UNIVERSITY OF NAIROBI

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DEPARTMENT OF METEOROLOGY

ASSESSMENT OF THE AVAILABILITY OF WATER FOR LIVESTOCK USE IN THE MARA RIVER BASIN

BY

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DECLARATION

This project is my original work and has not been presented for a PGD or any other academic qualification in this university or any other academic institution.

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DEDICATION

First and foremost, my dedications go to The Almighty God for giving me good health, wisdom and endurance throughout the study period.

Secondly, I dedicate it to my beloved family members, for their financial support, patience, understanding and encouragement throughout the study period.

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Finally my sincere gratitude goes to all my course mates who were the most important part of my life, while undertaking this project.

May God bless them abundantly.

ABSTRACT

The study was set out to assess the availability of water mainly for livestock use over Mara river basin. The basin rainfall pattern was compared to the Mara river (main ecological river in the basin) flow. The study was necessitated by the fact that about 62% of the households are smallholder farmers, with livestock rearing being the second dominant activity for social-economic development. Livestock and human populations as well as climate variability were cross checked from previous studies. The Mara River is the most ecologically significant river in the region. Meeting the water demands of the different sectors while maintaining a healthy environment ,requires understanding of the hydrology (water flux) and the major hydro meteorological processes responsible for the changes in the water balance.

Historical analysis of the rainfall information has shown that the annual rainfall amount did not change significantly but the seasonal and monthly distribution varied over the study period. The upper basin has shown little variability in the monthly mean rainfall amount as the lower. Analysis of the flow records now shows minimum and mean flows of the basin having positive trends as shown by both Amala and Nyangores in figures 9 and 10. The Amala's flow was much lesser than the adjacent Nyangores basin of a similar drainage area (figure 7) attributed to the areas of traverse

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SPI - Standardized Precipitation Index
TIWRMD –Transboundary Integrated Water Resource Development and Management

MRB – Mara River Basin

WEAP –Water Evaporation and Planning System

GCM-General Circulation Models

MAM- March-April-May Season

OND-October-November-December Season

WWF- World Wide Fund for Nature

CHAPTER ONE

This entails the general overview of the study, with introduction of problem addressed, the objectives alongside justification why the study was undertaken.

1.0 INTRODUCTION

Water availability describes a situation where there is sufficient water for use by livestock and able to sustain normal livestock production without interrupting other social-economic activities pegged on water .Wetlands in the Mara river basin depended on for the availability of adequate quality and quantity of water are under strain. Understanding the hydrology and the major hydro meteorological processes responsible for changes in the water balance is paramount in order to meet the water demands of various sectors while environmental health is maintained.

Recent studies showed that climate change, socio-economic activities, population growth, water pollution and the huge water abstraction are the main challenges that altered the natural hydrologic regime of the Mara River. The socio-economic activities have converted some forest lands for agriculture and urban uses for example in Mau forest complex and encroachment of reserved lands such as parks and National Reserves to feed the overstocked livestock. Other climate change studies conducted using General Circulation Models (GCM) showed that the basin will experience an increase in annual river volume and rainfall amounts with wetter rainy seasons and drier dry seasons. The variability will result in higher peak flows in the wet period and lower flows in the drier months (Osoro et al., 2018).

1.0.1 Livestock and the basin economy

Livestock production is the second important economic activity behind agriculture, and consists mainly of cattle, goats, and sheep (Yanda and Majule, 2004). Small and middle scale livestock rearing as well as extensive ranching is carried out in the upper region of the basin within the group ranches. Small and middle scale livestock rearing consists of pastoral herdsman, like the local Maasai tribesmen of Narok County, who herd their cattle based on environmental conditions, in search of both adequate grazing grounds and water supplies (Hoffman, 2007). The water demand in the basin is on the rise putting water in the basin under strain. The basin’s population growths for both people and livestock have resulted in larger water demand (Mati et al., 2008).

In the recent past the rearing of livestock has become almost untenable. The study aimed at assessing the water presence for livestock use in the basin is thus relevant. This involved the analyzing of the historical hydro meteorological data of the basin. This study was aimed at understanding the trends of Nyangores and Amala sub-basins flows with an attempt to incorporate them to help in planning, management and utilization of water resource.

1.1 STATEMENT OF THE PROBLEM

Agriculture, livestock, and wildlife activities in the highlands are favored by high, reliable, well-distributed rainfall and the fertile soils in such areas which have attracted heavy migration into the basin exerting high pressure on the limited land and water resources. Such resulting pressure on the land, water, pasture and other resources have led to many conflicts between the crop and livestock farmers since livestock farmers choose to graze their animals on other people's crop farms.

Livestock rearing in the Mara river basin is increasingly becoming untenable due to changing rainfall patterns (E.Mbogo et al.). The unprecedented changes have led to increased livestock fatalities, partly due to late responses by government agencies, ranch managers and individuals. This is caused by shifts in a bimodal rainfall pattern of wet and short rains that occur in March –June and September-December. Poverty index soars since livestock rearing takes second position. Conflicts between neighbors are ripe often leading to fights, loss of lives and destruction of property. When normal conditions resume cattle rustling is inevitable for restocking, often resulting in tribal strives.

Various studies carried out in the basin affirm the increased level of water insufficiency along the basin but no information on the distribution of the water resource has been given. This has led to increased livestock fatalities in the pastoralists' community and ranches practiced within the basin. The community still relies on the previous study by Lake Victoria Basin Authority with the support of WWF and USAID (Assessing Reserve Flows, 2010) which confirmed two annual peaks in flow levels in March-June and November–December associated with the MAM and OND long and short rains respectively. The shifts in rainfall pattern over the basin are apparent calling for a study to assess such occurrences for socio-economic sustainability for a better future.

This study was therefore aimed at accessing these shifts and consequently examining the observed trends in order to help in planning and formulation of control measures and policy governing proper use of water resources. The mean rainfall values of the basin vary from 600mm/yr on the plains, to 1400mm/yr on the highlands.

1.2 JUSTIFICATION

Livestock farmers constitute 62% of the inhabitants, so to the basin's economy (Water Resource and Energy Management (WREM). 2008). This can only thrive well if lasting solutions for ever reducing water availability in the basin are found.

The Mara River Basin Monograph which is a key output of the Mara Transboundary Integrated Water Resources Development and Management (TIWRDM) Project which was aimed at developing a comprehensive information and knowledge based on existing conditions in the basin that could guide future planning and development initiatives does not include the contribution of rainfall patterns to the increased water insufficiency.

It is therefore critical to adequately understand the causes and the trends in water deficiency in order to support individuals or water managers make realistic water use and conservation plans. This study will therefore be a milestone towards achieving better water resource management plans.

1.3 OBJECTIVES

Main objective of this study was to assess water availability for livestock use in the Mara river basin.

Specific objectives were:

i) To determine the monthly rainfall patterns over the basin

ii) To determine monthly stream flow patterns in the basin

iii) Determination of relationship between rainfall and stream flow patterns.

1.4 STUDY AREA

1.4.1 The background of Mara river basin

The study was done on The Mara river basin shared between Kenya and Tanzania covering seven districts namely: Nakuru, Bomet, Narok and Transmara in Kenya as well as Serengeti, Tarime and Musoma Rural in Tanzania. It is on the following dimensions; latitudes 0.331573^0S and 1.975056^0S and longitudes 33.88372^0E and 35.907682^0E. The catchment area of the basin is about 13,750 km^2 and is 395km long, divided into 65 %(8,941km^2) upper and 35 %(4,809km^2) lower basins in Kenya and Tanzania respectively.

Mara River is the most important river in the basin. It originates from the Enapuyapui swamp at 3000m above sea level in Mau Escarpment in Kenya meandering through different ecosystems eventually into L.Victoria through Musoma Bay of Tanzania. Amala, Nyangores, Talek, Sand and Engare Engito on Kenyan side, and Bologonja river of Tanzania are the major tributaries of Mara River. Amala and Nyangores sub-basins being focus of this study form the upper part of the Mara river basin thus forming the main sources of water throughout the year. Figure1 below shows the location and some features of the Mara river basin.

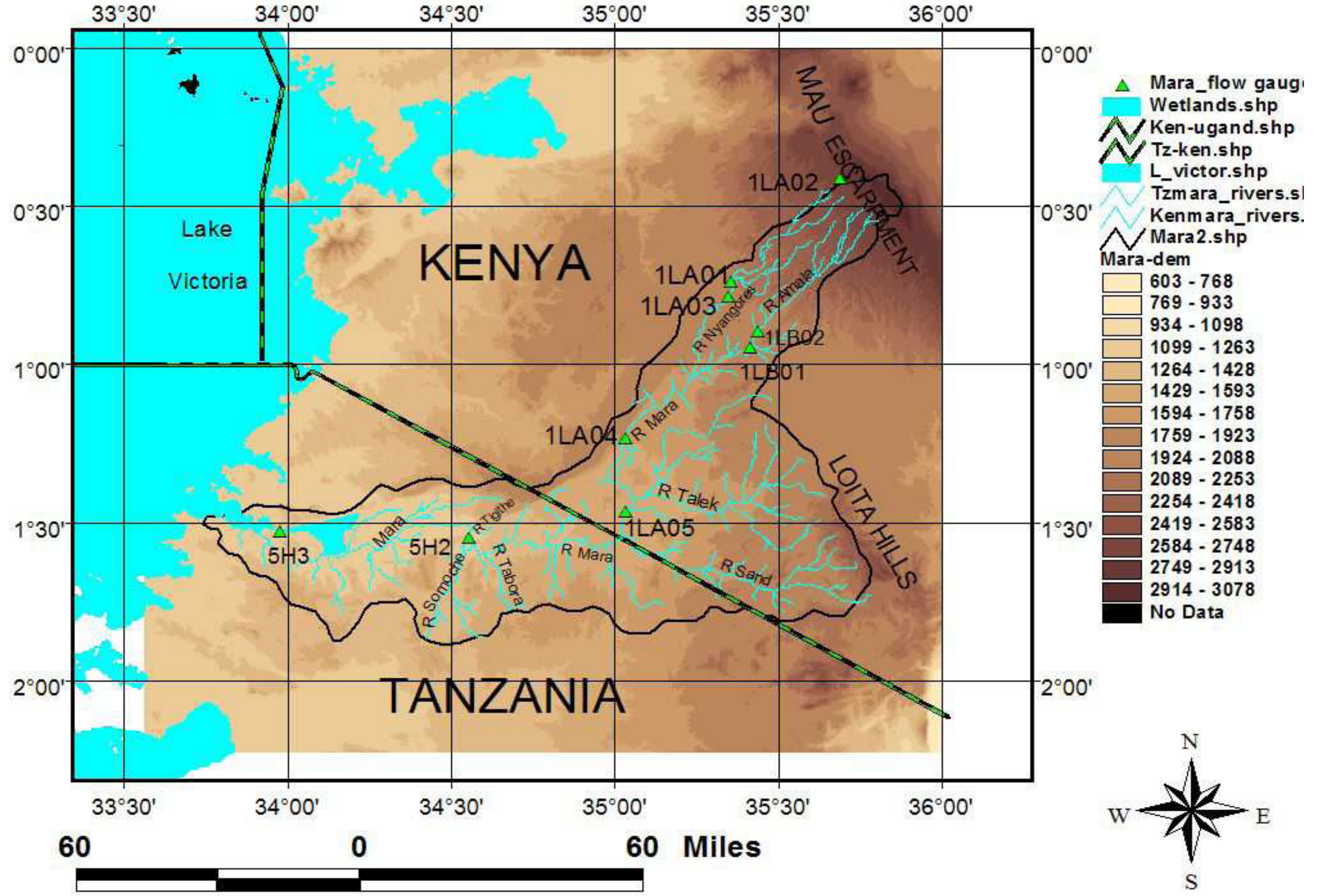

Figure1: Map showing the Mara River Basin (Source.Google map).

The mean annual precipitation ranges from 500mm in the south to around 1750mm at the northern and western parts of the basin.

1.4.2 The climatology of the basin

The basin experiences a bimodal rainfall seasons, long season lasting six weeks from March to May (MAM) in which the maximum precipitations begin in March through to June cresting in April and the latter short season lasting for about two weeks from October to December (OND) in which the short precipitations occur as early as September. The mean annual precipitation ranges from 500 mm in the south to around 1750 mm at the northern and the western parts of the basin. Further analysis on basin's rainfall placed the wettest month at April, and driest at July.

Temperatures are slightly higher from October to March, and cooler between June and September. The mean annual temperature of the basin is 25^{o}C**.** The high evaporation in the lower plain makes it dry (Valimba et al., 2004). Sunshine is good year round due to often clear skies. Cloudiness at times however, leads to thunderstorms.

CHAPTER TWO

LITERATURE REVIEW

1.0 Introduction

Water availability described a situation where there was sufficient water for livestock use sustaining normal livestock production and all social-economic activities. The study is confined to a time of low flow, identified to be between February and March as indicated by fig.7 for Amala and Nyangores rivers respectively. **(**Mango et al., 2010) studied the 'Land use and climate change impacts on the hydrology of the upper Mara river basin, Kenya' where they found out that, the flow of the Mara river has become erratic during the recent years. This is notable especially in the upper region, and the lack of understanding of the relative influence of different sources of flow alteration has hampered resource managers. Water is considered a critical resource in Kenya and the Mara river basin, central not only to ecosystems conservation but also to the development of agriculture, livestock production, and other important economic activities as well.

With erratic nature and water being a critical resource in the basin with an annual average rainfall of 500mm and population of about 1.1 million people with the growth rate of 2.7% (2002 census) , River Mara basin is a water scarce region (WRI, 2007) in which this crucial resource scarcity requires its proper management based on reliable information on rainfall and stream flows. The models that evaluate scenarios of changing land use and climate should be included in the information.

Petra Hulsman(April 2015) studied the main areas contributing to the suspended sediment loads in the Mara river, Kenya and found out that besides water scarcity, water quality is declining due to these suspended sediment loads. He relied on previous studies to achieve various findings. For example, the study carried out on 'Environmental Flow Assessments' (EFA) aimed at determining the minimum flow levels to ensure healthy river system. On invoking the study on water quality (Subalusky, 2011), he found that the water quality has declined in the past 15 years especially during extreme low flows when the quality is very poor. It is imperative to note that by comparing these minimum levels to the actual ones, it is found that during droughts the water availability is critical or even insufficient (LVBC, 2012).

2.1 Livestock water demand

Osoro et al., (2018) on their case study of the Mara river basin, Kenya on water demand simulation using WEAP 21 found that, the water demand for livestock which included cattle, sheep, goats, camels, and donkeys, is bound to increase gradually as a result of increasing livestock population more specifically in cows and goats. This corroborated the study which showed this larger water demand is caused by increased populations of both people and livestock (Mati et al., 2008). This situation might become even severe as the water demand has increased by about 40% between 2000 and 2010(Khroda, 2006). With the increasing demand, rainfall and stream flow patterns within the Mara river basin should be comprehensively understood for better management.

2.2 Mara river basin economic activities

Water Resources and Energy Management (WREM) International Inc(2008) The Mara river basin transboundary integrated water resource management project study found that in the Mara river basin, about 62% of the households are small holder farmers, with livestock rearing being the second dominant economic activity behind crop farming. Poor agricultural practices have led to decline in water quality and excessive abstractions have led to decline in water quantities. These issues notwithstanding, the basin is well endowed with natural resources which, if managed and developed sustainably, can become an engine of social economic development. This was the main objective of monograph; to develop a comprehensive investment strategy to address these challenges for positive and sustainable socio-economic change.

2.3 Main sources of water in the Mara river basin

The study on the domestic water supply and major water sources (SRA report, 2017) the study by County of Narok on short rain assessment. It was found out that the main sources of water for domestic use are dams, pans, ponds, boreholes, shallow wells and rivers. Recharge rates for these open water sources was about 40 percent of their capacities. Distance to water sources for domestic use was above normal range by 50 percent across all livelihood zones following the early drying of open water sources due to due to poor rainfall performance, seepage and competition between humans, livestock and wildlife. The current waiting time at water source has increased by 20-50 percent for all livelihood zones and is expected to increase in the near future.

The study on the drought conditions and management strategies (E. Mbogo et al., 2013) concluded that droughts are generally associated with the failure of the seasonal rains. The two major rainfall seasons in the area of study are (MAM) occurring between March and June, as long rains and (OND) between October and December, as short rains. These normal trends seem to shift and so drought prediction becomes difficult.

CHAPTER THREE

DATA AND METHODOLOGY

3.0 Introduction

This subsection entails relevant data collected for used based on the topic of study as well as the various methods used to fill in missing data, checking data quality as well as its eventual analysis.

3.1 DATA

Data is a set of values of qualitative or quantitative variables or information in raw or unorganized form. The data comprised of two categories. Meteorological and the stream flow data.

3.1.1 Meteorological data

Data used for this study was the mean monthly rainfall for the period (2000-2016) obtained from the Kenya Meteorological Service (KMS). The data was from two meteorological stations and one water supply station.

STATION (ID)	STATION NAME
(ID 9035279)	KERICHO METEOROLOGICAL STATION
(ID 9135001)	NAROK METEOROLOGICAL STATION
(ID 9035265).	BOMET WATER SUPPLY STATION

Table 1: Precipitation stations

3.1.2 Stream flow data

Data used was the Mara River mean monthly stream flow for the period (2000-2016) obtained from the Water resources management authority. The data was from two gauging stations.

STATION (ID)	STATION NAME
TSID 1200001191-1LB02	AMALA RIVER GAUGING
TSID 1200001192-1LA03	NYANGORES RIVER GAUGING

Table 2: Flow gauging stations

3.2 METHODOLOGY

Here various methods were employed for varied purposes. For instance, Arithmetic Average Method was used in estimating and filling in of missing data, drawing of single mass curves of rainfall and stream flow means for homogeneity test of the data and the application of time series analysis, hydrograph drawing and regression analysis for data analysis and processing.

3.2.1 Data management and quality Control

Data Management refers to the process of developing and executing policies, practices and procedures ensuring management of data lifecycle in an effective manner or data management can be described as the practice of organizing acquired data through various processes to meet that information relational logic needs and quality control consists of tests designed to ensure that meteorological and climatological data meets certain standards before use. It is involving looking for errors in the data set whose acquisition ranges from storage media problem to data inconsistency. Examples of such correcting procedures include estimation of missing data and homogeneity test.

3.2.1.1. Estimation of missing data

There are various problems associated with data discontinuity at various time intervals, that leads to missing weather records for example absence of observer, faulty equipment etc. Estimation of missing data is carried out before embarking on data analysis to ensure that the data has no missing gaps if any meaningful predictions are to be achieved. It requires that stations with more 10% of their data missing should be discarded from the analysis.

There are many methods available for estimating the missing data. These include arithmetic mean method, correlation method, isopleths method, Thiessen polygon and the weighted average method. This process involved estimation of the missing data with the mean value of corresponding values of a given data of that year containing missing data. For this particular project in which the rainfall data obtained from the Kenya Meteorological Department had some missing values in Narok and Bomet stations, Arithmetic mean method was applied in filling in that data before proceeding with analysis. It involved filling in the missing records with the mean rainfall value of corresponding mean monthly rainfall of surrounding stations. It requires that the missing mean rainfall data be within 10% o f that station's mean rainfall data for that station to be considered for analysis.

The formula used was given by:-

$$\overline{X} = \frac{1}{N}\sum_{i1}^{n} xi \ldots\ldots\ldots 1$$

Where X is the mean value of the sample, N is a number of adjacent stations, xi is the individual observation and n is the sample size.

3.2.1.2 Homogeneity test

This is a procedure of controlling data usage based on the results of plotted data against time. The results may either be homogeneous or non-homogeneous. Only homogeneous records are out-rightly fit for used whereas the other requires corrections before use.

Non-homogeneity was corrected through slopes ratio factor along the curve to ensure consistency of the data. In this method the ratio of the homogeneous slopes of the curves to the slopes of non-homogeneous sections was established. The resulting ratio is multiplied with the co-ordinates of the breaking curve to acquire new homogeneous co-ordinates. The formula employed is given by:

New co-ordinate $Nc = \frac{S1}{S2} * (xi)$……………………………………...………………………2

Where s_1 is the slope for the homogeneous section of the curve, s_2 is the slope of the broken section and xi are the non-homogeneous co-ordinates of the broken sections. The resulting values for both rainfall (mm) and discharge (cumecs) were accumulated and plotted against time (months) to obtain respective curves.

There are two such tests namely single and double mass curves. For this project, single mass curves involving plotting of accumulated records at the stations against time, were drawn for both the mean monthly rainfall of the three precipitation stations and the mean monthly stream flows from the two gauging stations in order to test for data homogeneity. This method involved drawing of the mean monthly cumulative against time for a period of seventeen years (2000-2016).

3.3 Data Analysis

This is the process of inspecting, cleansing, transforming, and modeling data with the goal of discovering useful information, informing conclusion, and supporting decision (Wikipedia).

Various methods were employed for this purpose. They included; Time series analysis, hydrograph drawing and Regression analysis to determine the mean monthly rainfall pattern, the mean monthly stream flow pattern and to deduce the relationship between the mean monthly rainfall and the mean monthly stream flow patterns respectively. These addressed specific objectives one, two and three respectively.

3.3.1 Time Series Analysis

This is defined as a collection of observations made sequentially with time**.** Observations were taken on daily intervals and were averaged to get monthly values from which monthly means were computed. Time series analysis could be used to give the cyclical, seasonal, trend and random components hence useful to see how the rainfall and discharge variables changed over time during the period of study (Sylvester, 2016). In this study, cyclical component is considered to show annual cycles for the rainfall pattern.

Time series analysis is the process of using statistical methods toextract meaningful statistics and characteristics of the data. It involved plotting of mean monthly rainfall against time in months in order to clearly bring out how the mean monthly varied with time regarding specific objective one. The graphical visual variations with time, can deduce clearly how the means of various months behaved with time.

3.3.2 Monthly hydrograph

A hydrograph is a graph showing the rate of flow (discharge) versus time past a specific point in a river, channel, or conduit carrying flow. The rate of flow is expressed in (m^3s^{-1}).The mean monthly stream flow (discharge) for both Amala and Nyangores river gauges were plotted as a function of time over a year on a month time step. This was aimed at showing the long-term balance of precipitation and stream flow in the basin addressing specific objective two.

3.3.3 Regression Analysis.

This is a statistical process that estimates the relationship among variables that helps to bring out how a dependent variable changes when one or more independent variables are varied. This is a process in which weather is predicted by use of predictors in developed linear regression models. Simple and multiple linear regression models are the two types. Simple model uses one predictor and the multiple models use many predictors. The multiple models can be forward stepwise or backward stepwise. Each model results in the respective regression analysis. In this project, multiple regression analysis method was applied since multiple linear regression models were used.

The regression coefficients of independent variables (rainfall amounts received) were used to determine their individual contributions on the dependent variables (water availability given by stream flow) in the Mara river basin. The multiple type was applied in this project to establish the relationship between rainfall amounts received and stream flow over the basin based on the aforementioned coefficients. The amounts of rainfall received in the basin's precipitation stations (Kericho, Narok and Bomet) and the stream flow (Amala and Nyangores) recorded in Mara River gauging stations were used. Kericho stations only contributed positively during heavy rains via Nyangores River fed by seasonal streams from there. The seasonal streams flow ceases as soon as rain ceases. The same process was repeated with the monthly totals instead of means and arrived at the same conclusions confirming the relationship.

The multi-variable regression formula used was given by:

$$Y = \phi_1 \chi_1 + \phi_2 \chi_2 + \phi_3 \chi_3 + K \qquad \text{……3}$$

Where Y is the available water given by mean stream flow in m^3s^{-1} (we're trying to solve or predict), $\chi_{1,}$ χ_2 and χ_3 are the mean monthly rainfall (in mm) for Kericho, Narok and Bomet respectively, K is the regression constant which is an equivalence of the flow at the stream when there is no rain (regression residual) and $\phi_{1,}$ ϕ_2 and ϕ_3 are the regression coefficients representing individual contributions to water availability (mean stream flow) Y, by mean monthly rainfall $\chi_{1,}$ χ_2 and χ_3 respectively.

Equation 3 above reduces to the below equation during dry season (our season of interest; low flow) during which Kericho precipitation station was excluded.

$$Y = \phi_1 \chi_1 + \phi_2 \chi_2 + K \qquad \text{……3a}$$

Now regression coefficients ϕ_1, ϕ_2 become the contributions of Bomet and Narok (rain, χ_1, χ_2) precipitation stations.

Regression graphical plots of the data scatter were done to determine how close the variables were through their resulting coefficient of determination R^2, significance F which is a measure of probability distribution of data was worked out with that less than 0.1(10%) would show a meaningful relationship between variables. The relationships can either be negative or positive based on the gradient of the trend lines.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

The results obtained from the study were discussed chronologically through various sub-heading in order to bring out a clear understanding of the relationship between the mean monthly rainfall and the mean monthly stream flow patterns over Mara river basin. This by no doubt would also help in drawing the right conclusions and making sound recommendations.

The subheadings are:

4.1 Results from estimation of missing data

There was no missing precipitation data for Kericho station. Narok and Bomet stations had missing precipitation data. They were filled using equation 1. The results for Narok were (May 2004=97mm and Oct 2005=14.275) and for Bomet station (Nov 2007=70.56667mm and Dec 2007=75.02222mm).

The results from the above method were accurate since the filled data was homogeneous to existing data when subjected to homogeneity test.

4.2 Results from homogeneity test

The single mass curves of mean monthly rainfall of Kericho, Narok and Bomet precipitation stations are shown in Figure 2 below. The plots generally resulted on single straight line for the data from all the precipitation stations. This implied that the data used in the study was homogenous. This could have been due to minimized errors, use of the correct formulae in filling in missing data etc. Therefore the data was suitable in the achievement of the objective one of this particular study. The lines however, had some slight deviations in some section of the curves which were corrected by slopes ratio factor given by equation2. This may be attributed to human errors in recording and reading of values from the instrument.

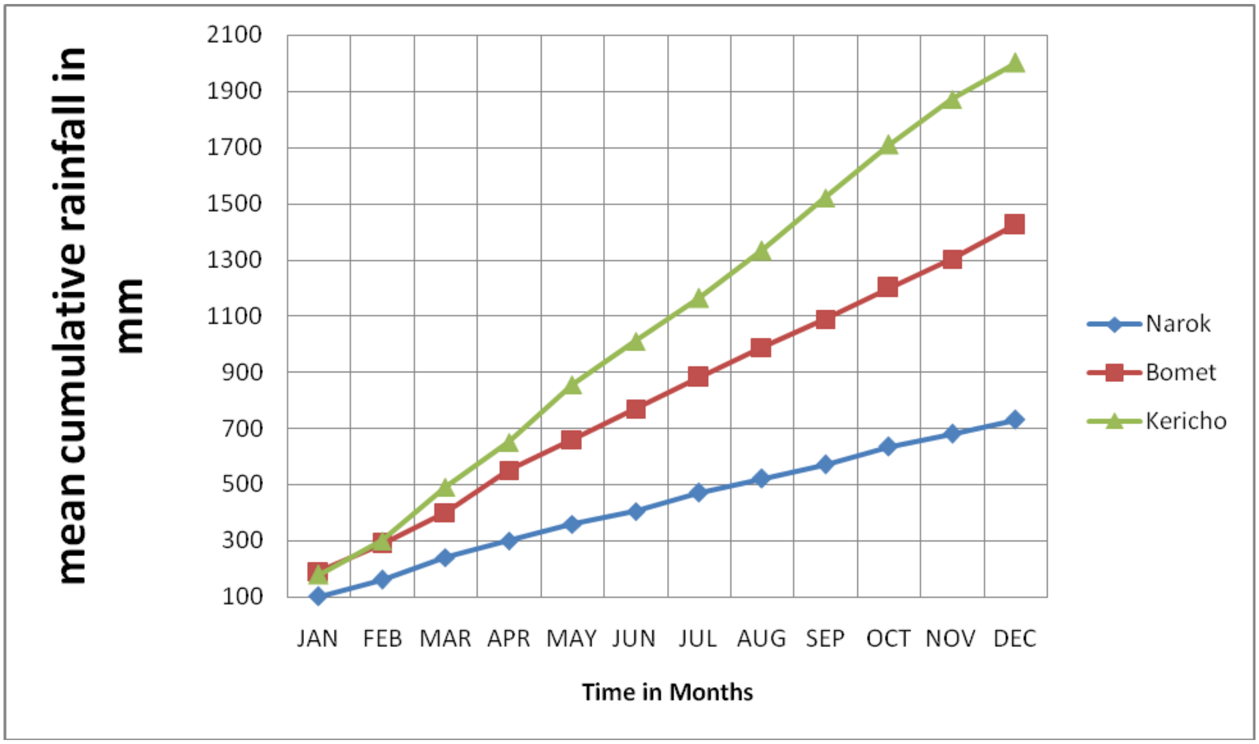

Figure2:The single mass curves of Kericho,Narok and Bomet precipitation stations mean monthly rain fall

The single mass curves of mean monthly stream flows Amala rivers in the Mara river basin are given in figure 3. Like precipitation, they too generally resulted in straight line implying the data was homogenous. Therefore the data was suitable to be used in the achievement of the stated objective two of this particular study. The source of slight deviations in some section of the curves and correction measures are as explained for rainfall.

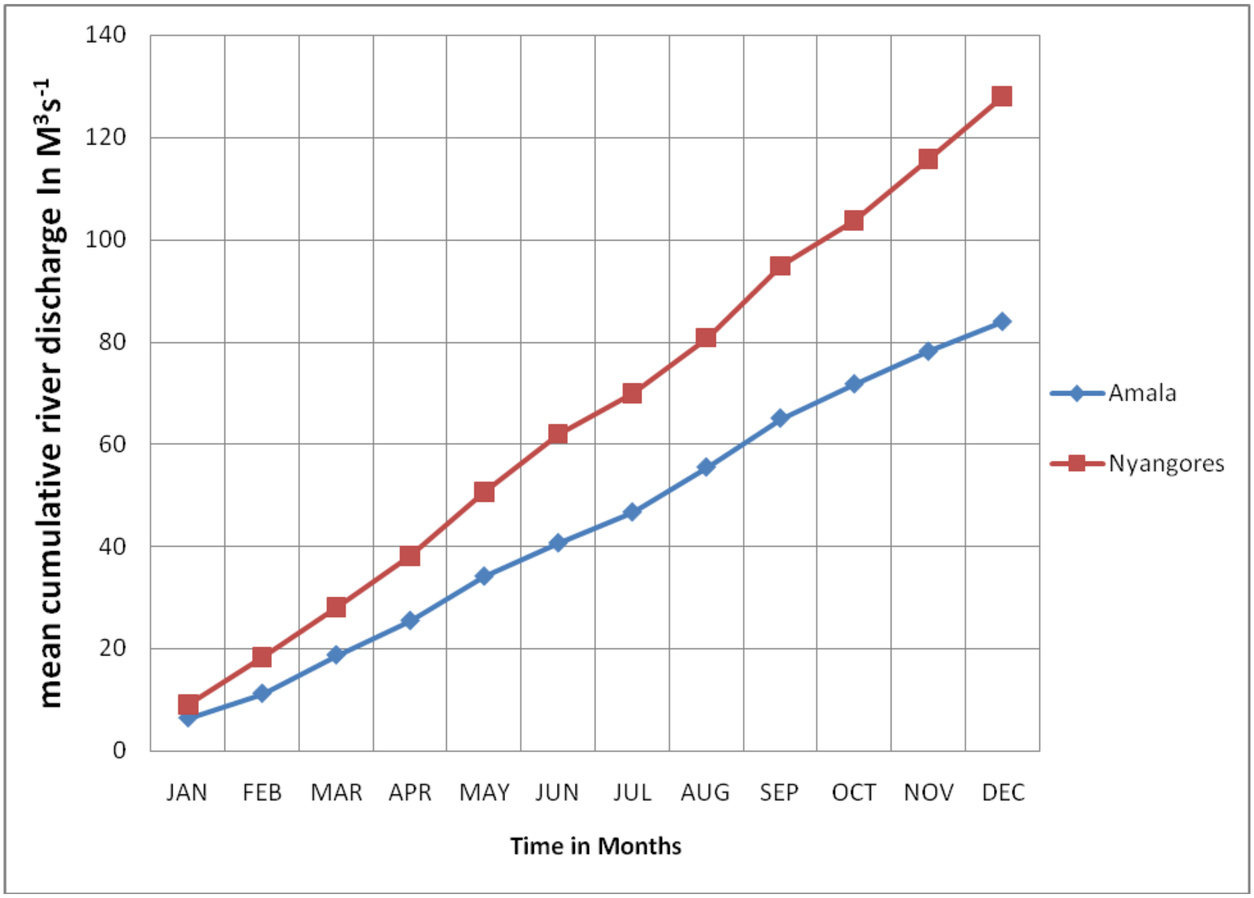

Figure 3:The single mass curves of Amala and Nyangores gauging stations mean monthly stream flows.

4.1.3 Results from time series analysis

The time series of mean monthly rainfall, drawn at monthly interval are given in figure 4 below where meaningful statistics and characteristics of data over 17 years (2000-2016) are shown. From the graph, MAM season in all the stations is clearly seen. OND season is also clear for Kericho station unlike that for Narok and Bomet. Generally MAM season (long rain season) is clearer with higher means compared to the OND (short rain season). The shifts witnessed in the basin is a likely product of shifts in the short rain season (OND),whose onset and cessation currently stand at September and early November respectively as opposed to expected October and December respectively.

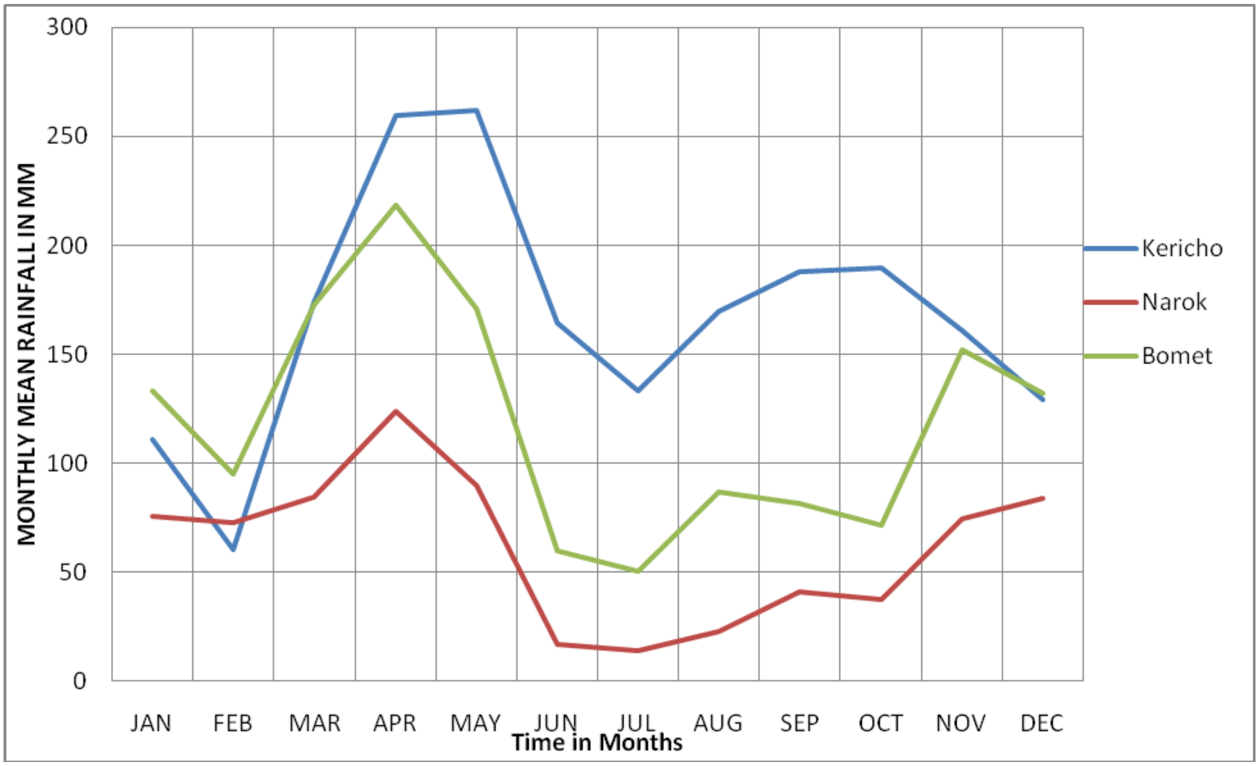

Figure 4: The Mara River basin mean monthly rainfall pattern as per precipitation stations.

The Kericho station is left out since its contribution to the basin flow is during peak flow through Nyangores River via its seasonal streams. This was informed by the fact that the interest of the project is to determine the availability of water for livestock use synonymous of dry periods. The seasonal streams will have since dried up hence no meaningful contributions to low flows.

The Narok seasonal annual rainfall trend is on positive throughout the study period as shown in figure 5 below. The slope of the trend line is gentle meaning the annual change is small. This however, is worth for further scrutiny to inform the measures taken and the improvements required therein for livestock sustainability.

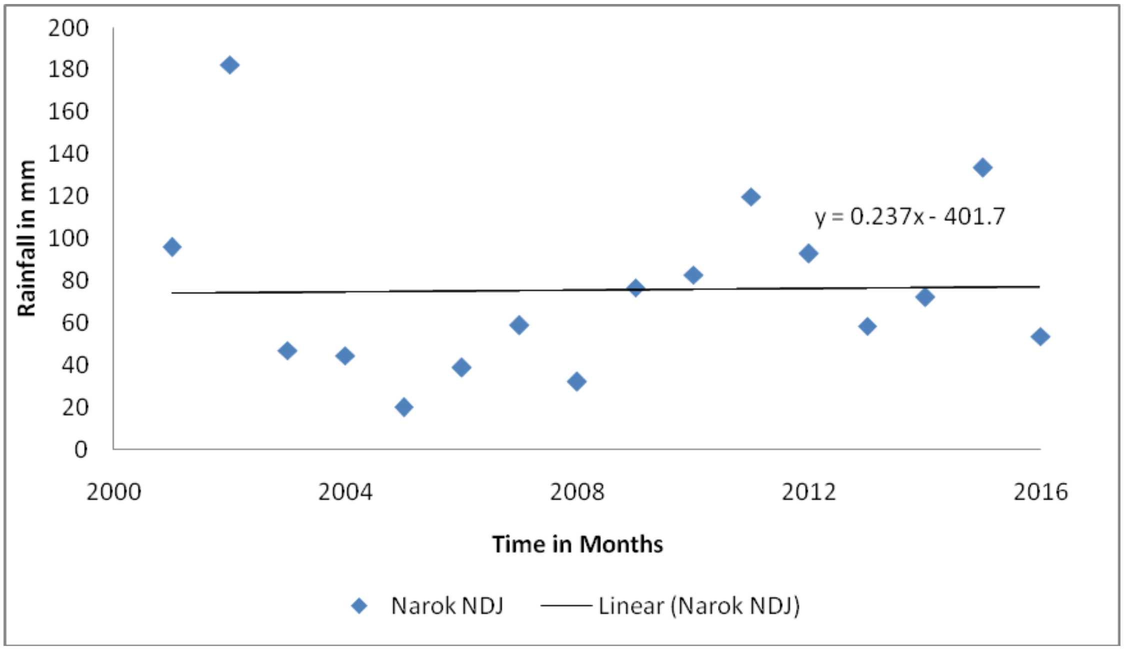

Figure 5: The dot plot showing (Nov-Jan**) annual seasonal trend of Narok precipitation station.**

The Bomet station annual seasonal rainfall is on positive trend throughout the study period as shown in figure 6 below. The slope of the trend line is gentle meaning the annual change is small. The change is bigger than that of Narok station as indicated by their respective slopes.

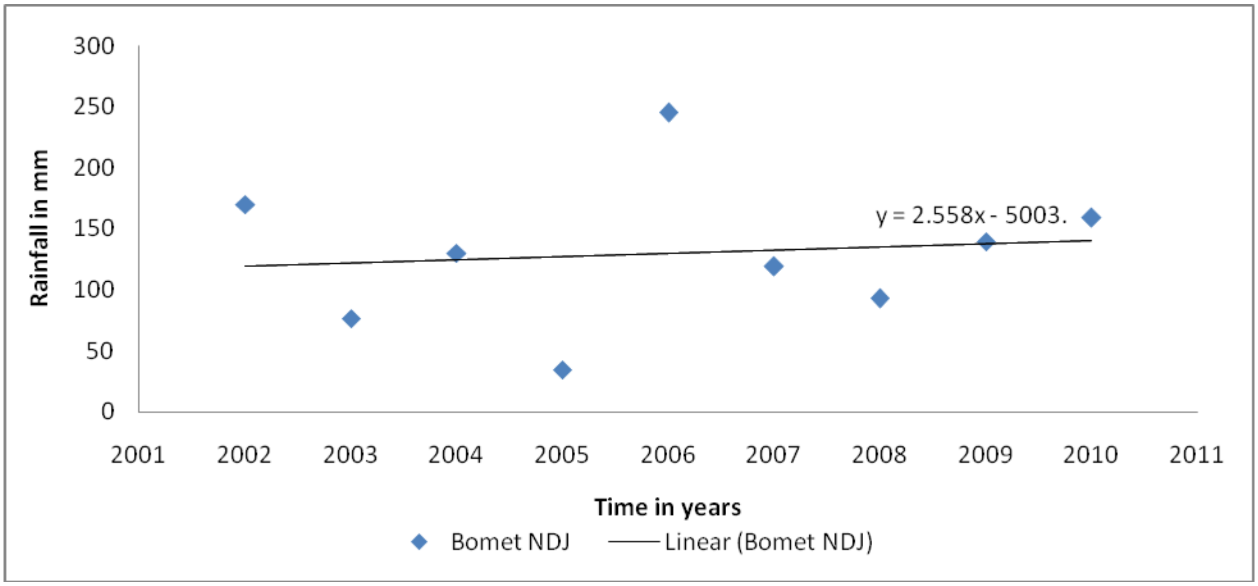

Figure 6: The dot plot showing (Nov-Jan) annual seasonal trend of Bomet precipitation station.

4.1.4 Results from monthly hydrograph analysis

The stream flow increase with the onset of seasons and fall with the cessation for both gauges though with a lag as shown in fig.10. This reflects the two seasons MAM and OND, though the latter season has its onset and cessation coming earlier between August and October which can further be an indicator for the shifts in basin's rainfall pattern. Stream flow from Amala is generally less compared to that from Nyangores experiencing barely same conditions. This can be attributed to the fact that some section of Nyangores River passes through rain-bound Kericho County (western part) contributing to its flow through its seasonal streams. The Amala River is exclusively influenced by Narok and Bomet (eastern part) conditions. Both the tributaries originate from Mau Forest whose water tower is under eminent interference.

The flow from both river gauges are fairly maintain throughout the year despite the rainfall challenges experienced in the basin. It can therefore mean, the river recharging results from direct run-offs as well as from the underground water in the areas of higher ground water table (GWT), and capillary action in areas graced with aquifer fissures. Mara River traverses the Great Rift Valley which is greatly known for such fissures. Ground water reserves however, require rainfall for replenishing though on long term effects. This can explains the increasing trends into and off the season.

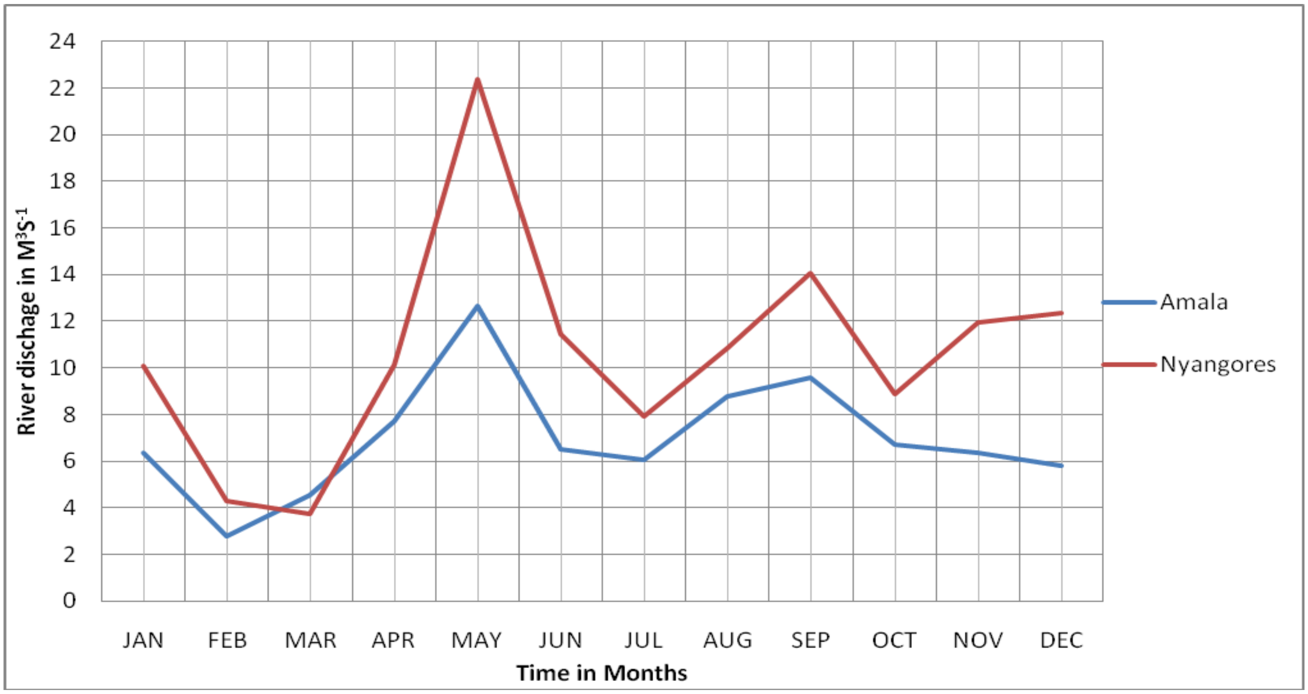

Figure 7: The mean monthly stream flow (discharge) over Mara River basin

The minima flows for Amala and Nyangores are shown in Figure 8 below. The Amala's minimum flow was recorded during February while that of Nyangores was during the month of March. There is a general increase of the minimum flow into the short season. This positive attribute could be as a result of the source rehabilitation measures as well as the underground water seepage happening after the rain ceases. For example of such rehabilitation is the Mau evictions which started from 2007 and now continuing.

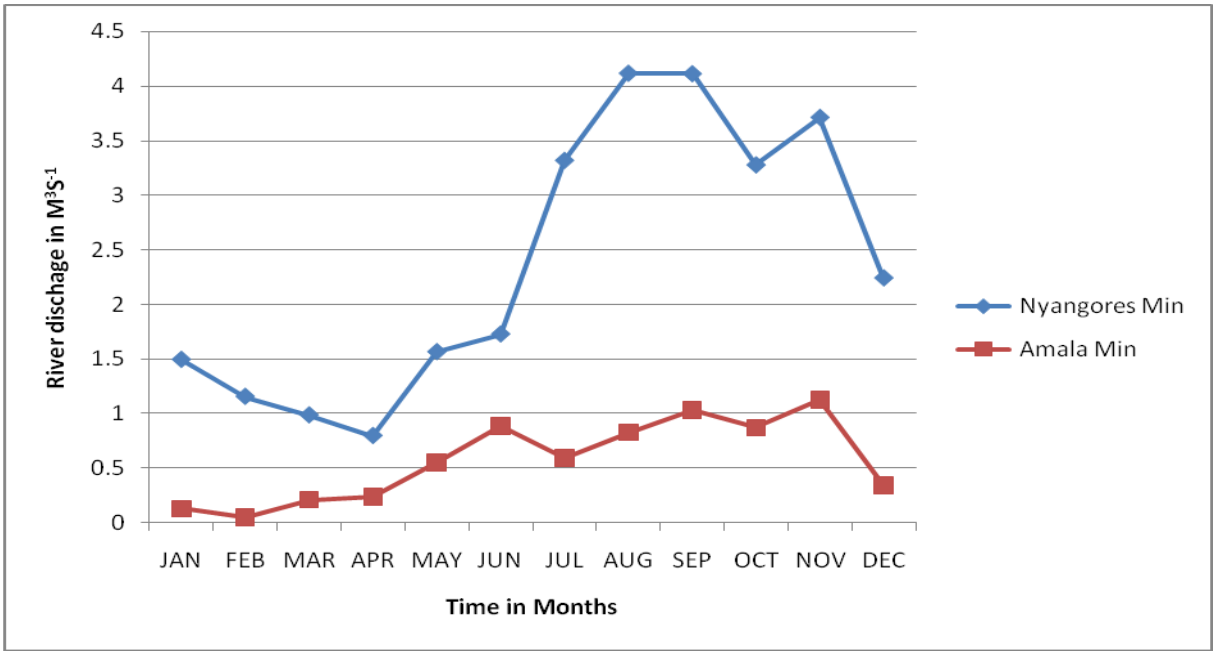

Figure 8: The basin's minima mean stream flows for Amala and Nyangores

Analysis of the Amala minimum annual seasonal flow showed a positive trend throughout the study period as shown by figure 9 below. The increase can mainly be attributed to the rehabilitation of (the source) Mau forest as the change is synonymous with the upper basin but yet to be felt at lower basin. The exercise was carried out through eviction and reforestation which started in year 2007. The Amala flow was generally much less than of Nyangores of similar drainage area attributed to areas of traverse.

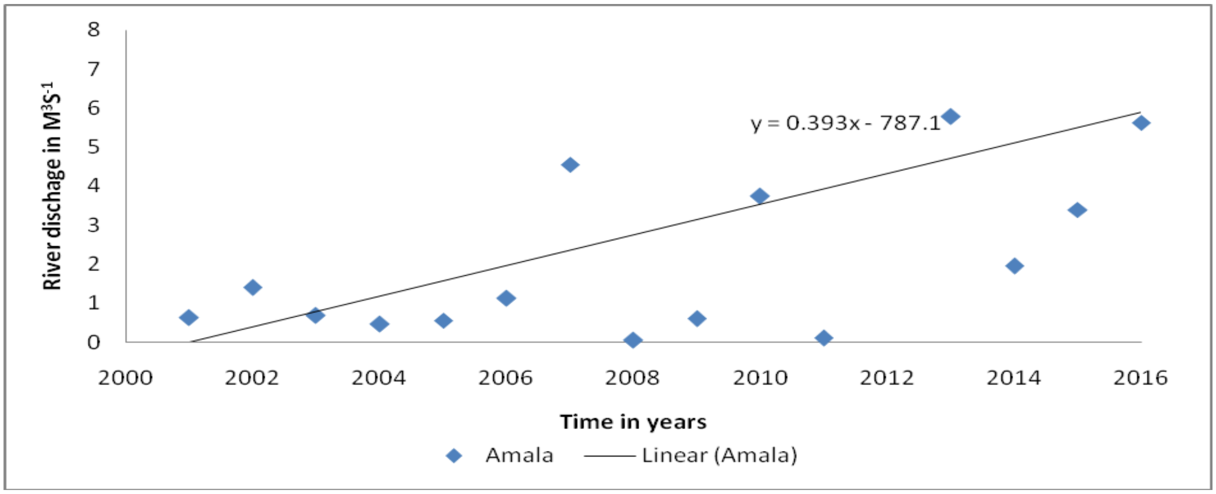

Figure 9: The dot plot showing the trend of annual minimum stream flow at Amala gauging station

Analysis of the Nyangores minimum annual seasonal flow showed a positive trend throughout the study period as shown by figure 10 below. The increase can mainly be attributed to the rehabilitation of its source; Mau forest as the change is synonymous with the upper basin but yet to be felt at lower basin. The exercise was carried out through eviction and reforestation which started in year 2007.

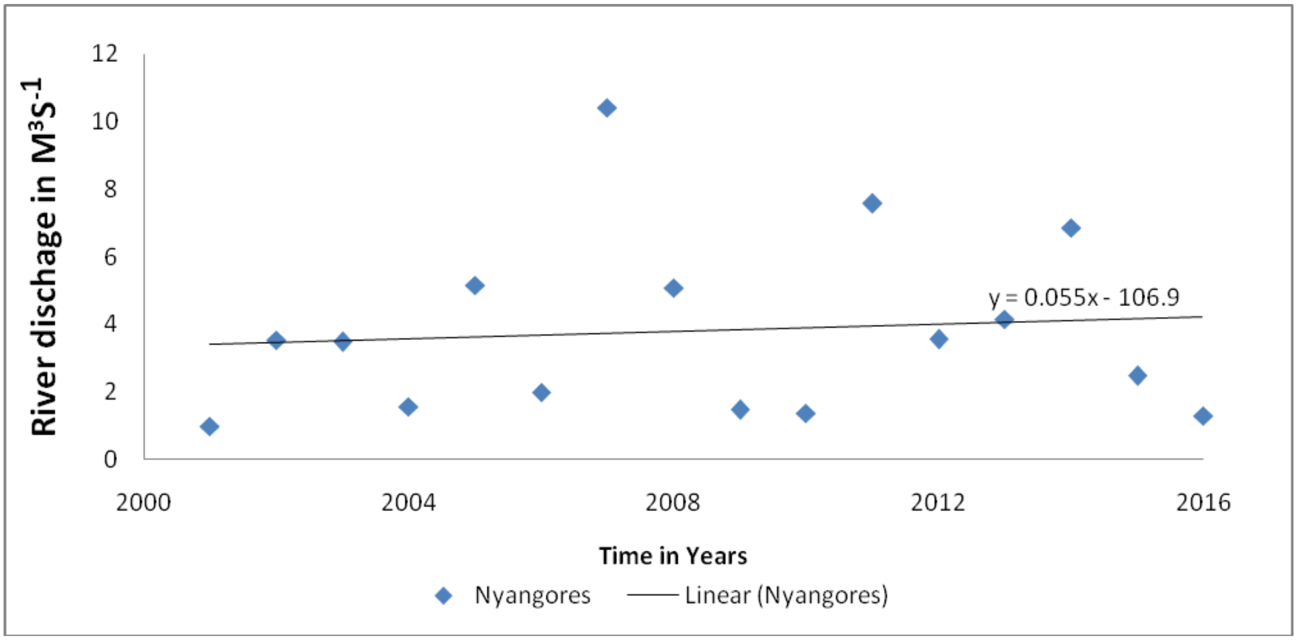

Figure 10: The dot plot showing the trend of annual minimum stream flow at Nyangores gauging station

4.1.5 Results from regression analysis.

When the Amala minimum flow which from the annual cycle at figure 7 is at February was regressed with the preceding seasonal rainfall for Narok and Bomet, the resulting model equation is given by:

$Y = 0.004361\chi_1 + 0.002456\chi_2 + 0.751777$…………………………………..……...3ai

χ_1 = Narok χ_2 = Bomet

From the equation 3ai above, both Narok and Bomet have positive relationship with the river flow. This relationship is indicated by the coefficients (contributions) of independent variables (rainfall, χ_1 and χ_2). When the same regression was done for Nyangores whose minimum flow was recorded during the month of March as per fig.7 on annual cycle, the resulting equation is given by:

$$Y = 0.01053\chi_1 + 0.004496\chi_2 + 3.7599408 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3aii$$

The effects and explanation of equation 3aii above is similar to that of 3ai.

The summary of the regression results is given in the table 3 below.

Rainfall stations	Gauging stations	R-Squared	significance F	X-Variable	Y-Intercept	Equation
Bomet	Amala	0.045	0.000682	0.005	0.744	Y=0.005X+0.774
	Nyangores	0.537	0.002516	0.007	4.051	Y=0.036X-0.799
Narok	Amala	0.017	0.033307	0.008	1.598	Y=0.008X+1.598
	Nyangores	0.006	0.003983	0.005	3.462	Y=0.005X+3.462

Table 3: A summary of results from regression analysis

Graphical scatter plots of regressed rainfall and the stream flow were done as shown by figures 11 to 14 below. The coefficients of determination R^2 were included to show how strong the relationships between variables are. The significance F based on the F probability distribution of the data was determined. A Significance F less than 0.1 (10%) showed that there was a meaningful relation between the variables but for this project resulting F values were too small show such relationship as shown in table 3 above.

From the results obtained in regression, there is positive linear relationship between the variables. The relationship between variables when Amala is regressed with both precipitations of Bomet and Narok is weak as shown by R^2 values of 0.045 and 0.017 respectively. When regressed with the Nyangores station, the relationship of Bomet seemed fairly strong and that of Narok is weak as shown by R^2 values of 0.537 and 0.006 respectively.

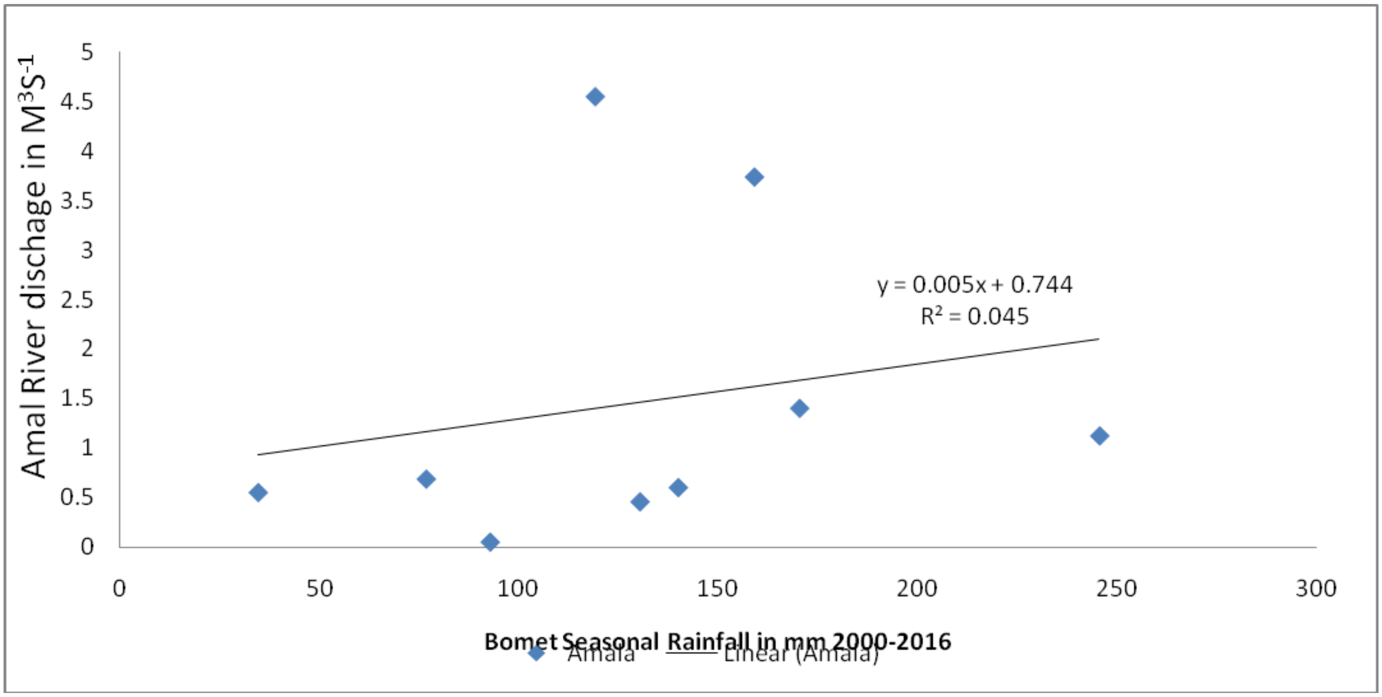

Figure 11: Regression analysis between Bomet and Amala

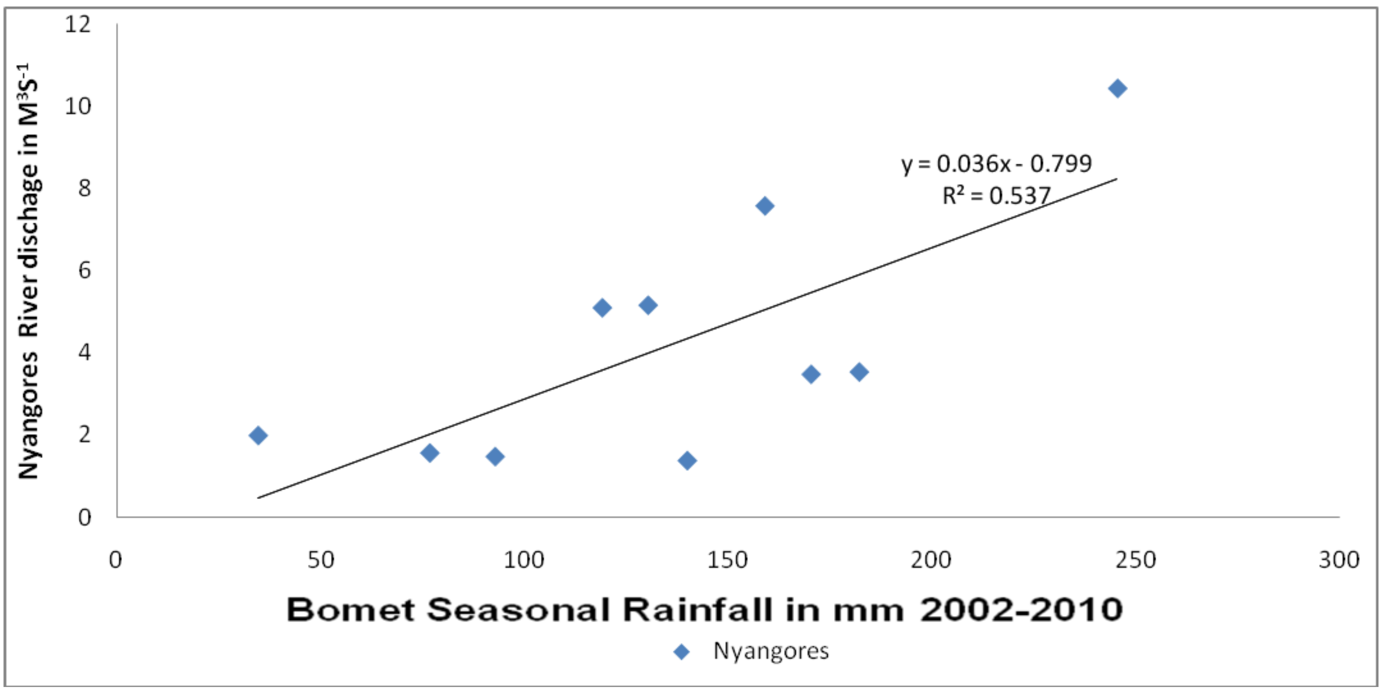

Figure 12: Regression analysis between Bomet and Nyangores

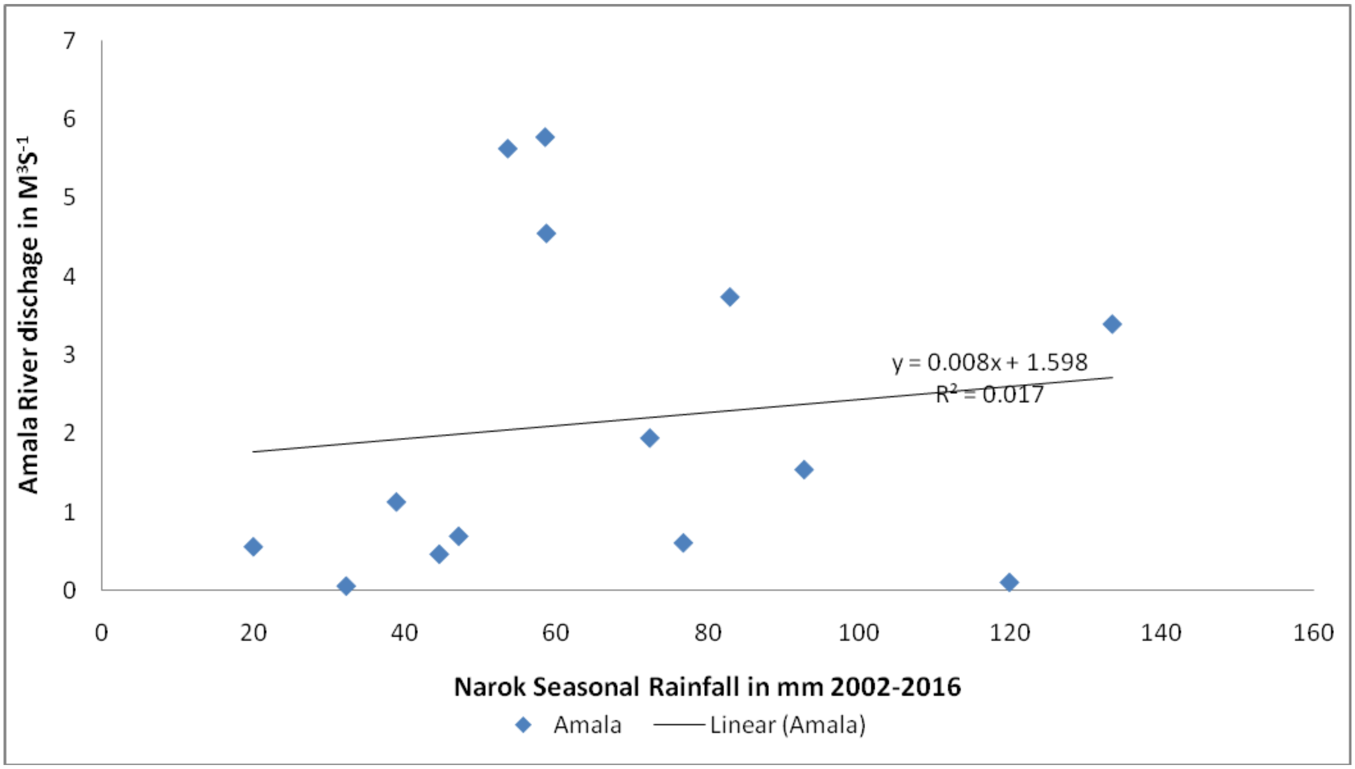

Figure 13: Regression analysis between Narok and Amala

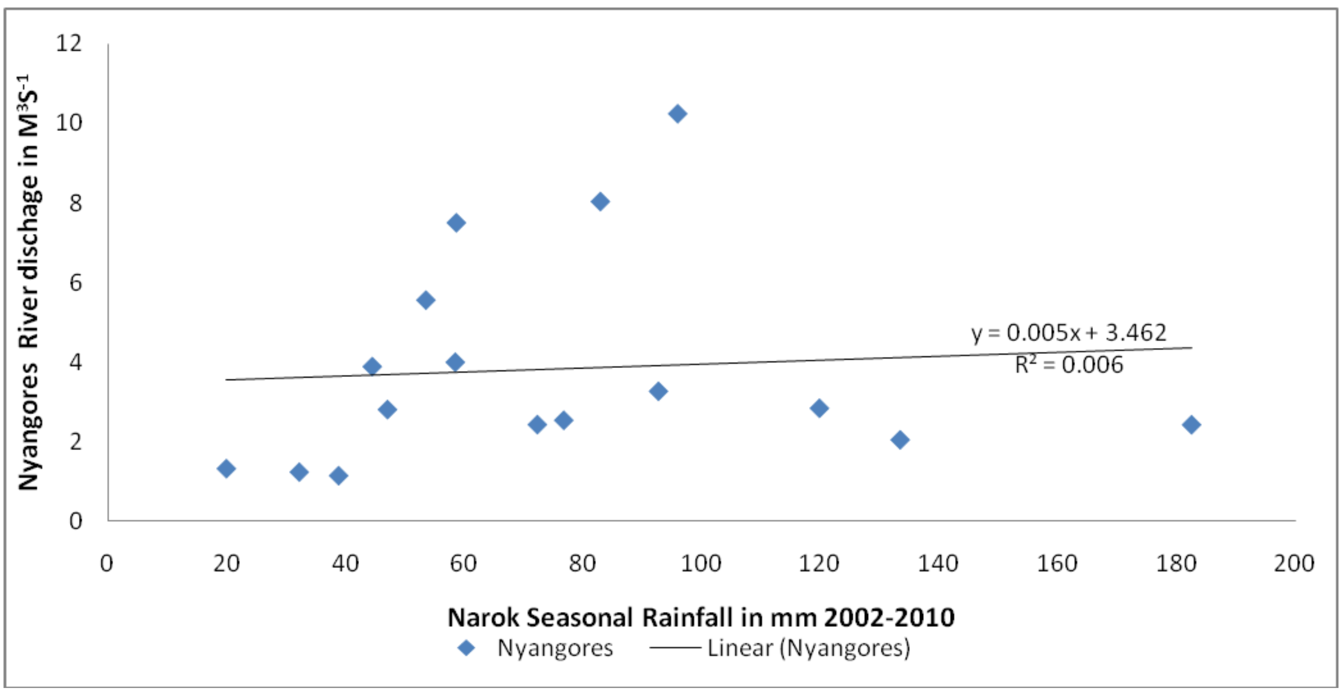

Figure 14: Regression analysis between Narok and Nyangores

The values obtained in correlation analysis results in table 4 below, corroborates that of coefficient of correlation (R^2) in table 3 pointing out that the variables have positive but weak relations. This meant that an increase in rainfall amounts would commensurately results into an increase in the river discharge and vice versa is true. Rainfall recorded at Bomet had fairly strong relation to the Nyangores river discharge but a fairly weaker relation to the Amala discharge. This can explained the fact that Nyangores gauging station is at entry point to Bomet County. Rainfall recorded at Narok had a fair relation to the Amala river discharge but a fairly weaker relation to the Nyangores discharge. The correlations were higher for the low flow month compared to that month's rainfall than when compared to the preceding month's rainfall as shown in table 4 below, February correlations are higher than that of January. This means any rain falling during low flow is significant.

Correlations	(r_{xy})	Gauging stations	
Precipitation stations	Month	Amala	Nyangores
Bomet	January	0.334564	0.148032
	February	0.691151	0.629996
Narok	January	0.187342	0.275978
	February	0.609881	0.339114

Table 4: Correlation coefficients between rainfall stations and gauging station

4.2 SUMMARY

The mean stream flow pattern in the Mara river basin remains fairly constant throughout the year recording minimum in the month of February and maximum in the month of May as shown in Figure 7 which also shows the months in the seasons (March-June, August-October) recording higher figures as are mean monthly rainfall in figure 4 in such seasons. This showed a direct correlation of the rainfall and stream flow patterns. Both tributaries, originate from Mau forest but Nyangores seems to have higher flow compared to Amala. This was attributed to the areas of traverse in which Nyangores traverses rain-bound Kericho county on the western side in which is also fed by seasonal streams as opposed to Amala which traverse the less rain-bound eastern side.

The minimum flow increased into short rain season as shown in figure 8 above. It can therefore mean that underground water at the areas of higher ground water table (GWT), and capillary action in areas graced with aquifer fissures play a critical role in the river recharge. Mara River traverses the Great Rift Valley which is greatly known for such fissures. Ground water reserves however, require rainfall to be replenished.

CHAPTER FIVE

5.1 CONCLUSION

Analysis of the flow records indicated low flows for both Nyangores and Amala now show positive change over recent times noted on trends analysis. The change is however, to small range shown by gentle slopes. The preceding season rainfall is also on positive trend for the concerned precipitation stations. Since the low flow increases into the short season, this can be attributed to the efforts by government to reclaim the water towers as well as underground water recharging. The evictions and reforestations in Mau witnessed between 2007 to date are such rehabilitation efforts.

There were weak relations between the variables as shown by values of coefficients of correlation r^2due to lack of correct precipitation data. It is however clear that minimum flow was still recorded in the basin even in absence of rain ,given by y-intercepts bringing in the importance of the ground water available in the basin and favored by its geology(Mara river basin has two types of aquifers: stratum and fissure),shown by WRMA reports. Besides the increase in the mean monthly flow in the basin, the full capacities are only realized shortly during and after basin's peak rainfall. Generally, a recharge rate for open water sources was about 40 percent of their capacities as per Narok short rain assessment report (SRA, 2017). Water demand has increased by about 40% between 2000 and 2010 (Khroda, 2006) which might make situation become even severe. People and livestock growths increase the water demand (Mati et al., 2008). This resource is projected to experience strain and pressure increases due to this positive robust growth in settlement within the basin and conversion of more previously forest lands into farms.

The basin bi-modal rainfall seasons are shown in figure 4, the long rain season starting in mid-March to June has remained unchanged while that of short now occurring between Septembers to late November has changed from previous October-December bracket. These shifts witnessed in the basin over the short rain season (OND),though has resulted in corresponding shifts in the monthly flow onsets, little impact on mean monthly flows on increasing trends across the seasons is noted. Rainfall variability is both spatial (shown by these

3 precipitations) and temporal (shown by month to month account, peaked at April and minimum at July) meaning different areas receive variable amounts of rainfall over different time of the year.

5.2 RECOMMENDATION

We propose the use of the correct precipitation data to ascertain the underlying correlation between rainfall and stream flow. Having understood that recharging of the Mara River is not entirely dependent on rainfall; it implies that groundwater constitutes a very important water supply source in the Mara Basin. It is abstracted through shallow wells and medium to deep boreholes. In Kenya, upto date records on boreholes and shallow wells are not available due to uncoordinated development and monitoring which have not been given the necessary attention they require as the case is in the Tanzanian side. Water Resources Management Authority (WRMA) records indicate that Mara River basin on Kenyan side has 34 boreholes in Narok South district unlike Tanzania with well coordinated and elaborate records. A study to quantify the potential of this ground water is not only important to the basin but to the country at large considering that over 85% of Kenya is arid and semi-arid is recommended.

Given that, the government efforts on rehabilitation of water towers show positive results, full implementations of the plan can ensure sustainability of water resource in the basin. Stringent policies on water abstractions during low flows (dry periods) should be developed to maintain minimum flow for human and livestock sustainability in the basin.

REFERENCES

Osoro George Marcellus Metobwa, Khaldoon Abdalah Mourad, Lars Ribbe. Water Demand Simulation Using WEAP 21: A Case Study of the Mara River Basin, Kenya. *International Journal of Natural Resource Ecology and Management*. Vol. 3, No. 1, 2018, pp. 9-18.doi: 10.11648/j.ijnrem.20180301.12

Rwigi (2004) Comparative Case Study of Rainfall - Runoff Models Over The Nyando River Basin

E. Mbogo, F. Inganga and J.M. Maina (2013) 'Drought conditions and management strategies in KENYA'

L. M. Mango et al., 2010 'Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management'

Narok short rain assessment (sra) report (2017) 'Domestic water supply and major water sources'

Petra Hulsman (April 2015) 'Determination of the main areas contributing to the suspended sediment load in the Mara River, Kenya'

The study by Water Resources and Energy Management (WREM) International Inc. (2008) 'Mara River Basin Transboundary Integrated Water Resources Management and Development Project'

M. Wekesa et al, 2002: Drought, Livestock & Livelihoods: Lessons from the 1999-01 Emergency Response in Kenya

Peden, D.; Alemayehu, M.; Amede, T. Nile basin livestock water productivity. CPWF Project Report Series, PN37. Colombo: CPWF, 2009.