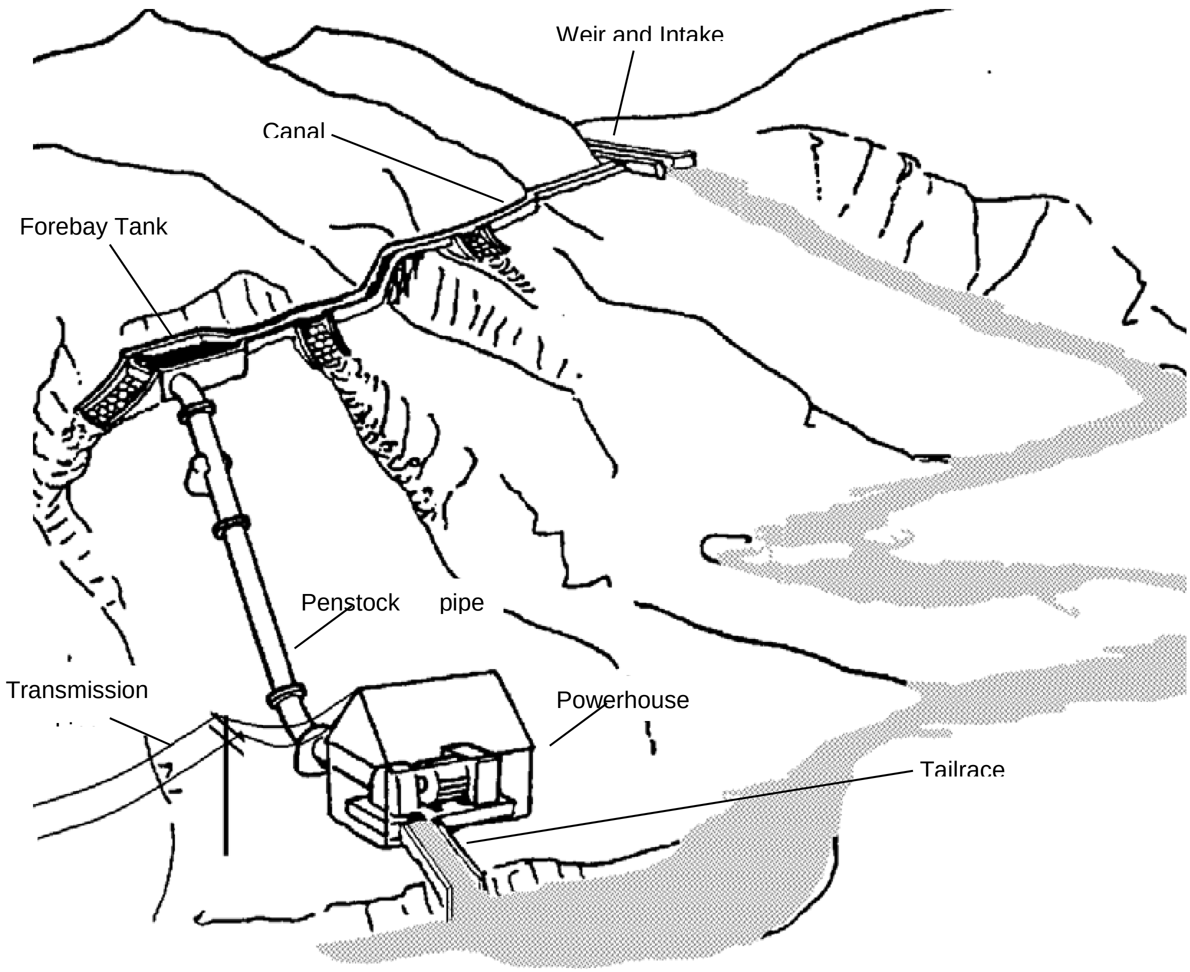

Figure 2.6: Schematic of a typical run-of-the-river small hydropower plant (BHA, 2005)

The Tungu-Kabiru micro-hydro Project is a showcase for micro hydropower development in Kenya. Funded by the United Nations Development Programme and developed by ITDG Practical Action East Africa and the Kenyan Ministry of Energy, the project has benefited over 200 households in the Mbuiru village river community. The project has demonstrated that pico-hydro technology is a sustainable and affordable technology for community electrification. (Amissah-Arthur et al., 2003; Klunne, 2007).

The power potential is a function of available water flow in cubic metres per second ($m^3 s^{-1}$) and the vertical head in meters (m) while the realizable power is the difference between potential power and the sum of efficiency losses occurring within the system.

Theoretical power (P) available from a given head of water is in exact proportion to the head and the quantity of water available (Singh, 2009).

$$P = Q \times H \times \eta \times 9.81 \text{ Kilowatts (kW)} \quad \text{........................... (i)}$$

Where,

P = Power at the generator terminal, in kilowatts (kW)

H = The gross head from the pipeline intake to the tailwater in metres (m)

Q = Flow in pipeline, in cubic metres per second (m3/s)

η = The efficiency of the plant, considering head loss in the pipeline and the efficiency of the turbine and generator, expressed by a decimal.

9.81 is a constant and is the product of the density of water and the acceleration due to gravity (g)

The hydro turbine in mechanical power will convert this available power.

The pressure of the water turning the turbine is dependent on the vertical head which is the elevation difference between the water intake and the turbine while the water flow rate depends on the amount of water that can be diverted through an intake into the pipeline.

Imperatively, the key design factors contributing to the power output potential of a micro hydropower installation beyond innate system loses are the head and water discharge.

Depending on the available head and water flow, different turbine configurations may be used to achieve maximum generation. Pelton, turgo and crossflow are impulse turbines best suited for high and medium available head. For medium and low available head reaction turbines such as Francis, propeller and Kalpan are most appropriate (Okot, 2013; Cobb & Sharp, 2013).

Table 2.2 and Figure 2.2 show the applicability of each turbine type against head classification while Figure 2.3 illustrates the respective turbine efficiencies.

Table 2.10: Turbine types and head application (Paish, 2002).

Turbine type	**Head classification**		
	High (>50 m)	**Medium (10–50 m)**	**Low (<10 m)**
Impulse	Pelton	Crossflow	Crossflow
	Turgo	Turgo	Not applicable
	Multi-jet Pelton	Multi-jet Pelton	Not applicable
Reaction	Not applicable	Francis (spiral case)	Francis (open-flume)
	Not applicable	Not applicable	Propeller
	Not applicable	Not applicable	Kaplan

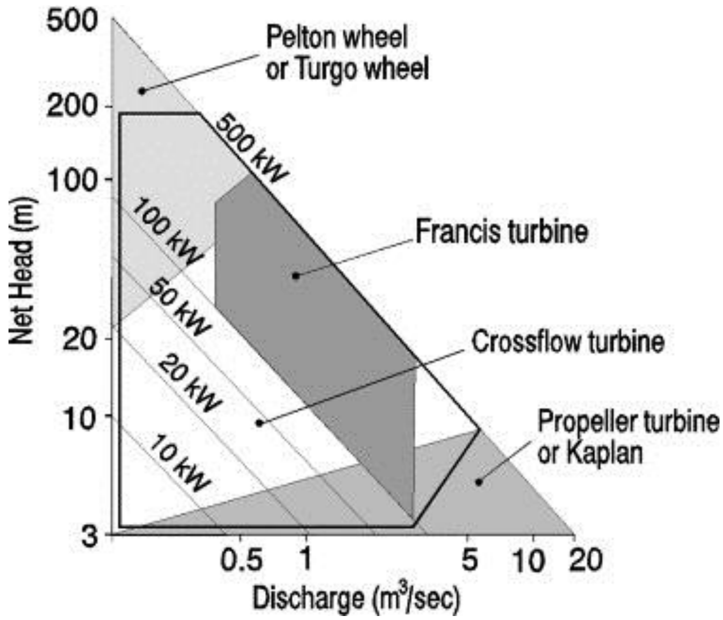

Figure 2.7: Turbine Sizing (Paish, 2002).

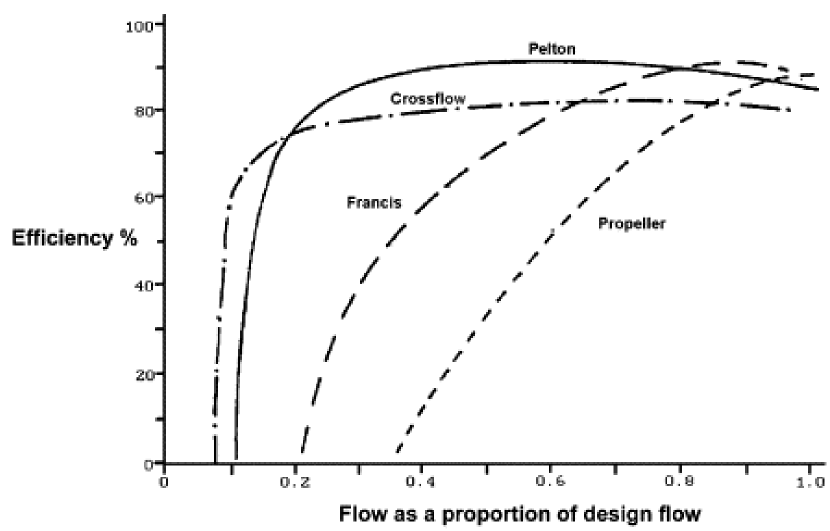

Figure 2.8: Turbine Efficiency (Paish, 2002).

2.8. Siting of micro hydropower generation plants

There are various factors that must be considered in choosing appropriate small hydro sites, which if suitably done, the extraction of energy from rivers can be made economically viable, especially to the rural communities.

Micro hydropower systems are much more site-specific than a wind or photovoltaic systems since a sufficient quantity of falling water must be available as well as vertical distance the water falls. An installation with more head is preferable as the system utilizes less water hence the equipment can be smaller. More flow is required at lower head to generate the same power level (Cunningham & Atkinson, 1994).

Feasibility for micro hydropower siting is normally done in a very abstract manner and most hydrologic and hydraulic information is currently collected in a manual process involving site visits, taking readings off river gauges. These methods are prone to error, expensive in terms of labour resources and sharing of the necessary information between concerned agencies is made difficult. (Khennas & Barnett, 2000; Mohibullah, Radzi & Hakim, 2004).

2.9. Flow Duration Curves

The flow-duration curve is a cumulative frequency curve that shows the percentage of time that specified stream's discharges were equalled or exceeded during a period of record. It combines in one curve all of the flow characteristics of a stream, ranging from flood flows to drought situations. (Hordon, 2005)

Prediction of FDCs is of great importance for locations characterized by sparse or missing streamflow observations. (Pugliese, Farmer et al., 2016). Flow duration curves have a long history in the field of water-resource engineering and have been used to solve problems in water-quality management, hydropower, instream flow methodologies, water-use planning, flood control, and river and reservoir sedimentation, and for scientific comparisons of streamflow characteristics across watersheds (Vogel & Fennessey, 1995.

The dominant runoff processes including storage and drainage capacity of soils influence flow duration curves where catchments inhabiting large storage have different duration curves than catchments with small storage. (Floriancic, Margreth & Naef, 2016). A detailed comparison by Pugliese and others of geostatistical Top-kriging techniques employing a linear weighted average of dimensionless empirical FDCs, standardised with a reference streamflow value versus multivariate regression of streamflow quantiles methods which are both capable of predicting an FDC at ungauged basins was made across 182 largely unregulated river catchments in the south eastern U.S. using a three-fold cross-validation algorithm. The results revealed that the two methods perform similarly throughout flow-regimes while the differences between the reproductions of FDC's occurred mostly for low flows with exceedance probability above 0.98. (Pugliese, Farmer et al, 2016).

Although FDCs have a long and rich history in the field of hydrology, they are sometimes criticized because, traditionally, their interpretation depends on the particular period of record on which they are based. Vogel and others propose that if one considers *n* number of individual FDCs, each corresponding to one of the individual *n* years of record, then one may treat those *n* annual FDCs in much the same way one treats a sequence of annual maximum or annual minimum streamflow. This new annual-based interpretation enables confidence intervals and recurrence intervals to be associated with FDCs in a nonparametric framework. (Vogel & Fennessey, 1994

For the purposes of this research, flow duration curves are used to assess availability of sufficient streamflow throughout the year for hydropower generation hence allowing determination of whether identified would be viable. In addition, an annual based interpretation of flow duration curves was not taken as there was a sufficiently large history of gauging point readings spanning decades for some stations.

2.10. GIS Technology

GIS is a system comprising of computer software, hardware, data and personnel to help manipulate, analyze and present information that is tied to a spatial location;

a. Spatial location – geographic location

b. Information – visualization of data

c. System – linking software, hardware and data

d. Personnel – Users exploiting the power of GIS

A geographic information system (GIS) is designed to visualize, store and analyze the information about the locations, topology, and attributes of spatial features. In most GIS programs, data are stored and managed in a relational database embedded in the system. A GIS program can perform regular database management tasks in addition to spatial analysis hence GIS can be considered as a relational database management system with a map interface for data presentation.

In GIS, location data and their map representations are dynamically linked so that any changes made in the databases are reflected immediately on its map presentation. This linkage makes GIS a powerful tool for spatial data visualization and analysis (Ian, 2010).

2.10.1 Main theories, models and methods that currently exist

In the history of the GIS modelling in the area of water resources, there has been a trend in the modelling approach from 'function-centric' where numerical models were self-contained and supported by their own data sets, through ‘data-centric’, where models were supported by some general database management systems, and towards ‘map-centric’ where models would be supported by or written in GIS (Zichuan, Maidment, & McKinney, 1996).

A hydrology simulation model is composed of three elements, which are

i. Equations that govern the hydrologic processes

ii. Maps that define the study area

iii. Database tables that numerically describe the study area and model parameters.

2.10.2 Data models and simulation models

A data model is distinct from a simulation model in that a data model provides a standardized framework for storing information, but contains no routines to simulate hydrologic processes. Data models are typically coupled with one or more simulation models with data and information being transferred from it to a simulation model and results being returned back. Arc Hydro, is an example of a data model and within itself, provides a means for linking simulation models through a common data storage system (Maidment, 2003).

2.10.3 ArcGIS Hydro Data Model

The Arc Hydro framework provides a simple, compact data structure for storing the important geospatial data describing the water resource system. Hydrologic Modelling within the Arc Hydro framework is achieved by mapping natural processes onto software tasks and aggregating land landscape characteristics to create a “Lumped parameter model” illustrated on Figure 2.4 (Maidment, 2002).

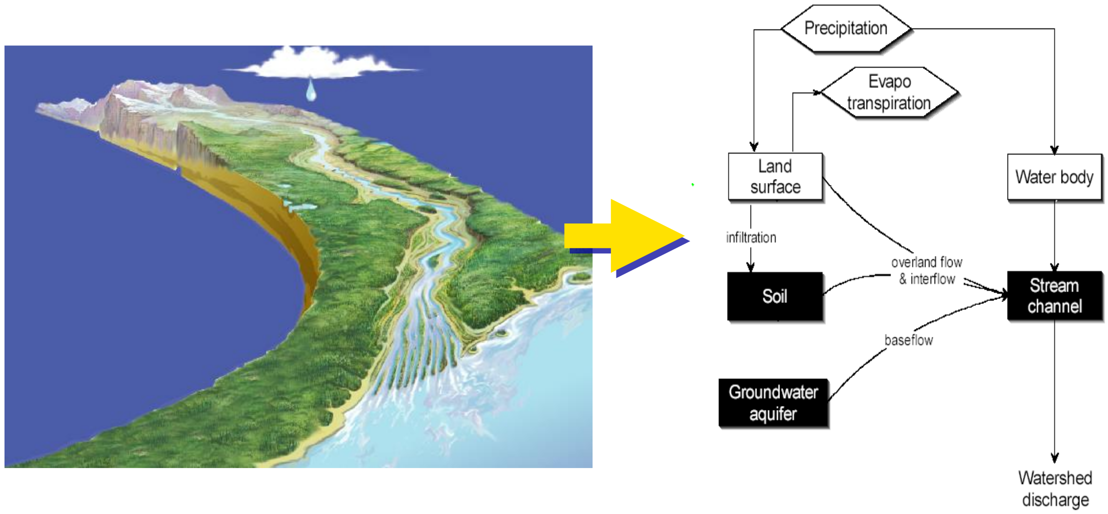

Figure 2.9: Lumped parameter model in Hydrologic Modelling (Maidment, 2002).

The ArcGIS Hydro Data Model (Arc Hydro) stores data in four feature datasets, each corresponding to one of the main domains of the UML analysis diagram:

i. Hydrography (map hydrography and associated data inventories),

ii. Drainage (drainage areas derived from digital elevation models or manually digitized),

iii. Channel (3-D profile and cross-section representation of stream channels),

iv. Network (a geometric network representation of the connectivity of the surface water features of the landscape).

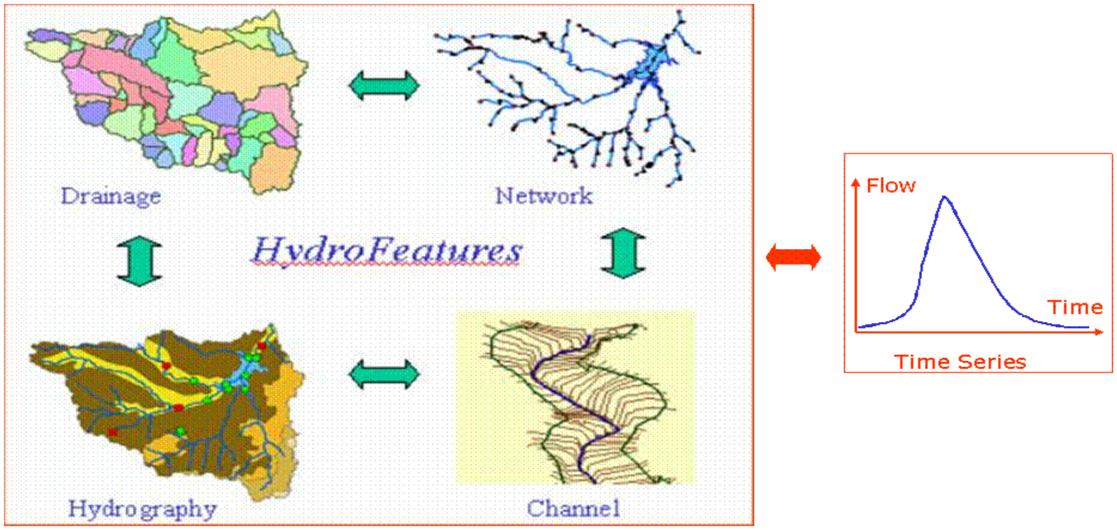

Figure 2.10: Arc Hydro Components (Maidment, 2002).

Associated with these four feature datasets displayed on Figure 2.5, are a set of object tables for additional information, such as events defined on the river network, and time series of monitoring data. The relationship between each of object tables is shown in Figure 2.6.

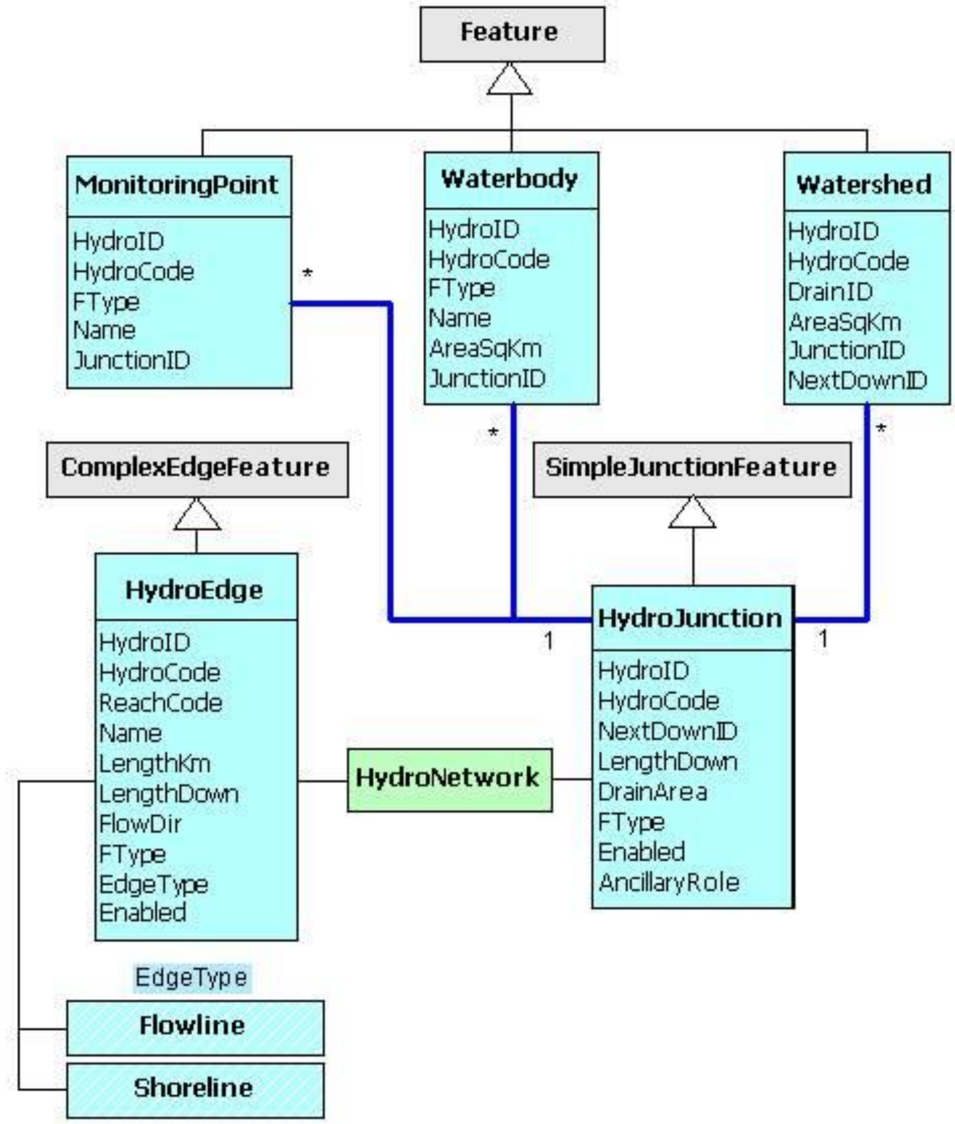

Figure 2.11: Arc Hydro feature datasets and relationships (Maidment, 2002).

2.10.4 GIS Mapping of Hydropower Sites

While the process of identifying potential micro hydropower sites can be an overwhelming exercise, remote sensing and GIS technology can play a pivotal role in the scientific assessment of drainage networks to accurately identify locations with the highest potential for hydropower development hence increasing access to affordable energy (Popli, 2012).

Hydropower potential is directly related to the geography of an area, amount of precipitation and soil saturation. GIS can be used to evaluate specific watersheds for runoff and the difference in elevation from where water can be collected and where a turbine can be located. Rojanamon, et al (2009) proposes new methods of application of GIS to site selection of small run-of-river hydropower that can help address some of the challenges encountered during site selection of small run-of-river hydropower projects occasioned by accessibility of the possible sites which are mostly located in rural and mountainous areas, the large amount of data required, and the lack of participation of the local communities (Rojanamon, Chaisomphob, & Bureekul, 2009). Similarly, Das & Paul (2006) note the difficulty of site selection for small hydro in the inaccessible tracts of Himalayan region while using conventional methods leading to considerable loss of time and money. Their research demonstrated the use GIS and Remote Sensing technology to arrive at various alternative sites available in the study area and finally to select the most technically suitable site (Das & Paul, 2006).

A study by Jha, R. (2010) used the hydro-meteorological data from Department of Hydrology and Meteorology for hydrologic analysis of all the rivers in Nepal. By incorporating hydrologic analysis, GIS and a purposely developed hydropower model as shown on Figure 2.7, the power potential and annual run-of-the-river energy estimate for the entire country was established.

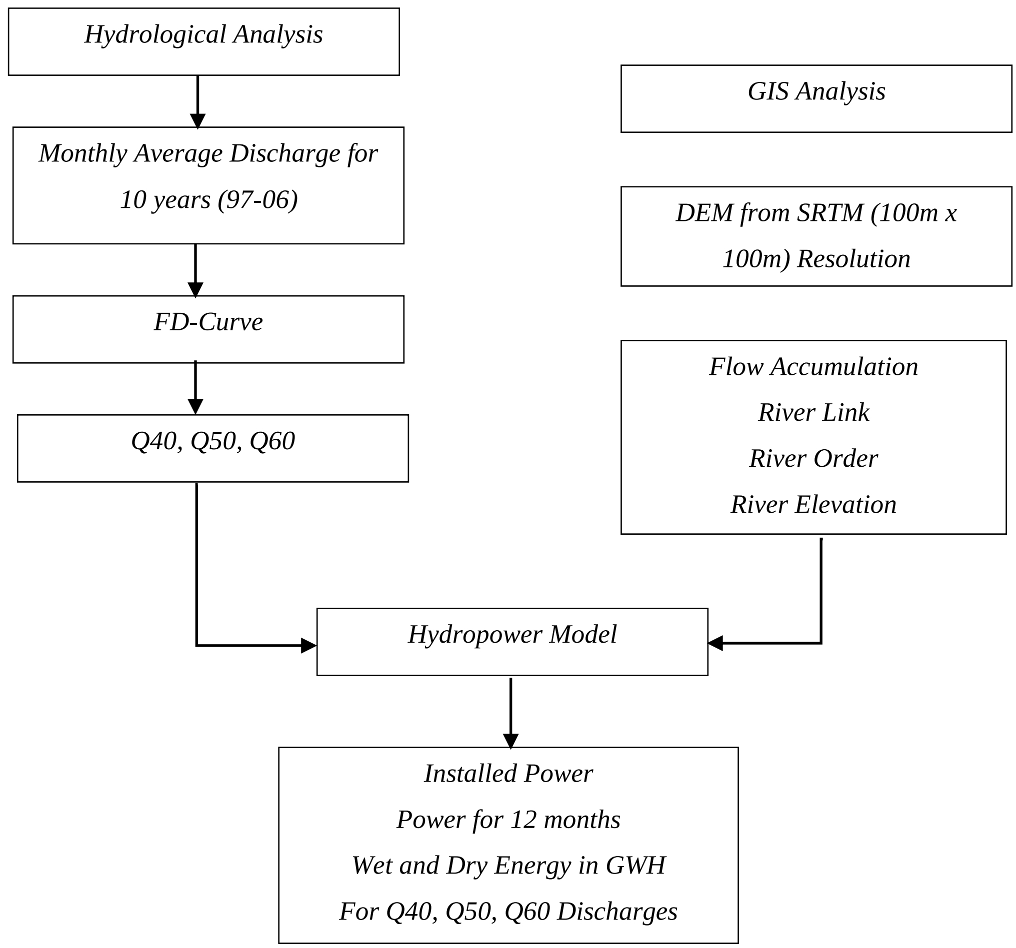

Figure 2.12: Model used to calculate the total run-of-river type hydropower potential of Nepal Jha, R. (2010).

A paper by Feizizadeh, B., & Haslauer, E. M. (2012) discusses the application of a GIS to calculate the theoretical surface hydropower potential of the Tabriz basin in Iran. GIS based hydrologic modelling is performed on equiareal raster cells using topographical and meteorological datasets. The input data was compiled and analyzed using GIS data layers, including topographic characteristics, monthly evaporation and precipitation data to identify areas of the river network the highest potentials that could be used to locate for hydropower plant. Figure 2.8 illustrates the schema of the model used.

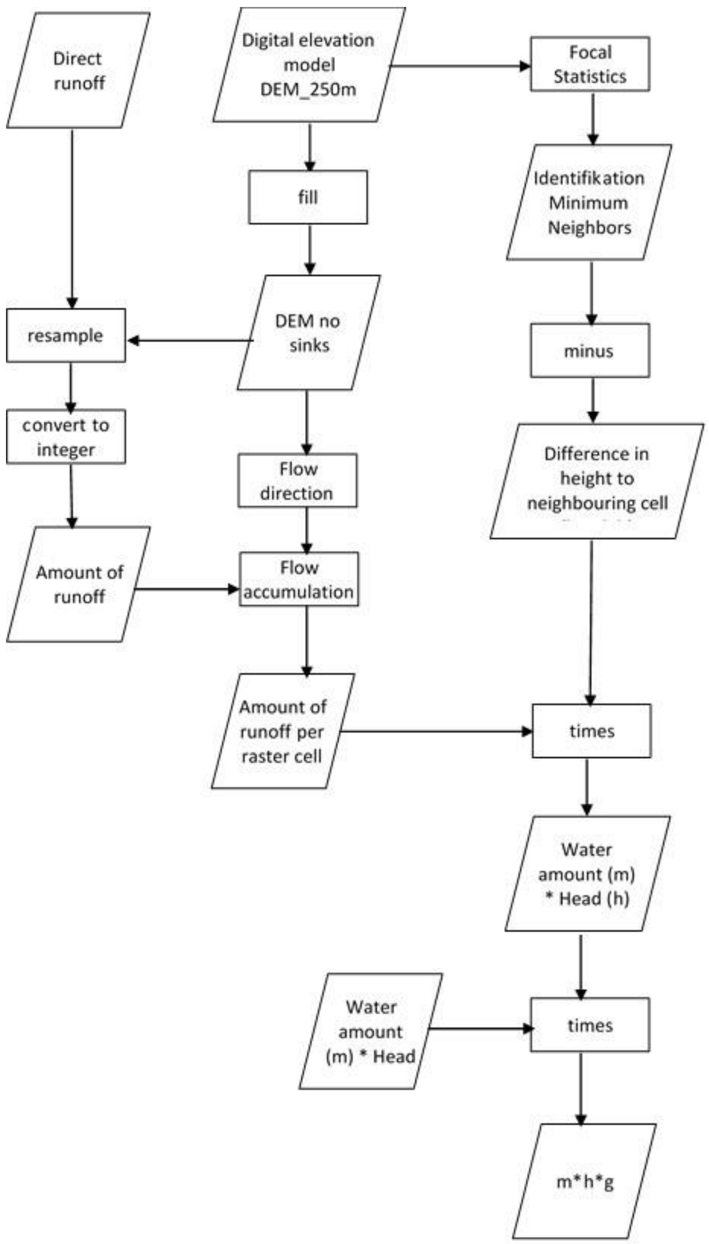

Figure 2.13: Model used to calculate hydropower potential for Tabriz Basin, Iran (Feizizadeh & Haslauer, 2012)

Jha, R. (2010) in his model, does not identify potential hydropower sites at discrete locations but determines the approximate hydropower potential of the entire Himalayan drainage basin within Nepal based on catchment discharges calculated using the area velocity method. However, flow duration curves are used to assess the Q40, Q50 and Q60 discharges beneficial for determining hydropower generation potential all year round.

The Model used to calculate hydropower potential for Tabriz Basin (Feizizadeh & Haslauer, 2012) similarly does not identify potential hydropower sites at discrete locations but determines and cumulates the hydropower potential at each river drop point along the Tabriz River based on direct runoff rather than actual river flows. Flow duration curves are also not used to assess whether the river flow would be beneficial for hydropower generation potential all year round.

From the above, GIS thus provides a proactive means of modelling both hydraulic and hydrologic data. This research adopts both models by Jha, R. and Feizizadeh & Haslauer to create an enhanced one capable of identifying focus areas for development of micro hydropower hence facilitating development and increased use of electricity and mechanical energy derived from micro hydropower with an aim of reducing or eliminating reliance on unsustainable energy sources associated with anthropogenic causes of climate change. As opposed to the adopted models which utilised approximated catchment discharges, this research based its river flows on actual gauging station readings while bringing in the respective strengths.

ArcGIS and ArcHydro tools were used in this research but the same can be replicated on other GIS application platforms that support terrain processing and stream network delineation. Arc Hydro is a geospatial and temporal data model for water resources designed to operate within ArcGIS.

CHAPTER 3: METHODOLOGY

This chapter describes the methods that were used in the study. As an overview, this research was carried out by means of the following;

1. A questionnaire administered to the households in the study area to establish the accessibility to energy on the following;
    a. Population demographics
        i. Age
        ii. Sex
        iii. Marital status
        iv. Level of education
        v. Employment or source of livelihood
    b. The main source of Energy used for cooking and lighting.
2. Hydrologic Analysis was carried to obtain the respective flow duration curves at gauging station points along the Perkerra River. The flow duration curves were necessary for calculations to determine the average flow magnitude in a year that could be expected to be equal or exceed 40, 50 and 60 percentile of the time. The exercise involved use of primary data containing river flows from gauging stations supplied by the Water Resource Management Authority (WRMA) and the Rift Valley Water Services Board.
3. GIS Hydrologic Modelling using ArcGIS Model Builder & ArcHydro tools. The process involved the use of the following sets of secondary data;
    a. DTM data in ASCII format from the Shuttle Radar Topography Mission (SRTM) containing elevation data at a 90m resolution.
    b. Derived flow magnitude from hydrologic analysis
    c. Climate data from the Kenya Meterological Department
        i. Precipitation
        ii. Temperature
    d. Topographic data

i. Topographic maps from the Survey of Kenya

3.1 Application of a Quantitative Questionnaire

Micro hydropower potential modelling determined the extent of suitable locations available for electric power generation in a largely quantitative exercise. It was however necessary to apply additional quantitative and qualitative research by means of a questionnaire to gain a better insight on current energy use by households within the study area and likelihood of the population adopting renewably generated electrical energy hence creating sufficient demand to justify further development of hydropower resources identified by the hydrologic model.

3.1.1 Questionnaire Design

The goal of the household energy use survey was to collect information that was unbiased, reliable, valid and discriminating. Considering the intended sample size, desired anonymity, cost and ease of analysis, a questionnaire was chosen as the appropriate data collection instrument to collect secondary data required for this research.

The questionnaire on appendix A was developed and administered to a population of adult respondents located across the study area using a descriptive research design. A descriptive study is targeted at finding out the what, where and how of a phenomenon (Cooper & Schindler, 2003) hence the questionnaire consisted of open-ended, close-ended and partially close-ended questions developed with a view towards apparent relevance, importance, and interest of the survey to the respondents. These measured the subjective responses to clarify the objective responses and at the same time, enhanced formulation of recommendations of the study.

A team of four field staff were trained on the objectives and how to administer the questionnaire through structured face to face interviews over a period of five days at selected trading centres namely Eldama Ravine, Arama, Poror, Metipso, Torongo, Kapcholoi, Kipkuyang, Sigoro, Kiptuno, Solian, Maji Mazuri, Igure, Makutano, Equator, Timboroa and Seguton.

The surveys interview time was limited to thirty minutes to track the length of time as those who take the longest to return the survey are considered closely similar non-responders (Moser and Kalton, 1971)

The geographical extent of the study area as well as finding the respondents within their households during the daytime guided the decision to limit the survey to towns and trading centres. As the individuals surveyed were interviewed away from their household locations, GPS coordinates were not captured on the study questionnaires as this information would not be accurate.

3.1.2 Sampling Design

A sample is a smaller but representative collection of units from a population used to determine truths about that population (Field, 2005)

Sampling was done due to the limited pecuniary, time as well as manpower resources required to administer the questionnaire across the entire study population. To eliminate bias, the sampling frame was drawn from local adult commuters alighting from public service vehicle during market days whereby one individual was randomly sampled.

105 respondents were sampled which was within the sampling design parameters below.

- Number of households in Koibatek: 34,686
- Desired Confidence Level: 95%
- Desired Confidence Interval: 10

- Sample size needed: 96

3.1.3 Units of Analysis and Observation

Units of analysis are units that are designed for purposes of aggregating their characteristics in order to describe some larger group or abstract phenomenon. (Mugenda and Mugenda, 2003) In this study, the unit of analysis were households within Koibatek district while units of observation were individuals representing the respective households.

3.1.4 Data Analysis

The data collected, through the questionnaire was collated for statistical analysis and results tabulated in a process involving data reduction, data display and conclusion drawing/verification. (Miles and Huberman, 1994).

3.1.5 Ethical Issues

The following ethical considerations were observed in the course of administering the questionnaire.

a) The sampled individuals were apprised on the purpose of the research, the use and disposal of the data and gave their informed consent without any compulsion.

b) The sampled individuals were guaranteed of the confidentiality of information provided to only those involved in the study including disposal of questionnaires via shredding after use.

c) The participants remained anonymous throughout the study and personally identifiable information was not collected.

d) Authorisation was sought from administrative authorities to carry out the research.

3.2 Hydrologic Analysis

Hydrologic Analysis was carried out to obtain the flow duration curves for gauging stations along the Perkerra River using daily discharge data collected between 1931 and 2013. More recent data was not available in electronic format as the information had not been collated and digitized by WRMA.

The flow duration curves were generated to obtain the Q40, Q50, Q60 discharges at each gauging station, representing the flow magnitude expected to equal or exceeded 40, 50 and 60 percent of the time in an entire year. This information was the necessary in order to approximate the hydropower potential for selected hydropower site obtained from the GIS hydrologic model hence determine its viability.

River gauging stations within the study area of which some were sampled and had available historical data records are listed on Table 3.1 with the relative locations displayed on Figure 3.1

Table 3.11: River Gauging Stations Sampled

STATION NAME	CODE	FREQUENCY OF READINGS	DATA OBTAINED & LENGTH OF RECORDS	LOCATION
TIGERI	2ED01	Weekly	YES – 51 years	Chepkungur - Past Kapcholoi at DANGER bridge towards Sigoro
LELGEL	2EC02	Weekly	YES – 59 years	POROR - Bridge before centre
RAVINE	2EC03	Weekly	YES – 62 years	RAVINE - Town at bridge before forest office
NAROSURA	2EC04	Weekly	YES – 45 years	KABIMOI - Bridge at centre
PERKERRA	2EE08	Weekly	YES – 26 years	KIMNGOROM - Near centre
ESAGERI	2EF03	None currently	NO – N/A	ESAGERI - Bridge at centre
PERKERRA	2EE07	Weekly	YES – 27 years	KIMOSE - On Nakuru Kabarnet Road
PERKERRA	2EE07B	Every 2 days	YES – 53 years	MARIGAT BRIDGE
PERKERRA	2EE07A	Monthly	YES – 9 years	MARIGAT BRIDGE
PERKERRA	2EE09	None currently	NO – N/A	MARIGAT IRRIGATION BOARD
PERKERRA	2EE10	None currently	NO – N/A	MARIGAT IRRIGATION BOARD

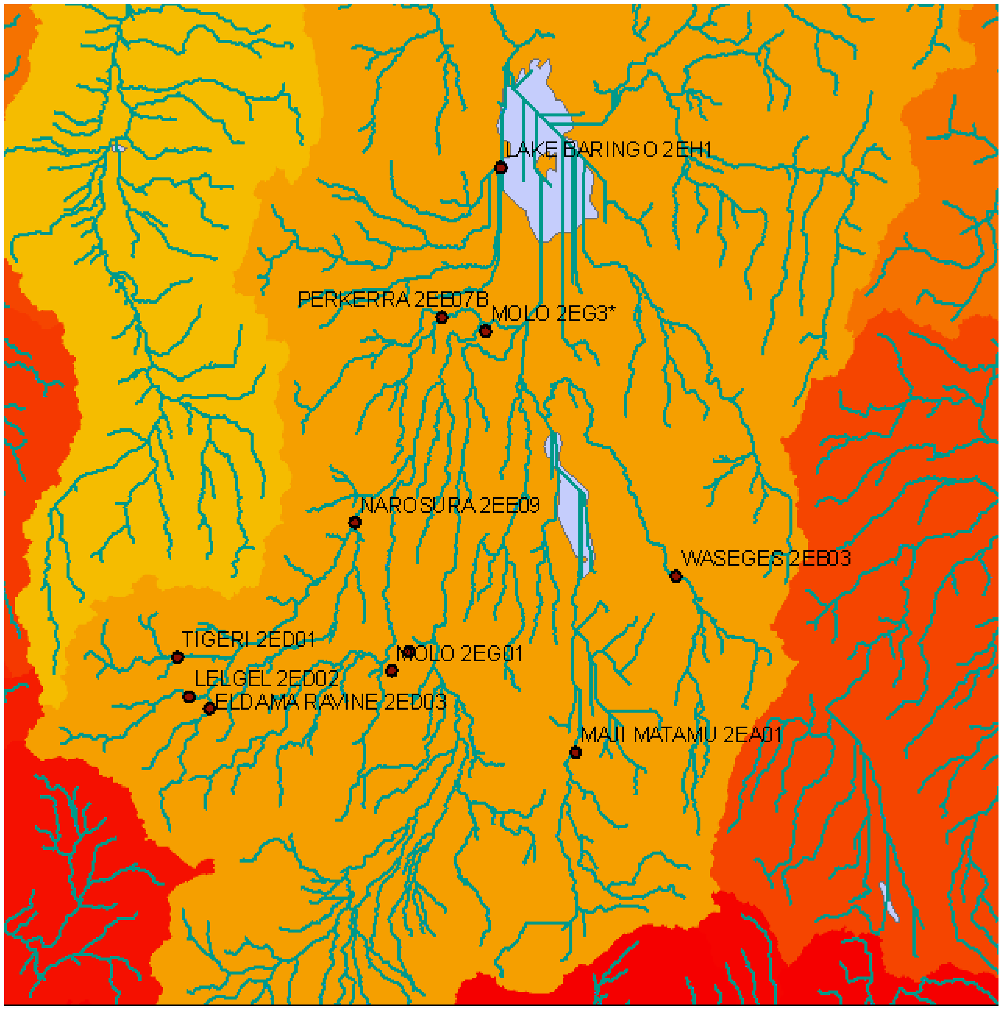

Figure 3.14: Relative Locations of River Gauging Stations

For each set of gauging station readings, the following steps below were followed to generate the respective flow duration curves with each iteration.

3.2.1 Selecting the time step value

For the purpose of this research, the analysis was done using a daily time step. The total number of time step intervals in the period of record was hence calculated.

3.2.2 Ranking of Discharge by Magnitude.

The gauging station entries were ranked by discharge, from largest to smallest. After this, the average value of the variable of interest within each time step (average daily value) over the period of record was calculated also noting largest and smallest of these average values. To automate the ranking process, a program was created using Python programming to process the raw data into a simpler format containing Gauging station ID, Date of Reading and Flow in cubic metres as shown on Table 3.2.

Table 3.12: Formatted Time-Series data obtained from Python programming

STATION	*DATE*	*DISCHARGE (m^3s^{-1})*
2EC02	12/10/1982	2.901
2EC02	12/9/1982	2.753
2EC02	12/11/1982	2.713
2EC02	12/8/1982	2.605
2EC02	12/7/1982	2.535
2EC02	12/12/1982	2.525
2EC02	12/6/1982	2.465
2EC02	12/5/1982	2.377
2EC02	12/13/1982	2.337
2EC02	12/4/1982	2.290
2EC02	5/13/1947	2.202
2EC02	12/18/1961	2.202
2EC02	12/3/1982	2.202
2EC02	12/14/1982	2.149
2EC02	12/17/1961	2.107

3.2.3 Data Classification and Plotting the Total Occurrence

The range of average values was divided into classes based on log cycles to enable selection appropriate interval. The class intervals selected were largely not equal and were limited to less than 30. Following this, the total number of occurrences of values in each class were tallied using the ranked data.

A plot of the total number of occurrences in each class versus discharge was generated creating frequency distribution.

3.2.4 Calculating Exceedance

The total number of occurrences in each class was divided by the total number of time steps giving the frequency with which the lower values of each class have been equalled or exceeded in the period of record.

3.2.5 Generating the Flow Duration Curve

A plot of the discharge on the vertical axis against exceedance frequency on the horizontal axis was generated creating flow duration curve.

3.3. GIS Hydrologic Modelling

3.3.1 Foundation Data Acquisition and creation of shapefile for Kenya's outline

The shape file of Kenya's outline and Baringo county boundary were obtained courtesy of USAID, FEWS, EDC-International Program, UNDP and the U.S. Geological Survey at a 1:1000000 scale. These map layers were authored by USAID/FEWS and modified by the Data and Information Management Unit of UNDP Somalia. The coverage is part of the Famine Early Warning System (FEWS)/Associates in Rural Development (ARD), African series and the data are intended to show the spatial distribution of the international and third administrative level boundaries for Kenya. The absolute horizontal accuracy of the DCW for all features derived from Operational Navigation Charts (ONC) is 2040 meters (6700 feet) rounded to the nearest 5 meters at 90% Circular Error (CE), World Geodetic System (WGS84). The absolute horizontal accuracy of the DCW for all features derived from Jet Navigation Charts (JNC) is 4270 meters (14006 feet) at 90% Circular Error. The absolute vertical accuracy of the DCW is the same as for the original ONC and JNC lithographs at 90% Linear Error (LE), Mean Sea Level (MSL).

The shape file of Kenya's railway and major road network were obtained courtesy of DCW, UNDP and ESRI. This map layer was authored by DCW and modified by the Data and Information Management Unit of UNDP Somalia. The coverage is the Kenya railway network was extracted from DCW. The absolute horizontal accuracy of the DCW for all features derived from Operational Navigation Charts (ONC) is 2040 meters (6700 feet) rounded to the nearest 5 meters at 90% Circular Error (CE), World Geodetic System (WGS84). The absolute horizontal accuracy of the DCW for all features derived from Jet Navigation Charts (JNC) is 4270 meters (14006 feet) at 90% Circular Error. The absolute vertical accuracy of the DCW is the same as for the original ONC and JNC lithographs at 90% Linear Error (LE), Mean Sea Level (MSL).

The shape file of Kenya's population was obtained courtesy of Oak ridge national laboratory and UNDP. This map layer was authored by Oak Ridge National Laboratory and modified by the Data and Information Management Unit of UNDP Somalia. The LandScan Global Population Project is a worldwide population database at 30" X 30" resolution for estimating ambient populations at risk. Best available census counts are distributed to cells based on probability coefficients, which, in turn, are based on road proximity, slope, land cover and night-time lights. Probability coefficients are assigned to each value of each input variable, and a composite probability coefficient is calculated for each LandScan cell. The use of this data is limited due to three factors namely;

(i) Census data were obtained from the United Nations Statistical Division, which makes no attempt to evaluate the accuracy of census counts provided by individual nations.

(ii) Census dates, ranging from 1979 to 1994 were projected to 1994 based on annual growth rates by country also provided by the United Nations.

(iii) The algorithm employed to distribute population from administrative units (usually provinces) to cells is purely cartographic and is based on population alone.

GIS data on Kenya drainage that included major streams, basins and water bodies was obtained from Data Exchange Platform for the Horn of Africa (DEPHA). The coverage shows the major towns in Kenya with a total of 53 towns represented in this layer Neither the original source of this map is nor the scale at which it was digitized is known.

3.3.2 Shuttle Topography Radar Mission (SRTM) elevation data

DTM data in ASCII format from the Shuttle Topography Radar Mission (SRTM) containing elevation data at a 90m (5 degree * 5 degree) resolution covering the country Kenya within the 6 tiles and downloaded from the Consortium for Spatial Information in geographic coordinate system - WGS84 datum. The SRTM DTM data has been processed to fill data voids, and to facilitate its ease of use by a wide group of potential users and the vertical error is reported to be less than 16m. (CGIAR-CSI, 2010)

The CGIAR-CSI SRTM was selected over data currently being distributed by NASA/USGS as the latter contains "no-data" holes where water or heavy shadow prevented the quantification of elevation. These are generally small holes, which nevertheless render the data less useful, especially in fields of hydrologic modelling. (CGIAR-CSI, 2010)

The identified study area was clipped out of the raster map generated after terrain processing was complete to limit the computing resourcing requirements associated with stream network delineation. Clipping out the area of interest after terrain processing was necessary as the geographical extent spanned across several tiles and was not clearly visible on the ASCII data tiles.

Six SRTM tiles listed on Table 3.3 were used and the same are illustrated on figure 3.2

Table 3.13: SRTM tiles

Tile ID	**General Area**
S_43_12	North Western Kenya
S_43_13	South Western Kenya
S_44_12	Northern and Central Kenya
S_44_13	Southern and Central Kenya
S_45_12	North Eastern Kenya
S_45_13	South Eastern Kenya

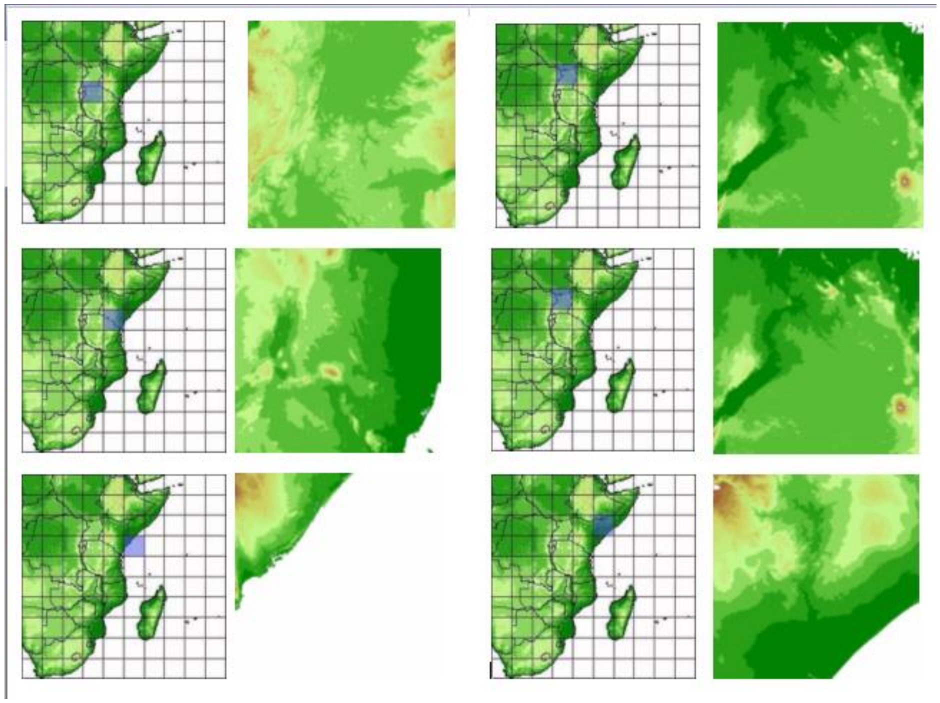

Figure 3.15: SRTM 90m DTM (CGIAR, 2014)

3.3.3 Processing SRTM data to create a grid for Kenya

a) **ASCII to Raster Conversion**

The downloaded ASCII format SRTM data files were converted to raster grids using **ArcMap: ArcToolbox: Conversion Tools: To Raster: ASCII to Raster**

This step illustrated on Figure 3.3 was necessary in order to display the raster grids on ArcMap.

For successful conversion, the ASCII file must consist of header information containing a set of keywords, followed by cell values in row-major order as shown on Table 3.4.

Table 3.14: ASCII to Raster Conversion

```
<NCOLS xxx>
<NROWS xxx>
<XLLCENTER xxx | XLLCORNER xxx>
<YLLCENTER xxx | YLLCORNER xxx>
<CELLSIZE xxx>
{NODATA_VALUE xxx}
row 1
row 2
…

row n
```

The quality of conversion is dependent on;

i. The type of DEM datasets of which some examples are;

   a) ASCII

   b) BINARY FLOAT

ii. The resolution of input DEM dataset of which some examples are;

   a) NASA's SRTM 90m DEM dataset, covering over 80 per cent of the Earth's land surface, including everything between 60 degrees North and 56 degrees South latitude.

   b) GTOPO30 which is a 30 arc second resolution data for most of the world.

iii. Whether the output data type parameters defined is specified as either INTEGER or FLOAT. Floating point values have a better accuracy whilst integer values are approximated.

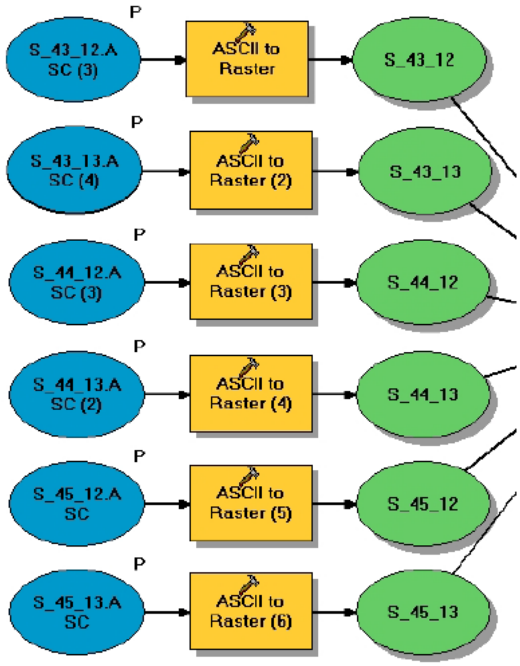

Figure 3.16: ASCII to Raster Grid Conversion

a) Mosaic Grids

Following the raster conversion, a mosaic of the six raster grids was created using **ArcMap: ArcToolbox: Data Management Tools: Raster: Mosaic_to_New_Raster** to form a composite grid representing Kenya as shown on Figures 3.4 and 3.5.

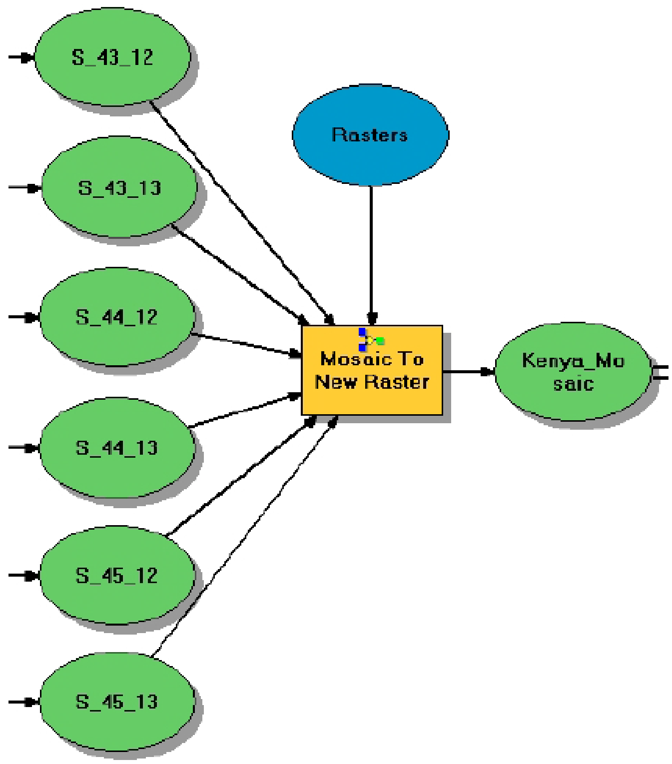

Figure 3.17: Mosaic Grids Process

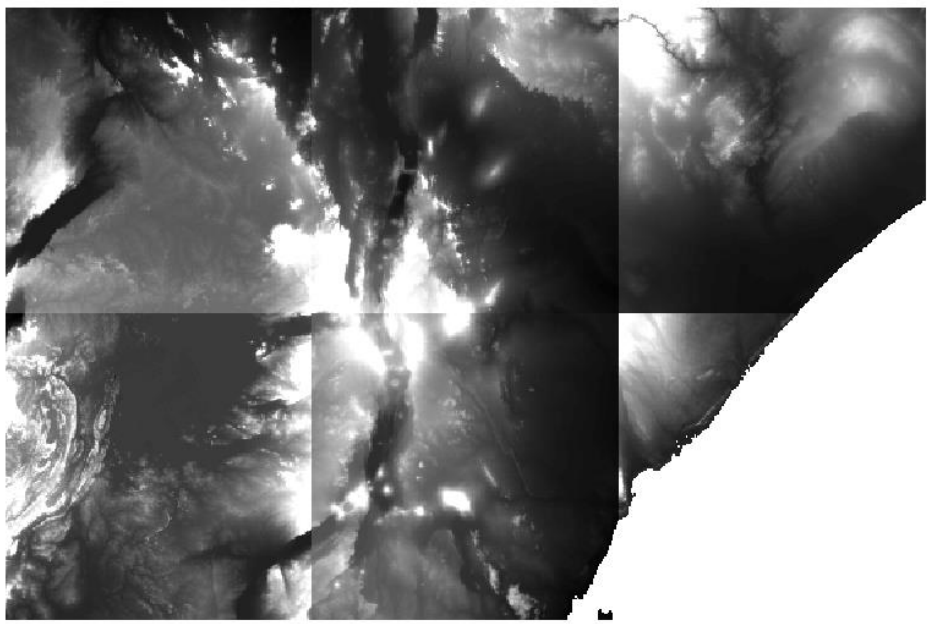

Figure 3.18: Mosaicked Raster Grids

During the Mosaic to new raster process, the spatial reference was defined as Geographic projection with decimal degrees (DD) on a WGS-1984 datum.

b) Removing "No Data" Values from DEM

During the mosaic multiple grids process, no-data values were received at the seams of the grids. These "No Data" values or holes represented cells with missing or unknown values that would have caused significant challenges during terrain processing. The term "No Data" should not be misconstrued to mean the same as zero value which is a valid cell value. In this research, two approaches were used to patch the holes and solve the "No Data" problem.

1. For small holes, the "No Data" value was set to zero using the following tool. **ArcMap: Spatial Analyst: Raster Calculator: Con (isnull ([raster]), 0, [raster])**
2. For medium holes, averages of the cells surrounding the "No Data" areas were obtained using focal statistics and used to fill the holes using **ArcMap: Spatial Analyst: Raster Calculator: Con(isnull([raster]), focalmean([raster] , rectangle, 5, 5), [raster])**

   The focal statistics process was repeated three times to completely eliminate medium sized holes. For each iteration of the focal statistics process, the resulting floating point data value was converted to integer to enable a successful run of the next process. This was done using **ArcMap: Spatial Analyst: Raster Calculator: Int([raster])** as shown on figure 3.6.

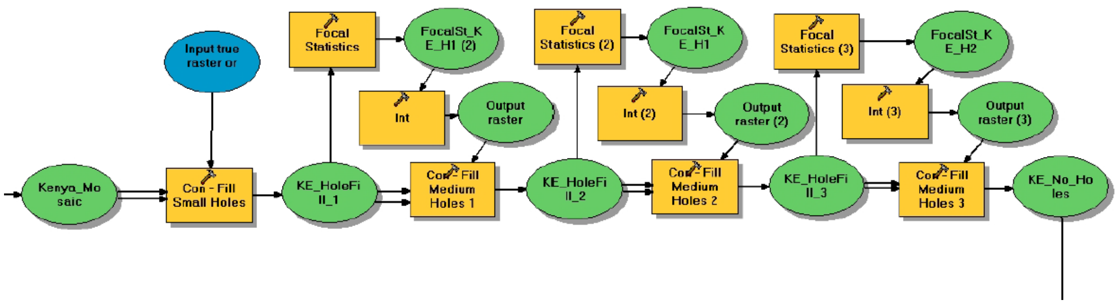

Figure 3.19: Filling “No Data” Values

Should the need have arisen to fill larger holes, resampled 1 km data would have been adequately used for the purpose which would have compromised the quality of the resultant data along the seams. 1 km data is available from the following site: http://edcdaac.usgs.gov/gtopo30/hydro/readme.asp#RasterDataFormats

The SRTM used consisted of void filled data but in the process of forming a composite grid using the mosaic process could potentially reintroduce holes around the seams.

c) Floating point to Integer data conversion and grid resampling

After patching the no data values, the resulting raster grid had its cell values converted to integer and resampled back to 90 m resolution. The resampling generated the correct pixel size for areas approximated using the focal statistics process. Both steps were intended to retain the consistency of the data prior to terrain processing as shown on figure 3.7.

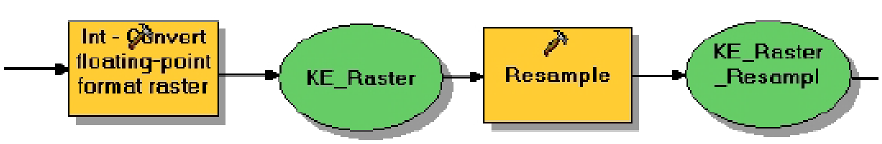

Figure 3.20: Grid Resampling

d) Defining the spatial reference for the Grid

Though the spatial reference was defined during the mosaic to new raster procedure to encode coordinates into the data set, the step was repeated to sanitize the raster grid before more rigorous processing using **ArcMap or ArcCatalog: ArcToolbox: Data Management: Projections** as shown on figure 3.8.

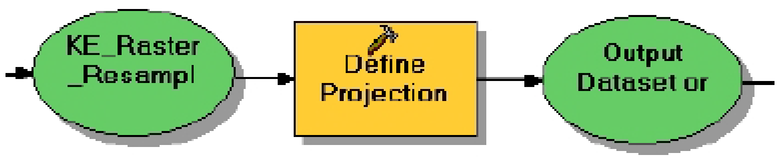

Figure 3.21: Defining Projection

The world geographic projection with decimal degrees (DD) and a WGS-1984 datum was selected. This coordinate system treats the globe as a spheroid.

e) Projecting the Raster Grid

The resulting grid was then projected into the working projection using the procedure illustrated on Figure 3.9 to enable making of measurements on the map. Since bulk of the study area lay North of the equator and between 35.5 and 36.5 decimal degrees, the WGS 1984 UTM Zone 36N was chosen as the best fit projected coordinate system as follows:

ArcMap or ArcCatalog: ArcToolbox: Transformations: Raster: Project Raster

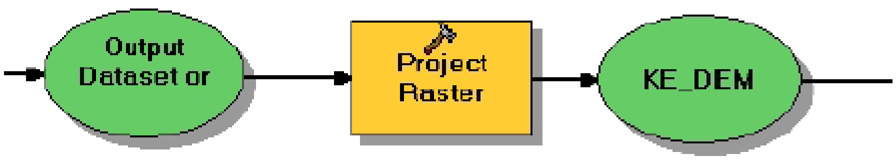

Figure 3.22: Projecting the Raster Grid

The WGS 1984 UTM Zone 36N System has the properties shown on table 3.5 and the projected DEM on Figure 3.10.

Table 3.15: Properties of WGS 1984 UTM Zone

Projection: Transverse_Mercator False_Easting: 500000.000000 False_Northing: 0.000000 Central_Meridian: 33.000000 Scale_Factor: 0.999600 Latitude_Of_Origin: 0.000000 Linear Unit: Meter (1.000000) Geographic Coordinate System: GCS_WGS_1984 Angular Unit: Degree (0.0174532925199433) Prime Meridian: Greenwich (0.000000000000000000) Datum: D_WGS_1984 Spheroid: WGS_1984 Semiminor Axis: 6356752.314245179300000000 Semimajor Axis: 6378137.000000000000000000 Inverse Flattening: 298.257223563000030000

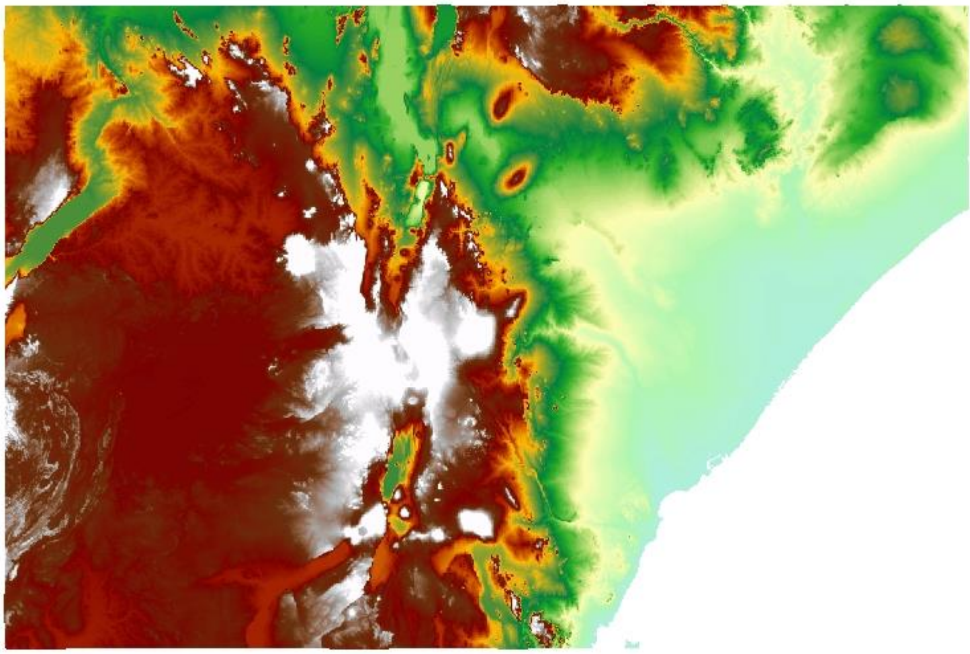

Figure 3.23: Resampled and Projected DEM

f) Creating a Buffer for Area of Interest

The following steps were carried out to mark out the area of interest.

i. A new Geodatabase for the project microhydro.mdb was created and within it a new Feature Dataset named Base having the same coordinate system as the Projected DEM created in process as shown on Figure 3.11.

Figure 3.24: Geodatabase Creation

ii. The Kenya outside boundary polygon was exported from the Projected DEM as with the process and Kenya DEM shown on on Figure 3.12 and 3.13 respectively.

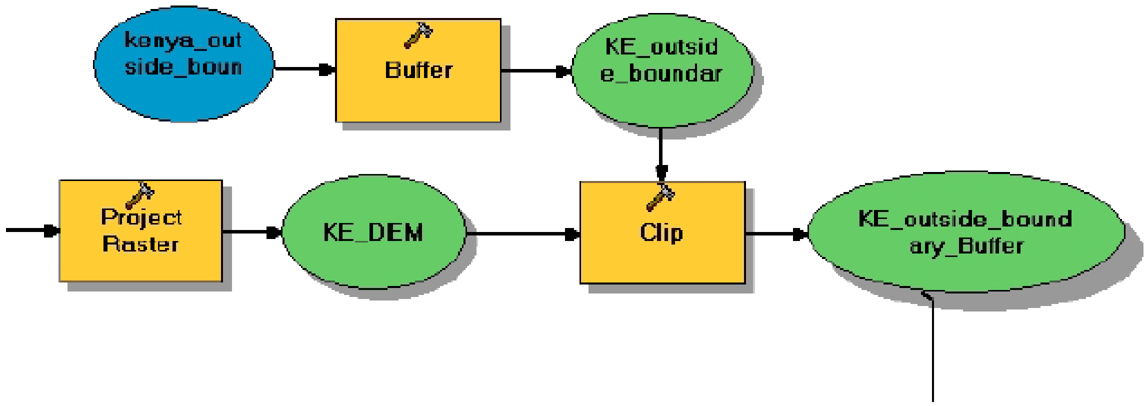

Figure 3.25: Extracting the Kenya Boundary from DEM

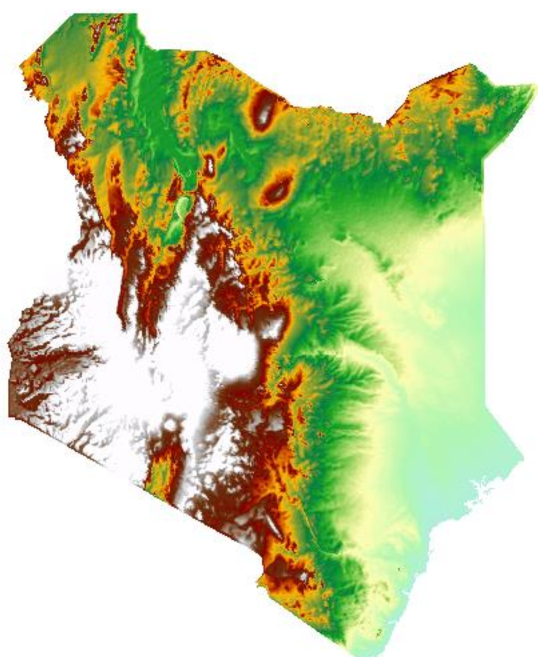

Figure 3.26: Kenya DEM

iii. The area of interest was then clipped from the resulting raster file to limit the amount of data to be processed during watershed and stream network delineation hence speeding up the resource heavy exercise. This process is illustrated on Figure 3.14

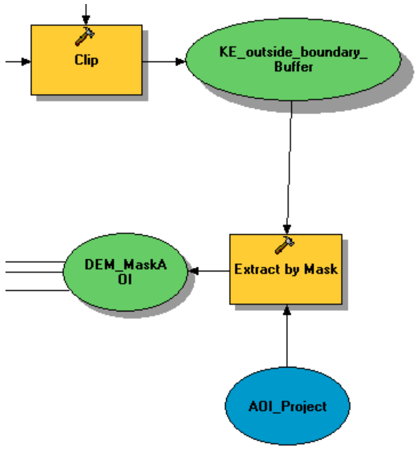

Figure 3.27: Clipping the area of interest covering the study area

The clipped area of interest is displayed on Figure 3.15.

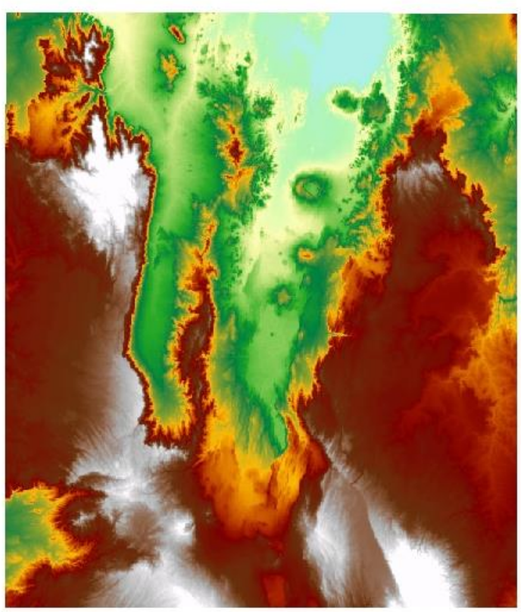

Figure 3.28: Clipped area of interests

3.3.4. GIS Hydrologic Modelling

Once terrain processing and extraction of a DEM representing the area of interest was completed, watershed and stream network delineation was carried out in a process comprising of the following steps

a. **Watershed and Stream Network Delineation**

Figure 3.16 shows the process of extracting hydrologic information, such as watershed boundaries and stream networks, from a digital elevation model (DEM).

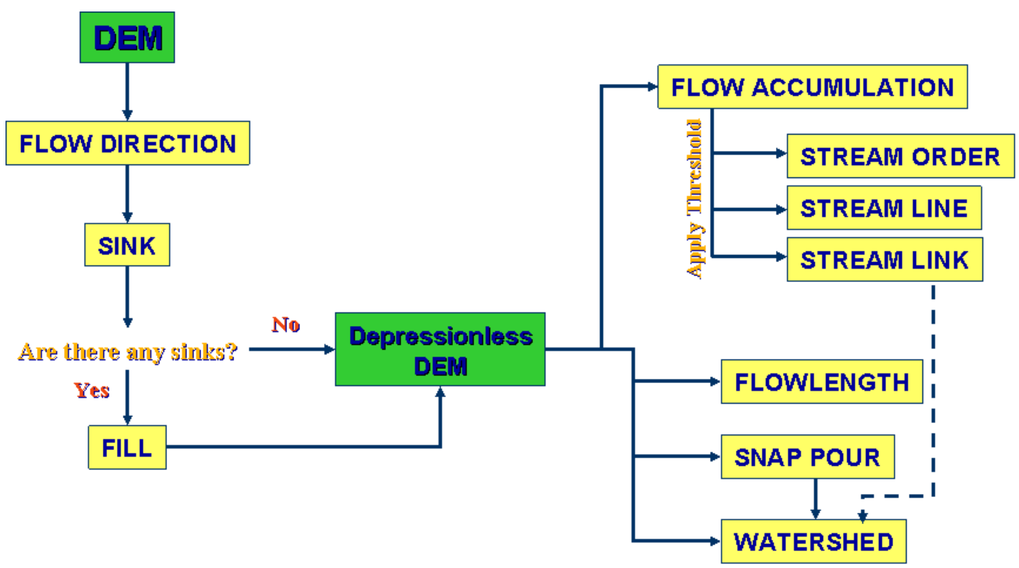

Figure 3.29: Function Processing (Maidment, 2002)

b. Filling the DEM Sinks and Creating a Sinks Grid

A depressionless DEM that is free of sinks is the desired input to the flow direction process as the occurrence of sinks may result in generation of an erroneous flow–direction raster file. Sources of sinks may vary from valid sinks in the data representing true features on the surface of the earth and while others are attributed to errors in the data.

The following steps illustrated on figure 3.17 were executed to fill DEM sinks and creating a sinks grid for the area of interest.

1. Sinks on the DEM shown on figure 3.18, were filled by using **Spatial Analyst Tools: Hydrology: Fill** output to a new DEM devoid of any sinks called *NoSinks*.
2. In order to view the sinks, a sinks grid was created by subtracting the Filled DEM from the original DEM. The connecting pixels were then grouped and assigned to unique zones.
   a. A Sinks Mask illustrated on figure 3.19 was created using **Spatial Analyst Tools: Math: Minus** to an output grid called *Sinks*
   b. A Region Group grid was created **Spatial Analyst Tools: Generalization: Region Group** output to an output grid named *RegionG_KE_S1*
   c. To Create a Sinks Mask, **Spatial Analyst Tools: Conditional: Set Null** was used and output to a grid named *SinksMask*. This grid contains all of the pixels the Fill Grid function modified as shown on figure 3.19.

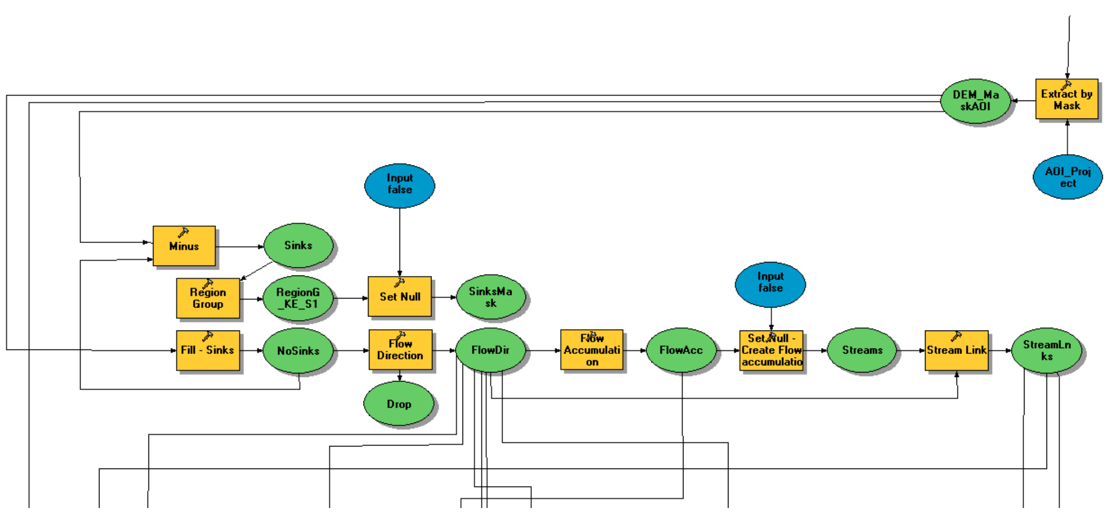

Figure 3.30: Creating a Sinks Grid

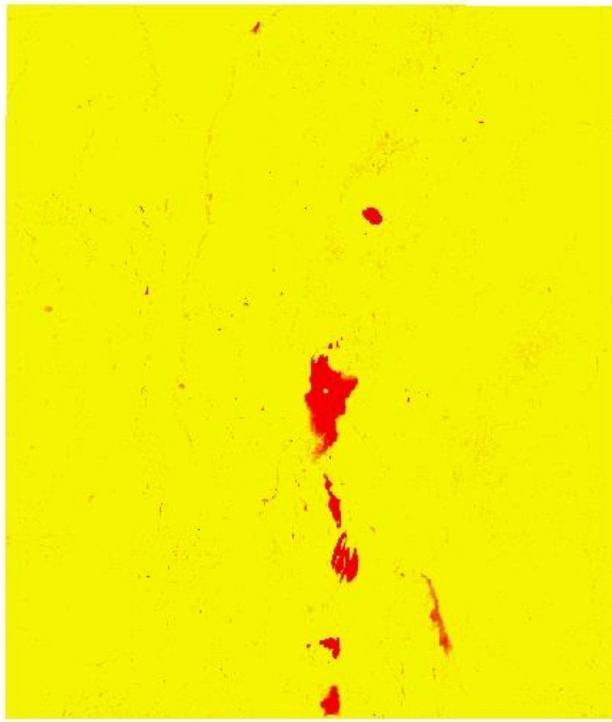

Figure 3.31: Sinks in red colour

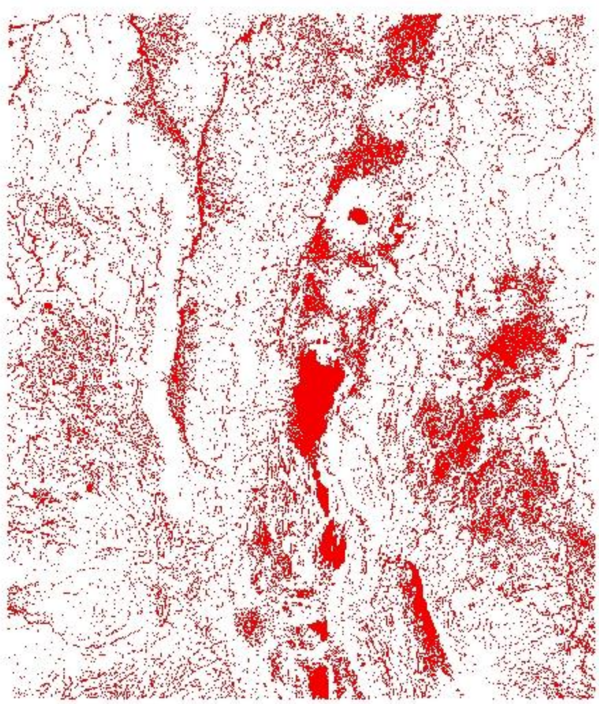

Figure 3.32: Sinks Mask

c. Creating the Flow Direction and Flow Accumulation grids

The general rule is that flow across a surface will always take the steepest downslope direction and path hence if the direction of flow out of each cell is known, it is possible to determine which and how many cells flow into any given cell. This information can then be used to define watershed boundaries and stream networks

The following steps captured on figure 3.20 were executed to create the Flow Direction and Flow Accumulation grids from the area of interest DEM

1. **Spatial Analyst Tools: Hydrology: Flow Direction** Tool
   a. Input: Filled DEM *NoSinks*.
   b. Output: *FlowDir* grid
2. **Spatial Analyst Tools: Hydrology: Flow Accumulation** Tool
   a. Input: *FlowDir*
   b. Output: *FlowAcc*

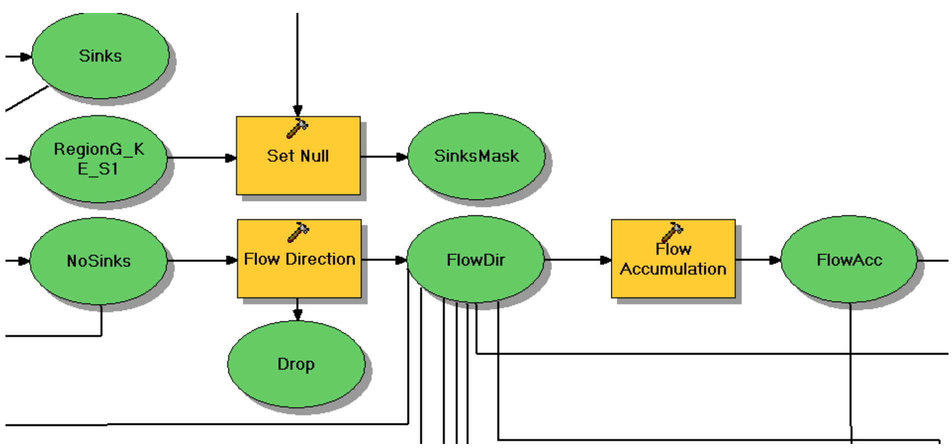

Figure 3.33: Flow Direction and accumulation

The flow direction and accumulation grids are displayed on Figure 3.21 and figure 3.22.

Figure 3.34: Flow Direction

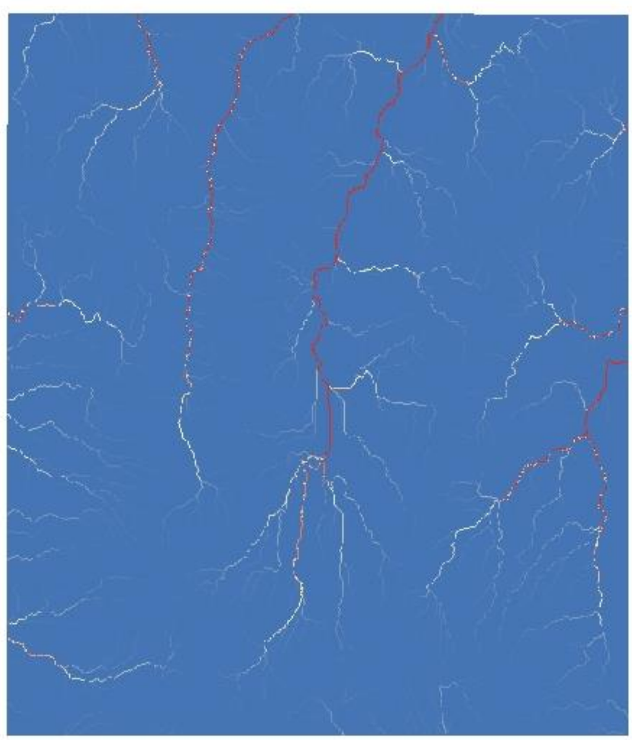

Figure 3.35: Flow Accumulation

d. Creating the Flow Accumulation Threshold grid

The **Spatial Analyst Tools: Conditional: Set Null** tool was use to create a Flow Accumulation Threshold grid for the area of interest DEM as illustrated on figure 3.23. An arbitrarily number of 1,000 representing large flows in the river bed was used to set the threshold Value (maximum value) < 1,000 in order to limit the stream grid density to a realistic and manageable level. The arbitrary number was arrived at using the generate-and-test method. The result of this was a raster layer for the resulting stream network.

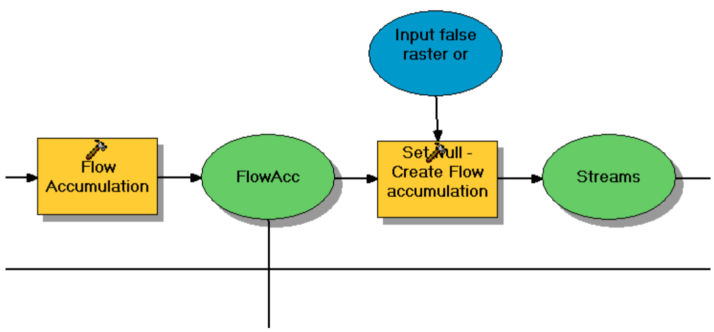

Figure 3.36: Creating Flow Accumulation Threshold Grid

e. Creating the Stream Links grid

The **Spatial Analyst Tools: Hydrology: Stream Link** tool was use to assign unique IDs to all segments in the stream network as show on figure 3.24.

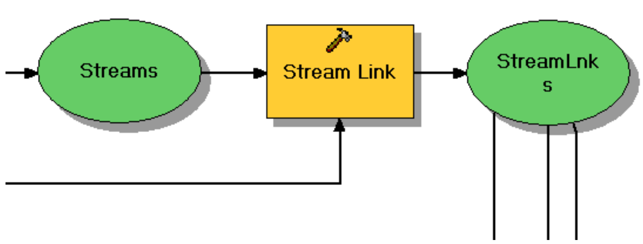

Figure 3.37: Creating Stream Links Grid

f. Creating the Stream shapefile

The **Spatial Analyst Tools: Hydrology: Stream to Feature** tool was used convert the raster representation of the stream network into a vector dataset.

g. Running the Watershed Tool

The **Spatial Analyst Tools: Hydrology: Watershed** tool was used to create a Watershed grid. Each watershed represented an area draining through a common outlet or pour point as concentrated drainage.

Figure 3.25 illustrates watershed processing..

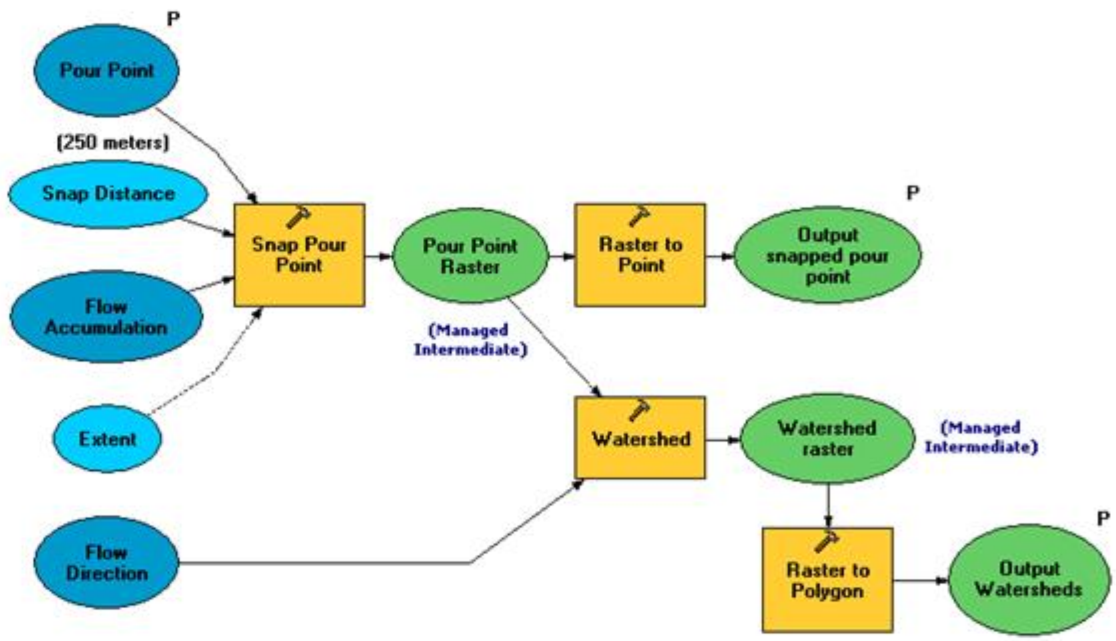

Figure 3.38: Watershed Processing (Maidment, 2002)

h. Running the Basin Tool

The **Spatial Analyst Tools: Hydrology: Basin tool** was used to delineate drainage basins within the area of interest by identifying ridge lines between basins. As shown on Figure 3.26 the flow direction raster was input and processed to identify all connected cells belonging to the same drainage basin resulting in a raster representation of drainage basins on Figure 3.27.

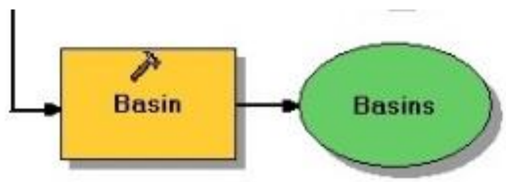

Figure 3.39: Basin processing

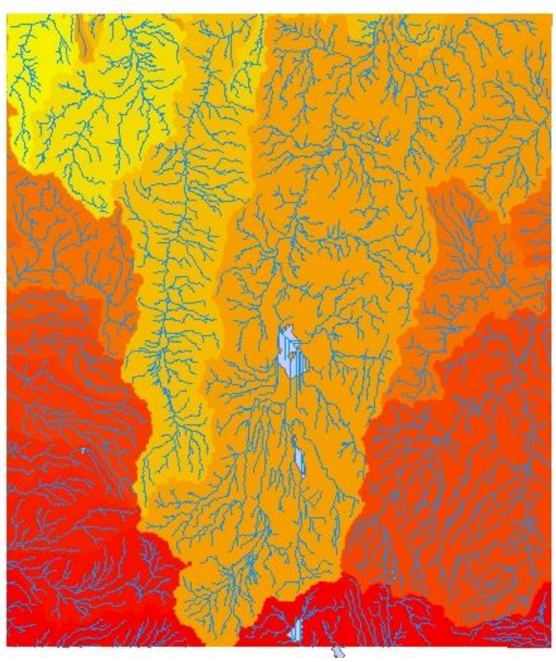

Figure 3.40: Basins

i. Arc Hydro Data Model And Framework

The use of the Arc Hydro model was limited to generating stream elevation as all other processing had been done using the Hydrology tool in the Spatial Analyst Toolbox within ArcMap. The stream elevation was necessary for determining stream head within the hydropower model discussed in section 3.4.

3.4 Hydropower Model

A Hydropower model was developed via extracting by mask, drop points within the area of interest from a 3D raster representation of the river network. The drop points were obtained by subtracting minimum neighbours from the area of interest DEM. The minimum neighbours were derived by applying 3 by 3 cell focal statistics against each pixel on the area of interest DEM. The river drop was colour coded and classified in terms of head as either high (> 50 m), medium (10-50 m) or low (< 10m) which would guide the type of turbine as discussed in Table 2.2 and Figure 2.2.

To establish the hydropower potential, the river drop was multiplied by gravitational acceleration 9.81 ms^{-2}.

The product of hydropower potential and river discharge would yield the extractable hydropower output of any identified site.

Using hydropower potential and discharge calculation from hydrologic analysis of the Perkerra River, the extractable Q40, Q50 & Q60 hydropower output potential was obtained for high head sites along the Tigeri, Lelgel and Eldama Ravine gauged sections of the River Perkerra.

A high-level flow chart of the model is shown in Figure 3.28.

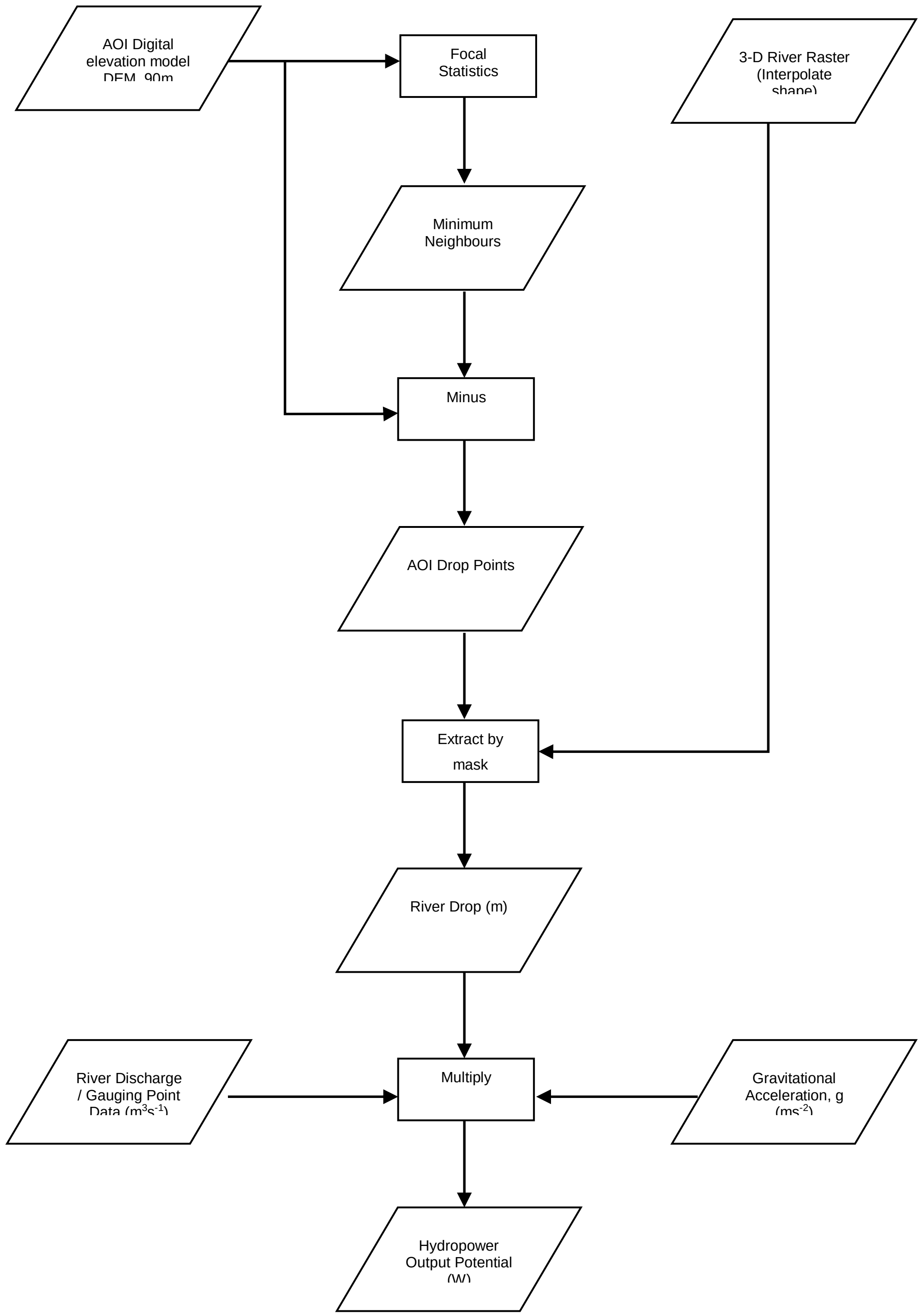

Figure 3.41: Hydropower Potential Model

CHAPTER 4: RESULTS AND DISCUSSION

This chapter reviews, analyses and discusses the results from;

a. Analysis of the questionnaires administered to the households in the study area

b. Hydrologic analysis and derived river flow rates

c. GIS hydrologic modelling.

4.1. Questionnaire Results

4.1.1. Household information

A total of 105 questionnaires and interview schedules were available for analysis from respondents drawn consisting of 60% male and 40% female as shown on Table 4.1. The respondents were sampled from commuters within trading centres hence the gender distribution does not accurately reflect that of the study area as the questionnaires were not administered at respective households. However, from conducting the survey on market days, it can be inferred that women are more involved in market trading than men.

Of the respondents, 11.9% attended up to primary school education, while 72.3% attained high school education level. 15.8% had attended either college or university as shown on Table 4.2. This indicates that economic activity within town and trading centres largely involves individuals with high school education and above as they constituted 88.1% of the sampled population.

Table 4.16: Percent distribution of respondents by sex

Sex	***Percent***	***Frequency (N)***
Male	40	42
Female	60	63
Total	100	105

Table 4.17: Percent distribution by level of education

Education level	***Percent***	***Frequency (N)***
Primary	11.9	12
High school	72.3	73
University/College	15.8	16
Total	100.0	101

4.1.2. Energy use

This research established that firewood is main source of energy for cooking in the study area is as tabulated on table 4.3 whereby 78% of the respondents use firewood for cooking, 13% use charcoal, 5% use kerosene, 3% use electricity and 1% other sources such as sawdust, dung or maize cobs. This implies that the forests around the homesteads are under threat of destruction for the search of the firewood.

Table 4.18: Cooking Energy Source

Cooking Energy Source	***Percent***	***Frequency (N)***
Firewood	75	79
Charcoal	13	14
Kerosene	5	5
Gas	3	3
Electricity	3	3
Other	1	1
Total	100	105

This compares closely to results on figure 4.1 from a study jointly carried out by the Kenya National Bureau of Statistics and Society for International Development (2013) exploring Kenya's Inequality which established that 1% of residents in Baringo County use liquefied petroleum gas (LPG), and another 1% use paraffin, 87% of the residents use firewood while 11% use charcoal. In the same research, Tiaty constituency was identified as having the highest level of firewood use in Baringo County at 97% while Eldama Ravine, which has the lowest level of firewood use at 76%. Conversely Eldama Ravine constituency has the highest level of charcoal use in Baringo County at 21% which 11 times the level of Tiaty constituency, which has the lowest share.

The selected trading centres at which the questionnaires were administered all lay within Eldama Ravine consistency.

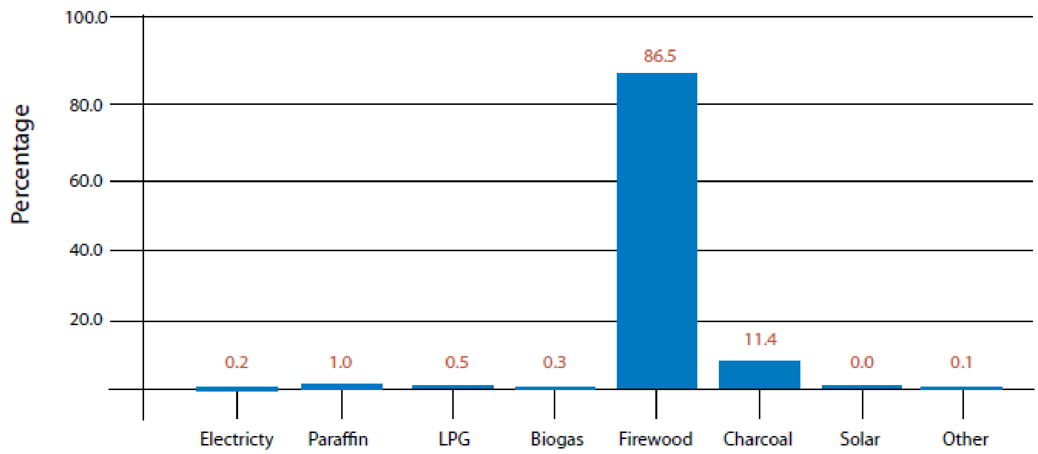

Figure 4.42: Percentage Distribution of Households by Source of Cooking Fuel in Baringo County (KNBS and SDI, 2002).

In this study, most of the respondents were found to use kerosene for lighting (84%). Those who use electricity for lighting were 3% while 1% use the gas lamp. The results are tabulated on table 4.4

Table 4.19: Lighting Energy Source

Lighting Energy Source	***Percent***	***Frequency (N)***
Kerosene	92	97
Electricity	6	6
Gas	2	2
Total	100	105

The study by the Kenya National Bureau of Statistics and Society for International Development (2013) in addition to investigating cooking energy use, established that only 9% of residents in Baringo County use electricity as their main source of lighting while a further 39% use lanterns, and 20% use tin lamps, while 28% use fuel wood. These findings are displayed on figure 4.2 below.

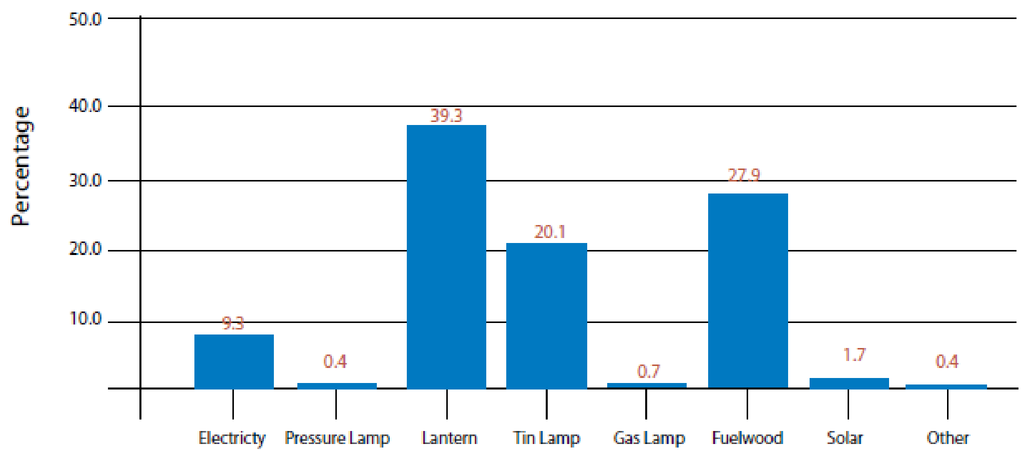

Figure 4.43: Percentage Distribution of Households by Source of Lighting Fuel in Baringo County (KNBS and SDI, 2002).

This study also established the distance travelled to obtain energy as well as assessed the respondents perception on accessibility, cost and impact of the various forms of energy sources used. These results are tabulated on tables 4.5 and 4.6 respectively.

Table 4.20: Distance travelled to obtain Energy Source

	Cooking Energy	***Lighting Energy***
Less than 1 km	19	27
2 - 4 km	9	45
More than 4 km	72	28

Table 4.21: Perception on access, cost and impact of Energy Source

	Do Not Agree	***Partially Agree***	***Fully Agree***	***Don't* Know**
Not easy to get	9	17	72	2
Expensive	62	19	14	5
Environmentally friendly	3	68	21	8
Waste time	12	6	77	5
Causes health complications	16	19	26	39

4.1.3. Results interpretation

The first specific objective of this research was to assess energy use within the study area hence determine whether sufficient demand for renewable exists whose adoption would alleviate the use energy sources associated with climate change. It was possible to carry out this assessment using data collected from the questionnaire from which we were able to confirm as following regarding the study area;

a. Biomass and fossil fuels are the primary sources of energy for both cooking and lighting within the study area. These energy sources are known to release greenhouse gas emissions which subsequently contribute to climate change. This correlates with findings on Energy use in Kenya from studies carrued out by Karekezi (2002), GoK, (2004), KNBS (2013) and Kamfor (2002).

b. Dependence for wood fuel is a significant driver of destruction of forest cover which releases stored carbon into the atmosphere as CO_2, a potent greenhouse gas whilst reducing available sequestration capacity hence contributing to climate change (Sovacool & Drupady, 2012). Groups of women and children as captioned on Figure 4.3 were seen emerging from forest carrying stacks of firewood as capture during one of the site visits to the area.

c. A significant portion of the local population is exposed to occupational health risks associated smoke emissions from fuel wood and kerosene. (Ezzati, & Kammen, 2001; Smith et al., 2000).

d. A significant amount of time is spent sourcing for energy which means less opportunity for the local population to engage in socioeconomic activity that can help alleviate poverty. Table 4.5 indicates a majority of respondents travel in excess of 1 kilometres to collect cooking and lighting energy.

e. Providing access to cheaper, accessible and cleaner alternative energy to the local population will reduce demand for unsustainable energy sources associated with anthropogenic climate change. Table 4.6 suggests likely adoption of alternative energy and knowledge of the inherent risk of using traditional energy sources. (Sovacool & Drupady, 2012).

Figure 4.3: Villagers Fetching Firewood for Cooking

4.2. Hydrologic Analysis

4.2.1. Flow Duration Curve Analysis

For each gauging station with data flow-duration curves were derived with the cumulative frequency curve that showed the percent of time specified discharges were equalled or exceeded over the period which readings were recorded. The flow-duration curve represents the long-term characteristics of the gauged stream segments hence were used to predict the distribution of future flows for hydropower estimation. The respective Q40, Q50 and Q60 are tabulated on Table 4.7 below. Appendix B contains the respective flow duration curves for reference.

Hydrologic Analysis was carried out to obtain the flow duration curves for 8 gauging stations along the Perkerra River using daily discharge data collected between 1932 and 1982. More recent data was not available in electronic format as the information had not been collated and digitized by WRMA.

Table 4.22: Q40, Q50 and Q60 Discharge Values by Gauging Station

GAUGING STATION CODE	NAME	LOCATION	Long	Lat	Q40 m^3s^{-1}	Q50 m^3s^{-1}	Q60 m^3s^{-1}
2EB01	WASEGES	KISANANA	36.211000	0.186000	0.37	0.34	0.31
2EC02	RONGAI	RONGAI	35.931000	0.106000	0.111	0.078	0.056
2EC03	RONGAI	RONGAI	Not located	Not located	0.093	0.062	0.045
2EC04	RONGAI	RONGAI	Not located	Not located	0.02	0.02	0.019
2ED01	TIGERI	KAPCHOLOI	35.688683	0.100679	0.82	0.8	0.8
2ED02	LELGEL	POROR	35.700373	0.058783	0.35	0.30	0.28
2ED03	ELDAMA RAVINE	ELDAMA RAVINE	35.721810	0.046887	0.0.30	0.28	0.24
2EE07	PERKERRA	KIMOSE	35.919792	0.292362	2.718	1.7515	1.187
2EE07A	PERKERRA	MARIGAT BRIDGE	35.969636	0.458992	6.612	5.766	4.788
2EE07B	PERKERRA	MARIGAT BRIDGE	35.966000	0.458000	0.907	0.687	0.525
2EE08	PERKERRA	KIMNGOROM	35.819631	0.160988	1.589	1.2	0.91
2EF04	NAROSURA	KABIMOI	35.784011	0.022426	0.907	0.687	0.525
2EG01	MOLO RIVER	KELELWA	35.913000	0.086000	0.863	0.575	0.404

4.2.2. Results interpretation

The derived flow duration curves indicated that, most sections along of River Perkerra had sufficient flows all year round from which requirements for hydropower generation would be met or exceeded of 60% of the time. In addition, highest flows in the rivers are experienced between the months of April to September coinciding with the period of highest precipitation. When a hydropower plant is set up then it is expected that in these months, the power generation will be maximum.

4.3. GIS Modelling

4.3.1 Hydrologic Modelling

a) Stream network and watershed delineation

The River Perkerra watershed and its stream network were delineated the from digital elevation model data. Figure 4.4 show the resultant stream network while figures Figure 4.5 and Figure 4.6 illustrate the 3D rendering of the river elevation and TIN surface respectively

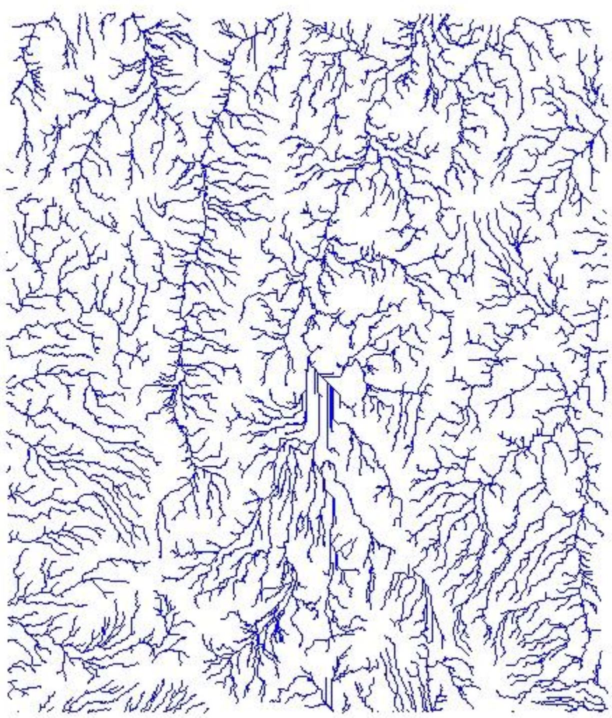

Figure 4.44: Stream to Feature

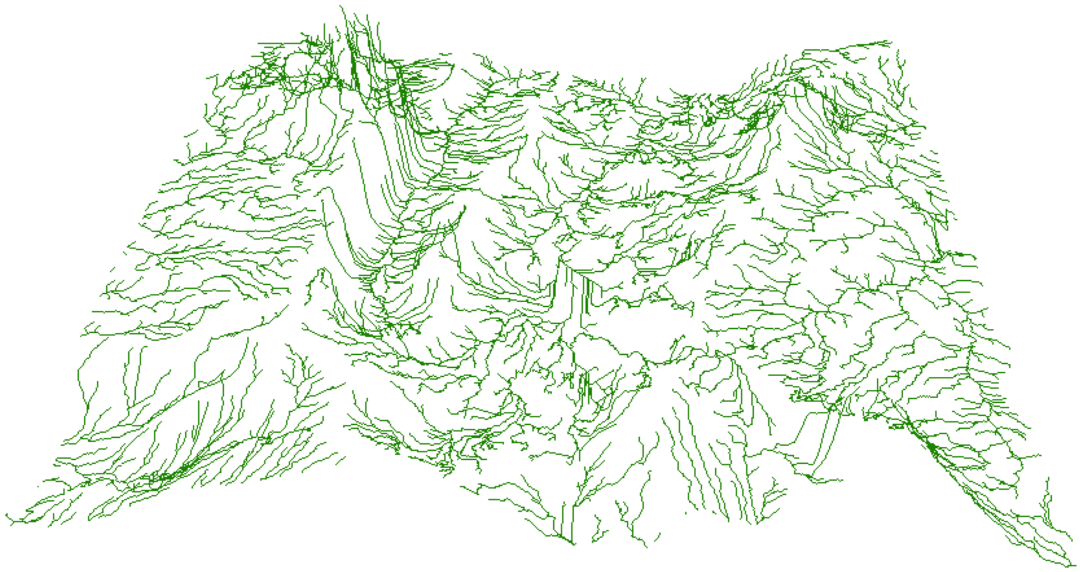

Figure 4.45: Stream Elevation Using ArcHydro Tools and 3D rendering using ArcScene

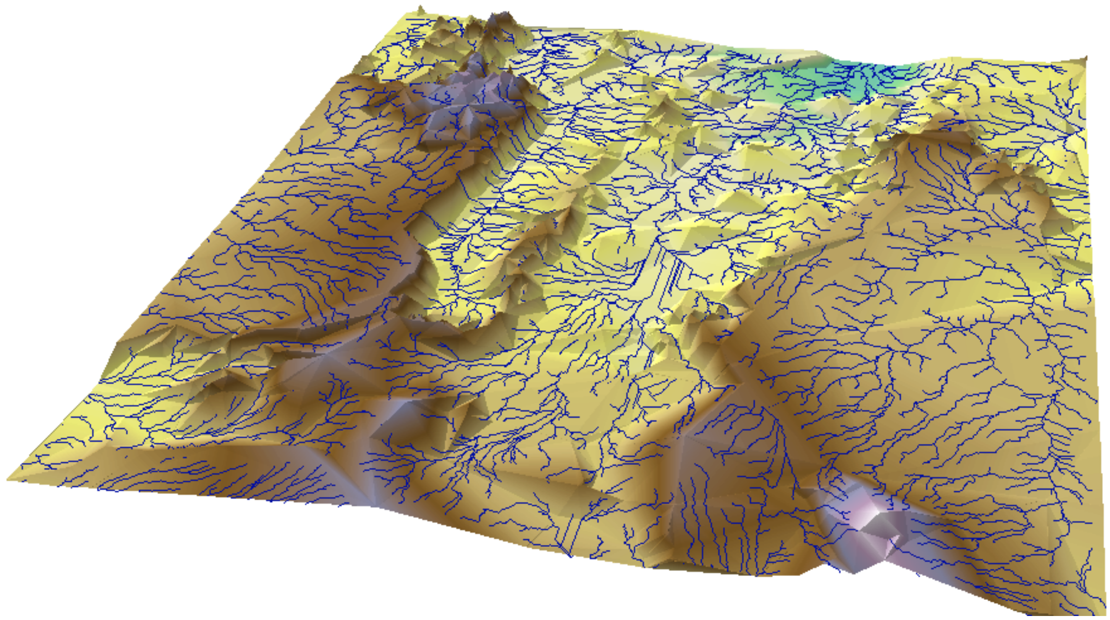

Figure 4.46: TIN Surface 3D rendering using ArcScene

b) Ground truthing of the derived Stream network

The derived stream network compared well against those obtained from digitized maps. Figure 4.7 shows an overlay with a stream network obtained from DEPHA. The threshold value selected to determine defines the raster cell that had enough accumulation to be classified as streams, did not have a significant effect on the resulting delineated stream and provided a marginally higher of detail.

Digitised maps carry a bigger approximation due to the scale of representation being lower that the SRTM data used in this research. With use of a higher quality DTM such as 30 m SRTM, the accuracy of the delineated stream network could possibly be increased further.

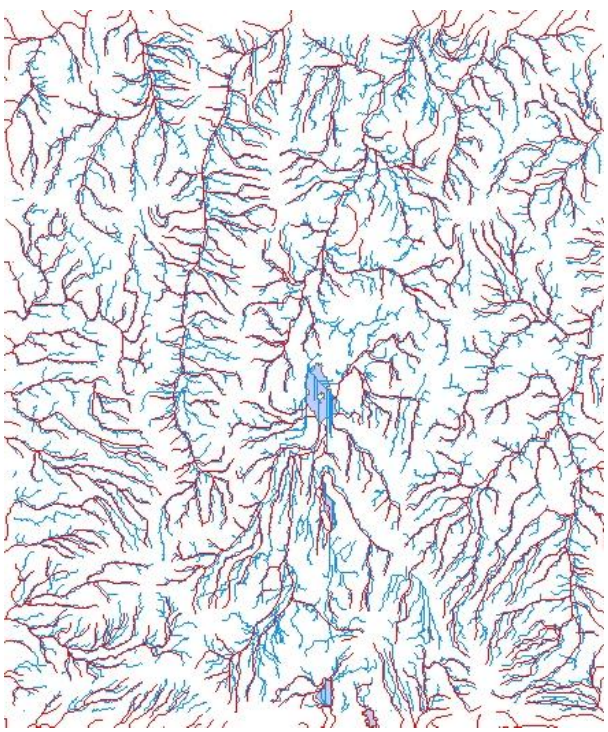

Figure 4.47: Comparison between Derived Stream Network (Blue) and that Digitized from Topographic Maps (Red)

Similarly, the coordinates of gauging station obtained using a GPS during site visits all fell within the derived network confirming accuracy of the model. Figure 4.8 shows the relative positions of the gauging stations with respect to the derived stream network while figures 4.9, 4.10, 4.11, 4.12 and 4.13 are photographs of some of the gauging stations captured during the site visits.

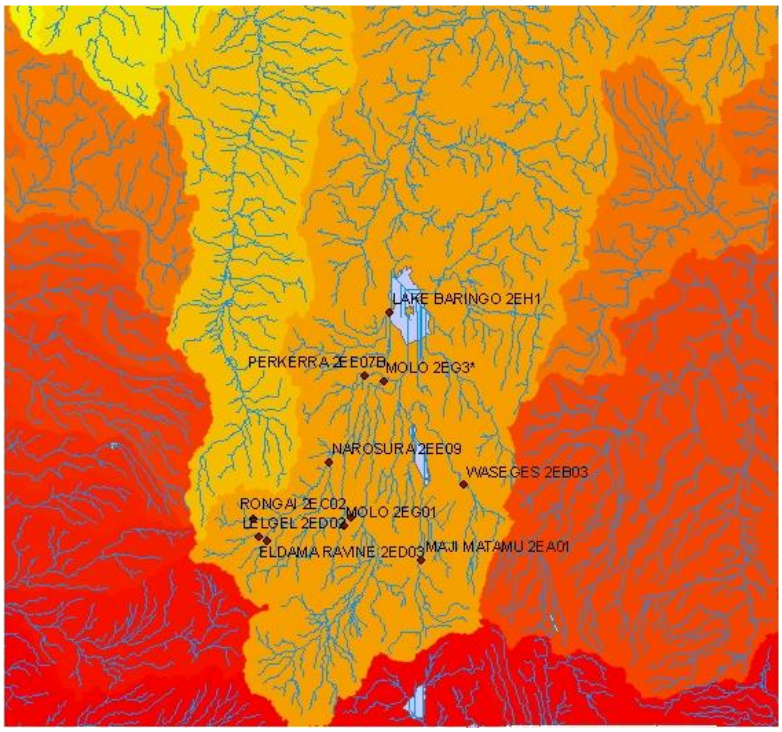

Figure 4.48: Collected Gauging Station Coordinates against Derived Stream network

Figure 4.49: Tigeri gauging station 2ED01 at coordinates 35.688683 E 0.100679 N

Figure 4.50: Eldama Ravine gauging station 2ED03 at coordinates 35.721810 E 0.046887 N

Figure 4.51: Narosura gauging station 2EF04 at coordinates 35.784011 E 0.022426 N

Figure 4.52: Esageri gauging station 2EF03 at coordinates 35.82417 E 0.017767 N

Figure 4.53: Perkerra gauging station 2EE08 at coordinates 35.819631 E 0.160988 N

c) Identifying sites with the largest drop

River drop points were extracted from the DEM and stream network in order to identify sites along delineated stream network that potentially have suitable head requirement for locating micro hydropower plants. A figure 4.14 shows a close up view of one of the stream segments and drop points classified by available head. Majority of sites with large drop were located in areas with high population density meaning that development of hydropower resources would be able to serve residents within the study area without incurring significant transmission cost due to the relatively short distance.

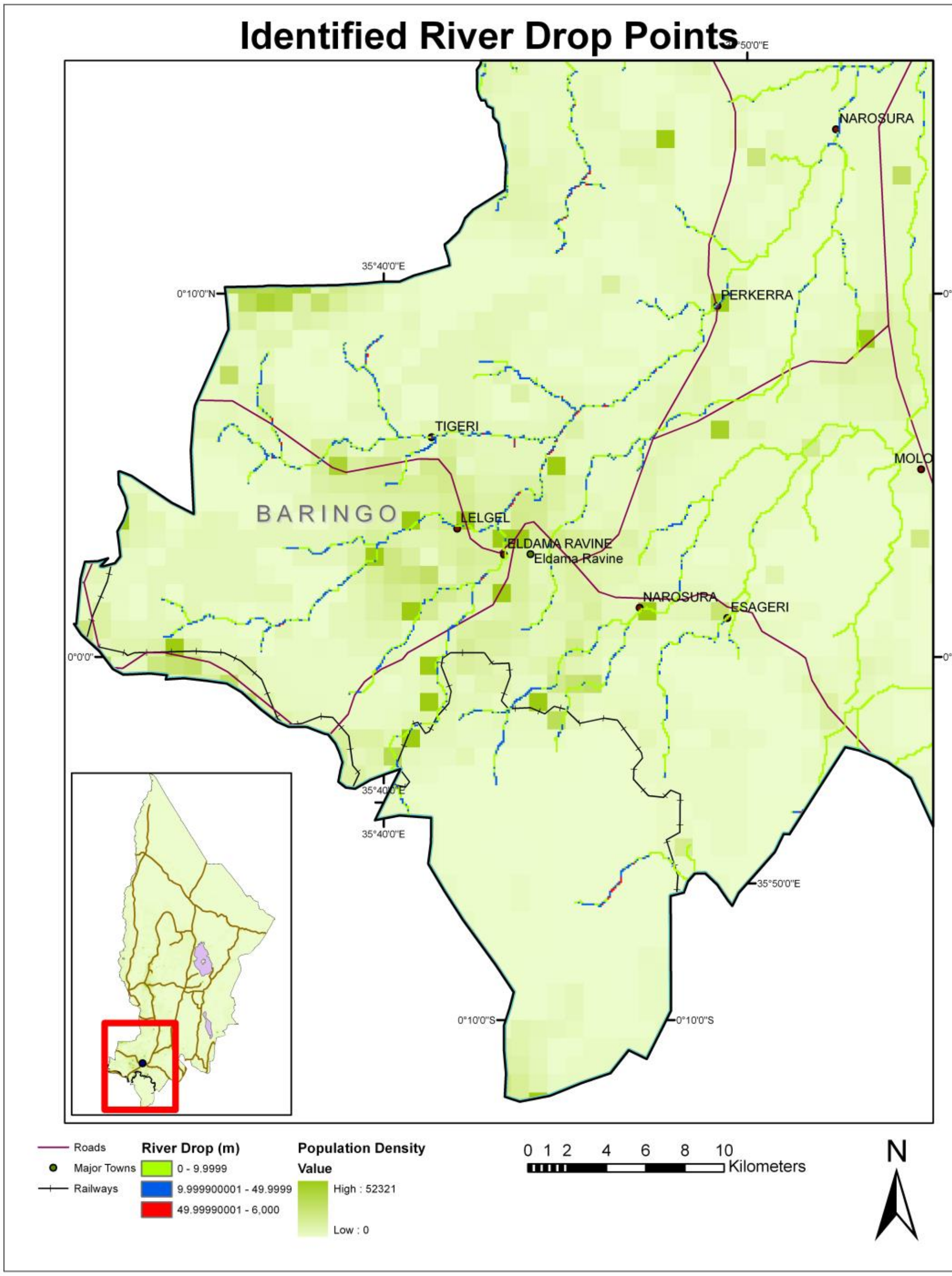

Figure 4.54: Close-up Image of River Drop Points by Head Classification

4. 3.2 Hydropower Modelling

The extractable Q40, Q50 & Q60 hydropower output potential for sites along the Tigeri, Lelgel and Eldama Ravine gauged sections of the River Perkerra identified to have a head drop of 50 metres and above are tabulated on Table 4.8 below. An analysis was conducted on the available head for each drop point along the river network. The spread of distribution illustrated in Figure 4.15 below indicates a significant number of potential hydropower sites falling within pico, micro, mini and small hydro categories.

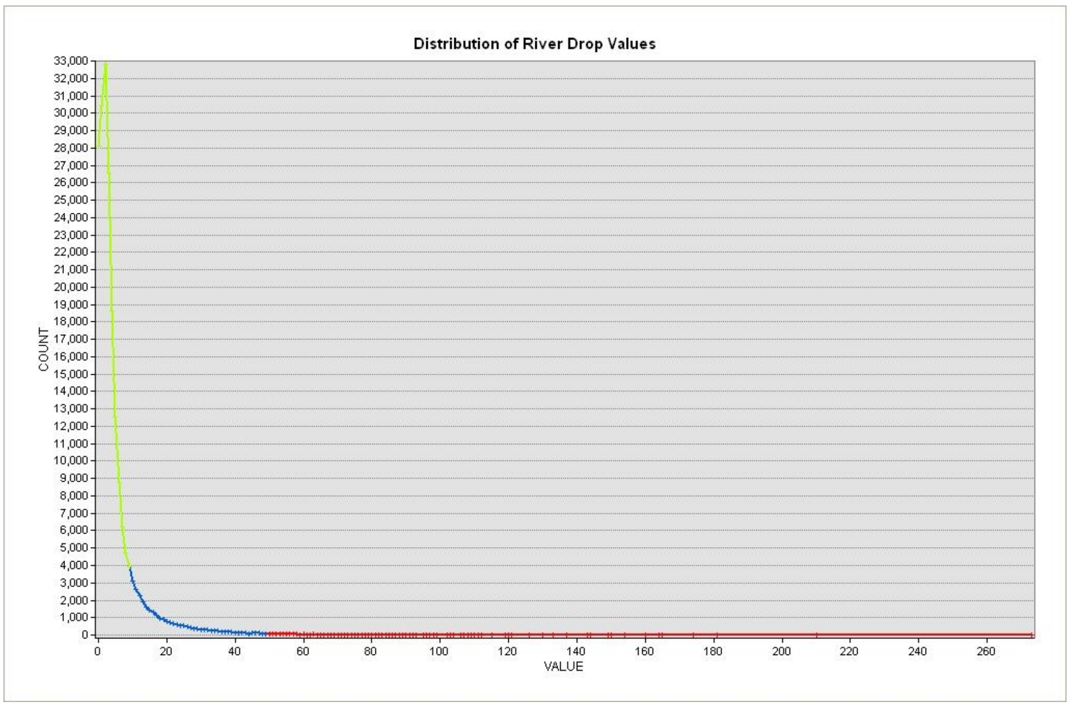

Figure 4.55 Quantitative distribution of River Drop Points by height

Table 4.23: Potential Hydropower Output Sites with 50 m or More Head

Reference Gauging Point(s)	Head Drop (m)	Hydro Site Coordinates (decimal degrees)	Total Available Discharge (m^3s^{-1})			Total Available Power Output (MW)			Hydropower Category
			Q40	Q50	Q60	Q40	Q50	Q60	
TIGERI 2ED01	51	35.712236 0.102368	0.82	0.80	0.80	0.410	0.400	0.400	Mini-Hydro
ELDAMA RAVINE 2ED03	52	35.711548 0.035348	0.30	0.28	0.24	0.153	0.143	0.122	Mini-Hydro
ELDAMA RAVINE 2ED03	50	35.712513 0.036192	0.30	0.28	0.24	0.147	0.137	0.118	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	58	35.725049 0.069461	0.65	0.58	0.52	0.370	0.330	0.296	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	63	35.725772 0.069943	0.65	0.58	0.52	0.402	0.358	0.321	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	55	35.726978 0.071630	0.65	0.58	0.52	0.351	0.313	0.281	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	62	35.728304 0.074523	0.65	0.58	0.52	0.395	0.353	0.316	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	51	35.729388 0.075126	0.65	0.58	0.52	0.325	0.290	0.260	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	58	35.739343 0.086141	0.65	0.58	0.52	0.370	0.330	0.296	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	78	35.742660 0.092853	0.65	0.58	0.52	0.497	0.444	0.398	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	69	35.743586 0.093778	0.65	0.58	0.52	0.440	0.393	0.352	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	79	35.744357 0.094704	0.65	0.58	0.52	0.504	0.449	0.403	Mini-Hydro
LELGEL 2ED02 & ELDAMA RAVINE 2ED03	85	35.746131 0.099024	0.65	0.58	0.52	0.542	0.484	0.434	Mini-Hydro
TIGERI 2ED01 & LELGEL 2ED02 & ELDAMA RAVINE 2ED03	73	35.748615 0.103190	1.47	1.38	1.32	1.053	0.988	0.945	Small-Hydro
TIGERI 2ED01 & LELGEL 2ED02 & ELDAMA RAVINE 2ED03	67	35.754556 0.110750	1.47	1.38	1.32	0.966	0.907	0.868	Mini-Hydro
TIGERI 2ED01 & LELGEL 2ED02 & ELDAMA RAVINE 2ED03	62	35.755250 0.111599	1.47	1.38	1.32	0.894	0.839	0.803	Mini-Hydro
TIGERI 2ED01 & LELGEL 2ED02 & ELDAMA RAVINE 2ED03	55	35.756253 0.112370	1.47	1.38	1.32	0.793	0.745	0.712	Mini-Hydro

4.2.2. Results interpretation

In this research, the use of GIS in accurately delignating river networks was demonstrated. Exploiting the capability of GIS to manipulate and analyse geospatial data, the delineated river network was further processed to successfully derive all drop points along River Perkerra. By evaluating drop point raster data against flow duration curves obtained from hydrologic analysis, it was possible to identify discrete locations along River Perkerra that have sufficient flows throughout the year for hydropower generation in the scale of pico, micro, mini and small hydropower installations. The number of such locations was found to be significant and widely spread across the study area while the extent of hydropower potential was evaluated as sufficient to warrant exploitation as an alternative source of clean and renewable energy.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

This chapter provides a summary of the entire research highlighting the conclusions, recommendations, areas for further study as well as policy implications. This summary is based on findings documented in the preceding chapter and research objectives.

5.1 Summary of Findings

The first specific objective of this research established that the use of fossil or biomass energy sources for lighting and cooking is widespread within the study area albeit recognised environmental, health, safety and economic drawbacks.This finding correlates with the outcome from similar studies on Energy use in Kenya carried out by Karekezi (2002), GoK, (2004), KNBS (2013) and Kamfor (2002) which also associated the use of these energy sources to the release greenhouse gas emissions which subsequently contribute to climate change. The local population partially recognise the benefits of cleaner energy hence an appetite for adoption of renewable that can be exploited. Based on the established disposition by the residents towards adoption of renewable energy, micro hydropower generated electricity provides a prospect for cheaper, cleaner and accessible energy as its potential within the study area was confirmed as sufficient warrant exploitation. If exploited, there would be less demand for energy sources linked to progression of climate change.

By successfully carrying out the second specific objective of this research, it was possible to delineate the River Perkerra watershed and its stream network from DTM data. Ground-truthing the derived river network against digitized hydrologic maps confirmed the aptness of GIS in accurately modelling surface hydrology.

The micro hydropower model developed to achieve the third and fourth specific objectives confirmed that the use of GIS can be extended to identify sites at discrete locations along the River Perkerra network with suitable head requirement and potential for micro hydropower development as well as estimating the hydropower generation potential of selected sites along the gauged segments of River Perkerra. The need for no customisations specific to River Perkerra catchment being applied to the model attests the use of GIS as a valuable tool in reliably modelling and assessing micro hydropower within any river drainage network. This presents an opportunity that can be employed to mitigate climate change at a local, national, regional or global scale.

The model further established that sites with micro hydropower potential within the study area are sufficiently large to warrant further development. These sites have hydropower potential characteristics of the scale of pico, micro, mini and small hydropower installations.

5.2 Recommendations

A key recommendation from this research is for government and research agencies to adopt GIS based hydropower potential modelling to assess and map out all sites across the country that offer viable prospects for development of pico, micro, mini and small hydropower generation assets.

Potential sites for hydropower development are numerous within the study area and can reliably generate electricity all year round. Another recommendation is for both national and county governments to engage investors and local community groups in setting up private public partnerships to rapidly develop this resource in order to alleviate energy scarcity by providing low cost energy whilst mitigating climate change, spurring growth of local industries, creating employment, generating revenue by selling surplus to the national grid as well as conserving the ever scarce forest cover.

To avail crucial data necessary for evaluating hydropower potentials for river basins across the country, this research recommends that government and county agencies responsible for managing water resources invest in adopting automated methods of electronically logging and storing river gauging point data as both current and historical records are not readily available in digitised form while readings are not consistently made on a regular basis. If this is implemented, the number of gauging stations can be increased to cover all major stream segments with readings made at regular intervals without the added staff resourcing overhead.

5.3 Areas for Further Research

Opportunities exist in the following areas related to this research and are proposed for pursuance.

i) With sufficient data on catchment discharge, the model can be further enhanced to obtain the total micro hydro-power potential of River Perkerra whereby the potentials of every stream segment are aggregated.
ii) DTM data with a higher resolution of 30 metres is now available and it would be worthwhile to establish how the results compare.
iii) This research can be replicated to assess hydropower potential for any river network hence proposed for application on other river drainage basins.
iv) Ground truthing of the respective output potentials for identified hydropower sites was not carried out extensively. Further research can be carried out to compare actual generated power to values derived from the model.

5.3 Policy Implications

The findings of this research can be used to address the challenge of identification, mapping and detailed assessments hydropower resources highlighted on Kenya’s National Energy Policy (GoK, 2004) and aid the country in achieving its energy objectives in line with the Vison 2030 goals (GoK, 2006).

REFERENCES

Acker, R. H., & Kammen, D. M. (1996). The quiet (energy) revolution: analysing the dissemination of photovoltaic power systems in Kenya. Energy Policy, 24(1), 81-111.

Action et al., 2014). The Bioeconomy to 2030; designing a policy agenda - Main Findings and Policy Conclusions. OECD, Paris.

Action, P., Turbines, W., Plant, M. H. P., & Electrification, D. R. (2014). Micro-hydropower. Practical Action.

Amissah-Arthur, H., Atugba, S., Ackon, S., Ageby, S., Meena, H., Mwakifwamba, S., & Mwakasonde, S. (2003). KITE.

Arrhenius, S. (1896). XXXI. On the influence of carbonic acid in the air upon the temperature of the ground. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 41(251), 237-276.

Asamenaw, S.A. and D.C. McKinney, (2005). ArcHydro Data Model for Ethiopian Watersheds, The University of Texas at Austin, Centre for Research in Water Resources Online Report No. 2005-06, 2005 http://www.crwr.utexas.edu/reports/2005/rpt04-5.shtml

Baringo County Annual Development Plan 2015/16 County Government Posted June 2, 2015 Baringo Year of Publication: 2014 Language: English Source URL: http://baringo.go.ke - See more at: http://devolutionhub.or.ke/blog/2015/06/baringo-county-annual-development-plan-201516#sthash.DkgxKtmq.dpuf

Bergkamp, G. J. J., Orlando, B., & Burton, I. (2003). Change: adaptation of water resources management to climate change. IUCN.

British Hydropower Association. (2005). A guide to UK mini-hydro developments. Britishhydro. org.

Brown, Michael (2003). A Blueprint for decentralized electricity, WADE. http://www.localpower.org/pdf/RightRulesforDE.pdf

Central Bureau of Statistics (CBS), 2005, Statistical Abstract 2005, Ministry of Planning & National Development.

Central Bureau of Statistics (CBS), International Centre for Economic Growth (ICEG) & K-EP Holdings Ltd, 1999, "National Micro and Small Enterprise Baseline Survey" Survey Results, Nairobi.

CGIAR, Consortium for Spatial Information (CGIAR-CSI), March 20, 2005 http://srtm.csi.cgiar.org

Cheng, B. S. (1995). An investigation of cointegration and causality between energy consumption and economic growth. Journal of Energy and Development, 21(1).

Chow, V.T., Maidment, D.R., and Mays, L.W. (1988) Applied Hydrology, McGraw-Hill, New York, pp. 530-537.

Cobb, B. R., & Sharp, K. V. (2013). Impulse (Turgo and Pelton) turbine performance characteristics and their impact on pico-hydro installations. *Renewable Energy*, *50*, 959-964.

Consortium for Spatial Information (CGIAR-CSI) (2010, July 15) Retrieved from http://srtm.csi.cgiar.org

Cooper, D. R., and Schindler, P. S (2006). *Business Research Methods* (9th Edition). McGraw-Hill Publications. New York, United States.

CRA (2011) Commission of Revenue Allocation: Kenya County Fact Sheets, Kenya Bureau of Statistic. https://opendata.go.ke/Counties/Kenya-County-Fact-Sheets-Dec-2011/zn6m-25cf

Cunningham, P., & Atkinson, B. (1994). Micro hydro power in the nineties. Online, accessed: 7-4-2004], URL: http://www. elements. nb. ca/theme/energy/mi cro/micro. htm.

Danish Hydraulic Institute Water Models http://www.dhi.dk

Das, S., & Paul, P. K. (2006). Selection of site for small hydel using GIS in the Himalayan region of India. Journal of Spatial Hydrology, 6(1).

David Arctur and Micheal Zeiler, Designing Geodatabases, ESRI, 2004

DWC, (2003). The National Drought Management Policy Guidelines

Ellene Kebede, John Kagochi, Curtis M. Jolly, (2010). Energy consumption and economic development in Sub-Sahara Africa, Energy Economics, 32 (3) ,

Energicentre Denmark, The electricity reform, 2005. http://www.ecd.dk/UK-dk-resleg.htm

ESRI, World Base Map, April 19, 2005 http://www.esri.com/data/download/basemap/index.html

ESRI. “ArcHydro Tools Overview.” V. 1.1 (2005), Redlands, CA.

Evans, A., Strezov, V., & Evans, T. J. (2009). Assessment of sustainability indicators for renewable energy technologies. Renewable and sustainable energy reviews, 13(5), 1082-1088.

Ezzati, M., & Kammen, D. M. (2001). Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. The Lancet, 358(9282), 619-624.

Ezzati, M., & Kammen, D. M. (2001). Quantifying the effects of exposure to indoor air pollution from biomass combustion on acute respiratory infections in developing countries. Environmental health perspectives, 109(5), 481.

FAO, Land and water development division, May 10 2005. http://www.fao.org/geonetwork/srv/en/metadata.show?id=12&currTab=summary

Feizizadeh, B., & Haslauer, E. M. (2012). GIS-based procedures of hydropower potential for Tabriz basin, Iran. *International Journal*, 495-502.

Floriancic, M., Margreth, M., & Naef, F. (2016, April). What can we learn about low flow storage properties from flow duration curves?. In EGU General Assembly Conference Abstracts (Vol. 18, p. 14269)

Florides, G. A., & Christodoulides, P. (2009). Global warming and carbon dioxide through sciences. Environment international, 35(2), 390-401.

Fraenkel et al 1991, Microhydro power- a guide for development workers, Intermediate Technology Publications, London.

Frey, G. W., & Linke, D. M. (2002). Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. Energy policy, 30(14), 1261-1265.

Glantz, M. Kartz, R. and Krenz, M. (ed.), Impact: Climate Crisis. United Nations, New York, USA, 1987.

GoK (Government of Kenya), 2004, "Sessional Paper No.4 of 2004 on Energy." National Energy Policy. Nairobi.

GoK, (2006).vision 2030.

Gopalan, H. and D.R. Maidment, WRAPHydro Data Model: Finding Input Parameters for the Water Rights Analysis Package, The University of Texas at Austin, Center for Research in Water Resources Online Report No. 2003-03, 2003 http://www.crwr.utexas.edu/reports/2003/rpt03-3.shtml

Harvey, A. (1993). Micro-Hydro Design Manual: a guide to small-scale water power schemes (No. 621.24/H341).

Hordon, R. M. (2005). Flow-Duration Curves. Water Encyclopedia. 3:102–106.

Houghton, J. T., Albritton, D. L., Meira Filho, L. G., Cubasch, U., Dai, X., Ding, Y., & McFarland, M. (2001). Technical summary of working group 1. Cambridge University Press.Ian, (2010). Nuclear Energy and the Fossil Fuels 'Drilling and Production Practice'. SpringMeeting of the Southern District. Division of Production. American Petroleum Institute. ShellDevelopment Company, San Antonio, Texas, pp. 22–27.

Ian, H. (2010). An introduction to geographical information systems. Pearson Education India.

IEA (2005). Renewable Energy Sources Act (2004) (Erneuerbare-Energien-Gesetz EEG). International Energy Agency Renewable Energy Policies & Measures Database.

IEA, (1998).World energy outlook International Energy Agency, Paris.

Jaetzold et al., (1983). Water pollution by agriculture. Philosophical Transactions of the Royal Society B363(1491): 659-666

Jaetzold R, Schmidt H, Hornetz B, Shisanya C (2010). Ecosystems and Human Well-Being: Biodiversity Synthesis. World Resources Institute: Washington, DC.

Jet Propulsion Laboratory, Shuttle Radar Topographic Mission the Mission to the World map. http://www2.jpl.nasa.gov/srtm/instrumentinterferometry.html

Jha, R. (2010). Total run-of-river type hydropower potential of Nepal. *Hydro Nepal: Journal of Water, Energy and Environment*, *7,* 8-13.

Kabat, P., Schulze, R. E., Hellmuth, M. E., & Veraart, J. A. (2003). Coping with impacts of climate variability and climate change in water management: A scoping paper. DWC-Report no. DWCSSO-01 Dialogue on Water and Climate: Wageningen, The Netherlands.)

Kamfor Company Limited (2002) "Kenya's Energy Demand, Supply and Policy Strategies for Households, Small Scale Industries and Service Establishments" (Kamfor Study), Kamfor Company Limited, Nairobi

Karekezi S and Timothy R (1997), Renewable Energy Technologies in Africa, Zed Books Limited, London

Karekezi, et al. (2009). Micro hydro power resource assessment handbook. APCTT, September.

Karekezi, et al. (2009). Global Status of Commercialized Biotech/GM Crops: 2009 The first fourteen years, 1996 to 2009.

Karekezi, S. (2002). Poverty and energy in Africa—A brief review. Energy Policy, 30(11), 915-919.

Kathleen M. Flynn, Paul R. Hummel, Alan M. Lumb and John L. Kittle, Jr., User's Manual for ANNIE, Version 2, a Computer Program for Interactive Hydrologic Data Management, U.S. GEOLOGICAL SURVEY, Water-Resources Investigations Report 95-4085

Kebede and others (2010). European quality agriculture as an alternative bio-economy. In G. Ruivenkamp, S.Hisano and J. Jongerden (eds.)

Kenya National Bureau of Statistics and Society for International Development (2013) Exploring Kenya’s Inequality: Pulling apart or pooling together? Nairobi, Kenya: Kenya National Bureau of Statistics and Society for International Development.

KNBS – Kenya National Bureau of Statistics - Statistical Abstract (2013) http://www.knbs.or.ke/index.php?option=com_phocadownload&view=category&id=106:statistical-abstract&Itemid=1177

Khennas, S., & Barnett, A. (2000). Best practices for sustainable development of micro hydro power in developing countries.

Kinuthia, J.H., Agatsiva, J.L. and Aligula, H.M., Greenhouse gases inventory from land use and forestry changes in Kenya, CNA interim report, Nairobi, 1995.

Klunne, W. J. (2007). Small hydropower development in Africa. America, 2, 6-1.

Klunne, W. J., & Michael, E. G. (2010). Increasing sustainability of rural community electricity schemes—case study of small hydropower in Tanzania. International Journal of Low-Carbon Technologies, 5(3), 144-147.)

Kozloff, Keith Lee (1995). "Rethinking Development Assistance for Renewable Electricity Sources".

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). Geographic information science and systems. John Wiley & Sons.

Maidment, D.R. GIS and Hydrologic Modeling, in Environmental Modeling with GIS, ed. by M.F. Goodchild, B.O. Parks, and L.T. Steyaert, Oxford University Press, New York, 1993.

Maidment, David R. "Arc Hydro: GIS for Water Resources." Redlands: ESRI Press, 2002.

Maidment, David R, GIS in Water Resources Fall 2004 http://www.ce.utexas.edu/prof/maidment/giswr2004/ex3/ex32004.htm

Martinot, E., & McDoom, O. (2000). Promoting Energy Efficiency and Renewable Energy: GEF Cliamte Change Projects and Impacts. Global Environment Facility Facility.

Masih, A. M., & Masih, R. (1996). Energy consumption, real income and temporal causality: results from a multi-country study based on cointegration and error-correction modelling techniques. Energy economics, 18(3), 165-183.

Michael Lazarus, Von Hippel David et al, A Guide To Environment Analysis For Energy Planners, Stockholm Environment Institute, Tellus Institute, Boston, December 2005

Michael Lazarus, Von Hippel David et al, A Guide To Environment Analysis For Energy Planners, Stockholm Environment Institute, Tellus Institute, Boston, December 2005

Ministry of Energy, 2003, "Energy Sector Reform Strategy Report of the Rural Energy task Force", Ministry of Energy Kenya, Nairobi

Ministry of Energy, 2004, Draft National Energy Policy (Sessional Paper No. 4). Nairobi, Kenya: Ministry of Energy

Ministry of Energy, http://www.energy.go.ke/renewable.php

Mirza, U. K., Ahmad, N., Majeed, T., & Harijan, K. (2008). Hydropower use in Pakistan: past, present and future. Renewable and Sustainable Energy Reviews, 12(6), 1641-1651.

Mohibullah, M., Radzi, A. M., & Hakim, M. I. A. (2004). Basic design aspects of micro hydro power plant and its potential development in Malaysia. In Power and Energy Conference, 2004. PECon 2004. Proceedings. National (pp. 220-223). IEEE.

Moser CA, Kalton G. Survey methods in social investigation. 2nd ed. Aldershot: Gower; 1971.

Mugatsia, E. A. (2010). Simulation and scenario analysis of water resources management in perkerra catchment using WEAP model (Doctoral dissertation, MOI UNIVERSITY).

Mugenda, A. and Mugenda, O. (2003). Research Methods: Quantitative and Qualitative Approaches. Nairobi: African Center for Technology (ACTS).

Okot, D. K. (2013). Review of small hydropower technology. *Renewable and Sustainable Energy Reviews*, *26*, 515-520.

Okoth-Ogendo, W.H.O. and Ojwang, J.B. (ed.), A Climate for Development: Climate Change Policy Options for Africa. ACTS press, Nairobi, 1995, p. 264.

Onyando et al., (2005). Local and Global Consequences of the Renewable Directive for Biofuels-Testing the Sustainability Criteria. Report 5000143001/2008, Netherlands Environmental Assessment Agency, Bilthoven

Ottichilo, W.K., Kinuthia, J.H., Ratego, P.O. and Nasubo, G., Weathering the storm: Climate Change and Investment in Kenya, ACTS Press, Nairobi, 1991.

Pacala & Socolow, (2004). Agroecological approaches to agricultural development. Background paper for the2008 World Development Report. Rimisp-Latin American Center for Rural Development,November, 2006

Pack, R. T., D. G. Tarboton and C. N. Goodwin, (2001),"Assessing Terrain Stability in a GIS using SINMAP," in 15th annual GIS conference, GIS 2001, Vancouver, British Columbia, February 19-22.

Paish O. (2002). Micro-Hydro Power: Status And Prospects, Journal of Power and Energy, Professional Engineering Publishing.

Paish, O. (2002). Small hydro power: technology and current status. Renewable and sustainable energy reviews, 6(6), 537-556.

Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., & D'haeseleer, W. (2005). Distributed generation: definition, benefits and issues. Energy policy, 33(6), 787-798.

Popli, K. S. (2012). Barriers in small hydro power development in India. IASH Journal-International Association for Small Hydro, 1(2), 3-7.)

Pugliese, A., Farmer, W. H., Castellarin, A., Archfield, S. A., & Vogel, R. M. (2016). Regional flow duration curves: Geostatistical techniques versus multivariate regression. Advances in Water Resources, 96, 11-22.

Renöfält, B., Jansson, R., & Nilsson, C. (2010). Effects of hydropower generation and opportunities for environmental flow management in Swedish riverine ecosystems. Freshwater Biology, 55(1), 49-67.)

Reynolds, T. S. (2002). Stronger than a hundred men: a history of the vertical water wheel (No. 7). JHU Press.)

Rojanamon, P., Chaisomphob, T., & Bureekul, T. (2009). Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/environmental criteria and social impact. Renewable and Sustainable Energy Reviews, 13(9), 2336-2348.

Singh, D. (2009). Micro hydro power resource assessment handbook. APCTT, September.

Smith, K. R., Samet, J. M., Romieu, I., & Bruce, N. (2000). Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax, 55(6), 518-532.

Sovacool, B. K., & Drupady, I. M. (2012). Energy Access, Poverty, and Development. The Governance of Small-scale Renewable Energy in Developing AsiaAshgate, Farnham.

Spain, S. D. (2011). Hydro Power Generation: Global and US Perspective. In Energy and Power Generation Handbook. ASME Press.)

Stockholm Environment Institute, LEAP: Long Range Energy Alternatives Planning System, User Guide, Stockholm Environment Institute, Tellus Institute, Boston, 1997

UNDP, (2004). Land and ocean nutrient and carbon cycle interactions. Current Opinion in Environmental Sustainability 2: 258-263.

United Nations (UN) (2002).General Assembly, Implementation of the United Nations Millennium Declaration, United Nations, New York, NY

United Nations Development Programme (UNDP), (2004). In: Seeta, G., Tek, B.G., Aminul Islam, M., et al. (Eds.), Energy for Sustainable Development in Asia and the Pacific Region: Challenges and Lessons from UNDP Projects. United Nations, New York, NY.)

Vogel, R. M., & Fennessey, N. M. (1994). Flow-duration curves. I: New interpretation and confidence intervals. Journal of Water Resources Planning and Management, 120(4), 485-504.

Vogel, R. M., & Fennessey, N. M. (1995). Flow duration curves II: A review of applications in water resources planning 1.

WEC, (1993).Renewable energy resources: opportunities and constraints 1990–2020, World Energy Council, London

Wilkinson, R. Theme editorial: Low-cost electrification; the need for access to energy services.

Yannopoulos, S., Lyberatos, G., Angelakis, A. N., & Theodossiou, N. (2014). Water Pumps through the Ages. In e-Proceedings of IWA Regional Symposium on Water, Wastewater and Environment: Traditions and Culture. Hellenic Open Univ., Patras, Hellas (pp. 615-626).)

Zichuan, Y. E., Maidment, D. R., & McKinney, D. C. (1996). Map-based surface and subsurface flow simulation models: An object-oriented and GIS approach. CRWR Online Report. Available from: http://www.ce.utexas.edu/centers/crwr/reports/online.html

Appendix A: QUESTIONNAIRE

Introduction

Do you want the opportunity to have your say on the development of a new energy sources in your neighbourhood? If so, please take a few minutes to fill in this questionnaire. The information you provide will help in developing a new source of energy for the benefit of all Kenyans.

Please tick (√) inside the box as appropriate.

Date of interview ………………………………………………………………………………

Place of interview………………………………………………………………………………

Part I: Interviewee background

Sex: Male ☐ Female ☐

Marital status: Married ☐ Single ☐

Level of education: Primary ☐ High school ☐ University ☐

Age: 15-25 ☐ 26-35 ☐ 36-45 ☐6-60 ☐)+ ☐

Occupation: Farmer ☐ Teacher ☐ Government official ☐ Other ☐

Part II: Energy use

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1) What is the main source of energy you use for:

a) Cooking?

Cow dung ☐

Firewood ☐

Charcoal ☐

Kerosene ☐

Gas ☐

Electricity ☐

b) Lighting?

Kerosene ☐

Electricity ☐

Gas lamp ☐

2) What is your opinion about the source of energy you use for cooking?

	Do not agree	Partially agree	Fully agree	Don't know
Not easy to get	☐	☐	☐	☐
Expensive	☐	☐	☐	☐
Environmentally friendly	☐	☐	☐	☐
Waste time	☐	☐	☐	☐
Causes health complications	☐	☐	☐	☐

3) Are you satisfied with your source of energy?

Yes ☐

No ☐

4) On average, what distance do you travel looking for your main source of energy for cooking?

Less than 1KM ☐

2-4KM ☐

More than 4KM ☐

5) On average, what distance do you travel looking for your main source of energy for lighting?

Less than 1KM ☐

2-4KM ☐

More than 4KM ☐

6) At the moment, what would prevent you from using electricity (*Tick whichever ones apply to you)*

Risky ☐	It is not available ☐	Cost of electricity ☐
Expensive ☐	Far away ☐	Do not know ☐

7) Which of the following best describes you? *Please tick only ONE.*

I am not interested in the use of electricity. ☐

I have recently been thinking about becoming a consumer of electricity. ☐

I am intending to change my source of energy to a more efficient one. ☐

I have recently been involved in community managed projects. ☐

8) How would you describe the environmental condition of your area?

Very good ☐ Good ☐ Fair ☐ Poor ☐ Very poor ☐

9) In the last 12 months, roughly how many times have you suffered due to issues related with your source of energy?

.... times

10) Have you ever suffered from smoke related diseases?

Yes ☐ No ☐

If *Yes*, what long-term illness do you suffer from? *(Please state.)*

11) If the following energy sources were introduced in your neighborhood, how likely would you be to take part or use them?

	Extremely likely	Fairly likely	Undecided/ Don't know	Fairly unlikely	Extremely unlikely
Solar power	☐	☐	☐	☐	☐
Wind power	☐	☐	☐	☐	☐
Hydropower	☐	☐	☐	☐	☐
Charcoal	☐	☐	☐	☐	☐
Kerosine	☐	☐	☐	☐	☐
Biogas	☐	☐	☐	☐	☐

12) Please briefly comment on the above questionnaire

Thank you.

APPENDIX B: FLOW DURATION CURVES

a) 2EC02

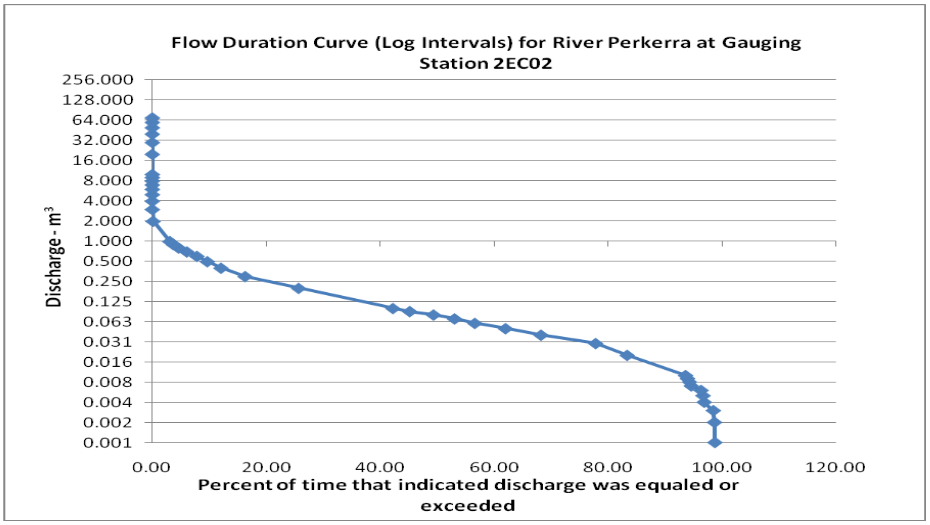

Figure 4.56: Flow Duration Curve (Log Intervals) for River Perkerra at Gauging Station 2EC02

b) 2EC03

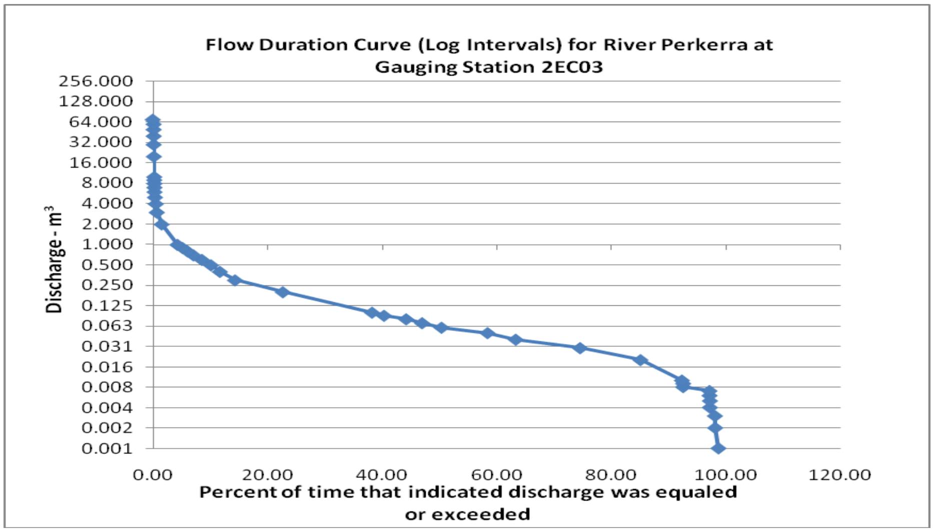

Figure 4.51: Flow Duration Curve (Log Intervals) for River Perkerra at Gauging Station 2EC03

c) **2EC04**

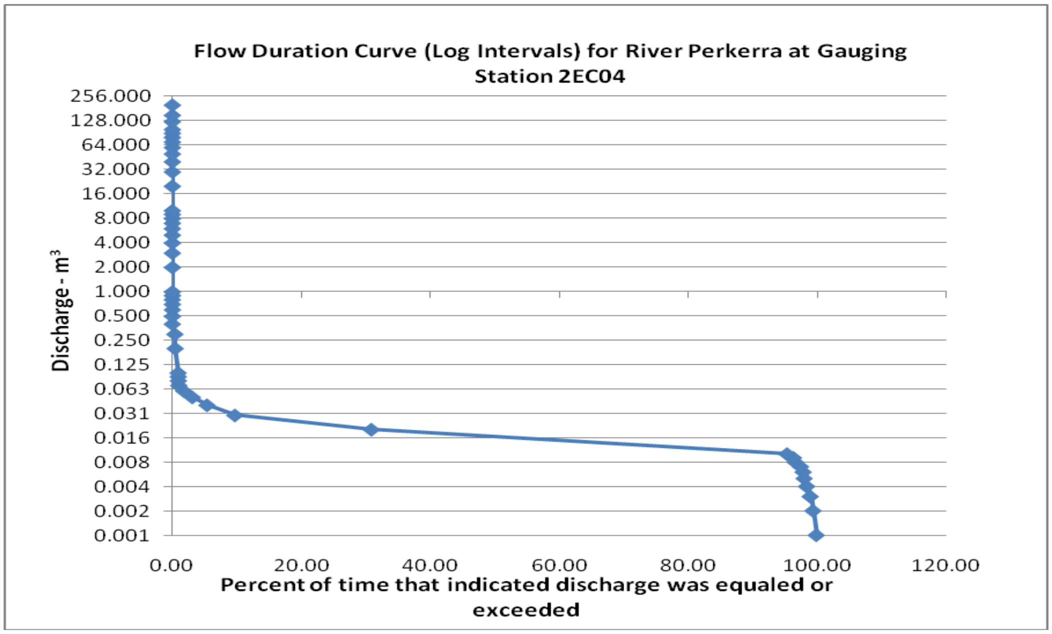

Figure 4.57: Flow Duration Curve (Log Intervals) for River Perkerra at Gauging Station 2EC04

d) **2ED01**

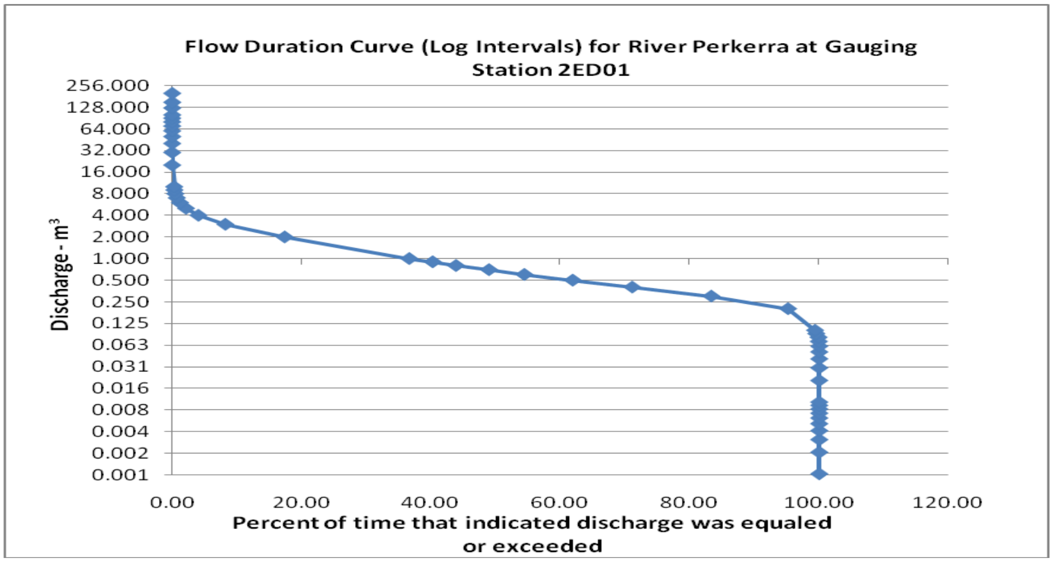

Figure 4.53: Flow Duration Curve (Log Intervals) for River Perkerra at Gauging Station 2ED01

e) 2EE07

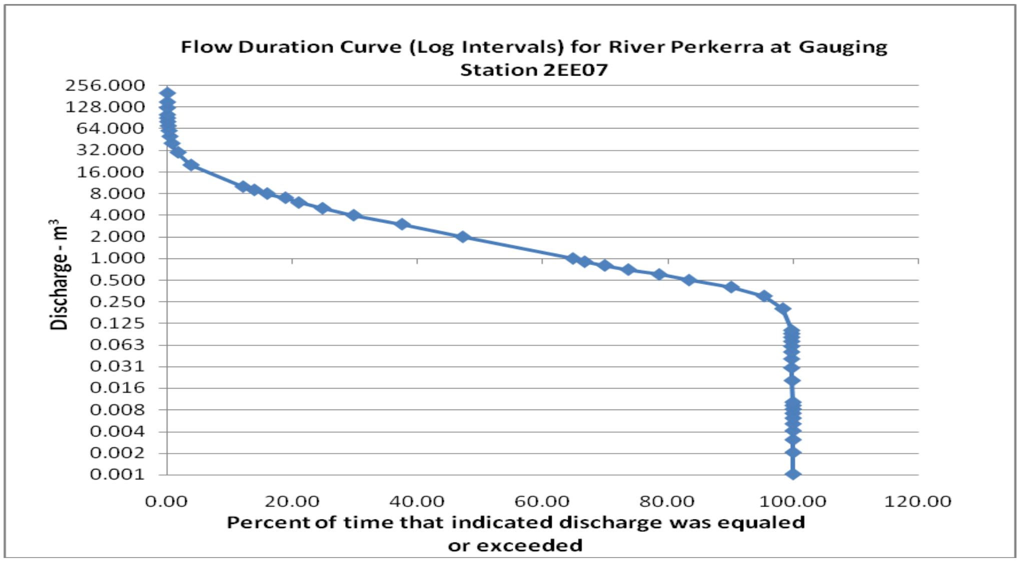

Figure 4.58: Flow Duration Curve (Log Intervals) for River Perkerra at Gauging Station 2EE07

f) 2EE07A

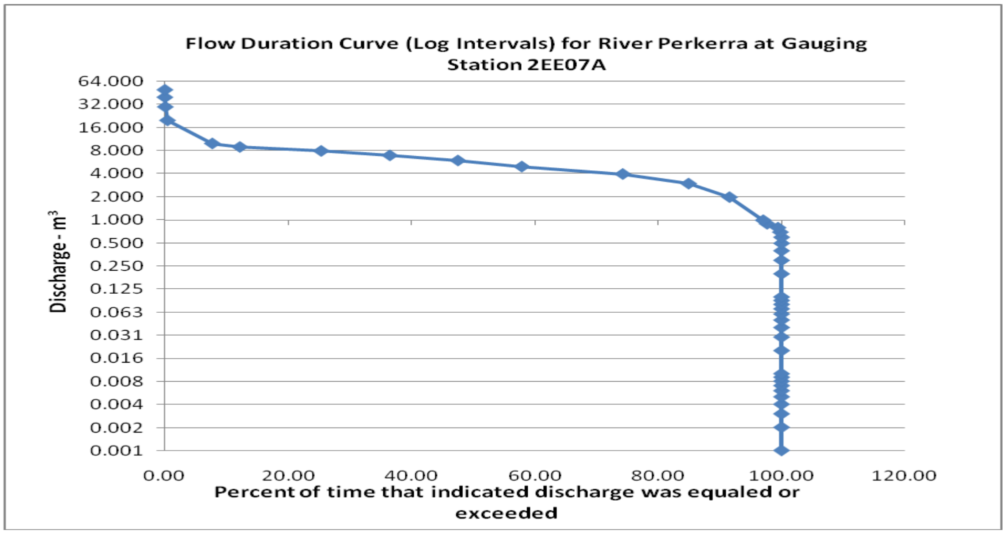

Figure 4.59: Flow Duration Curve (Log Intervals) for River Perkerra at Gauging Station 2EE07A

g) 2EE08

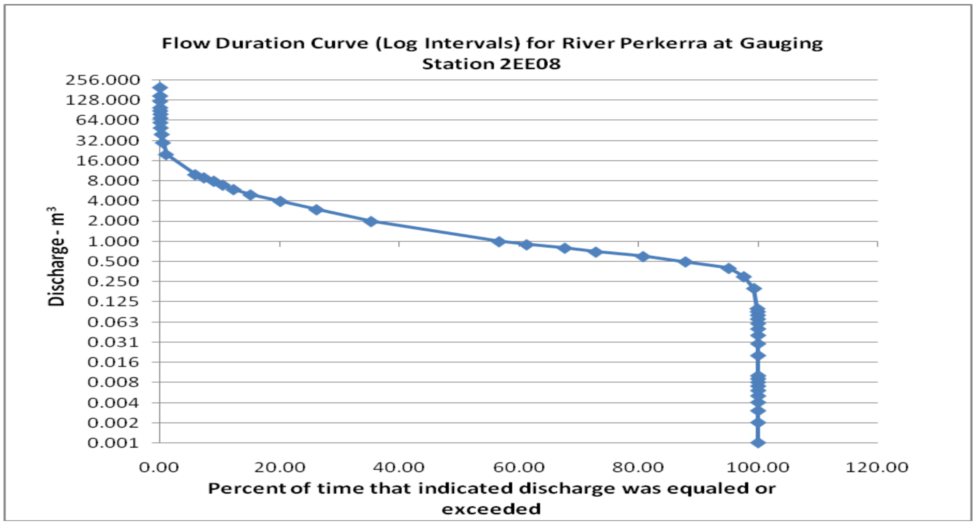

Figure 4.60: Flow Duration Curve (Log Intervals) for River Perkerra at Gauging Station 2EE08

h) 2EG01

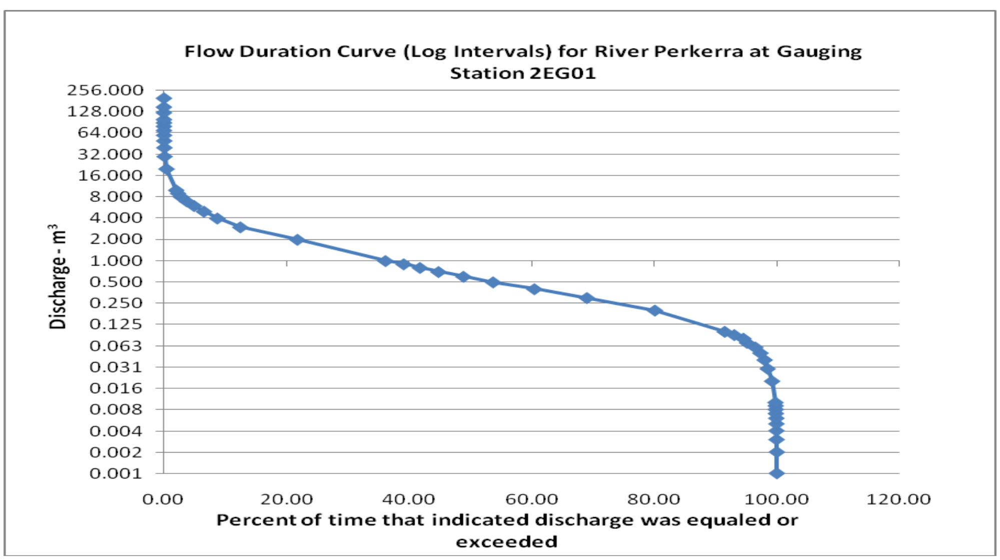

Figure 4.61: Flow Duration Curve (Log Intervals) for River Perkerra at Gauging Station 2EG01