SOUTH EASTERN KENYA UNIVERSITY

SCHOOL OF WATER RESOURCES SCIENCE AND TECHNOLOGY

The study of the effects of Mau Catchment Degradation on the Flow of the Mara River, Kenya

by

Oruma Samuel Kipampi

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This thesis is my own original work and has not been submitted for examination in any other university

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MR. ORUMA SAMUEL KIPAMPI

(W502/KIT/20121/2012)

This thesis has been submitted for examination with our approval as university supervisors

...

DR. JOHNSON U. KITHEKA PhD.

(University Supervisor)

...

DR. MOSES MWANGI PhD.

(University Supervisor)

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LIST OF ACRONYMS AND ABBREVIATIONS

AGWA	Automated Watershed Assessment Tool
ANOVA	Analysis of Variance
CN	Curve Number
DEM	Digital Elevation Model
EFA	Environmental Flow Assessment
ETM	Enhanced Thematic Mapper
FAO	Food Agricultural Organization
FDC	Flow Duration Curve
FGD	Focussed Group Discussion
ILWIS	Integrated Land and Water Information System
KMD	Kenya Meteorological Department
LVBWO	Lake Victoria Basin Water Office
MEWNR	Ministry of Environment, Water and Natural Resources
MMNR	Masai Mara National Reserve
MRB	Mara River Basin
MSS	Multispectral Scanner
NSE	Nash and Sutcliffe Efficiency
RMSE	Root Mean Square Error
RSR	Standard Deviation Ratio
SI	Sensitivity Index
SNP	Serengeti National Park
SRTM	Shuttle Radar Topography Mission
SWAT	Soil Water Assessment Tool
TM	Thematic Mapper
USDA	United States Department of Agriculture
WRMA	Water Resources Management Authority

ABSTRACT

The Mara River is the lifeline of the Trans boundary Mara basin across Kenya and Tanzania. The basin is considered one of the more serene sub-catchments of the Lake Victoria Basin and ultimately the Nile Basin. The basin traverses the famous Maasai Mara and Serengeti National Parks in Kenya and Tanzania respectively. The basin also contains forests, large-scale farms, smallholder farms, pastoral grazing lands, as well as hunter gatherers and fishers. There is growing concern however, regarding land degradation in the basin, particularly deforestation in the headwaters, that is affecting the natural resource base and the river flows. Scientific studies are required to advise on policy issues, and to plan appropriate mitigation measures. This study utilizes remote sensing and geographical information system (GIS) tools, and hydrological and ground-truth studies to determine the magnitude of the land-use/cover changes in the Mara River Basin, and the effects of these changes on the river flows over the last 30 years. The results of the studies indicate that land-use/cover changes have occurred in the basin. In 1973, for example, rangelands (savannah, grasslands and shrublands) covered 10,989 km^2 (79%) of the total basin area. The rangelands have now been reduced to 7,245 km^2 (52%) by 2000. The forest areas have been reduced by 32% over the same period. These changes have been attributed to the encroachment of agriculture, which has more than doubled (203%) its land area over the same period. To investigate the effects of land cover change on river flow, stream flow was generated from derived land cover thematic maps of 1973 and 2000 using the same rainfall and evaporation data of 1983 to 1992 period. The other model input datasets for topography and soils were held constant during the two runs. The differences in the generated hydrographs could only be associated to changes in land cover, which was the only variable. The percentage difference between the mean annual stream flows of the two hydrographs was negligible at 0.01%. This study therefore concludes that land cover changes in the basin have changed the day to day flow characteristics of the river but the annual flow volumes remain unaffected. There is need for urgent action to stem the land degradation of the Mara River Basin, including planning and implementing appropriate mitigation measures.

CHAPTER 1

BACKGROUND TO THE STUDY

1.1 Introduction

Catchment degradation and the resultant impact on stream flow has been a major issue in Africa (Cleaver *et al*., 1994), including Kenya. The degradation of water catchments affects not only the stream flow regime but also the ecosystem and livelihoods of the people depending on the ecosystem (Krhoda, 2005 and Gereta *et al*., 2009). This chapter introduces the study. It begins by defining the problem which was under investigationincluding the root causes and impacts of stream flow modification. The subsequent subsections of the chapter outline the main and specific objectives of the study including also the hypothesis. The chapter also discussesthe environmental and socio-economic benefits of the study. Lastly, the chapter discusses the consequences of not addressing the problem and how the study will help in dealing with the problem.

1.2 Statement of the problem

This study was carried in order to determine the impact of land use/cover change on the flow of the Mara River and provide recommendations for sustainable development in the Mara River Basin. The basin is a sub-catchment of the Lake Victoria basin that is in turn part of the larger Nile River Basin. It covers an area of 13,750 km^2 (Dessu & Mellesse, 2012) in southwestern Kenya and northwestern Tanzania. In the upper parts of the basin is the Mau Forest where the Mara River originates from, at an attitude of about 3000 m above sea level. The forest is a key water tower and source region also for other rivers including Sondu, Njoro and Ewaso Ng'iro rivers. Mara River flows to the southwest over a stretch of 395 km before draining into Lake Victoria at Musoma in Tanzania at an attitude of about 1000 m (Dessu & Mellesse, 2012).

The Mara River is an important hydrologic system that not only serves the bordering countries of Kenya and Tanzania, but also exists as a valuable source of river discharge to Lake Victoria- the world's second largest freshwater lake which forms the headwaters of the Nile River. The Mara River contributes approximately five percent of the total volume of water that flows into Lake Victoria (Nile Basin Initiative 2004). However, despite its minimal contribution in terms of water volume into Lake Victoria, the Mara River is probably one of the most important rivers with regard to conservation for it supports both the Masai Mara National Reserve (MMNR) in Kenya and Serengeti National Park (SNP) in Tanzania (Nile Basin Initiative, 2004).

With increasing population in the Mara River Basin,demand for water in the basin has also increased significantly in the recent years(Dessu *et al*., 2014). Aboud (2002) and Hoffman (2007) note that over 50% of households within the Mara River Basin rely on Mara River for domestic and livestock needs. Therefore, this river is crucial to the survival of the people as well as wildlife and livestock.Tourist facilities also use water from Mara River and thus impact the overall water balance.

Despite the increasing demand for water in the Mara River Basin, previous studies indicate a decline in annual average flows of the Mara River (Dessu & Mellesse, 2012; Gereta *et al*., 2009;Krhoda, 2005). Krhoda (2005)and Gereta *et al*. (2009)attribute the decline of the flows to over grazing resulting from increased wildlife population and pastoral farming whileDessu and Mellesse (2012) attribute the decline to increased human activity in the basin and climate change which they claim has resulted to erratic rainfall pattern.A recent study by Juston *et al*. (2013)using a 44 year historical data to study the rating curve uncertainty and change in discharge time series of the Nyangores Riverdetected a reduction in the lowest base flow from four Flow Duration Curves (FDC) of eight year data intervals.

This study focused on the impact of the change in the land cover of the Mara River Basin to the flow of the Mara River and its tributaries. Change in land cover can lead to degradation of the basin(Defersha *et al.*, 2012). The major cause of land cover changeis encroachment byhuman populations requiring land for settlement, farming and cutting trees for timber and charcoal burning(Defersha *et al.*, 2012) (see also Figure 1). Degradation of the basin has led to increased overland flow, flash floods and soil erosion. The eroded soils if carried by overland flow and deposited in the rivers, lakes and dams/pans may lead to reduced storage/carrying capacity of the same. This may lead to increased chances of flood and droughtoccurrences(Defersha *et al.*, 2012). Another major effect of degradation of the basin is reduced quantity and quality of the water in the river which consequently impacts the river ecosystem negatively (McCabe, 2011; Tharme *et al.,* 2007). Knowing the extent of the impacts of land use change is crucial not only to water resources managers but also to land use planners.

The data and information generated in thisstudy may be used as the basis for formulating policies for sustainable conservation of the Mara River Basin including supplementing mitigation measures on the negative impacts of land degradation.

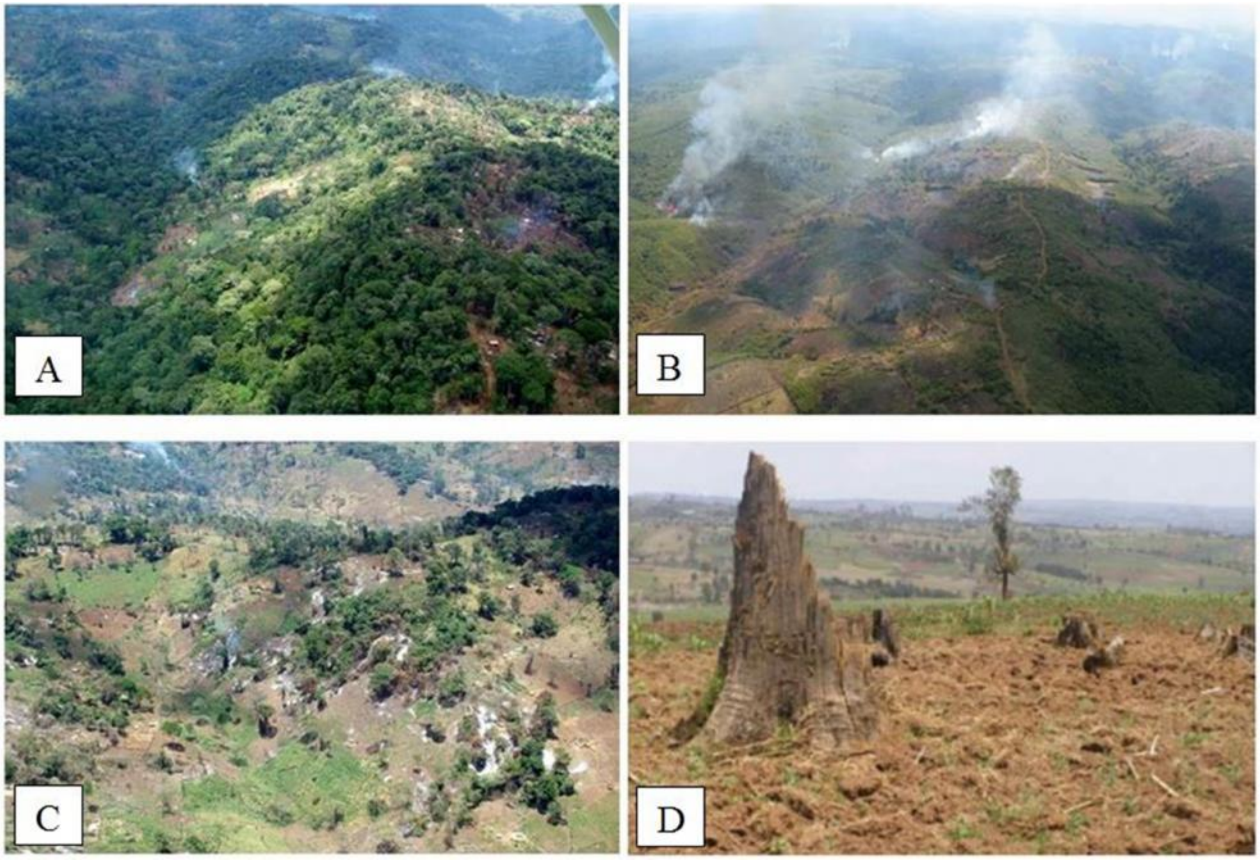

Figure 1(A-D):(A) - (C)Destruction of the Mau Forest Complex; (D) Conversion of forest land into farmland inthe Amala sub-catchment, upper Mara River Basin. Photos: Walubengo (2007)

1.3 Objective of the study

The main objective of the study is to determine the impact of land use/cover changeon the flow of the MaraRiver and provide recommendations for sustainable development in the Mara River Basin.

The specific objectives of this study are to:

1. Establish the relationship between changes in land cover and the flow of Mara River through analysis of long-term satellite observed land cover data and hydrological data for river gauging stations within the Mara River Basin.

2. Examine the relationship between stream flow and rainfall through analysis of long-term hydrological and climatological data for stations located in the Mara River Basin.

3. Simulate flow of the Mara River under different land cover scenarios using theSoil Water Assessment Tool (SWAT) model.
4. Examine the hydrological, environmental and socio-economic impacts of stream flow changes in the Mara River Basin.
5. Evaluate the impact of catchment degradation on water resources planning and management in the Mara River Basin

1.4 Hypotheses

The following are the hypothesis of the study.

1. $H_{0:}$ There is no significant relationship between changes in the forest cover and flow of Mara River.

H_1: Alternative

2. $H_{0:}$ There is no significant relationship between changes in rainfall and flow of Mara River.

H_1: Alternative

3. $H_{0:}$ There is no significant impact of changes in the hydrology of Mara River due to catchment degradation.

H_1: Alternative.

1.5 Significance of the study

Globally, there is growing awareness of the pivotal role of the river flow regime as a key ‘driver’ of the ecology of rivers and their associated floodplains (McCabe, 2011). Every river system has an individual ‘signature’ flow regime with particular characteristics relating to flow quantity and temporal attributes such as seasonal pattern of flows, the timing, frequency, predictability and duration of extreme events (e.g. floods and droughts), rates of change and other aspects of flow variability(Tharme*et al.*, 2007). Each of these hydrological characteristics has individual as well as interactive regulatory influences on the biophysical structure and functioning of river and floodplain ecosystems, including the physical nature of river channels, sediment regime and water quality, biological diversity/riverine biota and key ecological processes sustaining the aquatic ecosystem (Tharme *et al.*, 2007). These processes in turn govern the ecosystem goods and services that rivers provide to humans such as flood attenuation, water purification, production of fish and other foods and marketable goods (Tharme*et al.*, 2007). When these hydrological regime changes significantly due to causes of human activities ranging from high demand for natural resources, the ecosystems in the aquatic environment are bound to respond to these changes.

An Environmental Flow Assessment (EFA) conducted in the Mara River Basin in 2007 (LVBC Report, 2010) found that river flows are currently sufficient to sustain basic human needs and aquatic ecosystem health during wet months of years with normal rainfall. However, during dry months particularly in drought years, the critical minimum flows are too low. In addition, high flows appear to be shorter in duration than historically, suggesting a "flashier" hydrograph resulting from reduced infiltration of rainwater into the ground (Mati*et al*., 2005; Mati*et al*., 2008). Water quality is also decreasing, with increased sediment loads throughout the basin and very high nutrient loads coming from the upper catchment (GLOWS, 2007; Mati*et al*., 2008). To meet the increasing water demand in the Mara River Basin, water resources managers have to investigate the main causes of declining trend of the annual flows of the river. This is important as it would form the basis for planning mitigation measures for the decline.

The thriving tourism industry, agriculture and pastoral farming including the unique ecosystem are all being threatened by the declining water flows in the Mara River especially during dry months (Albergel *et al*., 2012; Gereta *et al*., 2009). A third of available arable land in Mara River Basin is under small scale farming(Dessu *et al*., 2014). Its water resources management is therefore an issue of very high significance, because of the great socio-cultural, ecological and economic values.

The Mara River Basin key threats include fast loss of forest cover in the upper catchment and along the Mara River and its tributaries(see Figure2). Agricultural expansion and intensification, including irrigation, human population growth and the large number of tourist facilities along the river, water pollution and unregulated water abstraction by industries have all played a role degrading water quantity and quality. This has been worsened by unplanned and unregulated urban settlements mainly attributed to laxity in implementation of local by-laws, and national legislations in both Kenya and Tanzania.

The main reason for the decline of water quality and quantity is thought to be degradation of the catchment due to forest destruction and poor farming practices (Defersha *et al*., 2012). The poor farming practices result from the sub-division of land into small parcels and the intensive farming carried thereon. The expansion of agriculture into forested areas is in turn driven by the high population growth and the requirement for more food.

Soil and water conservation measures in the upper catchment of the Mara River Basin could reduce rapid water runoff and soil erosion, improve water quality to water users downstream, and sustain reserve flows in the basin. The result of the degradation of the catchment of the Mara River is that while the water at the source is clear and of good quality, less than 100 km downstream, the water quality is low due to heavy siltation. Furthermore, when there is not enough water downstream, some downstream users migrate upstream. This migration leads into conflict for resources as well as more forests being converted into agricultural land.

The need for adequate water supply to meet the ever growing demand and efficient allocation plans for Mara River Basin stems from the fact that there is often not enough water of a desired quantity and quality to satisfy all the needs of different users or uses (GLOWS, 2007), therefore, decisions have to be made on how best the scarce water resources can be conserved and sustainably utilized. This study assessed the extent of Catchment degradation and its impact on the Mara River water flows. The study focused on establishing the patterns of variability of Mara river stream flows with respect to changes in rainfall patterns as well changes in land cover. The study also involved simulation of stream flow in the basin under different land cover scenarios using SWAT model. The results of this study will provide water resources managers and other stakeholders in the Mara River Basin with useful insights on the importance of forest cover in water conservation. Such information is crucial in sustaining the flows of the Mara River especially during the dry periods.

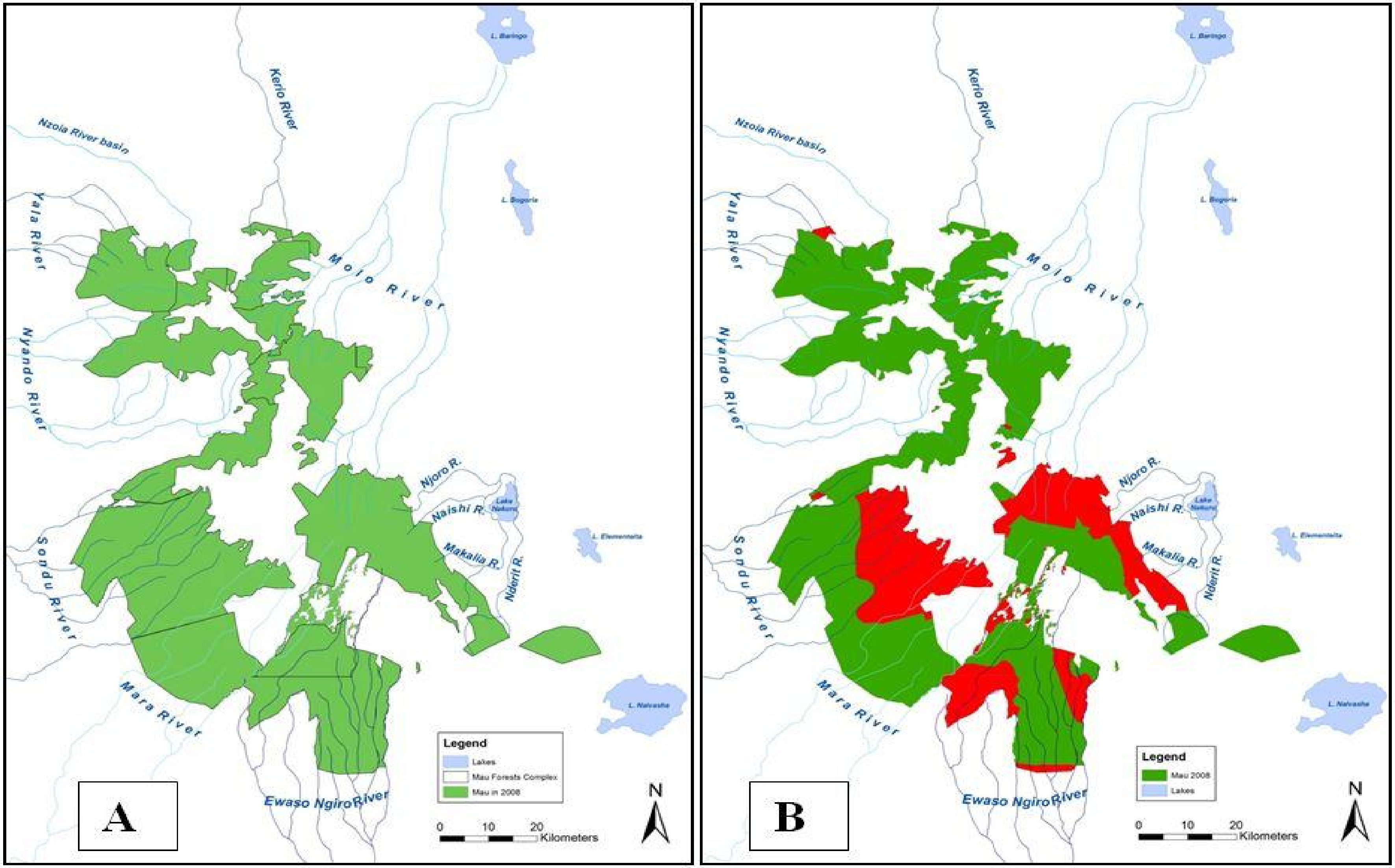

Figure 2: The Mara River Basin forests cover in the years 1995 (A) and in 2008 (B) as per GoK Report Presented by Mau Forest Complex Interim Coordinating Secretariat, November, 2009.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A lot of research on the relationship between land use/cover and river discharge have been done previously. This chapter discusses previous studies which have been and are related to the current study. The literature review focused on studies done at global and regional levels while the second section discusses studies done at national and local level. It is worth noting that not much similar research has been done at local level.

2.2 Studies Done at Global and Regional Levels

Human activities such as agriculture and urban development affect land cover/use. Land cover is the biophysical state of the earth's surface and immediate subsurface, which include: Biota, Soil, topography, surface and underground water, and human structures (Hartemink *et al*., 2006). The land use involves the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation for which the land is used (Lambin *et al*., 2003; Hartemink *et al*., 2006).

Land use and land cover change are significant in catchment studies especially in assessing environmental change. The environmental impacts at local, regional and global levels significantly affect hydrological response of a catchment. Alterations in the earth's surface have major implications for the radiation balance, complexity and, water quality and quantity, surface runoff dynamics, lowering of groundwater tables (Lawal, 2004; Mungai *et al*., 2004). Furthermore, vegetation modification, whether resulting from harvesting or planting, alters the water balance of the site. This may eventually alter the hydrologic regime of the catchment. If vegetation is significantly reduced the flow path of precipitation can be altered and significant surface flow can take place causing erosion, and sedimentation of water bodies. Catchment land use change is always due to natural and man-made causes, where the man-made causes are mainly attributed to the search for resources to meet human needs.

For instance, deforestation is a resultant of the need for timber for construction, fuel wood, and clearing for agricultural development and for settling the ever increasing population (Chemelil, 1995). The need for fertile land to meet the ever increasing demand for food has left the rural population with no option but to clear the natural and artificial forested areas for agricultural development (Maingi and Marsh, 2001). As the landscape in a catchment is altered in both space and time, the factors that influence hydrologic response of the catchment also change (Singh and Fiorentino, 1996).

The evaluation of the relationship between the land use and land cover is important for the efficient catchment management. This evaluation has normally been done using several types of models that vary from strictly empirical to physically based distributed models (Barkhordari, 2003). Physically distributed models in particular need specific data on land use and soil types and their locations within a catchment (Chakraborty *et al*., 2005).

Remote sensing and Geographical Information System (GIS) have been used as powerful tools for managing and analyzing geographic data to levels of coverage and accuracy not possible before, especially land use and land cover data. For instance, it has been shown that there is a direct linkage in catchment factors that can easily be expressed using GIS in combination with remote sensing and modeling (Baldyga, 2004). This combination provides the framework within which spatially distributed data are collected and used to prepare model files and evaluate model results. One application of remote sensing technique is in the acquisition and analysis of satellite imageries. For instance, the multi-spectral data can be utilized for land use and land cover classification using supervised and unsupervised classification algorithms. Supervised classification algorithms use training data to locate similar pixels in an image with similar spectral characteristics. This is the most commonly used classification method, which employs maximum likelihood classifier technique (Mekonnen, 2005).

A research by Golosov and Panin (2006) showed that hydrological regime andsediment flux change drastically following the farming activities within a basin. The study showed that cultivation of land exerts a major influence on the relationship between surface and subsurface flow. Annual surface runoff from a loam soil increases by four times in a cultivated catchment, according to data from long-term observations done in paired catchments in the forest zone of Central Russia (Golosov and Panin, 2006).
Surface runoff is extremely limited under grass or forest vegetation compared with agricultural land (Golosov and Panin, 2006). The hydrological effects of land use/cover changes are manifested in many ways and atdifferent spatial and temporal scales (Singh and Fiorentino, 1996). Most obvious is the immediate and direct effects on thequantity and quality of catchment's runoff. For instance, land cover change is the mostsignificant factor

driving hydrologic changes such as runoff volume, timing and variability(Fohrer*et al.*, 2001; Maingi and Marsh, 2001; Miller *et al*., 2002; Donner, 2004). The simplest method to assess these effects on hydrological response of a catchment is by comparing stream flow and runoff generated from the catchment areas with the contrasting land use types (Barkhordari, 2003). The main concern is with the direct and local effects of land use change on hydrology within a catchment level (Maidment, 1993).

The Upper Mississippi River Basin is arguably one of the leading examples of extensive land use/cover change in the United States. The basin has experienced a remarkable agricultural intensification since the mid-1800s (Steyaert and Knox, 2008).Conversion of natural vegetation in the region began as early as the 1850s with Euro-American settlement (Steyaert andKnox, 2008). The natural vegetation of the basin consisted of grassland (17%), wooded grassland (51%),mixed forest (23%), evergreen needleleaf forest (7%), anddeciduous broadleaf forest (2%) (Ramankuttyand Foley, 1999). Since the mid-1800s, approximately halfof all the land within the 443,000km^2basin has beenconverted largely to annual row crops of maize and soybean,at the expense of grasslands, wooded grasslands, and forests in the northwest, southeast, and central parts ofthe basin, respectively. During theperiod of 1918–2007 for which hydro-climatic observationsof reasonable quality are available, the basin's cropland fraction grew from 43% to as high as 58% in 1980 and has gradually decreased since then to ~49% in 2007 (Ramankutty and Foley, 1999).While several studies have proposed land use/land cover change as the primary cause of runoff increase, little is known about the dominant controls of hydrologic change in the basin.

Parallel with land use/cover change, theUpper Mississippi River Basinbasin has also experienced climate change. Over the course of the 20th century,the climate of the region has become wetter (Villarini *et al*., 2011), and the diurnal temperature range has narrowed (Bonan, 2001). Little is known about the relative influence of climate and land use and land cover changes in shaping the hydrology of the basin at varying spatial scales. The majority of the previous studies have either examined the influence of climate change (Qian *et al*., 2007; Milly and Dunne, 2001; Pan *et al*., 2004) or land use and land cover change (Zhang and Schilling, 2006; Schilling *et al*., 2010) on the basin hydrology, while only a few studies considered their joint influence (Tomer and Schilling, 2009; Mishra *et al*., 2010). The work of Mishra *et al*. (2010) examined the hydrologic impacts of deforestation in Wisconsin, while Tomer and Schilling (2009) used a water-energy balance approach for watersheds in Iowa and Illinois.

A study conducted by Palamuleni *et al*. 2011 to investigate impacts of land cover changes on flow regimes of the Upper Shire River in Malawi showed that significant changes had occurred in the basin between 1989 and 2002, mainly in areas of human habitation. The study used remote sensing techniques to inventory temporal changes of land-cover changes in the basin. Trends in land cover change in the basin depicted land cover transition from woodlands to mostly cultivated, grazing and built-up areas. The land cover mapping showed that 23% of the land was covered by agricultural land in 1989. The study showed that agricultural area had increased by 18%, occupying 41% of the study area in 2002. The effects of the derived land cover changes on river flow in the Upper Shire River were investigated using the SWAT Model. The study established that river flows were highly variable and sensitive to land-cover changes in the basin. Simulation results show that 2002 land cover data produces higher flood peaks and faster travel times compared to the 1989 land cover data. The changes detected indicate the effects of land use pressure in the catchment. The study highlights the importance of considering effects of land-use and land-cover changes on ecosystems and water resources for an informed decision on proper catchment planning and management.

A study by Natkhin *et al*. (2013) identified land use and changes in climate boundaries as the reasons for the changes in the run-off characteristic of Ngerengere River in Tanzania during recent years. In the study a combination of statistical analysis and SWAT model were chosen to handle the problem of poor data quantity and quality with non-overlapping periods. The study showed that climate boundaries and changing land use do not have a uniform effect on discharge in the catchment. It also showed that changing land use affected surface run-off and increased floods in the mountainous areas. Changes in climate boundaries led to increased duration of low flow and no flow in the Ngerengere catchment. The study concluded that changes in climate conditions and land use in the catchment had antipodal effects on parts of the discharge regime hence the observed changes in land use and climate conditions partially compensate for each other.

2.3 studies at national and local levels

Deforestation has been a common practice in Kenya for the last four decades although highly resisted by the government. The effect of forest removal on water availability and rainfall changes has not been adequately explored in Kenya. In the past three decades or so,the Mau Forest Complex has undergone significant land use changes due toincreased human population demanding land for settlement and subsistence agriculture.The encroachment has led to drastic and considerable land fragmentation, deforestation ofthe headwater catchments and destruction of wetlands previously existing within the fertileupstream parts. Today, the effects of the anthropogenic activities are slowly taking toll as isevident from the diminishing river discharges during periods of low flows, anddeterioration of river water qualities through pollution from point and non-point sources(Kenya Forests Working Group [KFWG], 2001; Baldyga *et al.*, 2007).

Augmented by theadverse effects of climate change and variability, the dwindling land and water resourceshave given rise to insecurity and conflicts associated with competition for the limitedresources. It is hence becoming urgently important that renewed efforts are focused on thisregion to avail better information for appropriate planning and decision support.Such a process will nonetheless, require an integrated characterization of the changing landand water flow regimes, and their concerned socio-economic effects on resource allocationand distribution (Krhoda, 1988; King *et al.*, 1999). Assessing the impacts of theenvironmental changes on water flow regimes generally require provision of time seriesmeteorological, hydrological and land use datasets. However, like in a majority thedeveloping countries, the Mau Forest Complex does not have good data infrastructure for monitoringpurposes (Corey *et al.*, 2007;Kundu *et al.*, 2008).

Mango *et al.* (2011) applied the Soil Water Assessment Tool (SWAT) to investigate the response of headwater hydrology of the upper Mara River basin to scenarios of continued land use change and projected climate change. Under the data-scarce conditions of the basin they improved the model performance using satellite-based estimated rainfall data. The result of their analysis indicates that any further conversion of forests to agriculture and grassland in the basin head waters is likely to reduce dry season flows and increase peak flows leading to greater water scarcity at critical times of the year and exacerbating erosion on hill slopes. Their climate change projections for the region call for modest and seasonally variable increases in precipitation (5–10 %) accompanied by increases in temperature (2.5–3.5◦C). From their analysis, simulated runoff responses to climate change scenarios were non-linear and suggest the basin is highly vulnerable under low (−3 %) and high (+25 %) extremes of projected precipitation changes, but under median projections (+7 %) there is little impact on annual water yields or mean discharge.

Opere and Okello (2011)in their hydrologic analysis of River Nyando using SWAT model varied the available water capacity within the range of ±0.05 mm of water/mm of soil. The result of the analysis showed that the available water capacity affectedboth the surface flow and base flow hence the stream flow. An increase in available water capacity resulted in decrease on the stream flow. The researchers attributed the decrease to the increase in the ability of the soil to hold more water. The results of the analysis also showed that an increase in the initial curve number led to increase of the stream flow, but the effect was more pronounced on the effects on surface run off. The study attributed the slight increase in total stream flow the ration of surface run off to base flow.

Olang *et al*. 2014 evaluated the effects of conceptual land cover change scenarios on the generation of storm runoffs in the Nyando Basin. The spatial scenarios represented alternatives that varied between full deforestation and reforestation. In the study, synthetic storm events of depths 40, 60 and 80 mm were formulated according to the rainfall patterns and assumed to have durations corresponding to the runoff times of concentration. The researchers used the Natural Resource Conservation Service–Curve Number model to generate runoff volumes within the sub-catchments, which were subsequently routed downstream to obtain effects in the whole basin. The simulated land cover change impacts were evaluated relative to values obtained from the actual land cover state of the basin in the year 2000. From the results, an agricultural land cover scenario constituting of about 86 per cent of agriculture indicated increased runoff volumes in the entire basin by about 12 per cent. In the study, an agricultural-forested land cover scenario with 40 and 51 per cent of forest and agriculture respectively revealed reduced runoff volumes by about 12 per cent. Alternatively, a scenario depicting a largely forested land cover state with about 78 per cent of forests reduced the runoff volumes by about 25 per cent according to the model estimates. The study found out that runoff volumes in the basin were likely to reduce by about 15 per cent if the appropriate land cover scenario for the respective sub-catchments were to be assumed for runoff management purposes. Considering the prevalent data uncertainty, the study effectively highlighted the potential hydrological vulnerability of the basin.

CHAPTER 3

DESCRIPTION OF THE MARA RIVER BASIN

3.1 Introduction

This chapter presents information of theMara River Basin. The chapter begins by describing the drainage and hydrological characteristics of the basin followed by the description of the vegetation andland usesystems. The chapter also describes the climaticcharacteristics rainfall, temperature and evapotranspiration,the main socio-economic activities, the main soil types and their characteristics, the population characteristics and, the main land use/cover in the Mara River Basin.

3.2 Mara River Basin

The Mara River Basin is a trans-boundary basin shared between Kenya and Tanzania.The basin is located between longitudes 33.88372^0 and 35.907682^0 West, latitudes -0.331573^0 and -1.975056^0 South (see Figure 3). The basincovers a surface area of about 13,750 km^2, of which about 65% is located in Kenya and 35% in Tanzania.The basin can be divided into four distinct physical and/or land-use sections, mainly on the basis of location along the river. The upper basin comprises two of these sections: first, the forested Mau Escarpment where the Mara River originates from at an attitude of about 3000 meters above sea level (m.a.s.l). The forest is a key water tower and source region also for the rivers including Sondu, Njoro and Ewaso Ng'iro rivers. The second section is characterized by large-scale agricultural farms and ranches. Some of the large-scale agricultural farms are irrigated using water from the Mara River. The Mara River then runs through the third section, which is open savannah grassland protected by the MasaiMara Reserve on the Kenyan side and the Serengeti National Park on the Tanzanian side, two important and renowned protected areas in the region (Figure 3). The tropical savannah vegetation supports the unique Mara-Serengeti ecosystem, famous for the scenic large scale seasonal wildebeest migration.The River flows in a south-westward direction over a stretch of 395 km before draining into Lake Victoria at Musoma in Tanzania at an attitude of about 1000 meters above sea level. The flood plains and wetlands comprise the fourth section and are located in Tanzania where the Mara River discharges into Lake Victoria (GLOWS, 2007; Mturi, 2007; WWF, 2007).

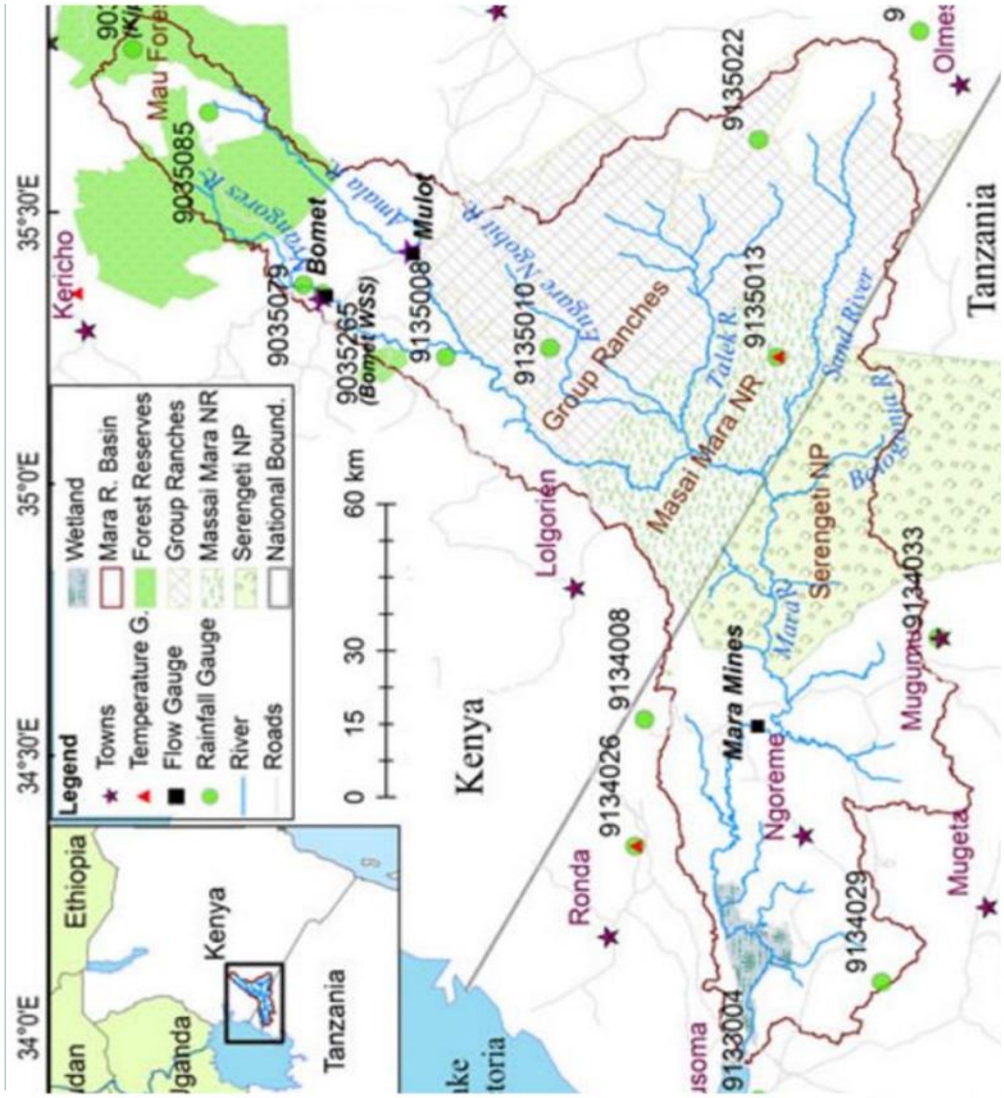

Figure 3: Map of the Mara River basin showing the main drainage pattern Source: Dessu and Mellesse (2012)

3.3 Climatic Characteristics

3.3.1 Rainfall

There are usually three main airmasses that significantlyinfluence the rainfall regime of the Mara River Basin. The apparent movement of the Inter-Tropical Convergence Zone (ITCZ) determines the seasons on the basins. The catchment is majorly dominated by dry northeasterly winds from the Sahara Desert from November through March causing little rainfall. The short rains are experienced from October to December.

The Southeast Trade winds from the Indian Ocean which influence rainfall pattern of the region between March and June, weakening considerably between June and September. The less dry months are January and February. The southwest trade winds, or sometimes known as the Congo air mass, which bring rain from the west in July with storms and hailstorms.Despite the various air masses, the rainfall amount and distribution are governed by altitudinal variations, giving rise to a bimodal rainfall pattern of wet and short rains. The north-south and east-west rainfall gradients are very sharp. The mean annual rainfall varies from between 1000mm to 1750mm on the Mau Hills, supplemented by mountain mist, to 300-800mm in the south. The northern and the western parts of the Mara Basin are the wettest, recording 1200mm to 1800mm per annum. The rainfall at Narok Town, which has one of the oldest rainfall stations, is 1016mm per annum. The long rains start in mid-March to June with a peak in April while the short rains occur between the months of September and December.

3.3.2 Temperature and Evapotranspiration

The temperature variations in the Mara River Basin are determined by altitudinal as well as rainfall variations, such that in elevated areas with high rainfall amount the temperatures drop to 10^{o}C, while the lowlands in the central and southwestern parts of the basin the temperatures rise to 20^{o}C. Temperatures are lowest in the wet months of March to May and the highest in the dry months of January and February. In general temperatures increase southwards and decrease northwards.

Estimates have been used to complement the existing records. Table 1 shows the temperature zonation for mountainous areas in Kenya. The altitude of the Mara River Basin ranges from 3063 to 1134 m.a.s.l. as illustrated in Figure 6.

Table 1: Temperature zonation in the mountain regions of Kenya

Altitude (m)	Mean annual To	Mean max. To	Mean min To	Night frost
Above 3,050	Less than 10	Less than 16	Less than 4	Very common
2750-3050	10-12	16-18	4-6	Common
2450-2750	12-14	18-20	4-8	Occasional
2150-2450	14-16	20-22	8-10	Rare
1850-2150	16-18	22-24	10-12	Very rare
1500-1850	18-20	24-26	12-14	None

Source: Krhoda, G.O. (1988)

The annual mean temperature may be estimated using the following expression:

$T = a – b. EL$(1)

Where:

T is annual mean temperature (^{o}C);

EL is the elevation (m) and;

a and b are constants, equivalent to 30.2 and 0.00650 respectively.

Evaporation in the Mara River Basin is determined by rainfall patterns and altitudinal variations. Evaporation reaches 1800mm per year in central and southern plains and about 1400mm within an altituderange of 1800m. Evaporation is measured by Class "A" evaporation pans. The relation between evaporation and elevation (m) in the Mara River basin takes the form (JICA, 1992):

$E_o = 2,575 – 0.4838.EL$(2)

Where:

E_o is evaporation (mm)

Using the above equation , evaporation rates may be determined given the elevation of any section of the catchment.Evapotranspiration, ET_o, is the total water vaporized from the ground by plant transpiration and evaporation from free water surface and soil. While ET_o is determined by the vegetation cover and rainfall, the inter-relationship between rainfall and natural vegetation types is fairly obvious. The relation between evapotranspiration and elevation in the Mara River basin takes the form of (JICA, 1992):

$ET_o = 2319.9 – 0.03235.EL$(3)

Where:

ET_o is evapotranspiration (mm)

3.4Drainage and Hydrological Characteristics

The main tributaries of Mara River in the highlands are Amala and Nyangores. The tributaries originate from the Mau forest and flow south-west and join to form Mara River (see Figure 3). Rivers Talek and Sand are seasonal tributaries in the middle part of the basin originally from semi-arid areas. An analysis of historical discharge data(1970 to 1996) by Dessu and Mellesse (2012) for Mara River at Mara mines, Nyangores at Bomet and Amala at Mulot showed a mean of 33.9 m^3s^{-1}, 8.4 $m^3s^{-1}$and 9.9 $m^3s^{-1}$with standard deviation of 60 m^3s^{-1}, 7.1 m^3s^{-1} and 19.9 m^3s^{-1}, respectively. The river experiences seasonal flow pattern characterized by high flows during rainy season and low flows during dry seasons. The peak river flows occurs during the months of May and September. The period of low flows is observed to be from January to March. The seasonal peak flows coincide with the long and short rains in the basin.

3.5 Geology and Soils

The local geology, topography and rainfall determine the types and distribution soils of the Mara River Basin. In some areas, Quaternary lacustrine and fluviatile unconsolidated sediments of Pleistocene age overlie the Basement complex System rocks forming good aquifers. The soils fit into three broad categories, namely, the mountains, plains and swamps. The mountains have rich volcanic soils suitable for intensive agricultural production including wheat, barley and zero grazing. The soils include the shallow but well-drained dark-brown volcanic soils (ando-calcaric and eutric-regosols) found on mountains and escarpments. On the remnant ridges and their apperrons, reddish brown gravels and sandy soils invariably formed from Basement Complex rocks, grade into coarse scree as the outcrops are approached (Krhoda, 1988).

Alluvial silts and gravels occur along the Mara River while the tributaries are clogged with silt and sand after floods. The superficial deposit of alluvial and colluvial are common; the first along the river valleys while the latter debuting the scarps of SoitOlolo and remnant hills in the lowlands (Krhoda, 1988).On the hills and minor escarpments, shallow and excessively drained dark-reddish brown soils (lithosols, mollicandosols) are found. The imperfectly drained grey-brown to dark-brown soils are found on the plateaus and high level plains of Siria, NiaragieEnkare and Narosura (Krhoda, 1988). The deep, dark-greyish soils (verto-eutric and planosols) are mainly found on Kapkimolwa plains, Shartuka and Maasai Mara National Reserve. Surficial deposits occur in the entire basin (Krhoda, 1988).

3.6 Vegetation and Ecological Systems

The upper part of Mara basin consists of protected forest and woodland within the gazetted area of Mau Forest Complex. Some of the areas which were originally forest have been cleared for cultivation. The middle part consists of grassland and bush land which is in the Maasai Mara National Reserve in Kenya or Serengeti National Park in Tanzania. Some of it is also under large-scale farming or ranching or small scale agriculture. The lower part in Tanzania consists also of agricultural land. Wetlands are found in the area close to Lake Victoria. The Mara basin has been subject to rapid changes in land cover over the last 50 years. The forest provides honey, forest employment and forest farming, firewood, medicinal herbs. Besides these forests cover being the major water catchment of Bomet, Trans-Mara and Narok district, nearly 50% has been cleared for farming and settlement. The marked drop in dry season discharge may be attributed to the destruction of the Southwest Mau Forest while both deforestation and degradation of the grazing areas may explain the high wet season discharges. The forests also provide soil erosion protection. The greatest threat of the forest is both legal and illegal excisions and over-exploitation.

3.7 Population Characteristics

Communities in the Mara River basin can be divided into four main groups: forest dwellers, farmers, pastoralists and fisher-folk. The forest dwellers are found in the catchment area and although many years ago they were hunters and gatherers, some of them are now farmers. Most of the farmers are found in the middle basin in Bomet and Narok counties in Kenya, as well as in Tanzania close to the lake. Pastoralists are found mostly in Narok County. Fisher folk are found along the river close to the lake

The latest population census in Kenya was carried out in 2009, while in Tanzania, this was done in 2002. In 2002, the total population of the basin was estimated to be 805,000 (Gereta *et al*., 2002). Thus most of the basin has a population density of around 70 people per square kilometer with the urban centers of Bomet and Musoma having higher densities. Figure 4 shows the population densities in the Mara River basin in 2002. The increase in water demand being experienced in the basin is caused by the rapid population growth in the area which stands at 7% (Mati *et al*., 2005).

3.8 Land Use

The dominant and important land uses in the Mara River Basin are: forests conservation, especially in the catchment (and expanding tea farms); livestock production and agriculture in the Kenyan savannah rangelands; wildlife conservation and tourism in Serengeti-Mara ecosystem rangelands, and; gold mining, small-scale agriculture and fishing (Mango *et al*., 2011). Figure 5 shows the dominant land uses and tenure systems in the Mara River Basin. The basin has experienced substantial land use changes in the past 30 years that has seen a shift from forest and bush-land to agricultural farming (Mango *et al*., 2011).

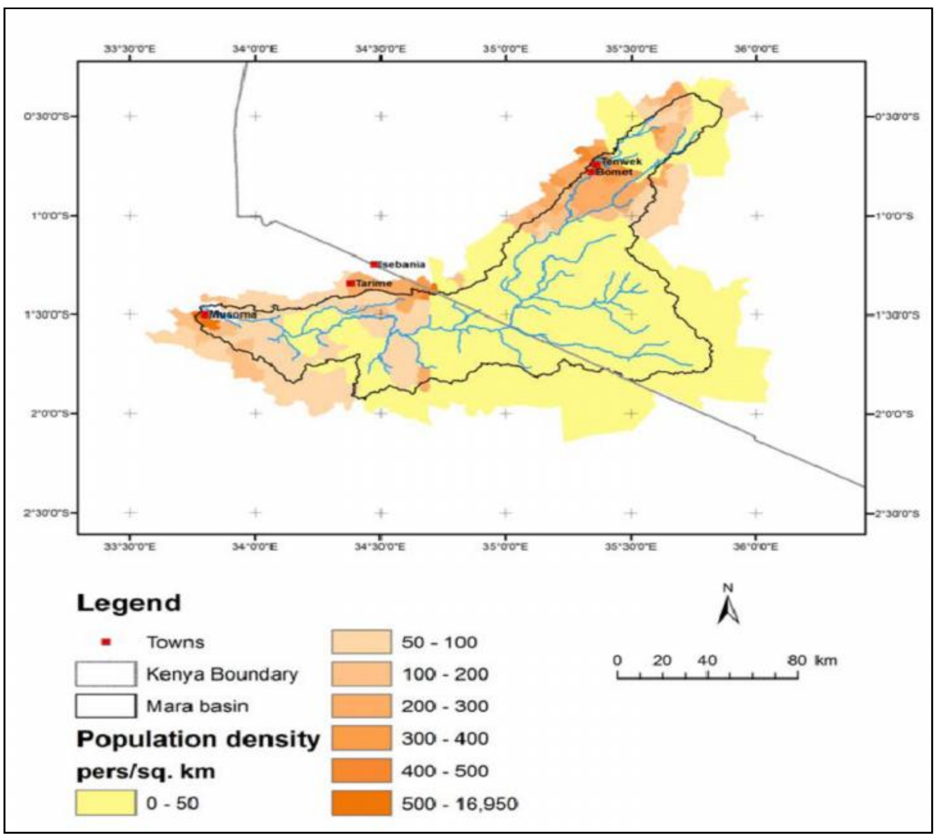

Figure 4: Estimated population density in the Mara river basin as of 2002 (Source: Gathenya, 2011)

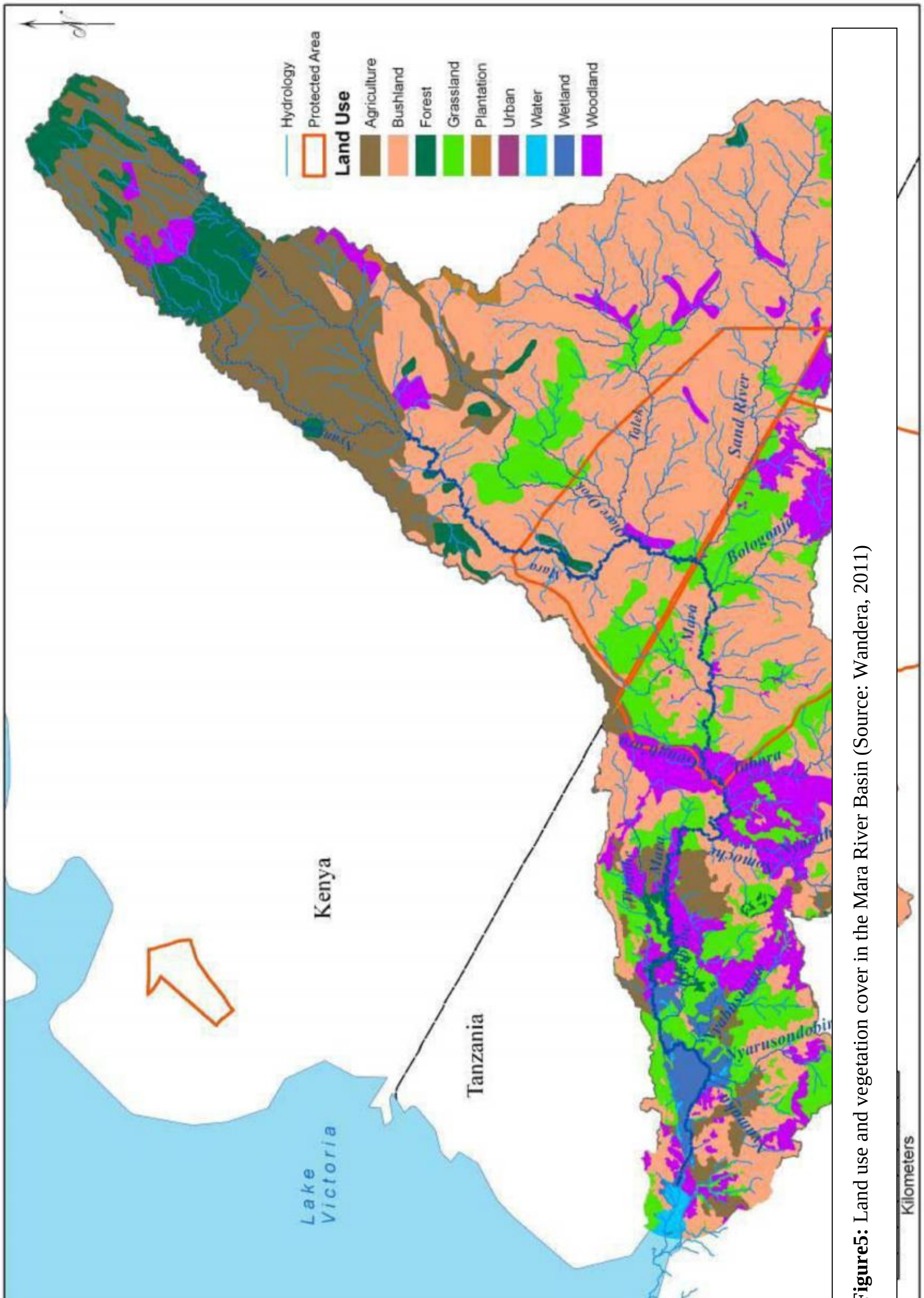

Figure5: Land use and vegetation cover in the Mara River Basin (Source: Wandera, 2011)

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commerce and trade are important in the urban areas. Forest conservation and management takes place in the eastern and south-western Mau forest in Bomet, Nakuru and Narok

Counties. Logging is an important source of income and employment in the forested areas. Agriculture is practiced almost everywhere in the Basin except in the Mara-Serengeti conservation areas. Small scale farmers are found in the upper catchment and along the shores of Lake Victoria. Large scale farmers are found in Bomet and Narok Counties.

Wildlife Conservation and Management takes place in the Masai-Mara National Reserve in Kenya, Serengeti National Park in Tanzania. This goes hand in hand with tourism. Thus most tourist lodges and hotels are found inside or just outside these protected areas. Livestock keeping is found mainly in the middle of the basin. Most of the livestock found here is free ranging and during the dry season, it is moved all the way to the upper catchment areas in search of pasture and water.

Gold mining is an important source of revenue and a major employer in the Tanzania segment of Mara River Basin. Barrick Gold mine located in the segment is so important that it is quoted on the New York Stock Exchange. Trade and commerce on the other hand is a feature of urban centres like Bomet and Kilgoris in Kenya; and Tarime and Musoma in Tanzania. All in all, a majority of economic activities in the basin thrive because of the availability of water in basin. Any major negative changes in the quality and quantity of the basin's water may have an impact on the economy of the area.

CHAPTER 4

THE STUDY METHODOLOGY

4.1 Introduction

This chapter presents the method that was applied in this study. The first section of the chapter describes the data used in the study and the collection and pre-processing procedures. The sources of the various data sources are also provided. The second section describes the model used including: the model parameters, the calibration and validation procedure and the model performance criteria. The last two sections describe the hydrological and statistical data analysis tools/procedures respectively.

4.2 Data Collection and Pre-Processing

This research heavily relied on secondary data (historical) archived by various government agencies. The other secondary data sources included data bases for satellite data sets. The primary data collected during field study included land cover/use and social-economic data. The following sub-sections explain in detail the data collection and pre-processing procedures.

4.2.1River Discharge

There are five functional River Gauging Stations (RGS)along the Mara River and its tributaries (see Table 2 and Figure 6 and 7). These stations are equipped with semi-automatic data loggerswith readings being recorded twice daily i.e. at 6am and 6 pm. The time series data for the gauging stations on the Kenyan side of the basin were obtained from the Water Resources Management Authority (WRMA)regional office in Kisumu while for the stations in the Tanzanian side wereobtained from Lake Victoria Basin Water Office (LVBWO) in Mwanza, Tanzania. For each of the stations, rating curves have been developed by the respective authorities. During collection of data, errors may be introduced in several ways such as: erroneous reading, recording, copying and by instrument defects (Shaw, 1996).

Table 2: River gauging stations along Mara River and its tributaries including their start and end year of operation

Discharge gauging station name	Station code	Start Year	End Year
Nyangores	1LA03	1963	2008
Amala	1LB02	1955	2007
Mara-Lalgorian bridge	ILA04	1970	1977
Mara Mine	5H2	1969/2011	1994/2013
Mara Ferry	5H3	1969	1978

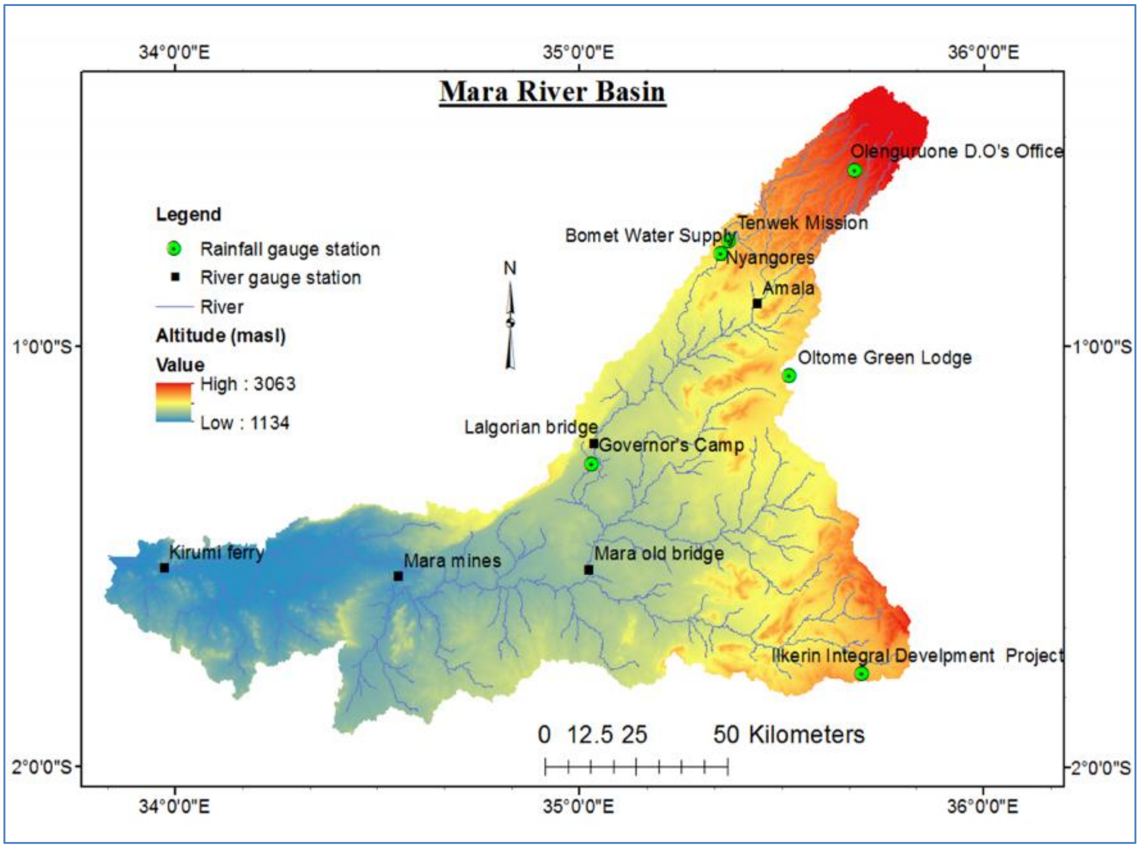

Figure 6: Amap showing rainfall and river gauging stations contributing to data used in this study. The map also shows the elevation above sea level in meters

Therefore, the collected data was analysed and the necessary corrections done. The single mass curve was used to carry out homogeneity and consistency tests in this research. River discharge data was used to calibrate and validate the SWAT model in this study.

Figure 6: From left to right:Mr. Oruma at river gauging station 1LB02 in Mulot along Amala River, a tributary of Mara River

4.2.2 Rainfall Data

The Kenya Meteorological Department (KMD), Water Resources Management Authority (WRMA), Ministry of Agriculture, Livestock and Fisheries Development, Ministry of Environment, Water and Natural Resources (MEWNR), Lake Victoria Basin Water Office (LVBWO) in Mwanza, Tanzania and other private operators have rainfall measuring stations (RGS) in the area. In total, there are forty three rainfall gauging stations within and around the Mara River basin. However in this research only data from KMD and LVBWO recognised rainfall gauging stations and those approved by the same was used. These stations (six in number) are shown in Table 3 and Figure 6.

The data underwent quality control measures which involved consistency test using double mass curve method. The rainfall data was used as an input to the SWAT model in this study.

Table 3: Rainfall stations within and around Mara River Basin to be used in this research including their geographic coordinates

		Location	
Station Name	**Station Code**	**Latitude ^{o}S**	**Longitude ^{o}E**
Tenwek Mission – Sotik	09035079	-0.75	35.37
Olenguruone D.O's Office – Molo	09035085	-0.58	35.68
Bomet Water Supply	09035265	-0.78	35.35
Oltome Green Lodge – Narok	09135004	-1.07	35.52
Ilkerin Integral Development Project	09135025	-1.78	35.70
Governor's Camp	09135026	-1.28	35.03

4.2.3 Land Use/Cover

The historical land cover data used in this research was retrieved from Landsat MSS and Landsat MSS/TM/ETM images. The data was downloaded from www.glovis/usgs.com. The data was pre-processed and classified using Integrated Land and Water Information System (ILWIS 3.8) and ArcGIS software (image classification is the process of finding the relationship between land cover and measured reflection values on satellite imagery). In this research the supervised classification method was used. The method involved defining land cover classes; sampling and land use/land cover classification. Hand-held GPS units were used to conduct field surveys and to collect ground-data on land-use/cover which was used to validate the classification of the Landsat images.

4.2.4 Soil Data

Soil classification data for this research was based on Food Agricultural Organization of the United Nation Version 3.6 (FAO/UNESCO, 1995) data. The soil data is in a format supported by the SWAT model. Soil texture for various soil types was derived from the soil map obtained from the Soil Survey Department of Kenya. Primary data on soil characteristics for validation was also gathered using random sampling method. Soil data is a significant component of the SWAT model.

4.2.5 Collection of Socio-economic Data

A questionnaire for Focused Group Discussions (FGDs) was used to collect socio-economic data on local knowledge and perceptions regarding changes in land use, vegetation cover, river flows and water availability including conflicts in the use of the river waterand ecosystem impacts. The target population for the survey was sampled using the stratified sampling method. Stratified sampling is the commonly used probability method in socio economic surveys that is superior to random sampling because it reduces sampling error (Tashakkori and Teddlie 2003b). In this method, a stratum is a subset of the population that shares at least one common characteristic.

Stratified sampling is often used when one or more of the stratums in the population have a low incidence relative to the other stratums (Weber, 1978; Tashakkori and Teddlie 2003b). Stratums in this particular study included: males and females;pastoralists; small scale and large scale agricultural farmers; hoteliers and other business people etc. After identifying the relevant stratums and their actual representation in the population, random sampling was then used to select a sufficient number of subjects from each stratum.

4.3 Hydrological Data Analysis

4.3.1 Flow Duration Curves

A flow duration curve (FDC) was used to show the relationship between the magnitude and duration of stream flows. Duration in this context refers to the overall percentage of time that a particular flow is exceeded (Black *et al*., 2005). The shape of the FDC for any river strongly reflects the type of flow regime and is influenced by the character of the upstream catchment including geology, urbanisation, artificial influences and groundwater (Black *et al*., 2005). The FDC is a very useful tool for assessing the overall historical variation in flow, though one drawback is that it offers little information about the timing or persistence of low flow events (Swanson, 2002).

4.3.2 Hydrological Time-Series and Trend Analysis

The main aim of time series analysis was to detect and describe quantitatively all generating processes underlying a given sequence of observations (Shahin *et al*., 1993). The time series analysis was used for developing mathematical models to generate synthetic hydrological records, to forecast hydrological events, to detect trends and shifts in hydrological records, and to fill in missing data and extend records (Salas, 1993). In this study, time series plots were done for Mara River RGSs (Mara Mines, Nyangores and Amala) for the period of 1960 to 2000.

4.4 Statistical Data Analysis

4.4.1 Regression Analysis

Regression analysis is a statistical tool for the investigation of relationships between variables. Usually, the investigator seeks to ascertain the causal effect of one variable upon another (Webster, 1995).The analysis reveals the magnitude of change of the dependent variable in response to change in the independent variable.

The main assumptions of regression analysis are as follows

1. All the error terms have normal distribution.
2. The variables should be continuous.
3. There should be a linear and additive relationship between dependent variable and independent variable
4. The error terms must have constant variance .this phenomenon is known as homoscedasticity The error term is additive; no interactions.
5. At every value of the dependent variable the expected (mean) value of the residuals is zero .No non-linear relationships
6. There should be no correlation between residuals. The independence assumption (lack of autocorrelation)

A regression model is given by:

$$y = a + bx + e \quad (4)$$

Where:

y = dependent variable

x = independent variable

a = intercept

b = slope

e = random error or residual

4.4.2 Correlation Analysis and Coefficient of Determination

Correlation and regression analysis are related in the sense that both deal with relationships among variables. The correlation coefficient is a measure of linear association between two variables (Webster, 1995).Values of the correlation coefficient are always between -1 and +1. A correlation coefficient of +1 indicates that two variables are perfectly related in a positive linear sense; a correlation coefficient of -1 indicates that two variables are perfectly related in a negative linear sense, and a correlation coefficient of 0 indicates that there is no linear relationship between the two variables. For simple linear regression, the sample correlation coefficient is the square root of the coefficient of determination, with the sign of the correlation coefficient being the same as the sign of $b1$, the coefficient of $x1$ in the estimated regression equation (Webster, 1995). If x and y is independent and dependent variables respectively and n is the number of samples, then, correlation coefficient and coefficient of determination can be defined mathematically as:

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\left(\sqrt{n(\sum x^2) - (\sum x)^2}\right)\left(\sqrt{n(\sum y^2) - (\sum y)^2}\right)} \quad (5)$$

Coefficient of determination (R^2) is measured by squaring correlation coefficient (r). Neither regression nor correlation analyses can be interpreted as establishing cause-and-effect relationships (Webster, 1995). They can indicate only how or to what extent variables are associated with each other. The correlation coefficient measures only the degree of linear association between two variables.

4.5 Land Cover Data Processing and Analysis

The Landsat images were processed, in order to remove radiometric and geometric sensor errors, using standard techniques (Lillesand and Kiefer 1987; Coppin and Bauer 1996).The data was geo-referenced and corrected for sensor irregularities to yield real ground coordinates and to remove shifts in heights. This was achieved using the tie point technique - a technique where the row/column numbers are specified so as to obtain correct X, Y coordinates. The process involved identifying same locations on the map and on the image. After specifying the tie points, projection transformation was then carried out.

Distortion free images, after geo-referencing were created by executing the transformation defined during geo-referencing. This was done using a geocoding process. Geocoding is a process of producing a new image in which the pixels are arranged in the geometry of the master image or map. Radiometric values of the image were found by resampling the image using the nearest neighbour interpolation method. This is an interpolation method in which the value for a pixel in the output image is determined by the value of the nearest pixel in the input image.

4.6 Hydrological Modeling

The stream flow modellingwas undertaken using the Soil Water Analysis Tool (SWAT) model, which is open source software. The model was originally developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch *et al.*, 2002b). The latest version SWAT2000 has a comprehensive structure that models basically all hydrologic processes in a watershed. The model is semi-distributed therefore the basin is subdivided into sub-basins to account for differences in soils, land use, crops, topography, weather, etc.

SWAT uses a grid of soil depth values to determine the average soil depth in each of the sub basins within the basin. The process for estimating the soil depth uses the median soil depth for each soil depth category and the percentage of each mapping unit that is in that depth category.

The soil hydraulic conductivity is based on the soil texture. The SWAT interface uses a grid of hydraulic conductivities to estimate the average hydraulic conductivity for each sub basin within the basin. The model assumes hydraulic conductivities of clay, silt and sand as $10x10^{-7}$, $10x10^{-4}$ and $10x10^{-3}$m/hr respectively. The SCS curve numbers for each hydrologic soil groups are determined from a lookup table depending on the land cover as suggested by Artan *et al*. (2001).

The hydrologic cycle as simulated by SWAT is based on the water balance equation (Source: Neitsch *et al*., (2002b)):

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{qw}) \quad (12)$$

Where:

$SW_t$is the final soil water content (mm);

$SW_0$is the initial soil water content on day *i*(mm);

*t*is the time (days);

$R_{day}$is the amount of precipitation on day*i*(mm);

$Q_{surf}$is the amount of surface runoff on day *i*(mm);

$E_a$isthe amount of evapotranspiration on day*i*(mm);

$W_{seep}$is the amount of water entering the vadose zone from the soil profile on day *i*(mm) and;

$Q_{gw}$is theamount of return flow on day *i* (mm).

In this study, modellingwas done basically to: analyse the relationship between changes in land cover and stream flow and; determine the future scenario of the flow of Mara River. Topographical data was mapped from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM).

4.6.1 Model Parameters

SWAT model requires several physical and model parameters, in addition to daily rainfall data. These parameters are discussed in the sections below. The files were prepared in Automated Watershed Assessment Tool(AGWA)and input into SWAT model for catchment hydrologic response simulation. AGWA - a component of SWAT - is a multipurpose hydrologic analysis system for use in catchment scale analysis (Semmens *et al*., 2002)

4.6.1.1 Curve Numbers

The curve number *(CN)* is a dimensionless index that describes runoff as a range between 1 and 100, with 100 indicating maximum runoff potential. *CN* is dependent on the hydrologic soil group cover complex of the catchment. This cover complex comprises the hydrologic soil group, land use and treatment condition. The curve numbers are assigned to each complex to indicate their specific runoff potential.

4.6.1.2 Hydraulic Conductivity

Hydraulic conductivity is the measure of the ability of the soil to transmit water and depends upon both the properties of the soil and the fluid. Each soil type under Food Agricultural Organization (FAO) classification is assigned a hydraulic conductivity value. This will be used in developing the hydraulic conductivity map.

4.6.1.3 Conceptual model Parameters

The conceptual parameters of the SWAT model which were determined to effect the simulations were base-flow factor, evaporation from groundwater coefficient and minimum depth in shallow aquifer. These parameters are shown in Table 4.The optimal values of these parameters were determined during model calibration.

Table 4: Conceptual parameters for SWAT model

Parameter	Description
Alpha_BF	Baseflow alpha factor in days, which refers to groundwater flow response to recharge. When set to zero, there is no connection to groundwater (no return flow). Consequently when rainfall stops, the hydrographs falling limb immediately drops.
GWQ mn	Depth of water in mm required in the shallow aquifer before return flow can occur.
GW_Revap	'Revap' coefficient indicates how restricted water flow is from the shallow aquifer into the unsaturated zone to be taken up by plants.
Revapmn	This is the minimum depth in mm that must be present before water from shallow aquifer can percolate into the unsaturated zone or deep aquifer

4.6.2 Model Calibration and Validation

Models are used to represent hydrologic responses of the catchments and they enable studies of very complex problems. The reliability of the model results depend on the parameter estimation. SWAT model was developed for different catchment where the conditions and catchment parameters do not resemble the one for the Mara River catchment. Thus there was need to determine conceptual parameters using data from the study catchment before undertaking the simulation.

Determination of key conceptual parameters was done through a process called sensitivity analysis. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model parameters. It is a recommended step before calibration to identify key parameters and parameter precision (Moriasi*et al.*, 2007). The process was done by changing one parameter while holding the others constant.

The parameters which were sensitive were chosen for calibration and for the less sensitive a mean was taken and presented.

Calibration and validation was carried out using the split sample method. Split sample is a method commonly used in determining model parameters and testing their validity. It involves dividing the data into two sets one for calibration and the other for validation. Calibration was performed by comparing the simulated stream flows with the observed flows. SWAT model was run first using the default parameters set by AGWA and then adjustments within recommended ranges of maximum and minimum values were done. A number of simulations were run while iteratively adjusting the conceptual parameters to match the simulated flows with the observed flows. The process was carried out by changing one parameter while holding the others constant as simulation was being done. During the calibration process the Nash and Sutcliffe efficiency (see section 4.2.3) whose value varies from less than zero for poor fit to one for perfect fit was used as an objective function. The parameter combination which gave the highest value of efficiency wastaken as being representative of the catchment. These parameters were used for simulation in validation decade to verify their validity for use with other data sets within the same catchment.

The simulation was run in two 7yearperiod segments, where 5 years of discharge dataavailability was more than 80% of the time except forAmala (74%). Thefirst segment (1978–1982) was used tocalibrate the model and the second segment (1988–1992)for validation. Additional 4 years of warming upsimulations were included for calibration (1976–1977)and validation (1986–1987). The 5year gap (1983–1988)between calibration and validation is due to relativelylarger gap of missing discharge.The SWAT model was calibrated with 5 years of dischargedata (1978–1982) and validated over (1988–1992) at Bomet(Nyangores River), Mulot (Amala River) and Mara Mines(Mara River) stations. The calibration for Nyangores and Amala wasindependent.

4.6.3 Model Performance Criteria

General model performance assessment involves comparing the simulated results and the observed ones using both statistical methods and visual observation through graphical display. There are several statistical techniques which have been recommended for use in assessing the model performance (Nash and Sutcliffe, 1970; ASCE, 1993; Moriasi*et al.,* 2007).

Statistical techniques that wereused in this research were Nash and Sutcliffe Efficiency (NSE), and Root Mean Square Error (RMSE) observation Standard Deviation Ratio (RSR).

The NS Efficiency is given as;

$$E = \frac{\sum_{i=1}^{n}(Q_o - Q_{av})^2 - \sum_{i=1}^{n}(Q_o - Q_s)^2}{\sum_{i=1}^{n}(Q_o - Q_{av})^2} \qquad (13)$$

Where:

NSE is the Nash and Sutcliffe Efficiency;

Q_o is the observed discharge;

Q_{av} is the average observed discharge and;

Q_s is the simulated discharge;

Nash and Sutcliffe coefficient is a statistical method recommended by ASCE (1993) and is the most commonly used objective function for hydrologic studies (Shuol*et al.*, 2008). It expresses the proportion of the variance of the observed flows that can be accounted for by the model and provides a direct measure of the ability of the model to reproduce the observed flows. When E = 1.0, it indicates that the predicted flows are the same as the observed flows (Chemelil, 1995; Moriasi*et al.*, 2007). When E = 0.5 or less, it indicates that the model simulation does not correspond to the observed and there is no strong correlation between the observed and simulated flows. In other words it defines the relative percentage difference between the average simulation and measured data time series over any given n time steps (Tolson and Shoemaker, 2007).

RSR standardizes the Root Mean Square Error (RMSE) using the standard deviation. RMSE is one of the commonly used error index statistics. RSR is calculated as a ratio of RMSE and standard deviation of the measured data as shown in equation 14.

$$(14) \qquad RSR = \frac{RMSE}{STDEV_{obs.}} = \frac{\left[\sqrt{\sum_{i=1}^{n}(Q_o - Q_s)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}(Q_o - Q_{av})^2}\right]}$$

RSR incorporates the benefits of error index statistics and includes a normalization factor. The RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation and therefore perfect model simulation. It is used in current study to test and ascertain that the model simulated the catchment response with low residual errors.

CHAPTER 5

RESULTS OF THE STUDY

5.1 Introduction

This chapter presents the key results of this study with respect to the methodology used. The chapter begins by presenting results of the analysis of hydrological time series data. The data includes rainfall, river discharge and evaporation. This is followed by results of characterization of soil data and land cover/use analysis.After this then the chapter presents results of SWAT model analysis, which includeresults of model parameters' sensitivity analysis, calibration and validation and; long term stream flow simulation. The fifth section presents results of the analysis of the effect of different land cover change scenarios (current situation, business as usual scenario, basin conservation scenario, basin degradation scenario, completely forested land, completely agricultural land and completely bare land) on the streamflow of Mara River. The last partof this chapter presents results of the analysis of socio-economic impacts of stream flow changes in the Mara river basin.

5.2 Hydrological Time-Series/Trend Analysis

5.2.1 Rainfall Time Series Analysis

Daily mean rainfall for the entire basin calculated from an isohyetal map developed from the six stations used in this study (shown in Table 3) for the period of 1978 to 2000 showed two distinct rainfall seasons in the basin (Figure 8).The first and longer rain occurs between mid-March and June, whereas the second and shorter rain is between September and December. The heaviest rains occur during the long rain season with a mean highest peak of 8.8 mm in the month of April. The peak for the short rain season is 5mm and is in November. The other months are relatively dry with the recorded rainfall lying between 2 and 3 mm. The annual rainfall decreases with altituderanging from 1000 to 1750 mm in the upper reaches, from900 to 1000 mm in the middle and from 300 to 850 mm atthe lower reaches of the river. Daily mean evaporation in the basin also has two high seasons (Figure 8). The highest value of 6.9 mm occurs in the month of March, whereas the other peak of 6.6 mm occurs in the month of September. The two evaporation peaks occur during the dry seasons just before the onset of the rains. The trend of the rainfall for the last 30 years shows a very slight decline in rainfall in the recent years. This could be attributed to climate change but more research needs to be done to ascertain the reasons with certainty.

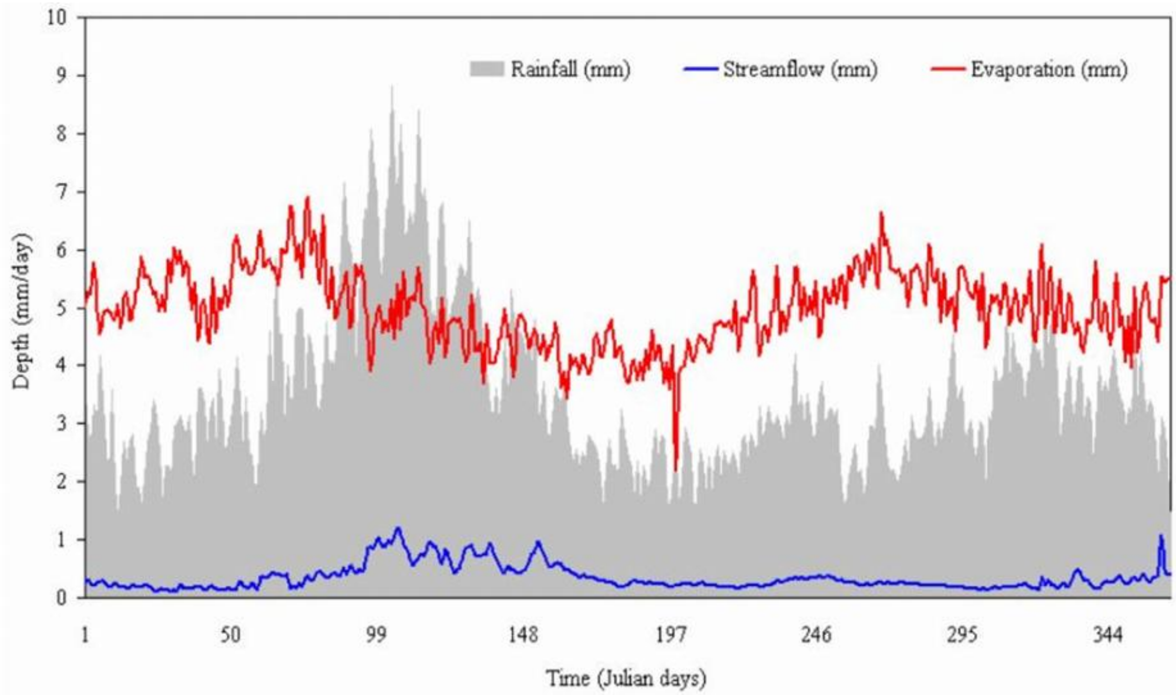

Figure 7: Average seasonal mean depths of rainfall, evaporation over the entire Mara River Basin and discharge at Mara Minesfrom 1978 to 2000. Source of data:Rainfall and evaporation, KMD and; streamflow, WRMA.

5.2.2 River Discharge Analysis

Results of the analysis of long-term (1978 to1993) river discharge data for Mara Mines, Nyangores and Amala river gauging stations are illustrated in Figure 9 and 10. From thesetwo figures it is shown that Amala River has a higher and early peak runoff than Nyangores. This could be attributed to the fact that Nyangores has more vegetation cover. It is also shown that Nyangores has higher base flow compared to Amala. The daily mean streamflow at Mara Mines gauging station calculated as depth over the entire basinshows that thereare two peaks in the river discharge corresponding to the two wet seasons in the basin. The peak corresponding to highest rainfall season is 1.2 mm and occurs in the month of April. The peak flow in the September to December season is 0.58 mm and occurs in the month of December. The monthly mean streamflow at Nyangores River (1LA03 gauge) is $8.7m^3s^{-1}$ though it does not always prevail in all years due to temporal variability of rainfall. The trends at the adjacent Amala tributary gauging station (1LB03) are relatively similar to those at Nyangores tributary. The long term trend for the time series discharge data from Mara Mines, Nyangores and Amala RGSs shows a decline in monthly average flows (Figure 9).

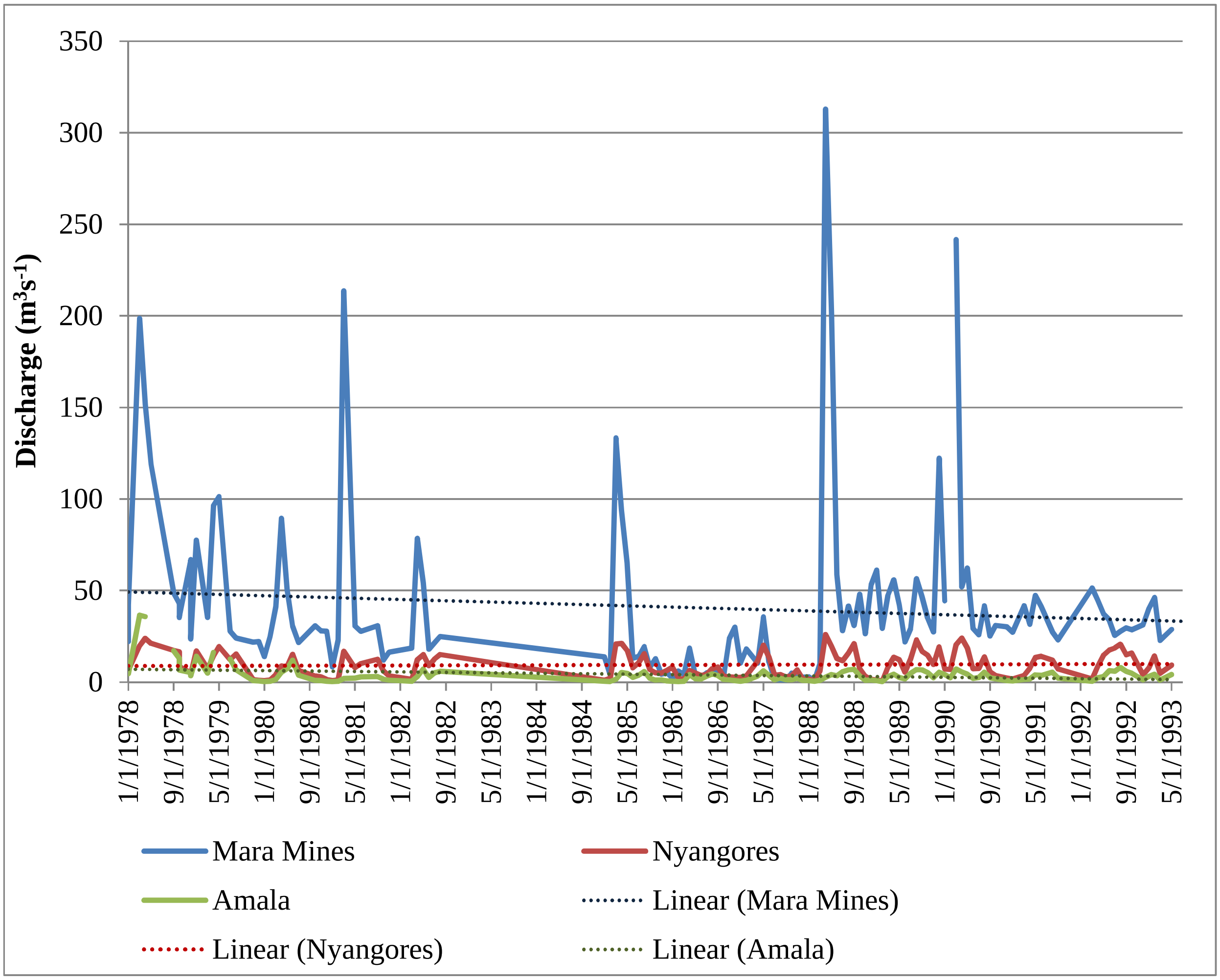

Figure 8: Time series plot for monthly average discharge for Mara Mines, Nyangores and Amala RGSs. The plot also includes the linear trends of the data from 1978 to 1993

Two high flow seasons whose magnitudes are related to the rainfall amounts are clearly evident at this station. One season occurs from May to August followed by recession in month of September then another season around November to December. At Mara mines gauging station flow seasons are clearly defined. Two seasons with the first one occurring from March to July and the second one from October to December are clearly identifiable. The March-July flow is the highest. The mean flow at the station is 36.8 m^3s^{-1} contributed from Amala, Nyangores and other seasonal tributaries upstream of this station during the rainy season

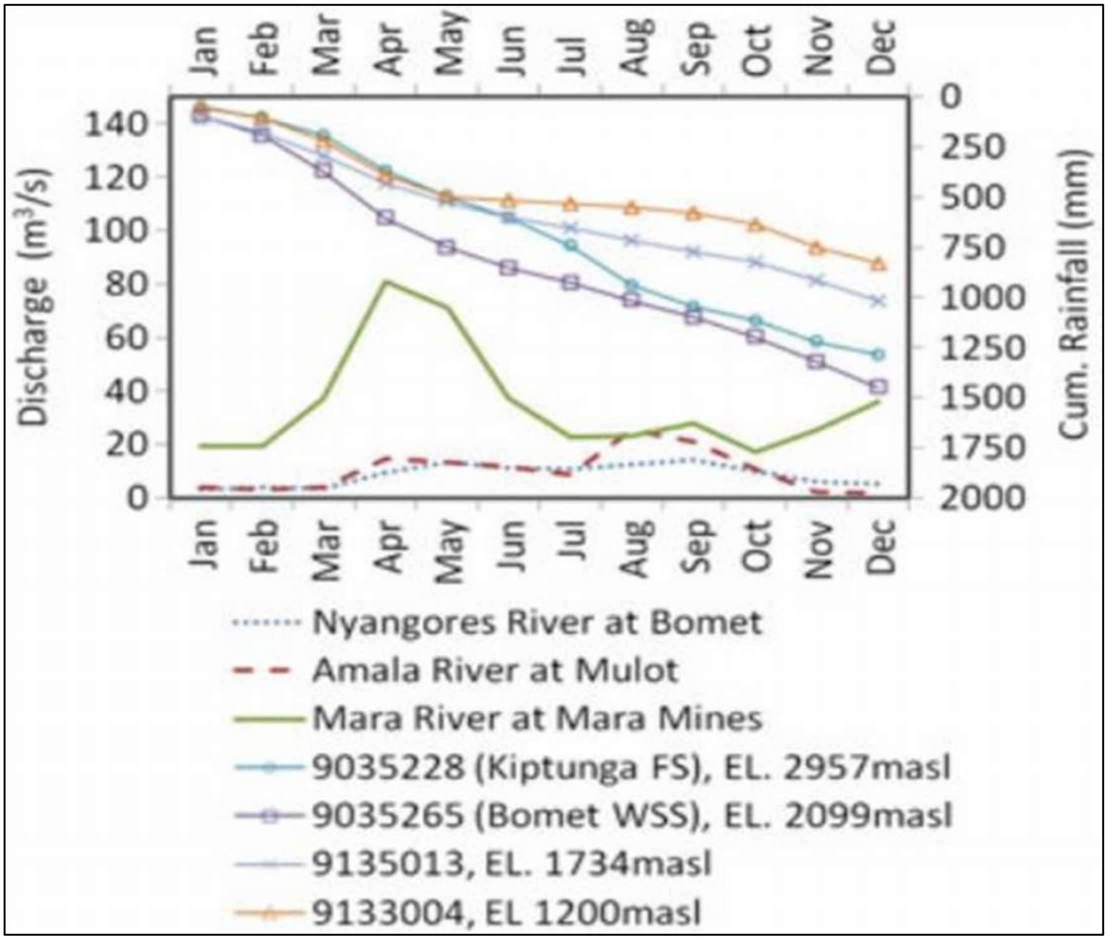

Figure 9: Long-term (1978 to 1993) average monthly cumulative rainfall and discharge at selected Monitoring stations of the Mara River Basin.

5.3 Soil Characterization

The soils were classified as suggested by United States Department of Agriculture, USDA (1999). Additional soil data was extracted from the Harmonized World Soil Database (HWSD) (FAO *et al*., 2012) and used to identify the soil types with respect to the classificatio. The results of the analysis are illustrated in Table 6.The soils were further classified as very shallow, shallow, moderately deep, deep or very deep using the SWAT model interface. The resulting classified map layer was used as an input in the SWAT model. Each class has range of depthsas defined by FAO, (1997). Figure 12 shows soil map of the Mara River Basin extracted from the 1:5 million HWSD raster map including the soil sampling points for this research.

Table 5: Results of soil particle distribution analysis (*S Pt.* is sample point; C is clay; Slt silt; Snd sand and; G gravel). The samples were classified with the USDA Texture Class.

S Pt	**Long. ^{0}E**	**Lat. ^{0}N**	***C* %**	***Slt* %**	***Snd* %**	***G* %**	**USDA Texture Class**	**HWSD Soil type**
1	35.51	-0.87	17	55	26	27	Loam	Humic Cambisols (CMu)
2	35.50	-0.87	17	49	34	0	clay loam	Haplic Phaeozems (PHh)
3	35.54	-0.82	14	39	35	12	clay (light)	Mollic Andosols (ANm)
4	35.57	-0.77	10	48	18	24	clay (light)	Mollic Andosols (ANm)
5	35.52	-0.77	13	46	39	2	clay (light)	Mollic Andosols (ANm)
6	35.45	-0.81	18	52	27	3	clay (light)	Mollic Andosols (ANm)
7	35.41	-0.96	13	67	18	2	silty clay	Vertic Luvisols (LVv)
8	35.23	-1.06	14	32	49	5	Silt	Eutric Vertisols (VRe)
9	35.42	-0.71	10	42	46	2	clay (light)	Mollic Andosols (ANm)
10	35.33	-0.83	13	53	34	0	sandy clay	Luvic Phaeozems (PHl)
11	35.25	-0.93	23	51	26	0	Silt	Eutric Vertisols (VRe)
12	35.25	-1.08	4	33	57	6	sandy clay	Luvic Phaeozems (PHl)
13	35.24	-1.17	10	47	41	2	Silt	Eutric Vertisols (VRe)
14	35.20	-1.18	10	44	41	5	Silt	Eutric Vertisols (VRe)
15	35.12	-1.20	10	53	35	2	Silt	Eutric Vertisols (VRe)
16	34.28	-1.47	19	58	23	0	loamy sand	Eutric Fluvisols (FLe)
17	34.12	-1.65	12	35	53	0	silty clay loam	Eutric Planosols (PLe)
18	34.26	-1.58	15	63	22	0	silty clay loam	Eutric Planosols (PLe)
19	34.57	-1.52	5	37	56	3	silty clay loam	Eutric Planosols (PLe)
20	34.51	-1.50	13	59	28	0	silty clay loam	Eutric Planosols (PLe)
21	34.63	-1.55	6	38	54	2	silty clay loam	Eutric Planosols (PLe)
22	34.87	-1.57	6	46	45	4	silty clay loam	Eutric Planosols (PLe)
23	34.68	-1.66	5	37	56	3	sandy clay	Luvic Phaeozems (PHl)
24	34.71	-1.74	5	36	59	0	sandy clay	Luvic Phaeozems (PHl)

5.4 Land Use/Land Cover Analysis

Based on the analyses of Landsat MSS, TM and ETM images of Mara River basin for the years 1973, 1986 and 2000, land cover/use thematic maps (Figure 14) were obtained. The area of the basin covered by each land cover/use type for 1973, 1986 and 2000 were calculated. The resultsare shown in Table 7 and graphically illustrated in Figure 13. It can be seen from the table and figure that the spatial areas of the natural forests, rangelands (shrub land, grassland, and savannah) and water bodies have declined while the areas under tea and open forests, agricultural land and wetlands have increased. Between 1973 and 2000 there hasbeen a decrease in closed forests of 31%. Tea plantations and open forests have increasedby 214%. The rangelands (shrub land, grassland and savannah) which were the grazing areas for livestock and wildlife have decreased by 35%. Agricultural areas have increased by 203%.

Land cover changes in the basin between 1986 and 2000 are depicted in Figure 15. The map in the figure was developed using image differencing technique in GIS. The map shows the areas that have been forested, deforested, changed to agriculture and changed to wetlands. It can be seen that agricultural fields have been opened in most parts of the basin except at the centre where the protected Serengeti and Maasai Mara wildlife sanctuaries are found. Overlying the river channel on the change maps show that the opening of agricultural fields is more intense along the river channel.

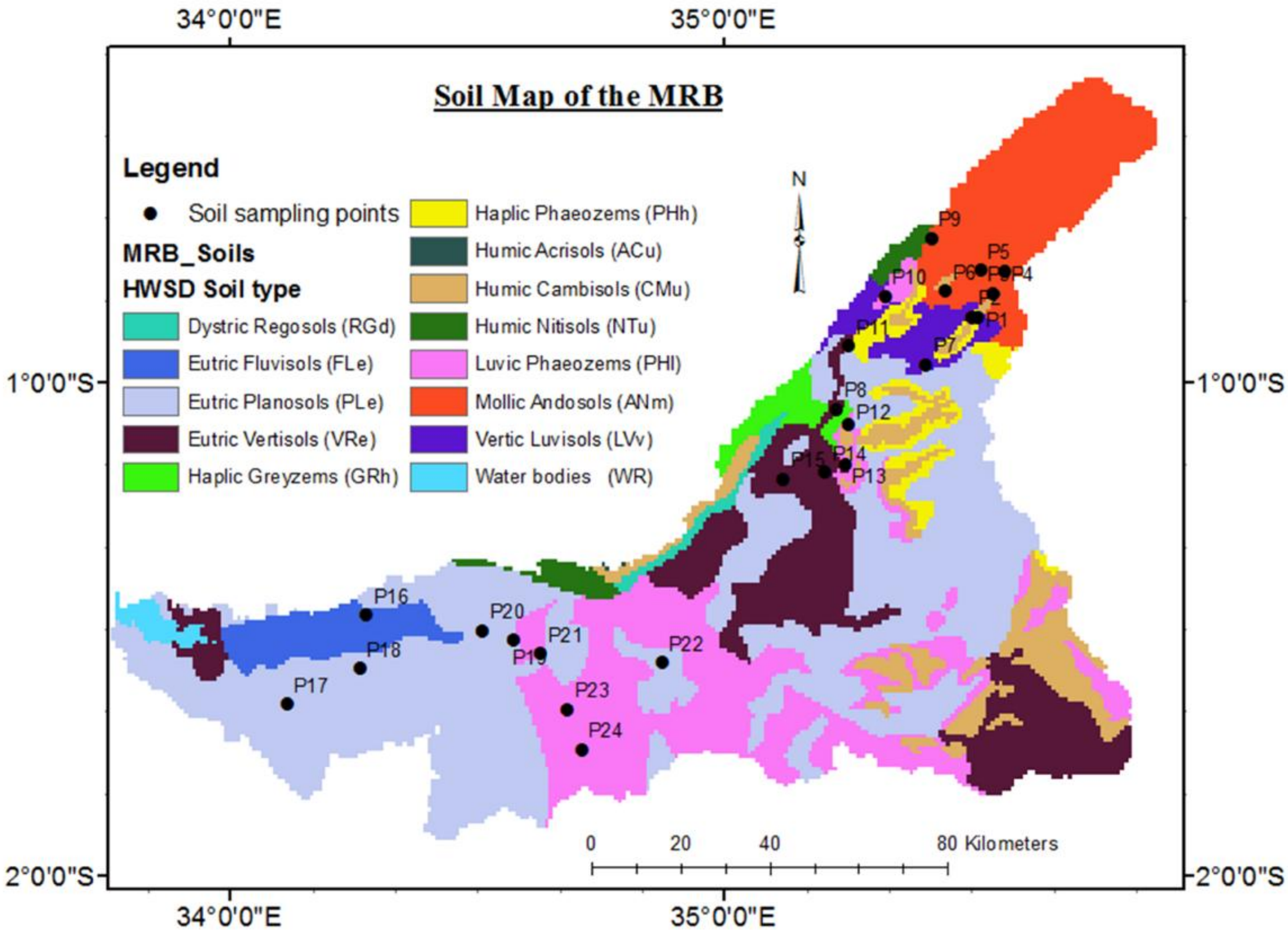

Figure 10: Soil Map of the Mara River Basin extracted from the HWSD raster map. The sampling points for this research are also shown in the map.

Table 6: Land use/land cover areas change statisticsas analysed from classified Landsat MSS, TM and ETM images of Mara River basin for the years 1973, 1986 and 2000 respectively.

Land cover/use type	**1973 (km^2)**	**1986 (km^2)**	**2000 (km^2)**	**Change (1973-2000) (km^2)**	**Change (%)**
Forests	1008	893	689	-319	-32
Tea/Open Forests	621	1073	1948	+1327	+214
Agricultural land	826	1617	2504	+1678	+203
Shrubland	5361	5105	3546	-1815	-34
Grassland	2465	1621	1345	-1120	-45
Savannah	3163	2867	2354	-809	-26
Wetlands	286	604	1394	+1108	+387
Water Bodies	104	54	55	-49	-47

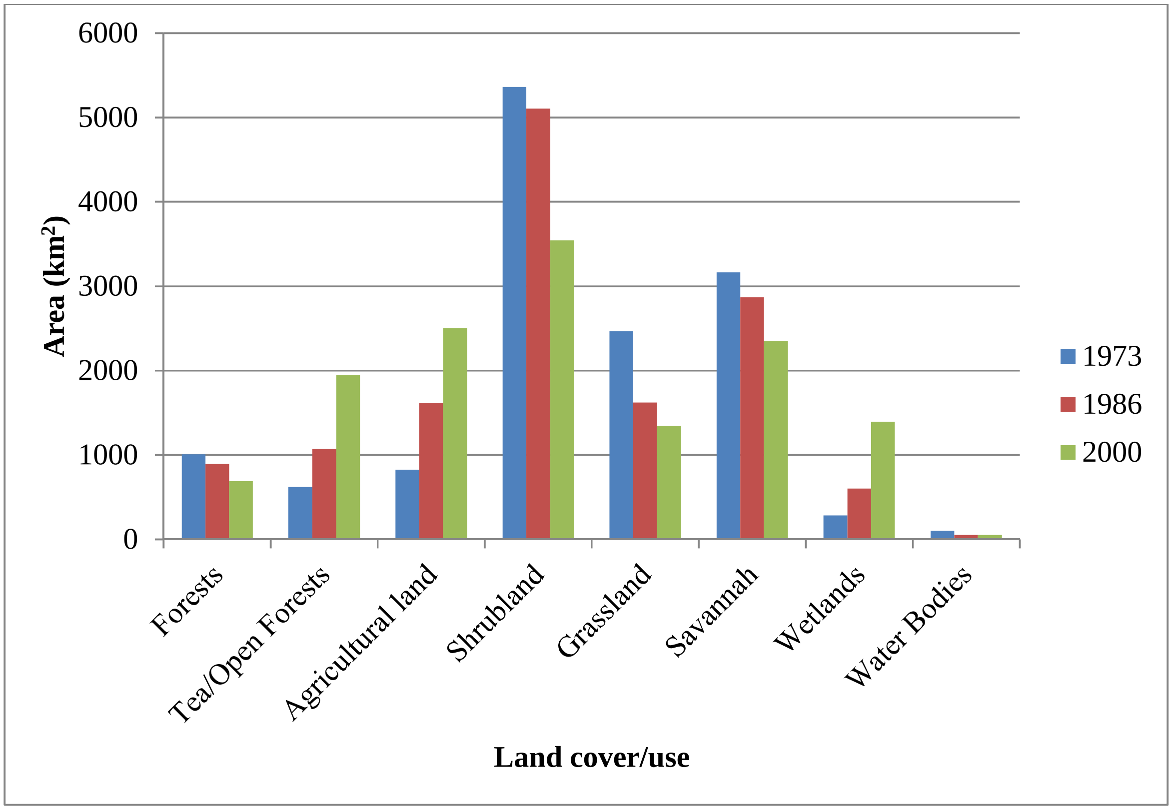

Figure 11: Land cover/use in area (km^2) derived from classified Landsat MSS, TM and ETM images of Mara River basin for the years 1973, 1986 and 2000 respectively

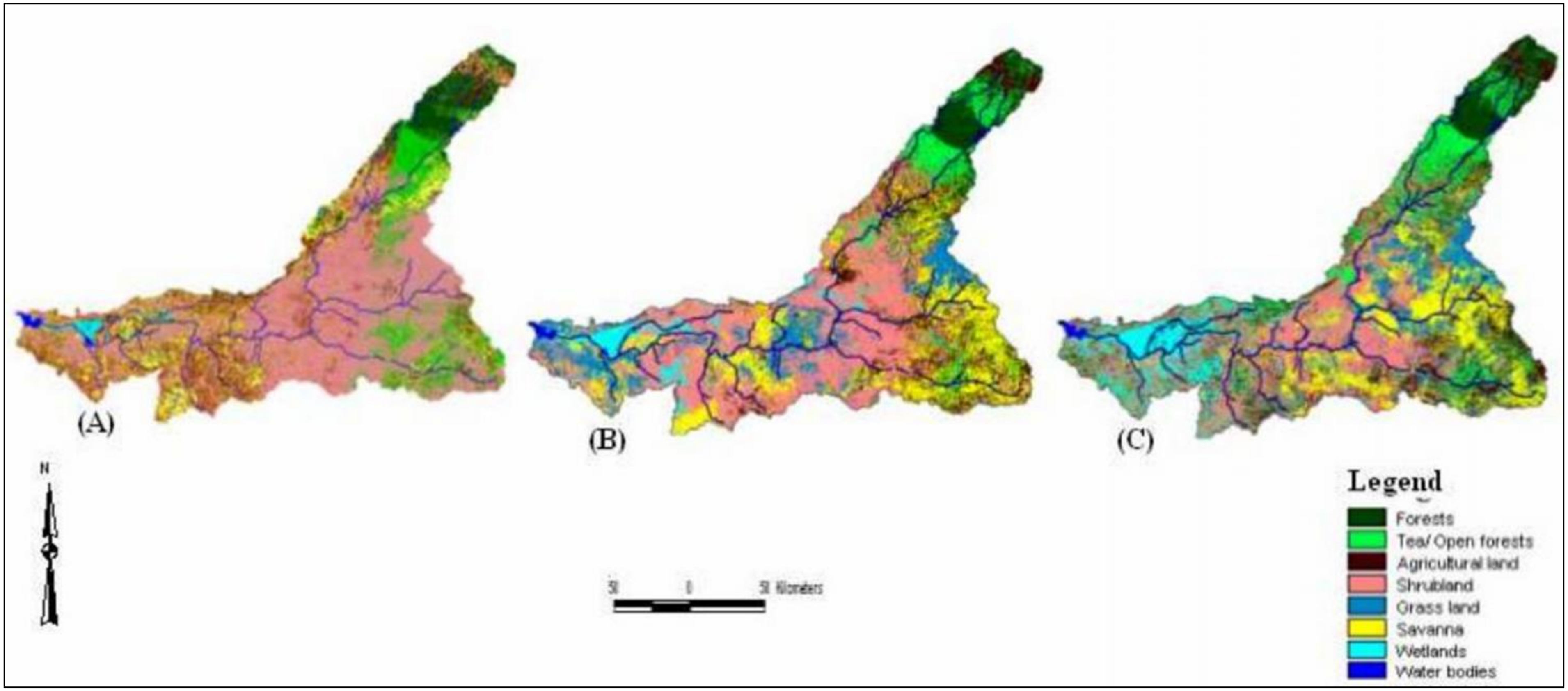

Figure 12: Land use/land cover maps of (A) 1973, (B) 1986 and (C) 2000 for the trans-boundary Mara River Basin.

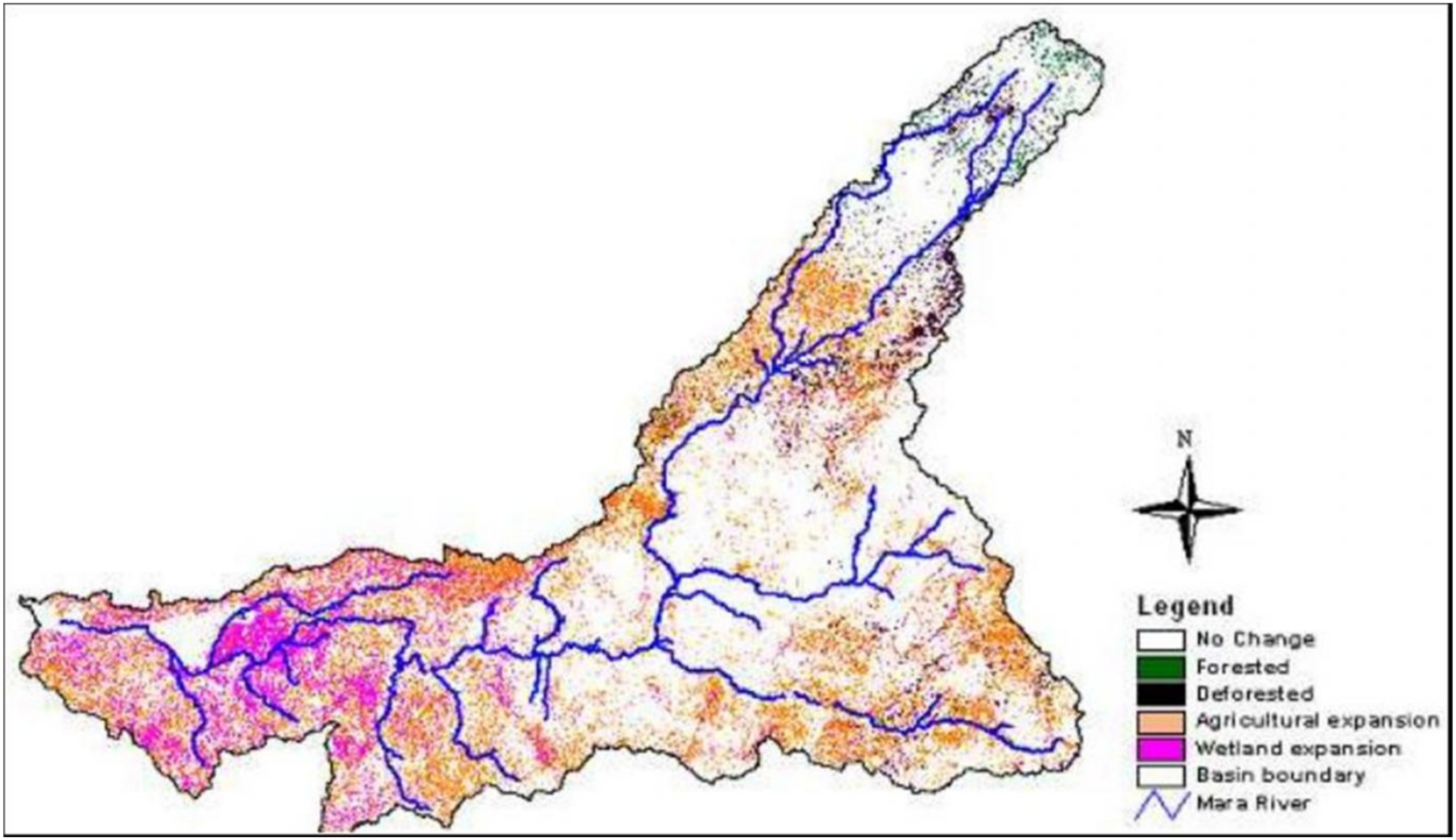

Figure 13: Land use/cover change in the Mara basin between 1986 and 2000.

5.5 Model Performance Analysis

5.5.1 Sensitivity Analysis

Sensitivity analysis was done on the following SWAT model parameters:

- Sol_AWC(available water capacity);
- Cn2 (moisture condition II curve number);
- Esco(soil evaporation compensation factor);
- Rchrg_Dp(deep aquifer recharge factor);
- Revapmn(threshold water depth in the shallow aquifer for“revap”to occur);
- Canmx(maximum canopy storage);
- Gwqmn(threshold water depth in the shallow aquifer forflow);
- Blai(maximum potential leaf area index at the end of the period);
- Slope (sub-basin slope);
- Sol_K(soil hydraulic conductivity);
- Ch_K2 (channel effective hydraulic conductivity);
- Sol_Z(soil depth);
- Ch_N2 (manning roughness coefficient) and;
- Alpha_Bf(baseflow alpha factor).

The automatic sensitivity analysis of SWAT was used to rank flow parameters with and without observed discharge at the three flow gauging stations. The results of the analysis (shown in Table 8) were used to facilitate the calibration of the model where the correlation between parameters was equally important.

Table 7: Mean Sensitivity Index (SI) of the top 10 ranking flow parameters of SWAT model with and without observed discharge

Parameter	Mean SI with observed flow			Mean SI without observed flow		
	Nyangores	**Amala**	**Mara Mines**	**Nyangores**	**Amala**	**Mara Mines**
Sol_Awe	1.36	0.86	5.01	1.76	2.64	3.28
Cn2	0.61	0.28	6.41	1.09	0.93	2.81
Esco	0.60	0.32	2.03	0.97	0.88	0.85
Rchrg_Dp	0.37	0.26	0.39	0.76	0.91	0.39
Revapmn	0.27	0.11		0.21	0.23	
Canmx	0.22	0.09	0.16	0.29	0.31	0.12
Gwqmn	0.18	0.16		0.37	0.59	0.10
Blai	0.17	0.13	0.66	0.26	0.33	0.28
Slope	0.17			0.27	0.26	0.07
Sol_K	0.16	0.07		0.27	0.26	
Ch_K2			0.27			0.11
Sol_Z		0.07	0.23			0.13
Ch_N2			0.17			
Alpha_Bf			1.07			

5.5.2 Calibration and validation

The model was calibrated for 5 years (1978–1982) using observed discharge at Bomet, Mulot and Mara Mines stations. Table 9 shows the parameter values of the calibrated model for the three stations. A separate 5year (1988–1992) simulation was used for validation. Results of the calibration and validation process are shown in Table 10.The calibrated average flow was fairly underestimated at Bomet and Mulot (4% and16%, respectively) and overestimated at Mara Mines (+12%). The SD indicated a smoothing effect during the calibration period with a consistent lower SD of simulated flow. Mean and SD observed and simulatedflow ofvalidation period closely resembled results obtained forcalibration (Table 10).The simulated FDCs (Figure 16) at Amala and NyangoresRivers had similar pattern as these two sub-basins sharedsame rain gage data and had almost similar drainage areasize. In comparison with their respective observed flow (Figure 17), however, Nyangores was closer to the observed whereas the Amala River flow indicated larger deviations from the observed with peak flows dominating less than 25% exceedence while over estimating the remaining

75% of simulation. The simulated FDC at Mara Mines generally compares well with observed with fair under estimation of the mean/median discharge and over estimation of extreme flows.

Table 8: Parameter values of calibrated model for Mara River Basin

Parameter	Suggested range of values	Nyangores	Amala	Mara Mines
Cn2	± 25%	-25%	-10%	-20%
Alpha_Bf	0 - 1	0.05	0.05	0.02
Esco	0 – 1	0.6	1.0	0.80
Sol_Awc	± 25%	+25%	+25%	+25%
Rchrg_DP	0 – 1	0.05	0.05	0.80

The simulated daily flow matches the observed values for calibration and validation period with regression coefficient of determination R2 = 0.69, 0.44 and NS = 0.68, 0.43 respectively for the catchment outlet at Mara Mines. The summary of the model performance at sub catchment level is illustrated by the table 10 below.

Table 9: Summary of model performance assessment

	Calibration (validation)		
Statistics	**Nyangores**	**Amala**	**Mara Mines**
No. events	59 (56)	44 (57)	49 (49)
Observed mean,	9.3 (10.2)	12.1 (14)	51 (57.9)
Simulated mean	9 (10.5)	10.2 (11.7)	57.3 (54.3)
Observed SD	6.5 (7)	15.9 (20.5)	47 (69.4)
Simulated SD	5.7 (6.4)	6.6 (7.7)	37.4 (45.5)
Correlation coefficient	0.73 (0.62)	0.68 (0.6)	0.83 (0.66)
Root Mean Square Error	4.5 (5.8)	12.5 (17.5)	26.6 (51.7)
Mean Root Error	0.6 (0.8)	1.7 (3.0)	0.6 (1.4)
Mean Absolute error	3.2 (4.6)	7.6 (12.3)	20.6 (31.3)
Coefficient of determination	0.53 (0.38)	0.45 (0.36)	0.69 (0.44)
NS	0.5 (0.3)	0.37 (0.3)	0.68 (0.43)

5.5.3 Model Simulation

To investigate the effects of land cover change on river flow, stream flow was generated from derived land cover thematic maps of 1973 and 2000 using the same rainfall and evaporation data of 1983 to 1992 period. The other model input datasets for topography and soils were held constant during the two runs. Results of the comparisons of the daily stream flow hydrograph generated using 1973 land cover to that generated using 2000 land cover (Figure 17) are presented in Table 11. The 2000land use/land cover dataset gave higher flood peaks compared to the 1973 dataset. The hydrograph generated from 2000 land cover dataset produced the highest peak of 877.9m^3s^{-1} whereas the 1973 land cover data set produced a high peak of 827.0m^3s^{-1}. The 2000 dataset peak was higher by 6% compared to the 1973 dataset. The time of these peaks for the 1973 and 2000 data sets was May 8th and May 4th respectively. Therefore the hydrograph generated from the 2000 land cover dataset was shifted 4 days to the left when compared to that of the 1973 land cover dataset. The mean stream flows of the 1973 and 2000 data sets were 35.26m^3s^{-1} and 35.61m^3s^{-1} respectively. Figure 18 shows the graphs of simulated daily stream flow from 1973 and 2000 land cover datasets for the rainfall of 1988 flood year at the Mara mines gauging station. From the figure it can be seen that the 2000 land cover data produced stream flow even at small magnitudes of rainfall for which the 1973 data produced no stream flow. At prolonged dry seasons the two data sets produced the same stream flow rates. The percentage difference between the mean annual stream flows of the two hydrographs was negligible at 0.01%.

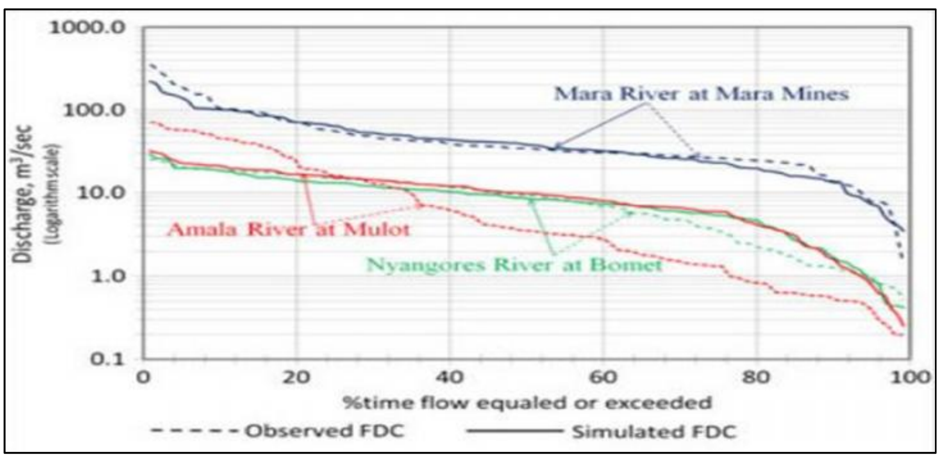

Figure 14: Observed and simulated Flow Duration Curves of Nyangores River at Bomet, Amala River at Mulot and Mara River at Mara Mines

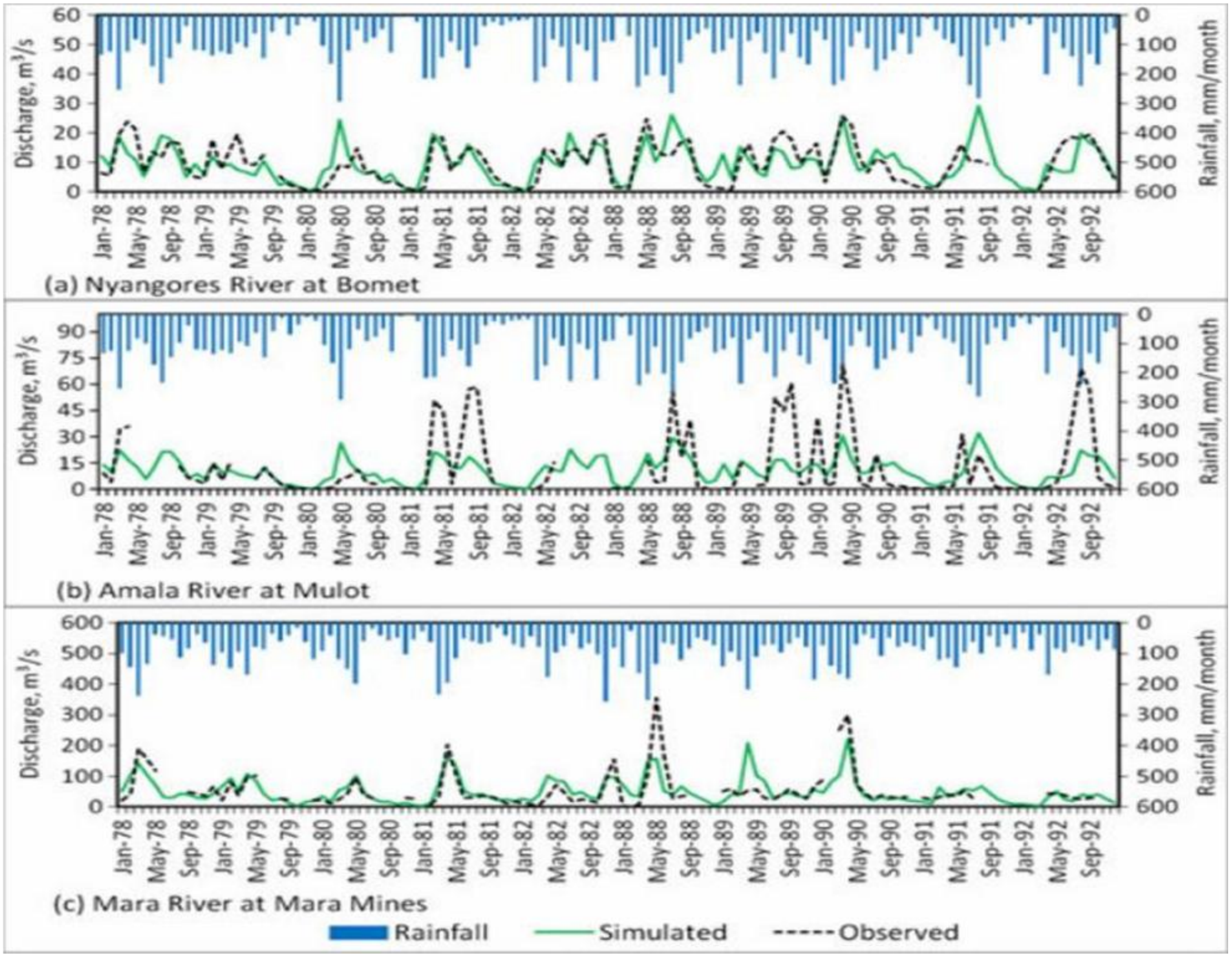

Figure 15: Rainfall hyetograph and hydrographs of observed and simulated discharge

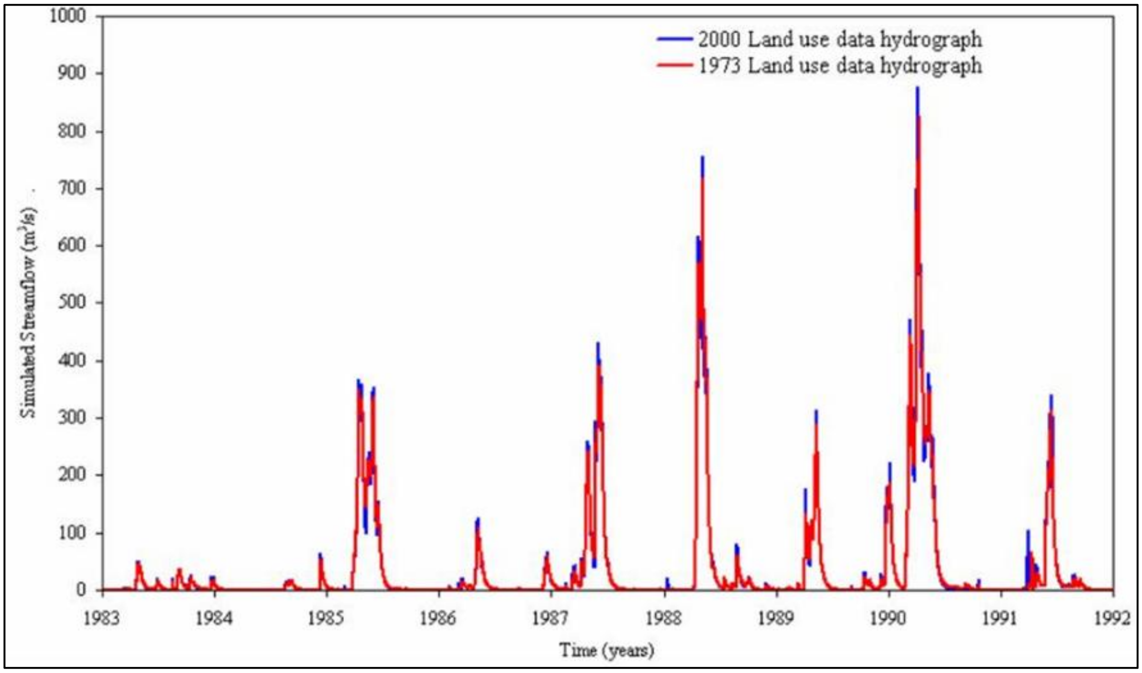

Figure 16: Simulated hydrographs for 1973 and 2000 land cover data sets for Mara River Basin at Mara mines.

Table 10: Parameters obtained from the hydrographs generated from 1973 and 2000 land use/land cover data sets.

Item	1973 Land cover data	2000 Land cover data
Peak flow	827 m^3/s	877.9 m^3/s
Time of peak	May 8^{th}1973	May 4^{th}2000
Mean flow	35.26 m^3/s	35.62 m^3/s

5.6 Analysis of Different Land Cover Change Scenarios on River Mara Streamflow

SWAT model was run for each condition under: current situation, business as usual scenario, basin conservation scenario, basin degradation scenario, completely forested land, completely agricultural land and completely bare land. Runoff curve number and evapotranspiration parameters (Table 12) associated to each scenario were the only parameters that changed in the basin text to reflect the different scenarios in land cover change. The resulting river flow hydrographs were plotted (Figure 19 and 20) then analysed for differences. Table 13shows the different streamflow parameters obtained from the hydrograph under each scenario.

Table 11: Runoff curve numbers (CN) and Evapotranspiration coefficients for the model under each scenario.

Scenario	**CN**	**Evapotranspiration**
Business as usual	83	0.64
Forest conservation	76	0.83
Forest degradation	81.5	0.66
Completely bare land	85	0.60
Completely agricultural land	82	0.65
Completely forested land	74	0.90

Table 12: parameters differentiating hydrographs from each of the scenario developed.

Scenario	**Flow peak (m^3/s)**	**Time of peak**	**Mean flow (m^3/s)**
Current	271.8	7th May	32.1
Business as usual	275.3	8th May	28.7
Forest conservation	283.5	7th May	33.6
Forest degradation	248.1	9th may	25.2
Completely bare land	400.2	3rd May	41.2
Completely agricultural land	376.2	7th May	36.6
Completely forested land	225.3	9th May	23.8

In Business as usual (BAU) scenario the forest cover of the year 2000 (current scenario) was reduced by 1.2% from 689 km^2 to 509 km^2 in 2025. This reduction was opened up for agriculture. The resulting hydrograph did not show any observable shifts from the year 2000 hydrograph. However the peak of BAU scenario was 275.3m^3s^{-1} compared to 271.8 m^3s^{-1} of the current situation. The time of occurrence of the peaks was the same, on April 10th. The mean annual flow rates for the current scenario and BAU in 2025 were 32.1m^3s^{-1} and 28.7m^3s^{-1} respectively. Therefore under this scenario the flood peaks increased by 1.3% and lagged behind by one day, whereas the mean flow increased by 0.6%. Similar analyses were done for the other scenarios and the results are presented in Table 14.

From the table it can be seen that reduction in forest cover increased the flow peaks as well as the mean flows. The peaks occurred at an earlier date.

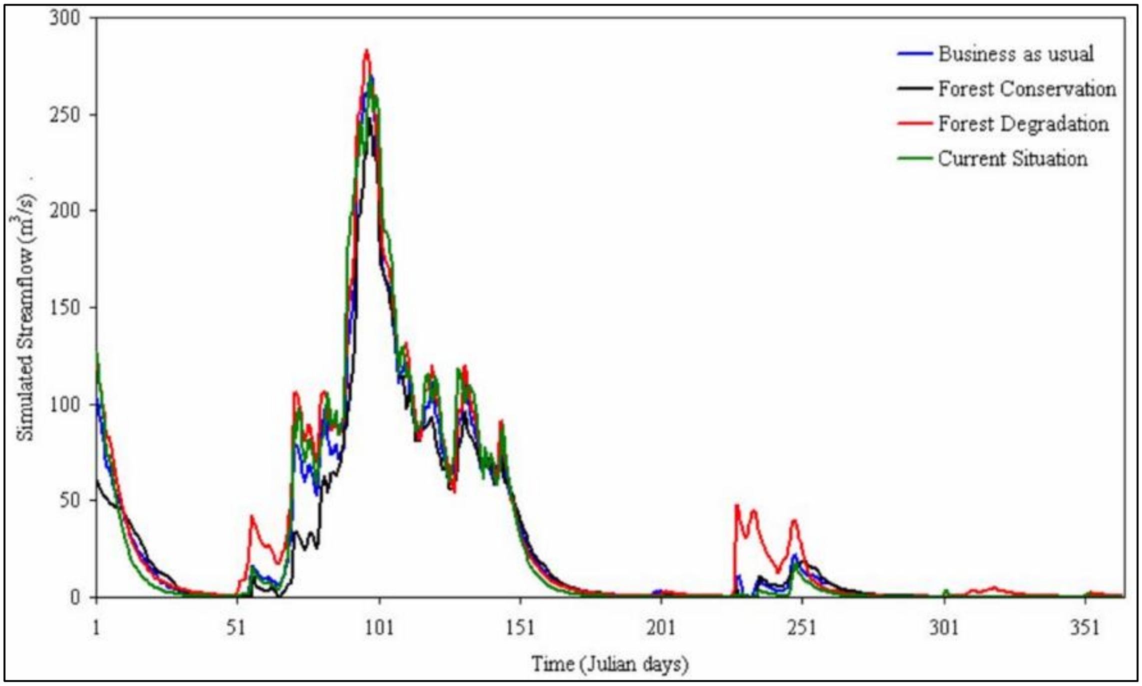

Figure 17: Simulated hydrographs of Current scenario Business as usual, Forest conservation and Forest degradationscenarios for Mara River Basin at Mara mines.

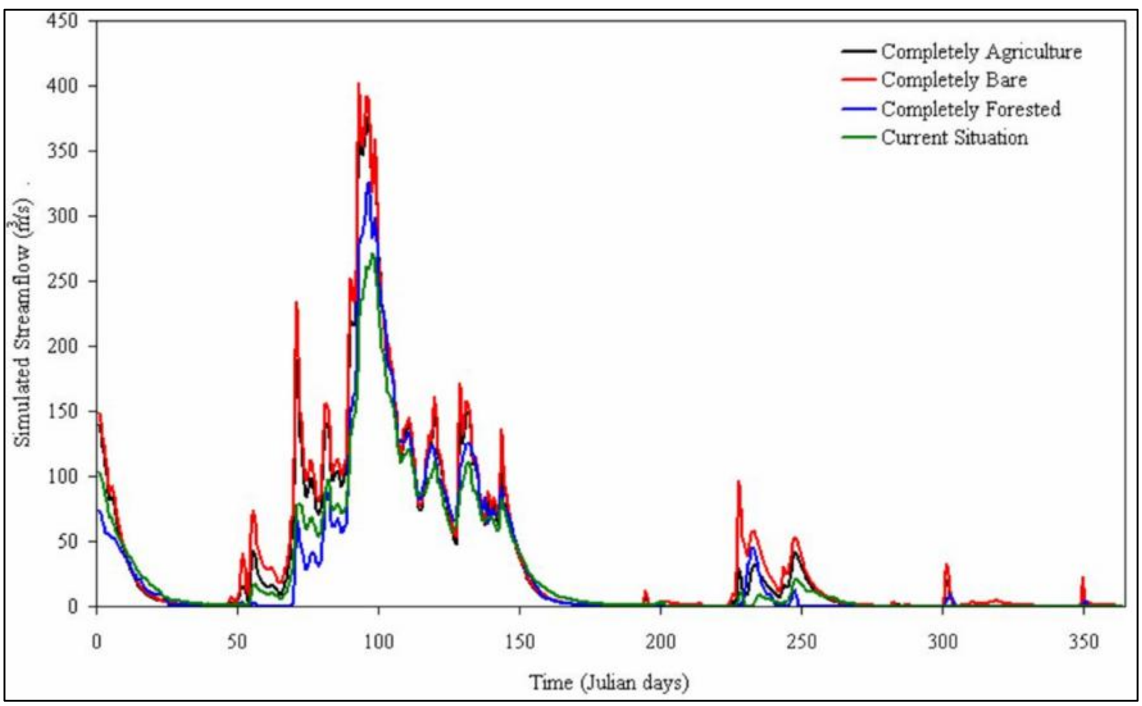

Figure 18: Simulated hydrographs of current situation, completely agriculture, completely bare and completely forested scenarios for Mara River Basin at Mara mines.

Table 13: The differences of the various parameters of the hydrographs generated from scenarios of year 2025 compared to the current situation of year 2000.

Scenario	**Flow peak change (%)**	**Shifting of peak occurrence (days)**	**Mean flow Change (%)**
Business as usual	+1.3	+1	+0.6
Forest conservation	+4.3	0	+0.9
Forest degradation	-8.7	+2	-2.5
Completely bare land	+47.2	-3	+3.3
Completely agricultural land	38.4	0	+1.7
Completely forested land	-17.1	+2	-3.1

5.7 Socio-Economic Impacts of Stream Flow Changes

The assessment of the socio-economic impact of the changes in stream flow in the MaraRiver Basin was based on the questionnaire and Focussed Group Discussions. The results revealed that there has been visible decrease in forest cover though those interviewed could not quantify the decrease. Forests have been cleared to pave way for farming and settlement. As forests decrease there has been an increasing trend in the number of tea plantations. The results showed that there is increasing small holder irrigation farming along the river banks. Change in land cover has led to more severe drier dry seasons with low river flow especially in the downstream areas.

Lack of sufficient water has led to pastoral farmers taking their livestock into game reserves and private ranches causing conflicts with the ranch owners. Declining water quantity and quality water and frequent flooding which interviewees attributed to declining forest cover and farming along river banks has also led to increase in waterborne diseases according to the interviewees, diseases like malaria, typhoid, bilharzia, dysentery.There was also an indicator that there been change in land ownership, with the community embracing land subdivision and shifting from communal land ownership.

This has led to communities in the middle of the basin to gradually change from pure pastoralists to agro-pastoralists. Some individual farmers have also started growing high value horticultural crops.

5.7.1 Water use conflicts

With the ever increasing population in the MRB, the demand for water in the MRB has also significantly increased in the recent years. Water for livestock demands in the Mara catchment, increased from 159-190m3/year between the years 1990 and 2000 [JICA, 2000]. Aboud [2002] &Hoffman [2007] note that over 60% of households within the MRB rely on Mara River for domestic and livestock needs. Therefore, this river is crucial to the survival of the people as well as wildlife and livestock. Domestic uses include cloth laundering, personal bathing, consumption and watering livestock. Many of the small-scale farms are rain fed while the large-scale farms are also irrigated via extractions from the Mara River. The major abstraction points are; urban water supplies to towns like Bomet and hydropower generation in the Tenwek region of Kenya. The tourism and hotel industries are also noted as abstracting water from the river for various domestic uses. The Barrick gold mines in Tanzania also extract substantial water for mining processes [Hoffman 2007].

The climate changes and variations in the recent years are expected to exacerbate water supply problems within the MRB. Consequently, competition in accessing and using water sources will intensify [Mwiturubani, 2010]. The main competing interests for water resources in the Mara River include the large scale irrigation plantations on the Kenyan side, the Maasai Mara and Serengeti Wildlife protected areas, small scale farmers and pastoralists on both sides of the basin, the mining industry in Tanzania, small scale fishing activities, and urban and rural domestic water supplies.

Water use conflicts, herein referred to as disputes about social, economic, political and territorial-related issues, will most likely ensue as water scarcity intensifies. Several levels and types of water-use conflict are likely to emerge in such scenarios. At the family level water-use conflicts relate to the gender division of labor where men, women and youths; and adults and the young have different roles. For instance, in the MRB, men are responsible for taking care of livestock and farming, while women are responsible for household chores and farming [Onyango, 2007]. Here the men wanting to utilize some water sources for livestock may be opposed to the women‟s uses, hence creating water-use conflicts. Furthermore, because of a water shortage, some family activities that require water may not be performed.

Depending on which group wields the greater power- men, women, the youth or adults, girls or boys - conflict is likely to occur between these groups in the use of the available water for gender-specific activities. For instance, because of water scarcity, women walk up long [up to 10km] return trips to collect water daily for domestic chores such as cooking and washing utensils and babies. In some instances, men may request some water for a shower, but when the women refuse to part with their water, given the long distance they walk to collect it, conflict may arise between spouses, particularly because the patriarchal system gives men the right of decision making in the family.

On every rainy season of the year, when water is plentiful, members of one village can access water sources at another nearby village. However, as water becomes scarce owing to prolonged drought, villages may prohibit members from another village from using water sources located within their jurisdiction. That kind of restrictions on water access and use has sometimes resulted in inter-village fighting, especially where members of the two villages are from different ethnic groups. Water access and use conflict at this level involves mainly livestock keepers who take their livestock for water at a nearby village.

Since time in memorial, livestock owners migrate with their livestock to areas with permanent water sources where they put more pressure on the resource. Conflicts arise when the local community feels that the immigrant communities are impacting on their resources.

Water scarcity may also force people to encroach on marginal lands and protected areas in search for water and pasture. Access to protected areas such as game reserves and national parks and their natural resources is prohibited. However, owing to the scarcity of resources, especially water resources, local people do encroach on forest protected areas for agriculture crop production and livestock keeping. This creates not only conflicts between the institutions that manage these protected areas and the encroachers, but those involving human and wildlife.

The Mara River downstream water users also blame their upstream users for polluting the water in the river, claiming that the brown water in the river is a result of cultivation carried out along the river banks. That, however, is caused by the loss of forest in the Mau complex, the main source of water for the Mara River. Because the Mara River is a trans-boundary water source, water-use conflicts between downstream and upstream water users on the Mara River, although they currently mainly affect individuals, can develop into an interstate conflict.

5.7.2 Poverty and income level

The most important impact of communal organizations on livelihood types within the MRB relates to financial savings. An average of 15% of the sampled MRB dwellers admitted as benefiting from financial assistance from communal groups. Other beneficiary groups included education assistance (14%) and agricultural improvement (6.8%). This means in terms of easing poverty, the MRB dwellers are likely to engage positively in communal financial assistance groups.

5.7.3 Farming systems and risk reducing strategies

Majority of communities within the MRB are mainly farmers engaged in mixed cropping and livestock husbandry, or both. In fact, this study found that farmers engaging in both intercropping and mixed cropping make 66% of the households within the MRB. As also noted before, other economic undertakings include tourism, mainly in the Serengeti and Maasai Mara game reserves, and to some extent mining, fishing and petty businesses. However, lumbering is also a significant undertaking, especially in the upper Mara River.

We note that these communities living in the lower Mara Basin are very poor, it is also vital to evaluate their farming systems and technologies. Established from our study findings, about 60% of farmers in the MRB employ ox-plough whereas 35% are hand hoeing, meaning that there is virtually no mechanized agriculture. Strikingly, 92.1% of the inhabitants admit harvesting crops manually and 58% of them transport the crop harvests to the market place by head loads. Motorized transportation of harvests is also scarce, done only by less than 10% of the inhabitants.

5.7.4 Agriculture and Livestock Production

The economy of the upper reaches is based on mixed small-scale intensive farming due to abundant rainfall. In the middle reaches, however, the economy is mainly driven by nomadic pastoralism, crop plantations and tourism.

In the basins' protected area tourism is the main economic activity [Onyango, 2007]. Apart from Serengeti National Park, the economy within the lower catchment section of the MRB is dominated by agriculture, livestock production, mining, and to some extent fishing, business and petty trading [Majule, 2010]. Data by Makalle et al. [2008], shows that about half (51.5%) of the community members within the basin are engaged in both livestock keeping as well as cultivation while 2.5% relied solely on livestock with a herd size per household of 50-1,000 cattle.

Tillage is by ox-ploughing whereas the use of fire to clear land for farming and land management is widespread. Only 2.5% of the respondents in the basin admit using crop residues as animal feed [Makalle et al. 2008]. These results confirm that subsistence farming is widespread in the lower catchment. Food crops grown in the lower catchment region include: cassava, maize, sorghum, finger millet, paddy, sweat potatoes and beans. Most of the cash crops grown in the Mara River basin include: cotton, coffee, sunflower, tobacco and groundnuts. The production trend of these cash crops shows fluctuating yields, probably due to a corresponding fluctuation in weather conditions in the region [Majule, 2010].

Cattle and donkeys are widely used for transportation of crops and other domestic goods and for ploughing of farms. Most of the livestock kept in the area is grazed in the Mara River Basin, particularly in the flood plain during the dry season due to water and pasture availability and grazed in the uplands during the rainy season. There is no proper land allocated for grazing in many areas, which is one of the major setbacks in pasture and water management in the Mara river basin.

Fishing is not widely practiced in Mara River Basin for various reasons, including avoidance of wildlife (snakes, crocodiles, hippopotami) attack. Where fishing is practiced, the catch is limited (10km/session/fisherman) due to poor fishing gear or fish scarcity in waters. Fishing gears are simple, including hooks, nets, baskets and spears/harpoons (Makalle et al. 2008).

5.7.5 Mining

It is evident trade and industry is not so significant to the Mara River basins' economy. Further, there are rich mineral deposits in the region including gold, kaolin, limestone and gemstones. For instance, both artisanal and large-scale miners are operating within MRB.

Artisanal mining is significantly seen as an on-going activity in the areas around the large-scale mining, though illegally. The data on revenues that are generated by big private companies from gold mines are not accessible.

5.7.6 Tourism and wildlife

Tourism is practiced in the contiguous protected reserves of Masai-Mara National Reserve in Kenya and Serengeti National Park in Tanzania. These areas are iconic wildlife spectacles and contribute significantly to the local and national economies of the two countries (Gereta et al. 2003). The two protected areas are also important in terms of local community employment and a range of other tourism-related socio-economic benefits [Wakibara & Shirima, 2010; Gereta et al. 2003].

CHAPTER 6

DISCUSSIONS OF THE RESULTS

6.0 Introduction

This chapter discusses in depth the results that were presented in chapter 5. An effort is made to interpret the results and also compare them with those from other related studies in the basin and other parts of the world.

6.1 Rainfall and Changes in the Flow of the Mara River

Analysis of the results of the rainfall time series data for the entire basinshows two distinct rainfallseasons in the basin with the first and longer rainsoccurring between mid-March and June, and the second and shorter rain occurring between September and December. The highest mean peak (8.8 mm) is experienced during the long rains. The upper catchment of the basin has the highest mean annual rainfall ranging from 1000 to 1750 mm with the middle and lower catchments ranging from 900 to 1000 and from 300 to 850 mm respectively. Daily mean evaporation in the basin has two high seasons with the highest value of 6.9 mm occurring in the month of March and the other peak of 6.6 mm occurring in the month of September. Analysis of the long term trend of the rainfall time series data showed a very slight decline.

Just as the results of the rainfall data analysis, the daily mean stream flow at Mara Mines river gauging station calculated as depth over the entire basinshows that there are two peaks in the river discharge corresponding to the two wet seasons in the basin. The peak corresponding to highest rainfall season is 1.2 mm (occurring in the month of April) while the peak flow in short rains season is 0.58 mm (occurring in the month of December). Results of the analysis of long-term (1978 to 1993) river discharge data for Nyangores and Amala river gauging showed that Amala River has a higher and early peak runoff than Nyangores. Due to the higher vegetation cover in this sub-catchment, it may be assumed that it has higher infiltration than Amala hence the higher base flow. The long term trend for the time series discharge data from Mara Mines, Nyangores and Amala RGSs shows a decline in monthly average flows. The decline is more pronounced in the Mara Mines River gauging stations. The reason for the change was investigated using the SWAT model and is elaborated in section 6.4.

6.2 Land Use Changes and Flow of Mara River

The clearing of closed forests in Mara River Basin has resulted in a high increase in tea plantations and open forests by 1327 Km^2. The rangelands (Shrub land, grassland and savannah) which were the grazing areas for livestock and wildlife have decreased by 35%. The decrease in rangelands has been caused by the expansion of agriculture which has increased by 1678 Km^2. The clearing of natural vegetation and the increase in agriculture has resulted in severe soil erosion in the basin. It can be seen that agricultural fields have been opened in most parts of the basin except at the centre where the protected Serengeti and Maasai Mara wildlife sanctuaries are found. Overlying the river channel on the change map shows that the opening of agricultural fields is more intense along the river channel. This is an indication that agriculture is one of the competitors of the water resources in the basin. This rampant increase in agricultural fields was attributed to increase in population.

6.3 Simulation of Stream flow Changes in the Mara River

The fundamental objectives of modelling the flow of Mara River is to analyse the extent of forest land degradation and its influence to river flows. The SWATmodel used in the studypresents the most accurate results. During sensitivity analysis, the observed flow at Mara mines is found to be more sensitive to curve number (Cn2), but the model structure favours Sol_AWC. This difference indicates the added value of calibration and validation as well as the caution to be exercised in simulating rainfall–runoff process of the other sub-catchments of the basin. On the basis of the mean Sensitivity Index, Sol_AWC was highly sensitive (≥1.0) followed by Cn2. The Sensitivity Index may suggest that the uncertainty due to coarse resolution soil data might considerably affect the overall performance of SWAT model.

The observed SD at Mulot (Amala river gauging station) is 56% higher than the calibrated flow, which could be due to the spikes in the observed monthly hydrograph not captured in the simulated flow. A small hydroelectric dam serving Tenwek Hospital, 7 km upstream of Bomet gauging station and commissioned in August 1986, could have a smaller contribution to the lower R^2 and NSE during validation at the Nyangores River. The satisfactory model performance at Mara Mines could possibly be attributed to the larger area or better quality of the observed discharge

Quantitative analysis of long term runoff simulations shows that Nyangores and Amala sub-catchments which make about 12% of the total area of Mara River Basin contribute about 54% and 32% of the total simulated runoff in the Mara River respectively. This is in agreement with previous studies which indicate that Nyangores has higher base flows than Amala (Dessu et al., 2014;Dessu & Mellesse, 2012; Mango et al., 2011; Mati et al., 2008 and; Mwania, 2014).A comparison of groundwater runoff components by Mwania (2014) indicates that Nyangores sub-catchment generates higher volumes of the same than Amala sub-catchment.It can thus be deduced that in Nyangores sub-catchment there is higher infiltration than in the Amala sub-catchment. These results support the arguments by previous studies which attribute the high infiltration in Nyangores to the relatively higher forest cover compared with Amala sub-catchment(Dessu et al., 2014; Dessu & Mellesse, 2012; Gereta et al., 2009; Mango et al., 2011; Mati et al., 2008).The reasoning is that the forest cover promotes infiltration hence more water is available to sustain base flow. Amala with less forest cover and steep slopes quickly drains most of the rainfall as quick runoff with little left infiltration.

6.4 Effects of Land Cover Changes and Use to Mara River Flow

The principal effects of a forest on the hydrological cycle are in the reception and disposal of precipitation. When compared, with grasslands, forests provide: a greater surface area for canopy and litter interception; enhanced re-evaporation of intercepted water; effective "traps" for the adsorption of solar radiation and; generally deeper roots than grasses which tap a larger sample of soil moisture (Schulze and George 1987).

To investigate the effects of land cover change in Mara River Basin, runoff was generated from derived land cover thematic maps of 1973 and 2000 using the same rainfall and evaporation data of 1983 to 1992 period. Since the other model input datasets for topography and soils were held constant during the two runs, the differences in the generated hydrographs could only be associated to changes in land cover, which was the only variable. The percentage difference between the mean annual runoff of the two hydrographs was negligible at 0.01%. Since the annual flow volumes remain unaffected, the change in the day to day flow characteristics of the Mara River can be attributed to land cover changes in the basin.

The effects of forests on streamflow behaviour and water yield are clearly seen in the three scenarios developed that is: completely forested land; completely agricultural land and; completely bare land. The differences in the hydrographs can be explained in context of obstructions and evapotranspiration under each scenario. Land cover change affected the runoff curve number and evaporation aspects of the model. Increase in forest cover as opposed to agricultural and bare land, reduced the runoff curve number and increased evapotranspiration whereas increase in agricultural/bare area increased runoff curve number and decreased evaporation. The reduction of forests reduced the interception and obstruction hence reducing the infiltration of runoff to interflow. This resulted in the increase and early occurrence of flood peaks. The increase in mean flow was due to decrease in evapotranspiration. Evapotranspiration decreases with decrease in tree cover.

Similar results were obtained by Luijten et al. (2000) in their study of the impacts of land cover change in the water balance of the Cabuyal watershed in California. In their study, they compared scenarios of completely cropped, forested and bare. Comparing each case against the actual land use, under forests scenario, the surface runoff and base flow both reduced by 41.5 % and 22.6% respectively. He associated this decreases to the forests ability to intercept rain and to extract water from deeper soil. Because of the increase in evapotranspiration, less water was left for surface runoff and base flow. Completely cropped land increased the basin surface runoff by 5%. Bare soil produced more frequent and higher surface runoff. The average river flow increased by 49% and the minimum flow decreased by 77%. Douglas (1987) in their study on the changes in stream flow peaks following timber harvest of a coastal British Columbia watershedshowed that clearing 19% of the forest in a basin could increase the peak flows by 13.5%.

6.5 Socio-Economic Impacts of Stream Flow Changes in The Mara River Basin

During the ground truth studies, the people interviewed pointed out changes in land cover although they could not quantify them. The respondents pointed out that the land cover has been changing at a high rate, forests and grasslands in the basin are being cleared for settlement, building materials and agriculture. As forests decrease there has been an increasing trend in the number of tea plantations. The people interviewed attributed the increased occurrence of more severe drier dry seasons with low river flows especially in the downstream to the changes in land cover.

Lack of sufficient water has led to pastoral farmers taking their livestock into game reserves and private ranches causing conflicts with the ranch owners.

There is a changing land ownership system in the region. Land was previously owned collectively under group ranches but nowadays the land is being subdivided and title deeds issued to individual owners. The subdivision has led to new land use practices like growing of high value horticultural crops.The subdivision was pointed out to be the key driver of the gradual change of the communities in the middle of the basin from pure pastoralists to agro-pastoralists. The interviewees pointed out the deteriorating water quality which they attributed to increased farming along river banks. This was in agreementwith the results of the analysis of land cover change as shown in section 6.2.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter presents the key findings of the study, including conclusions and recommendations three sections with the first section presenting the key findings of this study. The second section presents conclusions arrived at by this study.The last section outlines the recommendations given by the researcher. The recommendations are targeted to the key government institutions.

7.2 Key Findings

This study made significance contribution to research by being able to come up with the key findings elaborated below:

- The base flow of the Mara River is sustained by Nyangores and Amala sub-catchments. Nyangores and Amala sub-catchments which make about 12% of the total area of Mara River Basin contribute about 54% and 32% of the total runoff in the Mara River respectively. These two sub-catchments are in the upstream of Mara River.
- This study found out that the SWAT model performed better with larger areas of the basin and higher number of sub basins. In calibration and validation of the model, the Mara mines gauging station had the highest coefficient of determination (R^2) value of 0.83 and the least standard deviation between observed and simulated flow of 0.7. The R^2 values for Amala (1LB03) and Nyangores (1LA03) were 0.76 and 0.74 respectively. The study established that the model captured the high flows fairly accurately but invariably under estimated the low flows in all the three stations.
- Mara River Basin has in a period of 28 years (1973-2000) undergone significant changes in land cover/use with the natural cover of forests, shrubs and grass being opened up for other uses. The basin's closed forests and shrub lands have decreased by 32% and 34% respectively. The grassland, savannah and water bodies have decreased by 45%, 26% and 47% respectively. Tea plantations and open forests have increased by 214% while agricultural areas have increased by 203%. The study found out that deforestation is mostly occurring on the highland forests whereas opening the land for agriculture is concentrated in the upper midlands and upper lowlands along the river channels. However in the midlands, where the protected Mara Serengeti ecosystems are

found there has been minimal changes. A socio-economic survey indicated that land cover change have been caused by excision of the forests by squatters, opening land for agriculture, logging and charcoal burning and the deposition of sediment at the delta of Mara River.

- Based on the analysis of generated hydrographs from derived land cover thematic maps of 1973 and 2000 using the same rainfall and evaporation data of 1983 to 1992 period, land cover/use changes in the basin have changed the day to day flow characteristics of the river. To this regard, the study found out an increase of flood peak flows from $827m^3$/sto 877.9 m^3/s which translates to 7%, and an earlier occurrence of these peaks by 4 days between 1973 and 2000. However this study found out that the percentage difference between the mean annual runoff of the two hydrographs was negligible $35.26m^3$/s and $35.62m^3$/s at 0.01%, an indication that the annual flow volumes remain unaffected.
- Based on the scenarios of plausible pathways in land cover change in Mara River Basin, this study found out that, in scenarios where forest cover was increasing, there was reduction in peak and annual mean flows and the peaks occurred later by some days. In scenarios where forest cover was decreasing there was a decrease in peak and annual mean flows. The peak flow occurred earlier by some days.
- The impacts of the decreasing forest cover are majorly increased flooding and reduced base flows in the river. Bare land mass prevents water to infiltrate to the underground sub basins to increase the base floor, hence result into flash floods.
- The cause of decreasing forest cover is as a result of increased human activities in the catchment. Increased migration of population into the forest land in search of extra land for agriculture, charcoal burning, and habitation.

7.2 Conclusions

Mara River Basin has a pristine and sensitive biodiversity. The population in the basin isprojected to increase through the 21st century putting more pressureon the basin's water resources. It is likely that more land will continueto be allocated to agriculture. With the current trend of traditional farming practices, the basin may continue to experience severe water shortage. Sustainable management approaches in the basin may require being flexible and embracing the prevailing conditions on the ground so as totackle the intertwined challenges of water shortage and environmentalsustainability. This may require both structural interventions such asthe construction of in/off-river water storage structures to augmentdry period lowflows as well as non-structural interventions such asraising public awareness on the efficient and sustainable resource utilization.

The results from the six scenarios of plausible pathways in land cover change in Mara river basin to the year 2025 can be used to plan the management of the basin. Results of the study may also assist in planning of future waterresources development and reducing ecological threat and avoid socialunrest that may prevail in Mara River Basin due to water scarcity.The study provides insight to the vulnerability of the water resources in the basin.Catchment scale runoff model calibration is challenging andis impeded by uncertainties like processes unknown to themodeler, processes not captured by the model and simplification of the processes by the model. The challenge is even greater in data scarce regionsof Africa. But these regions are often those most in need ofscientific guidance to inform and back up the efforts of basin water resource managers and other decision makers.

This study has demonstrated that the set-up and calibrationof a semi-distributed hydrological model such as SWAT ina poorly-gauged rural African basin with variable landcover, soils and topography can yield useful results givensatellite-based land cover/use thematic maps and proper attention to calibration of the SWAT model. In this study, the modeling exercise produced fair results and it is therefore considered an exploratoryanalysis and evaluation of trends describing the response ofthe Mara River basin to future land use/cover scenarios.Much of the original forest in the Mara Basinhas already been converted to agricultural lands, and water managers are arguing for protection of remaining forests.Our analysis concluded that any additional forest conversion,whether to agriculture or pasture lands, is likely to reducedry-season flows and intensify peak flows. These changeswould exacerbate already serious problems related to water scarcity in dry periods and hillslope erosion during wetperiods. Long-term planning in the basin is also complicated by uncertainties related to projected climate change.These resultsemphasize the importance of building adaptation to climatechange into current and future planning efforts.

The methodology used in this study can generally be considered to have achieved the objectives of the study. However the author believes that the use of structured questionnaire as opposed to focused group discussions would have brought out distinctively the social and economic impacts occasioned by the changes in river flow in the Mara River Basin.

7.3 Recommendations

Drawing from the experience and lessons learned during the course of this study, The Researcher wish to make the following recommendations with regard to: water resources management and stakeholders in the basin and; further research.

7.3.1Recommendation on the management of the Mara River Basin

- River discharge data from 2000 onwards is scanty and full of gaps for most of the river gauging stations in the Mara River Basin. Most of these stations are dilapidated owing to negligence and poor maintenance. Lack of up to date data/information on river discharge greatly hampers the work of water resource management especially where timely and accurate decisions have to be made.This study recommends that WRMA takes immediate steps towards rehabilitation and upgrading of existing river monitoring network in the Mara River Basin. The stations should be installed with modern data loggers able to transmit data in real time.
- Rainfall measurements are basically intended to provide water resources managers with information on the intensity, duration and storm movement in order to predict floods among other uses. For this purpose, this study recommends that the rainfall stations need to be equipped with modern automated equipment which record and transmit correct data in real time to a central station for analysis.
- The Evaporation estimates based on measurement from evaporation pans suffer from gross inaccuracies due to instruments/calibration and human errors. Besides, the manual stations common in the Mara River Basinhave high overhead costs in supervision and maintenance. For forested catchment and wildlife areas, wild animals will greatly impair their operations. For more accurate data, this study recommends installation of modern automated instruments to measure temperature wind speed and humidity.
- The decrease in forests cover has resulted in higher peak flows hence the likely occurrence of incidents of floods during the rainy season. In this regard this study recommends replanting of trees and shrubs, and agroforestry to be undertaken so as to increase the basin forest cover. Trans-boundary policies that favour increase in forest cover should be put in place so as to reduce floods and increase the availability of water especially during the dry season.

- The Ministry of Water and Irrigation to formulate policy on Development of effective Institutional and Strategic management Plan and on Integrated Water Resources Management, Monitoring and Evaluation of the Mara River Basin by establishing a Mau Forest Management Authority to coordinate and oversee its management. The authority Board to comprise of all stakeholders.
- The Government should enforce boundary demarcations, issue tittle deeds and monitoring of illegal encroachments to critical water catchments. There is need for close strict routine monitoring to prevent new encroachment, charcoal burning, tree felling that can further attenuate the deforestation process.
- Responsible government institutions to apportion equitable water use for upstream and downstream users. This can be possible by posting extension officers on the ground to monitor daily use. Fence off all identified hot spots of human wildlife conflict.
- Water Users Association to redouble their effort in conservation of the catchment areas which they are responsible. They should coordinate and carry out periodic tree planting activities in the affected areas with the help of other stakeholders.Forest conservation and restoration should be done on annually basis.
- Agricultural extension officers be stationed in every sub location in order to capacity build the communities on best practices in the upstream of the catchment
- The interviewed part of the community recommendedthat training on water related conflict resolution and alternative method of farming like rabbit rearing, poultry farming be done in order to diversify their economic activities. The community also recommended training on greenhouse farmingwhich is more efficient in water utilization.
- Relocation and Re-settlement all people living in the demarcated protected forests should be carried out by government and offer necessary support to start their new life in the alternative settlement schemes.
- The Government and support institutions to provide effective public awareness programmes and community sensitization. This mainly addresses the needs of the local communities living around the forest. The communities should be consulted during all restoration activities for them to benefit either directly or indirectly for example in employments and managing nurseries and in planting tree seedlings.

7.3.2 Recommendation for further research in the Mara River Basin

- Further research should be done to determine the significance of land cover/use change impacts to erosion and sedimentation in the Mara River Basin. This is important in that it affects both the quantity and quality of Mara River water.
- To reduce the uncertainty brought by in-situ measured runoff data, investigations on the possible calibration of the data with satellite based evaporation and rainfall data through water balance modelling need to be done.
- To improve simulation of low stream flows, there is a need to do more investigation on improving the routing process of the SWAT model. It would also be interesting to see the effect of using satellite observed meteorological on the overall performance of the model.
- To reduce uncertainties of projected hydrologic responses, studies that include dynamic land use/cover change with respect to climate change are recommended.

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APPENDICES

Appendix 1: List of Land cover/use imageries used in this study

No.	Image Scene	Satellite sensor	platform	Date
1	P181R60	MSS	LandSat 3	1st Jan 1973
2	P181R61	MSS	LandSat 3	29th Jul 1975
3	P182R61	MSS	LandSat 3	31st Jul 1973
4	P169R60	TM	LandSat 5	28th Jan 1986
5	P169R61	TM	LandSat 5	28th Jan 1986
6	P170R61	TM	LandSat 5	18th Oct 1986
7	P169R60	ETM+	LandSat 7	27th Jan 2000
8	P169R61	ETM+	LandSat 7	27th Jan 2000
9	P170R61	ETM+	LandSat 7	12th Jul 2000

These images were downloaded from: http://earthexplorer.usgs.gov/

Appendix 2: Focused Group Discussions questionnaire used in this study

Examination of socio-economic impacts of stream flow changes in the Mara River Basin.

Questions:

1. What changes have occurred in land cover in the last 10 years?
2. What are the main causes of land cover change?
3. How are the changes affecting economic activities within the area?
4. What do you think the community can do to minimize the changes?
5. Do you experience floods? If yes how many times per year?
6. What other disasters do you experience within the basin?
7. What main diseases within the basin?
8. What are you suggesting for the other stakeholders within the basin to alleviate the severe impacts brought by the changes?
9. Do you experience conflicts within the basin?
10. How do you solve the conflicts?
11. How do conflicts affect relationship with each other?
12. What are the main means of transport?
13. Questions from participants

Appendix 3: List and details of persons/stakeholders who were interviewed in this study

S/No	Name	M/F	Upper/Middle/Lower MRB	Occupation
1.	Janet Langat	F	Upper MRB	Farmer

2.	Christine Chepkosgei	F	Upper MRB	Agro pastoralist
3.	Hadija Halake	F	Upper MRB	Agro pastoralist
4.	Teresa Kavuta	F	Upper MRB	Agro pastoralist
5.	Paul Mwangi	M	Upper MRB	Businessman
6.	Josphine Kalaine	F	Upper MRB	Agro pastoralist
7.	Lydia Kigen	F	Upper MRB	Farmer
8.	Domiziano Cheruiyot	M	Upper MRB	Agro pastoralist
9.	Wilson Igweta		Upper MRB	Agro pastoralist
10.	Henry Lithuya	M	Upper MRB	Agro pastoralist
11.	Geoffrey Gitonga	M	Upper MRB	Agro pastoralist
12.	Colleta Kobia	F	Upper MRB	Farmer
13.	Julius Karithi	M	Upper MRB	Businessman
14.	Timothy Kosgei	M	Upper MRB	Businessman
15.	Lucy Mwingirwa	F	Upper MRB	Farmer
16.	Silas Ruto	M	Upper MRB	Farmer
17.	Raphael Kimathi	M	Upper MRB	Farmer
18.	Isaiah Singei	M	Upper MRB	Farmer
19.	Andrew Ntongai	M	Upper MRB	Farmer
20.	Jane Chepngetich	F	Upper MRB	Businessman
21.	Sabina Kananu	F	Middle MRB	Agro pastoralist
22.	Jane Sopiato	F	Middle MRB	Agro pastoralist
23.	John Ekiru	M	Middle MRB	Agro pastoralist
24.	Ibrahim Racho	M	Middle MRB	Agro pastoralist
25.	Tanei Sironka	F	Middle MRB	Agro pastoralist
26.	Sabore Sankei	F	Middle MRB	Pastoralist
27.	Sopiato Ntimama	F	Middle MRB	Pastoralist
28.	Tigis Sipanto	F	Middle MRB	Pastoralist
29.	Terenua Sabore	F	Middle MRB	Pastoralist
30.	James Ntimama	M	Middle MRB	Pastoralist
31.	Simel Pameras	F	Middle MRB	Pastoralist
32.	Santamo Oloishona	M	Middle MRB	Pastoralist
33.	Ntimama Sironka	M	Middle MRB	Pastoralist

34.	Sankei Lemashon	F	Middle MRB	Agro pastoralist
35.	Naserian Oleposo	F	Middle MRB	Agro pastoralist
36.	David Ntoinya	M	Middle MRB	Agro pastoralist
37.	Harriet Karimu	F	Middle MRB	Agro pastoralist
38.	Bernard Kingaki	M	Middle MRB	Agro pastoralist
39.	Safia Ali	F	Middle MRB	Agro pastoralist
40.	Ahmed Kasimu	M	Middle MRB	Agro pastoralist
41.	Mumin Abdullahi	M	Lower MRB	Agro pastoralist
42.	Jamila Guyo	F	Lower MRB	Agro pastoralist
43.	Mohammed Hassan	M	Lower MRB	Businessman
44.	Ibrahim Hassan	M	Lower MRB	Farmer
45.	Joseph Militi	M	Lower MRB	Businessman
46.	Faranu Kalute	F	Lower MRB	Pastoralist
47.	Emma Kisela	F	Lower MRB	Businessman
48.	Christine Muthinja	F	Lower MRB	Businessman
49.	Isaiah Mbura	M	Lower MRB	Farmer
50.	Suleiman Ndungu	M	Lower MRB	Farmer
51.	Helen Lokapet	F	Lower MRB	Farmer
52.	Steveson Mwatano	M	Lower MRB	Farmer
53.	Lasat Jamita	F	Lower MRB	Agro pastoralist
54.	David Nabea	M	Lower MRB	Businessman
55.	Banis Oleitiptip	M	Lower MRB	pastoralist
56.	Amina Hassan	F	Lower MRB	Businessman
57.	Amos Kalasi	M	Lower MRB	Pastoralist
58.	Lena Mjovi	F	Lower MRB	Businessman
59.	Wilson Mwiyati	M	Lower MRB	Pastoralist
60.	Amos Mtamba	M	Lower MRB	Agro pastoralist