RAINFALL TRENDS AND FLOODING IN THE SONDU MIRIU RIVER BASIN

By

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A Research Project submitted in partial fulfillment for the requirements of Master of Arts Degree in Climatology in the Department of Geography and Environmental Studies, University of Nairobi

2016

DECLARATION

This Research project is my original work and it has never been submitted for examination or degree award in any other University.

Sign……………………………… Date……………………………….

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(C50/79658/2012)

This Research Project has been submitted for examination with our approval as the University Supervisors.

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DEDICATION

To the Mary knoll sisters.

ACKNOWLEDGEMENT

Many people helped in the writing of this project to make it a success, I may not be able to thank each one of them individually, but my heart is spacious enough to accommodate their wonderful assistance and the strengths of this study I owe it to them. I want to first thank my supervisors Dr.Nyandega and Mr. Isaac Ndolo who gave valuable guidance, suggestions, critisms and encouragement that made me stay focused. My deepest regards goes to professor Khroda who through Mr.Karicho and Mr.Ngessa both of WRMA enabled me to acquire the necessary hydro meteorological data. I would like to thank Dr.Omoke for his constant academic advice. My deepest regards goes to Dr.Nyanganga for his tremendous contribution to my study.

I am indebted to Mr.Ayuyo for proofreading my work and making constant corrections and also to Mr. OliverOgembo and Nicholas Mwakavi for their technical support. My deepest regards also goes to Mr.Sonn for his endless financial support and to my family the “Ombogo’s“for their financial, spiritual and moral support and my child who gave me every reason to work hard I cannot forget to thank my colleagues especially Mr. Opole who was a helpful companion during the entire course study and the entire staff of Department of Geography and environmental Studies.

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LIST ACRONYMS

APFM:	Associated Program on Flood Management
ANOVA:	Analysis Of Variance
ASALS:	Arid Lands Resource Management Project
BCM:	Billion Cubic Meters
DMC:	Disaster Management Committee
ENSO:	El-nino Southern Oscillation
FAO:	Food and Agricultural Organization
GCM'S:	General Circulation Model
ICRAF:	International Centre for Research in Agro Forestry
IPCC:	Intergovernmental Panel on Climate Change
KRCS:	Kenya Red Cross Society
LVNCA:	Lake Victoria North Catchment Area
LVSCA:	Lake Victoria Southern Catchment Area
MWRD:	Ministry of Water Resource Management and Development
NCCRS:	National Climate Change Response Strategy.
NOAA:	National Oceanic Atmospheric Administration
ROK:	Republic Of Kenya
RVCA:	Rift Valley Catchment Area
SOK:	Survey of Kenya
SWM:	South West Mau

UNEP:	United Nations Environmental Programme
USAID:	United States Aid
WRI:	World Resource Institute
WRMA:	Water Resource Management Authority

ABSTRACT

This study was focused on the rainfall trends and flooding in the lower Sondu-Miriu catchment which is one of the sub basins in the Lake Victoria basin in Kenya. The broad problem that was investigated is the relationship between rainfall in the upper catchment and flood frequency in the lower basin. The specific objectives of the study were to determine rainfall trends, frequency and the relationship between the rainfall trends and flood occurrence, within the Sondu-Miriu basin respectively. The study was based on the hypothesis that there was no relationship between the trends in rainfall in the upper catchment of the river and flood frequency in the lower basin of the Sondu-Miriu River.

Data required to solve the stated problems and meet the objectives of the study included monthly rainfall data from 3 rainfall stations in the basin as available in meteorological department databases and, the monthly river discharge data at Nyakwere bridge station (1JG01) as available in the Water Resource Management Authority databases. For both rainfall and river discharge data, the period of record used was 1960-1990 that provided the least number of missing records and therefore the most consistent. To determine trends in rainfall and river discharge, time series analysis technique was used where trend computation was based on the long term mean variance. For flood frequency determination, the study used unit hydrograph technique. Relationship between rainfall and flood was measured using the simple linear regression statistical technique. Significance testing was in all cases at α 0.05. The regression analysis had an r value of 0.509 which indicated an average relationship between the rainfall trends and the flooding in the lower plains.

The results of data analysis were that rainfall in the Sondu-Miriu basin showed decline in the amount 1960-1990 period while flood frequency did not show any definite return periods hence posing danger to the low land regions of the basin. Two of the three rainfall stations showed a decline in the mean annual rainfall with Tenwek being the only station showing annual increase in its rainfall. The flood frequency within this catchment is random with most floods having a range of 2-10 year return period. The findings of this study can be used for flood forecasting, to establish appropriate relief services and the physical planning for the development in the lower Sondu-Miriu River.

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background of the Study

Rainfall and river flow patterns in most parts of Africa exhibits high levels of variability in terms of space and time across a range as explained by Conway (2002) in his studies in the sub-Saharan Africa. The variability has impacted so significantly on the society causing widespread acute human suffering and economic damages. Prolonged periods of high flows for most rivers draining large parts of East and central Africa and multidecadal anomalies in river flow regimes in parts of West Africa (Mahe ´ and Olivry 1999) are some of the examples of such disparities.

As the manifestation of anthropogenic climate change is said to increase the possibility of shifts inflows and variability underscores the need for better understanding of the drivers of Variability and rainfall–runoff interactions. It is most likely that events such as drought and floods are going to pose a great challenge in the socioeconomic sector. Although most studies have shown that the sub- Saharan Africa is generally linked with drought- related influences, based on anecdote there seems to be increased frequency and spatial extent of damaging floods in particular East Africa and Ethiopia.

An example is in the year 2006 and 2007 where Extreme floods led to substantial socioeconomic disturbances in Mozambique (2000; Christie and Hanlon 2001) and East Africa (1961, 1978, and 1997; Conway 2002) although smaller floods may be somewhat overlooked but they appear to be locally significant, for example the year 2006–07 experienced major floods of unexpected spatial extent and timing) in most parts of East Africa and its neighbourhood for example Somalia and Ethiopia, which is in consistence with projections in the Intergovernmental Panel on Climate Change's Fourth Assessment Report for increases in autumn and winter rainfall (Christensen *et al.* 2007).

The core driver of much of the so much observed differences in the flows of the river is rainfall, in particular at the larger levels of the rivers Hulme *et al.* (2001). Above average and sometimes-extreme rainfall in East Africa tends to be associated with periodic circulation dipole events in the Indian Ocean and complex interaction with the El Nino Southern Oscillation (ENSO), particularly during the short October–December rains (Saji *et al.*1999; Webster *et al*. 1999). In the view of (Ahern *et al*.,2005) the future climate change scenarios are likely to alter patterns of precipitation resulting to increased sea level rise and this is expected to lead to increased frequency and intensity of events such as floods and drought e.g.floods in many regions of the world.

ICPAC(2009) on the same noted that increased frequency of extreme weather events would have a potential impact almost in all economic and social sectors in East African Region possibly affecting agriculture health status of the people, and availability of necessities such as water, energy use, biodiversity and ecosystem services(including tourism).Floods have majorly been attributed to precipitation in terms of intensity, volume, timing, as well as the initial stages of rivers and the drainage basins but recently, human interference into flood plains and being unable to deal with the floods at the required time are said to escalate the level of destruction caused by floodings (Trenberth2008).Durojaye *et al*., (2012) identified three forms of flooding: coastal flooding, river flooding and urban flooding. River floods are the most common floods in Kenya they occur along floodplains or wash lands because of increased stream flow capacity leading to the bursting of the natural banks or artificial embankments (Smith and Ward, 1998). Major rivers in Kenya such as Nzoia, Nyando, Yala, Athi, Nairobi,Tana and Sondu experience seasonal river floods coming from the country's highlands that receive high amount of annual rainfall which ranges from 1600-2000mm(Otiende2009).In Kenya, floods are emanating as the common climatic disaster (GoK, 2007; ISDR) with the annual flooding in the low-lying regions of the country such as river valleys, swampy areas, lakeshores and the coastal strip of the five drainage basins.Otiende (2009)on flooding in the Lake Victoria basin observed that flooding tended to be geographically distributed in Kenya with the western, northern, eastern, central and South-eastern parts as the most vulnerable to seasonal floods in the wet seasons of (MAM) and (OND). The Lake Victoria Basin in western Kenya is the most flood-prone region in the country (GoK, 2007) since.

Western part of Kenya is featured with wet seasons throughout the year with no unique dry Season. The rainfall regime in Western Kenya is characterized by high rainfall occurring in the months of Mar- Sept, while a significantly lower rainfall tending to occur in Jan and Feb (SoK, 2003 in WRI *et al*., 2007). Compared to the rest of Kenya bimodal rainfall pattern, Western

Kenya experiences a third rainfall season during the cool and dry months of June-July-August (ICPAC, 2007), the mean annual rainfall in Western Kenya is above 1600 mm (WRI *et al*., 2007) During the wet period in Kenya, heavy downpours usually turns into high stream and river flows (runoffs) causing seasonal floods. In the work of (Osbahr *et al*., 2006) and WRI *et al*., 2007) it is observed that rainfall seasons can be very wet and erratic

Resulting in both large and small rivers flooding their banks with devastating effects as was the case in 1997/98 El Niño period. Odingo (1962) estimated the total flood damage to have been around five million pounds.Otiende (2009) noted that the frequency of flood losses in Kenya has been higher than that of drought losses. Mogaka *et al*., (2006) associated the 1997/98 El Niño flood with one of the largest flood losses in the country in 50 years and Karanja *et al.*, (2001) estimated the economic and financial losses to be in the range of US$800 million while the World Bank estimated the cost of the flood at Ksh 70billion (US$ 1 billion).Flooding in the lake Victoria basin mostly occur in the flood plains of rivers Nzoia,Yala,Nyando, Sondu-Miriu, Kuja (Kucha), AwachKibuon and AwachTende among others.Some of the most devastating floods in the Lake Victoria basin occurred in 1937,1947,1951, 1957-59, 1961-63 and recently in 1997-1998,2002-2003 and 2006 mainly due to exceptionally heavy and widespread rainfall.

In October-November of 1961 exceptional heavy countrywide rainfall began and this resulted in unusual severe floods in the Kano Plains,Yala Swamp and other low-lying regions of Lake Victoria and this was because of over bank flows of the six main rivers of the basin. The 1961exceptional heavy rainfall and associated flooding could have been due to the effects of El Nino during the months of Oct-Nov.The 2002 -2003 floods were associated with heavy and concentrated rainfall in the upper catchment of Nyando and Nzoia rivers. Contrary to the general view that flooding in the Lake Victoria basin is due to heavy rainfall, Khan *et al.*, (2011) observed that since the middle 1990s, the basin had been having high peak of discharges despite having relatively less amount annual rain even though there was a linear relationship between rainfall and run off for dry and wet. The meaning of this is to be found in the work of

(Opere 2014) and (WRMA (2013) where it has been observed that apart from the

marginal hydrological and climatic regime being a major factor to consider in the

flooding of major rivers in the lake Victoria basin, factors such as high levels of

sedimentation leads to reduction of reservoir storage, topography, land use practices, deforestation and other human related factors allow increased surface runoff and increased soil erosion leading to increased frequency of flooding. Even though other factors may aggravate flooding in a region, the role of climate especially rainfall cannot be underestimated (Otiende 2009 and Okello 2010).Shongwe *et al*., (2010) have predicted an increase in rainfall in the climate change and long term climate variability model scenarios for Kenya during the season of wetness and increase in flood risk but with mixed seasonal rainfall trends. ACCI (2010), however, on western Kenya climate scenario indicated that cyclic patterns between drought and flooding were becoming more frequent with changing magnitude, time distribution and severity of impacts.

The IPCC (2007) climate change scenarios for Kenya also predicted increased frequency of heavy precipitation events over many areas with more severe consequences including the floods. Generally flooding in the Lake Victoria basin has become a major concern to the country's socio-economic development due to the associated economic and financial loss and it is therefore useful to have some measure of rainfall and flooding trends in one of the river basins to have a better understanding of the potential impacts

1.2. Statement of the Problem

This study determined the trends of rainfall and its implications in flooding in the Sondu-Miriu sub-basin of Lake Victoria Basin of Kenya. An Analysis from General Circulation models (GCM's) indicated an upward trend in rainfall as a result of global warming over much ofUganda,Kenya,Rwanda Burundi and Southern Somali and this would be expected to lead to subsequent flooding in the regions mentioned above. The (IPCC 2007) report showed a warm climate coupled with increased climate Variability could be having significant impact on the frequency and magnitude of Climate related disasters like floods. floods in Kenya are emerging as one of the most prevalent climatic disasters with perennial floods in the low-lying regions but these regions are unevenly distributed in the drainage basins of country of Lake Victoria basin,Rift Valley basin, TanaRiver basin and EwasoNgiro river basin GoK(2007).

In Western Kenya the Lake Victoria Basin is the most flood prone region in the country with its climate of mostly rainfall throughout the year and no distinct dry season (GoK2007). The climate regime of rainfall throughout the year is characterized by relative high rainfall in the months of Mar- Sept and relatively low rains season in Jan and Feb and a third rainfall season in the cool and dry period of June-July (Survey of Kenya 2003).The torrential rainfall experienced during the wet months often translates into high stream river flows in permanent and intermittent streams and rivers in the Lake Victoria basin resulting to seasonal floods. Rainfall seasons in the Lake Victoria Basin can be extremely wet and erratic resulting to devastating floods and since there is a high possibility of rainfall increase in the great lakes regions (Khan *et al.*, 2010), it should be expected that when there is extreme rainfall events during the long-rain season there might be long-term impacts on flooding in the region. Flooding in the lake Victoria basin has been attributed to heavy rains upstream of rivers within the basin such as Nyando river, Nzoia river and Sondu-Miriu river which often burst their banks resulting in devastating effects on the physical landscape and socio-economic activities(KRCS 2012).

Flood occurrences in this region are said to be rising and this has posed a major concern to the socio-economic development of the country due to the substantial economic and financial losses that are required to respond to the frequency of the flood disasters. For example the perennial flooding experienced River Nyando catchment have put billions worth of livestock at risk in the lower eareas of Nyando, Miwani, and Nyakach division (Nyakundi *et al*., 2010). The low lying areas of the Nzoia River are exposed to flooding nearly every year, despite the construction of dykes. In the year 2003 nearly twenty five thousand of the fifty three thousands of Budalang's population were displaced by floods, some tenthousand people were accommodated in the D.O camp (Onywere *et al.*, 2007).

Apart from the periodic flooding of Nyando and Nzoia basin that have been widely researched on, Denga(1990) and Okinda *et al.,* (2011) reported increased incidences of floods in the Sondu-Miriu with varying characteristics resulting in

destructive abundance of water in the river and its tributaries causing havoc. WRMA (2012) and the KRCS (2013) associated the high rainfall in the upper Sondu catchment with flooding and associated impacts in the mid and lower parts of the basin. Most studies on flood problems in the Sondu-Miriu basin have not directly dealt with the rainfall characteristics and flooding in the sub-basin but have concentrated on the effects

of sedimentation on the basin, flood hazards, limnology of the river and fisheries. Despite the increasing reports on flooding and the enormous damages related to the event .This study therefore focused on the trends of rainfall within the Sondu-Miriu basin and frequency of floods in the recent past. The specific questions addressed were:

1.5. Justification of the Study

Although extensive studies have been done on flooding in Kenya and more especially in the western Kenya in the Lake Victoria basin most of these studies have concentrated on the impacts of flooding and the factors that aggravate flooding and in this context the anthropogenic activities. This might be because of the enormous socio-economic losses related to flooding and the risks involved. Otiende (2009) observed in his research on the impacts of climate change in the economy of Kenya that the prevailing level of floods is at 27% and that the total population affected by disasters flood related fatalities Includes a whole 60% of disaster victims, on the other hand (Karanja *et al*.,2001) estimated the financial and the economic losses due to the El Niño flood to be of millions of money .

These studies have also observed that the flood occurrences trends in western Kenya especially in the Lake Victoria basin just like in most areas of the world are said to be propagated by heavy rainfall interacting with the hilly slopes. Little attempts have been made to determine the specific characteristics of rainfall related
to flooding in the Lake Victoria region and more especially in the sub basin of Sondu- Miriu with the (UNEP 2007) Report showing that there is high possibility of increased rainfall in the great lakes regions and this could mean there will be increased rainfall events in the seasons of long-rains and this could have long-term implications for the consequences of floods. This may increase the need for many research to be carried on the current and emerging climate-related hazards to be
researched on to manage and to curb the negative impacts at the sub-sector level and then harmonize with other sectors. It is for this reason therefore

that this study tends to concentrate on climatic aspect of increased flooding in the Sondu-Miriu sub basin so that the findings may provide baseline data for the future monitoring of fluctuation in the flood occurrence and hence being able to predict flooding in the basin. The information can be used for flood forecasting, to establish appropriate relief services and the physical planning for the development in the lower Sondu-Miriu River for the Sondu people. This can be applied to the other rivers in the country. This study is also aimed at creating a better understanding of climate and climatic variability and especially rainfall and this can be used to monitor the effects on livelihood of people and economic productivity of the region.

The findings will also have a major contribution to the already existing literature about the sub basin which can prompt research on how other aspects of the climate and drainage characteristics can affect flooding in the sub basin. .

1.6 Operational Definitions

Climate change: Any systematic change in the long term statistics of climate parameters such as rainfall, temperature, pressure or wind sustained over several decades.

Climate variability: Short term disparities observed in the climate parameters for a short time-scale of months or a decade.

Extreme events: These are severe, rare and intense weather and climatic events that are determined by their spatial scale (e.g. thunderstorm, river flooding)

temporal scale (hours days, weeks) and complexity.

Flooding: It is a natural event or occurrence where a piece of land (or area) that is usually dry land, suddenly gets submerged under water.

Flood Frequency: it is the concept of the probable frequency of the occurrence of a given flood.

River Discharge: it is the measure volume of water that moves past a point in the river in a given amount of time usually expressed in cubic feet per second.

Rainfall Variability: short term rainfall inconsistencies observer in the rainfall for a short time scale of months.

Recurrence Interval (Return Period) the average number of years between floods of a certain size.

1.7. The Study Area

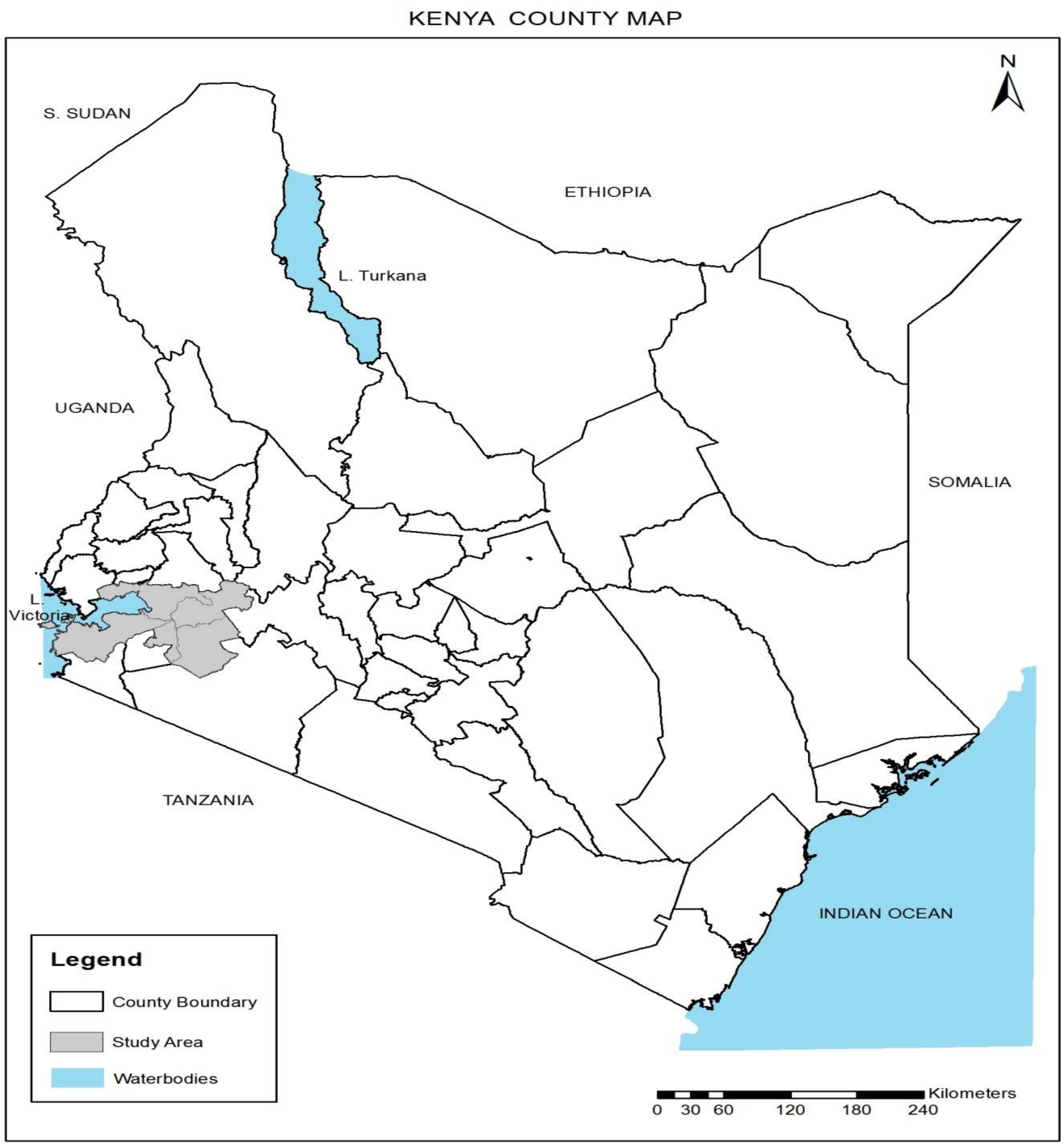
1.7.1 Location and Size

Sondu-MiriuRiver basin, code 1Jis located within latitudes 00˚23'S and 01˚10'S and longitudes 34˚46'E and 35˚45'E.The main water course in this basin is River Sondu which is fed by several tributaries, whose head waters originate from the South West Mau(SWM) forest block. The river crosses the basin in a general east-west direction as indicated in (Figure 1.1), and drains its waters into Lake Victoria at an annual rate of about 1.37 BCM/yr.(WRMA2009).The Sondu basin is located on the western part of Kenya, itlies within Lake Victoria South Catchment Area (LVSCA) which is located at the south-western part of Kenya and borders Lake Victoria North catchment Area (LVNCA) to the north, Rift Valley Catchment Area (RVCA) is to the eastern part, Tanzania is to the southern part , and to the western part is Lake Victoria. LVSCA covers an area of about 31000 km2 out of which about 4000 km2 is under Lake Victoria water (WRMA, 2009).

The river is found in three administrative counties, which are Kericho, Kisumu, and Bomet, Therefore there is need for more concerted effort to the use of this River. The basin is also bordered by GuchaMigori to the south east, Awachkibuon to the west and south west and kuja to south and south east. The basin covers an area of about 3500km2 and it has a total length of about 173 km2 (WRMA, 2009).The origin of the river is at Mau forest complex which is known to be a broad water tower in Kenya in which various rivers which drain into lakes Natron, Nakuru and Bogoria originate.

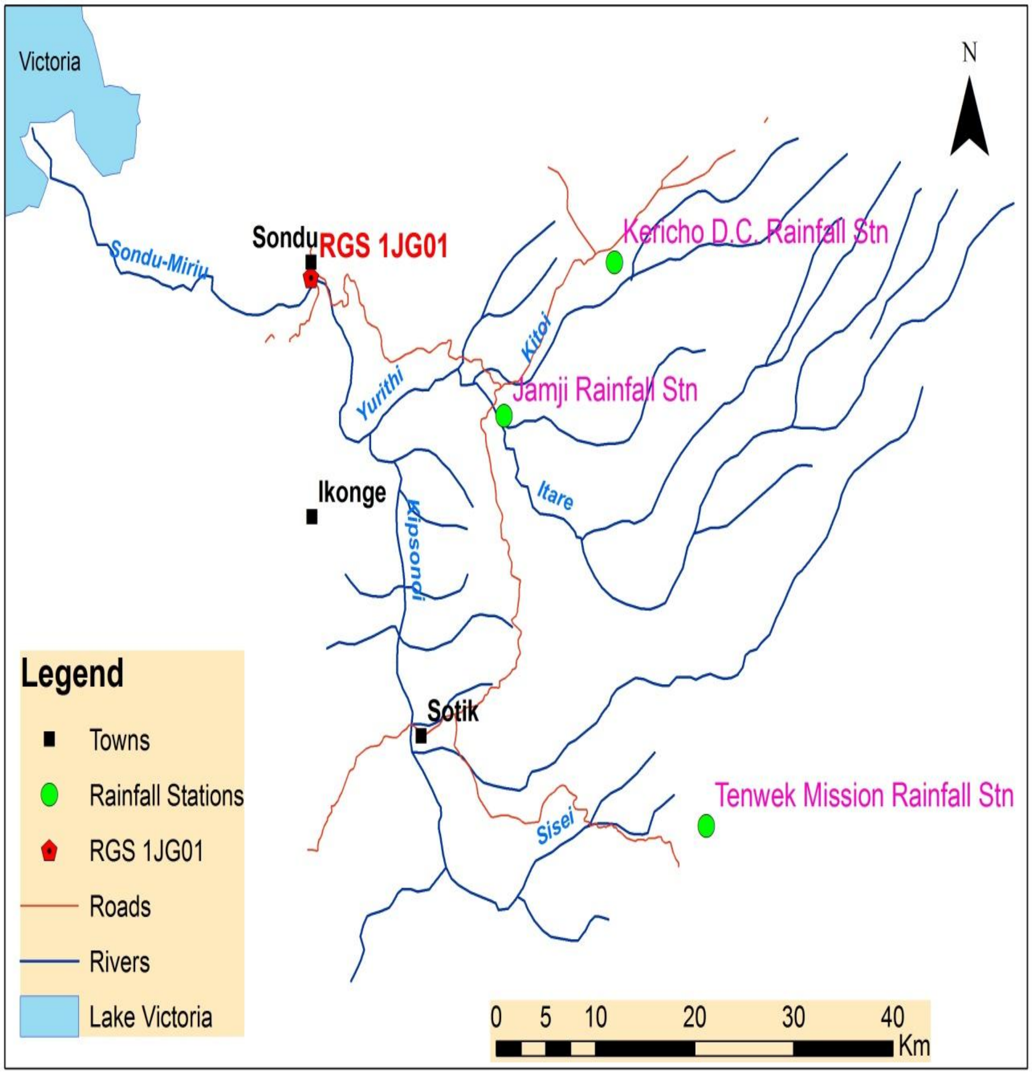
The curving out of the forest and the land subsequently being converted to the use for agriculture however has led to reduction of its vegetation cover and this has been said to be one of the causes of increased flooding in the lower Sondu-Miriu basin.

Figure 1.1: Kenya County Map



Source: Kenya Survey 2014

Figure 1.2: River Sondu and its Tributaries



Source: Modified Topographical Map 2014

1.7.2 The Physiography of Sondu-Miriu Basin

The four primary basin characteristics that govern water yields into the river network (Arnold *etal*., 1998) include those that affect runoff response time (topography and size), those that affect subsurface base flow (geology and soils), those that affect hydrologic abstraction and runoff volumes (land use/land cover), and those that affect the amount of rain water arriving in the basin (climate) and this is what the study is based on. These characteristics affect different aspects of stream flow hydrograph and therefore deserve to be mentioned briefly.

1.7.3 Topography

Topography and size of the basin influences how much and how quickly rain water

reaches the river network. Topographic characteristics that affect runoff response time include watershed shape, drainage pattern, watershed slope and the stream channel slope. Which this study didn't look at in details. Steep-sloped basins are often associated with quick response to rainfall events in terms of flashy runoff unlike the case in the relatively flat basins. The landform of the Sondu watershed consists of low plains near the lakeshore and rises eastwards to volcanic plateaus with dissected margins in the middle parts and rugged terrain with deep gorges and V-shaped valleys in the upper eastern parts of the catchment (JICA, 1987).

These landforms comprise the Kano plains on the western side and the Londiani

Mountains on the eastern side which form the lower and the upper Sondu catchment areas respectively. Land elevation in the basin varies from about 1134 m above sea level at the lakeshore to about 2900 m above sea level at the summit of Londian Mountains,facilitates fast movement of waters from the upper streams, and the basin generally slopes from east towards west with relatively flat areas towards Lake Victoria. The relatively flat terrain facilitates easy spreading of flood water hence inundating the low-lying areas.

1.7.4. Geology and Soils

The three main geological units include: The volcanic rocks, The Bukoban system and theAlluvium characterize the Geology of the catchment. The Bukoban system is approximated to be 670 million years old and this is further divided into andesite, rhyolites, and basalts. The Volcanic rocks are further divided into Phenolites, trachites and tuffs which weather into deep.Stone free soils and uniform in physical structure up to a depth of about 6 m (Edwards and Blackie, 1979).These are believed to have been formed in the middle Miocene age.

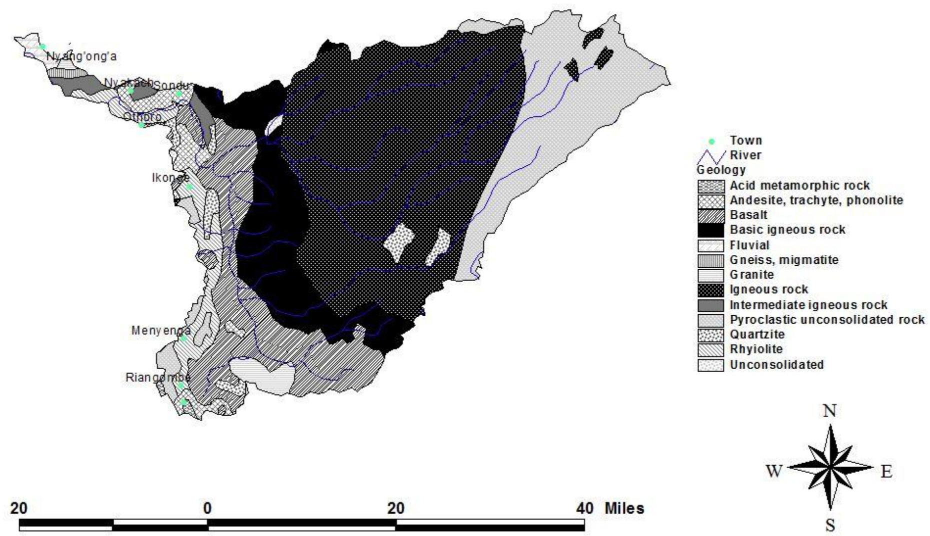
The widespread occurrence of tuffs indicates that lava ash showers were the Characteristics of the eruptions.

The soil typology follows closely the underlying geology. The soils that are appearing in the Volcanic foot ridges in the upper catchment as well as in the upper middle level include HumicNitosols; which are well drained, extremely deep, dark reddish brown, friable Clay with acid top soil on the interfluves, MollicAndosols developed on recent volcanic ashes and pyroclastic rocks. The plateau areas are characterized by quartzite and humicferrasols. The well drained characteristics of the soils in the upper catchment area make them more susceptible to erosion, which together with changes in land use tend to lead to serious catchment degradations whose impacts result in reduced stream flow volumes during dry seasons and siltation during the rainy season. The high levels of the soil fertility have attracted settlements, farming and other land use activities such as industrial development in the area, therefore, there is need to research on the extent to

which these changes would have an effect on the lower catchment where floods are
experienced (Nyangaga, 2008; Edwards and Blackie, 1979)

On the lower level uplands rankers with lithosols and rock outcrops occur and these are excessively drained, their features include shallow, dark brown, very friable, rocky, sandy loam to clay loam with acid humic topsoil. The middle and the lower part of the river are characterized byAcrisols and Regosols. There are some other types of soil located in the catchment but smaller proportions for example Andosols, Cambisols, Greyzems, Lithosols, Phaeozems, Planosols, Rankers, Vertisols, and Xerosols with Vertisols and Planosol said to be deep and poorly drained and to be of sandy clay to clay texture. The clay soil has a low capacity of infiltration and this has facilitated the rapid generation of surface runoff leading to floods.

Figure 1.3: Geology and Soils of Sondu Catchment



1.7.5 Climate and Drainage

The climate of Sondu basin, just like that of the rest of the eastern side of Lake Victoria basin is largely influenced by the north-south movement of the Inter Tropical Convergence Zone (ITCZ) modified by the local orography and the proximity of Lake Victoria, Atlantic and Indian oceans. The ITCZ is a zone characterised by low and medium level convergence and it is marked by a line of thunderstorms and showers in most areas and marks the boundary between the two interhemispheric monsoon wind systems over the region. This is the main synoptic scale system that affects the intensity, distribution and migration of seasonal rainfall over the Eastern Africa region (Omeny*etal.*, 2008).

The Sondu-Miriu River catchment can be divided into three major Climatic regions: humid, sub humid and semi humid considering its Temperature and rainfall characteristics. The rainfall is in two main seasons with the mean annual rainfall of approximately 1,000mm although studies have shown that a third season is always experienced in June, July, August(JJA). The long rainy season is between April, May June, the period experiences very high peaks as compared to the other season. The short rains fall around October, November and December.This seasonality however is much clearer in the lower region compared to the highland regions. The Highland region receives a total amount of annual rainfall of approximately 1,835 mm annually since it is in the Mau catchment and these leads to a high river discharge from the upstream which has to be accommodated with the narrow channel down the stream where flooding occurs and the total amount of annual rainfall decreases to about 1,500mm towards the lowlands.

The temperatures range from about 16˚C in the upper parts (Timbilil) in July to about 24˚C in the lower parts (Kisumu) in March. The warmest temperatures in the area are observed in March while the coolest are observed in July. The average temperature over the catchment area is at least 18˚C in all the months and hence the area is warm throughout the year. The seasonal difference in average temperature over the area is small (2.2˚C) while the difference between day time and night time temperatures is large(12.4˚C) hence the area can be described as being in a tropical type of climate zone (Ahrens2009).

The main water course in this basin is River Sondu which is fed by several tributaries, whose head waters originate from the South West Mau (SWM) forest block these tributaries contribute a lot to the amount of waters that flows downstream. The main tributaries are the Yurith River which drains parts of Kericho,Bomet,and parts of Kisii, Kipsonoi river which drains parts of Nyamira and Homabay county at Ikonge where they form theSondu river downstream from the confluence covering a total length of about

173 km. River Sondu flows through narrow hilly gorges by passing the Nyakach then meanders into the Odino falls with a steep drop at Fotobiro hills before entering the flood plains of Nyakwere and eventually drains into the Winam Gulf of Lake Victoria at Osodo Bay approximately 22 km south east of Kisumu with the elevation ranging 2,750 meters at the source to 1,145 at the mouth. The river crosses the basin in a general east-west direction and drains its waters into Lake Victoria at an annual rate of about 1.37 BCM/yr. (WRMA, 2009)

1.7.6 Vegetation

The land cover influences the hydrologic abstractions and runoff volumes through canopy interception, evaporation and evapotranspiration dynamicsThe upper zone of the river has an altitude that ranges from 1686 to 2003m above the sea-level and it experiences a humid climatic conditions. It is mostly covered by forests and woodland while the remaining part is under tea both plantations and small-holder farms. vegetation cover is important since it plays a major role in the hydrological cycle which eventually leads to rainfall formation, it is also essential as it retards the flow of surface runoff thus encouraging more water to infiltrate into the soil and replenishes soil moisture in contrast large scale deforestation and poor cultivation practices may result to increased flood peaks as indicated in some studies in the Sondu-Miriu basin.

The middle zone falls within an altitude range of 1496 to 1630m above the sea level and experiences sub humid climatic conditions, the zone is mostly hilly and is covered by herbaceous vegetation however most of the natural vegetation has been replaced by exotic trees species mainly eucalyptus inter planted with crops. Cultivation on steep slopes without applying soil conservation measures promotes soil erosion which leads to sedimentation within the river channel and rapid generation of surface runoff which may lead to flooding in the low lying areas of the river.

The lower zone whose altitude ranges from 1137 to 1394 m above the sea level falls within the semi humid climatic regime it is generally semi-arid with bare soils covered by sparsely distributed shrubs dominated by acacias. The reduced vegetation in this zone poses a great risk to flood hazard in this region, the zone is also settled by people practicing subsistence agriculture of both crop and livestock.

1.7.7.Population Density

Based on the 2009 Census published in 2010, LVSCA has a population of about 7.37 million (19.1%of the country's total population) with a population density of over 2273 persons per km^2 country as a result of the high population density, pressure on high potential agricultural land has increased leading to the encroachment of water catchment areas; mainly the Mau forest complex and South West Mau (SWM) forest reserve in particular. This has resulted in the degradation of the catchment's main water tower (Kinyajui, 2011; WRMA, 2009; Edwards and Blackie, 1979). The LVSCA has undergone drastic changes as a result of anthropogenic activities in the last fifty years.

Analysis of 50-year daily discharge data for the rivers in the LVSCA showed significant variations in high and low flows during wet and dry seasons respectively. The flash flood incidents have continued to increase during wet seasons and base flows have continued to decrease during dry seasons (WRMA 2009). This has been attributed to catchment degradation, mainly the Mau forest complex, which has resulted in an increase in runoff coefficient as a result of decreased infiltration capacity

1.7.8. Land use

The dominant land use activities in the Sondu-Miriu Basin include crop and dairy farming. Large areas of the basin have been deforested over time mainly for purposes of agricultural activities. The local economy is mainly subsistence farming, small and large scale tea plantations and other annual crops that are almost entirely rain fed. Other economic activities in the area include dairy farming, sheep rearing, fishing and industrial activities such as agro-based industries (Nyangaga2008), The river also provides hydroelectric power, support irrigation livestock and domestic purposes, because of the combined effects of these human activities and the increase in their scale and intensity over the years they impose multiple threats to the river channel and the general ecology of the river. These land use activities have significant impacts on the hydrological regime of the catchment area as they lead to the destruction of the natural vegetation cover resulting into faster overland flow, less infiltration, more erosion, less ground water recharge and thus the frequent flood events during wet seasons and to reduced discharge during dry seasons.

CHAPTER TWO

2.0.LITERATURE REVIEW

2.1.Introduction

This literature review is for the purpose of having a better understanding of the subject of rainfall and flooding in river basins and also to avoid unnecessary and unintentional duplication. Equally important in this review is the need to have a proper grasp of the strategies, procedures and measurements in studying rainfall and floods in the river basins.

The literature review is organized topically starting with the general literature on rainfall and floods to specific studies (empirical studies) of rainfall and floods in the river basin. The specific topics covered in the review include: climate variability and flooding, analysis of rainfall patterns and flooding in Kenya and the impacts of flooding in Kenya.

2.2. Climate Variability and Extreme events

Berger (1980) defined Climate variability as the year to year anomalies which are commonly occurring in climatic parameters including solar radiation, temperature, rainfall and evapotranspiration. The (IPCC 2007) however defined climate variability as the variations in the mean state and other statistics of extreme climate on all temporal and spatial scales beyond that of individual weather events. Since rainfall is identified as one of the climate parameters that have the highest degree of variability in both space and time (Conway 2002) and the extreme of it would lead to events such as floods and droughts, this study therefore adopted the IPCC (2007) definition which seemed more relevant to the study. Most studies have linked climate variability with the occurrence of extreme climatic events such as droughts and flooding, (Fowler and Kilsby2003) noted in their work that Future projections from climate models and recent observations show a worldwide increase in both the frequency and intensity of heavy rainfall, coinciding with widespread flooding and landslides in Europe. In their work it was estimated, using regional frequency analysis, that the magnitude of extreme rainfall has increased two-fold over parts of the UK since the 1960s, intensities previously experienced on average every 25 years now occur at 6 year intervals; a consequence of both increased event frequency and changes in seasonality. This study has also focussed on the changing trends of rainfall and how is it related to the increased flooding in the region.

These climatic changes may be explained by persistent atmospheric circulation anomalies and have huge economic and social implications in terms of increased flooding.Dyson (2001) estimated the flood damages to be in the billions of U.S dollars annually with thousands of lives and properties being lost whenever these extreme hydrological events are experienced. The analysis done by (Pielke 2000) on precipitation and damaging floods in the US showed a stronger relationship between precipitation measures and damaging floods and that different measures of precipitation were most closely related to damage in different regions, this study further suggested that climate plays an important, but by no means determining role in the growth in damaging floods in the United States in recent decades.This observation calls for further investigation on the significance of rainfall intensity, duration, and how this would contribute to the general damage. The methods of analysis used was adopted to relate the rainfall trends and flooding in this study as this knowledge would be important for policy makers for pre-floods response.

The (IPCC 2007) report noted that heavy precipitation events over many areas have become more frequent and this has resulted to more severe consequence which has been manifested in decreased crop yields, increased pest outbreaks, rampant soil erosion and water logging. The report further observed that the poor countries in the developing world will be more at risk, with Sub-Sahara Africa (SSA) already experiencing changes in seasonal patterns and timing, and in particular the distribution and intensity of rainfall (CARE, 2012). In the view of its findings climate variability will lead to increased droughts and more uncertainties in rainfall, although the report was not clear on how the seasonality of rainfall might impact on the extreme events that are likely to be experienced in the region.Hulme *et al*., (2001); IPCC, (2007) observed that East Africa is not exempted from many of the impacts of climate change which is said to materialize through changes in extreme events such as droughts, floods, and storms which in the past have resulted in severe human suffering, and hamper economic development and poverty reduction.

This idea of changes in the extreme events within East African region especially flooding was confirmed in the results of the time series analysis of average rainfall over the Rift Valley and its vicinity by (Shongwe *et al*., 2010) which showed that much of this area has experienced a slight wetting trend over the 20th century, the results further indicated that there are high prospects of rainfall increase in the Great Lakes region and that it is the rainfall intensity in a given season that is likely to increase with little evidence of a notable change in the duration of the rainy season. This study wanted to found out how the wetting trends have also impacted on the rainfall trends in the Sondu-Miriu Basin which is one of the basins in the Great lakes region. The tendency of the models to underestimate the total precipitation during the long-rains season however limits the confidence on predictions in a future climate. The indications of an increase in extreme rainfall events during the long-rains season could have long-term implications for flood impacts although some small-scale in homogeneities in rainfall caused by local features do exist (such as mountains and lake-land contrasts) and short-term fluctuations did not hide this trend.

ICPAC (2009) on the other hand showed some mounting evidence that future climate change may lead to a change in the frequency or severity of such extreme weather events, potentially worsening these impacts as earlier noted in the work of(Fowler and Kilsby 2003) the report further explained that future climate change will lead to increases in average mean temperature and sea level rise, and changes in annual and seasonal rainfall, these changes will have potentially important effects across all economic and social sectors in the region. Any resulting impacts are therefore likely to have a strong distributional pattern and amplify inequities in health status and access to resources, as vulnerability is exacerbated by existing developmental challenges, and because many groups (e.g. rural livelihoods) will have low adaptive capacity as it has been noted in the study.

According to (Boko *et al.,* Climate Change 2007)Kenya's climate is also expected to warm across all seasons during this century under a medium emission scenario, the annual mean surface air temperatures are expected to increase between 3°C and 4°C by 2099, which means it will rise at a rate of 1.5 times that of the global average, this is expected to lead to overall increase in annual rainfall to a certain percentage over the same period especially during the long rains as noted by (Situma *et al*., 2010) although this change will not be experienced uniformly across the region throughout the year (Okello *et al*.,2010). Situma *et al*., (2010) further noted that the increased variability of rainfall and warmer temperatures are likely to increase the intensity and frequency of extreme weather events in the region and this would mean that many areas in East Africa will be faced with an increased risk of longer dry spells and heavier storms. The (IPCC 2007) argued that these regional trends are largely reflected in the climate projections for Kenya and that the mean annual temperatures in the country are expected to increase by 1-2.8°C by the 2060s, and 1.3-4.5°C by the 2090s which will be accompanied by an increase in mean annual rainfall by up to 48 per cent, with the increase in the total rainfall greatest from October to December while the proportional change will be largest in January and February (Shongwe *et al.,*2010).

The (IPCC 2007) further noted that the regional variation within Kenya will mean that rainfall increases are expected to be concentrated from the Lake Victoria region to the central highlands east of the Rift Valley where most of the rivers within the Lake Victoria region originate. For the purpose of this study, it is important therefore to note that the regions of Lake Victoria are expected to see an overall increase in precipitation due to climate change and this would further lead to increased flooding within the Lake Victoria basin and the subsequent sub basin within the region although the work of (Situma *et al.,*2010)have noted that an increase in the total quantity of rainfall does not always capture the impact of rainfall variability (including when, where and how much of the rain falls each time), which has serious implications for the capacity of the population to adapt.

From the literature above it is very clear that most studies attribute frequent flooding to increased rainfall. Trenberth (2008) from his findings does not refute this fact but also argues that flooding can also be aggravated by factors that are not directly related to climate such as rainfall but also to situations such as change in land use, encroachment of catchment areas, and sedimentation of river channels. Brown *et al*., (2000) supported Trenberth findings although they said that such factors have a minor effect on flood frequency. Climate variability has become of increasing concern to decision makers in addition a number of scientists have predicted that one of the consequences of anthropogenic emissions of greenhouse gases to the atmosphere will be an enhanced hydrologic cycle. In the words of the Intergovernmental Panel on Climate Change (IPCC):there was now mounting evidence to suggest that warmer climate will be one in which the hydrological cycle will in general be more intense, leading to more heavy rain events and the subsequent flooding.(IPCC 1996a, p. 335).

2.3.Analysis of Rainfall Trends and Flooding

The work of Uduak (2012) noted that Rainfall trend is among the important characteristics of rainfall that varies both in time and space. The large inter-annual variability of rainfall may often results in climate hazards, especially floods and severe droughts with their devastating effects on food production and associated calamities and sufferings(Hulme *et al*., 1998).The changing precipitation pattern associated with global warming have showed a strong indication that rainfall changes are already taking place on both the global (Bradley *etal*.,1987; 1989; Hulme *et al*.,1998) and regional scales (Maheras, 1988; Yu and Neil, 1993; Rodrı´guez-Puebla *et al.*, 1998) and its impact on surface water resources, is an important climatic problem facing society today. The implications of these changes are particularly significant for areas already under stress, such as regions that suffer a water shortage through a combination of a dry climate (or a highly seasonal rainfall regime) and excessive demand.

The rainfall variability in Africa has been studied by numerous authors since the beginning of the recent drought period in the 1970s. Although many studies have been focused on the Sahelian areas (Lamb & Peppier, 1992; Hulme, 1992). Other studies also compared Sahelian rainfall with rainfall over West and Central African regions (Thompson *et al*., 1984; Buishand1985). Mahe *et al.,*2001 analysed the standardized regional mean annual rainfall series for a period of 38 years and their results confirmed the difference of mean annual rainfall between west and central Africa these results were consistent with results of (Moron 1994), (Nicholson & Kim 1997) for the same regions. They concluded that the long-term trend of rainfall series of West and Central African showed major climatic discontinuity, therefore it is important to assess the changes that may be occurring on a spatial and on a temporal basis because a complete description of Intraregional rainfall variability and changes is of great interest, especially in areas with strongly contrasting rainfall regimes and with associated environmental problems (Bigg 1991).

In East Africa large water bodies and varied topography give rise to a range of climatic conditions, from a humid tropical climate along the coastal areas to arid low-lying inland elevated plateau regions across Ethiopia, Kenya, Somalia and Tanzania. The presence of the Indian Ocean to the east, and Lake Victoria and Lake Tanganyika, as well as high mountains such as Kilimanjaro and Kenya induce localized climatic patterns in this region (KNMI 2006). ICPAC (2007)stated that the annual cycle of East African rainfall is bimodal, with wet seasons from March to May and October to December, the long Rains (March to May) contribute more than 70% to the annual rainfall and the Short Rains less than 20% . WWF (2006) in their analysis found out that Much of theinterannual variability comes from short rains with a (coefficient of variability = 74% compared with 35% for the long rains).Results from recent work from stations in Kenya and Tanzania, indicate that since 1905, and even recently, the trend of daily maximum temperature is not significantly different from zero. The daily minimum temperature   results however suggest an accelerating temperature rise (Christy *et al*., 2009) with day and night temperatures in the northern part of East Africa generally indicating night time warming and daytime cooling in recent years.

The trend patterns however, are said to be reversed at coastal and lake areas with large geographical and temporal variations being observed. Schreck and Semazzi (2004) related the temperature variability patterns with the recurrence of extreme values where they noted that the recurrence significantly correlated with the patterns of convective activities, especially El Niño-Southern Oscillation (ENSO), cloudiness, and above/below normal rainfall. This might explain (Webster *et al*., 1999, Hastenrath *et al*., 2007) findings which indicated that East Africa has suffered both excessive and deficient rainfall in the recent times; in particular, the frequency of anomalously strong rainfall is being related now to the increased flooding.

Shongwe *et al* (2009) in their analysis of data from the International Disaster Database (EM-DAT) indicated that there has been an increase in the number of reported hydro meteorological disasters in the region, from an average of less than 3 events per year in the 1980s to over 7 events per year in the 1990s and 10 events per year from 2000 to 2006, with a particular increase in floods. The report further indicated that the period between 2000-2006 disasters affected almost two million people per year. This phenomenon raises the need for more studies on the rainfall variability and its impact on the environment that is why the study sought out to study how the rainfall trends impacts on flooding in the Sondu-Miriu basin.

Kenya like the rest of East Africa experiences a bimodal seasonal pattern as it lies astride the equator, the long rains are generally from March to May as theITCZ moves northwards, and the short rains are typically from October to December as the ITCZ retreats southwards (Van desteeg *et al*., 2010).According to (Osbahr and Viner 2006)Kenya experiences a significant inter-annual and spatial variation in the strength and timing of these rains, the two related the spatial variability to topography where they explained that the highest elevation regions receive up to 2300 mm per year whilst the low plateau receives only 320 mm.This might explain the fact that most waters from the upper stream of major rivers within Lake Victoria basin which originates from major highlands in Kenya are responsible for the flooding in the low-lying areas of these sub-basin although most studies have showed that there are other factors that may aggravate the situation such as encroachment of the catchment areas, sedimentation which results from erosion and deforestations. The peaks reached during the rainy season was an important characteristic to consider in the study as it was used to determine the periods of maximum stream flow and how this related to the frequent flooding in the region.

The UNDP's climate change country profile shows that Kenya's mean annual temperature has increased by 1°C since 1960. This increase has been noted to be higher from March to May, and has resulted to an increase in the number of hot days and hot nights. Although the report has not shown any statistical significant trend for the annual precipitation in the country but an increase in the proportion of rainfall amounts which fall during heavy rainfall events has been noted.ICPAC (2007) however noted that the increase in the total quantity of rainfall does not always capture the impact of rainfall variability (including when, where and how much of the rain falls each time), which has serious implications for the capacity of the population to adapt.WRI *et al*.,(2007)indicated that variability of rainfall is expected to increase and warmer temperatures are likely to increase the intensity and frequency of extreme weather events in the region, meaning that many areas in East Africa will be faced with an increased risk of longer dry spells and heavier storms.

ICPAC (2009) also linked the intensification of heavy rainfall especially during the wet seasons with an associated flood risk, although they evaluated that the seasonal rainfall trends are mixed with some locations indicating increasing trends while others showing no significant change. The study found out that the annual rainfall totals show either neutral or slightly decreasing trends due to a general decline in the main long rains(MAM) seasons with long rains in March – May (MAM).The (NCCRS 2010) confirmed the statement by indicating that rainfalls have become irregular and unpredictable, and when it rains, downpour is more intense. The rains have showed increased variability year to year, and during the year. There is also a general decline of rainfall in the main rainfall season of March-May (the “Long Rains”), there is a general positive trend (more rains) during September to February. This suggests that the “Short Rains” (October-December) season is extending into what is normally hot and dry period of January and February measured by the volume of rainfalls in a 24 hour period, more intense rainfalls occur, and more frequently, over the coastal strip and the northern parts of the country during September – February rains this would mean frequent occurrence of severe floods in those areas with no significant trends in the 24-hour rainfall amounts being observed in other areas of the country(Situma *et al*.,2010).

The report by the Kenya weather and climate however contradicted these findings indicating that prolonged rainfall isn’t that uncommon, the typical pattern is for rain to fall as a torrential downpour, lasting perhaps half an hour to an hour, with the sun then coming out and drying the wet ground in minutes. The report also affirms that the theory of Kenya’s climate is one thing: predicting the actual weather for specific dates is increasingly difficult as climate change impacts more and more, bringing floods and droughts, unseasonably cool and unseasonably hot weather. These impacts can be more than inconvenient: the (ACCI 2014) also added that these incidences of climate change and variability present a number of socioeconomic and environmental challenges and opportunities for Kenya. Some of the challenges include intensified natural resource degradation, increased flooding, storms, excessive and erratic rainfall, droughts, invasive weeds, pest-and-disease epidemics, infrastructure damage, and increased risk of resource use conflicts, reduced agricultural production and increased food insecurity. While vulnerability to these impacts is differentiated and context-specific, it has the potential to result in significant economic costs that can derail attainment of development goals.

A study undertaken by researchers from Kenya Meteorological Department (KMD) and International Centre for Research in Agro Forestry (ICRAF 2009) to assess climate variability and change in the Lake Victoria Basin pilot area of HomaBay and Busia, counties in western Kenya, showed general declining trends in both annual and seasonal rainfall in the two counties but the change was not statistically significant, although the temperature change was significant. The Mean annual rainfall in the study region ranged from 1000 to 2000 mm in the baseline scenario, with the lowest rainfall amounts falling along the lake shore and highest in the highlands, however projections generally showed rainfall patterns similar to the baseline for all future scenarios with only slight decreases, but with possibilities of a marked increase in rainfall, reaching more than 2500 mm in the highlands. With the increase in rainfall in the highland the possibility of floods increasing may be evident in the sub basins within the Lake Victoria region since studies have showed that it is the waters from the upper stream of the rivers that causes the flooding in the low-lying areas of the catchments. This poses a great challenge to the settlements within such regions with substantial gains for October through April. Therefore it is important to understand to what extent the gains and losses will have in the rainfall variability and on the extreme events such as flooding within the rivers in the larger basin which the study did not look at.

2.4. Impacts of Flooding in Kenya

With two-thirds of Africa having semi-arid to arid climates, extreme climatic events, notably droughts and unusually heavy rainfall that cause floods are common phenomena. Droughts occur when there is deficiency in precipitation over extended periods of time causing human suffering to about 60% of the world's population (ICPAC 2009) On the other hand, floods occur when total precipitation exceeds evapotranspiration, surface run off and infiltration of water into the ground creating water surplus inundating the earth's surface. Unlike droughts which have slow onset and may persists for long, floods are short lived but more disastrous. Between 1947 and 1980 floods ranked third in severity after tropical cyclone and earthquakes leading to loss of lives (Houghton, 1977). Unfortunately, flood hazards have been increasing in magnitude with number of people affected increasing much more rapidly than those suffering from droughts worldwide Drought Management Centre (DMC), 2004).

Increase in magnitude and frequency of the floods have been observed in Poland, Japan, Germany and Kenya (Pinter, 2010). There have been remarkable floods in the last half of the twentieth century (Ngaira, 1999). The period between 1980 and 1985 experienced more than 160 major floods in Asia causing damage estimated at US$ 2 billion (Houghton, 1997). In South America, North America, south Asia and Africa floods and mudslides make regular news. In North America, for example, floods and mudslides are the leading cause of deaths from natural disasters. The number of deaths associated with floods increased from 5.2 million per year in 1960s to 15.4 million per year in 1970s in South America. In India, the number of lives lost was fourteen times greater in 1980s compared to 1950s (Clerke, 1991; Cohen and Miller, 2001). In economic terms, floods are the most expensive natural disaster. In Australia, for example, directs costs associated with floods averaged at US $370 million per year between 1967 and 2005.

The impacts of floods in Africa however is extensive (USAID 2003) causing both loss of human life and destruction of property. Serious damage to road infrastructure, breakouts of waterborne diseases and food shortage follow in the affected areas. For instance towards the end of 1961 an extreme rainfall event occurred that extended over much of East Africa stretching across the Indian Ocean to India. This event caused widespread flooding, rapid and prolonged increases in the levels of many lakes in East Africa and significant economic disruption (Odingo, 1962; Mörth, 1967). During the last few months of 1997, in a similar fashion to 1961, heavy rainfall caused flooding across East Africa (FAO/GIEW, 1998; Birkett *et al.*,1999).Extensive flooding occurred in the region leading to loss of homes and lives, damage to crops, and emergency, food had to be flown in to marooned villages. Odingo (1962) estimated the total flood damage costs at the time for Kenya to have been around five million pounds.

However Otiende 2009 noted that the flood losses in Kenya have been .Increasing tremendously as compared to drought losses. The 1997/98 El Niño flood was associated with one of the largest flood losses in the country in 50 years (Mogaka, *et al*; 2006). The economic and financial losses associated with the El Niño flood is in the range of up to US$800 million (Karanja *et al*., 2001). The World Bank estimated the cost of the flood at Ksh 70 billion equivalent to US$ 1 billion. In the health sector alone There was an overstretch of health resources as a result of over 3 million families suffering from poor health after the 1997/98 El Niño floods in Kenya. Bovine disease was responsible for an 80% reduction of livestock in northern Kenya according to a WHO report on the health impacts of the El Niño flood of1997/98.

During the flood of 2003, the ASAL district of Garissa incurred flood losses of over Ksh.500 million following a flash flood according to the Arid Lands Resource Management Project (ALRMP). A report by the Met office 2011 showed that During the 'short rains' season (October to December) of 2006, a long-lasting drought in the Greater Horn of Africa ended with heavy rainfall and reports of the worst flooding in 50 years. Some areas received more than six times their average monthly rainfall. Flood waters from the Tana River in Kenya inundated a large region of eastern Kenya. Damage was made worse by the preceding drought which had left soil parched and unable to absorb the rain water. Approximately 60,000 people were forced from their homes and diseases such as cholera, measles and malaria spread in the resulting cramped living conditions and lack of water and sanitation. The floods also destroyed large areas of crops and damaged farmland, provoking fears of renewed food insecurity in the months that followed. Aid and health workers had problems reaching areas as the rains had destroyed several bridges and damaged roads. People in cut-off communities were increasingly vulnerable, and food prices for basic commodities shot up, in some cases by over 200%.

Floods in Kenya also result in the destruction of water and sanitation infrastructure. This had negative impacts on public health as a result of coming into contact with contaminated water that increases the prevalence of water-related diseases such as malaria, cholera, diarrhea and typhoid. The 2006 floods were associated with one of the highest human deaths from malaria and rift valley fever epidemic. The Perkerra River changed its course, depriving the Perkerra Irrigation Scheme of water for some years (Mogaka *et al*; 2006) Floods in Kenya also results in the inundation of productive agricultural land leading to destruction of crops. This has an impact on agricultural productivity leading to food security in the areas directly affected and those that produce food consumed in other parts of the country. Floodwaters may also destroy harvested food that has been stored production once every three years. The Kano Plains was almost fully inundated and agricultural crops were completely destroyed during the El Niño Floods in 1997/98. It is estimated that 200 acres of crops along the banks of Tana River in the Coastal province were destroyed during the floods (Osbahr and Viner, 2006). About 1,200 hectares of bananas, tomatoes, and vegetables were reportedly washed away in Garissa district. In Tana River district, 100% of bananas, mangoes, rice, maize and pulses were destroyed (Gadain *et al;* 2006). The destruction of crops resulted in drastic increase in commodity prices as the food shortage had a major effect on the health of children under five years old. This was evident by the prevalence of delayed malnutrition disorders such as kwashiorkor and marasmus. Tana River, Garissa and Lamu districts recorded cases of marasmus that soared for several months after the flood (Mogaka *et al*; 2006).

In addition to physical impacts on build environment, floods have a negative impact on the natural environment as well. The El Niño floods resulted to land degradation and increased soil erosion with consequent silting of hydropower dams. A weir on Kipchoria River the tributary of the Nyando was washed away and a water supply dam in Kericho district was silted up (Otiende 2009). The Ecological damage has negative impacts on the tourism industry in Kenya. Coral reefs, a major attraction of tourists in the coastal town of Mombasa were damaged from sediment deposits, and coral production was inhibited by lack of light. More than 50 percent of the coral reefs in Malindi were killed as a result of the 1997/98 El Niño floods. There was also a significant reduction in light penetration around the discharge points of the rivers, and the waters became atrophied and deoxygenated.

In the recent flooding a report by the Kenya Red cross 2012 indicated that Kenya is experiencing a complex situation, where parts of the country, mainly in Nyanza, Rift Valley, Coast provinces and the Nairobi Metropolitan area have experienced flooding, following heavy rains that began mid-April 2012 and the rains are still pounding in most of these places. Preliminary assessment reports by KRCS teams indicate that at least 16,119 households (HH) and some 96,714 people have been displaced majority being in Nyanza and the Rift Valley.

The total number of those affected is estimated at 280,670 (conservative). At least 66 people have lost their lives to reasons directly attributable to floods (drowning and road traffic accidents relating to vehicles being washed away). It is expected that the number of people displaced in Nyanza will increase, if rains continue in the Mount Elgon Region. This region is drained in Lake Victoria through River Nzoia, which causes serious flooding in Budalangi and its environs.

Flood assessment studies recently undertaken along the last 20 km reach of the Nzoia River in western Kenya indicate that annual flood damages amount to about US$4.8 million in the Budalangi floodplains. The average annual flood damages in the Kano Plains is about US$ 850,000 (Ochola and Eitel 2009)1997/98 El Niño flood (ICPAC, 2007; Osbahr and Viner, 2006). Major infrastructure that supports national economy such as roads, bridges and water pipelines are prone to damages as result of floods.

From the above literature it is evident that extreme events such floods are majorly caused by anomalies in precipitation, however the contribution of anthropogenic factors to increased flood risk cannot be ignored as most studies have shown that the possibility of these factors contributing to flooding in the flood prone areas are evident. It is quite clear that the effects of floods in the country as discussed in the literature is enormous while the trajectories of extreme events as a result of future climate change and variability impacts in Kenya are uncertain. There is need to institute robust strategies to prepare for the uncertain future rather than using uncertainty as a reason for inaction. Although Vision 2030 recognizes that the key sectors of the economy are heavily weather dependent, it does not contain an in-depth discussion of the effects of climate change and variability on the numerous set of goals under the economic, social and political pillars. The current and emerging climate-related hazards need to be researched on and managed to minimize their negative impacts and to take advantage of the opportunities they present. In addition, there is an urgent need to address the potential inconsistencies in the adaptation and mitigation strategies to climate change by shifting from a sectorial perspective to a holistic and integrated approach (Mickwitz 2009).

2.5 Rainfall and Flooding in the Lake Victoria Basin

Lake Victoria is most prone to flood disasters. It has a total catchment area of 194,000 Sq.km shared between five countries – Uganda, Rwanda, Burundi, Kenya and Tanzania with the water from Rwanda and Burundi being referred to as sub catchment water (Otiende 2009). The Lake receives part inflows from rivers Sio, Nzoia, Yala, Nyando, Sondu, and several other streams, with a total catchment area of 46,229 Sq. Km from the Kenyan territory. River Nzoia with a catchment area of 12,709 Sq. Km and a length of 334 Km up to its outfall into the Lake is the largest among them. Mungai *etal.*,(2004)stated that Lake Victoria receives most of its water (80%) from precipitation and from thousands of small and large streams, the largest stream being the Kagera River on the western shore, on the Kenyan portion of the lake, the main influent rivers are the Sio, Nzoia, Yala, Nyando, Sondu-Miriu, Mogusi, and the Migori.

The basin is said to be wet throughout the year with no distinctive dry season, but there are two maxima, one in April and the other in October (Onywere *et al.,* 2011). The research further argued that the highest rainfall occurs in the northwestern parts, and gradually reduces in the southeastern parts. The average annual rainfall for the basin is 1,424 mm and varies between 891 mm in parts of Mara catchment to a maximum of 2,168 mm in the middle reaches of Yala basin. Areas affected by flooding within the basin are the rivers Nzoia, Yala, and Nyandowhich causes extensive flooding in their lower reaches especially the Budalangi Division of Busia district and the Kano Plains.

The rivers Sondu and Kuja inundate low-lying areas in their outfall reaches. Floods in the basin affect parts of six districts; these are Busia, Kisumu, Nyando/Ahero, Bondo, Migori and Siaya Districts, which fall under Rift Valley, Western and Nyanza provinces. Out of a total area of 8770 sq. km in the six districts more than a quarter falls under the water bodies or is covered with Swamps.

A unique feature of floods in the Lake Victoria Basin that was noted by (Onywere *et al*., 2011) is that most of the runoff is generated in the upper catchments which receive much higher rainfall than the plains in downstream reaches. As a result, population living in the plains is often taken unawares, this cause considerable loss of human lives and livestock, in many low lying areas around the mouths of the rivers and natural swamps the inundation lasts for weeks leading to total loss of crops, the worst affected are the poor who inhabit the flood plains and riverine lands to eke out a meager living from agriculture, Livestock farming and fisheries. Because of poverty, lack of education and poor rural infrastructure, they are the most vulnerable to floods and post-flood consequences.

The floods severely limit and hamper the developmental process, further increasing the vulnerability of the rural society and thereby perpetuating and increasing the incidence of poverty (Otiende 2009). Stagnant floodwater also causes vector borne diseases, which result in high incidence of morbidity with consequent loss of alternative employment opportunities. People from the inundated areas move to makeshift relief camps where they cluster together such makeshift homes soon become slums creating social problems and unhygienic conditions which are conducive for the spread of contagious diseases and sexually transmitted diseases (KRCS 2012).The report also noted that often women and young girls are the worst sufferer. Pollution of drinking water sources like wells and bank erosion, silting of river beds and consequent lateral shifting of river channels, displacement of wildlife and cutting down of trees for firewood around relief camps are some of the adverse environmental impacts of floods in the Lake Victoria Basin as per the assessment made after recent flood KRCS (2012).

In the last 20 Km reach of the Nzoia River the annual damage is in the order of US$4 800,000 (Onywere 2011) Every year around 1 million US$ is spent on relief and rehabilitation of about 12,000 displaced people. In the Kano Plains, more than 5,000 people are affected every year by flood spills of Nyando River. The average annual damage is about US$ 850,000 with annual relief and rehabilitation measures costing US$ 600,000 (APFM 2004). A recent analysis of floods by the Ministry of Water Resources Management and Development (MWRMD) for the period 1969 to 1997 indicated that flood discharges for different return periods have since increased significantly within the basin the study also drew broad inferences that during the period 1980 to 1987 the peak discharges had decreased due to the forestation programs that were undertaken, whereas during 1988 to 1997 these peak discharges had increased sharply due to massive destruction of forest cover. The analysis however suggested that it would be desirable to collect and analyze data from different parts of the watershed and also it is very necessary to analyze the rainfall pattern, before drawing any firm conclusions this is because of the growing concern about the impact of climate change on the frequency of floods.

Therefore the role that climate plays in the increased incidences of flooding cannot be ignored. A number of studies on the potential impacts of climate change on flooding by IPCC (2009) point towards future increases in the incidence of flooding due to increased storm activity and overall increase in depth of precipitation. Increased climate variability can lead to excessive floods or droughts with consequential adverse impacts. The GCM based future rainfall scenarios for Kenya for the year 2030 broadly indicate that the region extending from Lake Victoria to central highlands east of the Rift Valley will experience mild increases in annual rainfall with highest increments of rainfall in the vicinity of Mount Elgon. If these projections are accurate, there are likely to be far reaching implications on intensity and frequency of regional floods.

2.5.1 Flooding in the Sondu-MiriuBasin

Sondu-Miriu river basin (referred as Sondu basin hereafter) which is one of the rivers found within the lake Victoria southern catchment which has an area of approximately

3, 487 km². The Upstream Sondu-Miriu Basin receives more than 2,000 mm of rainfall annually, with peaks during the long rains in March-May and the short rains in September-October. The heavy rainfall results in flooding twice a year to an average depth of 0.3-0.6 m. Sondu-Miriu River is the third largest river among the Kenya Rivers draining their water into the lake. KenyaThe River originates from the western slopes of the Mau Escarpment and inflows through a narrow gorge, penetrating the Odino Falls before entering the flood plains of Nyakwere where it drains into the Winam Gulf of the Lake Victoria.

The Population in the catchments area is engaged in agricultural production, mostly as small-scale farmers for crops such as sugar, tea, maize, cotton and livestock keeping. The river provides hydroelectric power, support irrigation, livestock and for domestic purposes. The Sondu catchment area is dominated by Nitisols at the upper area, Acrisols at the middle and by Regosols at the lower part of the river. The high rainfall received in the upper Sondu catchment caused flooding in the mid and lower parts of the basin. In mid catchment at Kipsonoi River bridge, crops were destroyed when the River burst its banks in early May 2013. The water level at 1JF06, Kipsonoi rose from an average of 0.22m in March 2013 to above 1.79m on 3rd May 2013 while at RGS 1JD03 the gauge height was 2.25m which is very high compared to an average of 0.45m in March.

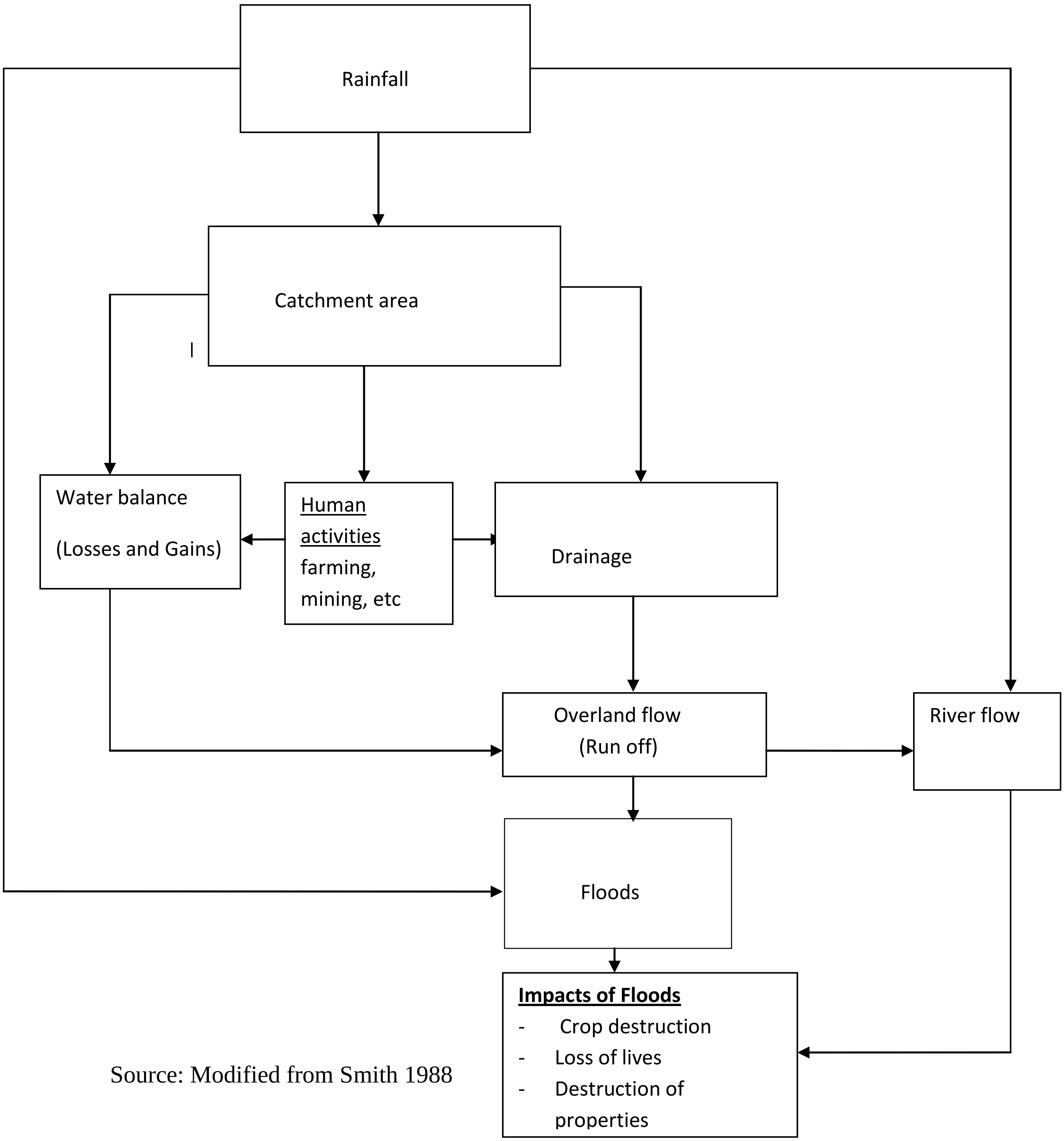
The floods ravaged the riverine and caused a lot of damage, displacing humans and destroying houses and infrastructures. The crops, planted along the river were also destroyed. Maize farms were washed away and the bridge connecting Kapchemagemwa and Chemanga locations was overtopped by flood water rendering it impassable. The locations are in Sigowet division of Kericho West district. The lower part of Sondu River basin at Nyakwere was the most seriously affected area. River Sondu burst its banks in early May 2013 with the flood marks indicating that the 4.5m-6.0m gauge plates overtopped. Three 12 villages namely Kobongo, Kamungo and Kopiyo in lower Kadiangasub locationwere adversely affected. Mr. Dan Oketch, a resident in the lower Sondu reported that two hundred and twenty eight (228) households were flooded and people displaced. Pit latrines were overtopped by flood water. Crops were destroyed as well as livestock. The roads were eroded and flooded and the bridges were damaged. Waterborne diseases such as bilharzia, cholera and malaria cases were reported. The intervention measures were undertaken included establishment of evacuation and rescue centers at various centers. UNICEF provided blankets and utensils to the community affected. Red Cross society of Kenya also intervened by providing tents and food stuffs.

2.6. Conceptual Framework

Whenever it rains the Rain waters reaches the Earth's surface and in this case the catchment area once it is in the catchment water evaporates, infiltrates into the soil, or runs over the surface. The kinds of ground cover and the nature of the drainage greatly influence the proportion of each of these actions, the rain waters flows across the surface as a confined flow. If the Rainfall intensity exceeds the evaporation rate and infiltration capacity of the soil, the excess flow will be converted into the surface runoff and if the drainage and in this case the River is incapable of accommodating the excess water through a combination of evaporation, infiltration into the ground then localized flooding are likely to occur.

The study assumed that the Rainfall (independent variable) has a uniform distribution, both in space with minimal variations across the basin and in time; in other words, the Rainfall rate does not vary much during the event contrary to the ideal situation. Once we know how much rainfall has occurred, we have an idea of how much of this turned into Runoff, and therefore how the Runoff affected the flow of a stream over time. The study used the surface water budget model, where Rainfall was used as the major input, and the estimation of infiltration and other losses such as evaporation was made an integral part of the calculation of the Runoff. This approach implies that infiltration will continue to occur, as the average depth of excess water on the surface is infinite. Rainfall was an independent variable and the River discharge, which causes floods was the dependent variable.

Figure 2.1: CONCEPTUAL FRAME WORK



Source: Modified from Smith 1988

CHAPTER THREE

RESEARCH METHODOLGY

3.0 Introduction

3.1. Study Design

The study carried out a River Drainage basin survey. The variables of the study chosen were River discharge which was measured at river gauge (RGS 1JG01) Rainfall was measured from three rainfall stations that is kericho DC rainfall station,Jamji rainfall station and Tenwek rainfall station. River discharge is known to reflect an integrated response of the entire River basin while Rainfall served as one of the major input into the runoff processes where there was an input flow inform of Monthly Rainfall and the output flow inform of floods. Thesurvey was carried out from the upper part of the catchment to the lower part of the stream where flooding occurs to establish the relevant locations of the Rainfall Stations and the River Gauges that was used for the collection of the secondary data from the relevant authorities. The survey helped in the checking of the River Flow Measurements from the River Gauges available, and also to locate the relevant Rainfall Station that were found within the catchment.

3.2. Data Types and Sources

The study was based on the Monthly Rainfall data and the monthly Stream flow data. The monthly rainfall data was for the whole year that is January, February, March, April, May, June, July, August, September, October November ,December for the year 1960-1990.The Stream flow was also for the same months and period. This is because the catchment experiences a trimodal pattern of rainfall.

The Rainfall data was retrieved from the computer stores at Dagoretti Corner, Meteorological Department Headquarters Nairobi. This was only made possible after the Rainfall stations had been identified and mapped to show a spatial representation of the stations.

The data on River Flow was retrieved from the Water Resource Management Authority, computer stores in Kisumu on a Monthly basis for each Month from January to December for 1960-1990 the data were recorded on computer sheet for each month with the corresponding years.

Generally, the data used secondary sources of data no attempt was made on collecting primary data in the study because of limited resources and the time to carry out the research.

3.3. Data Collection

To get the necessary data for the study all the Rainfall recording Stations in the upper catchment were first marked out from the list of the Stations provided by the Meteorological Department stations with the longest records and consistency.

The choosing of the Representative Stations was based on the data consistency and the length of records. The nine stations were cross-checked with three rainfall regime of the lake basin then again weighed and on the basis of spatial representation, the length of the data and the consistency only three stations were chosen, after selecting the stations the Rainfall data were collected on monthly basis from January –December the Monthly data was then arranged under the corresponding years for the period 1960-1990 then the data was entered into the Microsoft excel and then later imported into the SPPS package for statistical analysis. The same method was followed when collecting data for the River Flow at Sondu Basin

3.3.1. A Pre-visit

A pre visit was conducted in order to be familiar with the study area. This helped in identifying the location of relevant Rainfall Stations together with the River Gauges, the pre visit also helped in identifying the relevant authorities where the data for the Rainfall and Stream Flow was collected for the Study. Flood areas were also identified, the pre-visit also enabled me to understand the difficulties that were to be encountered during the data collection.

3.3.2. Target Population

The study identified all the rainfall stations which are operational within the catchment from the Meteorological Department and this constituted the target population and they were six and only those stations within the catchment with longest and consistent records of data at least 30 years and those that showed the three rainfall regime were considered and this consisted of three rainfall station.

3.3.3. Data Collection Instruments

The study used past historical records and the past publications on the study topic.

3.4.Data Processing and Analysis

3.4.1. Data processing

The acquired Rainfall data wasin tab-delimitedformat, which was then converted to excel spread sheet format. The spreadsheet format was considered particularly useful where data was time dependent and where there were sequential recordings as was the case with monthly Rainfall records from the Rainfall Stations. The Rainfall data and the River Flow data was arranged on monthly basis from January to December of each year from 1960-1990 for the three stations that is (kericho DC,Jamji,and Tenwek rainfall stations)and the River Gauge 1JG01 and this was subjected to various statistical analysis to bring out the required results. The spreadsheet format also made it easy to search for missing records as well as wrong entries before subjecting the data to any statistical analysis. The Time Series analysis was used in order to allow temporal presentation of data this technique was used to identify the peaks for both the Rainfall and Stream Flow that may be used to describe flooding. This was done in the excel but other analysis were done on the SPSS after the importation of the data from excel.

The missing rainfall data were common in data records for the Rainfall and this study solved for the missing records using the cross-correlation formula 3.1 provided by World Meteorological Organization as shown below.

Equation 3.1

$$\mathbf{X_m = \frac{X_t x_y}{X_n}} \text{---------------------------- } \mathbf{(3.1)}$$

Where

$\mathbf{X_m}$ is the estimated rainfall for the month at the station.

$\mathbf{X_t}$is the observed rainfall for the same month at the neighboring station.

$\mathbf{X_y}$is the average rainfall of the station with missing data which is highly correlated with the station.

$\mathbf{X_n}$ is the average rainfall of the neighboring station **m** and **n** are the length of record for stations with missing data and the neighboring station.

3.4.2 Data Analysis Techniques

A brief discussion of methods used to analyze the processed data for purposes of meeting the stated objective are presented in this section. They include descriptive analysis, determination of long-term means, variance, and trend analysis of time series of observed Rainfall and Stream Flow between 1960 and 1990.

3.4.2.1 Measuring Distribution Tendencies in the Rainfall and River Discharge

The Rainfall data and the River Discharge data were first subjected to descriptive statistical analyses as exploratory measure to reveal the distribution tendencies. The summary statistics (the mean, standard deviation (SD), minimum, maximum, median, skewness, kurtosis ar**e** given in table 4.1 they have been used to describe the basic features of the data in the study they provide simple summaries about the sample and the measures to allow simple interpretation of the data.

Trend analysis was done to reveal the general movement of the rainfall pattern and the flooding to bring out evidence of any changes in the trend of rainfall amounts. Such patterns were investigated by use of both graphical and statistical methods. Graphical methods were used as a tool for Visualization of temporal variation of annual and monthly rainfall as well as the stream flow amounts over the study period**.**

Variability of annual and monthly rainfall was assessed using the Analysis of Variance (ANOVA) techniques.

3.4.2.2. Time Series Analysis of Rainfall and River Discharge

The research used the Time Series technique in analyzing both the Rainfall and the River Discharge data which was suitable for time dependent observations for monthly Rainfall and the monthly River Discharge. There was a disjoint in the duration for the Rainfall and River Discharge data, where the Rainfall records started from 1956-2010 while the records for the River Discharge were only available for the period 1946-1990.The sequencing was from the earliest year of record that is 1960 to 1990the time series plot were to show variability in the distribution of Rainfall and the flows of River Discharge respectively on a monthly basis. In mathematical terms Time Series was defined by values $\mathbf{Y_1, Y_2, Y_3 \ldots\ldots\ldots Y_n}$ of a variable Y (Rainfall and River Discharge in the study) where y is a function of time (t) years (Nyandega 1990). The duration of time series analysis used to infer association between Rainfall and River Discharge was 30 years. The sequential plotting of Rainfall amounts were generated to show Rainfall characteristics. The irregular distribution of the missing data was handled through smoothening procedure and running mean this was to reveal persistence tendencies in the Rainfall. The unit hydrographs were used to show the magnitude of the flow within the Sondu catchment and the peaks and lows of the Discharge at the same time.

Time series can either be additive or multiplicative. The Time domain auto correlation technique or Frequency domains Fourier technique is used to separate the series into basic components of trends, cycles, seasonality or irregular distribution. However in Climatology the commonly used technique is the Time domain. The time series is therefore expressed as explained in (Equation 3.2) Rainfall observations and the River Discharge were on monthly basis.

Equation Yi=T+C+S+I or Y_i=TCSI ----------------------- (3.2)

Where: **Y_i** is the individual time series observation Rainfall or River Discharge.

T is the Trend

C is Cycles

S is Seasonality

I is Irregular

3.4.3 Determining Flood Frequency in the Lower Sondu-Miriu Basin

The study of flood frequencies can enable one to judge dependably from available records, the information on floods is basic to the development of water-supply works, river sanitation and navigation. To determine the flood frequency the study used maximum Discharge for each year these peak discharges were listed according to the magnitude with the highest discharge first. Then the recurrence interval that is the period of years within which a flood of a given magnitude or greater will occur was determined by the equation

$$T = \frac{n+1}{m} \text{ ----------------------------- (3.3)}$$

Where: T-is the recurrence interval

n-the number of years of records

m-the magnitude of the floods

The calculated data was then run through hydro frequency software to obtain the required results of the flood frequency log Pearson type III distribution was considered. The advantage of this particular technique is that extrapolation can be made of the values for events with return periods well beyond the observed flood events. This is helpful when designing structures in or near the river that may be affected by floods. It is also helpful when designing structures to protect against the largest expected event.

3.4.4. Determining the Relationship between Rainfall and River Discharge

To examine the relationships between Rainfall and the River Discharge a Simple linear regression model was used this model is defined by (Ndolo 1985) as a test of the degree of association between two variables. It is assumed that a certain type of relationship between two variables exist and the relation is linear which is known as the unknown parameters refer to Ndolo's class notes 2012the unknown parameters are estimated under certain other assumptions with the help of available data and a fitted equation is obtained and a fitted straight line which can be called simple linear regression is constructed when such pairs of observation are available for example **$(x_1,y_1),x_2y_2$-------(x_ny_n)**describes the linear relationship between two variables that is the Rainfall and River discharge

The general simple linear regression equation is presented as:

Equation $\mathbf{Y_i = \beta_0 + \beta_1 X_i + £}$-- **(3.4)**

Where

Y_i =dependent variable

β_0 and β_1 = the intercept and the slope for the regression equation respectively

Xi=independent variable

£=error term

The regression parameters β_0 and $\beta_1$are estimated by the method of least squares to minimize the sum of squares of the residuals. The estimated value denoted by b_0 and b_1 respectively are given by the equations:

$$\boldsymbol{\beta_i = \frac{\sum(X_1 - \bar{X})(Y_1 - \bar{Y})}{\sum(X_1 - \bar{x})^2}}$$

and

$$\boldsymbol{\beta_0 = \bar{Y} - \beta_i \bar{X}}$$

Therefore, the linear regression equation is given as:

$Y_i = b_0 \pm b_1 x_1$-- (3.5)

This is the regression line whose Y- intercept is $b_0$and b_1 is the gradient of the regression line

To validate the obtained linear regression equation correlation analysis is necessary this is done to test the goodness-of-fit of the regression equation for the research data. The measure of association for the interval variables commonly used is the Pearson correlation(r) it explains the strength and the direction of the linear relationship between y_i and x_i that is if (r)is larger then there is a strong linear relationship between y_i and x_i and vice versa the obtained value of (r) is always in the range-1 to 1,thus -1≤ r≥

In this study the linear regression equation relating the Rainfall to River Discharge was done for the lower Sondu catchment.

$$\textbf{Equation} \quad r = \frac{\sum(R_1 - \bar{R})(T_1 - \bar{T})}{\sqrt{\sum(X_1 - \bar{X})}^2 \sqrt{\sum(T_1 - \bar{T})^2}} \text{ ------------------------------------ } \textbf{(3.6)}$$

$$r = 1 - \frac{6\sum d^2}{(n^3 - n)}$$

Where:

d=is the annual difference in the rank of Rainfall and the River Discharge

n=the number of the paired variable.

The linearity of the obtained regression equation are tested by the method of Analysis of variance

Source of Variation	**Sums of Squares (SS)**	**Degrees of freedom (df)**	**Mean Squares (MS)**	**F**
Accounted for by regression	$SSB = \Sigma n_j (\bar{X}_j - \bar{X})^2$		$MSB = \frac{SSB}{k-1}$	$F = \frac{MSB}{MSE}$
Unaccounted for by regression(residuals)	$SSE = \Sigma\Sigma(X - \bar{X}_j)^2$	**N-k**	$MSE = \frac{SSE}{N-k}$	
Accounted for by the mean(Total)	$SST = \Sigma\Sigma(X - \bar{X})^2$	**N-1**		

Source:

Where

X = individual observation:

$\overline{X}$ = sample mean of the (group),

$\overline{X}$ = overall sample mean,

k = the number of independent comparison groups, and

N = total number of observations or total sample size.

The analysis of variance apportions the variability for dependent variable Y into variability accounted for by regression equation and variability unaccounted for by the regression. The analysis of variance table is subjected to a test of significance of the linear regression α=0.05

The F statistic has two degrees of freedom. These are denoted $df_1$and df_2, and called the numerator and denominator degrees of freedom, respectively. The degrees of freedom are defined as follows:

df_1= k-1 and df_2=N-k

Where:

k = the number of independent comparison groups, and

N = total number of observations or total sample size.

The obtained F-value is compared to given F-value from the distribution tables with k-1and N-degrees of freedom at α significance level to determine if the mean square explained by the linear regression is large enough in comparison to the residual mean square this effects a decision on whether the regression is due to a real effect rather than random sampling therefore if the obtained F-value is greater than the given F-value from F-distribution table at α then there is a significant linear relation between X and The practical significance of the regression is however measured by the squared correlation coefficient (r^2)which is obtained from the Anova table. The ($r^{2|}$) is used as an explanation of the total variability of Y explained by the fitted linear regression

3.5: Scope and the Limitation of the Study

This study focused on the Sondu-Miriu catchment, which is one of the sub basins in the Lake Victoria region, other sub basins include Nzoia, Yala and Nyando that this study did not consider this is because of the limited resources. The study also concentrated on only one aspect of climate and that is Rainfall Trends since the study wanted to find out if there are any changes in the rainfall trends and how it is related to the flooding in the region, this might have influenced the findings of the study. However, this was intended to be used as a benchmark for determining the role of rainfall on flooding in other sub basins in Lake Victoria region. The data used was secondary data for the three rainfall stations from Kenya Meteorological Department Dagorretti and the River Discharge data was acquired from (WRMA) in Kisumu upon verification by the researcher (plate3.1).The study did not concentrate on the primary data because of the limited resources and time to carry out this research.

The study investigated on the impact of rainfall variability on flooding in the Sondu Catchment. However the study did not investigate on the impact of seasonality of rainfall on flooding the study was based on a single weather element and that is Rainfall other elements such as temperature, evaporation, the antecedence condition of the river and the change of the basin overtime was not considered which required more time and resources even though they play an important role in flooding.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

4.2 Distribution tendencies in the Rainfall and the River discharge.

The mean monthly rainfall for the year 1960-1990 for the three stations was 1575 mm as shown in table 4.1there was high variability of the monthly rainfall within the catchment with the months of April, August and November recording high amounts of rainfall. This conforms to the trimodal pattern of rainfall reported about the region (ICPAC 2007) and the low months recorded in January February and December respectively (SoK).The discharge at 1JG01Sondu also exhibited high variability in the maximum and minimum flows for the 1960-1990 as shown in table 4.2.

Table 4.1: The mean monthly rainfall for the three stations used in the study for the year 1960-1990

MONTH	JAMJII	TENWEK MISION	KERICHO DO	SONDU MONTHLY AVERAGE RAINFALL
JAN	87.4	91.5	81.0	86.6
FEB	92.3	88.7	86.6	89.2
MAR	167.1	141.1	157.3	155.2
APR	261.6	249.6	246.4	252.5
MAY	185.6	148.6	231.9	188.7
JUN	121.0	75.7	141.2	112.6
JUL	109.3	70.6	139.9	106.6
AUG	130.8	84.9	164.6	126.8
SEP	115.0	86.0	139.2	113.4
OCT	119.3	89.4	131.5	113.4
NOV	131.0	130.1	132.9	131.3
DEC	92.1	126.1	80.4	99.5
TOTAL	1612.5	1382.3	1732.8	1575.9

Table 4.2 Mean Annual Discharge for Sondu Station (1JG01)

YEAR	DISCHARGE 1JG01 (m3/s)
1960	36.61
1961	42.28
1962	63.17
1963	63.17
1964	56.39
1965	21.63
1966	35.91
1967	19.90
1968	65.57
1969	24.27
1970	58.78
1971	27.33
1972	24.63
1973	32.83
1974	43.59
1975	43.68
1976	26.13
1977	69.51
1978	63.65
1979	42.69
1980	22.53
1981	40.76
1982	43.48
1983	42.73
1984	15.42
1985	46.65
1986	19.54
1987	35.67
1988	63.42
1989	43.86
1990	65.89
Annual flow	41.02

4.2: The Results of the Time Series Analysis of Rainfall and River Discharge

4.2.1 Monthly Rainfall Characteristics of the Sondu basin

This sub-section presents results of annual cycle of mean monthly total rainfall and their trends showing temporal variation within the year and over longer-term periods. The annual cycle of mean monthly rainfall totals as indicated in Figure 4.1 shows the seasonal variation of rainfall. This confirms the three rainfall seasons in this part of Kenya with the main rainfall season experienced in March-April-May (MAM) followed by a minor peak in June-July-August (JJA) centered in August and another minor rainfall peak in September-October-November (SON) centered in October. The period from December to February (DJF) is relatively dry compared to the other seasons.

This trimodal pattern of rainfall is attributed to the geographical location of the catchmentwhich lies on the high plateau between the Rift Valley and Lake Victoria, the area is said to be under the influence of the easterly air stream of the Indian Ocean monsoons and the large scale thermal winds of Lake Victoria which together with low level westerly winds, from the Atlantic Ocean bring in the Congo air mass which tends to enhance the JJA rainfall in the area (Rwigi 2009).

4.2.2: Rainfall Characteristics at Jamji Rainfall Station

Jamji rainfall station recorded a high rainfall of 2000 mm in the year 1961, which coincides with the MWI report of 2009 that explains Kenya's worst flood records in the year 1961-1962 which had an average mean annual discharge 63.17m3/s. The lowest records of rainfall in this station were in the years' of 1982-1986-1987however, 1978 experienced a peak as indicated in Appendix 2.The months of June and July recorded stable rainfall for all the recorded years. The months of October, November experienced the same stability but with a slight increase in November then a decrease in December.

An average monthly rainfall characteristic at Jamji station revealed a trimodal rainfall pattern with the trend declining from the month of May.

Figure 4.1 The average Monthly characteristics at Jamji for years 1960-1990

The time sequence plot for annual rainfall of jamji rainfall station between the years 1960 to 1990 indicates variation in the annual rainfall record near the mean of 2000mm as indicated in Figure 4.2, however the annual rainfall went to the maximum rainfall peak in 1978 and minimum in the year 1982. The annual rainfall betweenthe year 1968-1990 indicated a decline.

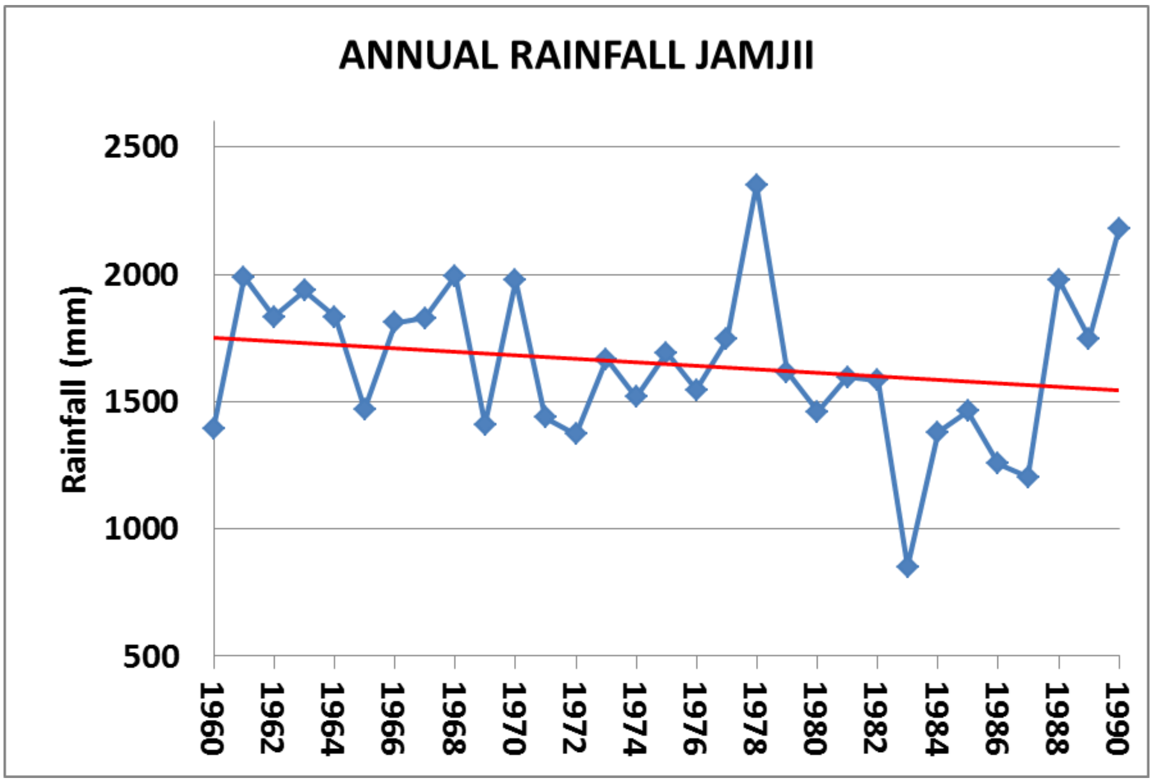


Figure 4.1The annual rainfall characteristics at Jamji rainfall station for the years 1960-1990.

4.2.3: Rainfall characteristics at Kericho D.O Office Rainfall station

In the months of January, February and December the station experienced low monthly rainfall with low records of below 100mm.The months of June, July and November experienced a stable rainfall of 150mm with a slight increase in August. However high rainfall was experienced in the years 1967, 1970 and 1983 as shown in Appendix 3.The year that recorded the lowest rainfall was 1980. The month of April on all the years recorded an average rainfall of about 250mm although the average monthly rainfall characteristic at Kericho D.O station revealed a bimodal rainfall pattern as shown in Figure 4.2**,**studies have shown that the station also experiences a trimodal pattern.

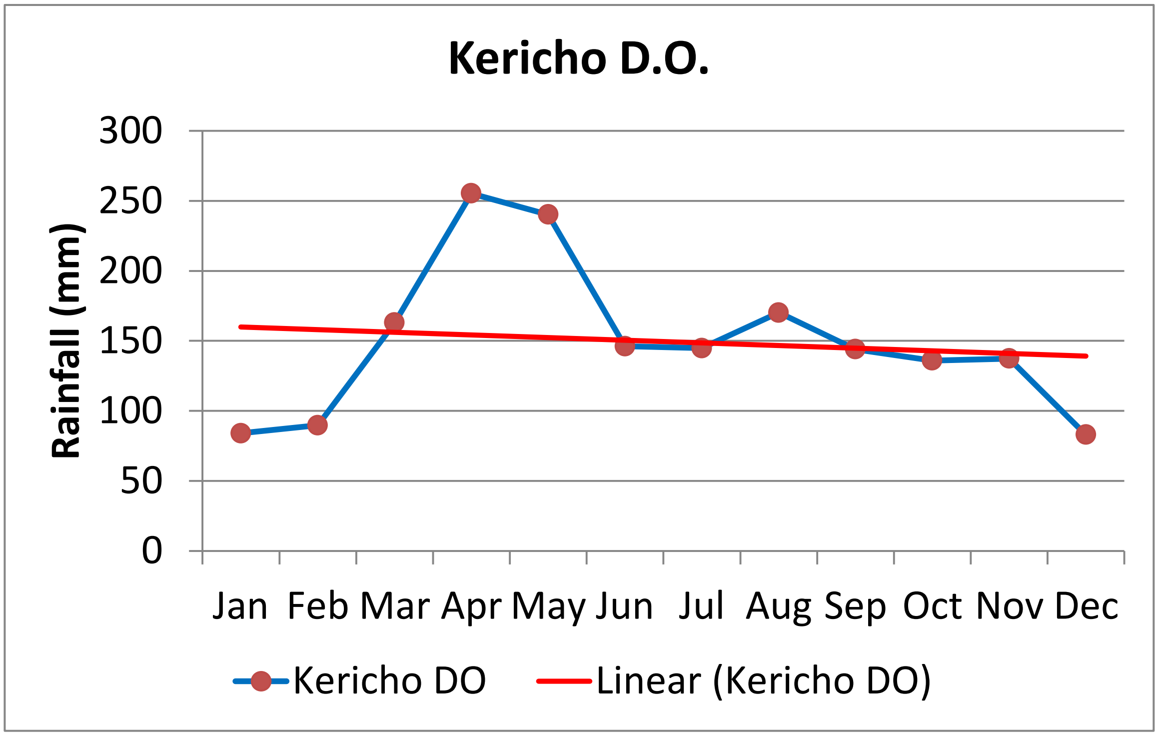


Figure 4.2 The average monthly characteristics at Kericho D.O for years 1960-1990

The time sequence plot for annual rainfall at kericho rainfall station between the years 1960-1990 indicates variation in the annual rainfall record at an average of 2000mm as indicated in Figure 4.1. However the annual rainfall went to a maximum peak of 2500mm in 1970 and a minimum rainfall peak of 1300mm rainfall trend between the years 1965-1990 indicated a decline.

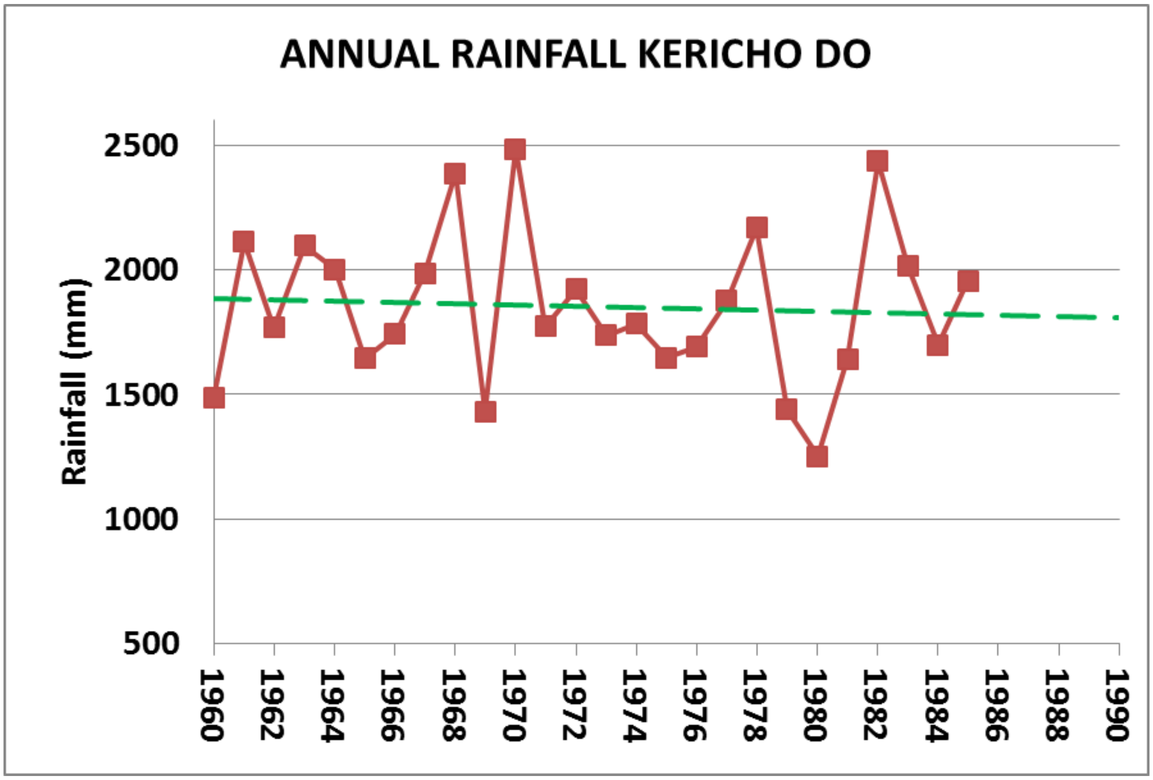


Figure 4.3The annual rainfall characteristics at Kericho D.O Rainfall station for years 1960-1990

4.2.4 Rainfall Characteristics at Tenwek Station

In the month of January between the years 1960-1990 the area experienced the high rainfall with a peak of about 1800 mm in the year 1962 and the low rains in the year 1971 as shown in Appendix 4.The month of April experienced an average rainfall of about 250mm with the lowest amount of rainfall being in the month of June and July which also showed some stability with as low as 60mm. The month of October and November experienced an average rainfall of about 150mm throughout the year.The low rains were experienced in the year 1964,1970,1976,1986 see figure 4.4. The high rains were experienced in 1970, 1978 and 1989 with an average rainfall of about 1500mm. An average monthly rainfall characteristic at Tenwek station revealed a trimodal rainfall pattern although the June, July and August did not indicate a clear peak as shown in Figure 4.4.The monthly rainfall trend indicated a decline from the month of May through to December.

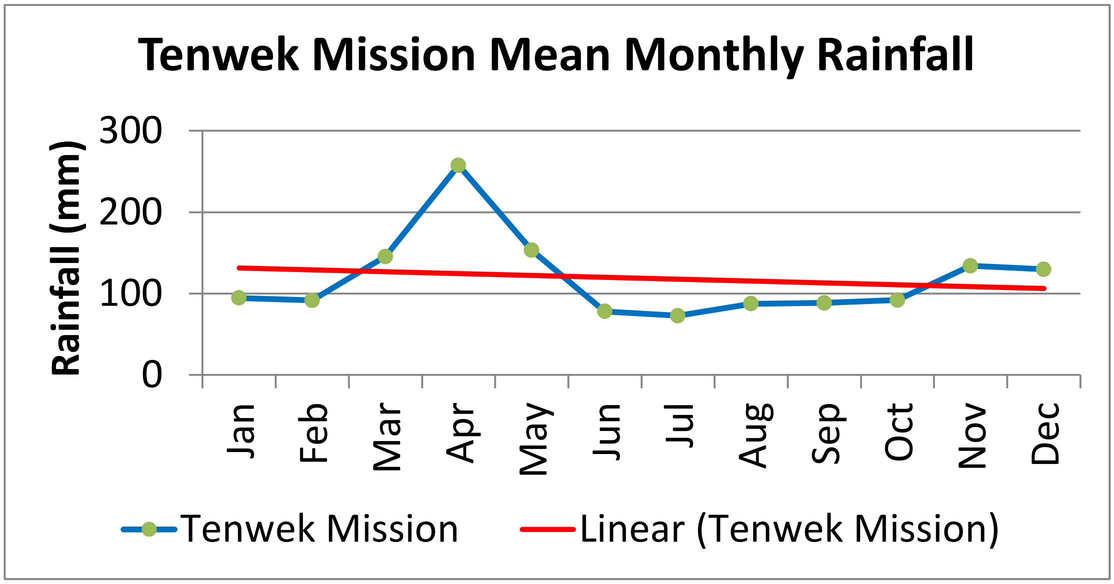


Figure 4.4The average monthly characteristics at Tenwek station for years 1960-199

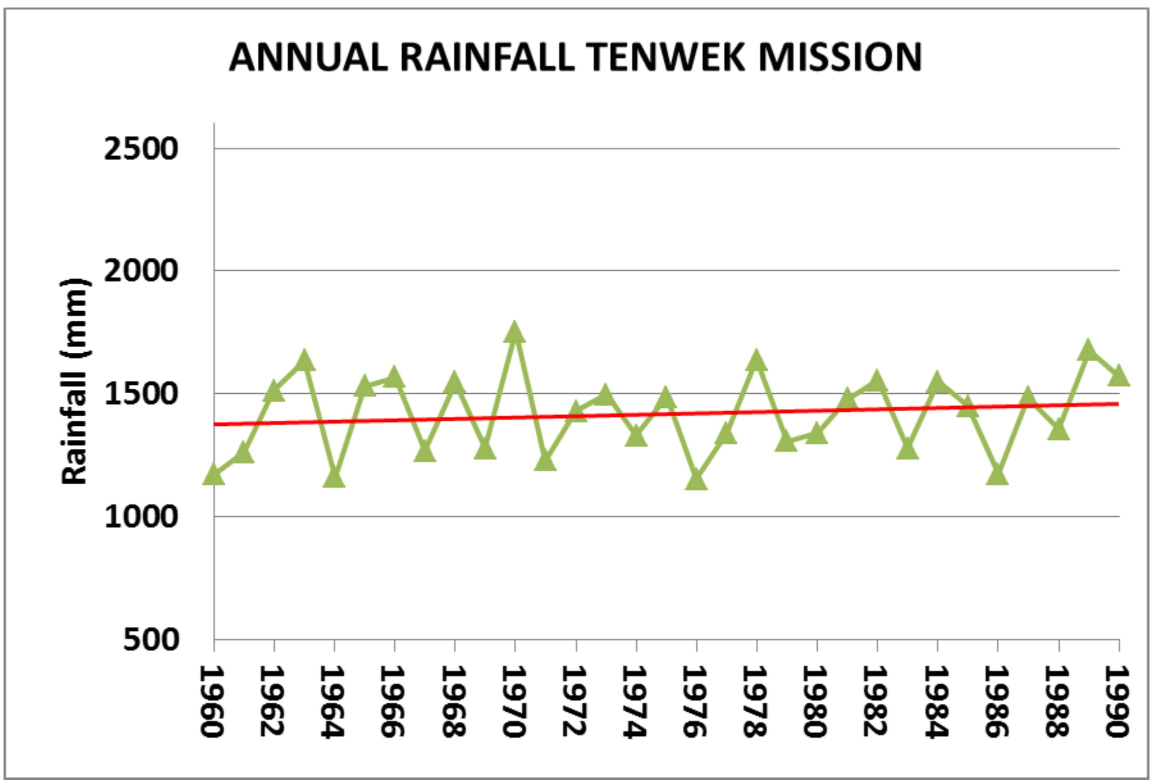


Figure 4.5. The annual rainfall characteristics of Tenwek rainfall station for year 1960-1990

The time sequence plot for annual total rainfall of Tenwek station between the year 1960-1990 indicates high variation in the annual rainfall record most below the mean of

2000mm as indicated in Figure 4.6, However the annual rainfall went to the minimum peak in 1960 and maximum peak in 1970. The rainfall trend at this station indicated an increase in annual total rainfall between the years 1972 to 1990.

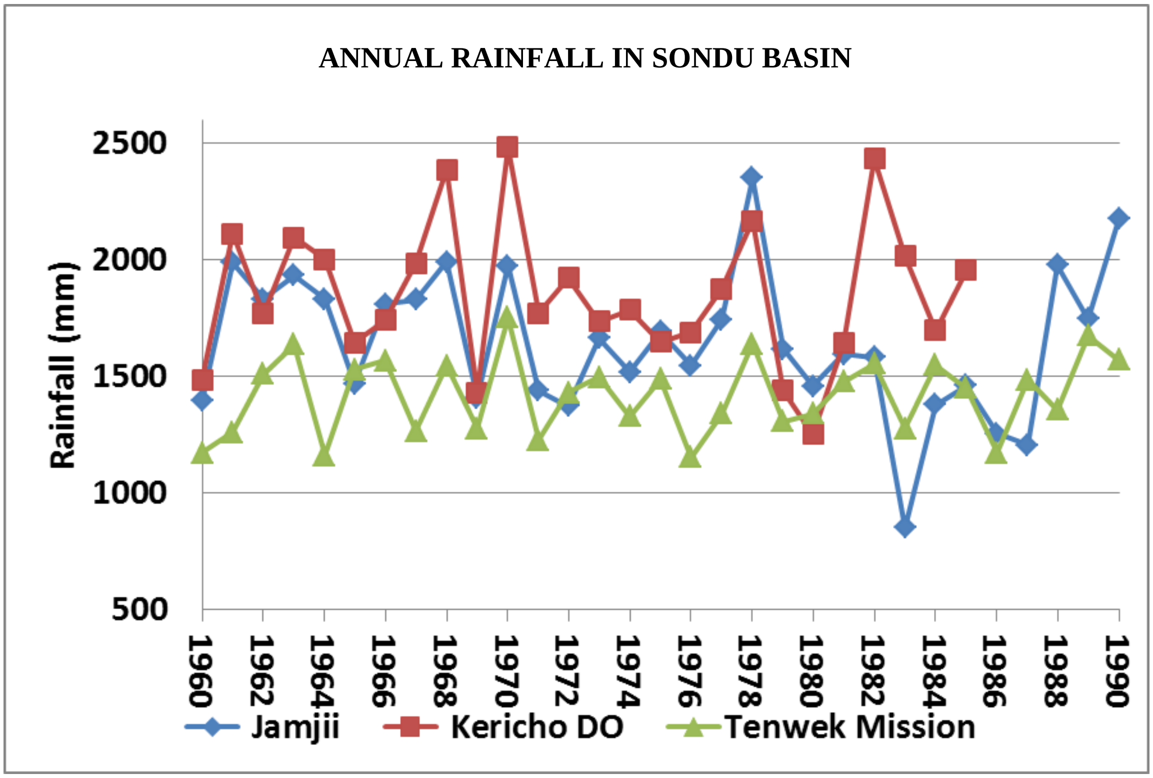


Figure 4.6.The annual characteristics of rainfall in the Sondu basin.

4.2.5 Rainfall Characteristics at Sondu Basin

High variability exist in annual rainfall within the Sondu catchment with some years receiving more than 1500 mm of rainfall and others below 1000 mm per annum (pa) in both stations as shown in Figure 4.6. However itwas noted that the three stations have almost similar rainfall patterns of peaks and lows. This might mean that rainfall trends have not experienced so much change although the amount of rainfall from each station have shown slight variations, the reductions in total amounts of short and long rains as in Figure 4.7 may imply that there are other factors apart from rainfall within the basin that may also contribute to the continuous flooding in the basin.Kericho D.O station has been observed to contribute more rainfall to the catchment with an average mean annual rainfall of 2000mm except in the year 1978 when jamji received rainfall slightly above kericho DC station.

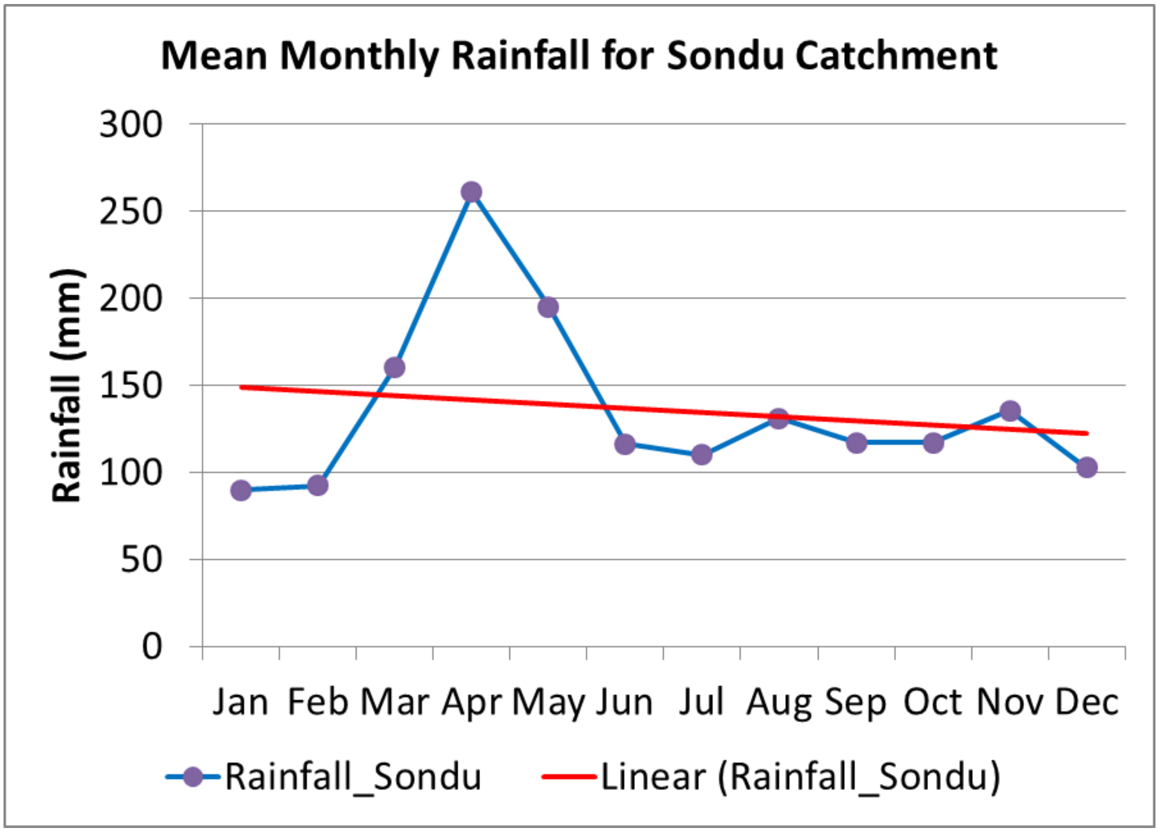


Figure 4.7.Themean monthly characteristics of rainfall in the Sondu catchment

The monthly rainfall distribution across the catchment varies. The peak flows are experienced at different months, depending on the season the low rains are observed in the first two month of the year which can be as low as 90mm these are considered to be the dry months whereas the peaks are observed in April/May, August and November. This exhibits a trimodal pattern of rainfall.

The months of April/May have the highest rainfall followed by August and then November although some studies have showed some fluctuations on August and November rains. This may be consistent with the lack of a strong relationship between rainfall and runoff for the months of May and November due to other factors such as antecedent soil moisture conditions and the intensity of rainfall, which is not directly taken into account in this study. Largely, rainfall in this region is dependent on the Inter Tropical Convergence Zone (ITCZ), which lags behind the overhead sun.

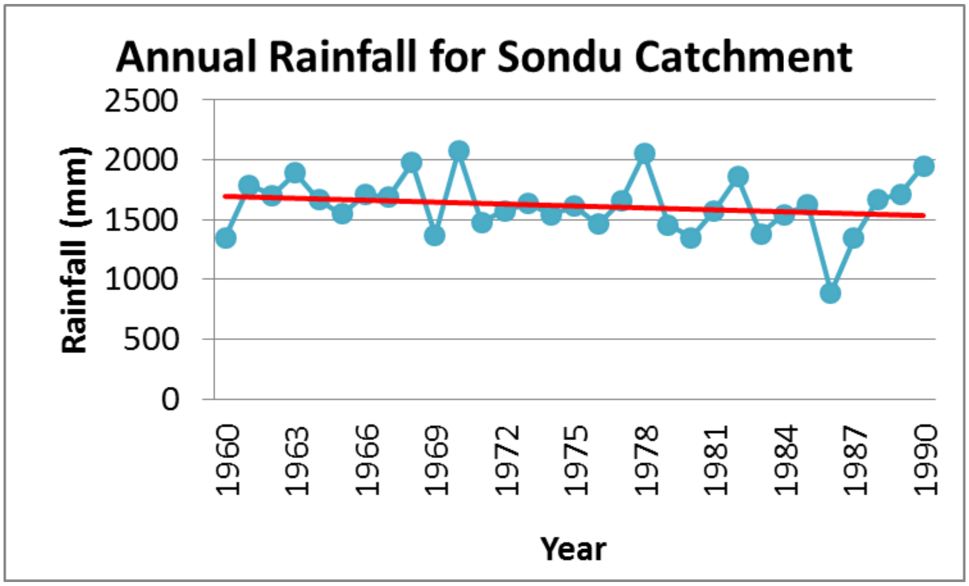


Figure 4.8. The mean annual characteristics of rainfall in Sondu Catchment

Figure 4.8gives the trends as well as the annual variations of the rainfall 1971 achieved the highest peak of 2000mm with the lowest amount recorded in the year 1986.From Figure 4.8 it is quite clear that, there has been a decreasing trend in the annual rainfall since 1969-1990. This is in consistent with denga‘s work 1990 which noted a decline of rainfall within the catchment despite increase in the flooding.

4.2.5 The results of the analysis of River Discharge

Figure 4.9 shows the hydrographs of observed mean monthly discharge at 1JG01 Sondu

RGSs. From the Figure, it was evident that February has the lowest discharges in the area while May and September have the highest. Hence the hydrological year in this basin may be considered to begin in February and end in January.94% of the catchment area drains, at Sondu RGS, which shows a trimodal pattern of discharge. The peaks and low flows follow the general rainfall pattern in the area quite closely but generally lag by about one month except in the month of May where they coincide see figure 4.10. This may be attributed to antecedent soil moisture condition in the month of May followed by April.

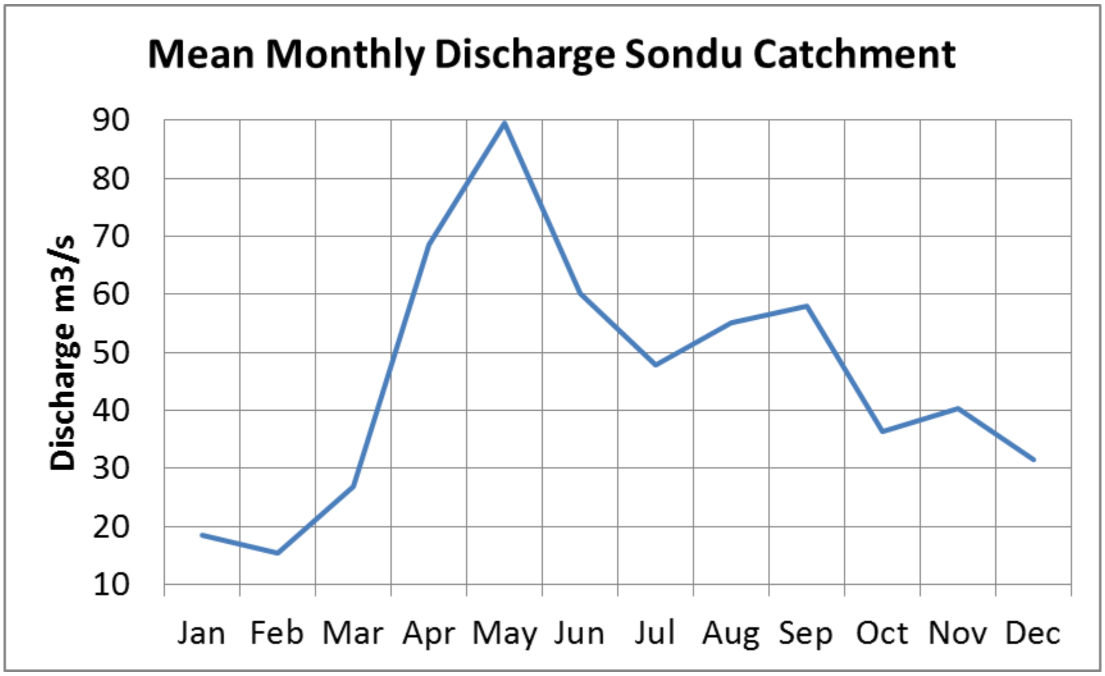


Figure 4.9: Mean Monthly discharge of Sondu Catchment

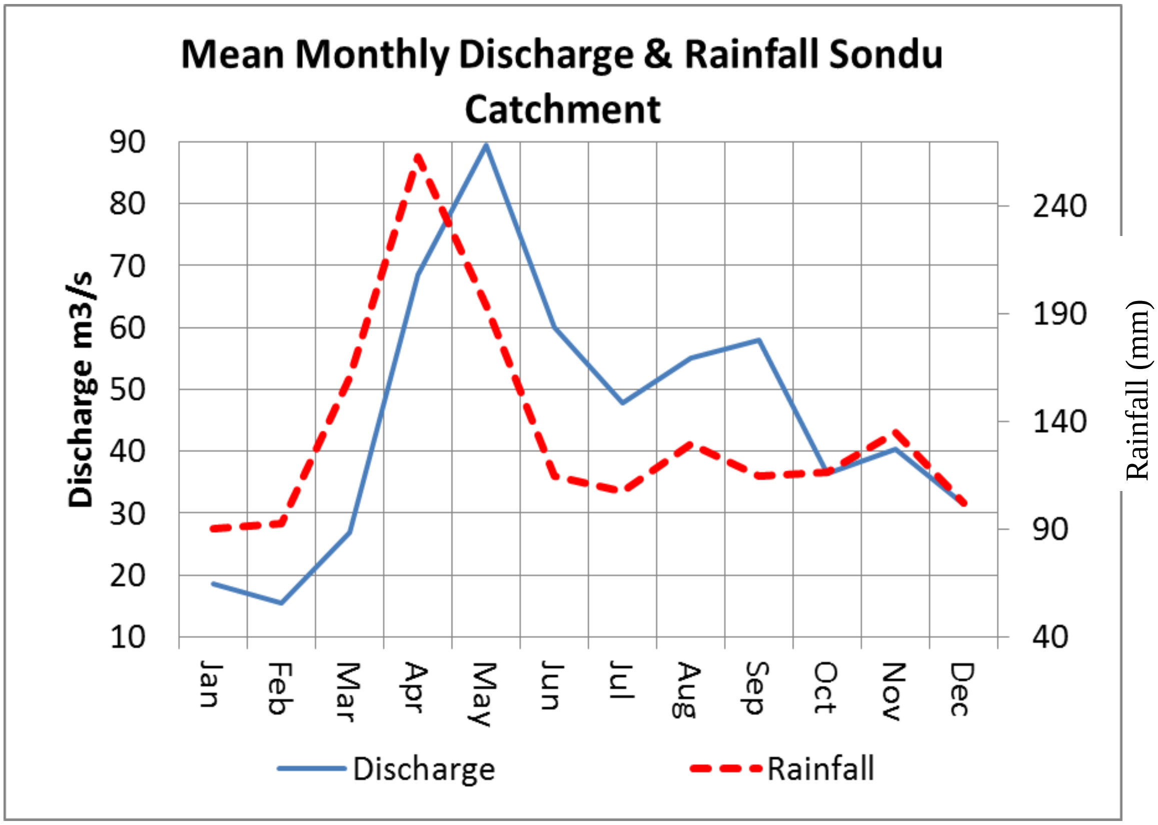


Figure 4.10: Mean Monthly Discharge and Rainfall at Sondu Catchment

Figure 4.10 shows time series of mean annual discharge at Sondu RGSs. From the above figures It was noted that 1960 had the least flow followed by 1966. The highest flows were recorded in the year 1961-1962,1968,1971,1978,1988,1990.This is in consistent with the (MWI) report of 2009 which confirmed that in the year 1961,1978,1988 major floods occurred in the low lying parts of the lake Victoria catchment where there was exceptionally heavy and widespread rainfall during October and November though it has been observed that the year 1970,1978,1988 also received high flows this would only mean that any major flooding in the lake Victoria basin would have a major impact on Sondu, however the report established that the major floods in Sondu have been recorded in the year 1962,1968,1990.Figure 4.10 shows a time lag of one moth from the time of maximum rainfall and the time of maximum discharge this may imply that there is a good vegetation cover which contradicts most studies within the basin that shows that there is a lot of sedimentation as a result of the interference with the vegetation cover.

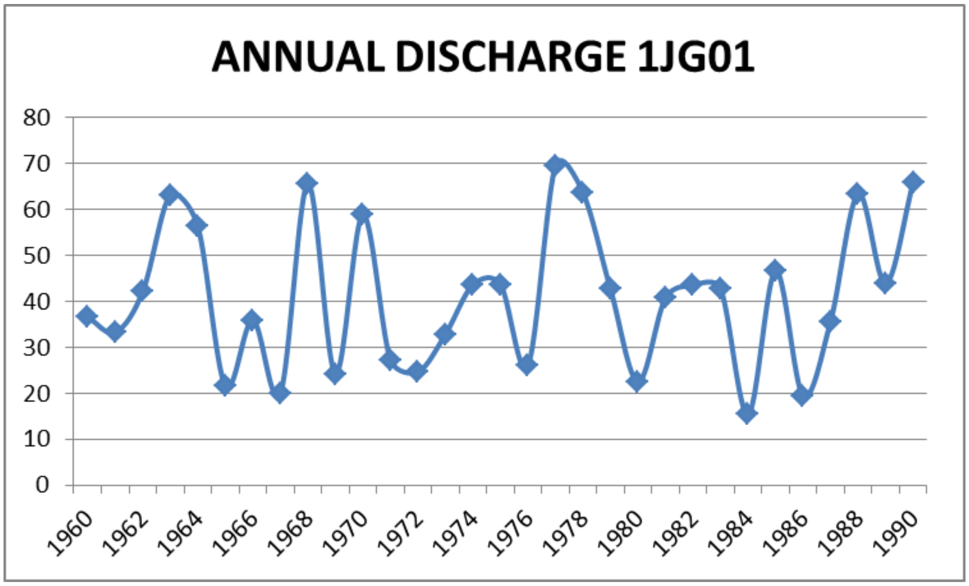


Figure 4.11. The annual characteristics of discharge in Sondu Basin

Figure 11 shows the frequency of floods in the Sondu basin the major floods in the Sondu were recorded in the year 1962, 1968,1978 and 1990. The years 1970 1978 1988 have also shown high flows. However the recent reports on flooding on the basin have continued to show an increase especially the most recent report by WRMA 2013 that observed that in the early May of 2013 there was a serious flood that overtopped 4.5m-6.0m gauge plates.

Table 4.3 shows the analysis of frequency of floods in the Sondu catchment where maximum flows for all the years (1960-1990) were used they were ranked from the highest to the lowest and then run through the hydro frequency Programmeto bring out the above interpretation.

Table 4.3: The Frequency distribution of floods

	Flows	Log of Flows		
Mean	211.09	5.15	Programme used for analysis is HydroFreq	
St. Dev	137.29	0.68		
Skew	1.3	-0.52		
Return Period (RP)	GEV (General Extreme Value)	LN3 (Lognormal 3 Parameter	LP3 (Log Pearson Type III)	P3 (Pearson Type III)
2	176.07	178.24	180.58	182.75
5	294.15	301.04	305.42	309.06
10	385.42	391.78	391.35	393.63
20	484.27	485.08	473.86	474.13
25	518.16	515.95	499.91	499.53
50	630.96	614.9	579.52	576.99
100	756.67	719.09	657.46	653.2
200	897.2	829.1	733.93	728.48
500	1109.12	984.23	832.95	826.84
Fit Method	L Moments	Max. Like	Max. Like	Moments
Location	142.37	5.34	8.12	211.09
Scale	89.17	0.55	-0.15	137.29
Shape	-0.17	-31.13	19.46	1.3

Figure 4.12

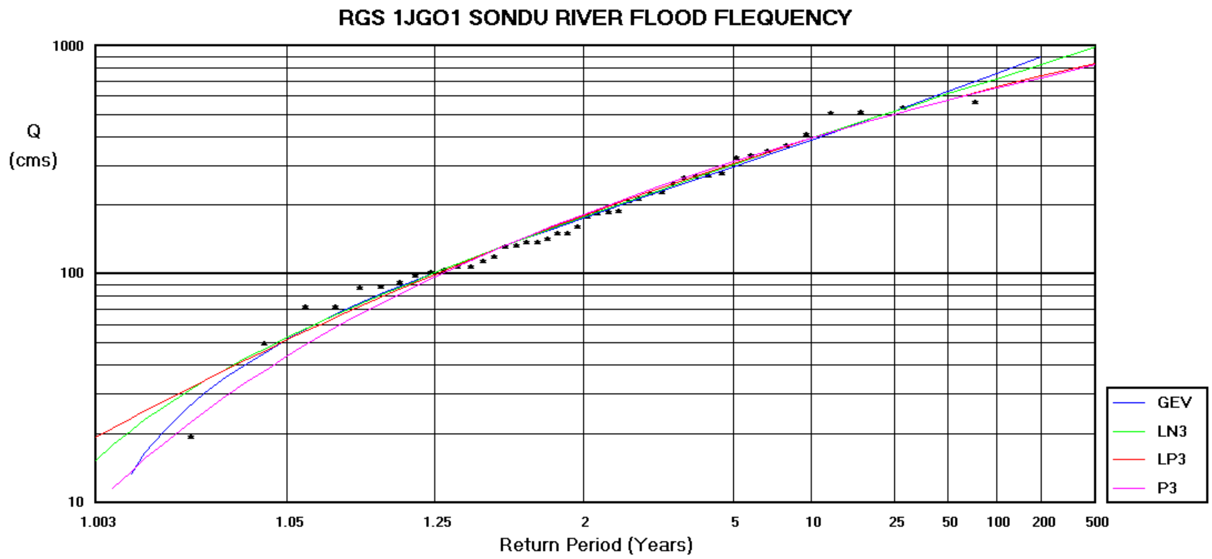


Figure 4.12

Selected distribution: Pearson III

Figure 4.13

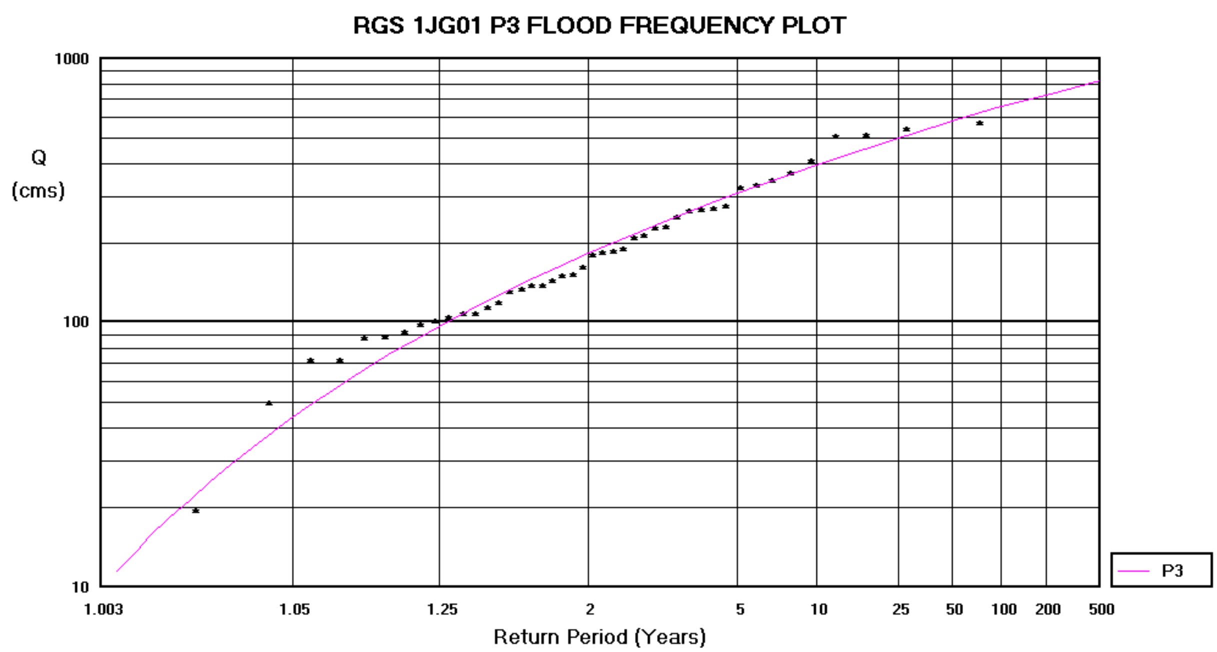


Figure 4.12 indicates flood discharges for different return periods. It was noted that the most common floods within the basin were of between 1 year to 10 years return period

which is between a discharge of 90m400m the frequency of the floods is not uniform as such but a bit random. This is likely to pose danger to the low land regions since there are no any definite return periods for the floods.

The Results of the Determination of Rainfall-Flooding Relationship in the Sondu Catchment

In this section, the relationship between Rainfall and the River Discharge was determined understanding the response of the River Discharge to the Rainfall variability especially during the rainy seasons was of main significance. The two variables were analyzed for the purpose of validating the previously stated hypotheses.

Figure13 show the seasonal differencing for the three stations and the River Discharge, the figure shows there exist almost the same pattern for the Rainfall from the three stations and the River Discharge where the peaks and the lows for the Rainfall tend to relate with the maximum flows and the minimum flows of the River this would only mean that to a larger extent Rainfall tend to have an influence on the River Discharge. However this doesn’t necessarily indicate that the rising reports of the flooding as reported by WRMA2012 is as result of increased rainfall within the catchment, several studies have continued to show that in spite of the increased flooding rainfall has continued to decrease over time as it has also been observed in this Study.

Figure 4.12: Transform Sessional differences

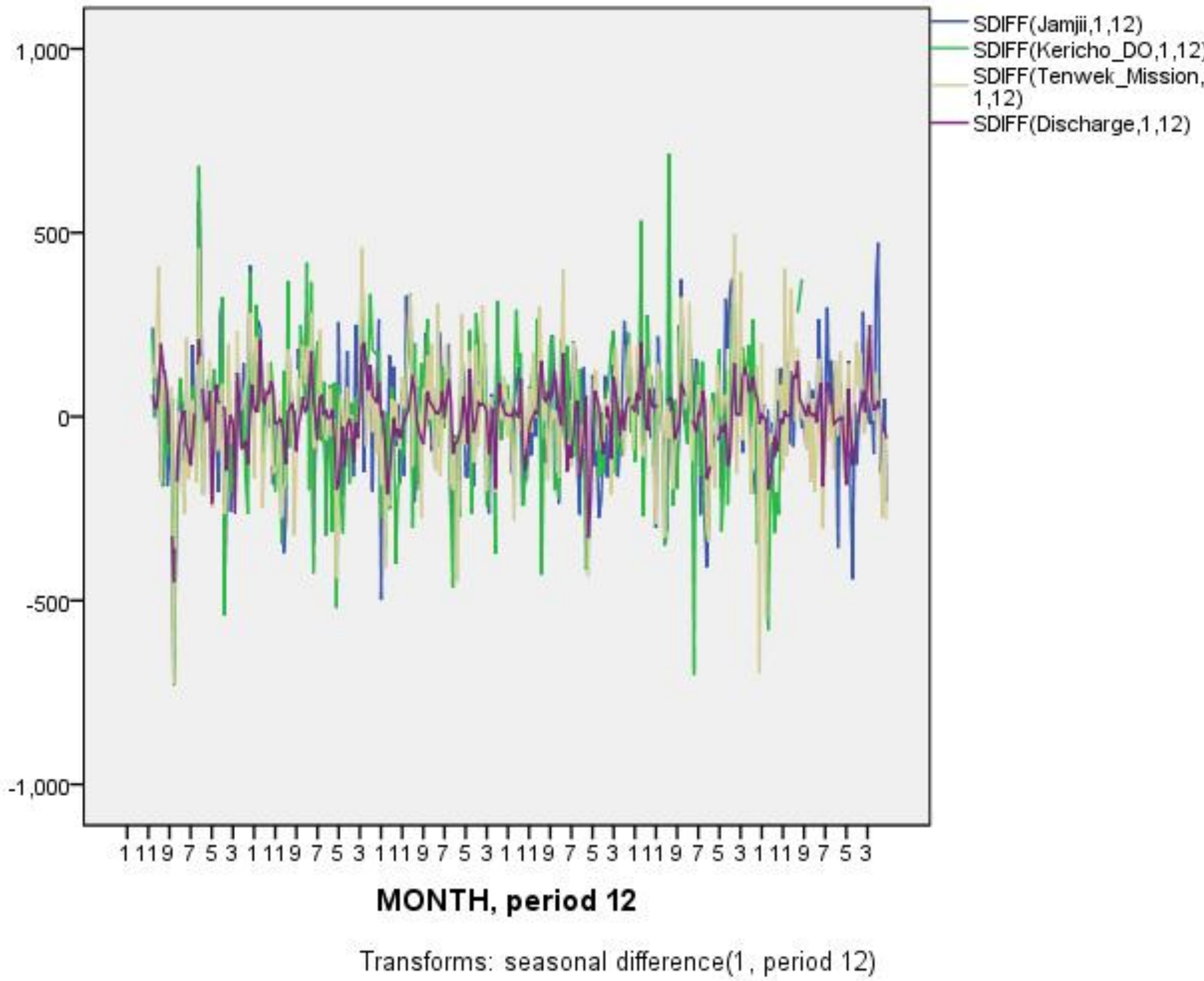


Table 4.4 shows a summary of the association between the Rainfall and the River discharge

Table 4.4: Model summary

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.509[a]	.259	.252	35.60738

a. Predictors: (Constant), Tenwek_Mission, Kericho_DO, Jamji

b. Dependent Variable: Discharge.

To understand how rainfall responds to flooding in the Sondu Basin the correlation analysis found the R Square value for the three stations that is Kericho, Tenwek and Jamji and the River Discharge to be 0.259 this value indicated a weak linear association and that there were other factors that affected flooding apart from the rainfall trends factors such as rainfall intensity, duration and other factors as earlier mentioned. The R value was 0.509 which indicated neither a strong nor a weak significant association. The stations had a coefficient value of 0.260 and a t-value of (1.866) therefore an increase in rainfall in the three stations also increases flooding in the lower areas of Sondu.

Table 4.5 Analysis of variance results of Rainfall and river Discharge

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	136532.900	3	45510.967	35.895	.000[b]
	Residual	390508.736	308	1267.886		
	Total	527041.636	311			

a. Dependent Variable: Discharge

b. Predictors: (Constant), Tenwek_Mission, Kericho_DO, Jamjii

Computed F-value =35.9

Critical F-value at (3,308, 0.05) =2.06

Table 4.6 shows that the three rainfall stations had an F-value of 35.859 therefore there was no significant value difference in the Jamji, Kericho and Tenwek rainfall station because the F-value was more than 0.05.

Table 4.6: Model Summary and parameter Estimates

Model Summary and Parameter Estimates

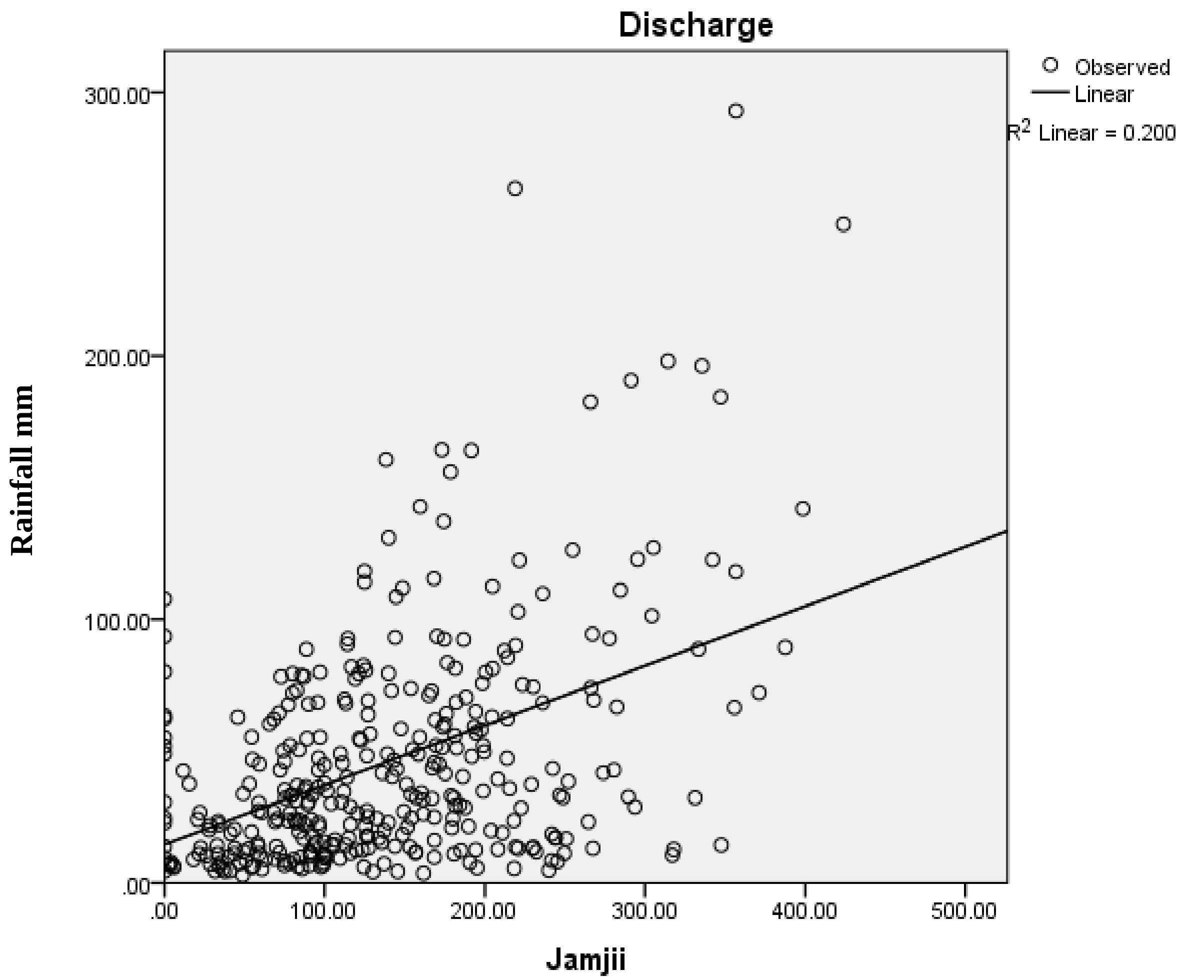
Dependent Variable: Discharge

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.200	88.307	1	354	.000	14.579	.226

The independent variable is Jamjii.

At the Jamji rainfall station the correlation analysis had an r value of 0.447;the annualrainfall at this station indicated a weak significant relationship between rainfall and flooding.The station had standardized coefficient value of 0.084 and t-value of 1.143 and a significance of 0.254, to indicate how rainfall at this station explained the river discharge a regression line was generated with a line fitting as shown in figure 4.14.The figure indicated a fewer rainfall observation with 20%of river discharge explained by the rainfall in the station..The F-value was 88.307 therefore the rainfall station was not statistically significant.

Fig 4.14: The Relationship between Rainfall and River discharge at Jamjii



The correlation analysis at kericho DC had an r value of 0.500 this indicated an average significant relationship with the river discharge.This particular station revealed that the 25% of discharge is explained by the rainfall in the station.Annual Rainfall in the station had standard cofficient of 0.387,a t-value of 5.737 and significance of 0.136. a regression line generated showed fairly distributed rainfall observation explaining the River Discharge.The station recorded the highest mean annual rainfall in the study.

Table 4.7: Dependent variable Discharge

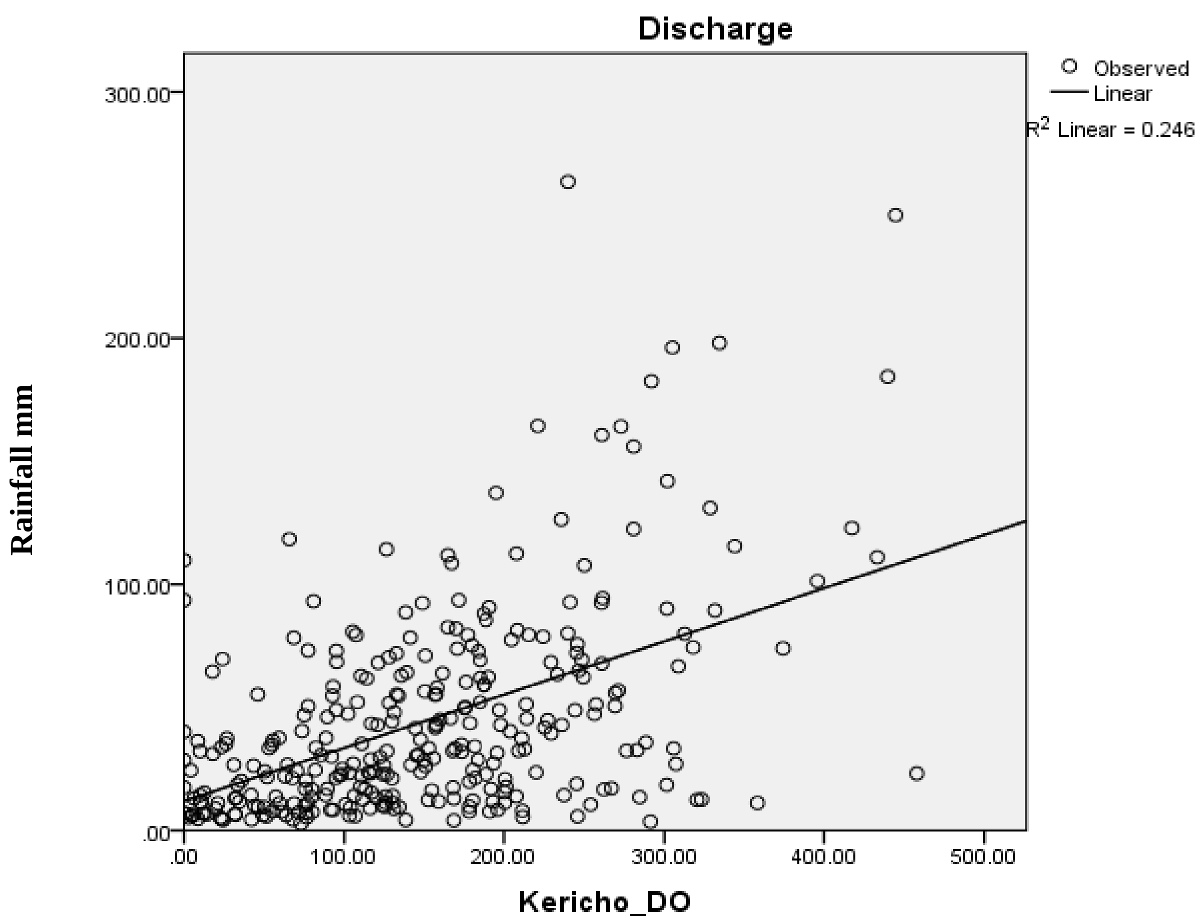
Model Summary and Parameter Estimates

Dependent Variable: :Discharge

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.246	102.330	1	313	.000	11.955	.216

The independent variable is Kericho_DO.

Figure 4.15: The Relationship between Rainfall and River discharge at Kericho D.O



At Tenwek Rainfall station the correlation analysis had an r value of 0.387 this indicated a weak association between the rainfall and the River Discharge the station revealed that 15% of the river discharge at Sondu is explained by the rainfall in this station. Despite being the least contributor it is the only station that revealed an increasing trend in Rainfall. The station had a standards coefficient of 0.096 and a t-value of 1.493.

Table 4.8: Model summary and parameter estimates

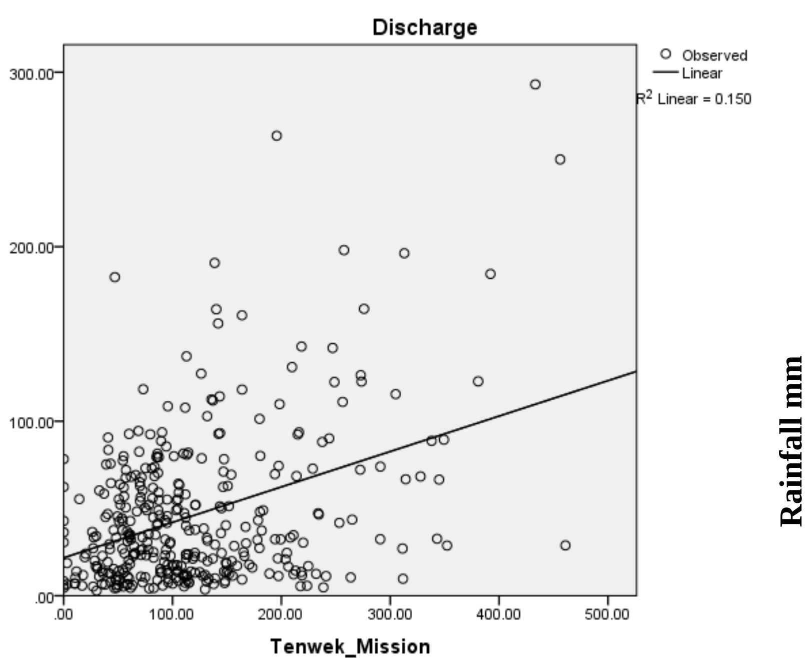
Model Summary and Parameter Estimates

Dependent Variable: Discharge

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.150	63.168	1	357	.000	21.756	.203

The independent variable is Tenwek_Mission.

Figure 4.16: The Relationship between Rainfall and River discharge at Tenwek Mission



CHAPTER FIVE

5.0: SUMMARY, CONCLUSIONS, AND RECOMMENDATION

5.1: Summary

The study has shown that between 1960-1990, the rainfall has been changing and this has had an impact on the stream flow. The mean Monthly patterns of rainfall have showed high peaks over MAM (March April May) and this has coincided with the long rains and maximum flows within the catchment although there was much variability on JJA (June July August) and the OND (October November December).The low rainfalls over the months of January and February also coincided with low flows within the catchment. The mean monthly rainfall pattern indicated a decreasing trend from the three stations for the years 1960-1990.The study also revealed that there is a one month time lag from time of maximum rainfall to time of maximum discharge rainfall this would only mean there was a good vegetation cover which contradicts most of the studies done in the region. The three stations in the study had an F-value of more than 0.05 this showed that there was no significant value difference in the rainfall stations. The three stations showed an average relationship with the river discharge within the basin which may imply that the rainfall trends fairly relates to the flooding in the sondu basin.

The mean annual rainfall patterns also varied within the catchment with decreasing trends of rainfall. However, one of the rainfall stations that are Tenwek rainfall station indicated a slightly increasing trend with the kericho DC station recording the highest mean annual rainfall. The annual peaks of rainfall coincided with the major floods with the catchment; the frequency of floods within the catchment was between 2 to 10 year return periods since most floods were within this range.

5.2: Recommendation

Arising from the results of this study and the challenges encountered therein, the author wishes to make the following general recommendations to policy makers and researchers.

5.2.1: Recommendations to policymakers

There was a great challenge on the quality of the data with a lot of disjoints in between the years and it was quite a daunting task to make sure that the researcher had the quality data that was expected. As such, other types/sources of data such as remotely sensed data (e.g. for rainfall and river discharge could be explored to provide a wider coverage of rainfall distribution and complement the already existing records.

The current and emerging climate related hazards need to be researched and managed to minimize negative impacts at the sub-sector level and then harmonized with other sectors.

5.2.2: Recommendation for the Researchers

There is need for further study within the catchment to compare the rainfall intensity with the amount of flooding in the catchment, as this would bring an understanding on the rainfall intensity impacted on the flooding in the area.

More studies need to be done on the role of the climate on flooding's in the region to assess the rising reports of flooding in the region as most of the studies in the region have dealt with the anthropogenic causes of increased floods in the region,

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APPENDICES

Appendix 1: The Monthly Rainfall Data for selected stations at Sondu Catchment Area and the River Discharge.

YEAR	MONTH	Jamjii	Kericho DO	Tenwek Mission
1960	Jan	85.4	125.2	60.0
1960	Feb	124.5	103.2	63.3
1960	Mar	179.3	200.7	203.8
1960	Apr	236.1	229.2	327.8
1960	May	0.0	190.2	0.0
1960	Jun	97.2	45.9	50.7
1960	Jul	88.5	55.3	26.3
1960	Aug	142.2	73.5	85.8
1960	Sep	85.7	224.4	126.8
1960	Oct	242.5	116.8	93.0
1960	Nov	69.3	116.1	93.1
1960	Dec	43.9	6.3	40.9
1961	Jan	5.8	5.1	0.0
1961	Feb	0.0	67.9	0.0
1961	Mar	145.6	138.2	46.8
1961	Apr	245.5	211.5	131.4
1961	May	218.0	220.1	112.6
1961	Jun	99.9	200.4	30.9
1961	Jul	26.1	75.5	10.7
1961	Aug	222.5	149.6	64.6
1961	Sep	168.4	166.1	95.2
1961	Oct	193.2	187.4	87.2
1961	Nov	423.8	444.6	456.1

1961	Dec	241.2	245.6	226.1
1962	Jan	169.0	113.9	82.0
1962	Feb	22.0	31	42.6
1962	Mar	208.0	111.4	152.3
1962	Apr	289.7	283	343.0
1962	May	266.1	291.9	47.0
1962	Jun	148.6	164.5	137.1
1962	Jul	88.7	138.2	89.5
1962	Aug	113.3	121.1	61.9
1962	Sep	129.1	144.2	128.9
1962	Oct	192.0	216.8	162.7
1962	Nov	78.5	43.3	94.2
1962	Dec	126.9	110.1	170.4
1963	Jan	167.0	173.1	178.0
1963	Feb	126.9	98.8	82.4
1963	Mar	151.6	129.6	118.6
1963	Apr	266.3	373.9	290.9
1963	May	218.8	239.9	195.7
1963	Jun	124.9	65.6	73.1
1963	Jul	101.6	172.9	61.3
1963	Aug	199.5	175	104.9
1963	Sep	15.4	88.5	45.8
1963	Oct	33.2	68.6	58.9
1963	Nov	318.0	323.1	189.0
1963	Dec	212.1	187.2	237.6
1964	Jan	49.3	23.2	60.0
1964	Feb	220.7	168.2	95.9
1964	Mar	189.8	181.7	112.4
1964	Apr	347.2	439.7	392.1

1964	May	144.6	166.8	95.7
1964	Jun	109.9	95	76.2
1964	Jul	127.2	184.9	66.1
1964	Aug	80.1	132.4	57.3
1964	Sep	174.9	175.8	32.8
1964	Oct	198.4	245.8	43.0
1964	Nov	34.0	62.9	19.4
1964	Dec	156.6	125.6	110.1
1965	Jan	40.1	44	139.0
1965	Feb	55.7	32	38.0
1965	Mar	130.2	168.2	78.6
1965	Apr	248.9	276.3	290.8
1965	May	166.7	183.8	228.8
1965	Jun	77.4	115.1	112.3
1965	Jul	135.6	116.9	88.8
1965	Aug	106.5	154.4	57.8
1965	Sep		89.3	108.0
1965	Oct	232.2	158.7	130.0
1965	Nov	161.3	195.7	132.1
1965	Dec	116.1	110.9	127.0
1966	Jan	59.4	59.5	50.0
1966	Feb	116.2	200.4	197.3
1966	Mar	331.3	167.5	199.3
1966	Apr	387.5	331.5	349.3
1966	May	125.7	105.3	113.1
1966	Jun	79.3	168.9	48.2
1966	Jul	120.5	124.6	77.8
1966	Aug	154.2	180.1	205.0
1966	Sep	165.1	150.4	146.8

1966	Oct	81.4	119	64.8
1966	Nov	139.8	124.1	98.2
1966	Dec	49.6	10.2	17.8
1967	Jan	33.9	14.3	3.0
1967	Feb	37.7	24.4	82.7
1967	Mar	161.7	291.3	129.9
1967	Apr	244.1	191.8	224.7
1967	May	304.3	395.9	179.9
1967	Jun	175.9	138.9	105.4
1967	Jul	141.7	95	81.0
1967	Aug	160.4	181.2	29.9
1967	Sep	90.0	146	76.9
1967	Oct	115.1	113	99.6
1967	Nov	242.0	301.4	149.7
1967	Dec	121.7	92.6	103.7
1968	Jan	95.0	12.7	46.0
1968	Feb	244.3	267	159.2
1968	Mar	173.3	213.9	151.8
1968	Apr	295.5	417.4	380.8
1968	May	138.3	261	163.8
1968	Jun	174.7	260.8	79.6
1968	Jul	194.3	271.3	55.5
1968	Aug	170.1	171.3	90.4
1968	Sep	55.1	74.9	40.4
1968	Oct	126.5	201.3	95.5
1968	Nov	181.6	155.5	139.0
1968	Dec	144.0	80.7	143.6
1969	Jan	96.4	98.2	166.0
1969	Feb	139.2	197.1	183.2

1969	Mar	208.0	229.4	167.1
1969	Apr	89.5	122.2	97.6
1969	May	228.9	211.1	115.2
1969	Jun	84.1	147.6	114.6
1969	Jul	32.7	130.1	50.6
1969	Aug	133.8	75.6	30.8
1969	Sep	198.9	54.8	84.3
1969	Oct	93.5	106.2	35.2
1969	Nov	100.9	46.2	133.3
1969	Dec	3.4	12.6	100.1
1970	Jan	347.6	237.4	213.0
1970	Feb	87.1	96.9	120.3
1970	Mar	282.5	308.7	314.2
1970	Apr	255.0	235.7	272.9
1970	May	168.2	343.8	305.0
1970	Jun	124.3	164.5	69.4
1970	Jul	11.6	157.4	50.9
1970	Aug	200.5	312.6	101.3
1970	Sep	139.9	215.4	85.3
1970	Oct	173.8	187.2	105.7
1970	Nov	58.8	105.5	27.1
1970	Dec	127.4	120.2	88.8
1971	Jan	100.2	100.7	75.0
1971	Feb	2.4	11.6	10.4
1971	Mar	41.1	23.5	48.9
1971	Apr	249.8	358	241.0
1971	May	274.0	225.3	253.2
1971	Jun	90.0	261	71.6
1971	Jul	127.1	161.1	51.7

1971	Aug	186.7	148.6	215.1
1971	Sep	114.3	190.7	40.8
1971	Oct	75.1	89.3	88.2
1971	Nov	86.7	79.6	29.5
1971	Dec	91.0	123.6	103.0
1972	Jan	180.7	77.2	71.0
1972	Feb	109.6	103.7	163.9
1972	Mar	47.0	71.4	111.6
1972	Apr	99.7	177.8	72.6
1972	May	149.4	307.2	311.3
1972	Jun	136.0	156.6	94.9
1972	Jul	59.4	159.6	38.4
1972	Aug		129.7	53.5
1972	Sep	61.0	141.5	72.5
1972	Oct	203.7	177.9	132.1
1972	Nov	230.1	317.9	197.5
1972	Dec	96.3	102.2	110.8
1973	Jan	167.1	178.2	265.0
1973	Feb	157.2	209.1	194.2
1973	Mar	27.8	35.6	28.4
1973	Apr	185.0	179.9	211.2
1973	May	246.8	305.7	208.3
1973	Jun	214.1	188.6	94.2
1973	Jul	82.1	126.6	35.6
1973	Aug	158.5	244.3	87.0
1973	Sep	204.4	135.4	150.7
1973	Oct	96.2	8.5	0.0
1973	Nov	104.1	92	167.5
1973	Dec	22.5	32.4	55.3

1974	Jan	28.4	76.1	10.0
1974	Feb	31.5	42	61.5
1974	Mar	195.1	245.9	223.6
1974	Apr	371.2	245.3	272.4
1974	May	182.3	257.4	143.5
1974	Jun	128.4	150.1	70.8
1974	Jul	140.0	328.5	209.8
1974	Aug	95.8	95.2	83.4
1974	Sep	159.3	132.5	105.0
1974	Oct	72.3	120.6	61.2
1974	Nov	70.6	70.2	55.9
1974	Dec	43.7	21.1	32.6
1975	Jan	5.4	5.5	58.0
1975	Feb	49.0	72.9	30.3
1975	Mar	218.2	211.7	217.6
1975	Apr	293.8	183.5	352.2
1975	May	178.9	212.9	131.6
1975	Jun	84.1	77.3	74.7
1975	Jul	145.0	157.1	178.6
1975	Aug	267.3	261.5	68.7
1975	Sep	174.3	195.1	112.8
1975	Oct	116.7	169.7	114.5
1975	Nov	53.2	59.2	54.1
1975	Dec	106.0	41.8	94.6
1976	Jan	18.0	19.7	51.0
1976	Feb	97.6	63.6	48.4
1976	Mar	86.0	76.5	110.6
1976	Apr	241.8	196.2	148.4
1976	May	264.8	457.8	75.8

1976	Jun	175.2	144.2	86.4
1976	Jul	197.6	157.7	111.9
1976	Aug	198.9	184.8	121.2
1976	Sep	82.8	77.3	75.2
1976	Oct	28.3	51.8	82.6
1976	Nov	91.3	130	127.8
1976	Dec	63.1	130.9	113.8
1977	Jan	156.9	193.1	219.0
1977	Feb	91.7	50.3	65.5
1977	Mar	143.8	207.7	11.8
1977	Apr	219.1	301.5	243.9
1977	May	191.5	272.9	140.2
1977	Jun	204.8	208.4	86.1
1977	Jul	124.9	126.2	143.3
1977	Aug	87.3	141	0.0
1977	Sep	54.6	157	14.4
1977	Oct	161.6	150.6	70.6
1977	Nov	236.2	0	198.3
1977	Dec	72.9	68.4	147.3
1978	Jan	59.1	145	220.0
1978	Feb	210.9	245.3	149.0
1978	Mar	335.6	305	312.9
1978	Apr	314.4	334.3	257.5
1978	May	178.5	280.8	141.9
1978	Jun	280.7	197.9	0.0
1978	Jul	147.6	93	37.1
1978	Aug	181.2	269.4	81.6
1978	Sep	188.2	127.7	86.6
1978	Oct	153.8	170.3	83.5

1978	Nov	113.9	0	112.4
1978	Dec	187.6	0	156.6
1979	Jan	96.7	67.5	137.0
1979	Feb	112.4	24	194.0
1979	Mar	191.7	131	180.3
1979	Apr	268.1	248.5	153.9
1979	May	277.9	241.2	142.2
1979	Jun	223.4	179.5	39.1
1979	Jul	78.5	108.1	52.1
1979	Aug	0.0	233.3	106.3
1979	Sep	87.7	110.8	77.9
1979	Oct	41.3	33.3	3.1
1979	Nov	102.3	61.2	73.4
1979	Dec	137.1	0	147.8
1980	Jan	54.5	106.8	91.0
1980	Feb	61.0	2.9	27.0
1980	Mar	190.6	191.1	115.2
1980	Apr	240.2	8.6	238.6
1980	May	213.8	256.4	233.8
1980	Jun	89.1	133.7	87.4
1980	Jul	71.7	17.7	43.4
1980	Aug	79.6	152.6	27.7
1980	Sep	180.7	126.5	93.2
1980	Oct	58.7	125.7	116.8
1980	Nov	219.1	79.3	218.3
1980	Dec	0.0	50	48.2
1981	Jan	36.3	22.7	55.0
1981	Feb	83.5	49.2	50.4
1981	Mar	194.2	320.3	231.9

1981	Apr	398.5	301.9	247.1
1981	May	0.0	0	216.2
1981	Jun	92.4	53	72.5
1981	Jul	186.2	203.8	149.0
1981	Aug	121.4	176.8	86.0
1981	Sep	214.0	249.4	146.5
1981	Oct	153.8	82.2	61.0
1981	Nov	33.4	103	71.1
1981	Dec	81.2	80.9	91.4
1982	Jan	62.4	62.4	44.0
1982	Feb	62.2	78.3	50.5
1982	Mar	130.8	99.6	18.3
1982	Apr	245.9	266.4	287.0
1982	May	74.3	458.5	141.7
1982	Jun	45.9	110.4	70.2
1982	Jul	82.8	147.4	58.1
1982	Aug	194.2	246.7	69.9
1982	Sep	74.3	175.2	145.0
1982	Oct	215.4	288.5	144.5
1982	Nov	221.5	280.8	248.7
1982	Dec	173.1	221.1	275.9
1983	Jan	68.4	64.4	54.0
1983	Feb	90.9	34.5	113.3
1983	Mar	78.3	79.9	115.2
1983	Apr	251.0	262.3	206.3
1983	May	111.1	214.2	49.4
1983	Jun	154.9	269.2	57.0
1983	Jul	96.2	236.1	54.1
1983	Aug	0.0	156.5	95.0

1983	Sep	0.0	250.1	111.6
1983	Oct	0.0	239.8	180.6
1983	Nov	0.0	128	120.8
1983	Dec	0.0	81.8	120.5
1984	Jan	104.3	88.3	105.0
1984	Feb	35.5	55.1	43.2
1984	Mar		51.4	17.0
1984	Apr	317.1	254	263.7
1984	May	119.8	152.3	43.1
1984	Jun	68.8	116	47.6
1984	Jul	99.5	134.1	96.0
1984	Aug	126.5	193.6	179.8
1984	Sep	110.6	85.4	98.0
1984	Oct	126.9	167.7	104.3
1984	Nov	153.3	284.6	90.0
1984	Dec	116.1	116.5	460.9
1985	Jan	74.8	93	0.0
1985	Feb	51.0	91.4	105.6
1985	Mar	168.4	177.9	311.7
1985	Apr	284.7	433.2	256.3
1985	May	204.7	207.8	135.8
1985	Jun	80.1	107.3	87.4
1985	Jul	171.5	227.3	82.3
1985	Aug	119.1	204.7	54.4
1985	Sep	68.4	185	55.1
1985	Oct	43.9	76	59.6
1985	Nov	125.4	94.8	196.7
1985	Dec	69.9	57.2	104.2
1986	Jan	4.1	60.8	96.0

1986	Feb	99.1	1.8	35.3
1986	Mar	90.6	31.7	59.0
1986	Apr	267.6	31.7	149.3
1986	May	151.1	26.7	181.9
1986	Jun	75.1	26.2	59.8
1986	Jul	132.7	4.2	65.2
1986	Aug	75.4	10	61.7
1986	Sep	82.3	17.9	58.7
1986	Oct	92.7	0	101.4
1986	Nov	72.0	10.7	155.2
1986	Dec	113.2	10	150.4
1987	Jan	80.7		86.0
1987	Feb	75.0		137.8
1987	Mar	137.2		154.4
1987	Apr	168.4		165.3
1987	May	182.0		213.9
1987	Jun	159.6		218.5
1987	Jul	126.5		67.2
1987	Aug	0.0	188.8	64.0
1987	Sep	84.1		92.3
1987	Oct	58.3		54.2
1987	Nov	112.0		211.1
1987	Dec	20.7		20.2
1988	Jan	230.2		125.0
1988	Feb	52.8		36.2
1988	Mar	168.5		173.2
1988	Apr	333.4		338.0
1988	May	291.4		138.7
1988	Jun	65.6		72.5

1988	Jul	169.5		78.4
1988	Aug	220.6		131.9
1988	Sep	114.6		60.1
1988	Oct	176.5		41.0
1988	Nov	100.0		120.8
1988	Dec	54.5		40.4
1989	Jan	21.6		113.0
1989	Feb	123.5		110.2
1989	Mar	229.7		120.6
1989	Apr	355.8		344.9
1989	May	305.3		126.3
1989	Jun	122.6		70.2
1989	Jul	0.0		0.0
1989	Aug	0.0		103.3
1989	Sep	181.5		110.1
1989	Oct	164.1		231.1
1989	Nov	99.9		112.1
1989	Dec	143.2		234.4
1990	Jan	97.2		55.0
1990	Feb	180.0		145.1
1990	Mar	342.2		273.6
1990	Apr	356.8		433.3
1990	May	356.7		163.9
1990	Jun	77.4		57.0
1990	Jul	184.3		42.0
1990	Aug	252.3		128.7
1990	Sep	96.2		66.1
1990	Oct	85.3		146.2
1990	Nov	148.7		61.0
1990	Dec	0.0		147.3

Average of Discharge					
YEAR	MONTH	Total	MONTH	MONTH	IJG01_DISCH
1960	1	9.755	Jan-60	Jan-60	9.755
	2	6.042	Feb-60	Feb-60	6.042
	3	20.860	Mar-60	Mar-60	20.860
	4	68.347	Apr-60	Apr-60	68.347
	5	62.360	May-60	May-60	62.360
	6	55.258	Jun-60	Jun-60	55.258
	7	36.542	Jul-60	Jul-60	36.542
	8	40.457	Aug-60	Aug-60	40.457
	9	78.734	Sep-60	Sep-60	78.734
	10	43.433	Oct-60	Oct-60	43.433
	11	23.204	Nov-60	Nov-60	23.204
	12	13.087	Dec-60	Dec-60	13.087
1961	1	5.955	Jan-61	Jan-61	5.955
	2	4.526	Feb-61	Feb-61	4.526
	3	4.320	Mar-61	Mar-61	4.320
	4	8.075	Apr-61	Apr-61	8.075
	5	23.580	May-61	May-61	23.580
	6	15.533	Jun-61	Jun-61	15.533
	7	10.284	Jul-61	Jul-61	10.284
	8	28.380	Aug-61	Aug-61	28.380
	9	45.609	Sep-61	Sep-61	45.609
	10	59.201	Oct-61	Oct-61	59.201
	11	250.034	Nov-61	Nov-61	250.034
	12		Dec-61	Dec-61	
1962	1	61.789	Jan-62	Jan-62	61.789
	2	26.693	Feb-62	Feb-62	26.693
	3	12.753	Mar-62	Mar-62	12.753

	4	32.660	Apr-62		Apr-62	32.660
	5	182.559	May-62		May-62	182.559
	6	111.862	Jun-62		Jun-62	111.862
	7	88.672	Jul-62		Jul-62	88.672
	8	68.158	Aug-62		Aug-62	68.158
	9		Sep-62		Sep-62	
	10		Oct-62		Oct-62	
	11	26.368	Nov-62		Nov-62	26.368
	12	17.891	Dec-62		Dec-62	17.891
1963	1	32.002	Jan-63		Jan-63	32.002
	2	25.047	Feb-63		Feb-63	25.047
	3	21.191	Mar-63		Mar-63	21.191
	4	73.967	Apr-63		Apr-63	73.967
	5	263.585	May-63		May-63	263.585
	6	118.356	Jun-63		Jun-63	118.356
	7	34.963	Jul-63		Jul-63	34.963
	8	49.712	Aug-63		Aug-63	49.712
	9	37.606	Sep-63		Sep-63	37.606
	10	10.974	Oct-63		Oct-63	10.974
	11	12.679	Nov-63		Nov-63	12.679
	12	88.139	Dec-63		Dec-63	88.139
1964	1	33.804	Jan-64		Jan-64	33.804
	2	13.080	Feb-64		Feb-64	13.080
	3	21.432	Mar-64		Mar-64	21.432
	4	184.379	Apr-64		Apr-64	184.379
	5	108.556	May-64		May-64	108.556
	6	49.010	Jun-64		Jun-64	49.010
	7	69.172	Jul-64		Jul-64	69.172
	8	71.972	Aug-64		Aug-64	71.972
	9	60.299	Sep-64		Sep-64	60.299

	10	75.706	Oct-64	Oct-64	75.706
	11	22.088	Nov-64	Nov-64	22.088
	12	11.418	Dec-64	Dec-64	11.418
1965	1	10.013	Jan-65	Jan-65	10.013
	2	6.350	Feb-65	Feb-65	6.350
	3	4.151	Mar-65	Mar-65	4.151
	4	32.411	Apr-65	Apr-65	32.411
	5	72.804	May-65	May-65	72.804
	6	23.559	Jun-65	Jun-65	23.559
	7	15.365	Jul-65	Jul-65	15.365
	8	16.345	Aug-65	Aug-65	16.345
	9	16.999	Sep-65	Sep-65	16.999
	10	11.805	Oct-65	Oct-65	11.805
	11	31.549	Nov-65	Nov-65	31.549
	12	22.135	Dec-65	Dec-65	22.135
1966	1	11.014	Jan-66	Jan-66	11.014
	2	11.297	Feb-66	Feb-66	11.297
	3	32.302	Mar-66	Mar-66	32.302
	4	89.433	Apr-66	Apr-66	89.433
	5	80.776	May-66	May-66	80.776
	6	33.269	Jun-66	Jun-66	33.269
	7	26.444	Jul-66	Jul-66	26.444
	8	24.560	Aug-66	Aug-66	24.560
	9	71.091	Sep-66	Sep-66	71.091
	10	24.067	Oct-66	Oct-66	24.067
	11	22.889	Nov-66	Nov-66	22.889
	12	11.818	Dec-66	Dec-66	11.818
1967	1	6.540	Jan-67	Jan-67	6.540
	2	4.355	Feb-67	Feb-67	4.355
	3	3.659	Mar-67	Mar-67	3.659

	4	16.980	Apr-67	Apr-67	16.980
	5	101.334	May-67	May-67	101.334
	6	64.220	Jun-67	Jun-67	64.220
	7	72.993	Jul-67	Jul-67	72.993
	8	34.218	Aug-67	Aug-67	34.218
	9	30.815	Sep-67	Sep-67	30.815
	10	16.989	Oct-67	Oct-67	16.989
	11	18.545	Nov-67	Nov-67	18.545
	12	54.759	Dec-67	Dec-67	54.759
1968	1	15.327	Jan-68	Jan-68	15.327
	2	17.166	Feb-68	Feb-68	17.166
	3	51.297	Mar-68	Mar-68	51.297
	4	122.846	Apr-68	Apr-68	122.846
	5	160.672	May-68	May-68	160.672
	6	92.515	Jun-68	Jun-68	92.515
	7	56.946	Jul-68	Jul-68	56.946
	8	93.614	Aug-68	Aug-68	93.614
	9	46.806	Sep-68	Sep-68	46.806
	10	17.741	Oct-68	Oct-68	17.741
	11	29.277	Nov-68	Nov-68	29.277
	12	93.182	Dec-68	Dec-68	93.182
1969	1	22.758	Jan-69	Jan-69	22.758
	2	48.983	Feb-69	Feb-69	48.983
	3	39.465	Mar-69	Mar-69	39.465
	4	29.829	Apr-69	Apr-69	29.829
	5	37.431	May-69	May-69	37.431
	6	23.757	Jun-69	Jun-69	23.757
	7	14.171	Jul-69	Jul-69	14.171
	8	16.952	Aug-69	Aug-69	16.952
	9	34.900	Sep-69	Sep-69	34.900

	10	14.168	Oct-69	Oct-69	14.168
	11	9.575	Nov-69	Nov-69	9.575
	12	6.875	Dec-69	Dec-69	6.875
1970	1	14.377	Jan-70	Jan-70	14.377
	2	22.529	Feb-70	Feb-70	22.529
	3	66.758	Mar-70	Mar-70	66.758
	4	126.335	Apr-70	Apr-70	126.335
	5	115.537	May-70	May-70	115.537
	6	82.515	Jun-70	Jun-70	82.515
	7	42.561	Jul-70	Jul-70	42.561
	8	79.977	Aug-70	Aug-70	79.977
	9	79.506	Sep-70	Sep-70	79.506
	10	59.106	Oct-70	Oct-70	59.106
	11	27.212	Nov-70	Nov-70	27.212
	12	13.324	Dec-70	Dec-70	13.324
1971	1	10.571	Jan-71	Jan-71	10.571
	2	6.855	Feb-71	Feb-71	6.855
	3	4.610	Mar-71	Mar-71	4.610
	4	11.212	Apr-71	Apr-71	11.212
	5	41.804	May-71	May-71	41.804
	6	67.840	Jun-71	Jun-71	67.840
	7	63.840	Jul-71	Jul-71	63.840
	8	92.381	Aug-71	Aug-71	92.381
	9	90.642	Sep-71	Sep-71	90.642
	10	46.101	Oct-71	Oct-71	46.101
	11	16.809	Nov-71	Nov-71	16.809
	12	10.161	Dec-71	Dec-71	10.161
1972	1	10.947	Jan-72	Jan-72	10.947
	2	9.286	Feb-72	Feb-72	9.286
	3	7.444	Mar-72	Mar-72	7.444

	4	7.672	Apr-72	Apr-72	7.672
	5	27.066	May-72	May-72	27.066
	6	41.739	Jun-72	Jun-72	41.739
	7	45.079	Jul-72	Jul-72	45.079
	8	44.352	Aug-72	Aug-72	44.352
	9	26.686	Sep-72	Sep-72	26.686
	10	19.836	Oct-72	Oct-72	19.836
	11	74.407	Nov-72	Nov-72	74.407
	12	47.355	Dec-72	Dec-72	47.355
1973	1	43.608	Jan-73	Jan-73	43.608
	2	32.374	Feb-73	Feb-73	32.374
	3	20.080	Mar-73	Mar-73	20.080
	4	12.260	Apr-73	Apr-73	12.260
	5	33.295	May-73	May-73	33.295
	6	85.527	Jun-73	Jun-73	85.527
	7	22.819	Jul-73	Jul-73	22.819
	8	48.905	Aug-73	Aug-73	48.905
	9	62.931	Sep-73	Sep-73	62.931
	10	36.363	Oct-73	Oct-73	36.363
	11	30.034	Nov-73	Nov-73	30.034
	12	13.333	Dec-73	Dec-73	13.333
1974	1	7.120	Jan-74	Jan-74	7.120
	2	4.510	Feb-74	Feb-74	4.510
	3	5.717	Mar-74	Mar-74	5.717
	4	72.192	Apr-74	Apr-74	72.192
	5	51.228	May-74	May-74	51.228
	6	56.513	Jun-74	Jun-74	56.513
	7	130.995	Jul-74	Jul-74	130.995
	8	68.462	Aug-74	Aug-74	68.462
	9	55.263	Sep-74	Sep-74	55.263

	10	42.873	Oct-74	Oct-74	42.873
	11	24.269	Nov-74	Nov-74	24.269
	12	11.013	Dec-74	Dec-74	11.013
1975	1	6.473	Jan-75	Jan-75	6.473
	2	2.920	Feb-75	Feb-75	2.920
	3	5.491	Mar-75	Mar-75	5.491
	4	28.773	Apr-75	Apr-75	28.773
	5	33.087	May-75	May-75	33.087
	6	50.513	Jun-75	Jun-75	50.513
	7	43.261	Jul-75	Jul-75	43.261
	8	94.441	Aug-75	Aug-75	94.441
	9	137.200	Sep-75	Sep-75	137.200
	10	81.946	Oct-75	Oct-75	81.946
	11	37.585	Nov-75	Nov-75	37.585
	12	14.416	Dec-75	Dec-75	14.416
1976	1	8.892	Jan-76	Jan-76	8.892
	2	6.143	Feb-76	Feb-76	6.143
	3	5.370	Mar-76	Mar-76	5.370
	4	8.435	Apr-76	Apr-76	8.435
	5	23.164	May-76	May-76	23.164
	6	41.457	Jun-76	Jun-76	41.457
	7	58.080	Jul-76	Jul-76	58.080
	8	52.144	Aug-76	Aug-76	52.144
	9	73.095	Sep-76	Sep-76	73.095
	10	21.736	Oct-76	Oct-76	21.736
	11	11.254	Nov-76	Nov-76	11.254
	12	8.896	Dec-76	Dec-76	8.896
1977	1	11.667	Jan-77	Jan-77	11.667
	2	24.022	Feb-77	Feb-77	24.022
	3	13.906	Mar-77	Mar-77	13.906

	4	90.149	Apr-77	Apr-77	90.149
	5	164.147	May-77	May-77	164.147
	6	81.369	Jun-77	Jun-77	81.369
	7	114.198	Jul-77	Jul-77	114.198
	8	78.336	Aug-77	Aug-77	78.336
	9	55.369	Sep-77	Sep-77	55.369
	10	26.119	Oct-77	Oct-77	26.119
	11	109.792	Nov-77	Nov-77	109.792
	12	78.267	Dec-77	Dec-77	78.267
1978	1	30.441	Jan-78	Jan-78	30.441
	2	18.971	Feb-78	Feb-78	18.971
	3	196.233	Mar-78	Mar-78	196.233
	4	198.059	Apr-78	Apr-78	198.059
	5	156.002	May-78	May-78	156.002
	6	42.884	Jun-78	Jun-78	42.884
	7	58.504	Jul-78	Jul-78	58.504
	8	55.864	Aug-78	Aug-78	55.864
	9	70.389	Sep-78	Sep-78	70.389
	10	73.827	Oct-78	Oct-78	73.827
	11	40.110	Nov-78	Nov-78	40.110
	12	28.526	Dec-78	Dec-78	28.526
1979	1	21.277	Jan-79	Jan-79	21.277
	2	69.639	Feb-79	Feb-79	69.639
	3	48.036	Mar-79	Mar-79	48.036
	4	69.374	Apr-79	Apr-79	69.374
	5	92.778	May-79	May-79	92.778
	6	75.237	Jun-79	Jun-79	75.237
	7	52.140	Jul-79	Jul-79	52.140
	8	63.440	Aug-79	Aug-79	63.440
	9	35.268	Sep-79	Sep-79	35.268

	10	18.692	Oct-79	Oct-79	18.692
	11		Nov-79	Nov-79	
	12	7.299	Dec-79	Dec-79	7.299
1980	1	5.877	Jan-80	Jan-80	5.877
	2	5.237	Feb-80	Feb-80	5.237
	3	7.709	Mar-80	Mar-80	7.709
	4	4.782	Apr-80	Apr-80	4.782
	5	47.290	May-80	May-80	47.290
	6	54.749	Jun-80	Jun-80	54.749
	7	64.514	Jul-80	Jul-80	64.514
	8	33.425	Aug-80	Aug-80	33.425
	9	32.264	Sep-80	Sep-80	32.264
	10	13.889	Oct-80	Oct-80	13.889
	11	13.576	Nov-80	Nov-80	13.576
	12	9.548	Dec-80	Dec-80	9.548
1981	1	5.221	Jan-81	Jan-81	5.221
	2	6.229	Feb-81	Feb-81	6.229
	3	12.517	Mar-81	Mar-81	12.517
	4	141.980	Apr-81	Apr-81	141.980
	5	93.615	May-81	May-81	93.615
	6	33.390	Jun-81	Jun-81	33.390
	7	40.371	Jul-81	Jul-81	40.371
	8	79.430	Aug-81	Aug-81	79.430
	9	62.321	Sep-81	Sep-81	62.321
	10	33.655	Oct-81	Oct-81	33.655
	11	23.313	Nov-81	Nov-81	23.313
	12		Dec-81	Dec-81	
1982	1		Jan-82	Jan-82	
	2		Feb-82	Feb-82	
	3		Mar-82	Mar-82	

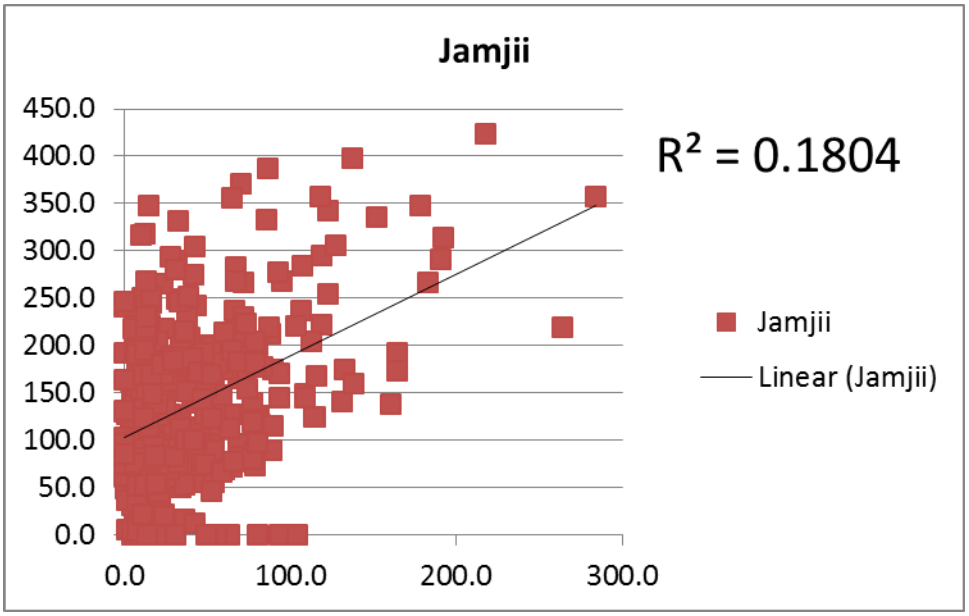
	4		Apr-82	Apr-82	
	5		May-82	May-82	
	6	62.885	Jun-82	Jun-82	62.885
	7	36.889	Jul-82	Jul-82	36.889
	8	65.021	Aug-82	Aug-82	65.021
	9	50.137	Sep-82	Sep-82	50.137
	10	35.849	Oct-82	Oct-82	35.849
	11	122.450	Nov-82	Nov-82	122.450
	12	164.390	Dec-82	Dec-82	164.390
1983	1	26.784	Jan-83	Jan-83	26.784
	2	11.731	Feb-83	Feb-83	11.731
	3	7.494	Mar-83	Mar-83	7.494
	4	16.694	Apr-83	Apr-83	16.694
	5	45.500	May-83	May-83	45.500
	6	50.570	Jun-83	Jun-83	50.570
	7	42.835	Jul-83	Jul-83	42.835
	8	55.078	Aug-83	Aug-83	55.078
	9	107.750	Sep-83	Sep-83	107.750
	10	80.177	Oct-83	Oct-83	80.177
	11	51.849	Nov-83	Nov-83	51.849
	12	24.575	Dec-83	Dec-83	24.575
1984	1	14.402	Jan-84	Jan-84	14.402
	2	7.812	Feb-84	Feb-84	7.812
	3	5.760	Mar-84	Mar-84	5.760
	4	10.511	Apr-84	Apr-84	10.511
	5	12.474	May-84	May-84	12.474
	6	9.042	Jun-84	Jun-84	9.042
	7	9.533	Jul-84	Jul-84	9.533
	8	27.327	Aug-84	Aug-84	27.327
	9	30.657	Sep-84	Sep-84	30.657

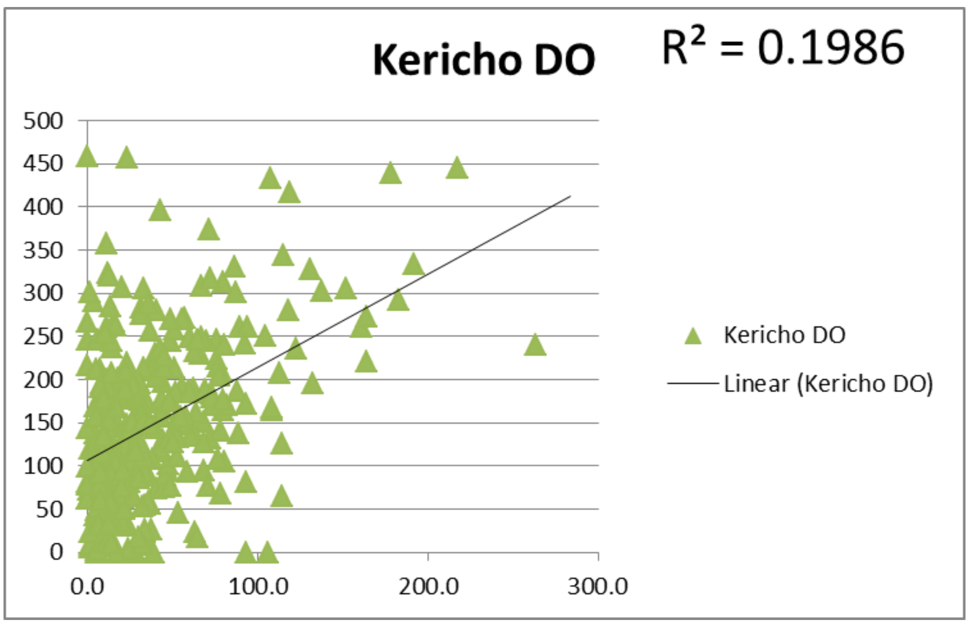
	10	17.541	Oct-84	Oct-84	17.541
	11	13.590	Nov-84	Nov-84	13.590
	12	28.831	Dec-84	Dec-84	28.831
1985	1	8.374	Jan-85	Jan-85	8.374
	2	8.509	Feb-85	Feb-85	8.509
	3	9.714	Mar-85	Mar-85	9.714
	4	111.067	Apr-85	Apr-85	111.067
	5	112.525	May-85	May-85	112.525
	6	79.415	Jun-85	Jun-85	79.415
	7	44.843	Jul-85	Jul-85	44.843
	8	77.427	Aug-85	Aug-85	77.427
	9	62.094	Sep-85	Sep-85	62.094
	10	20.309	Oct-85	Oct-85	20.309
	11	21.406	Nov-85	Nov-85	21.406
	12	13.768	Dec-85	Dec-85	13.768
1986	1	7.737	Jan-86	Jan-86	7.737
	2	6.768	Feb-86	Feb-86	6.768
	3	6.695	Mar-86	Mar-86	6.695
	4	13.085	Apr-86	Apr-86	13.085
	5	37.361	May-86	May-86	37.361
	6	35.307	Jun-86	Jun-86	35.307
	7	24.376	Jul-86	Jul-86	24.376
	8	32.203	Aug-86	Aug-86	32.203
	9	31.154	Sep-86	Sep-86	31.154
	10	17.522	Oct-86	Oct-86	17.522
	11	11.438	Nov-86	Nov-86	11.438
	12	14.357	Dec-86	Dec-86	14.357
1987	1	8.909	Jan-87	Jan-87	8.909
	2	6.673	Feb-87	Feb-87	6.673
	3	19.766	Mar-87	Mar-87	19.766

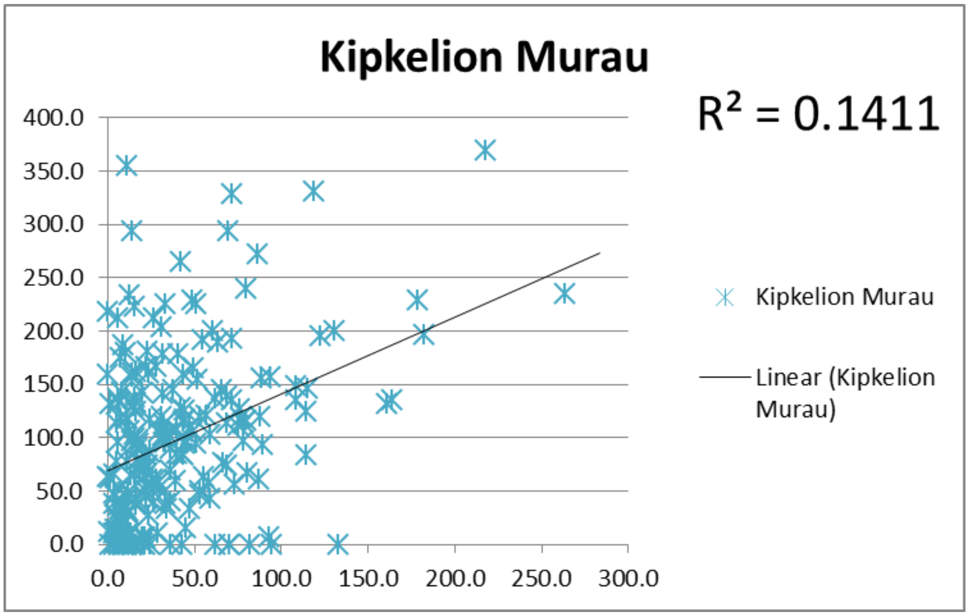
	4	24.912	Apr-87	Apr-87	24.912
	5	68.550	May-87	May-87	68.550
	6	142.794	Jun-87	Jun-87	142.794
	7	48.295	Jul-87	Jul-87	48.295
	8	22.879	Aug-87	Aug-87	22.879
	9	19.335	Sep-87	Sep-87	19.335
	10	14.931	Oct-87	Oct-87	14.931
	11	34.657	Nov-87	Nov-87	34.657
	12	24.061	Dec-87	Dec-87	24.061
1988	1	13.465	Jan-88	Jan-88	13.465
	2	12.885	Feb-88	Feb-88	12.885
	3	16.156	Mar-88	Mar-88	16.156
	4	88.747	Apr-88	Apr-88	88.747
	5	190.702	May-88	May-88	190.702
	6	60.325	Jun-88	Jun-88	60.325
	7	52.177	Jul-88	Jul-88	52.177
	8	102.865	Aug-88	Aug-88	102.865
	9	92.720	Sep-88	Sep-88	92.720
	10	83.529	Oct-88	Oct-88	83.529
	11	37.855	Nov-88	Nov-88	37.855
	12	19.296	Dec-88	Dec-88	19.296
1989	1	10.951	Jan-89	Jan-89	10.951
	2	12.331	Feb-89	Feb-89	12.331
	3	13.175	Mar-89	Mar-89	13.175
	4	66.527	Apr-89	Apr-89	66.527
	5	127.246	May-89	May-89	127.246
	6	54.163	Jun-89	Jun-89	54.163
	7	30.602	Jul-89	Jul-89	30.602
	8	49.006	Aug-89	Aug-89	49.006
	9	81.533	Sep-89	Sep-89	81.533

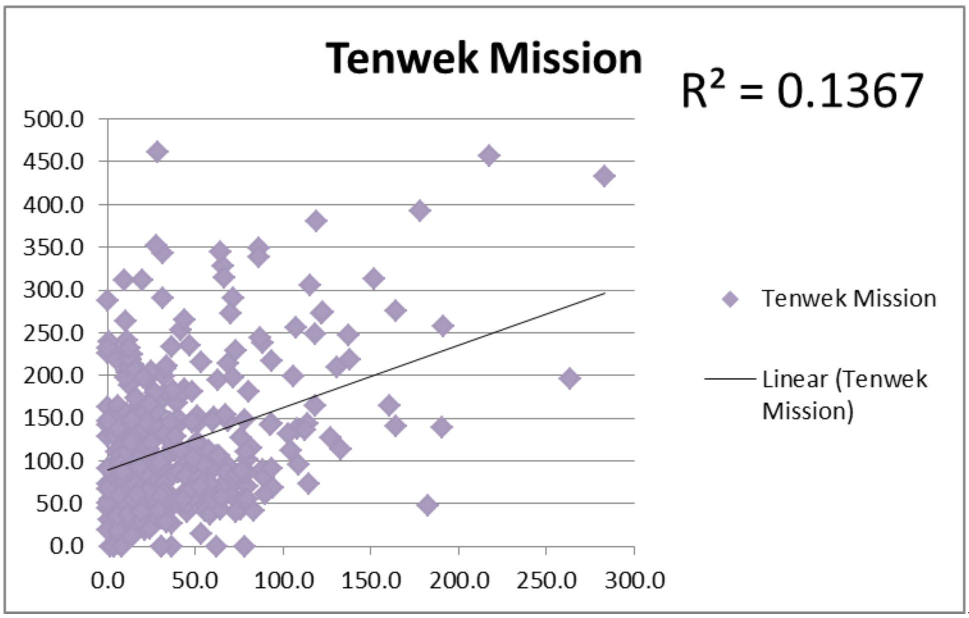
	10		Oct-89	Oct-89	
	11	44.753	Nov-89	Nov-89	44.753
	12	46.566	Dec-89	Dec-89	46.566
1990	1	79.940	Jan-90	Jan-90	79.940
	2	24.433	Feb-90	Feb-90	24.433
	3	122.692	Mar-90	Mar-90	122.692
	4	293.017	Apr-90	Apr-90	293.017
	5	118.127	May-90	May-90	118.127
	6	67.604	Jun-90	Jun-90	67.604
	7	29.509	Jul-90	Jul-90	29.509
	8	38.506	Aug-90	Aug-90	38.506
	9		Sep-90	Sep-90	
	10		Oct-90	Oct-90	
	11	18.308	Nov-90	Nov-90	18.308
	12	13.814	Dec-90	Dec-90	13.814

Appendix 2: Graphs showing correlation of different Rainfall station



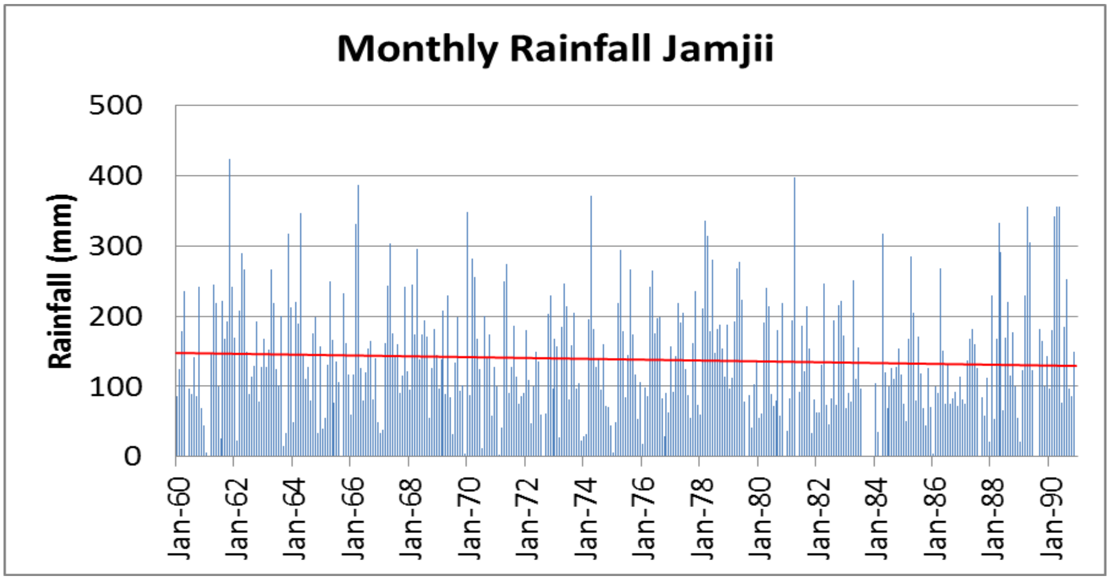


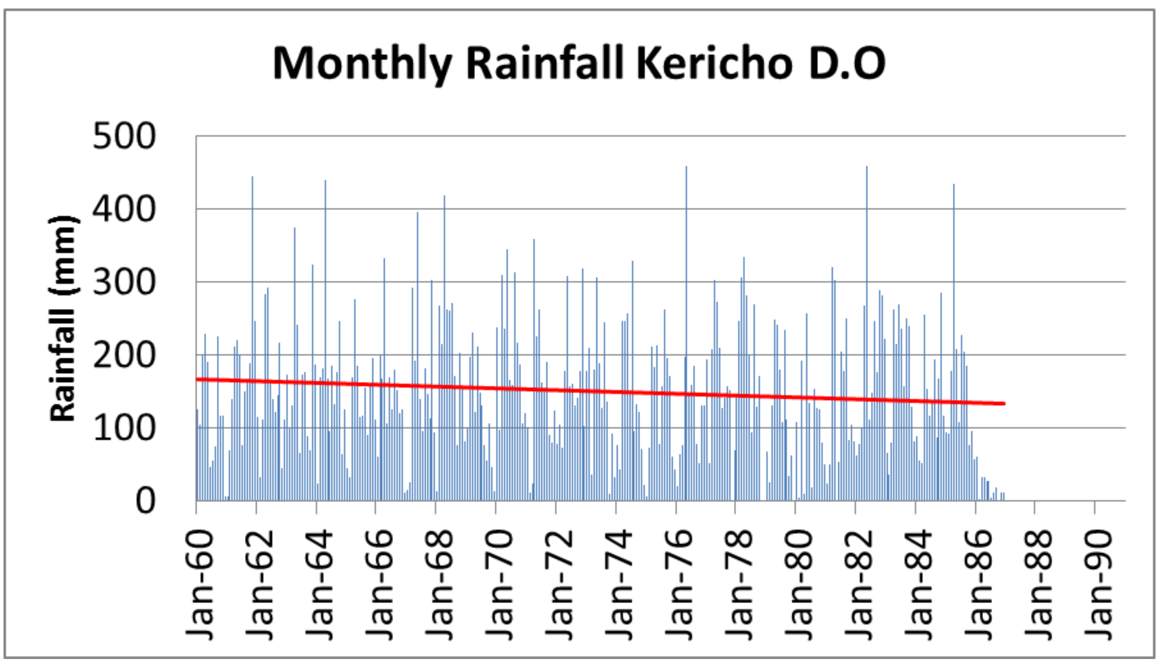

Kipkelion Murau
$R^2 = 0.1411$
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
Kipkelion Murau
Linear (Kipkelion Murau)

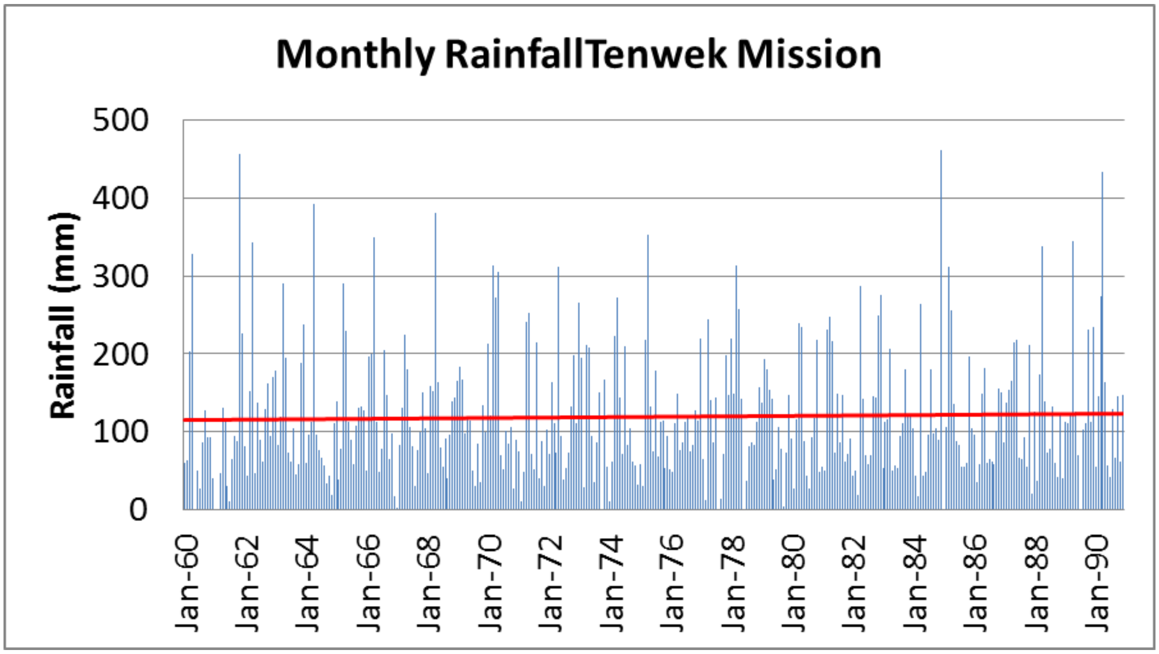

Tenwek Mission
$R^2 = 0.1367$
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
Tenwek Mission
Linear (Tenwek Mission)

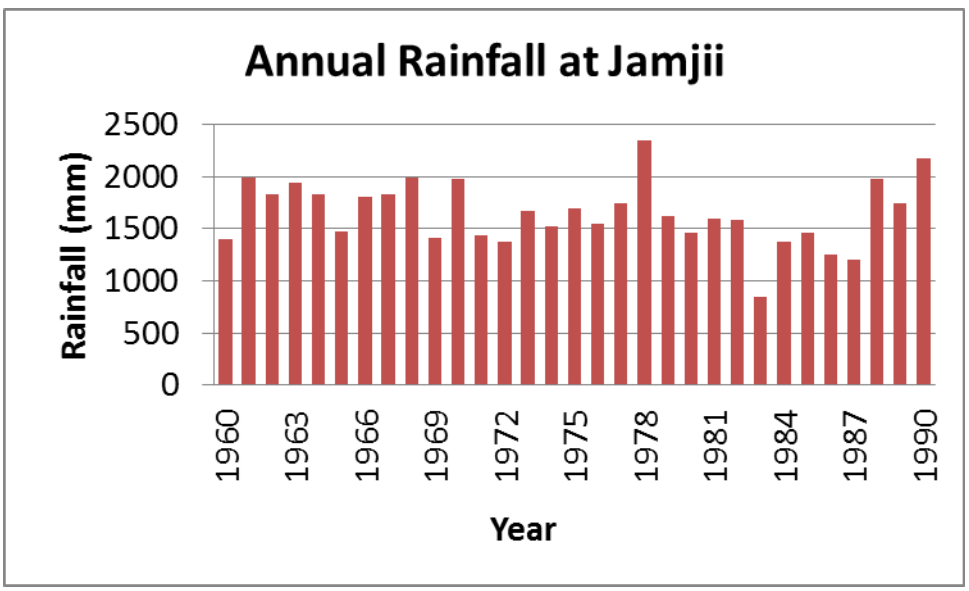
Appendix 3

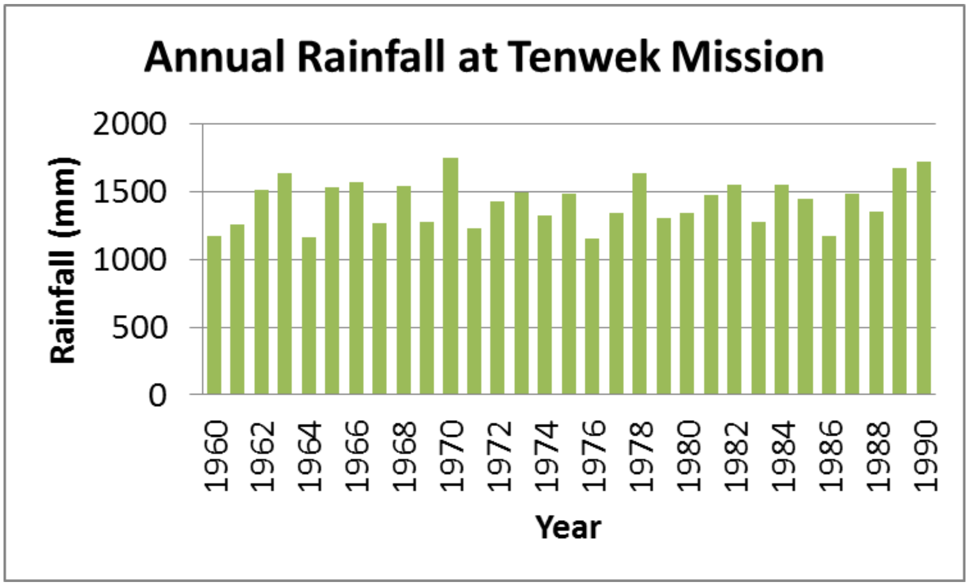
Appendix3: Graphs showing Time series Analysis of Rainfall and Discharge in the Study Area.

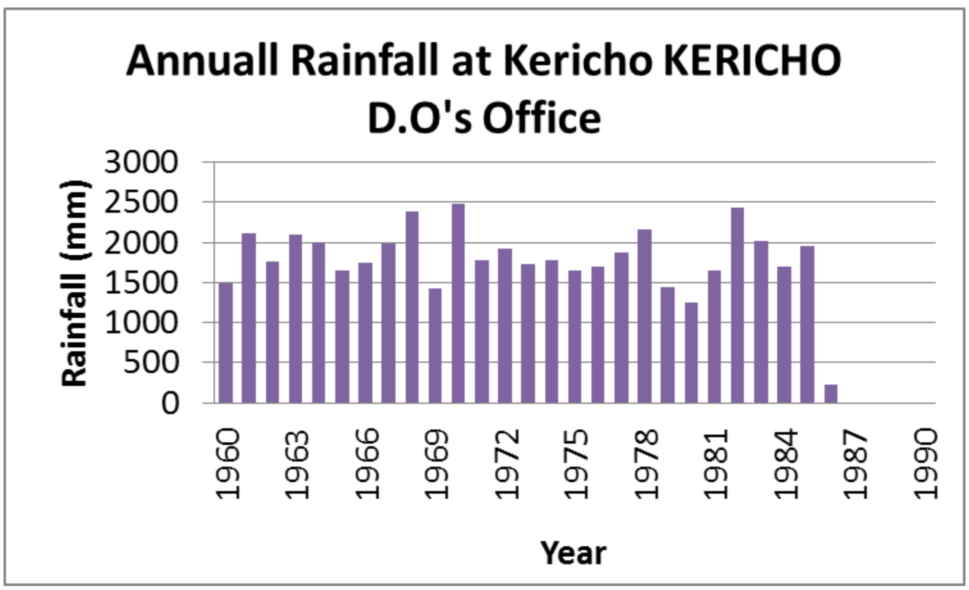


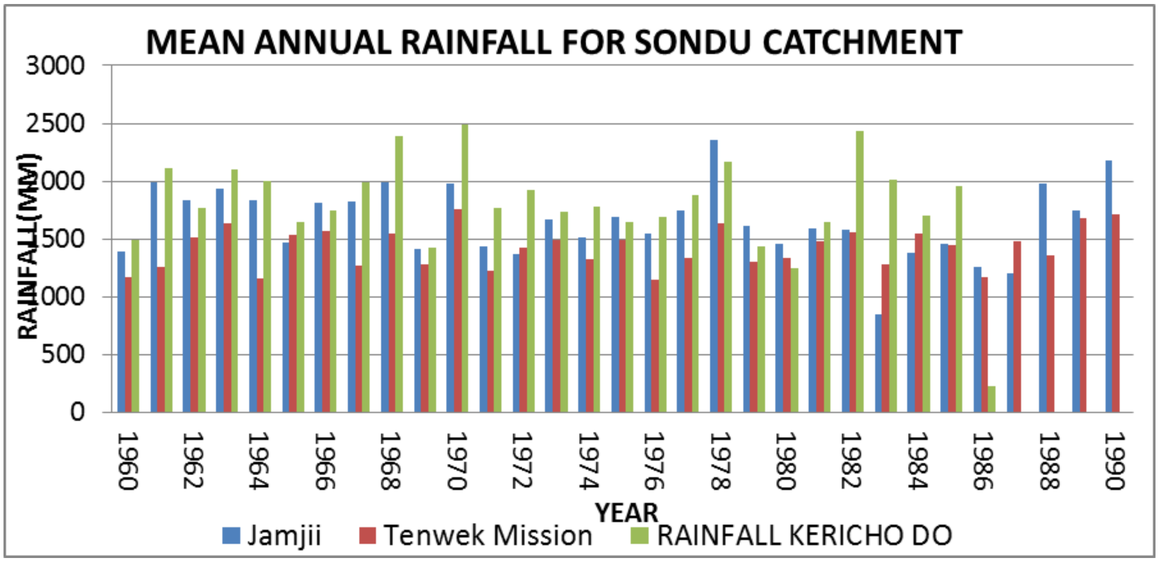



Monthly RainfallTenwek Mission
Rainfall (mm)
500
400
300
200
100
0
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90


Annual Rainfall at Jamjii
Rainfall (mm)
2500
2000
1500
1000
500
0
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
Year


Annual Rainfall at Tenwek Mission
Rainfall (mm)
2000
1500
1000
500
0
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
Year


Annuall Rainfall at Kericho KERICHO D.O's Office
Rainfall (mm)
3000
2500
2000
1500
1000
500
0
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
Year



MEAN ANNUAL RAINFALL FOR SONDU CATCHMENT
3000
2500
2000
1500
1000
500
0
RAINFALL(MM)
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
YEAR
Jamjii
Tenwek Mission
RAINFALL KERICHO DO