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MASTER THESIS

Flood Frequency Analysis of Kabompo Catchment in Zambia

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Declaration

I hereby declare that the thesis entitled: Flood Frequency Analysis of Kabompo Catchment in Zambia is solely my authorship. Acknowledgement is given to all the literature sources used to support this work. I am duly responsible for any shortcomings in this study.

In Prague on 22.04.2015 William Nkomoki

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Abstract

Floods cause devastating natural hazards, disasters that impact human life such as loss of life, property resulting in severe economic damage. These losses repeatedly affect poor people living in the surrounding floodplains with impacts on infrastructure and agricultural production which serve as a major source of livelihood. However, a limitation in data availability affects efficient estimation of occurrence and magnitude of floods for management planning.

The study focuses on calibration of the HEC-HMS (Hydrological Engineering Center's Hydrologic Modeling System) in combination with the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) for rainfall modeling to estimate maximum annual peak flows and flood frequency analysis of Kabompo catchment in Zambia. The Kabompo catchment has an area of 72 000 km^2, located in North western Zambia and is among the main tributaries of the upper Zambezi river. The model is calibrated and verified in basin using historical 30 year daily rainfall observed data. The computation in HEC-HMS model uses SCS curve number for infiltration, the SCS unit hydrograph and lag time for transform method and routing methods respectively. The important recurrence interval includes 2, 5, 10, 25 and 50 year event.

In general flood frequency analysis, the software HEC-SSP 2.0 uses the Log Pearson type III , Pearson type III , Log Normal and Normal distribution at 5 % and 95 % confidence limits to determine its statistical parameters. Estimation and flood frequency analysis with hydrological modeling is vital in implementation of flood protection measures. Conclusions show that the application of the model can serve as an appropriate tool in flood frequency analysis.

Key words: HEC-HMS model, flood frequency, Kabompo, rainfall, return period, Zambia.

Contents

CHAPTER ONE: INTRODUCTION

Background

Floods occur repeatedly and this has tremendous impacts worldwide causing huge economic and human life loss (Khan et al., 2011).The study by Saf (2008) reveals that good understanding of flood frequencies in a catchment is important for proper assessment of flood risk to implement effective flood measures. WDR (2010) indicates, flooding as a major disaster causing detrimental challenges all over the world and averaging affected people to 99 million per year. According to the IFRC (2007) , the poor in developing countries suffer more from the natural disasters as they lack preparedness as a result of no information on frequency of occurrence coupled with non engineered constructions escalate the effects.

Floods events refer to the case of severe storm occurrence. Anderson et al (2002) reveals the importance of providing reliable flood models with exacerbating climate change. This is supported by Tahmasbinejad et al (2012), highlighting the importance of flood models for analysis and forecasting as imperative for planning and development of management strategies. Furthermore, hydrological models are vital in computing return periods of floods (Bedient et al., 2003)

River floods and coastal floods are the major occurring natural disasters causing huge damages to buildings, roads and many other infrastructures. The floods have also had devastating effects on agriculture land. This implies that it is crucial to understand and identify potential flood areas so that early warning is issued to people in such areas. One of the non structural measures that can help minimize the amount of damage is the development of flood estimation hydrological models. In view of climate change, the challenge for hydrologists is the improvement of models to predict the flood frequency accurately (Yonatan et al. 2009).

In this study, the U.S. Army Corps of Engineers Hydrologic Engineering Center’s Hydrologic Modeling System (HEC-HMS) is used to model rainfall parameters of the catchment for annual maximum flow. The HEC-SSP (statistical tool) is applied to analyze flood frequency for different flows and return periods with probabilities of Kabompo basin in Zambia.

1.2 Statement of the problems

In spite of flooding been a major natural disaster and occurring in Kabompo basin, the flood management strategies have been limited to relief services after the floods. There is a lack of pre flood warnings for effective planning and management.

According to Zamcom (2012), the whole of the Zambezi river basin lack flood warning mechanism that leaves prone communities suffer repeated damages and loss. This is attributed to national hydrological meteorological station lack of hydrological model tools. However, with advances in flood modeling such as HEC-HMS and HEC-SSP, it is possible to have a reasonable idea of return periods, probability and extent on distribution of floods. Studies on floods in Zambia have not applied the use of this application in contrast to international analysis of floods in terms of forecasting, frequency which is highly automatic and integrated.

1.3 Significance of Study

The research will be beneficial in provision of information and hydrological tool in future use of flood recurrence in study area and the approach transferred to other areas. The lack of studies concerning problems of floods in the area shows the importance of conducting in depth studies. According to Tortorelli and McCabe (2001), knowledge and estimates of flood frequency event can be used to in management regulation, formulation of plans of evacuation from flood prone area and design of control structures

1.4 Objectives of the Study

The overall objective of the study is the calibration of the HEC-HMS for rainfall runoff modeling to estimate high daily flows and to conduct flood frequency analysis for Kabompo Basin in Zambia.

1.4.1 Specific objectives

- To highlight the maximum annual peak flow from historical data

- To relate the magnitude of extreme events to their frequency occurrence using probability distribution. The magnitude represents the flow and the frequency highlighting once recurrence in certain period (years).

CHAPTER TWO: LITERATURE REVIEW

2.1 Climate of Zambia and its Characteristics

Zambia is a landlocked country located in the central parts of Southern Africa between latitudes 8° S and 18° S, and longitudes 22° E and 34° E. It covers an area of approximately 752,614 km^2 and bordered by eight countries. To the south bordered by Botswana and Zimbabwe; to the east by Malawi; Mozambique to the south east; to the north Tanzania and the Democratic Republic of Congo; and to the west by Angola and Namibia to the south west. The figure 1 below shows Zambian map with water bodies highlighted.

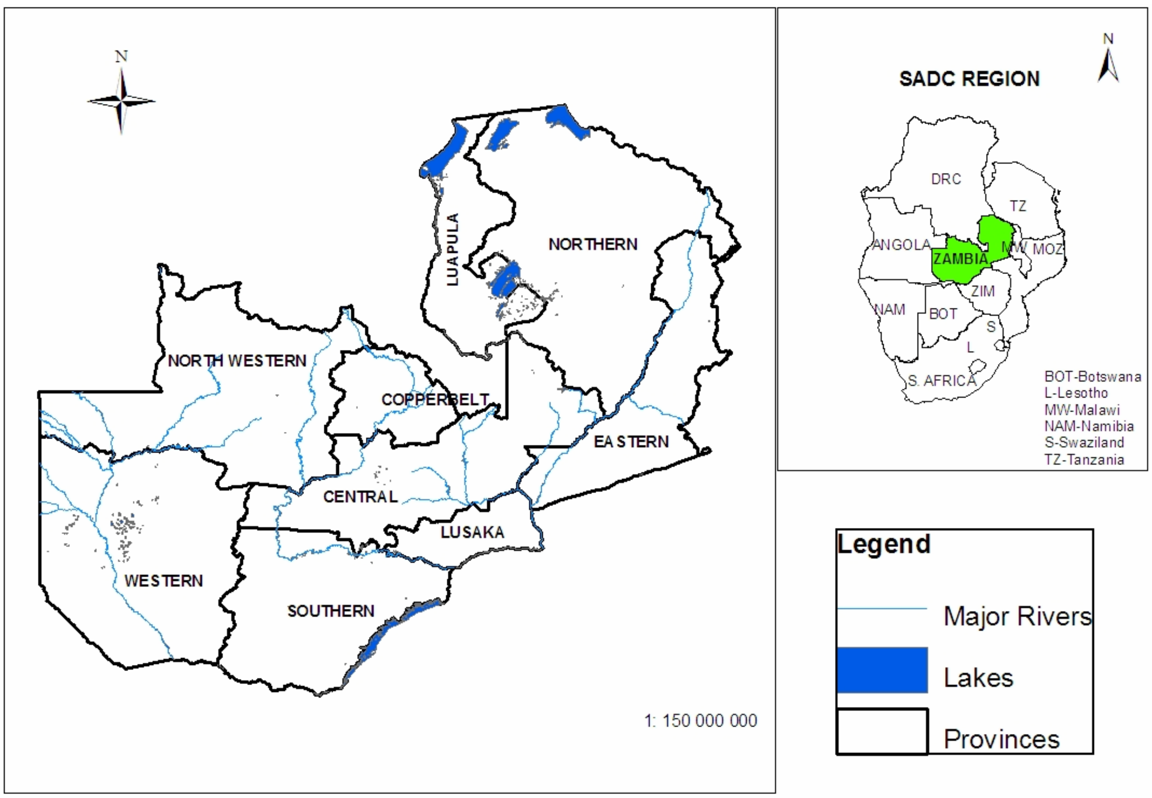


Figure 1: Location of Zambia's Water Bodies

The climate of Zambia is generally moderate that is divided into three seasons namely rain season (November to April), cold season (May to August) and hot season from September to October. The summer temperatures go up to maximum of about 35˚Celsius with variations in the annual distribution in temperatures and rainfall (Thurlow et al. 2008).

2.2 Agro Ecological Region

Zambia's land mass of 752, 620 square kilometers is divided in three Agro ecological regions namely I, II and III. Figure 2 below illustrates the division of Zambia's Agro ecological regions.

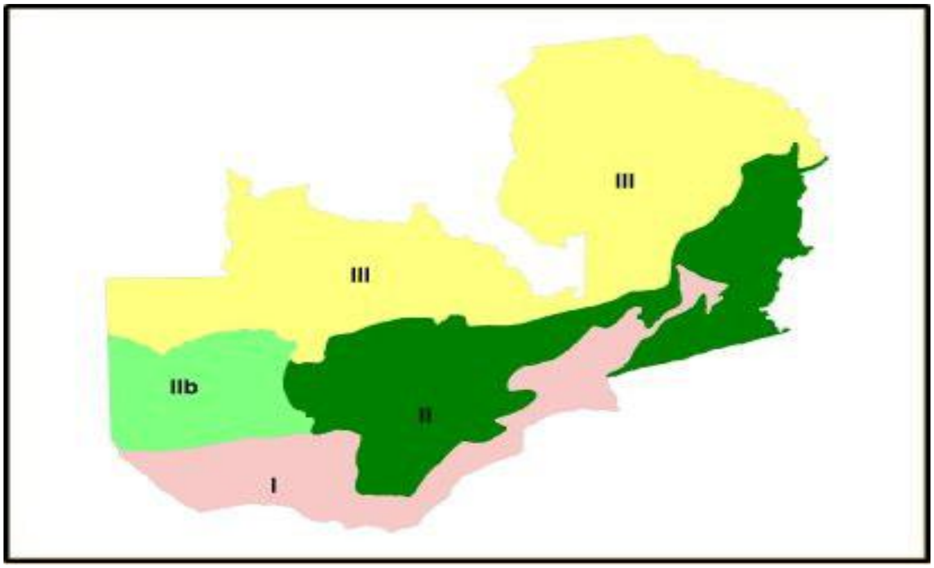


Figure 2 : Zambia Agro Ecological Regions.

Source: (CEEPA 2006)

Region 1 covers the Southern, Eastern and western parts of the country. It constitutes about 12% of Zambia's total land and receives less than 800 mm of rainfall annually. This region consists of loamy to clayey soils on the valley floor and fine shallow soils on the escarpment. Region II constitutes about 42% of the country with annual rainfall of between 800 -1000 mm. It is sub divided into region IIa and IIb. Region IIa covers Lusaka Central, southern and eastern fertile plateau. Region IIb consists of Sandy soils. Region III constitutes 46% of the country's total land area comprising the Copperbelt, Luapula, Northern and North western Provinces. The Region receives more than 1000 mm up to 1500 mm of rainfall annually. With exception of the Copper belt, the region is characterised by highly leached acidic soils (MACO 2004).

2.3 Types of floods

Floods can be classified into different type and each resulting from a different cause. The first is categorized as flash floods that are is as a result of heavy rainfall that pours where the streams and rivers fail to handle it and results in floods. The other type is the river floods that are attributed to seasonal precipitation that usually covers large catchment. According to UNEP (2004), the third type is referred to as coastal flood resulting from storms, wind causing the ocean water to overflow and generating floods.

2.4 Flood Situation

Flooding accounts for about 47% of world's natural disasters and is the most occurring global natural disasters, according to the world disaster report of 2011 (Lindsay 2011) .With the increase in environmental changes and rapid urbanization the floods events are expected to increase (Jha et al., 2011). The topic of frequency of flooding over the past few decades has raised interests worldwide due to the damages that have resulted (Ashley et al., 2005). These coupled with climate change effect that predicts increased floods in already flood prone areas calls for action (Wilby 2007).

Southern Africa is faced with several challenges that are related to environment and climate change. According to Boko et al (2007) and Collier et al (2008), it is projected that there will be a rise in temperatures; increase in floods frequency as a result of extensive rainfall while in other countries the occurrence of droughts and dry spells will be on the increase. The effects of the extreme changes will result in decrease in agricultural production, which will affect the farmers in southern Africa who are highly dependent on rain fed agriculture. According to UNNC (2011), countries in Southern African in particular Zambia forecasts serious flooding causing huge damages on crops, infrastructure and affecting tens of thousands of people. Saf (2008) reveals that that it is vital to understand the importance of the frequency of floods and magnitude on specific area. This is supported by literature of Kjeldsen et al (2002) indicating the importance of flood frequency in the planning of weather related emergencies and a wide range of engineering problems. The researcher endorse the importance of understanding the flood frequency , however further highlights the need to have fairly accurate estimations of magnitudes not to underestimate or overestimate as this may have huge cost repercussions . Siwila et al (2013) contend that an increase in flood event is expected in Zambia. However, this trend is not all attributed to rainfall but also due to other factors such as land use patterns that contribute significantly to flood events through water runoff. Parker (2000) argues that increase in urbanization has significantly contributed to the frequency of floods. To this end Milly et al (2008), emphases the need to predict frequency of floods for the purpose of planning and management of disasters.

Water is crucial in sustenance of life and support to development. In Zambia, just like other parts of the world its availability determines the pattern of human settlement as it serves as key to many developmental activities such as agriculture, mining and manufacturing industries (WMO 2007). In spite of the numerous benefits associated with water, it may cause loss of live, destruction of economic disasters and crop damages. Almost 50% of all water related natural disasters and 15% of all deaths are attributed to flooding. Without any discriminatory features, floods occur under different conditions at any location. Under low intensity rainfall event, floods occur if followed by predominate drought conditions or as a result of preceding rainfall event, if the soil has been previously saturated. In a different case high intensity of rainfall causes floods regardless of the condition of catchment, however, the severity is determined by hydrological conditions of a catchment (WMO 2011). The WMO furthermore notes the increase in flood trend with association to socio economic damages as a result of natural changes in rainfall intensity and duration. The above coupled with anthropogenic effects such as changes in land use and population in the prone areas worsen the situation. The damages cause a displacement of people in the area and in some cases these may be fatal.

In the Northern Western part of Zambia the flood season runs from December to April. Over the past three decades, floods and droughts have already cost Zambia approximately US$ 13.8 billion, equivalent to a 0.4% loss of annual economic growth. It is estimated that rainfall variability alone could keep an additional 300,000 Zambians below the poverty line and cost Zambia US$ 4.3 billion in lost Gross Domestic Product (GDP) over the next decade, reducing annual GDP growth by 0.9% (Thurlow et al. 2009). The region is characterized with heavy rains and tropical storms resulting in floods. The rain seasonal runs from November up to April with an average of 1500 millimeters per season. About 70% of the total rainfall is from flash storms lasting for about 30 minute. The main causes of these floods are natural and also due to lack of infrastructural services like drainage systems (Nchito 2007).The problems happen continuous among the poor due to low capacity to deal with these floods (Jha et al. 2011). Among the major causes are poor infrastructure like drainages which are either blocked due to waste blockages, poor design or inadequate drainage systems (Brody et al., 2008).With increase in unplanned settlements by the poor has resulted in reduced infiltration of rainfall and increasing runoff (Action aid 2006).

Floods problems can be categorized into socioeconomic and environmental. The socioeconomic problems are further broken down into tangible direct losses which have to do with the damage of physical infrastructure and the intangible human losses. Issues of land degradation and ecological systems fall under the environmental problems (Shrestha et al. 2011). Strategies to mitigate flood risk and the diverse problems are a vital tool at all levels. Carlos (2007) indicates that strategies can be groups into structure and non –structural. For optimum results in flood management both strategies have to go hand in hand in order to produce comprehensive results. Structural strategies focus on more protective and interventions measures such as engineered infrastructure like improved drainage. Various aspects are considered in infrastructure provision as to determine appropriate structures; these include nature and type of settlement, return frequency floods, the duration, severity of floods and depth (Kolsky and Butler 2000).Non structural strategies focus on preventative measures like flood forecasting and warning as well as the proper land planning. These are more effective even in poor communities as it calls much on behavior change (Smith and Petley 2009).

2.5 Definition of Flood Frequency Analysis

Flood frequency analysis is a process that is conducted on projects related to water resources such as construction projects and floodplain analyses. It is carried out to calculate the probable magnitude of a flood in relation to a risk tolerance level. The literature of Saf (2008) highlights that; exceedance probability is required in frequency of floods to facilitate planning for different weather conditions. The flood frequency analysis focuses on recurrence intervals indicated at different year periods such as 2, 5, 10 and 20 referring to return periods and the magnitude in terms of flow and discharge.

2.6 The Zambezi River Basin

Different countries share the largest river basin in Southern Africa called the Zambezi. The catchment area covers about 1 300 000 square kilometers. Among these countries include Zambia with the largest share, Zimbabwe, Tanzania, Namibia, Mozambique, Malawi, Botswana and Angola. The rainfall averages about 1600mm.The Zambezi river basin is further divided into 13 sub basins (Beifuss 2012).These sub basins are categorized as the upper Zambezi consisting of Kabompo Barotse, Luanginga, Lungwebungo and Cuando/Chobesub-basins the Middle Zambezi covering Kariba, Kafue, Mupata, and Luangwa .The lower Zambezi region covers Tete, Lake Malawi/Shire, and Zambezi Delta sub-basin (Zamcom 2012). Figure 3 below illustrates the planning division of the Zambezi basin. According to Beifuss (2012), the mean annual runoff is 8 615 mm/s average flow rate with a runoff efficiency of 0.09.

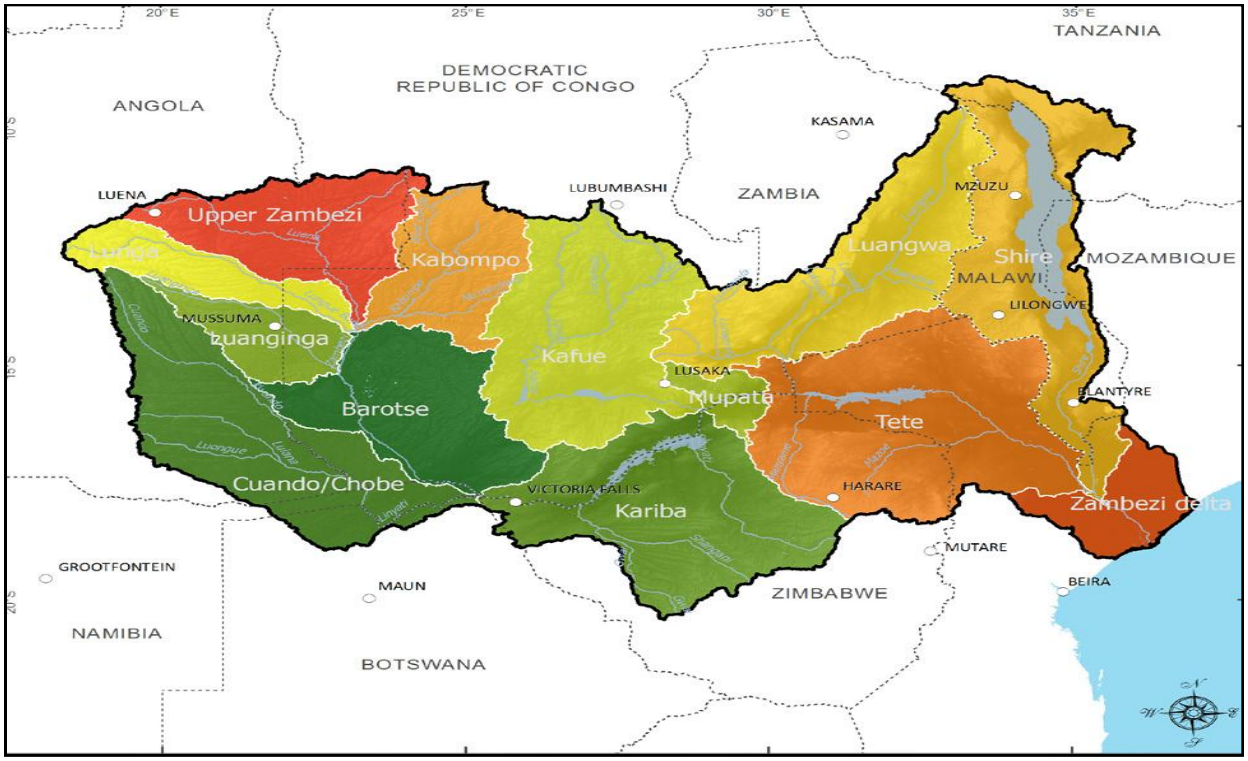


Figure 3 : 13 major sub-basins of the Zambezi River Basin

Source: Kahinda CSIR, South Africa

2.7 Hydro-meteorological description

2.7.1 Temperature of Kabompo

Figure 4 below illustrates the comparison maximum and minimum mean monthly temperature in Kabompo. The maximum temperature is higher in September with values reaching 30 degrees Celsius while the lowest mean monthly temperatures are observed in the month of June with value of 7 degrees Celsius.

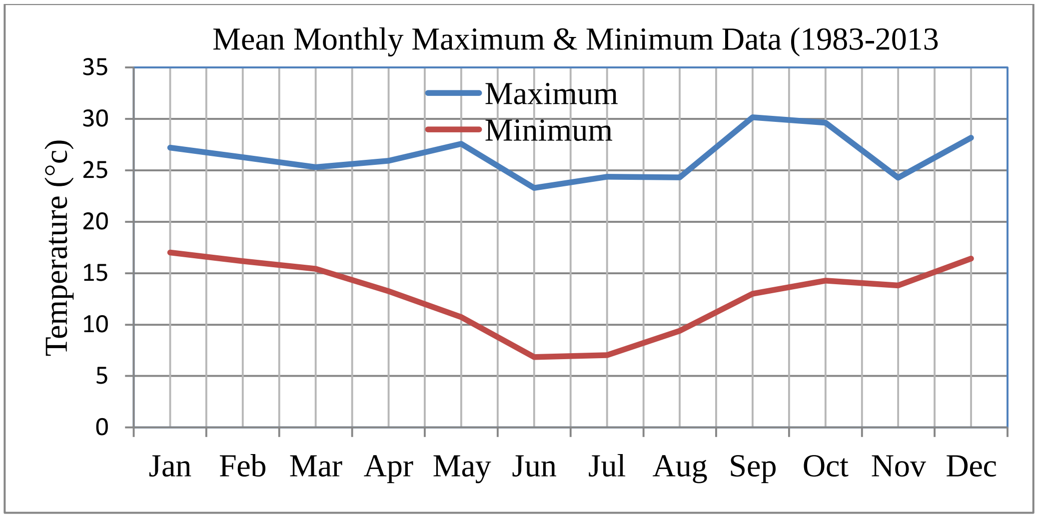


Figure 4 : Mean Monthly Temperatures Kabompo 1983-2013:

Author's computation

2.7.2 Kaoma Temperature

The temperature in Kaoma indicates higher maximum in March and lower minimum in July as low as 7°C. Figure 5 illustrates the minimum and maximum temperatures.

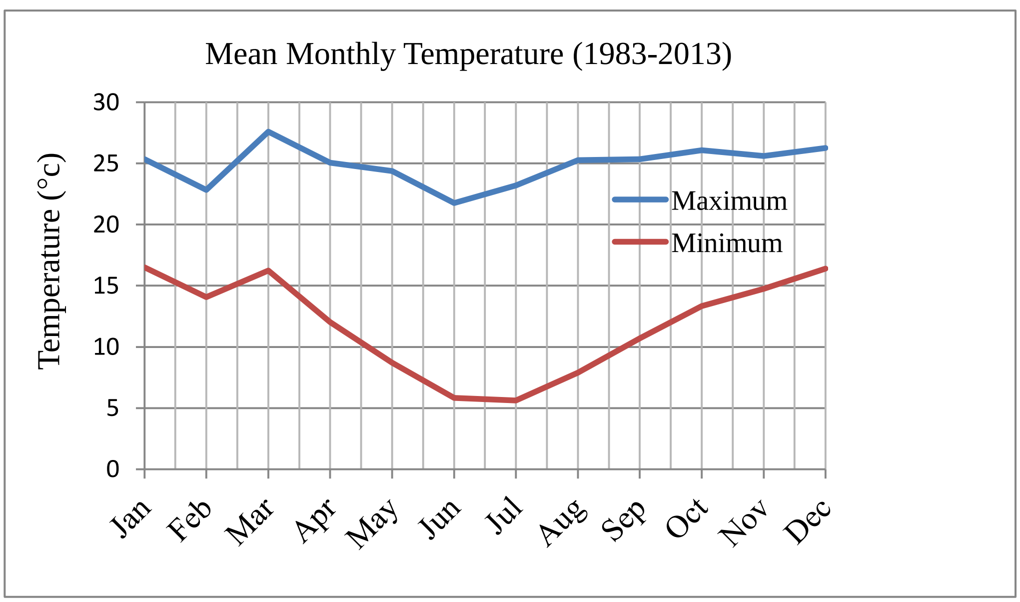


Figure 5 : Mean monthly temperatures Kaoma 1983-2013:

Author's computation

2.7.3 Evaporation in Kabompo

According to CEC (2011), the monthly evaporation in Kabompo range from 133mm in February and 289mm in September. Table 1 below describes the evaporation for various months.

Table 1 : Kabompo Catchment Monthly Evaporation

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Evaporation(mm)	256	198	146	136	133	152	164	179	174	203	239	282

Source: CEC 2011

2.7.4 Rainfall data

The Rainfall distribution for the Kabompo and Kaoma are plotted in figure 6 and 7.The rainfall pattern for Kabompo shows some decline while the Kaoma values show an upward trend. However, the average annual rainfall falls around 800mm and 1500mm.

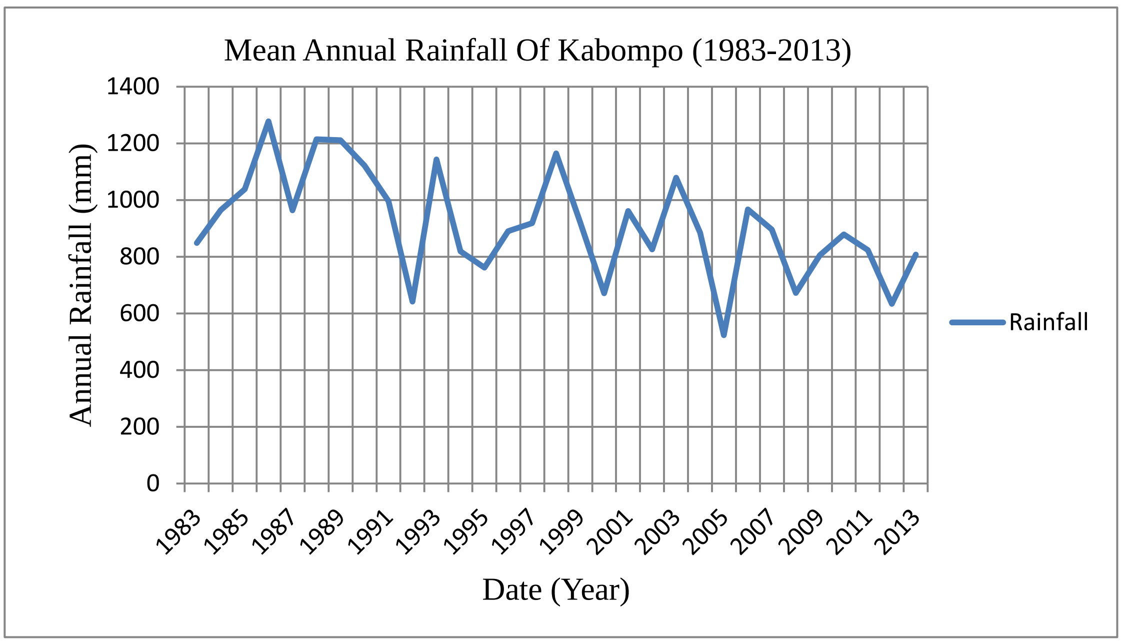


Figure 6 : Kabompo Rainfall: Author computation

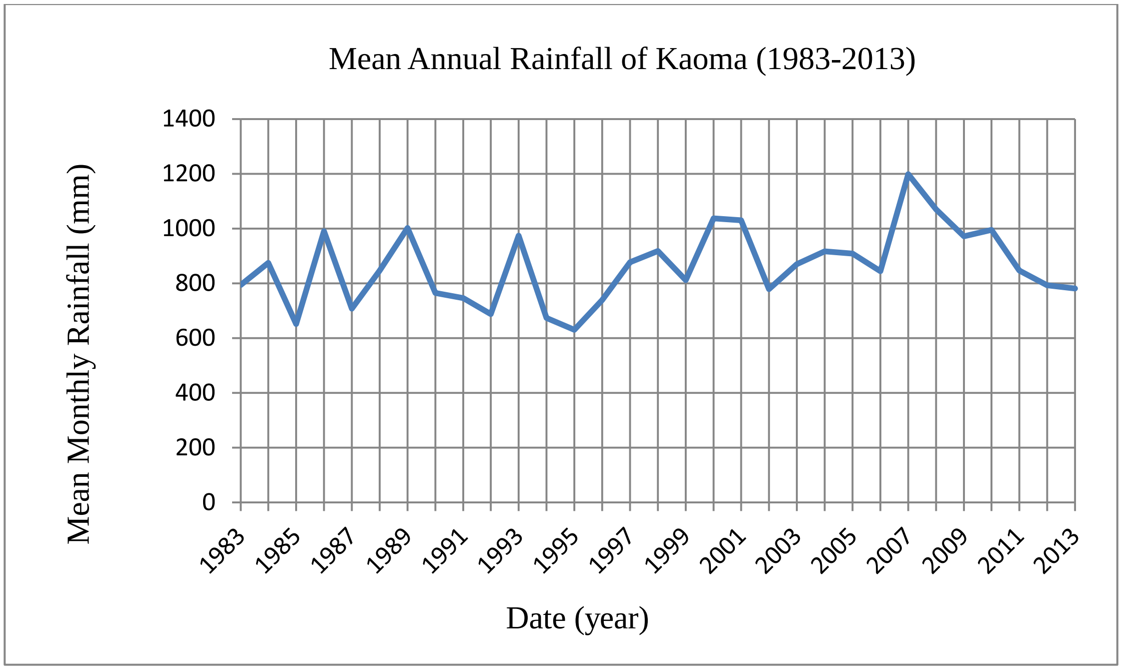


Figure 7 : Kaoma Rainfall

Author's computation

2.7.5 Topography

Kabompo catchment is falls in the sub tropical region. The elevation is between 1000 and 1400 above sea level. The wind speed for dry season from east to south east has mean of 2.4m/s while the maximum stand at 9.2m/s (MTENR 2008)

2.7.6 Vegetation

According to the IWRM (2006), the vegetation of Zambia is classified as savanna of tropical grasslands. The vegetation is rich in different types among them grasslands, woodlands and forests with the latter two found in high rainfall areas. Grasslands are further divided in two types namely flood plain and plateau. The Kabompo river basin is characterised by some miombo woodlands. The research conducted by Zorkeflee (2009) on Sungi Kuran basin reveals that land use change is critical hydrological characteristic and their impact in flood peak discharge is significant

2.7.7 Soils and Geology

Many parts of Zambia are categorized as plateau with elevation ranging from 600 to 1900m. JICA (1995) reveals that the geomorphologic class the northern and the north western parts are higher plateaus. Furthermore, in terms of the soils Kabompo is distributed with ferrasol and arenosol types.

2.8 Model Description

2.8.1 Hydrological Rainfall-Runoff Modeling

The Hydrologic Engineering Center–hydrologic modeling system model (HEC–HMS) was developed by the US Army's Hydrologic Engineering Center (HEC 2006). The basis is on a conceptual rainfall runoff process according to the theory of unit hydrograph and channel routing. The Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) simulates the precipitation-runoff processes of watershed systems. The HMS model applies the deterministic mathematical modeling to compute numerous components of the hydrologic cycle. Among them include precipitation, evapotranspiration, infiltration and runoff. As the rains fall from the clouds this becomes referred to as precipitation. After precipitation, some of the water is lost to the atmosphere and surface through process called evapotranspiration .The other amounts of water are seeped through the soil surface and the process is described as infiltration (HEC 2010).

2.8.2 Model Selection

In research, the selection of a model is essential as it plays a vital role in model suitability. The HEC-HMS is supported by the US Army Corps of Engineers. With limitation of input data on many catchments a model that can be utilized with minimum data is vital and Majidi and Shahedi (2012) points the HEC-HMS model as such a model. According to Yuan and Qaiser (2011), with 30 years data hydrologic simulation can be drawn. This makes it a good model for floods and management purposes. There are different ways for selecting an appropriate and suitable model. Cunderlik and Simonovic (2003), highlights some criteria on the choice of hydrological model .The criteria are the required output of the model, consideration of the input data available, availability and cost of the model and the structure of the model. HEC (2010) describes the necessary parameters of HEC-HMS as inputs and output in the model.

2.8.3 Parameters of HEC –HMS Model

2.8.3.1 Input data

Various input models are used and a number of methods are indicated in Table 3.

According to Lee et al (2014) the assumption on HEC–HMS is that a catchment is formed from dendritic watershed systems. It constitutes of loss, direct runoff, base flow, and routing models to calculate different elements in the runoff process and provision of various methods of parameter estimation function as shown in Table 3. The concept adopted in the HEC–HMS model is of semi-distributed modeling through the use of sub-catchments and channel routing components. These sub-catchments are routed as stream flows along river courses.

The HEC–HMS model comprises of four major components: loss, direct runoff, baseflow, and routing models. Below indicates the description of the models and methods and their description.

The first is the Loss model that calculates the actual infiltration, which interacts with the surface runoff and subsurface processes in the sub-basin (HEC 2006). In this study the SCS-CN method developed by US Soil Conservation Service is applied to estimate an effective rainfall in HEC–HMS. CN indicates a potential of runoff at catchment scale based on soil properties and hydrological conditions. This conforms to study done by Hong et al (2010) in Korea, suggesting the method as efficient and simple for the estimation of runoff from rainfall events in both gauged and ungauged catchments.

2.8.3.1.1 SCS Curve Number

The prediction of runoff was developed by the National Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA) in 1954. The options that are required in generation of the SCS constitute of two input parameters namely the Curve number and the impervious area percentages in the sub basin. In hydrology the curve number describes the infiltration or runoff amount after a rainfall event. The empirical calculations include hydrological conditions such as soil groups and land use. The interpretation is that the CN will reflect the runoff percentage and the higher CN the higher runoff (NRCS 1986).The Runoff equation is illustrated below.

Runoff Equation:

$$Q = \frac{(P - I\mathrm{a})^2}{(\mathrm{P - Ia\ +\ S})}$$

Where: Q is the runoff [L] P= Rainfall [L] S= Maximum soil Retention [L]

S= $\frac{1000}{CN} - 10$

I_a is the initial abstraction [L] =0.2S

The impervious percentage reflects the part of catchment surface that is impermeable to rainfall water. Different factors influence the impervious percentage such as the population growth, land use, land cover and structures.

Table 2 : Hydrological soil group and curve Number (CN)

Name	Hydrological Group			
	A	B	C	D
Forest	40	65	80	87
Grassland	30	58	71	78
Orchard	43	65	76	82
Scrub	68	79	86	82
Barren Land	72	82	82	89

Source: US-SCS (1986)

The second component is the direct runoff model that shows the actual surface runoff and the method is employed by a transformation method contained within the sub-basin. A total of seven different transform methods are provided (HEC, 2006). The unit hydrograph (UH) method is used for this study.

The Base flow model is the third component and this refers to the subsurface model that interacts with the infiltration and surface runoff processes. The actual subsurface runoff is calculated by the baseflow method contained within the sub-basin.

The fourth component is routing model that describes reach element conceptually describing a segment of a stream or river. The actual calculations are performed by a routing method contained within the reach. In HEC–HMS there are six routing methods .This study uses the lag time as the routing method. According to Viessman and Lewis (2003), the basin lag time refers to the difference in time between the center of mass of net rainfall and that of direct runoff. Different physical characteristics of the catchment affects the lag time. These include the slope, vegetation and land cover among the others.

Table 3 : The methods of model parameter estimation in HEC–HMS

Models	Methods
Loss models	Initial and constant rate
	Green and Ampt
	SCS Curve No.
	Deficit and constant loss
	Soil moisture accounting (SMA)
	Gridded SCS CN
Direct runoff models	Unit hydrograph(UH)
	Snyder's UH
	ModClark
	Clark's UH
	SCS UH
	Kinematic wave
Base flow models	Constant monthly
	Exponential recession
	Linear reservoir
Routing models	Kinematic wave
	Muskingum
	Lag
	Modified puls
	Bifurcation
	Muskingum–Cunge

2.8.3.2 Outputs

The model outputs that are included are flow volume and hydrographs.

2.8.4 Hydrologic model (HEC-HMS) Data components

2.8.4.1 Basin Model

In HEC-HMS, the basin model constitutes of three important processes; the loss, the transform and the base flow. In a sub basin specific functions are performed by individual element such as processes precipitation-runoff. Various representations are indicated by an element among them stream channels and surface runoff. The assignment of variable describing specific attribute of the element and mathematical relation to show physical processes is indicated. The purpose of the process of modeling is achieving and generation stream flow hydrographs at the point of basin outlet (Asadi and Boustani 2013).

It refers to the physical character of the hydrologic elements of a watershed. Numerous methods are applied to quantify the complex physical process of a basin. However, the user specifies the model elements in different instances. The data element values consists of information on how hydrological elements are connected .The basin model can be connected and the elements edited. There are seven types of hydrologic elements constituted in the basin model that include sub basin, diversion, routing reach, source, junction, reservoir and sink. The development of a basin model requires the specification of such elements and data that controls their 'behavior’ (HEC 2010). In this study, all basin parameters are prepared in GeoHMS with Arc-View GIS support.

2.8.4.2 Precipitation Model

The Precipitation Model is a data set required to define historical or hypothetical precipitation to be applied in conjunction with a basin model. Different options exist for specifying historical precipitation that include utilize cell based precipitation as required for the modified Clark method. Another approach is to import previously determined spatially-averaged precipitation. Even though the HEC-HMS can use any time step time series data, the case for flood modeling is effective with hourly data. (HEC 2010)

2.9 Research Conducted on the Use of HEC –HMS

Lee et al (2014), notes that floods are assessed on the national and regional scale based on historical hydrological data such as flooding, flows and rainfall to reflect the unique hydrologic processes of individual countries. In this study historical rainfall data is used. The interpretation is that every country has different flooding patterns and this entails that each has to develop their own flood risk management based on the country's specific hydrological, economic and social status. Studies are ongoing on flood prediction, flood frequency, prevention of flooding and many different scenario of analysis. Benito et al. (2004) in flood frequency analysis reveals the scientific approach for reconstructing of past flood events by use of historical data and highlighted its theoretical difficulties related to the use. The researcher follows a similar pattern on the use of historical rainfall data to analyze the flood frequency.

The use of the HEC-HMS is widely used in numerous types of studies involving flooding in hydrology. Application is conducted by Benavides et al (2001) in an approach of analyzing various flood control alternatives. Knebl et al (2005) employed the use of HEC-HMS in their research involving flood forecasting. Whiteaker et al (2006) applied the model in the flood induction models study. Matkan et al (2009) employed the model in the development of early warning flood system. Studies are ongoing on flood prediction, flood frequency prevention of flooding, and many different scenario of analysis. Various researchers have used the HEC-HMS in different studies as the hydrologic tool. In flood risk analysis research Samarasimghe et al. (2010) in Sri Lanka applies the HEC-HMS calibration and verification for creation of flood hazard maps of Kalu Ganga River for different returns periods (10, 20, 50 and 100 years) by using daily rainfall data for 10 year period. Razi et al (2010) use the HEC –HMS model to estimate floods for Johor River in Malaysia. The objective involves the estimation of peak for 10 year period. The findings indicate that the HEC-HMS can act as a good tool in peak discharge estimation. James and Zhi-j (2010), applies the HEC-HMS in China's Misai and Wan'an catchments for flood forecasting. In the study by Ramil and Harun (2012).the HEC-HMS is employed to simulate stream flow by calibrating historical data for 2007 and 2009 .The findings reveal that the accuracy of simulation is dependent on calibration and suitability of parameters. Majidi and Shahedi (2012), conducted a rainfall-runoff simulation using different rainstorm events, the model was calibrated with optimization methods. The findings revealed that lag time is one sensitive parameter and showed differences in peak flow. Further recommendation is made on the use of the HEC-HMS as a powerful tool in flood forecasting despite it been simple. In conforming to the suitability of the HEC-HMS as applied to studies, Asadi and Boustani (2013) results show flood volume and timing were fairly accurate. This was in a study of using the model to predict the accuracy of peak discharge using historical data

With available tools such as the HEC HMS and GIS tools flood modeling can simply be achieved. Once these tools are well calibrated the results obtained are reliable and offer proper information in planning and decision making at district and national level for policy makers. Geographic information systems are the science underlying geographical concepts, applications and systems. Google Earth is a well-known interactive web-based map service. Jahnson et al. (2001) investigated the application of HEC-HMS model in collaboration with the HEC-GeoHMS extension that are GIS related for generation of precipitation and rainfall distribution. The findings on simulation of maximum discharge were successful between observed and calculated. The limitation recorded was on inconsistence of rainfall data as some areas required radar data and that was not available. Okirya et al., (2012) applied the HEC-HMS and geographic information systems (GIS) tools in flood modeling with input data rainfall and GIS tools flood maps and prone areas were identified. The rainfall-runoff analysis was successfully obtained using the 3.5 version of the HEC-HMS. However, the findings from the study revels challenges in datasets as the catchment only had one rain-gauge station. The impacts of this were variations in of rainfall in the catchment. This challenge was solved by calibration of the hydrological model using river flow data. In recent years, the incorporation of GIS has become an important part of hydrologic research because of precipitation controlling hydrologic processes and spatial character of the parameters such as use of digital elevation model (DEM) (Asadi and Porhemat 2012).

2.10 HEC-SSP Statistical Software Package

A convenient feature for plotting frequency analysis results is provided by HEC-SSP (HEC-SSP 2010). The HEC-SSP constitutes of various components. The first component is the general frequency analysis which uses log-Pearson type III, Pearson type III, log-normal and normal probability distribution functions to execute frequency analyses for annual series of peak flows with application of the Weibull formula. The second component is the volume frequency analysis that is intended for analyzing daily stream flow. Based on an input daily dataset, annual series of minimum or maximum volumes each year during durations of days are analyzed. The Third component is the duration analysis that indicates the percent-of-time that a hydrologic variable exceeds specified values. An exceedance frequency relationship for a variable as a function of two other variables is developed by coincident frequency analysis component .The last component is the curve combination analysis that combines frequency curves from multiple sources into one frequency curve (Wurbs and Hoffpauir 2011)

2.10.1 Skew

When applying the log Pearson type method, assumption is made that normal distribution exists for the flow data and the visualization is as a bell curve. The data on floods does not fit a normal bell distribution but has a skew. Easton and McColl (2007) describes the skewness when the sample data values are asymmetry in distribution.

2.10.2 Outliers

According to NEDARC (2007) outliers can be classifies as high and low thresholds, which refers to extreme values in a frequency distribution that depart significantly from the trend of the remaining data and can have a disproportionate influence on the mean. This implies that historical data and personal analyses of data from nearby gauging stations to be well documented of outliers for required HEC-SSP computations.

2.10.3 Confidence Limits

Confidence limit describes a measure of the uncertainty of the estimated exceedance probability of a selected discharge. In the HEC-SSP, confidence limits is default to 5% and 95%,however the confidence limits can also be adjusted to a different value and the program will run the analysis included with the adjustment (Brunner 2006)

2.10.4 Expected Probability

The expected probability is defined as an average of true possibilities of flood frequency from samples of all magnitude estimates or in other terms it is the central tendency of the spread between confidence limits. The graphical representation is obtained when using the HEC-SSP (Brunner 2006)

CHAPTER THREE: METHODOLOGY

3.1 Study Area description

The study was conducted in Kabompo catchments which is a sub catchment of the Zambezi river basin. Kabompo River is 440 km flowing entirely in Zambia and is one of the main tributaries of the upper Zambezi River. It covers an area of 72,140 km^2 located on the North-Western province (UNEP 2010). Mean annual precipitation is 1500 mm on the North and 900 mm on the South with peak runoff occurring between February and April.

3.2 Data collection

The data was collected from the Zambia Meteorological Department and this consisted of daily rainfall and temperature data covering a time period from 1983-2013. The collection points were two meteorological stations namely Kabompo and Kaoma. Table xx shows the meteorological stations that were used for data collection and basic description. Zhang and Singh (2005) highlight the importance of complete data for many years and historical events, as critical in estimation of extreme events.

Table 4 : Description of meteorological stations

General location	Station name	Latitude (South)	Longitude (East)	Rainfall	Elevation
		(South)	(East)	(years)	(m)
North-Western	Kabompo Met	13.35	24.12	1983-2013	1090
Western	Kaoma Met	14.47	24.48	1983-2013	1158

3.3 Data Evaluation

Before use of the rainfall data it was statistically evaluated for accuracy as the goal of the hydrological data analysis is to check the rainfall record. The rainfall data was used to plot and analyze the cumulative departures from the mean to verify the consistency of the hydro-meteorological data. The relationship for cumulative annual rainfall at Mwinilunga meteological station (Met station in catchment) is shown in Figure 8 with the line showing that the rainfall is constant with the rainfall data records at Kabompo station. The correlation is strong at 0.99. After analyzing the accuracy of data, two stations were used namely Kabompo and Kaoma.

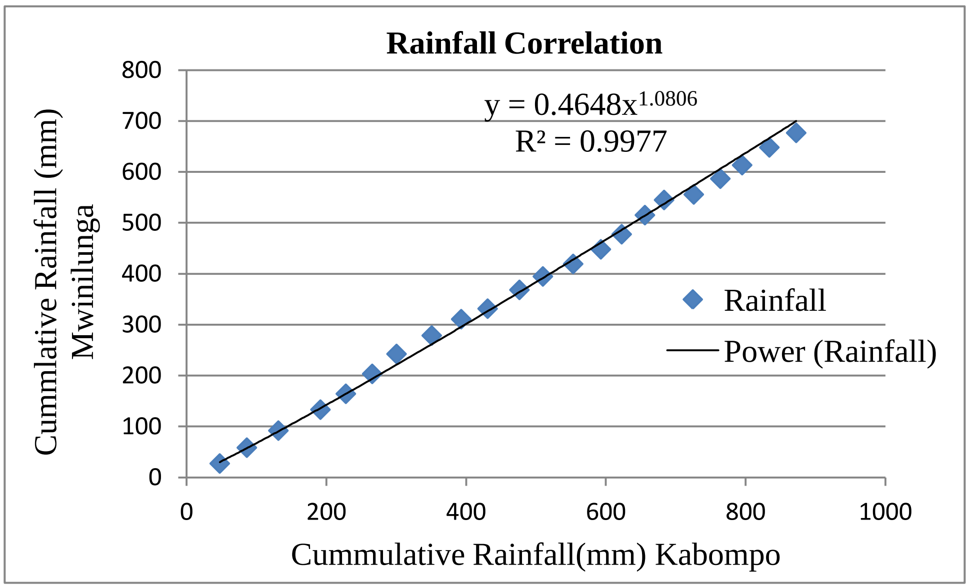
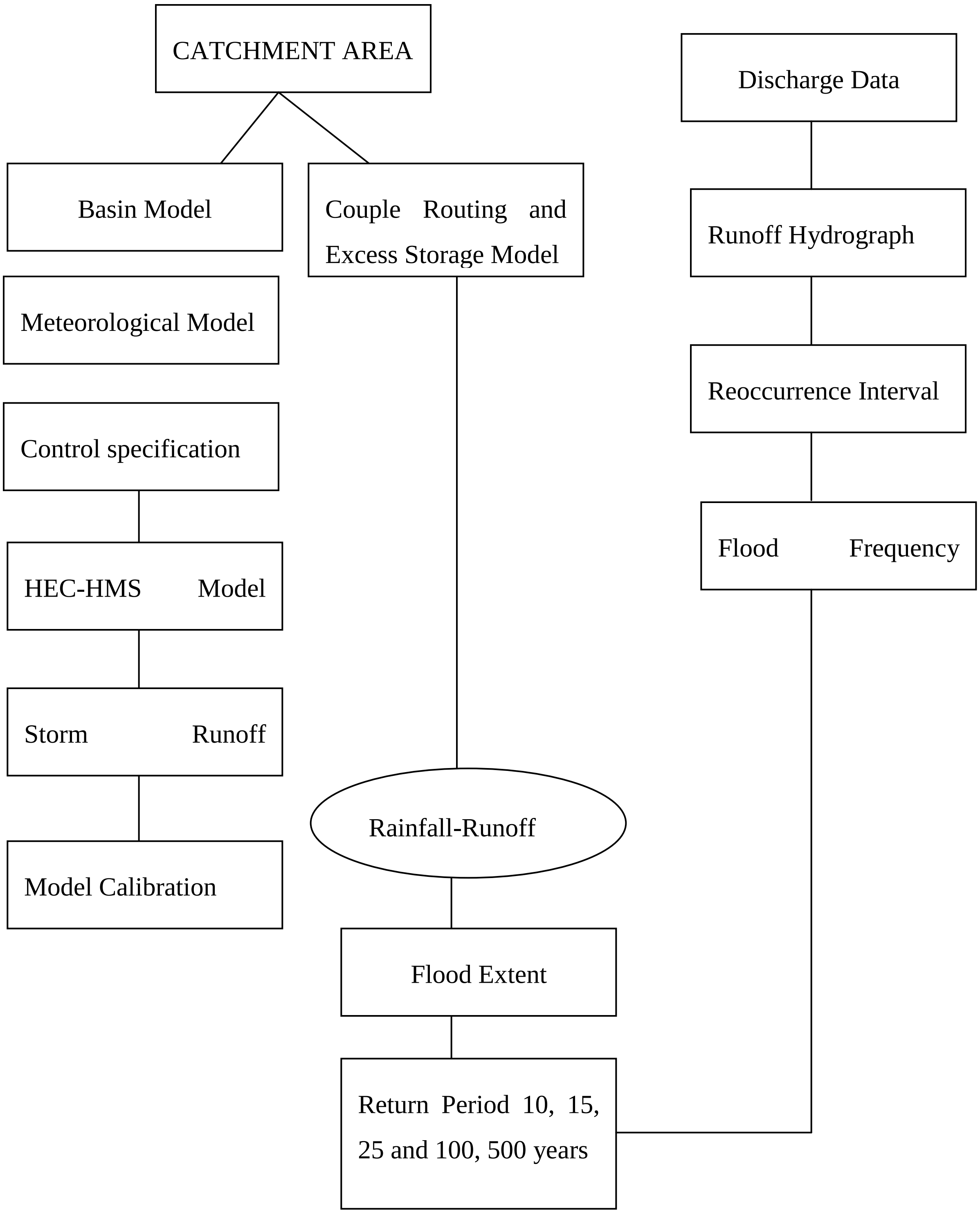


Figure 8 : Mwinilunga and Kabompo Rainfall Correlation

3.4 Methodology Flow Chart



3.5 Geographic Information System (GIS) and Application

A digital terrain model (DTM) is established based on ESRI ArcGIS and Google Earth. In this study, technology of Google Earth program is employed to illustrate the catchment area. A digital map, a high resolution ortho image, and other GIS information were prepared in Keyhole Markup Language (KML) files. These files were uploaded as a type of layer in ArcGIS 10 to create a shapefile. The data were manipulated in ArcGIS to provide detailed catchment information. The created shapefile was then loaded in HEC- GeoHMS.

3.5.1 HEC-GeoHMS Processing

Before the DEM is used in GeoHMS, it is firstly processed to create the required layers which include slope grid .flow direction, flow accumulation, stream, stream segments, catchment polygon, catchment grid delineation, adjoint catchment and drainage line layers.

These layers were created using the Arc Hydro Tools in GIS. The layers are used for further GeoHMS processing, for which the procedure is as adapted from HEC (2009) in this study.

3.6 Hydrologic Model Building

Numerous methods are utilized in defining the characteristics of the catchment. For instance development of water streams can be created with the help of GIS. According to Garbrecht and Martz (1999) in developing the watershed characteristics, Digital Elevation Models (DEMs) are widely used. Characteristics processing from the DEM are conducted which include the fill sink such as flow direction, flow accumulation, stream definition, watershed delineation, Watershed Polygon, drainage points and drainage lines..In this study, a DEM was used to develop elevation related characteristics for the catchment with the help of a GIS based tool namely Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) Extension in Arc-GIS for DEM hydro processing ‘Arc hydro tool’ in which this part is done and then it is applied in GeoHMS.

Figure 9 shows the raw DEM with elevation lower number at 1000 and the upper value of 1551m.

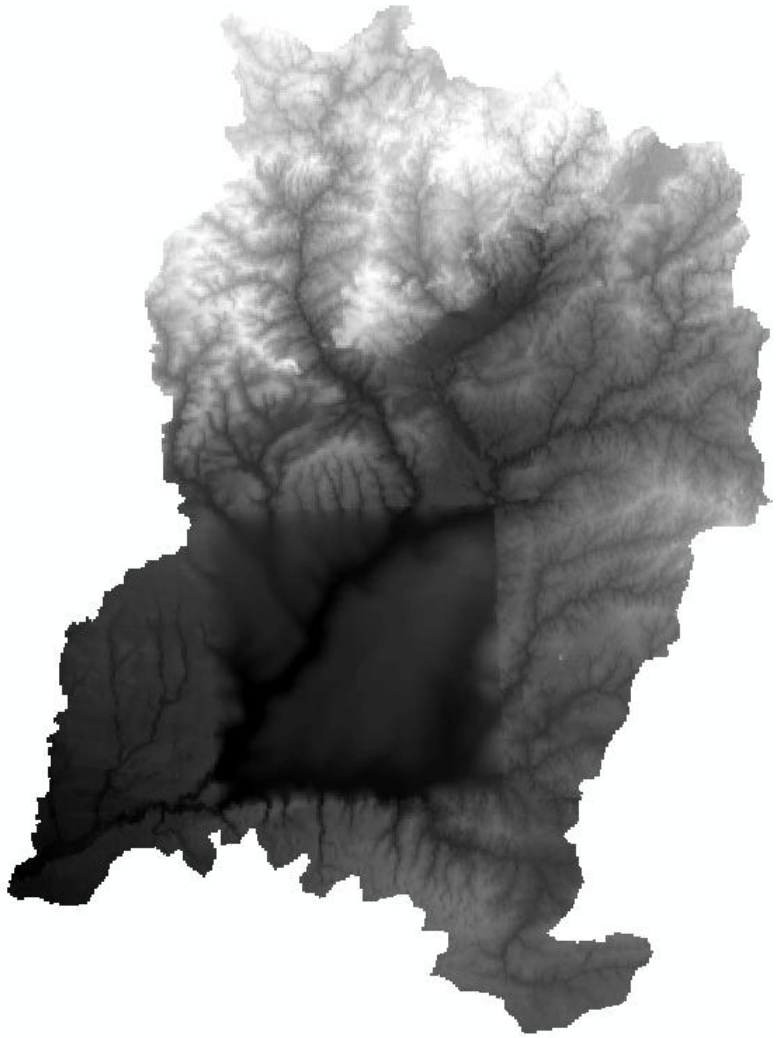


Figure 9 : Raw DEM

The Fill sink is illustrated below in Figure 10 and the lower elevation stands at 1039 m above sea level.

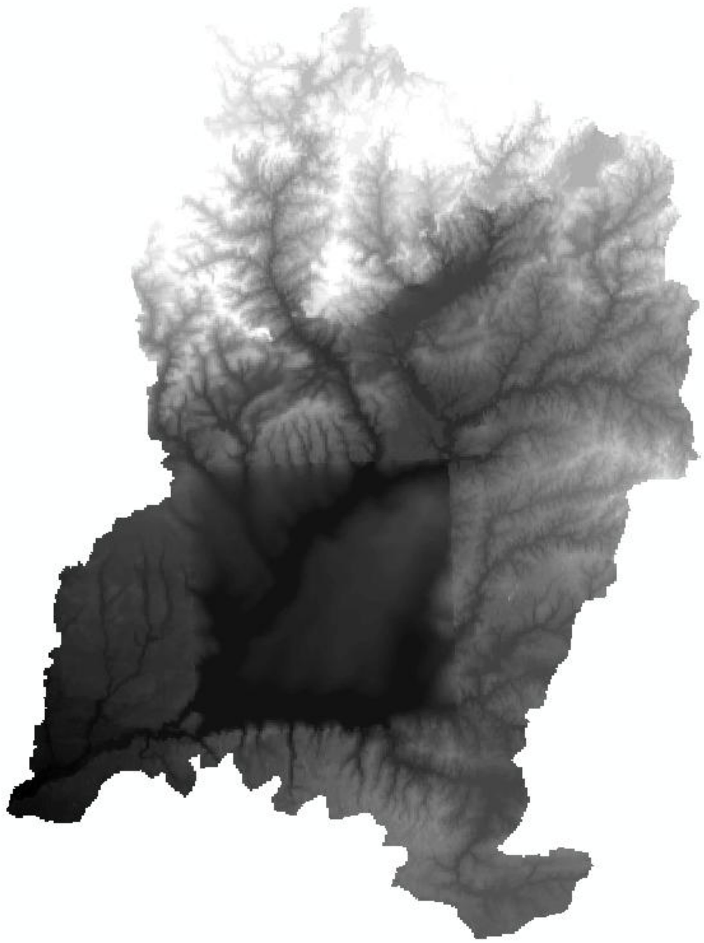


Figure 10 : Fill sink

Figure 11 shows the flow direction as seen in the catchment and the legend illustrates the findings.

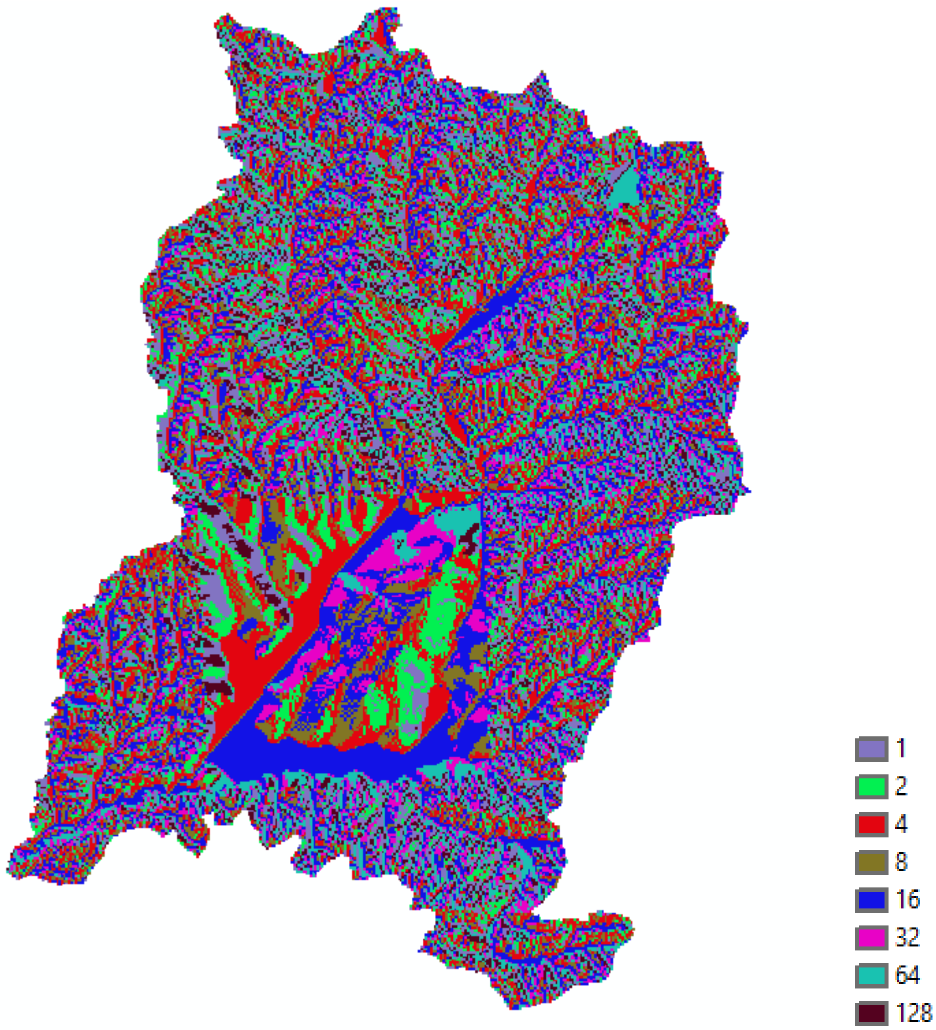


Figure 11 : Flow Direction

The flow accumulation in the catchment is indicated in figure 12.

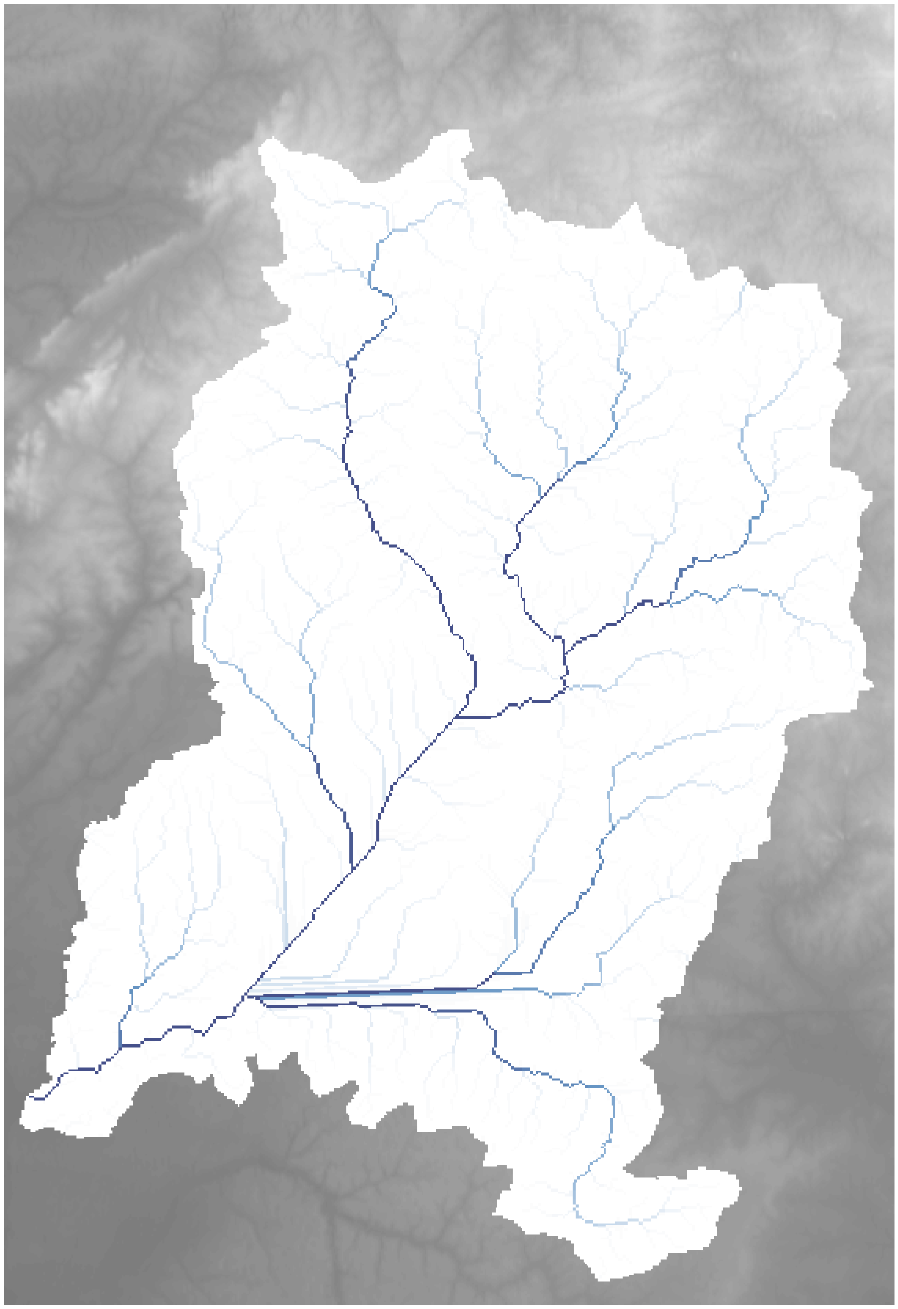


Figure 12 : Flow Accumulation

The drainage lines,adjoint catchments and drainage points are shown in figure 13.

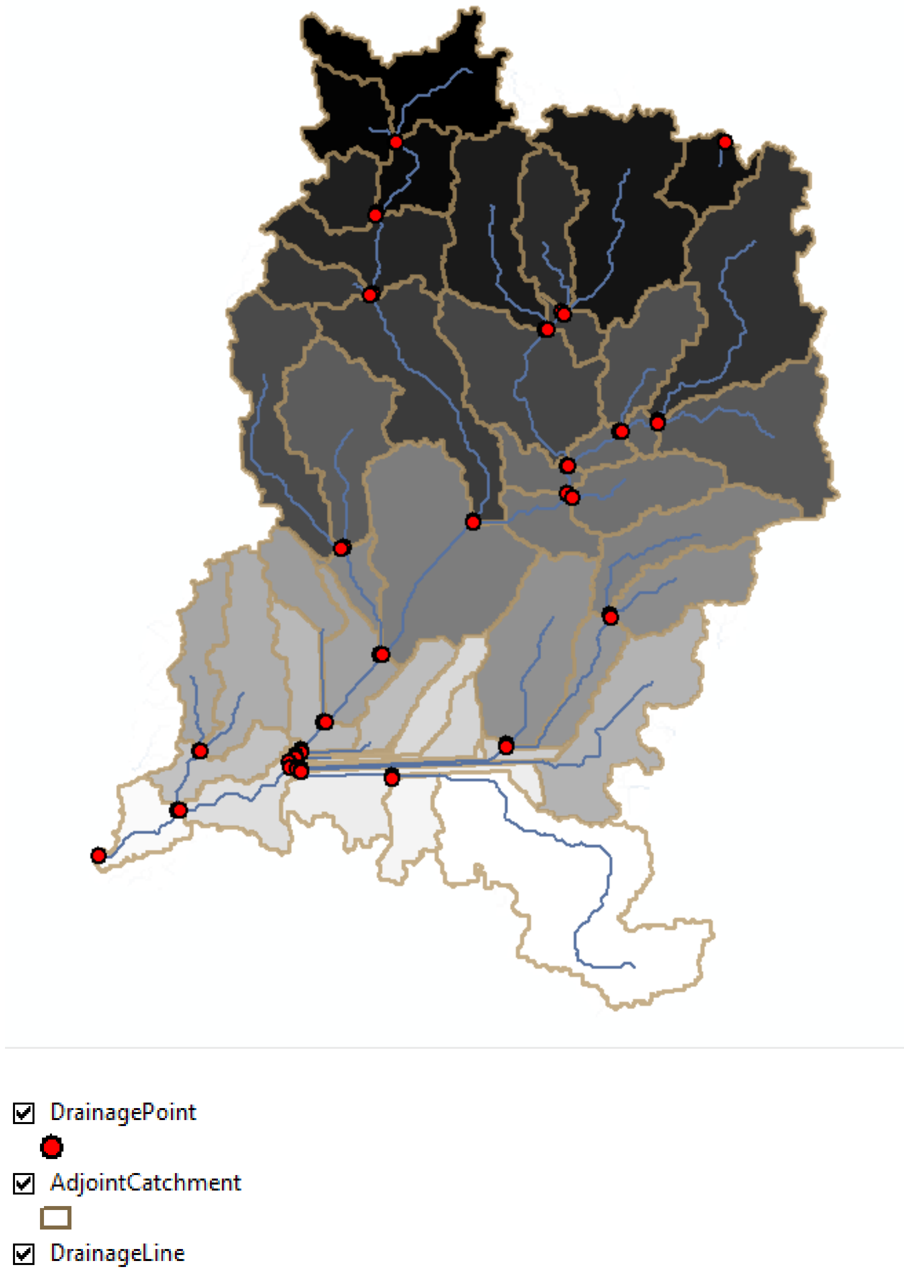


Figure 13 : Drainage Points and Drainage Lines

Before the application of the HEC-HMS simulations preparation is carried out in the HEC-GeoHMS that acts as a geospatial hydrology toolkit. Among the activities and processes carried out include visualizing spatial information, spatial analysis, describe watershed characteristics and many more inputs to hydrologic models (HEC 2010).

Table 5 : Physical characteristics HEC-GeoHMS

Properties	Characteristics
Stream	Slope and Length
Watershed	Area and Lag Time

3.7 HMS Parameters

In the HMS Processes function the appropriate loss method selected and employed in this study is the SCS-CN method. The selection of the SCS curve number was approximated from the values of land use classes. Similar approach was applied by Yuan and Qaiser (2011).Following the land characteristics of Kabompo catchment the soil conservation number used are 51 and 52 for Kabompo and kaoma gauges respectively.

After the rainfall losses are accounted for, the transform model in use is specified to account for surface runoff. According to Yaun and Qaiser (2011), the SCS unit hydrograph require one parameter with assumption of the shape of unit hydrograph. In comparisons to the Clark or Snyder methods, the parameters are challenging to estimate however more flexible in determining the unit hydrograph shape.

The transform model (runoff model) used is the unit hydrograph (UH).Lag time (runoff hydrographs) is selected as the routing model. The lag time is obtained by using 60% of the calculation from the time of concentration. According to HEC (2010), the lag time refers to the length of time it takes between the centroid of rainfall and the peak flow of the resulting hydrograph. The time of concentration defines the time it takes for water to travel to the sub basin outlet from the most distant (hydraulic) point in the sub area. After transformation of the excess rainfall into runoff and routed to the outlet of a sub basin, it enters the stream at the point and is added to stream flow routed from the upstream. Different methods are used to calculate the time of concentration among them Kirpich, Kerbay, SCS, California and Bransby-Williams. The findings of Majidi and Shahedi (2012) reveals that the use of the Bransby-Williams produces good model run results between the observed and simulated hydrograph. In this study the Kirpich method is used with empirical formula illustrated below.

$$Tc = \frac{KL^{0.77}}{S^{n}}$$

Where: L = basin length

S = basin slope

K = 0.0078

n = 0.385

The completion of the activities above is followed by other vital activities untaken in the HMS model. These descriptions include the following with their specifics;

In Meteorological Model Manager components tab a meteorological model file is created and rainfall specified. This is followed by selection of the hyetograph option and then creation of the precipitation gauge for the Basin by the use of the Time Series Data Manager in the components tab. In order to set the time period of the simulation run, the Control Specification Manager in the components tab is used for creation of the control specifications. This shows the starting and ending date, the duration and time of each simulation. The time span for starting and ending date (1st January 1983 to 31st December 2013), computation time steps (one day) is specified here. The description of reach point is represented in Table 6 showing the length, elevations, time of concentration and lag time.

Table 6 : Description of Reach point

Reach	Length (m)	Elevation 1 (m)	Elevation 2 (m)	TC (min)	Lag time(min)
1	101243	1071	1046	55.99	33.60
2	170401	1150	1051	60.14	36.09
3	76074	1051	1037	50.31	30.19

3.8 Flood Flow Data

Data entry of maximum flow can into HEC-SSP software through four different ways among them manually entering the data into a table, importation from another HEC-DSS file, importing data from the USGS website and importing from a Microsoft Excel spreadsheet that is employed in this study. The format of the data in Microsoft Excel is in either the dd/mm/yyyy or the ddmmmyyyy format in and it must be in the ddmmmyyyy format to be entered into HEC-SSP manually.

3.8.1 Estimation of a Frequency Distribution

The creation of frequency relation is created in U.S. Army Corps of Engineers Statistical Software Package (HEC-SSP) with confidence limit at 5 % and 95 %. After importing the data into HEC-SSP, the program ran the process of fitting the flood flow data to a predictive curve .The component used is the general frequency and applies method log-Pearson type III, Pearson type III, log-normal and normal probability distribution functions to execute frequency analyses for annual series of peak flows with application of the Weibull formula as the plotting position.

3.8.2 Annual Peaks with Weibull Probabilities

The Weibull formula estimates exceedance probabilities based on relative frequency as follows:

$$P = \frac{m}{N+1}$$

Where P represents annual exceedance probability, m is the rank of the values (m = 1, 2, 3, N),and N is the total number of years in the data series. The greatest flow or storage volume is assigned a rank (m) of 1, and the smallest is assigned a rank of N.

3.9 Limitation of the study

Lack of many distributed gauging stations in the catchment with complete years of data required for such an analysis was not possible for every stream. The lack of hydrological station for recorded discharge proves to be limit verification purposes.

More accurate outcome pertaining to using curve number value proves challenging due to land uses and land covers limitations data for Zambia and many African countries at large.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Model Simulation

The Basin model serves as a vital input in running model simulation of rainfall runoff of the basin. The creation of sub basin is divided in 2 sub basins and 3 routing reaches. An illustration of the HMS model for Kabompo is indicated in Figure 14. A junction shows the confluence of the streams from the sub basins

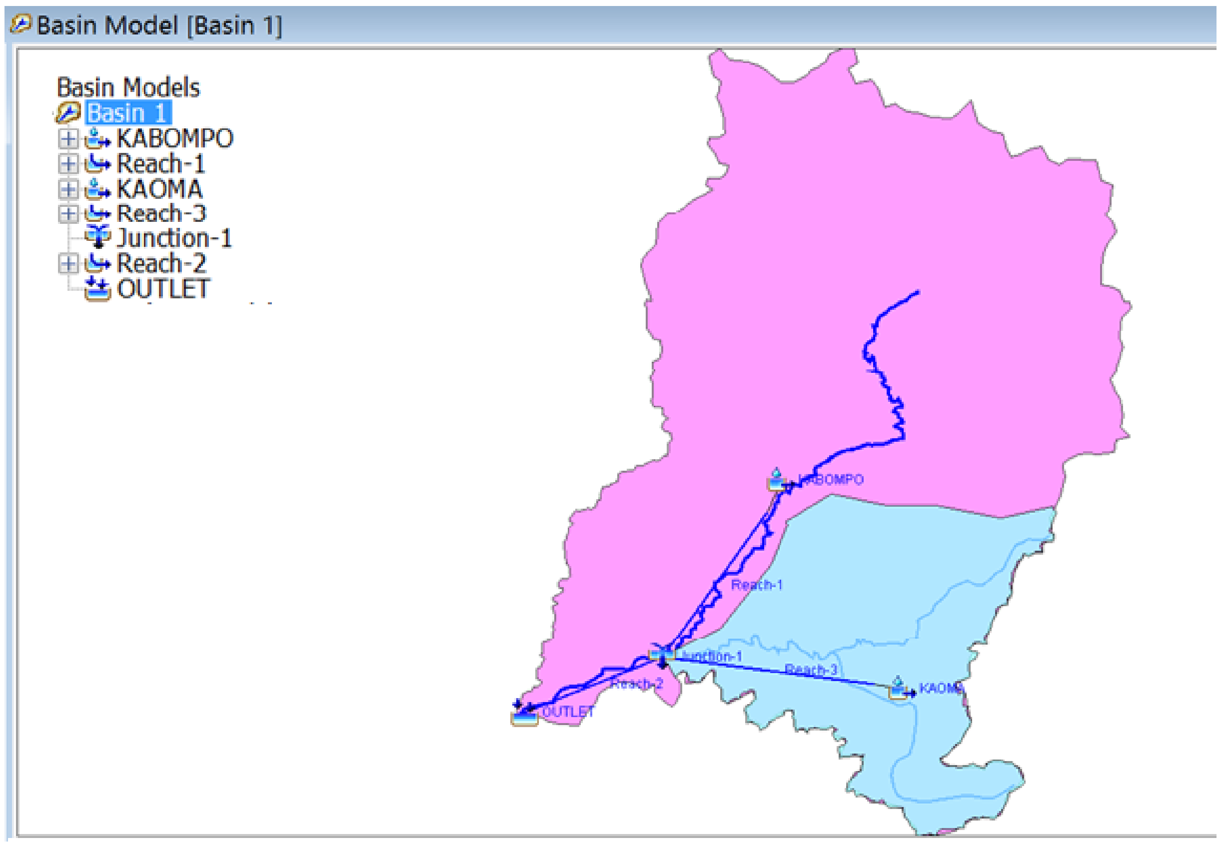


Figure 14 : Representation of Kabompo River in HMS model

4.2 Annual maximum flow peaks

The computations from the running of the HEC-HMS generated the daily flow data for Kabompo. The annual maximum daily flows are prepared in excel spreadsheet and uploaded in the HEC-SSP .The results are presented in Table 7. The findings from the historical data show that the spread of flow ranges from 513 m^3/s to 2 408 m^3/s .The lowest flow from events analyzed is observed in the water year 1984 which falls in as the lower outlier. The highest flow is observed in the water year 1989. However, the flow trend from events of 2009 to 2013 seem to be decrease ranging from 1 380 m^3/s to 1265 m^3/s in comparisons to the peak flows of 2 408 m^3 /s in 1989.The researcher attributes the decrease in flow to climate change that may increase the evaporation rate. Another reason is associated with water diversion for agriculture purposes. The findings from the report Table 7 on ordered events ,indicate the rankings of the flow from in descending order with application of the weibull plots position (p=m /n+1) where p denotes the exceedance probability , m is the ranking of flow with number 1 been the highest and the n denoting the ranked flow numbers. The highest flow observed of 2 408 m^3/s reveals that has a probability of 3.12 %. The flow of 2 049 m^3/s ranked third illustrates a probability close to 10% approximately a 10 year flood. Table7 further gives an idea on the magnitude for instance for a 10 year flood with 31 year period of data indicating that only two floods exceeding that magnitude have occurred.

Table 7 : Annual maxima flow peak

Events Analyzed		Ordered Events			
Day Mon Year	FLOW m3/s	Rank	Water Year	FLOW m3/s	Weibull Plot Pos
30 Dec 1983	513.9	1	1989	2,408.8	3.12
22 Feb 1984	1,104.5	2	1993	2,073.2	6.25
12 Apr 1985	1,330.4	3	1990	2,049.7	9.38
24 Feb 1986	1,851.2	4	1999	1,987.7	12.50

10 Feb 1987	1,432.6	5	1997	1,913.7	15.62
27 Mar 1988	1,432.6	6	1991	1,887.3	18.75
29 Jan 1989	2,408.8	7	1986	1,851.2	21.88
26 Jan 1990	2,049.7	8	1998	1,813.8	25.00
09 Feb 1991	1,887.3	9	1994	1,801.4	28.12
14 Jan 1992	1,331.1	10	2007	1,793.8	31.25
13 Mar 1993	2,073.2	11	2001	1,793.6	34.38
03 Feb 1994	1,801.4	12	2003	1,736.0	37.50
07 Mar 1995	1,468.6	13	2002	1,615.6	40.62
21 Mar 1996	1,443.8	14	2004	1,570.6	43.75
01 Feb 1997	1,913.7	15	2000	1,505.4	46.88
11 Feb 1998	1,813.8	16	1995	1,468.6	50.00
05 Feb 1999	1,987.7	17	1996	1,443.8	53.12
20 Mar 2000	1,505.4	18	1988	1,432.6	56.25
01 Mar 2001	1,793.6	19	1987	1,432.6	59.38
12 Feb 2002	1,615.6	20	2009	1,387.7	62.50
12 Jan 2003	1,736.0	21	2011	1,384.2	65.62
16 Jan 2004	1,570.6	22	2012	1,373.4	68.75
12 Jan 2005	1,146.9	23	1992	1,331.1	71.88
30 Dec 2006	1,249.8	24	1985	1,330.4	75.00
14 Jan 2007	1,793.8	25	2013	1,265.6	78.12
29 Dec 2008	1,213.4	26	2007	1,249.8	81.25
28 Mar 2009	1,387.7	27	2009	1,213.4	84.38
28 Dec 2010	1,384.2	28	2005	1,146.9	87.50
17 Dec 2011	1,373.4	29	2012	1,120.9	90.62
31 Dec 2011	1,120.9	30	1984	1,104.5	93.75
28 Mar 2013	1,265.6	31	1984	513.9*	96.88

* Outlier

4.3 Flood Frequency Analysis with HEC-SSP and implication

HEC-SSP results show the basic flood frequency analysis and also provide additional auxiliary information that includes confidence limits and frequency plots. Annual peak flow corresponding to annual exceedance frequencies of 99, 50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent, which correspond to recurrence intervals of 1.01, 2, 5, 10, 25, 50, 100, 200, and 500 years. The relationship between annual exceedance probability (P) and recurrence interval (T) in years is:

$$\boldsymbol{T = \frac{1}{P}} \qquad \text{Or} \qquad \boldsymbol{P = \frac{1}{T}}$$

Table 8 shows the preliminary results for flood frequency developed with the HEC-SSP statistical software package for the 31 annual maxima flow. Flood frequency analysis is conducted to set design flood peak discharge. The requirement for flood frequency analysis include the annual maximum flow data, distribution modeling. The annual peak discharges were plotted using the log-Pearson type III, Pearson type III, log-normal and normal probability distribution method. Further obtained are summary statistical information that consists of the mean, standard deviation and skewness. The expected probability in the table 8 below indicates the adjustments that are carried out to overcome bias in computations of frequency which may arise as a result of shortness in data.

Table 8 : Flood Frequency Flow at Kabompo

Computed Curve FLOW, m^3/s	Expected Probability FLOW, m^3/s	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, m^3/s	Confidence Limits 0.95 FLOW, m^3/s
3,370.0	3,656.5	0.2	4,275.1	2,868.1
3,094.7	3,291.0	0.5	3,844.3	2,668.1
2,884.5	3,026.3	1.0	3,522.8	2,512.7
2,671.1	2,768.9	2.0	3,203.5	2,352.3
2,452.3	2,515.6	4.0	2,884.4	2,184.4
2,380.2	2,434.2	5.0	2,781.2	2,128.2
2,148.5	2,178.9	10.0	2,457.0	1,943.9
1,897.8	1,911.7	20.0	2,121.6	1,736.2
1,496.9	1,496.9	50.0	1,630.1	1,374.6
1,180.7	1,172.2	80.0	1,290.7	1,056.2
1,043.0	1,028.4	90.0	1,152.8	912.0
941.4	920.6	95.0	1,052.9	805.7
776.9	740.5	99.0	891.8	636.1

4.3.1 Systematic Statistics

The systematic statistics show the computations of the preliminary results with outlier considered. The station skewness shows the distribution towards the negative with a higher standard deviation.

Table 9 : Systematic Statistics for preliminary results

Log Transform: FLOW, m3/s		Number of Events	
Mean	3.175	Historic Events	0
Standard Dev	0.122	High Outliers	0
Station Skew	-1.679	Low Outliers	0
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.000	Systematic Events	31

Following one outliner the adjusted frequency curve is presented in Table 10. The outlier sets differences in the preliminary results and the final results .Differences are observed in systematic and synthetic statistics in Table 9 and 12 respectively. The differences observed in skew are in outlier were with it appears negative (Table 9) and positive without the outliers (Table 12).

Table 10 : Frequency curve adjusted for 1 low outlier(s)

Log Transform: FLOW, m^3/s		Number of Events	
Mean	3.191	Historic Events	0
Standard Dev	0.088	High Outliers	0
Station Skew	0.156	Low Outliers	1
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.000	Systematic Events	31

4.4 Analytical Frequency

Final results of analytical frequency curve are presented in Table 11.These values are generated one the lower outlier has been adjusted and do not influence the analytical computations. The findings indicate a decrease in computed values in comparisons to the preliminary results in Table 8 which considers the outliner. At 50 % probability the findings shows a flow of 1538m3/s to at least occur once in two years with a 1 % probability expected for a flow of 2 568m^3/s for 100 year return period. The findings are further highlighted for different return periods , probability and flow in Table 11 below.

Table 11 : Analytical Frequency Curve for Kabompo Catchment

Computed Curve FLOW, m^3/s	Expected Probability FLOW, m^3/s	Percent Chance Exceedance	Confidence Limits 0.05 FLOW, m^3/s	Confidence Limits 0.95 FLOW, m^3/s
2,777.8	2,947.8	0.2	3,303.0	2,470.2
2,610.7	2,730.3	0.5	3,057.2	2,343.5
2,480.4	2,568.6	1.0	2,868.9	2,243.4
2,345.5	2,407.7	2.0	2,677.2	2,138.2
2,204.0	2,245.3	4.0	2,480.4	2,026.1
2,156.7	2,192.2	5.0	2,415.5	1,988.0
2,001.7	2,022.3	10.0	2,207.1	1,861.1
1,828.9	1,838.6	20.0	1,983.5	1,714.1
1,538.8	1,538.8	50.0	1,637.3	1,446.2
1,294.7	1,287.9	80.0	1,381.4	1,193.8
1,182.9	1,170.9	90.0	1,272.3	1,072.9
1,098.0	1,080.2	95.0	1,191.1	980.3
954.6	921.9	99.0	1,055.5	825.4

4.4.1 Synthetic Statistics

The findings of final synthetic statistics indicate a decrease in standard deviation and the station skewness moving towards zero creating a normal distribution bell curve.

Table 12 : Synthetic Statistics

Log Transform: FLOW, cms		Number of Events	
Mean	3.187	Historic Events	0
Standard Dev	0.089	High Outliers	0
Station Skew	0.167	Low Outliers	1
Regional Skew	---	Zero Events	0
Weighted Skew	---	Missing Events	0
Adopted Skew	0.000	Systematic Events	31

4.5 Flood Frequency Curves

4.5.1 Normal Distribution Curve

In the frequency plots , the computed curve is denoted in red line, the expected probability curve denoted with blue lines .The confidence limits are indicate by green line at 5 percent and purple line at 95 percent as lower and upper limits respectively. The observed events (weibull plotting position are denoted by a blue circle and green square shows lower outlier.

The full period of record (1983-2013) plot indicates the design storms from the gauged station match the fitted probability curve fairly well. This is more visible in the 5 year return period and 10 year return period moves slightly below the computed and expected curve. However, the 25 year return period fall above the expected probability curve close to a 5% confidence limit. The finding shows that the normal distribution underestimates the flow for larger return period.

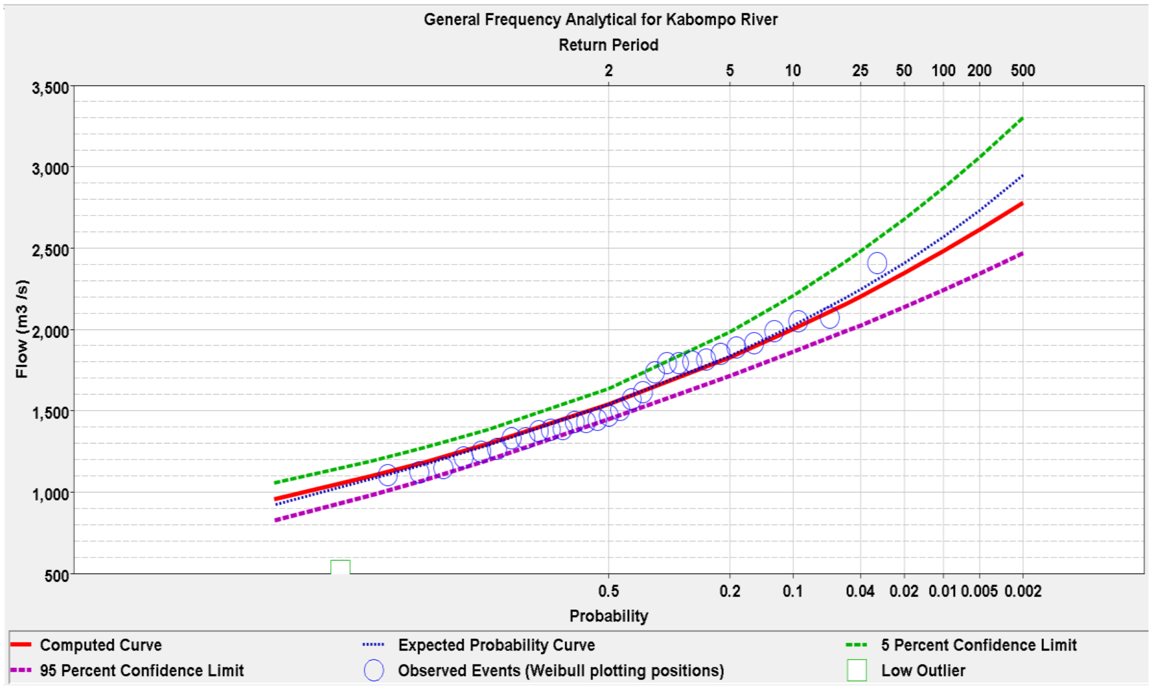


Figure 15 : Normal Distribution Frequency Curve

4.5.2 Pearson Distribution Curve

The Pearson distribution shows events of 25 year return period close to the 5% probability indicating a conservative estimate. The 10 year indicates well fit of observed event on computed and expected probability curve while some event falls below the computed fit .Similarly like with the normal distribution the 5 year return period observed flow fits well in expected probability curve and computed curve. From the 2 year return period some variation exists from the observed events moving from the 95 % confidence limit in earlier in 2year return period, fitting to the expected probability to the 5% confidence limit. Finally in the less than 2 year return period the events fit well in the expected probability and towards the 95% confidence limit.

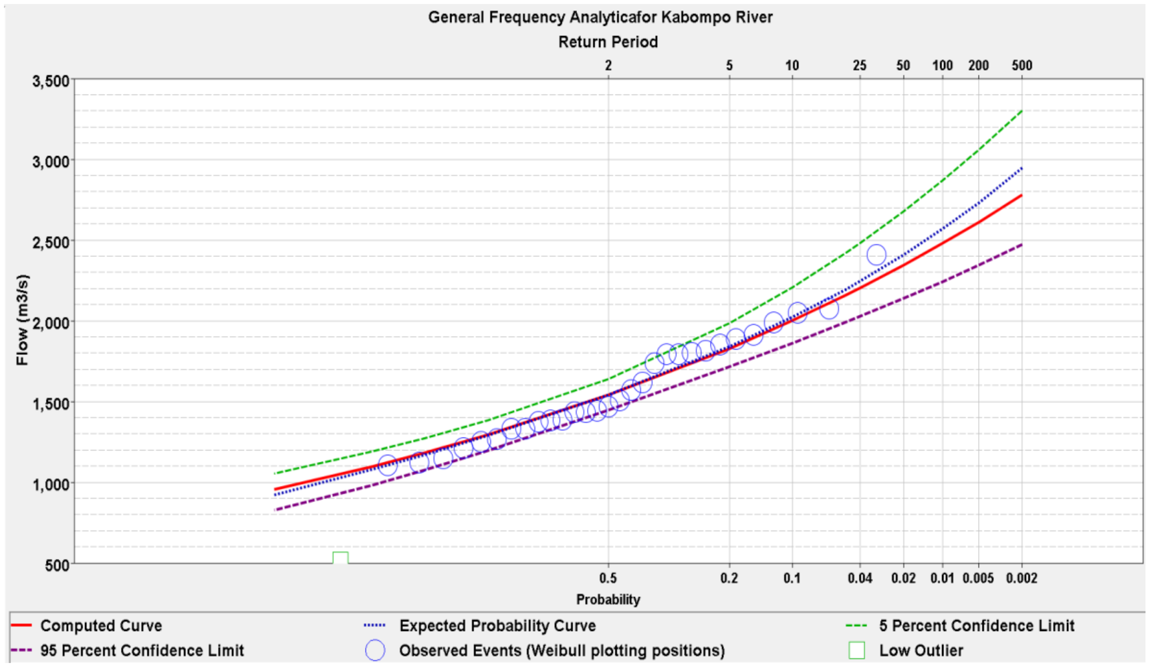


Figure 16: Pearson Distribution Frequency Curve

4.5.3 Log Normal Distribution Curve

Another distribution method applied is the log normal. In this method observation is made are similar to the normal and Pearson distribution where all the events fall with the confidence limit. The note at the 25 year return period of observed event slightly exceeds the computed curve and the expected probability curve.

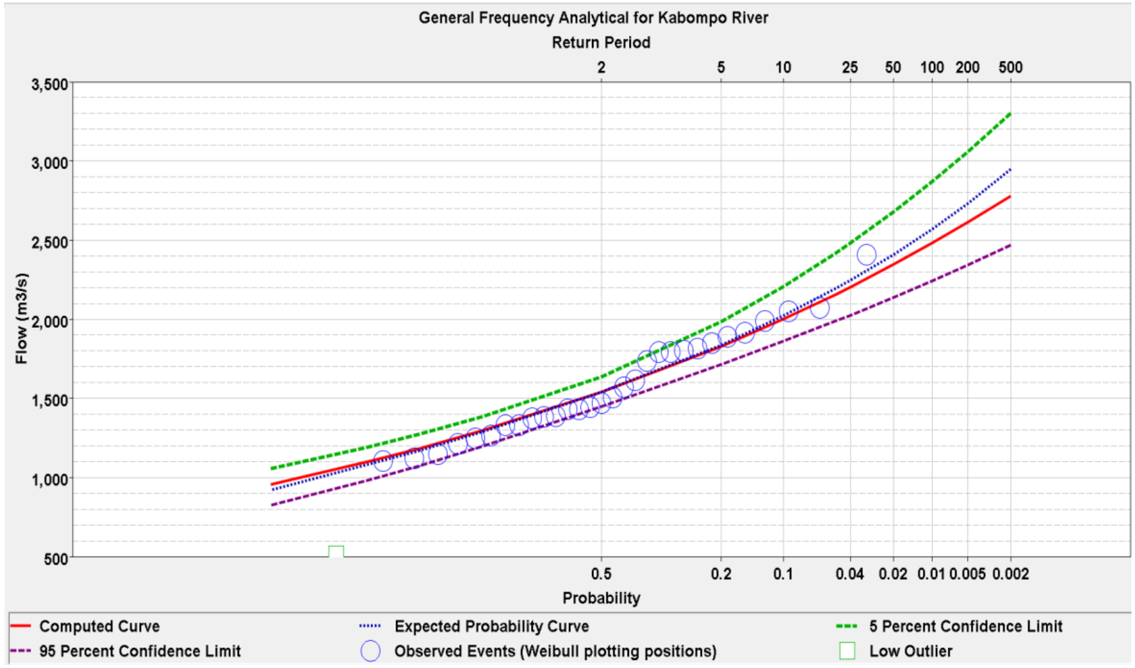


Figure 17 : Log Normal Distribution Frequency Curve

4.5.4 Log Pearson Distribution Curve

The log Pearson illustrates similar attributes such as the log normal and others distribution where the priority is given up to 25 year return period is given since onwards does not show an observed events.

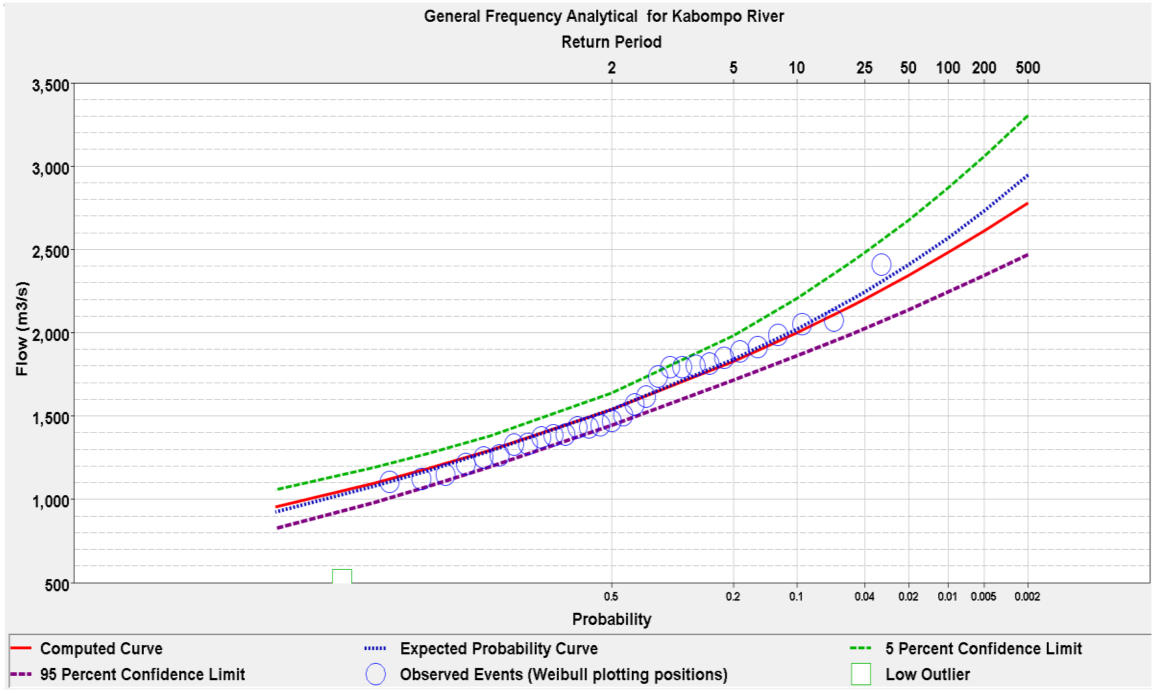


Figure 18 : Log Pearson Distribution Frequency Curve

Results of the frequency curve for different distribution are applied and findings discussed above. The distribution methods used do not show any differences .The major similarities in all the four distribution show that the observed event fits well in the 5 year return period with consideration on computed and expected probability curves. The other note in methods confirm the events falling within the confidence limit of 5% to 95% of computed frequency curve for return periods for 5,10 and 25 years. Return period year 2 indicates variations with some observed events falling on boarder of the 5 % confidence limit .Generally the implication is that the since computed events are within the confident limit there is no model underestimate or overestimates. Another note is that as the return period increases the probability of exceeding decrease. The translation is that there is an inverse proportion between the magnitudes of an extreme event to how frequently it occurs. The note is that more severe events occurrence is less frequent.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

The hydrologic impacts assessment of the study conducted is via flood frequency analysis. A general flood frequency analysis was presented, attempting to use hydrologic model HEC-HMS to improve alternatives to determine the annual peak flow and flood analysis using HEC-SSP from rainfall gauged historical data. In this study, the extreme value series hydrological data which indicates the largest value are used for frequency curve computations. This implies that the series of data containing all the daily data flow that is available and the annual maximum flows are calculated and used in the analysis. The finding does not show differences in flow and frequency in application of different distribution which include the normal, Pearson in comparison to the log normal and log Pearson. This is attributed to the rainfall data period which is 30 years. The researcher assumes that the distribution results may appear different if the rainfall data is for a shorter or longer period.

It has been recognized that hydrologic model when applied appropriately, could increase the success in provision of information about flood frequency analysis which can be used for planning and management purposes through computation of recurrence intervals.

For recommendations a more comparative statistical procedures of flood distribution and methods would provide a more comprehensive analysis rather than focusing on one method HEC-SSP. This in conjunction with distributed discharge records in the catchment would improve the verification process. To carry out comprehensive flood frequency analysis, it is recommended to fill in the gaps that exist in hydrological data such as rainfall, discharge (stream flow) recording and monitoring across the country to overcome the inconsistencies.

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Abbreviations

AEP	Annual Exceedance Probability
CN	Curve Number
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
HEC-GeoHMS	Hydrologic Engineering Center Geospatial Hydrologic Modeling Extension
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
HSG	Hydrologic Soil Group
IFRC	International Federation of Red Cross
NRCS	Natural Recourse Conservation Service
RP	Return Period
SCS	Soil Conservation Service
UH	Unit Hydrograph
USGS	United States Geological Survey
ZAMCOM	Zambezi Watercourse Commission