ASSESSING THE CORRELATION BETWEEN INTERANNUAL CLIMATE VARIABILITY AND LAND COVER CHANGE, AND FLOW REGIME OF SUB-CATCHMENTS, AND THEIR IMPACT ON COMMUNITIES OF THE MARA RIVER BASIN, KENYA

BY

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DECLARATION

Declaration by the candidate:

I hereby declare that this thesis is my original work and has not been submitted for award of a degree or any other award in any university.

This thesis has been submitted for examination with the approval of my supervisors.

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DEDICATION

This thesis is dedicated to my lovely wife Evaline Fredrick Mngube and children Innocent, Veronica, Erickson and Dorothea who stood by me throughout my studies.

ABSTRACT

Climate variability and Land Cover Changes (LC) have negative consequences on watershed management. Whereas, the role of climate variability on land cover changes and stream flow regimes have affected people's livelohoods and caused resources use conflicts in the Mara river basin, little is known of their impact at the sub-catchment level where majority of communities live, hence the need to fill this gap. The main objective of this study was to determine correlation between inter-annual climate variability, land cover changes and flow regimes and socio-economic status of communities of the Mara River Sub-catchments, Kenya. The specific objectives were to; determine the correlation between rainfall and temperature variability and LC in Amala, Nyangores, Talek and Sand river sub-catchments of the Mara River tributaries, Kenya; evaluate the effects of land cover changes on stream flow of Amala and Nyangores tributaries of the Mara River, Kenya; forecast future changes in LC for the Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya; assess the effects of land cover changes on the socio-economic status on the communities of Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya. Empirical and cross-sctional designs were used. Rainfall and temperature, Landsat images for LC and the Normalized Difference Vegetation Index (NDVI) and soil data were obtained from websites. The socio-economic data and focused Group Discussion (FGD) were collected using questionnaire from sample size of 422 adults derived from target population of 1,000,000. Mann-Kendall test was used to establish trends in climate, coefficient of determination used to measure the correlation between climate variables, LC changes and stream flows. Markov Chain model used to forecast future LC. A generalized linear model was used to correlate drivers of LC and stream flows. Results indicated that LC classes correlated with temperature and rainfall in different ranges ($r = 0.23$ to 0.99). Temperature showed strong correlation with built-up areas ($r = 0.99$), and weaker with grasslands ($R^2 = 0.23$). Rainfall showed positive correlation with bare land ($R^2 = 0.98$) and weaker with grasslands ($R^2 = 0.02$). Annual flow ranged between $R^2 = 0.07$ to 0.99). The strongest correlation was observed in built up areas ($R^2 = 0.99$) and the weakest in grassland land ($R^2 = 0.07$). Change detection matrix showed significant but varying degrees changes by 2027. Majority of the household (89.7%) reported having noticed changes in LC in the past 30 years, unpredictable rainy pattern and increase in temperature were the main drivers of LC and stream flows. FGD participants observed irregular rainfall patterns and increase in temperature, and were supportive of environmental protective measures to reverse negative land cover changes. There was a correlation between temperature and rainfall and land cover change. LC dynamics affected mean annual water flows in Nyangores and Amala. The simulated results indicated there were high water flows in built areas and lowest in grasslands. Future LC projection showed significant increase in grassland and reduced cropland. Types of trees planted, irregular rain pattern and increased temperature were the the drivers of LC change. The study recommends adaptation to temperature and rainfall variability; a multidisciplinary approach towards the hydrologic processes that maintain ecological health and communities' livelihood; suitable land use practices to improve future land cover; and an integrated plan to address the drivers of LC changes.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
APHA	American Public Health Association
DEM	Digital Elevation Model
E-Flows	Environmental Flows
ERDAS	Earth Resource Development Assessment System
ERDS	Entity Relationship Diagram Software
FAO	Food and Agriculture Organization
Geo-SFM	Geospatial Stream Flow Model
GIOVANNI	Goddard Earth Sciences Data and Information Services Center
GIS	Geographical Information System
GLM	Generalized Linear Model
GPS	Geographical Positioning System
HRU	Hydrological Response Unit
IPCC	Intergovernmental Panel on Climate Change
LVBC	Lake Victoria Basin Commission
MCM	Million Cubic Metres
MMNR	Maasai Mara National Reserve
MODIS	Moderate Resolution Imaging Spectroradiometer
MRB SEA	Mara River Basin Strategic Environmental Assessment
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NWFPs	Non-wood Forest Products
SOTER	Soil Terrain
SWAT	Soil and Water Assessment Tool
TANAPA	Tanzania National Parks
TDS	Total Dissolved Solids
TSI	Triple Sugar Iron
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey

OPERATIONAL DEFINITION OF KEY TERMS

Basin:	Part of land which collects rainwater from high elevation and direct it to one-point at lower elevation and form lake and/or river.
Catchment:	is a section of land walled or formed by mountains and or hills where rainwater is put together and flows from one side of mountains or hills (sideway) and form streams then a river;
Community	A group of people living and get their livelihoods from resources found in Nyangores, Amala, Talek and Sand sub-catchments of Mara river Basin
Chaos Theory:	Is the scientific approach of envisaging nonlinear and unpredictable characteristics of fundamental complex systems. It enables scientists to extract and explain structural orders necessary for the system to operate;
Image classification:	Is the process used in GIS technology where pixels are grouped into several classes of land cover based on applied statistical rules within multispectral domain rules in spatial domain.
Supervised classification:	Is an image classification process that uses spectral signatures acquired from training samples to classify images.
Climate:	A condition of the atmosphere mostly temperature and rainfall which shows long-term average weather of specific location;
Climate variability:	Is the spatial and temporal scales outside normal weather events.
Effect:	a change or results of change.
Fractal "Theory":	Is the theory which enables scientists to observe closely nonlinear functions of the system which displays the recurrences forever or most of time provide similar order.
Land cover:	is natural or manmade object(s) spatially and temporally located on land surface;
Land use:	Is the different uses people put on land for different purposes at a given time
Impact:	Means result or effects emanating from a change over a long time
Influence:	Is the power of independent variable to cause a change or effect of dependent variable

Remote sensing: Is the scientific method of getting objects information, or area from a distance through measuring their reflected and emitted radiation mostly from aircrafts or satellite sensors.

Soil infiltration: Is the process where rainwater or surface water penetrates soil particles. The process is governed by soil characteristics/ properties, and gravitation and capillary actions.

Stream flow: Is the volume of water which is flowing at specific time and area as ground or surface water in the Nyangores and Amala sub-catchments of Mara river basin, in Kenya. This stream flows is not including water flowing in Talek and Sand sub-catchments of Mara river Basin, Kenya.

Sub-catchment: Is a section of catchment (catchment has been defined above) walled or formed by mountains and or hills where rainwater is put together and flows from one side of mountains or hills (sideway) and form streams within catchment. In this study Sub-catchments refer Nyangores, Amala, Talek and Sand drainage areas

Transpiration: Is the movement of soil water pumped by vegetation through roots; and then evaporated through leaves pores. The process is governed by atmospheric conditions including amount of temperature, rainfall, humidity, winds among others in the locality.

Independent and Predictor Variables: A predictor variable is similar to independent variable as both are used to determine relationship to that of a dependent variable (s). However, the difference, predictor variable is only used for prediction purposes, while independent variable causes outcome. Predictor variable cannot be manipulated by researcher, while independent variable can.

Water yield: Is the amount of water as output of unregulated catchment and includes both ground and surface water flows.

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CHAPTER ONE

INTRODUCTION

1.1. Background to the Study

Changes in land cover (LC) pattern globally reflect the interaction between human activities and the natural environment (Li *et al.,* 2017). Climatic and land cover changes are increasingly becoming important components of sustainability especially for aquatic ecosystems (Pletterbauer *et al.,* 2018; Mango *et al.,* 2011). Due to anthropogenic activities, the Earth surface is under continuous alteration that influences heavily on the natural environment (FAO, 2011). Studies have linked changes in land cover to increased anthropogenic activities (Ye *et al.,* 2018). While the role of climate variability on land cover change has been extensively researched and discussed at the global and regional scales, knowledge of their impact at the local sub-catchment is limited, disjointed and anecdotal to draw any meaningful conclusions.

Studies show that the impacts of temperature and precipitation on land cover change are complex (Myhre *et al.,* 2013), and therefore require area specific studies to understand their correlation. This is because global analysis of the correlation between Normalized Difference Vegetation Index (NDVI), precipitation and land surface temperature gives different views. While some researchers have not found any significant correlation (Liu, 2015), others have reported negative or positive correlation between climatic factors and land cover categories (Guo *et al.,* 2008; Ichii *et al.,* 2002). A study in the northeast China by Luo *et al.* (2009), established presence of a strong relationship between NDVI, precipitation and temperature for different vegetation types. The effect of temperature on NDVI was more obvious than that of precipitation in that particular study (Luo *et al.,* 2009).

Zhang *et al.* (2011) also reported the existence of a positive correlation between NDVI and temperature but pointed out that the effect of precipitation on NDVI was not as significant. Additionally, Zhang *et al.* (2011) established that bushland NDVI correlated more strongly with precipitation than NDVI of other vegetation. Based on these observations, it is apparent that global and regional responses to climate change show wide variation (Chuai *et al.*, 2013). Therefore, there is a need to undertake studies that quantitatively measure the effect of changes in climatic factors on land cover change at the local level.

Given its many advantages, NDVI is best suited to monitor local or global vegetation changes resulting from a changing climate (Qiu *et al.*, 2011; Roerink *et al.*, 2013; Pang *et al.*, 2017).

Normalized Difference Vegetation Index has been widely used for studying climatic effects on vegetation productivity since the 1980s, though results vary by complexity of vegetation characteristics and region (Crucifix, Betts and Cox, 2005; Meng, Ni and Zong, 2011). It is predicted that by 2050, temperature and precipitation are likely to show increasing and decreasing signals, respectively, across the East African region (Muhati, Olago and Olaka, 2018). However, the magnitude of change is likely to vary by region and location. Predicting land cover change is therefore important in understanding and highlighting potential modifications and alterations that are likely to happen over landscapes in the near future. Such projections are useful to land use planners, resource managers, and conservation practitioners in their attempt to manage and mitigate impacts (Guan *et al.*, 2011). Prediction of LC change has been used in different applications, such as urban planning (Lu *et al.*, 2019); selection of conservation priority areas and setting alternative conservation measures (Menon *et al.*, 2001) studying dynamics of shifting cultivation (Wickramasuriya *et al.*, 2009), and in simulation of rangeland dynamics under different climate change scenarios (Freier, Schneider and Finckh, 2011). A solid understanding of the trends in land cover change at different time scales (past, present and future) at the local scale is therefore critical for decision making and policy formulation.

A review of the most commonly used approaches to modeling and land cover change prediction can be found in a study by Agrawal *et al.* (2002). Markov chain analysis has been extensively used to study dynamics of land cover change at different scales (Hamad, Balzter and Kolo, 2018). It is a simple method for modeling land cover change especially at large scales (.Weng, (2002). The stationary transitions assumed by the Markov chain models make it suitable for short-term projections (Sinha and Kumar, 2013). However, given its' shortcomings, Markov chain analysis is often integrated with other empirical models (Agarwal *et al,* 2002). The Markov-CA approach used in the current study is considered a spatial transition model as it combines the stochastic spatial Markov techniques with the stochastic spatial cellular automata method (Eastman, 2009). It has the advantage of predicting two-way transitions among the available LC classes, in contrast to the Geomod technique that only predicts one-way loss/gain from one class to another (Pontius and Malanson, 2005). Lu *et al.* (2019) noted that transition-based models that integrate spatial Markov model with spatial cellular automata model outperformed regression based models in predicting land cover change.

Mara River basin of Kenya which supports the great wildlife migration has witnessed remarkable expansion, growth and development since 1980s, just like many other river sub-catchments in Kenya. Coupled with current innuendo of climate variability, anthropogenic activities have resulted in increased land cover modification and alterations over time. However, there is limited information available on the extent to which climate variability has impacted the past and present land cover types as well as future impacts in the four sub-catchments of Mara River basin, Kenya. This study is a comprehensive attempt to evaluate the past, present and predict future land cover changes resulting from climate change to provide policy and decision makers with a basic tool for future planning.

Land cover change has been regarded as fundamental component of global environmental change because of its interactions with climates, ecosystems, biodiversity and human beings (Sun *et al.,* 2012). Understanding land cover dynamics and its socio-economic drivers is therefore crucial for resource management and land-use planning (Bagarinao, 2008). Temperature and rainfall are some of the natural climatic factors that may initiate modifications upon land cover. However, these natural drivers are exacerbated by anthropogenic activities such as agriculture and livestock rearing, forest harvesting, human settlements, and urban development among others (Minale, 2013). A host of studies has shown the cause-and-effect mechanism between changes in global land cover and climatic factors such as rainfall and temperature (Deryng *et al.,* 2011). For instance, vegetation removal by overgrazing and firewood collection reduces evaporation potential and may initiate a feedback mechanism that results in lower rainfall and hence affect crop production or induce stunted growth (Savenije and Hall, 1993; Hsiang *et al.,* 2011).

While several studies have investigated how potential crop yields may be influenced by changes in climate due to anthropogenic greenhouse gas forcing, assessments of the impacts of changing land cover on potential crop yields at major river basins remains scanty.

Globally cropland and pastureland increased five and six fold, respectively, between 1700 and 1990. Over the same period, forest cover decreased significantly, from about 5000 million hectares to 4300 million hectares (Lambin, Geist and Lepers, 2003). Analysis of land cover datasets indicates that pasture land is the most extensive form of land use; accounting for about

22% - 26% of the earths ice-free land surface (Ramankutty *et al.*, 2008; Goldewijk, 2010). While competition for limited land resources has been on the increase across the world, the magnitude of land cover change varies from one region to another (Foley *et al.,* 2010). Nonetheless, agriculture is expanding in response to increasing demands for food production, at the expense of natural vegetation and grasslands (Lambin and Geist, 2006). As a result, more than one-third of the global land surface is currently devoted to agricultural productivity that has now become one of the largest biomes on the planet (FAO (2004).

Croplands occupy roughly 15 million km2 of the Earth's surface currently, while pasture lands cover approximately 34 million km2. Agriculture has expanded into forests, savannas, and steppes in all parts of the world to meet the ever increasing demand for food and fiber (Lambin, Geist and Lepers, 2003). Therefore, forests and grassland have become the main targets for conversion to agricultural cultivation (Carmona and Nahuelhual, 2012). Over the past 300 years, 7 - 11 million km^2 of forest land has been cleared, while about two million km^2 of natural forest in temperate and tropical regions are now highly managed plantations with significantly reduced biological diversity (Foley *et al.*, 2010). Pressure to increase yields-per-acre has intensified agricultural activities through accelerated use of industrial fertilizers and pesticides, widespread irrigation, introduction of new crop varieties, and mechanization (Foley *et al.*, 2010), all of which impact on the ecosystem. In addition, land degradation, desertification, biodiversity loss, habitat destruction, water pollution and invasion by alien vegetation species are all consequences of land cover changes that eventually affect human wellbeing (Brown *et al.*, 2013).

About 40% - 75% of the world's arable land's productivity is reduced due to land degradation (UNCCD, 2013), often with serious consequences on the livelihood of rural communities Deresa and Legesse, 2015). Maitima *et al.* (2010), concur that changes in land cover have serious environmental, economical and social impacts on rural livelihoods in many parts of the world; more-so in developing countries. The severity of the impact is aggravated by the high dependency on natural resources, high poverty levels and variability in climate; given that most of their livelihood activities are natural climate dependent (Kalaba *et al.,* 2010). An estimated 300 million people depend on natural forests directly and indirectly (Belcher *et al.*, 2005), and any form of degradation of this critical resource puts to risk their livelihoods.

Many rural populations including those in the Mara River basin practice Agro-pastoral livestock farming system dependent on natural resources. For this critical mass, livestock is not only regarded as economic asset and social identity, but also represent socio-cultural and spiritual asset. Therefore diminishing pasture land triggered by land cover change may put such communities under risk of losing their herd especially during prolonged dry periods. Significant changes in land cover can also influence ground and surface water resources on which human beings, livestock and wildlife depend (Kashaigili, 2008). Water yield is altered through changes in transpiration, interception, infiltration and evaporation processes; which tend to be caused by land cover change. Although studies that relate small scale (<1 km^2) changes in land cover to variation in river discharge generally indicate that deforestation causes an increase in the annual mean discharge, those that evaluated the same in large-scale river basins (>100 km^2) did not find similar correlations (Bruijnzeel, 1990). This necessitated a study focused on the sub-catchments to ascertain the effect of land cover change on water resources at the local level.

With regard to human health, infectious diseases that are transmitted by vectors or those with non-human hosts or reservoirs are particularly sensitive to land cover changes Eisenberg *et al.*, 2007). Alteration of the biophysical conditions of vector habitats, changing exposure pathways, changing the pathogen's genetic material, alteration of pathogen and vector's life cycles and alteration of species composition within a community of organisms (Myers and Patz, 2009), are some of the ways through which land cover change can alter exposure to infectious diseases (Lemon *et al.,* 2008). Malaria exposure was reported to have increased with rate of deforestation in the Amazon, in South America (Tadei *et al.,* 1998), while the biting rates of A. darlingi in deforested areas of Peruvian Amazon were 278 times higher than biting rates in forested areas (Vittor *et al.,* 2006). A number of studies have also reported associations between deforestation and increased cases of onchocerciasis, yellow fever and cutaneous leishmaniasis in Latin America and increased malaria exposure in sub-Sahara Africa (Desjeux, 2001; Cohuet *et al.,* 2004; Patz *et al.,* 2005).

While overwhelming evidence points to a changing climate with corresponding changes in land cover across the world over, different regions are being impacted differently by virtue of their unique and varied characteristics. In the highlands of East Africa for instance, the urge to produce more has pushed farmers to intensify agricultural practices and expand their farms into previously uncultivated land all in a bid to increase their yields (Olson *et al.,* 2004). As a result, the area under cultivation has more than doubled over the last few decades (Olson *et al.,* 2004). Likewise, Kenya’s landscape is continuously changing under the influence of demographic trends, climate variability, national policies, and microeconomic activities. Over the last two decades, land cover change in a number of water towers across the country has adversely affected communities’ wellbeing by impacting on a number of livelihood sources.

Most of studies conducted in MRB forecasted the future land cover changes at basin scale (Mati *et al.,* 2005; Hoffman, 2007; Mwangi *et al.,* 2016). However, since most of modifications of land cover is happening at sub-catchment level, there is need to predict land cover changes at sub-catchment level to ascertain the land cover change dynamics to inform proper management of land cover to improve sub-catchment stream flows in the future. A broader perspective on how the communities within the Mara River Basin of Kenya was impacted socially and economically was also taken into consideration in this study through a household survey that sought to establish the link between climate change, land cover change, water resources and resulting socio-economic implications. This information is particularly important for land use planning and water resources management as well as for policy and decision making in the development, implementation, monitoring and evaluation of adaptation strategies.

1.2. Statement of the Problem

Climate variability and land cover changes are important characteristics in the runoff process that affects infiltration, interception, erosion, and evapotranspiration. These changes have caused severe stress on forest and water resources in Nyangores, Amala, Talek and Sand River Sub-catchments of the Mara River basin, Kenya. Due to rapid development in the sub-catchment, land cover is subjected to changes causing the area to form impervious surfaces. Climate variability coupled with deforestation, urbanization, and other landuse activities can significantly alter the maximum and minimum flows of the river. Although land-use changes in the area are a current phenomenon, the severity of their effects on both forest cover and hydrology of Nyangores, Amala, Talek and Sand River Sub-catchments might pose serious concern on the future functioning of these fragile resources if urgent actions are not taken. Understanding how these parameters influence stream flow will enable planners to formulate policies towards minimizing the undesirable effects of future land-use and land cover changes on the hydrology of the river. For nature conservation, the range of the discharges and the fluctuation is important. Regarding the basin water balance, annual average discharges are fundamental. How the discharge regime of Nyangores, Amala, Talek and Sand river Sub-catchments reacts to the changing climate and landuse/cover, which is a central question of interest to be integrated in watershed management at the watershed level. There was, therefore, a need for research on effects of climate variability and land cover changes of Nyangores, Amala, Talek and Sand river Sub-catchments Sub-catchment and impact on flow regime in Nyangores, Amala, Talek and Sand river.

Increased pressure on land resources and modification and alteration of land cover types in the catchment area in response to the rapidly climate variability has further altered the hydrological cycle, impacting directly on the flow regime of Mara River and its tributaries. As a result, the MRB is currently experiencing a myriad of challenges ranging from water shortage for human being, wildlife, irrigation to pollution with devastating effects on socio-economic wellbeing of the basin's inhabitants and wildlife migration in the world famous Masai Mara Serengeti. However, these effects are not uniform across the whole basin but instead show some variation driven by the differences in climate variability, topography, land cover characteristics, population size, soil type, land use types, among others in the different sub-catchments; necessitating sub-catchment specific studies.

Mara river Basin socio-economic developments and biodiversity conservation are driven by water availability in Mara River and climate variability. The Mara River basin is home of more than 1.1 million people and support more than 1.3 migratory wildlife and 1.9 million cattle. Mara river water support Mara Wetlands with total economic value of USD 5 million a year and improving the quality of freshwater entering Lake Victoria which is the second largest freshwater in the world. Tourism in the Mara River Basin represents 8% of Kenya's overall tourism income and 5% of Tanzania's total GDP and 30% of foreign exchange earnings. Despite of the socio-economic and biodiversity value of MRB has undergone remarkable changes driven by increased anthropogenic activities due to human populations growing at an annual rate of more than 3% and climate variability. This has been accompanied by a greater than 50% increase in agricultural lands in the last two decades at the expense of nearly a quarter of the basin's forests, shrubs and grasslands. In addition to the associated effects of deforestation, water abstractions for livestock, agricultural irrigation and other industries are on the rise. In addition, the impact of both climate variability on land cover change and stream flows overtime and their resulting socio-economic impacts on communities residing within the Mara River Basin have often been studied in isolation, yet they are intricately intertwined and therefore need to be studied holistically, particularly at the sub-catchment level, where their effects are greatly felt.

To avert above problems and to ensure increased Mara River flows to support socio-economic activities and Biodiversity conservation, many studies have been conducted to inform sustainable planning and management of MRB resources. Although extensive studies have been conducted linking climate variability and land cover change to the flow of the Mara River, most of these studies were generally conducted over shorter time duration and thus could not effectively ascertain the long-term influence of climate variability on land cover types and stream flow over three or more decades. Besides, most of the studies were global in scale, encompassing the entire transboundary Mara River basin, thus losing the localized effect that is likely to be experienced at the sub-catchment level.

Information on local climate variability at the Mara river sub-catchment level and how influences land cover changes and stream flow and the resulting effects on livelihood is missing, yet it is at the sub-catchment level where the effects of water scarcity and pollution is felt directly. In addition, empirical data on the impacts of climate variability and land cover change on river water resources and how these collectively effects on the socio-economic wellbeing of inhabitants within the sub-catchment is quite limited. This study thus sought to study the influence of inter-annual variability of climate on land cover change and stream flow regimes and the resulting socio-economic impact on the basin's inhabitants of Nyangores, Amala, Talek and Sand river sub-catchments of the Mara River.

1.3. Objectives of the Study

The study objectives were as outlined below:

1.3.1. Main Objective

To determine correlation between inter-annual climate variability land cover changes and flow regimes and socio-economic status of inhabitants of Nyangores, Amala, Talek and Sand River tributaries of the Mara River Sub-catchments, Kenya.

1.3.2. Specific Objectives

i. To determine the correlation between land cover changes (forest, grass, shrub, bare land, crop and built up areas) from 1987 and 2017 and rainfall and temperature patterns (trend) in Amala, Nyangores, Talek and Sand river sub-catchments of the Mara River tributaries, Kenya.

ii. To evaluate the effects of land cover changes (forest, grass, shrub, crop, bare and built up areas) on stream flow of the Amala and Nyangores tributaries of the Mara River, Kenya from 1987 and 2017;

iii. To forecast future changes in forest, grass, shrub, crop, bare and built up land cover type from 2017 to 2027 for the Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya;

iv. To assess the effects of land cover change (forest, grass, shrub, crop, bare and built up areas) and their socio-economic impact on the residents of Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya.

1.4. Hypotheses

The null hypotheses underlying the study were as follows:

i. Hθ1: There are no correlation between land cover changes (forest, grass, shrub, bare land, crop and built up areas from 1987 and 2017 and rainfall and temperature patterns (trend) in Amala, Nyangores, Talek and Sand river sub-catchments of the Mara River tributaries, Kenya

ii. Hθ 2: There is no effects of land cover changes (forest, grass, shrub, crop, bare and built up areas) on stream flow of the Amala and Nyangores tributaries of the Mara River, Kenya from 1987 and 2017;

iii. Hθ 3: There are no changes in forest, grass, shrub, crop, bare and built up land cover type from 2017 to 2027 for Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya.

iv. Hθ 4: There are no effects of land cover change "(forest, grass, shrub, crop, bare and built up areas on socio-economic status of the residents of Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya

1.5. Significance of the study and the expected output

Land-use and land-cover changes in the Mara River basin of Kenya are extremely rapid, and their direction of change is not clear (IUCN, 2009). With rapid developments, water resources become an important commodity that every sector is competing for. The influence of climate variability stream flow can only be approached from a catchments level, where the impact is most felt is important in the development of improved water management tools based on sound scientific principles and efficient technologies. Developing an approach for assessing land-use changes and their effects on land-use patterns and hydrological processes at the watershed level is essential in land-use and water resource planning and management. Understanding the consequences climate variability on land-use change for hydrologic processes, and integrating this understanding into the emerging focus on land-use change science, are major needs for the future.

Changes in temperature and/or rainfall may affect water resources positively or negatively over smaller spatial scales with corresponding effect on nearby land cover and stream flow. The MRB is an important hydrologic system that not only serves the bordering countries of Kenya and Tanzania, but also exists as a valuable freshwater input for millions of migratory wildlife, irrigated agriculture, socio-economic of habitants and also contributes to Lake Victoria water; the world’s second largest freshwater lake that doubles up as the headwaters of the Nile River.

Growing water demands and unsustainable use of forest, grass, shrub, crop, bare and built up lands within the MRB is placing an increased strain on the water resources and threatening the livelihood of the many populations that rely on the Mara River as their sole source of water (USAID, 2016). Water quantity is a major concern within the Mara River Basin (MRB), especially during the dry season when the threat of drought is high, while water of a desired quality is often scarce, and has to be carefully allocated to different uses among them human consumption, sanitation, food production, industrial use, energy production among others (Fidelis, 2014).

Due to the limited and or missing data and information to inform decisions, planning and policy on how rainfall and temperature variability has been influencing overtime the land cover change, stream flows and socio-economic of communities living in Nyangores, Amala, Sand and Talek sub-catchments, this study was designed and deemed most ideal in providing accurate information that informs required decision making on forest, crop, shrubs, grass, bare, built up lands management to increase stream flows at the sub-catchment level.

This study provided useful information through the findings and recommendations that the researcher made to policy makers and other stakeholders for the implementation in order to balance the outcome of land-use/cover change on the water sources. The current study is also useful in informing water, forestry, wildlife and agricultural experts on the present and projected impacts of climate variability on land cover changes and stream flows at the sub-catchment level. Where initiatives to improve stream flows are much needed and also predicts the status of the same for next 10 years by 2027 to inform policy, decision making and adaptive measures to address the changes being observed in climate variability, land cover and stream flows in the Mara River Basin.

1.6. Scope and Limitations of the Study

This study concentrated on the influence of climate variability on land cover change (forest, grass, shrub, crop, bare and built up areas) and soil physical properties on the hydrology of the Mara River sub-catchments (*i.e.* Amala, Nyangores Talek and Sand River) all located on the Kenyan side of the Mara River basin. The study used rainfall and temperature data series between 1987 and 2017, landsat images, socio-economics data. The study used questionnaires, key informants and focus group discussions to obtain ground truth data. The four tributaries were selected based on their spatial arrangement (upper, mid and lower parts of Mara River basin of Kenya) and their unique characteristics (flow, gradient, channel, catchments activities among others) that sets them apart and influences their reaction to climatic factors and human activities. Households within sub-catchments and officers from institutions that play a direct role in the management of the catchment resources such as the Ministries of Water, Agriculture, Forestry services and Environment as well as the provincial administration were also consulted during the study. However, a number of constraints were encountered during the fieldwork and data collection stage of the research study. Most of the offices in Mara River sub-catchments had short lengths of hydrological records and scarcity of information concerning land-use/cover change. However, appropriate measures were taken by the researcher to address these problems. These included extending time allocated for fieldwork as well as being patient and diplomatic.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Land-use planning is an important part of integrated river basin management (IUCN, 2003) because so much of what happens to water concerns development on land. It is important that land-use is managed in such a way that water supply can be assured and that hydrological processes are not interrupted (IUCN, 2009). The influence of inter-annual climate variability on land-use and land cover changes and hydrological system are considerable and deserve necessary pro-active planning for compensation of the negative effects. This section seeks to appraise the salient points of the literature review with a view to addressing the trends of climatic and land-use and land cover change, their driving forces and how they influence the hydrology of the sub-catchments. This section therefore seeks to provide an overview of different techniques and methodologies put forward to overcome the problems of land use and land cover change in water catchments in order to expose knowledge gap.

2.2 General Overview of Land Cover Change and its Causes

The term land cover originally referred to the kind and state of land, such as forest, crop land, protected areas, wetlands, pasture land, roads, grass land, shrub land, and bare land among others (Meyer, 1995 and Joseph *et al*, 2020). However, the definition has been broadened in subsequent usage to include other components such as human settlements, soil type, biodiversity, surface water bodies among others (Mohammed, 2011). Land use and land cover are distinct yet closely linked characteristics of the Earth's surface (Maina *et al.*, 2020). However, the uses to which people put land are many; some of which impact negatively on land cover (Amare and Kao, 2012). Today, land cover is altered principally by increased anthropogenic activities like agriculture and livestock raising, forest harvesting, urban and sub-urban development among other human activities. While land use can affect land cover and vice versa, change in either is not necessarily the product of the other (Ayuyo and Sweta, 2014). Likewise, change in land cover as a result of land use does not necessarily indicate degradation of the land.

Land-use changes are complex processes that arise from modifications in land-cover to land conversion process (Noe, 2003). Despite this complexity, little is known about how human and environmental factors operate and how they interact to affect land-use patterns and hydrological processes (LUCID, 2004). According to Lambin *et al.* (2002), land-use change is driven by the interaction in space and time between biophysical and human dimensions. There are also the potential impacts on physical and social dimensions. According to Bronstert *et al.* (2002) throughout the entire history of mankind, intense human utilization of land resources has resulted in significant changes on the land-use and land-cover. Since the era of industrialization and rapid population growth, land-use change phenomena have strongly accelerated in many regions. Land-use changes are frequently indicated to be one of the main human-induced factors influencing the hydrological system (Dams 2007). It was estimated that undisturbed areas represent 46% of the earth’s land surface (Mittermeier *et al.*, 2003). It is reported that 8000 years ago forests covered about 50% of the earth’s land area, as opposed to 30% today (Ball, 2001 in Lambin *et al.*, 2003). Agriculture has expanded into forests, savannas, and steppes in all parts of the world to meet the demand for food. Agricultural expansion has shifted between regions over time; this followed the general development of civilizations, economies, and increasing populations (UN-FAO, 2001). Regardless of the global spatial distribution of land-use/cover changes these studies did not attempt to give the contribution on the land-use trends and processes on the small sub-catchment, which affected its management in the near future. The present study clearly examines landuse/cover changes between 1987 and 2017 in the Mara river basin Sub-catchments.

Population expansion associated with increasing agricultural expansion, land-use change phenomena have strongly accelerated in many regions. Land-use changes are frequently indicated to be one of the main human-induced factors influencing the hydrological system (Dams 2007). Clearing of forest cover for human settlements and wood extraction for fuel are just but a few of the causes of land cover change (Belay and Mengistu, 2019). Information on Land Use and Land Cover (LULC) changes and the driving forces behind such modifications underpin a proper understanding of the dynamics of LULC changes (Alemenesh *et al.*, 2020). A study analyzing the dynamics of LULC change trends and its driving factors in Jimma Geneti District (JGD) between 1973 and 2019 reported a decline in forest land from 8632.5 ha to 5647.23 ha over the study period. Similarly, wetlands declined from 9919.5 ha to 2000.24 ha over the same period. Agricultural expansion, cutting down of trees for various purposes (such as firewood, charcoal and construction material), overgrazing and the expansion of settlements, were identified as the major proximate causes of these changes.

It is increasingly evident that competition for limited land resources by the rapidly growing human population has been on a steady rise, though the overall impact and magnitude of the human activities on land cover change is not uniform across the world (Vaibhav *et al.*, 2019). Demand for more food has led to expansion of land under agriculture at the expense of forests, grasslands, steppes and other natural vegetation cover (Vaibhav *et al.*, 2019). As a result, more than one-third of the global land surface is presently devoted to agricultural productivity; which is now the largest biome on the planet (Poore and Nemecek, 2018). Global cropland occupies about 14 % of the ice-free land of the Earth yet provides food for over 7 billion people. Nearly half (44 %) of the world's agricultural land is located in drylands, mainly in Africa and Asia, and supplies about 60 % of the world's food production. Demand for agricultural production puts these lands under intense pressure (FAO, 2014). Intensification of production on existing agricultural lands presents a real threat to the environment through the potential overuse of water, fertilizers and pesticides that affect local and regional water resources and ecosystems (FAO, 2014).

In almost all regions, forests and grasslands are often the main targets when increasing agricultural cultivation (Carmona and Nahuelhaul, 2012). Widespread deforestation has been on the increase causing profound changes to the global land cover (Longobardi *et al.*, 2016). Over the past 300 years for instance, between 7 and 11 million km^2 of forest cover has been destroyed. Besides just the trees, forest destruction often transform ecosystems from relatively undisturbed state to more intensive uses losing lots of biodiversity therein in the process (Longobardi *et al.*, 2016). Constantly shifting land use changes driven by a variety of natural and socio-economic causes result in land cover changes that can potentially affect biodiversity, water and radiation budgets, trace gas emissions and other processes all of which collectively impact on human wellbeing (Longobardi *et al.*, 2016). However, besides anthropogenic activities, land cover changes can also be triggered by climatic factors like temperature and rainfall.

In Mara river Basin, analysis of land cover change within the Mara River Basin established that forest cover, shrub lands and grasslands have changed with about, 44% of the forests cover (translating to about 416 km^2) having been lost between 1986 and 2015 (Mwangi *et al.*, 2016). This is a pointer to the massive changes in land cover that have occurred in the entire Mara River basin, necessitating a study of the land cover dynamics at sub-catchment level to ascertain the magnitude of change and its implication for longer periods of time, so that spatially explicit conclusions can be drawn.

2.3. Inter-annual variability in Rainfall and Temperature on Land Cover Change Overtime

Inter-annual climate variability and land cover dynamics are tightly coupled, with many researchers singling out rainfall and temperature as key influencers of land cover change (Jiapaer *et al.*, 2015; Liu *et al.*, 2015; Tagesson *et al.*, 2015). Many of the land cover changes seem to be directly and indirectly influenced by temperature and precipitation; a trend that is likely to continue under the ever changing of climate. Land cover types like grass lands, marshland and agricultural crop lands often have a narrow temperature range, reflecting their sensitivity to changes in temperature (Pang *et al.*, 2017). Frost for instance is a well-recognized determinant of species suitability and even survival, while minimum temperature has a generally broad impact on many aspects of plant physiology and growth. However, rainfall driven land cover change is often difficult to elucidate given the weak link and uncertain correlation (Dorji *et al.*, 2016).

A number of studies have demonstrated the relationship between climate variability and land cover change. Normalized Difference Vegetation Index (NDVI) has been used by many scientists to demonstrate relationship between land cover and rainfall and temperatures. Normalized Difference Vegetation Index (NDVI) range between −1 and +1. Increasing positive NDVI values indicate the dense vegetation, and close to zero or decreasing negative values indicate the non-vegetation surface such as water, settlement and bare land (Schnur *et al.*, 2010; Chuai *et al.*, 2013). Guo *et al.* (2008) reported that Normalized Difference Vegetation Index (NDVI) variations were significantly correlated with both temperature and precipitation. Rasmusen (1998) found a positive correlation between NDVI and precipitation. Ichii *et al.*

(2002) reported a strong positive correlation between NDVI and temperature in high-latitude districts of the northern hemisphere in both spring and autumn. In recent years, a few studies have analysed the relationships between NDVI, temperature and precipitation for different land cover types at a regional scale, but very limited at catchments and sub-catchments levels which is much far important for communities living near or within them (Luo *et al.*, 2009).

An early study by Nemani *et al.* (2005) established a significant increase in natural vegetation growth at high latitudes in the Northern regions of China between 1981 and 1990 as a result of elevated air temperature, while Pu and Dickinson (2013) observed changes in vegetation leaf area index following shifts in temperature and precipitation patterns in China. Global projections of climate impacts toward 2100 suggest that the significant change in temperature and rainfall is likely to reduce agricultural yield considerably, but the reduction will vary from one region to the other (FAO, 2011). Studies further show that climate change may affect food systems globally in several ways either directly through poor crop yield resulting from changes in rainfall patterns leading to drought or floods, or warmer or cooler temperatures leading to changes in the length of growing season or indirectly through unavailability of surface and ground water for irrigation (Gregory *et al.*, 2015).

According to Vashisht *et al.* (2013) there is a high likelihood that continued increase in temperature is likely to cause a reduction in wheat yield by 4%, 32%, and 61% in the mid-century periods between 2021-2030; 2031-2040 and 2041-2050, respectively, through increased water stress in the Punjab State of India. While some studies have reported an increasing trend of extreme rainfall in more than 8326 weather stations worldwide (Westra *et al.*, 2013), Owusu and Waylen (2009) using gridded monthly precipitation data showed that Africa had undergone a period of diminished rainfall with an apparent shift in the rainfall regime towards a longer dry season.

Africa is one of the most vulnerable continents to climate variability due to its low adaptive capacity (Niang *et al.*, 2014). Conway *et al.* (2009) assessed the trends and discontinuities in regional rainfall of West and Central Africa from 1951–1988 and revealed that that the whole of West Africa region experienced much more severe droughts than had been observed in the region in the past. Tagesson *et al.* (2015) reported a strong link between inter-annual variation in vegetation cover composition and rainfall distribution in a semi-arid Savannah grassland study site in West Africa region. A Mann-Kendal Trend test conducted by Lacombe *et al.* (2012) to assess drying climate in Ghana over the period 1960 - 2005 did not show any significant changes in annual rainfall. However, the study established a reduction in the number of wet season days, a delay in the wet season onset at several locations throughout the country and lengthening of rainless periods during wet season (Lacombe *et al.*, 2012).

It is reported that rainfall amount is likely to decrease for most parts of the Sub-Saharan Africa (SSA) while its variability is expected to increase (IPCC, 2014). The climate, particularly rainfall, in East Africa is known for its’ inter-annual variability, which has contributed to the devastating droughts and foods (Niang *et al.*, 2014; Tierney *et al.*, 2015). Several studies highlighted that the variability in rainfall in this region is linked to large-scale climate variability (Fer *et al.*, 2017, Mpelasoka *et al.*, 2018).

In the East African region, large water bodies and varied topography give rise to a range of climatic conditions, from a relatively humid tropical climate along the coastal region to arid low-lying regions across Ethiopia, Kenya, Somalia and Tanzania. The presence of the Indian Ocean, Lake Victoria and Lake Tanganyika, as well as high mountains such as Kilimanjaro and Kenya induce localized climatic patterns in this region (Fer *et al.*, 2017). As a result, the East Africa region, exhibits a wide range of ecological zones that have varying climates, with diverse land cover types and corresponding land cover dynamics (Gebrechorkos *et al.*, 2019).

Regional climate projections over the East Africa region suggest the likelihood of an increase in precipitation during the short-rain season (October–December) in large parts of the region in the 2020s (2011–2040), 2050s (2041–2070), and 2080s (2071–2100). During the long-rain season (MAM)) precipitation is expected to increase (up to 680 mm) in Ethiopia, mainly in the western part, and Kenya and decrease (up to −500 mm) in Tanzania between 2020s and 2080s. However, the western part of Ethiopia is projected to be much drier than the baseline period (1961–1990) during June–September (JJAS) between 2020s and 2080s; indicative of a shift in precipitation from JJAS to MAM (Gebrechorkos, *et al.*, 2019).

Kenya's climatic conditions vary from a humid tropical climate along the coast to arid areas inlands. While mean temperature varies with elevation, the more remarkable climatic variation is with respect to precipitation which exhibits a bimodal seasonal pattern (Ochieng *et al.*, 2016; United Nations Development Programme, 2017). Rainfall in Kenya is correlated strongly to topography. For instance, regions of higher elevation receive up to 2300 mm per year whilst the low lying areas receive only about 320 mm per year. Over two-thirds of the country receives less than 500 mm of rainfall per year, particularly areas around the northern parts of the country (Ochieng *et al.*, 2016). Rainfall is highly variable, especially in the arid and semi-arid regions, and unreliable for rain fed agriculture and livestock production. Changes in rainfall patterns, in addition to shifts in thermal regimes, influence local seasonal and annual water balances, in turn affecting natural vegetation cover and other agricultural crops. Climate impact on land cover is well reflected by agricultural crops since Kenya mostly relies on rain fed agriculture (Ochieng *et al.*, 2016).

Though few studies have been conducted on climate variability and land cover change within the Mara River (Mati *et al.*, 2005; Hoffman, 2007; Mwangi *et al.*, 2016), most of them often generalized their focus to the entire Mara River Basin, yet the basin's sub-catchments are heterogeneous each with its' unique climatic characteristics. Mati *et al.* (2005) for instance reported a 55% increase in crop lands at the expense of nearly a quarter of the basin's forests and grasslands. However, the response of land cover types to climatic factors are spatially and temporally heterogeneous (Mwangi *et al.*, 2016). Therefore, to account for this heterogeneity and to fully understand the response of land cover ecosystems to climate variability at the local level, it is important to conduct region specific studies for different geographic areas including river basins and sub-catchments. The resolve to establish the dynamics in land cover at the sub-catchment level within the Mara River Basin of Kenya under an increasingly changing climate was therefore critical to aid in the generation of credible information that can be used to inform decisions and policy aimed at helping sustain the integrity of the Mara River Basin ecosystem health.

2.4. Effect of Land Cover Change on Stream Flow

Land-use changes and their associated effects are known to impact the hydrology of the catchment area (Foley, 2005; Bronstert *et al.*, 2002; Ott and Uhlenbrook, 2004; Tang *et al.*, 2005). The effect of land-use and land cover change on low flows during dry periods depends on competing processes, most notably changes in evapotranspiration and infiltration capacity (Calder, 1998). Changes in land cover may alter the timing and volume of runoff into rivers, affecting the quantity of water in the receiving aquatic ecosystems (Guzha *et al.*, 2018). Besides altering the quantity and flow regime in rivers, massive changes in land cover can trigger increased sediment load into aquatic ecosystems raising the levels of turbidity, nutrients, pesticides and other pollutants in the rivers (El-Sadek and Irvem, 2014). Expansion of agricultural land and establishment of new settlements in water catchment areas are unfortunately compromising the most fragile ecosystems such as forests, wetlands, steep hills and river banks, causing significant changes in land cover (Pavanelli *et al.,* 2019). Though tropical forests exhibit large spatial variability in tree biomass globally, their variability is poorly documented as is their potential effects on the hydrologic cycle to which they respond (Cusack *et al.,* 2016).

Invasive alien plant species present a significant environmental problem to terrestrial and freshwater ecosystems in many parts of the world (Bartz and Kowarik, 2019). A number of studies on the impact of invasive alien plants on aquatic ecosystems have historically focused on surface and ground water resources. According to Le Maitre *et al.* (2020), many of these invasive alien plant species, especially trees and shrubs, tend to have higher evapotranspiration rates than indigenous species and therefore, use more sub-surface water compared to indigenous ones. Such high evapotranspiration levels use up ground water reserves more rapidly causing reductions in river flows or even complete drying up of rivers during prolonged dry spells (Le Maitre *et al.*, 2020). Besides influencing river flows, some of the invasive alien trees such as *Eucalyptus* species typically grow more rapidly, often increasing the proportion of biomass which includes leaves, bark, seed, flowers and twigs that become 'terrestrial litter' after abscission (Chamier *et al.*, 2012). Nevertheless, evapotranspiration rates are region, season and species-specific, necessitating sub-catchment specific studies.

Large reductions in magnitude and frequency of floods have been linked to increase in forest cover (Lana-Renault *et al.*, 2011), adversely affecting the water available for storage in reservoirs (García-Ruiz and Lana-Renault, 2011). Different land cover types are often associated with varying physical, chemical and biological soil properties that determine their hydric properties and infiltration capacity that eventually influences surface runoff and stream flow (Zhou *et al.*, 2008; Hu *et al.*, 2009). The amount of rainfall in excess of the infiltrated quantity flows over the ground surface following the topography of the land and soil properties eventually getting into nearby streams as surface runoff. Studies have shown that both the infiltration capacity and saturated hydraulic conductivity which are critical influencers of river flow regime are sensitive to changes in land use/land cover (Mireille *et al.,* 2019; Hu *et al.*, 2009).

To understand the natural hydrologic system, studies have investigated the relationship between climate variability, land cover, and hydrological processes (Bormann *et al.*, 2009; Tang *et al.*, 2011). These studies generally concur that stream flow generation capacity is dependent on vegetation type and area covered. He and Hogue (2012) used a semi-distributed model to evaluate the impact of future urbanization on flow regimes and established that increased magnitude rate of development resulted in an increase in the total annual runoff and wet season flows.

Likewise, Paul and Meyer (2008), in their study on streams in urban landscape reported that urbanization impacted on both sediment supply and bank-full discharge. Lee *et al.* (2018) observed an increase in discharge in South America’s Paraná River basin over the past 40 years despite no evidence of significant rainfall increases in the basin. They concluded that the discharge could be explained by the concomitant changes in land cover that occurred within the basin during the 40-year period. Coe *et al.* (2009) pronounced that the degree of vegetation removal and the deforestation rate of particular watersheds affected the discharge of the Amazon River basin, while land cover change was shown to alter the discharge flows in Ji-Paraná River (Rodriguez and Tomasella, 2016), and the Xingu River (Dias *et al.*, 2015). Many studies have associated a decrease in infiltrability with depth in most land cover types except for pastures, where infiltrability was found to be more stable (Zimmerman *et al.*, 2006). Nevertheless, a decrease in infiltrability was generally more pronounced in areas strongly affected by changes in land use and vegetation cover or those affected by variations in tillage practices (Wang *et al.*, 2016).

In Africa, land cover change has also been linked to stream flow variability. For instance, studies show that the upper Blue Nile which is the predominant source of the Blue Nile is facing intensive and extensive effects of land use and land cover causing significant fluctuations in seasonal and annual flows, and decline in flows in some watersheds (Melesse *et al.*, 2009; Ayana *et al.*, 2014). Studies suggest that the hydrological responses of catchments to LULCC vary with the climate and physical characteristics of the catchments. Qi *et al.* (2009) noted that future hydrological changes and LULCC are expected to be site-specific, and that climate variability will continue playing an important role on controlling the basin’s hydrological process. A study conducted in Hare River watershed, Southern Rift Valley Lakes Basin, Ethiopia by Tadele and Forch (2007) showed a 12.5% increase in mean monthly discharge for wet months while in the dry season it decreased by up to 30.5% during the 1992-2004 period as a result of land cover change.

Githui *et al.* (2009) observed that higher runoff flows were recorded in cropland than in forests given that rainfall satisfies the soil moisture deficit in agricultural land more rapidly than forest land thus generating more runoff in agricultural land, implying that lower infiltration rates were associated with agricultural land. Warburton *et al.* (2012) studied the difference in hydrological response in three diverse, complex, and operational South African catchments by using the conceptual and physical, Agricultural Catchments Research Unit (ACRU) model. The study established that the contribution of different land uses to stream flow generated from a catchment was not proportional to the relative area of land use and that the location of specific land uses within a catchment had a role in the response exhibited by the stream flows within the catchment.

In Kenya, an increase in stream discharge has also been attributed to land cover change – mainly clearing of forest and other vegetation cover for other land uses (Kathumo, 2011). Deforestation and vegetation removal in the past has been as a result of forest excision for farming, settlement and illegal tree felling for fuel and timber mainly witnessed in many parts of the country in the year 2000/01 (Akotsi, *et al.* 2006). This led to increased runoff, flash flooding, reduced infiltration, soil erosion, and siltation in the dams and other water reservoirs, negatively affecting water quality and recharge level in many catchment areas in the country (Mwangi *et al.*, 2016).

According to Coe *et al.* (2010), clearing of vegetation has altered hydrological and geomorphologic states of streams by decreasing evapotranspiration and increasing overland flow and river discharge. Kathumo (2011) reported an increase in stream flow by 30.36 and 7.53% along river Gucha following a 62.94 and 68.49% decrease in agricultural land and residential area between 1976-1993 and 1993-2010, respectively, while analysis of land cover changes in the Thiba river basin in central region of Kenya by Kasuni and Kitheka (2017) revealed decreases of 12.19% and 6.2% in forest cover, between 1984-2004 and 2004-2014, respectively. However, the change between 1984 and 2014 did not have any significant impact on stream flow variability during the dry season.

A similar study in Njoro catchment (Baker and Miller, 2013) established that conversion of forest cover to crop land led to a higher proportion of rainfall being converted into surface runoff, rather than infiltrating into the soil and recharging the aquifer. Their results demonstrated that the land use and land cover changes had significant effects on infiltration rates, runoff production, and water retention capacity of the soil. From the foregoing, many studies attributed denser catchment forests with lower base flows, due to high evapotranspiration rates among trees, while others attributed increased base flow to higher infiltration and recharge rate of sub-surface storage. The demonstrated effects of agriculture and urbanization are also inconsistent, due to varied additions of imported water and extremely variable background conditions (Price, 2011).

A number of studies have been conducted within the Mara River Basin relating land use to water resources. Earlier studies by Gereta *et al.* (2003) used an eco-hydrology model to predict the impacts of deforestation, water diversion and a hydropower project on the flow of Amala tributary, while Mutie *et al.* (2006), used remote sensing techniques and a Geo-SFM hydrological model to determine the extent of land use change and corresponding impact on flow regime of the Mara River as a whole. Hoffman (2007) analyzed water availability-demand use within the Mara River Basin, while more recent studies by Matano *et al.* (2015) analyzed the effects of land use on water quality and aquatic biota along the entire Mara River.

Although these studies generated useful information on the Mara River water quality and quantity, most of the studies were conducted over a larger scale; covering the entire Mara River Basin or focusing primarily on the perennial tributaries; Nyangores and Amala excluding seasonal sub-catchments like Sand and Talek tributaries. This makes it difficult to generalize the findings to the whole basin given that different sub-catchments that form the Mara River Basin are inhomogeneous in nature and vary greatly in terms of land cover, climate variability and stream flows. In addition, some of the studies only focused on major land use types like forests, wetlands, grass and agricultural crop lands; excluding contributions from human settlements or built-up areas, shrub lands, water bodies and bare land as critical land cover types that could also have significant influence on the Mara River.

Mati *et al.* (2008) reported a sharp increase in flood peak flows alongside increased soil erosion in the upper catchments of the Mara River resulting from deforestation and clearing of shrub lands and grasslands in favor of agriculture. The same study also showed evidence of large-scale land cover changes that occurred as a direct effect of land use changes (Mati *et al.*, 2008). According to the records from the Government of Kenya, over 7,000 hectares of Mau forest; the sources of Mara River, and one of the major water towers in Kenya, were reportedly destroyed between 2000 and 2003 (GoK, 2009).

While change in land cover may cause fluctuation in stream flow and hence trigger water shortages within the basin, details of such fluctuation of climate and land cover changes at the sub-catchments level are limited for the Mara River basin. Besides, the existence of amorphous land cover patterns coupled with lack of a clear definition between areas that intermittently vary between grass, small scale subsistence farming and settlements, further complicates accurate monitoring of the changes thus the need for sub-catchment specific studies. Situating findings emanating from basin wide studies of the Mara River to specific sub-catchments is confounded by the heterogeneity and diversity of the specific sub-catchments. While the decrease in water flow was obvious in many tributaries of Mara River Basin Sub-catchments; the exact mechanism leading to the decrease was somewhat unclear.This sub-catchment specific study was therefore important and best suited to collate the effects of land cover and stream flows, and forecast the future pattern of land cover at smaller scales.

2.5. Forecasting future pattern of the land cover changes and their impact on flow

The surface of the earth is undergoing rapid land-cover changes due to various socioeconomic activities and natural phenomena (Cheruto *et al.*, 2016), greatly influencing water resources (Zhao *et al.*, 2016; Zhang *et al.*, 2016). Land cover change is among the most visible response to increased human activities on the ecosystem, which together with climate change are probably the two foremost drivers of hydrologic processes, influencing the available water resources and flow regimes in a river basin around the world (Gashaw *et al.*, 2018; Wagner *et al.*, 2017; Wang *et al.*, 2014). Alterations of vegetation, modification in land cover classes and their spatial arrangements are all land cover changes that can have substantial influence the hydrologic regime of a river basin (Kindu *et al.*, 2018). Land cover change adversely affects the natural hydrologic system through increased variability in stream flow, surface runoff, evapotranspiration, infiltration, subsurface flow, infiltration, and precipitation interception (Wang *et al.*, 2017).

Some of the effects of land cover change on aquatic ecosystem include flooding, bank erosion among others (Trolle *et al.*, 2019). Ghuza *et al.* (2018) also noted that land cover change can alter surface runoff generation, result in changes in water demand and supply, and affect basin hydrological process including soil infiltration capacity and groundwater recharge and discharge. Such changes can disturb watershed hydrology by altering canopy interception, soil properties, infiltration, surface roughness, albedo and evapotranspiration. Therefore, interactions among these factors at basin scale can have a confounding effect that might result in variations in the timing and volumes of surface run (Shrestha *et al.*, 2017).

In the past 30 years, land use/land cover changes associated with rapid urbanization and deforestation have greatly altered a large proportion of the surface of the earth (Remondi *et al.*, 2016; Seyoum *et al.*, 2015; Wu *et al.*, 2017). This has made the effect of alteration in LULC on available water resources and hydrological processes a focus of study over the past few decades (Zeiger and Hubbart, 2016). Lei *et al.*, (2017) established that removal of vegetation cover led to an increase in the base flows when infiltration properties of soil remained unperturbed, while Rogger *et al.* (2017) reported a trend of increased flooding with decreasing forest cover noting that land use change impacts on floods involve a plethora of closely intertwined processes which makes it challenging to assess. Remondi *et al.* (2016) singled out urbanization as the most frequently witnessed driver of land cover change presently. Increase in impervious areas through urbanization results into decrease in the volume of water, which infiltrates into the soil.

Earlier studies by Guo *et al.* (2008) reported that both land cover and climate variabilty strongly influence seasonal variation in streamflow in a study conducted within Poyan Lake Basin, China. Likewise, Olivera and DeFee (2007) noted a significant increase in runoff depths and peak flows, since early 1970s in a study conducted in the northwest suburbs of Houston, Texas. At the time, they reported that urbanization accounted for 77% and 32% of the increase in the runoff depths and peak flows, respectively. On their part, Mishra *et al.* (2013) established that conversion of forests to cropland increased surface runoff by 20% and decreased ET by 2.5%, while replacing forests with urban areas increased surface runoff by 1200% and decreased evapotranspiration by 70%, respectively, in a study conducted in Wisconsin.

Xu *et al.* (2013) assessed potential impacts of biofuel production on water resources based on streamflow analysis for 55 unregulated Midwest watersheds between 1930s and 2010 and established that watersheds with no significant trends in climate showed statistically significant increasing trends in streamflow, possibly due to land cover change in most of the studied watersheds. Given that future land cover change in the Midwest is likely to be driven by agricultural expansion, demographic changes, climatic variability and socio-economic factors (Wright and Wimberly, 2013), assessment of the effects of future land cover change on water availability and stream flow will be crucial.

With a rise in scarcity of water, hydrologic impacts resulting from change in land cover have drawn substantial attention from the hydrologic community (Chawla and Mujumdar, 2015; Cuo *et al.*, 2013; Trang *et al.*, 2017). Effective planning and management of water resources requires better understanding of historic, present and future climate variability and land cover changes (Remondi *et al.*, 2016). Koko *et al.* (2020) concur that a good understanding of historical climate variability and land-cover changes is necessary in making valid predictions about future land-cover changes and their impact on aquatic resources.

For long-term land cover planning and water resources management, it is important to analyze the impacts of climate variability and land cover change on hydrology on a basin and sub-basin scale, to improve understanding of the potential effects of these processes on water resources in the future (Shrestha and Htut, 2016). Greater scientific effort is therefore needed to comprehensively explain how future land cover changes are likely to affect hydrological processes in the future (León-Muñoz *et al.* 2013). An evaluation of historical effects of land cover change on stream flow is essential in understanding the current situation and predicting future consequences. This is because, external factors that used to contribute to shift in land cover change in the past continue to shape the direction of land use and land cover change in the future.

Singh *et al.* (2015) employed the use of cellular automata Markov model and satellite data to analyze the decadal LULC changes whose results provided vital data on land use / land cover transitions due to the human induced activities in Allahabad district of India. Similarly, Zheng et al (2015) used the CA–Markov model in Hong Kong's urban regeneration areas, and provided alternative data for future urban renewal, relying on historical land use transitions. Moghadam and Helbich (2013) developed land-cover maps for the years 1973 and 2010 based on Landsat imagery for the city of Mumbai in India. Furthermore, they applied an integrated Markov Chains Cellular Automata (MC–CA) urban growth model to project urban expansion for the years 2020–2030. A number of other studies (Bhagyanagar *et al.* 2012; Rahman *et al.* 2012; Raja *et al.* 2013) focusing on India have mainly investigated changes in small-scale systems, mostly related to urbanization.

Most of these studies show that anthropogenic activities have engineered dramatic alterations on natural land cover that have a number of implications on aquatic ecosystems. The spatial extent of urban areas has globally undergone dramatic growth over the past century and the trend is likely to continue or even increase in the future (UN 2018). Existing studies show that changes in catchments, including expansion of urban areas, typically decrease baseflow by changing groundwater flow path-ways to surface water bodies (Aboelnour *et al.*, 2020). In addition, water quantity and quality in rivers have been particularly affected and the trend is likely to worsen in the near future (Hepinstall *et al.*, 2008). While a considerable number of studies have investigated the potential impacts of future climate change on surface water bodies, most of these studies did not integrate future land use and land cover changes in their analysis nor did they incorporate water quantity or quality modeling (Abbaspour *et al.*, 2009; Bekele and Knapp, 2010). As a result, the responses of stream flow and water quality to climate and land cover changes in many developing countries remain partially understood, especially at the sub-basin level. Furthermore, most of the future land characterizations are either oversimplified, or are not directly connected to existing land cover composition when performing the forecasting. As a result, the synergistic impacts of future detailed land cover change configurations and trends, under changing climatic conditions on stream flow at the sub-basin level are currently fuzzy.

The Mara River Basin has witnessed extremely large growth in human and animal population in recent times and a proper evaluation would reveal a change in land cover in the basin. Mango *et al.* (2011) provided a good example of a large-scale study to explore the impacts of LULC and climate change scenarios on the hydrology of the upper Mara River in Africa using SWAT. Nevertheless, the future impact of such land cover changes on flow of the Mara River tributaries remains unknown. It is therefore essential to get an understanding of how recent trajectories of land cover change will manifest in the future and their likely impact on aquatic ecosystem. This understanding is pivotal for natural resource scientists, planners, and decision makers when developing comprehensive medium- and long-term plans for dealing with potential environmental issues. This study thus sought to provide an in-depth insight on the future land cover at the Amala Nyangores, sand and Talek sub-catchments of the Mara River Basin to inform land management experts includes foresters, water experts and agriculture experts for adaptive management to ensure future improvement of water flows.

2.6. Socio-economic influence of Land Cover Change on Community's Well Being

Land cover change is perhaps the currently most prominent form of global environmental change phenomenon occurring at spatial and temporal scales. Land degradation is regarded as an extreme form of land-cover change that results from human's unsustainable use of land resources (Minale *et al.*, 2013). Change in land cover has a significant effect on human wellbeing (Agarwal *et al.*, 2002). About 40-75% of the world's agricultural land's productivity has been lost as a result of land degradation (UNCCD, 2013), often with serious consequences on the livelihood of farming communities (Deresa *et al.*, 2015).

Large scale negative environmental phenomena like soil erosion, desertification, biodiversity loss, habitat destruction, water pollution and alien species introduction are all consequences of land cover change that affect human wellbeing (Jewiit *et al.*, 2015). Aye and Htay (2019) concur that changes in land cover have serious environmental, economic and social impacts especially on rural livelihoods in many parts of the world. The severity of the impact is often aggravated by the high dependency on natural resources, high poverty levels and variability in global and local climate (Lebmeister *et al.*, 2018). A significant number of people are believed to obtain a substantial part of their livelihood in the form of timber and non-timber products from natural forests globally (Lebmeister *et al.*, 2018). Degradation of the forest resources can therefore hamper the basic human right to life and livelihood of indigenous communities, who depend on it directly (Banerjee *et al.*, 2013).

Pressure to increase yields-per-acre has intensified agricultural activities through accelerated use of industrial fertilizers and pesticides, widespread irrigation, introduction of new crop varieties, and mechanization (Binswanger-Mkhize and Savastano, 2017) all of which impact on the land cover. Expansion of crop lands in different parts of the world has transformed most of the natural land cover to more agro-ecological systems with more intensive use of fertilizer (Headey and Jayne, 2014). A number of studies have shown the cause-effect relationship between changes in global land cover and climatic factors such as rainfall and temperature (Zhu *et al.*, 2019). Studies have demonstrated the importance of interactions between climatic factors in driving vegetation dynamics and their responses to climate changes (Liu *et al.*, 2018; Sun *et al.*, 2015). A study in the Tibetan Plateau region by Zhong *et al.* (2019) established that vegetation cover was mainly affected by climatic factors and increased as temperature and precipitation increased, while in central Asia, precipitation was identified as the main factor driving vegetation growth, with temperature being identified as a control variable for vegetation greenness (Gessner *et al.*, 2013; Jiang *et al.*, 2017).

While several studies have investigated how potential crop yields may be influenced by variations in climatic factors, assessments of the impacts of changing land cover on potential crop yields at major river basins and their corresponding effect on socio-economic wellbeing of farming communities remain scanty. Livestock keeping, a major livelihood source for pastoralist communities is often affected directly by land cover changes. For most pastoralist communities, livestock is not only an economic asset, but is also regarded as socio-cultural and spiritual asset of social identity (Nyariki, 2017). Therefore, diminishing pasture lands triggered by land cover change may subject such communities to risk of losing their livestock especially during prolonged dry periods.

Significant changes in land cover can also influence ground and surface water resources which has direct implications on the sustenance of dry season river flows that many people, livestock and wildlife depend on (Näschen, 2019). Water yield is altered through changes in transpiration, interception and evaporation; all of which tend to be altered when there is significant change in land cover. Although studies that relate changes in land cover to river discharge generally indicate that deforestation causes a disruption in annual mean flow, its’ socio-economic impacts on the basin’s inhabitants is unclear.

With regard to human health, infectious diseases that are transmitted by vectors or those with non-human hosts or reservoirs are particularly sensitive to land cover changes (Rizzoli *et al.*, 2019). Alteration of the biophysical conditions of vector habitats, changing exposure pathways, changing the pathogen's genetic material, alteration of pathogen and vector's life cycles and alteration of the species composition within a community of organisms are some of the ways through which land cover change can alter exposure of communities to infectious diseases (Mastel *et al.,* 2018). Ambient temperature changes are associated with much shorter mosquito reproductive cycles (nearly 60% shorter), reduced larva-to-adult developmental time and increased larval and adult survivorship - all of which improve the vectorial capacity of the mosquitoes and increase exposure to malaria and other vector borne diseases (Marinho *et al.*, 2016).

Deforestation reportedly increased malaria exposure in different parts of the world MacDonald and Mordecai, (2019) while in the Peruvian Amazon, biting rates of *A. darlingi* in deforested areas were reported to be 278 times higher than biting rates in forested areas (Vittor *et al.,* 2006). Besides malaria, deforestation has also been reported to be responsible for increased incidences of cutaneous leishmaniasis in Latin America (Rodrigues *et al.*, 2019). A number of studies have also reported associations between deforestation and increased exposure to vector borne diseases in parts of Asia and Africa. In West Africa, for instance, deforestation was reported to have expanded the range of both onchocerciasis (river blindness) and yellow fever (Patz and Confalonieri, 2005).

The urge to produce more in the highlands of East Africa has pushed farmers to intensify agricultural practices and expand their farms into previously uncultivated land all in a bid to increase their yields (Olson *et al.*, 2004). Deforestation not only has ecological effects on disease vectors like mosquitoes; it is also associated with socio-economic changes that affect malaria rates in humans. For instance, Friedrich (2016) noted that deforestation was commonly associated with unstable conditions, including rapid in-migration, new human exposure in Malaysia.

In Kenya, the landscape is continuously changing under the influence of several factors among them demographic trends, climate variability, national policies, and macroeconomic activities. Over the last two decades, land cover change in a number of water towers across the country has adversely impacted communities' wellbeing through their influence on a number of livelihood sources among them water resources. While there is overwhelming evidence across the world supporting the occurrence of changes in land cover, different regions around the globe by virtue of their unique and varied characteristics are impacted differently by this phenomenon. Further research was therefore necessary to understand the full impacts of land cover change on socio-economic wellbeing of communities living in the sub-catchment level.

One of the major water catchments - the Mara River Basin has witnessed a gradual expansion in agricultural activities, and other anthropogenic activities like urban development, road construction, deforestation and human settlement (Mwangi *et al.*, 2016). This has resulted in pressure on the environment, resulting in land cover changes in the basin. Some reports have suggested that the rapid change in land cover could be attributed to high population which continues to grow; with a threefold increase in human population expected in the Mara River Basin by the year 2030 (Mwangi *et al.*, 2016). Mather and Needle (2000) noted that, high rates of deforestation in many developing countries are most commonly associated with population growth and poverty. Allen and Barnes (1985) argue that most tropical deforestation occurred by the pressure from population growth and demand for more food resources. It is also argued that, while not denying the role of population growth or poverty, most case studies failed to confirm this simplification in lieu of other more important, if not complex forces of deforestation.

Results of careful surveys of tropical deforestation supported the view that population growth was never the sole and often not even the major underlying cause of forest-cover change (Angelsen and Kaimowitz, 1999; Geist *et al.*, 2001). There is consensus that deforestation is driven by increased shifting cultivation and weak national policies (Rudel and Roper, 1996). But at longer timescales, the increases and decreases of a given population also have a large impact on land-use/cover change.

Besides, the high human population, the Mara River Basin of Kenya which covers only a quarter of the total Mara-Serengeti ecosystem, is very crucial to the survival of millions of animals as it provides forage and habitats for a great variety of domestic and wildlife among them wildebeests that number about 1.3 million, 500,000 Thomson's gazelles, 100,000 Topi antelopes, 18,000 elands, 200,000 zebras that migrate into the Maasai Mara game Reserve in search of pasture alongside many other predators around July every year (Reid *et al.*, 2012). Currently, the Maasai Mara ecosystem embodies many of the current challenges in biodiversity conservation. This is particularly so, given that only 25% of the wildlife habitat in the Maasai Mara region of Kenya is protected (found within the Mara Reserve); while the rest lies in pastoral and agricultural areas north of the reserve. This exposes lands outside the reserve to intense pressure compared to the rest of the ecosystem - a factor that is worsened by the high human population growth, expansion of wheat farming into wildebeest calving grounds and expansion of tourism facilities (Reid *et al.*, 2012). Expanding human settlements, commercial farming activities, tourism and other anthropogenic activities on land within and adjacent to the Maasai Mara National Reserve is threatening peaceful co-existence of community members and wildlife (Okello and Kiringe, 2010). According to the Mara River Basin (MRB) Strategic Environmental Assessment and the Mara River Basin Natural Resources Management Plan (LVBC, 2015), the Mara River basin has undergone unprecedented changes in the land cover change. Therefore, changes in land cover within the Mara Basin will continue impacting wildlife, domestic animals and even humans within the basin considerably.

It is believed that if the changes continue at the current rate, then the Mara River may cease to flow completely during dry years (LVBC, 2015). This may cause untold suffering to the wildlife, livestock and communities living within the Mara River Basin. While dynamic interactions are known to exist between human and environmental systems, linkages between land cover change and complex socio-economic interactions between various factors remain largely understudied within the Mara River sub-catchments. Likewise, little is known about the impacts of land cover changes as a function of rural livelihood sources in the Mara River sub-catchments. To effectively address the resultant socio-economic impacts of land cover change on community members' wellbeing, it was necessary to determine the nature and extent of these impacts. This study therefore sought to establish the drivers of land cover change and their resultant socio-economic impacts on livelihoods of communities residing within the Mara River sub-catchments of Kenya.

2.7. Theoretical Framework

2.7.1. Climate system at global, regional and local levels involves chaotic dynamics

Fundamental changes of any environment may be attributed to natural or anthropogenic activities. According to World Meteorological Organisation (WMO, 2019), climate variability is defined as variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events. The term "Climate Variability" is often used to denote deviations of climatic statistics over a given period of time (e.g. a month, season or year) when compared to long-term statistics for the same calendar period (Singh, 2017). Some scientists are of the opinion that this period can transcend to decades of over 30 years. Variability may be due to natural internal processes within the climate system “internal variability”, or anthropogenic external factors “external variability” (Umar, 2017). Climate variability and trends have enormous influences on the environment and social development on which a growing human population depends on (Mishra *et al.*, 2010).

United Nations Food and Agricultural Organization (FAO) defines land cover as ‘the observed biophysical cover on the Earth’s surface’. Includes what exists on land surfaces the natural biophysical features of vegetation, water, ice and even bare rock and soil, together with additions made by human activity such as agriculture and urban landscapes/built up areas. In reality land cover can be very complex, even in a small area. Due to the change in global climate, the land surface temperature (LST) has increased greatly affecting land use/land cover change (LUCC), vegetated areas, water resources among others (Choudhury *et al.*, 2019). Various land cover types such as high density built up areas, vegetation, bare land and water bodies are areas where heat signature are measured using remote sensing image (Ibrahim *et al.*, 2016).

Land cover types like grass lands, marshland and agricultural crop lands often have a narrow temperature range and hence reflecting their sensitivity to changes in temperature (Pang *et al.*, 2017). High Temperature variability has a generally broad impact on many aspects of plant physiology and growth. Forest species composition, productivity, availability of goods and services, disturbance regimes, and location on the landscape are all regulated by climate variability (James *et al.*, 2012). High temperatures cause high evapotranspiration from forest, shrubs and grass and hence increases loss of water from vegetation. High temperatures also cause evaporation of water in the soil and hence reduces soil moisture which vegetation depends on and cause wilting or death of vegetation. Soil moisture, the major water source for vegetation in arid and semiarid regions, is generally dependent on temperature-controlled evaporation. Therefore, we can hypothesize that air temperature modifies the sensitivity of vegetation greenness through intervening factors such as soil properties, relative humidity, topography/ slope and altitude (Jaeil *et al.*, 2015).

Stream flow, or discharge, is the volume of water flowing in a stream channel expressed as unit per time (cubic meter per second). Stream flow is an important determinant of water quality and aquatic habitat conditions (McBain *et al.*, 1997; Fikru *et al.*, 2019). Rainfall is major source of water to rivers. In the well managed land with a lot of forests, shrubs and grass, more rainfall is percolated in the soil and increase soil moisture/water and becomes the source of water during dry seasons. Some factors governing the increase of water percolation/infiltration rates include the amount of rainfall, distribution of infiltration capacity for a given area, which is a measure of the spatial variability of soils and vegetation of that area (Stone *et al.*, 2015). According to Ochieng et al (2016), rainfall has a positive effect on all crops grown. From these studies, there is need to conduct studies at specific geographical areas and land covers so as to understand the dynamics and implications of the climate variability.

Understanding climatic patterns is therefore of great significance especially now that many global challenges such as food insecurity, water crisis, biodiversity loss, and health issues are mostly linked to the increased climate variability (Pachauri, 2014). It has been recognized that the climate system has chaotic dynamics with high variability (Nunes, 2011), but trend analysis does not fully reveal these dynamics. Basic elements of farming, soil moisture, heat and sunlight are affected by variability of temperature, rainfall, solar radiation, and the frequency and amplitude of extreme climate events like droughts and floods (Alexandrov, 2000). In attempts to understand the characteristics of climatic dynamics, many studies have focused on quantifying the variability of one or two climatic factors' long-term dynamics with different methods being used (Nunes, 2011). One of the methods is fractal dimensional analysis which is well-established tool for studying geophysical time series dynamics, and it has been widely adopted to analyse the variability of climate factors over time (Morata, 2006).

Chaos theory is therefore required to understand these dynamics and how these dynamics correlate with landcover and stream flows in the sub-catchments. Chaos theory demonstrates how simple, straightforward, deterministic laws can exhibit very complicated and seemingly random long term behaviour. In climatic systems, weather demonstrates how chaos theory is applied. Weather forecasting is classical example of chaotic dynamics because may not be always accurate. Weather forecasting depends on whether predictors at a given time and space. Chaotic systems like climatic systems are very sensitive and are dependents not only on initial but also subsequent future predictors conditions. Using initial predictors impact can be very small at a particular time and space; but after a given time in the same space, impact can be big and very different. Researchers, therefore use Chaos theory to shed light on what is happening in some given complicated phenomena. One of the methods applied to address chaotic dynamics is fractal dimensional analysis (Morata, 2006). Many researchers use fractal dimensional analysis to understand the climatic dynamics. Many researchers have demonstrated chaos theory in climate and found that rainfall and temperature as critical factors in plant development, however this simple finding is complicated when it comes to real process involved. Rainfall and Temperature are independent factors which cause plant to grow. In Initial stage, rainfall and temperature can only directly influence seed germinations through initial predictor, that is oxygen. When continuing adding or changing predictors, like water and soil among other soil properties the dependent variable which was germination is changing. Water in the soil comes from rainfall, and this water make nutrients in the soil available for plant. Plant uses roots to transport nutrients from soil to the leaves (green colour -Chlorophyll). Chlorophyll in the leaves captures sun energy and carbon dioxide respectively to change nutrients to another dependant variable that is plant food; the process is called photosynthesis. Temperature is also required in the photosynthesis process as well as removing water from plant "evapotranspiration" (Alexandrov, 2000). Furthermore, other dependant variables the plant physiology, growth, composition, yields among others on land are controlled by climate variability (James *et al.*, (2012(; Yao, (2015), and Ibrahim *et al.*, (2016).). Air temperature transforms vegetation greenness through intervening factors such as soil properties, relative humidity, topography/ slope and altitude (Jaeil *et al.*, 2015). According to Linshan *et al.* (2017), three decades (last 30 years) are required to demonstrate climate variability due to its chaos behaviour.

Since the climate system has similar characteristics on different temporal scales applying fractal theory to assess the variability of climate change can show a more comprehensive picture of the variability of climatic dynamics ranging from days to decades. A detailed study aimed at depicting variability of climatic dynamics that includes multiple key climatic factors simultaneously currently does not exist (Zhenci Xu, 2017). According to Yao (2015), since global challenges such as food security, biodiversity loss, air pollution, water scarcity and human health are affected by the dynamics of evapotranspiration, temperature, solar radiation, and precipitation simultaneously assessing their dynamics together helps reveal the nonlinearity of climatic dynamics much more holistically than studying one or two climatic factors separately.

Thus, climate change studies at a national scale can have a more direct relevance to policy making of a country than studies at other scales (e.g., regional or global scales). Furthermore, since climatic dynamics may vary across space within one country, exploring the relationship between geographic variables (e.g., longitude, latitude, elevation, basins, sub-basin, catchments and sub-catchments) and the daily variability of climatic factor dynamics offers a more comprehensive understanding of achieving human well-being and environmental sustainability in different areas (Yao, 2015).

Different scientific studies point out that long-term effects of climate variability (in relation to temperature) on crop production are larger than short-term effects, an indication that farmers need to adapt effectively to reduce extreme effects of climate variability. Temperature and rainfall are key climate factors required in the land cover development. Through intervening variables (relative humidity, soil properties and topography), temperature and rainfall accelerate the influences of the climate variability to the land cover and stream flow. According to Linshan *et al.* (2017), the results outcomes of analysis of data collected over the last 30 years, show that the climate variability has significant impact compared to land cover on flow regimes in the study region. Climate variability was thus more relevant to shifting the flow regimes and could be seen to dominate the hydrological processes changes in northeast Tibetan Plateau.

Grass, shrubs and forest play important role in boosting rainfall percolation and by extension to stream flow which is important for vegetation during dry seasons. Climate variability therefore directly or interactively (with intervening variables) affect land cover and hydrological changes and hence impacting stream flow in catchments. The spatial distribution of urban vegetation cover is strongly related to climatological conditions, which play a vital role in urban cooling via shading and reducing ground surface temperature and effective strategy in mitigation urban heat island (Salwa *et al.*, 2020). The values of Normalized Difference Vegetation Index (NDVI) range between −1 and +1. Increasing positive NDVI values indicate the dense vegetation, and close to zero or decreasing negative values indicate the non-vegetation surface such as water, settlement and bare land (Schnur *et al.*, 2010; Chuai *et al.*, 2013). Guo *et al.* (2008) reported that Normalized Difference Vegetation Index (NDVI) variations were significantly correlated with both temperature and precipitation.

Rasmusen (1998) found a positive correlation between NDVI and precipitation. Ichii *et al.* (2002) reported a strong positive correlation between NDVI and temperature in high-latitude districts of the northern hemisphere in both spring and autumn. In recent years, a few studies have analysed the relationships between NDVI, temperature and precipitation for different vegetation types at a regional scale, but very limited at catchments and sub-catchments levels which is much far important for communities living near or within them (Luo *et al.*, 2009). According to Chuai (2012), different correlations can be explained by their different temporal and spatial growth environments, and differences in their degree of human disturbance. From above studies, any interruption to the independent factor (Climate) would undoubtedly through intervening variables cause a corresponding effect on the Land Cover and later stream flows and socio-economic; and any interruption to the independent factor (climate) directly causes corresponding effect to stream flow and socio-economic.

Quantifying climate variability is important to fully understand its individual direct or indirect effects on the land cover change and stream flow; and the resultant effect on socio-economic wellbeing of the basin’s inhabitants of key tributaries within the Mara River Basin. In the four Mara River tributaries (Amala, Nyangores, Talek and Sand River), the conceptual framework (Figure 2.1) presents the components and relationships that were used as a framework of data collection and analysis in this study to model influence of Climate factors to the land cover change, stream flow and socio-economic wellbeing of inhabitants.

The framework defines three key broad and interlinked variables namely: (a) independent variable the Climatic factors (rainfall and temperature), (b) dependent variables including land cover (forests, shrubs, grass, Bare and built up areas land), stream flow and socio-economic wellbeing of inhabitants; and (c) intervening variables namely topography, soil properties, altitude, relative humidity, slope and anthropogenic factors that ultimately influences the relationship between independent and dependent variables.

The variables are described in two influence stages, (a) first the variability of climatic factors (temperature and rainfall) overtime through intervening variables influence land cover change; then the change of land cover dynamics and intervening variables influence the stream flows and socio-economic wellbeing of the basin’s inhabitants. (b) Secondly the variability of climate factors (rainfall and Temperature) directly influences both stream flow and socio-economic wellbeing of the basin’s inhabitants.

Using fractal dimensional analysis, climate (rainfall and temperature) are independent variables which directly can impact stream flow regimes and socio-economic of communities as dependent variables (Salwa *et al.*, 2020). More rainfall directly means more stream flows, and extreme rainfall cause floods which affect directly socio-economic of communities.

Temperature and rainfall using predictors of dependent variable (stream flow regimes and socio-economic) such as land cover (Forest, shrubs, Bare lands, Agriculture, Settlement and Grass), soil properties, topography and slope influences indirectly stream flow regimes and social-economic of communities. Amount and distribution of rainfall is source of water to rivers and soil moisture which are important factors for vegetation growth distribution (Stone *et al.*, 2015). In the well managed land with a lot of forests, shrubs and grass, more rainfall is percolated in the soil and increase soil moisture/water and becomes the source of water during dry seasons. Grass, shrubs, forest, crop, settlements, and bare lands play important role in boosting rainfall percolation and by extension to stream flow which is important for vegetation during dry seasons. Extreme temperatures influence vegetation growth (Zaitunah *et al.*, 2018). Stream flow is linked to the water quality and aquatic habitat conditions among others (McBain *et al.*, 1997; Fikru *et al.*, 2019).

However, the relationship between the independent and dependent variables is not always linear as many other intervening variables contribute to this relationship.

2.8 Conceptual framework

Conceptual framework (Figure 2.1) is based on theoretical framework. Conceptual framework defines and links:

(a) **directly** the independent variable the **Climatic factors** (rainfall and temperature) with dependant variables the **stream flow regimes and socio-economic of communities**, and

(b) **indirectly** the independent variable the **Climatic factors** (rainfall and temperature) with dependant variables (**stream flow regimes and socio-economic of communities**) using **Predictors** of dependant variable the land cover (Forest, shrubs, Bare lands, Agriculture, Settlement and Grass), soil properties, topography and slop).

The process is described in two stages:

(a) Climate factors (rainfall and Temperature) variability directly influences both stream flow regimes and socio-economic wellbeing of the communities in sub-catchments. More rainfall directly influences stream flows by increasing water into streams. Extreme temperature cause evaporation of water directly from streams or river.

(b) Climatic factors (temperature and rainfall) overtime indirectly through Predictors of dependent variables (**stream flow regimes and socio-economic of communities**) the Forest, shrubs, Bare lands, Agriculture, Settlement and Grass), soil properties, topography and slop influence and impact stream **flow regimes and socio-economic of communities.**

The rainfall increases stream flows by drooping on the land cover, then percolates into the soil and come as stream flows. Rainfall increases soil water and hence contributes to crops, shrubs, grasses, wildlife, and livestock health by extension to increased socio-economic of communities and hydrological cycle. Temperature reduces stream flows through evapotranspiration of vegetation and through evaporating soil water and hence affects crops, shrubs, grasses, wildlife and livestock health by extension to decrease socio-economic of communities and hydrological cycle. However, correlation of independent and dependent variables mentioned above not always linear as many other predictors variables contribute to this relationship.

Conceptual framework also demonstrates the importance and contribution of both independent variables and Predictors to the dependent variables which are stream flow regimes and socio-economic of communities. This is why it is important to study and understand their correlation, implications and future trends to inform the required adaptive management and natural resources management decision making.

The Theoretical and Conceptual framework therefore formed basis for my study objectives. The conceptual framework below depicts the interrelationships between variables (Figure 2.1).

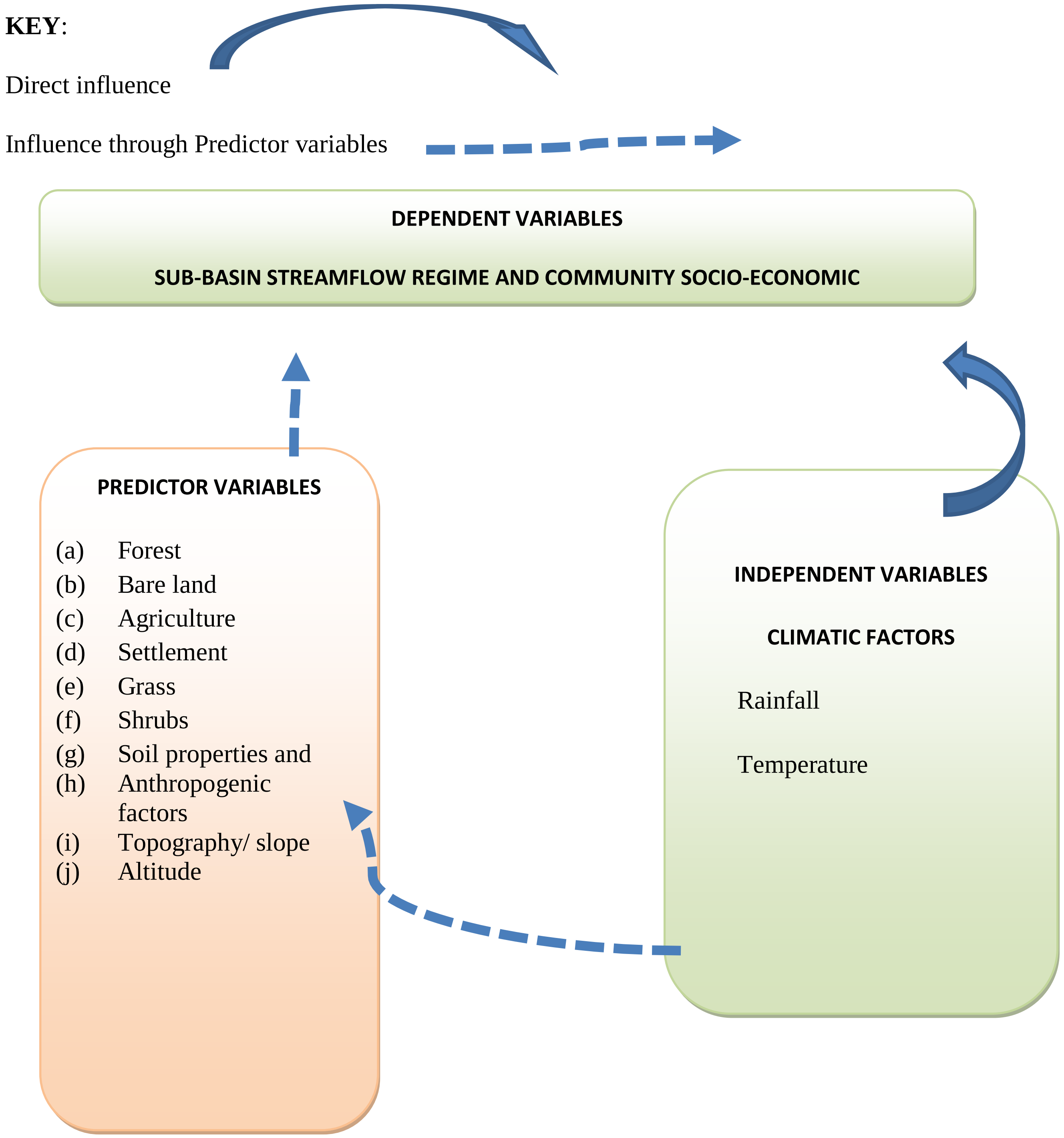


Figure 2. 1: *Conceptual Framework. Source-researcher, 2015*

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This section describes the methods and materials employed in conducting the study. This study aimed at determining the influence of inter-annual climate variability influence land cover changes and flow regimes and socio-economic status of inhabitants of Nyangores, Amala, Talek and Sand River tributaries of the Mara River Sub-catchments, Kenya. Different approaches or combinations of approaches were employed during this study to establish relationships between, climate variability, land use and land cover and the river flow regime. A triangulation of information sources was applied including a review of available literature on the land-use and hydrologic changes in the four rivers of the sub-catchments. Remote sensing and GIS analysis was used to establish changes that have occurred in the sub-catchment. A household survey, focus group discussions and key informants interviews gave the historical perspectives of the land-use and land cover and hydrology in the studied areas.

3.2. Study Area

The transboundary Mara River Basin covers approximately 13,750 km^2 and lies between South Western Kenya and North Western Tanzania, between longitudes 33˚47'E and 35˚47'E and Latitudes 0˚28'S and 1˚52'S (Figure 3.1). The basin is shared between two countries; the Republic of Kenya (65%) and the United Republic of Tanzania (35%). The 395 km long Mara River originates from Kenya in the Napuiyapui swamp in the Mau forest escarpment at an altitude of approximately 3000 metres above sea level (m.a.s.l) and flows South West through Maasai Group Ranches, the Maasai Mara National Game Reserve in Kenya and the Serengeti National Park and joins Somoche, Tigithe and Tobora tributaries in Tanzania (Mati *et al.*, 2008) before draining into Lake Victoria in Musoma Tanzania at an altitude of 1134 metres above sea level (Mwangi, 2016).

The Mara River Basin experiences a bimodal rainfall pattern with long rains being received between April and May and short rains between November and December. Rainfall varies inter-annually by a factor of about four between extreme wet and dry years (McClain *et al.*, 2014). Potential evaporation is approximately 1730 mm year^{-1}, while the maximum monthly evaporation is 169 mm in October during the dry season (178 mm in September for Tarime). The mean maximum and minimum temperatures for the upper region are 24.5°C and 10°C respectively. Night temperatures as low as 4°C have been recorded while day temperatures of 25°C are typical (LVBC and WWF-ESARPO, 2010). Discharge patterns in the Mara River Basin are bimodal, reflecting the occurrence of a short and long rainy season (McClain *et al.*, 2014).

Mara River supplies 23,812,454.2m^3 water per year (Hoffman, 2007), with up to 65% of the people getting water directly from the river. The basin hosts about 1.1milion humans and 1.7 million head of cattle, sheep and goats. In Kenya, the population of livestock consisting of cattle, sheep and goats was estimated at around 2.2 million. The Mara River Basin is also home to over a million wildebeest, 300,000 zebras and 300,000 Thomson gazelles among others wildlife that migrate into the Maasai Mara National Game Reserve in Kenya from Serengeti National Park in Tanzania annually between July and October (Hoffman, 2007). Besides the herbivores, all the "Big Five" (lion, leopard, African elephant, African buffalo, and black rhinoceros) are also found in the Mara River Basin, in addition to hippopotami and Nile crocodiles. Tourism within the Maasai Mara National Game reserve and conservancies represents 8% of Kenya’s overall tourism income.

In Tanzania, the Serengeti national Parks represents 33% of all visitors to the national parks in the Country. Tourism represents 6% of Tanzania's GDP and 4% of foreign exchange earnings. In Kenya, conservation represents 2.5 billion USD annually (30% of the Country's GDP) (WWF-Kenya, 2019). Since Mara River is the only Perennial River during the driest years and the sole source of water for the millions of wildlife, the death of over 400,000 wildebeest in 1993 was attributed to lack of water due to severe drought (Gereta *et al.*, 2003).

Study area is in Africa and in Republic of Kenya

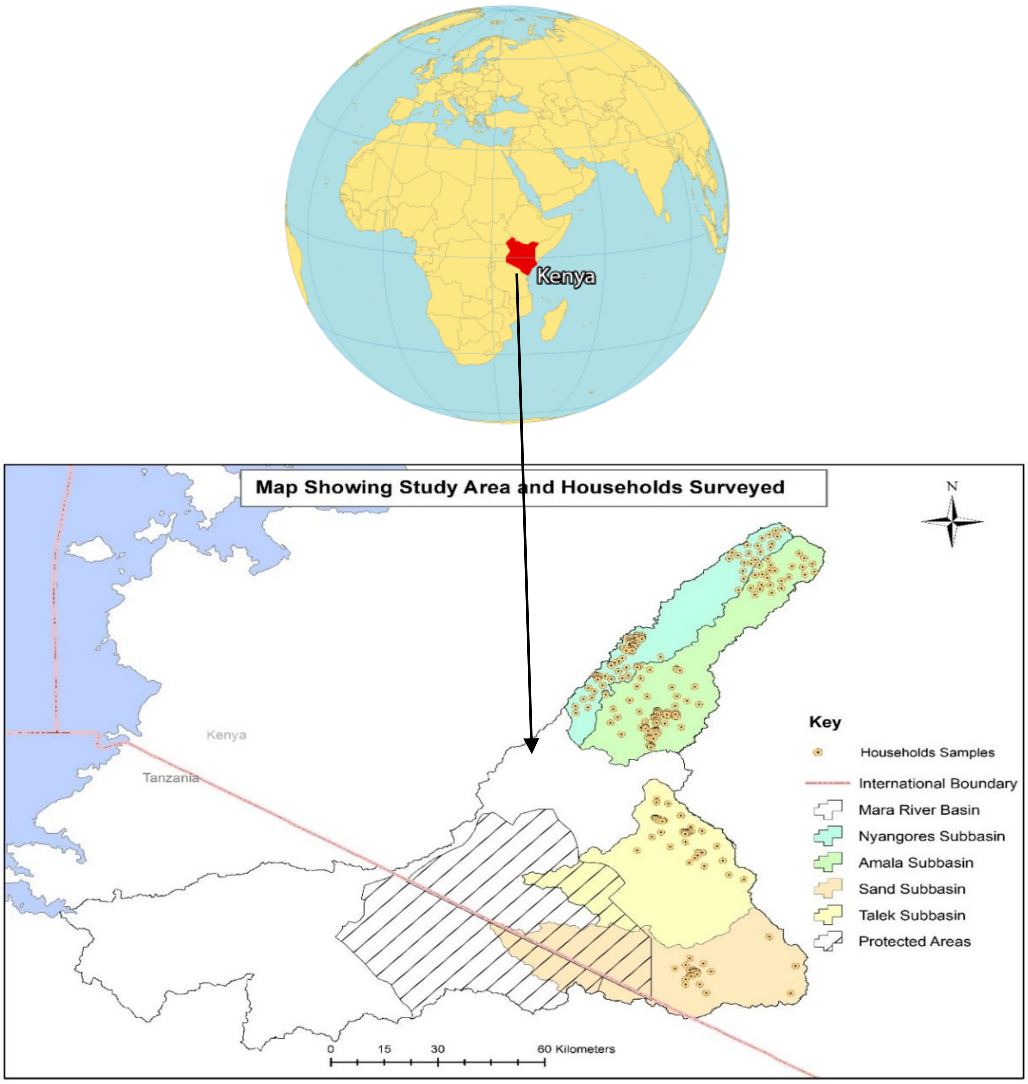


Figure 3.1. *Map of Mara River Basin showing the four sub-catchments*

(Source: Researcher, 2018; Google Earth, 2022).

3.1.1. Land cover of the Mara River sub-catchments, Kenya

Land cover within the Mara River Basin transforms through a sequence of zones from highly enclosed canopy forests on the escarpment in upper Mara river basin to scattered woodland and extensive grasslands on the lowlands. The upper Mara River catchment is composed of natural forests including: (i) Kiptunga Forest Block which is located in the Eastern Mau Forest Block in Nakuru County and covers an area of 10,360 hectares, (ii) Transmara Block composed of Olenguruone, Nairotia and Nyangores forests, covering a total of 35,270 hectares, (iii) Olpusimoru Block composed of 16,832 hectares of indigenous forest cover, (iv) Loita forest which covers over 20,000 hectares and under the management of the local community, and (v) Chepalungu forest which covers an area of close to 5,000 hectares (LVBC, 2015).

However, owing to population pressure within the basin, significant areas of forests and grasslands have been cleared to pave way for agricultural lands (Mwangi *et al.,* 2014). Deforestation and increased anthropogenic activities like irrigation and damming activities coupled with increased people, livestock and wildlife water demand have severely aggravated the hydrological problems resulting in reduction in stream flow and poor water quality (Hoffman, 2007; Mwangi *et al.*, 2014). The Mara River Basin is also dotted with important riverine forests along some stretches of the main river and its tributaries. The current land cover classification within the Mara River Basin includes: forests, cropland/ agriculture, bare land, shrub land, grassland, water body, game reserves/ protected, wetlands and built up areas comprising of settlements, roads and market Centres (LVBC, 2015).

3.1.2. Soil characteristics

The local geology, topography and rainfall determine the types and distribution of soils of the Mara River Basin (Krhoda, 2002). The soils fit into three broad categories; the mountains, plains and swamps. The mountains and escarpments have rich and well drained dark brown volcanic soils; (the ando-calcaric and eutric regosols) that are suitable for intensive agricultural production of barley and supporting zero grazing. According to the trans-boundary Mara river basin strategic environmental assessment (LVBC. 2012), on the hills and minor escarpments, shallow and excessively drained dark-reddish brown soils; the lithosols, mollisols and andosols are found. These soils are prone to sheet erosion and mass wasting processes. The imperfectly drained grey-brown to dark-brown soils are found in the Plateaus and high level plains of Siria, Niaragie Enkare and Narosura. These plateaus and high plains of imperfectly drained soils are conducive for grass and sorghum. The deep, dark-greyish soils (verto-eutric and planosols) are mainly found in the Kapkimolwa plains, Shartuka and Maasai Mara National Reserve.

The clay soils (eutric-flurisols) are found along the floodplains of Mara River, Ol Punyuta and Likirigi Swamps. These soils are moderate to high in fertility and some are being reclaimed for irrigation agriculture. Currently farming within the Mara Basin has shifted to fragile soils accelerating the rate of erosion and fertility loss. The different soil types have a bearing on surface water flow and infiltration and thus indirectly affect stream flow.

3.1.3. Human population and socio-economic activities

According to transboundary integrated natural resources management plan for 2020 – 2030 (LVBC, 2019), an approximate 1.1 million people live within the Mara catchment. High population densities exist in the upper and middle basin reaches, while the lower and middle reaches are sparsely populated. The lower population density is due to the semi-arid nature of the lower catchment, the Maasai Mara Game Reserve, and the Serengeti National Park. Downstream of the Serengeti National Park in Tanzania, the population density again increases. The total human population on the Kenyan side of the MRB based on the National Census carried out in

2009 stood at 564,266. With an annual growth rate of 2.8% current population is estimated at 665,900. According to the 2012 Tanzania Population and Housing Census, about 1,000,000 inhabitants lived in the districts of Butiama (241,732), Rorya (265,241), Serengeti (249,429), and Tarime (339,693). The average population density for the Mara Region according to the 2012 population and housing census was 38 people per km^2.

According to Nile Equatorial Lakes Subsidiary Action Program (NELSAP; 2008), Mara River is of significant importance to the economies of both Kenya and Tanzania because it supports a wide range of socio-economic and environmental needs in both countries. The river is a source of drinking water supply for both rural and urban communities, it is a back-bone to the basin’s agricultural, livestock, fisheries, wildlife, tourism, industrial, and mining activities. The river traverses the internationally acclaimed Masai Mara Game Reserve in Kenya and Serengeti National Park in Tanzania and is thus of vital importance for tourism and biodiversity conservation efforts in both countries. Agriculture is a major economic activity in the Mara River basin with more than 80% of the basin riparian being dependent on agricultural activities for their livelihood. Livestock keeping is a major economic activity in the basin, especially among the Masai. 1.7 million head of cattle, sheep and goats are found in Mara river Basin.

Besides income generated through the sale of livestock and livestock products such as meat, milk, ghee and hides, livestock also provide animal traction power for land tilling and farmyard manure. Fishing is a major socio-economic activity and source of food and livelihood for several communities in the basin, especially those adjacent to river and Lake Victoria. Tourism is one of the major economic sectors in the basin. The Mara ecosystem is a world famous wildlife sanctuary and contains the most diverse combination of grazing animals in the world. It is home to the Masai Mara game reserve in Kenya and the Serengeti National Park in Tanzania. The incredible biodiversity, concentrations of wildlife and annual wildlife migrations in the savannah grasslands of Kenya and Tanzania draw tourists from around the world. The annual animal migration is a spectacular event in this renowned game park, offering a unique wildlife viewing experience.

The Mara River Basin is endowed with significant forest resources that constitute a major component of the basin ecosystem. Specifically, forests are a source of livelihood for adjacent communities who depend on them for their daily subsistence needs like hunting of game meat, honey collection, crop farming, grazing, pole wood, bamboo extraction, fuel wood collection, charcoal production, collection of medicinal plants, and collection of grasses and vines for basket making and thatching. The human population within Talek and Sand River sub-catchments is lower compared to Nyangores and Amala sub-catchments. According to Hoffman (2007), about 60% of the population of the Mara River basin in Kenya lives below the poverty line, and 60% of all residents in the Basin obtain their water from the Mara River and its tributaries. The six main water uses within the Mara River basin include: human consumption, livestock use, wildlife use, hotels and lodges, irrigation and mining. While the water resources are reportedly decreasing, the demand for the same is ever increasing. However, farming activities often spread into wildlife corridors, especially those residing near the game reserves and protected areas, hence aggravating human-wildlife conflict in the catchment basin.

3.1.4. Mara River Sub-catchments (Amala, Nyangores, Talek and Sand River)

This study focused on four Mara River sub-catchments (*i.e*. Amala, Nyangores, Talek and Sand River) all located within the Mara Basin of Kenya. The four tributaries are located at the upper, middle and lower parts of Mara River in Kenya. Amala and Nyangores tributaries are perennial and flow throughout the year compared to Talek and Sand River tributaries which are seasonal and often dry up during prolonged dry seasons. The Nyangores and Amala tributaries form the upper part of Mara River and flow through sections of Mau forest complex, large scale tea plantations, mixed small and large-scale agricultural farms, human settlements and market Centres while Talek and Sand River tributaries join the Mara River inside the Maasai Mara Game Reserve in the middle and lower part of the Kenya portion of the Mara River Basin and flow though grasslands, shrub lands and sparsely populated regions (Mati *et al.,* 2005).

Talek and Sand River sub-catchments are relatively smaller streams, compared to the other two but are very important as they both support large numbers of livestock and wildlife. Talek River joins the Mara River approximately 16 kilometers north of the boundary between Kenya and Tanzania. Sand River lies within Maasai Mara National Park; while Talek meanders through extensive pasture lands and the Maasai Mara protected areas. The eastern part of the Mara River Basin receives approximately 600 mm rainfall per year and is drained by the Talek River, a seasonal river that floods in response to isolated showers within the Olare Orok, Ntiantiak, Sekenani and Loita drainages (Mati *et al.*, 2008). The dominant land cover in the Talek and Sand River sub-catchments are shrubs and grass with sparsely distributed riverine forests along the two tributaries (LVBC, 2015).

From the foregoing, it is apparent that while the four tributaries drain into the Mara River they are highly inhomogeneous and differ spatial temporally with regard to sub-catchment size, climate (rainfall amounts and temperature), land cover, vegetation type, land use type, soil characteristics, topography, human population and resulting socio-economic activities pressure. It is on the strength of the apparent differences between the four tributaries that Amala, Nyangores, Talek and Sand sub-catchments were all studied to establish their contributions to the greater Mara River.

3.3 Research Design

This study adopted an empirical study design, combined with a cross-sectional survey. Given the vastness of the Mara River Basin, only four sub-catchments (Amala, Nyangores, Talek and Sand River) out of five all lying within the Kenyan portion of the Mara River Basin were selected and studied (3.1.). Scientifically Digital Elevation Models was ised to delineate sub-catchments and then used following criteria to select sub-catchments as study area:

a) **Water flow characteristics:** Included amount of water, and perennial and seasonal rivers;

b) **Topographical differences:**

The study required area to included Upper, Middle and lower part of Mara river in Kenya to ensure major part of the basin is captured.

c) **Sub-catchment land uses:** Land uses included agriculture (Small and large scale agriculture), Livestock keeping/ grazing and wildlife which are major land uses in Mara river basin in Kenya.

The following are the criterial used to select sub-catchments:

Name of the Sub-catchment	**Stream gradient (reflecting the potential velocity during the average flows)**	**Topographical differences (Altitude in masl)** • **Upper -2000-3000masl** • **Middle-1400-<2000masl** • **Lower <1400masl**	**Sub-catchment land uses**
Nyangores (Perennial river)	0.0136	Occupy Upper and middle	Mau forest moderately destroyed, more tree farm , Small and large scale farming of dairy cattle, wheat, pyrethrum, and barley
Amala (Perennial river)	0.014	Occupy Upper and middle	Mau forest very highly destroyed, more tree farm, Small and large scale farming of dairy cattle, Tea, Maize, wheat, pyrethrum, and barley
Engare Ngobit (Seasonal river)	0.014	Middle	Small scale farming Maize, beans, Sorghum, millet, sweet potatoes, livestock
Talek (Seasonal river)	0.012	Lower	Small scale farming Maize, beans, Sorghum, millet, sweet potatoes, livestock and wildlife
Sand River (Seasonal river)	0.012	Lower	Livestock and Wildlife

From criteria Engare Ngobit sub-catchment was eliminated because was found to be very similar to Talek sub-catchment and remained with Nyangores, Amala, Talek and Sand sib-catchments (Figure 3.1.). Reasons for selection: Although Nyangores and Amala rivers are perennial and adjacent to each other with similar area and both originate from Mau forest, study by Melesse (2007) found that have different hydrological responses. Amala had lower dry flows and high wet flows compare to Nyangores. In terms of land use Nyangores and Amala sub-catchments includes both large scale and mixed farming. Engare Ngobit, Talek and sand rivers are seasonal rivers. Engare Ngobit originate from Ilotyookoit Ap Soyet ridges and join Amala river almost one kilometre downstream of the Mulot Market. Main land uses are small scale farming and livestock grazing. While Talek and Sand river are originating from Loita hills and drain to the Sannia and Loita plains for both livestock and wildlife uses, with farming. The fifth Engare Ngobit tributary was left as it is just the lower side of Amala, bordering and joined Talek at open savannah grasslands and both join main Mara River as Talek tributary. It was deemed important to study four tributaries on the Kenyan side that drain into the Mara River given their varied contribution to the Mara River flow regimes owing to their inhomogeneous nature and their corresponding differences in contributions to the Mara River flow regime.

3.3. Sample Size Determination for socio-economic study

For the cross-sectional household survey, the sample size was determined by the Fisher formula from target population of over 10,000 adults living within the four sub-catchments (Amala, Nyangores, Talek and Sand River) of the Mara River Basin. Confidence interval of 95% and expected responses of 50% was used. The margin error of 5% were used. The formula yielded a sample size of 422 respondents drawn proportionately from the four sub-catchments.

The formula as described by Fisher *et al.* (1998) for sample populations exceeding 10,000 is as given below.

$$\mathbf{n = \frac{\underline{Z^2pq}}{d^2}}$$

Where:

n= minimum sample size

Z= Standard normal deviate at the required confidence level (error 5% Z = 1.96)

P= Proportion of subjects in the sample population estimated to be affected by the flow regime.

q=1-p

d= Absolute precision expressed as a fraction of 100 (accuracy level of 5 % chosen = 0.05).

$$n = \frac{1.96^2 \text{ x } 0.5 \text{ x } 0.5}{0.05^2} = 384$$

An additional 10% was added to cover for anticipated non-responses and spoilt questionnaires and to increase the statistical power of the study.

10% of 384 = 38.4≈ **38**

n = (384 + 38) = 422

The minimum sample size was therefore 422 respondents.

Sample size from each catchment was determined by proportionate method, where the formula bellow was applied.

ni = n * nj / N

ni: Sample size of a catchment

n: Sample size of the study

nj: Target population of the catchment

N: Target population in the study area

An estimated population of 1,000,000 people are supported by the Kenyan side of the Mara Basin (Metobwa *et al.*, 2018), with Amala, Nyangores, Talek and Sand river sub-catchments having an estimated population of (437, 271; 576, 068; 140, 120 and 80, 200, respectively). Thus, the minimum sample size required were; Amala (140), Nyangores (170), Talek (75) and Sand River (37).

3.4. Data Acquisition/Collection Procedure

The data acquired for purposes of this study included: meteorological data, stream flow data, land cover change, soil and topographic data and socio-economic data obtained from selected respondents using a household questionnaire across the four sub-catchments. The data collection/ acquisition procedure was as detailed below:

3.4.1. Meteorological data acquisition

3.4.1.1. Temperature and Precipitation data acquisition and analysis

Temperature and rainfall data sets were obtained from Giovanni website. The data obtained were of high resolution (0.1° latitude × 0.1° longitude) daily gridded sets. Averages were calculated to obtain monthly and annual mean temperature and precipitation for the period between 1987 and 2017 (October). The Normalized Difference Vegetation Index technique was used to extract the various features presented in satellite imagery. Vegetation indices allowed the delineation of vegetation distribution and soil, based on the characteristic reflectance patterns of green vegetation. NDVI of the four sub-basins were generated following their different land cover categories in the study area. This yielded different NDVI values depending on vegetation healthiness and extend.

The NDVI images for the month of October (driest month) from the years 1987 to 2017 were utilized to obtain specific NDVI values. Random points were generated for specific land use category and the multi values extracted using geo-statistical tool. Land cover was overlaid on NDVI images to extract random points of specific land cover types *i.e*. forest, bare land, grassland, shrub land, cropland, and built up areas. The generated points were later extracted through a process of geo-statistical analysis by multi values regression function. The process is as shown in Figure 3.2.

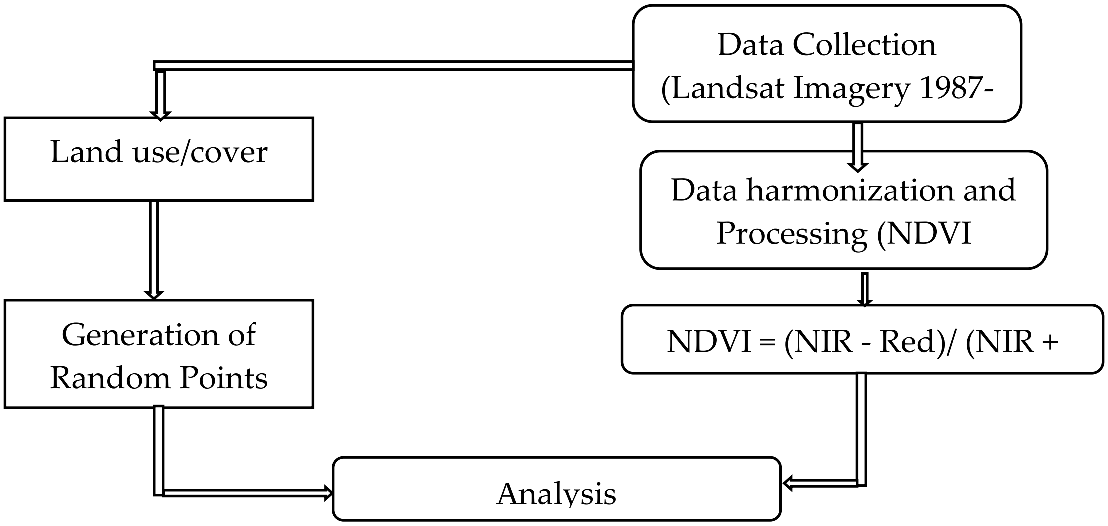


Figure 3.2. *NDVI process*

3.4.1.2 Impacts of temperature and precipitation on different land cover categories

Kriging methods were employed in ArcGIS to produce monthly and annual precipitation and temperature gridded maps for each sub-basin. The average values of NDVI, temperature and precipitation associated with a particular vegetation type were calculated from the averages of all Pearson’s correlations (P) between monthly variables in MS Excel and P-values used to determine significance levels. Considering the lagged response of NDVI to temperature and precipitation, the correlation analyses were also carried out between each seasonal NDVI and the previous season’s temperature and precipitation for the month of October.

3.4.1.3 Determination of the accuracy of land cover maps

The overall accuracy of the land cover maps for 1987, 1997 and 2017 was determined and the Validation Kappa indices for each map were: 0.901 for Amala, 0.898 for Nyangores, 0.938 for sand and 0.963 for Talek. The land cover maps in the study area from 1987 to 2017 are shown in the results section. A confusion matrix was applied in the present study to check the accuracy of the results (see the below equations). The overall accuracy and Kappa concordance coefficient of agreements (Kappa coefficient) in each year were calculated, and finally the overall accuracy of all classification results obtained as an average value. The equation of Kappa coefficient is as shown below [32]. If p_a = the proportion of observations in agreement and p_ε = the proportion in agreement due to chance, then Cohen’s kappa is:

$$k = \frac{p_a - p_s}{1 - p_s} \qquad \text{(eq.1)}$$

Alternatively

$$k = \frac{n_a - n_s}{n - n_s}$$

Where n = number of subjects, n_a = number of agreements and n_s = number of agreements due to chance.

Retrospective daily rainfall data spanning 30 years (1987-2017) was downloaded at intervals of 10 years (*i.e.*, 1987, 1997, 2007 and 2017) from the NASA Giovanni website, yielding a high-resolution (0.1° latitude × 0.1° longitude) daily gridded rainfall data for the period 1987/04/01 to 2017/10/30. Observational data of the same parameter was also obtained from the Water Resources Authority (WRA) field station; and FEWSNET and IGAD Climate Prediction and Application Centre obtained from the Climate Hazards Group Infrared Rainfall with Station Data (CHIRPS) for comparison and quality assurance purposes. A comparison between the Giovanni, FEWSNET and IGAD data sets yielded no significant differences.

3.4.2. Land cover, Normalized Difference Vegetation Index (NDVI), topographic and soil data

For land cover change analysis, Landsat 4 & 5 and Landsat 7 and 8 images were downloaded from the earth explorer United States Geology Survey (USGS) website. The image used were of the same resolution of 30x30m, and clouds of less than 5% were downloaded. Earth Resource Development Assessment System (ERDAS) Imagine 2013 software (one of the first remote sensing software programs initial released in 1978) was used to process the images obtained from the three scenes of Landsat, 4 & 5, Landsat 7 and Landsat 8 images of Path/Row 169/060, 169/61, 170/61. The Digital Elevation Model (DEM) of 90m by 90m resolution was obtained from the NASA Shuttle Radar Topography Mission (SRTM). The Normalized Difference Vegetation Index (NDVI) were obtained from the U.S. Geological Survey (USGS) website. The DEM was delineated and processed using ArcMap software.

Land cover classification covering the four sub-catchments (Amala, Nyangores, Talek and Sand) was consequentially processed and derived by supervised classification using ERDAS Imagine 2013. The year 1987 was taken as base year of study while Landsat imageries were used due to their suitability for vegetation cover analysis especially vegetation discrimination, measurement of chlorophyll absorption and vegetation type and biomass content analysis. The Landsat imageries used were for October (driest month) for the years 1987, 1997, 2007 and 2017. These intervals were believed to be sufficient enough to show substantial changes in land cover. Since land cover dynamics is the function of soil properties, slope and climate data, soil data was downloaded from FAO website.

3.4.3. Stream flow data

Daily stream flow data for the Amala and Nyangores tributaries were obtained from Water Resources Authority (WRA) Kisumu office computed from developed stage-discharge relation (rating). Nyangores flow data was collected from station number 1LA03 located along Nyangores tributary near Bomet town for the period between 1987 and 2000, while Amala flow data was obtained from station number 1LB02 located along Amala tributary near Mulot town for the period between 1987 and 1995. Stream flow data for Talek and Sand River were obtained from the Maasai Mara and Serengeti Ecosystem (MaMaSe) project with technical guidance from WRA staff. However, data for Talek and Sand River was not in the WRA database and was therefore not used in this study given that its accuracy could not be ascertained.

3.4.4. Socio-economic data collection

3.4.4.1. Household survey

A multi-stage sampling method was used in the socio-economic household survey in which 422 respondents were drawn proportionately from households in the four sub-catchments (*i.e.* 152 from Amala, 157 from Nyangores, 70 from Talek and 39 from Sand river sub-catchment). Firstly, a total of 24 villages were purposively selected from all the four sub-catchments from which the 422 respondents from randomly selected households were picked to participate in the study. Prior to the survey, the questionnaires were pre-tested in a different river basin (Nyando River Basin) having similar characteristics with Mara river Basin and are both managed by Water Resources Authority (WRA) Kisumu office and enters Lake Victoria. After pre-test correction were made to the tool based on the pre-test exercise.

The household survey sought to collect primary data on: (1) household characteristics, (2) land size and duration lived in study area, (3) land use/land cover types and changes that have occurred over time, and (4) impacts of land cover change on various socio-economic and livelihood sources like, livestock keeping, crop farming, water availability and accessibility shocks, vulnerabilities and coping strategies. Each questionnaire took on average about 45 minutes to administer. For confidentiality purposes, respondents to the survey were not identified either by name or by location but by number assigned to questioners and geographical coordinates taken. The survey was conducted in June 2018.

3.4.4.2. Focus group discussions

A total of four focus group discussion sessions (one in each sub-catchment) were conducted. The purpose of triangulation was to provide a better understanding of the socio-economic impact of land cover change from the community members' own perspective. The FGD sessions consisted of between 8-12 discussants comprising of men, women and youths obtained from each sub-catchment with assistance from Water Resources Users management to ensure required geographical representation and composition of participants. Each session lasted approximately one hour and was facilitated by the researcher. A Focus Group Discussion guide containing a number of questions on land cover changes and socio-economic wellbeing among community members was used to achieve focused discussions. The participants were mostly small scale farmers and pastoralists while the FGD sessions were conducted in English, Swahili, and Maasai or Kalenjin languages depending on the respondents' preference.

3.5. Data Analysis Methods

3.5.1. Meteorological data

The daily mean temperature was calculated over the observation period as the average of maximum and minimum temperature. The monthly average temperature and rainfall were obtained by computing daily average temperature and precipitation, respectively, from January to December for the year 1987, 1997, 2007 and 2017 and further computed into mean annual temperatures and precipitation. The Box-whisker plots of annual temperature and rainfall time series were used to depict systematic spatial gradients. Trends were analyzed using the nonparametric Mann-Kendall trend test and Sen's slope estimator. A normalized test statistic (Z-score) was used to check the statistical significance of the increasing or decreasing trend of mean rainfall and temperature values at a significance level of 0.05. The website data were compared with field observed data from weather and gauging stations to verify the accuracy and validity.

3.5.2. Land cover change analysis

Customised to this study, Food and Agriculture Organization (FAO) Land Cover Classification System (FAOLCCS of 2000 was used. Supervised classification method was used to classify the six distinct land cover types (Forest land, grass land, shrub land, crop land, bare land and built-up areas/ human settlements). To understand the land cover changes that occurred in each of the four Mara River sub-catchments between 1987 and 2017, a post-classification change detection analysis of the four different dates of satellite images were performed using ERDAS Imagine software for the dry (October) seasons and land cover change maps developed. To understand the land cover change dynamics (how the land cover changed from one land cover to another), the information classes of the 1987, 1997, 2007 and 2017 satellite images were overlaid to get three overlay land cover change dynamics maps.

That is, 1987 satellite image was overlaid on 1997, 1997 satellite image was overlaid on 2007 and lastly 2007 satellite image was overlaid on 2017 and the quantities of change in each class for each dataset computed in that sequence and changes combined into one “change” image (comprising of the 1987-1997 -2007 -2017 period) in which each of the “from-to” land cover changes were extracted. A total of Three “from-to” change matrices were obtained for the 1987-1997, 1997-2007 and 2007-2017 periods, in that order. Tables and charts showing trends and magnitudes were developed using Excel software and both descriptive and inferential statistical analyses conducted to show relationships between climatic factors and land cover change.

3.5.3. Determination of correlation between climate variability and land cover using Normalized Difference Vegetation Indices (NDVI)

The NDVI images for the month of October between 1987 and 2017 were utilized to obtain specific NDVI values. The random points were generated for specific land cover category and the multi values extracted using geo-statistical tool. Land cover was over-laid on top of the NDVI image in order to extract random points of a specific land cover i.e. forestland, bare land, grassland, cropland, and built up areas. The generated points were later extracted through a process of geo-statistical analysis by multi values regres-sion function. The random points were separately obtained through computed averages for respective monthly NDVI values in order to get the mean monthly NDVI for specific land category.

3.5.4. Hydrological modelling –stream flow analysis

To understand the impact of LC change on stream flows, hydrological modelling was performed using Soil and Water Assessment Tool (SWAT) plugin in QGIS software. The SWAT watershed model is one of the most recent models developed at the United State Department of Agriculture during early 1970 (Arnold *et al.*, 2012). The model is semi distributed physically based simulation model and can predict the impacts of land cover change and management practice on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool. The land phase of the hydrologic cycle modelled in SWAT based on the water balance equation.

The main components used in running the SWAT model included climate data *i.e*. daily rainfall (mm), Min and Max temperature (ºC), daily wind speed (ms-1), daily solar radiation (MJ/m^2) and daily relative humidity (Wm^2), land cover maps, Soil Map, and the Digital Elevation Model (DEM) for year 1987/04/01 to 2017/10/30. Observed stream flows and simulated flows were used to calibrate the SWAT model. This exercise was carried out in four steps. (a) A database including land cover maps were reclassified to SWAT classification. The following SWAT classification was used to define the normal informational classes of the land cover. Table 3.1 below illustrates the land cover types generated and classified from SWAT.

Table 3. 1. *SWAT classification code against the normal classification*

SWAT land use code	Normal classification
FRSD	Forest
AGRL	Cropland
GRAS	Grassland
TUBG	Bare land
SHRB	Shrubland
URBN	Built up area

Other data included climate, soil, DEM of 1987, 1997, 2007 and 2017 in each sub-catchment was produced and inputted in the SWAT model. The process involved running the SWAT model, where the model used DEM to further fragment (delineate) sub-basin into several sub-watersheds which then further sub-divided into small units to form the hydrological response units (HRUs). Hydrologic response units are portions of a sub-basin that possess unique land cover /soil attributes among other characteristics. (b) The input of land cover, soil type and slope (slope of range values from (0-5, 5-10, 10-15, 15-25, >25) were used to divide and generated full hydrological response units (HRUs). (c) Weather data Rainfall, wind, solar, humidity, radiation and Temperature were inputted into the SWAT model. (d) The SWAT model was run to produce Results Output. (e) SWAT simulation run was carried out using set of input variables and sensitivity analysis performed to identify parameters that most influenced predicted streamflow. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model parameters (Arnold *et al.*, 2012).

The sequential uncertainty fitting (SUFI-2) found in SWATCUP was used to calibrate and validate the SWAT model. The degree to which all uncertainties are accounted for were quantified by a measure of P-factor, which is the percentage of measured data bracketed by the 95% prediction percentage uncertainitiey-95PPU and evaluate the model simulation stream flows in relative to the observed stream flows data. The efficiency (calibration) of the model was assessed by comparing simulated and observed annual and monthly streamflow. In order to test the assumption that land cover change has an effect on streamflow, further simulations were performed using calibrated model.

The model run using a daily data of 31 years (1987-2017) for the examination of the trend of hydrological process under a land cover maps of 1987, 1997, 2007 and 2017. The choice of stream flow for the calibration and validation was preferred with a period of relatively free gaps carefully attempting similar dry and wet years of both periods. The SWAT CUP software was used to run iteration of the results obtained from the QSWAT. Simulated annual evapotranspiration, annual precipitation, surface runoff, average annual water yield, groundwater contribution to stream flow and streamflow were estimated based on the input data for a 30-year period from 1988 to 2017 (one year was excluded). Figures 3.3, 3.4, 3.5 and 3.6 below show the SWAT analysis land cover, DEM, slope, soil input files, respectively used for Nyangores sub-catchments and Figures 3.7, 3.8, 3.9 and 3.10 show the SWAT analysis land cover, DEM, slope, soil input files, respectively used for Amala sub-catchment to help understand the impact of LC change to stream flows.

3.5.3.1. SWAT Analysis Input Files for Nyangores Sub-catchments

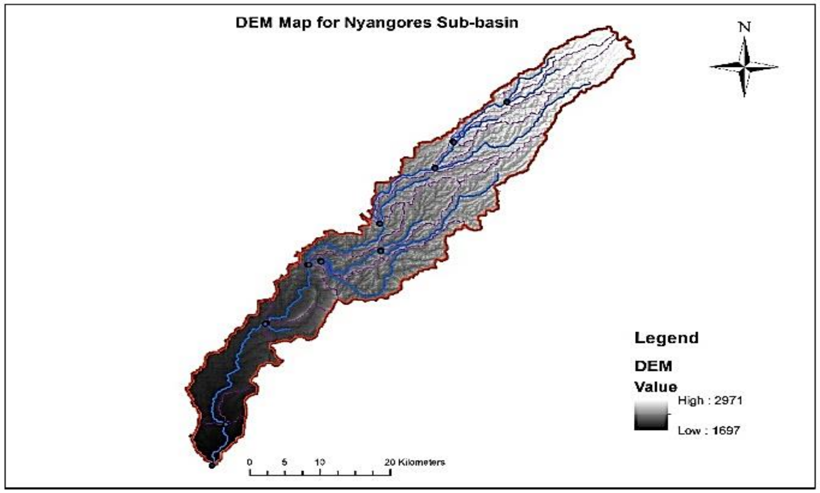


Figure 3.3. *Land cover map 2017 Nyangores*

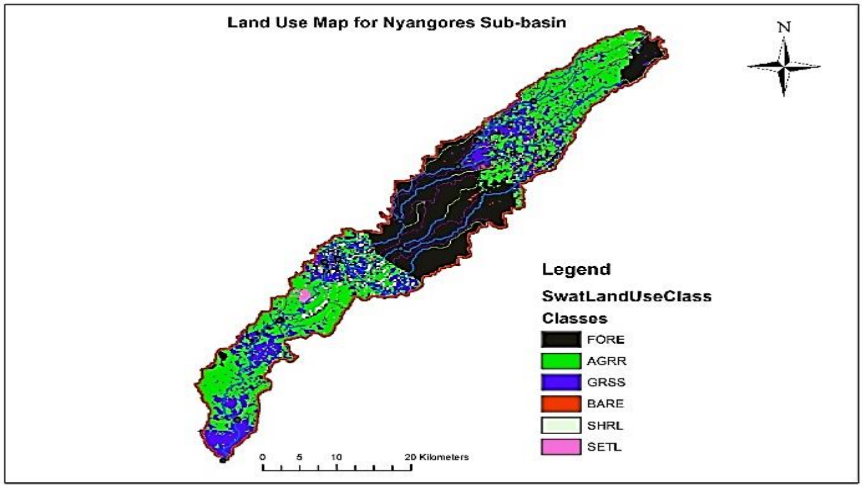
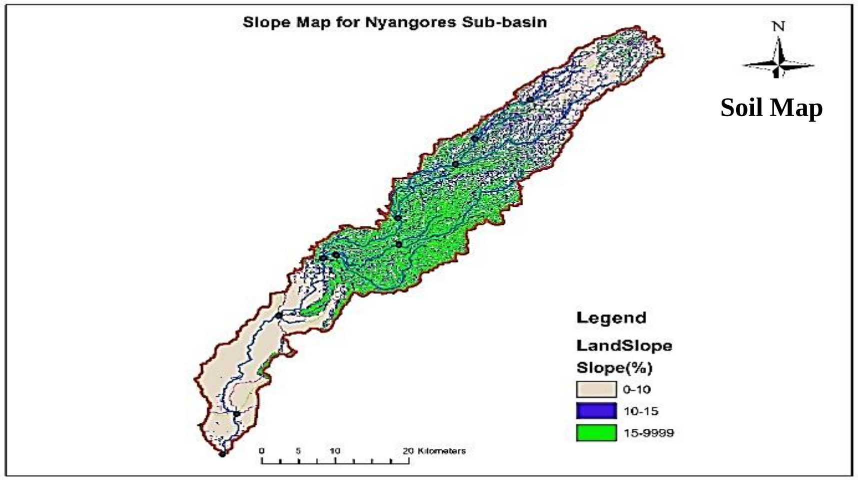


Figure 3.4. *DEM Map Nyangores*



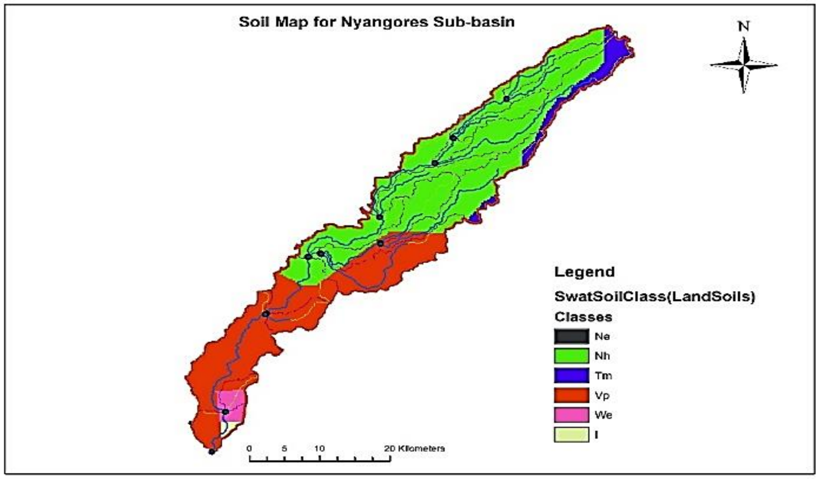


Figure 3.5. *Slope Map Nyangores*

Figure 3.6. *Soil Map Nyangores*

3.5.3.2. SWAT Analysis Input Files for Amala Sub-catchments

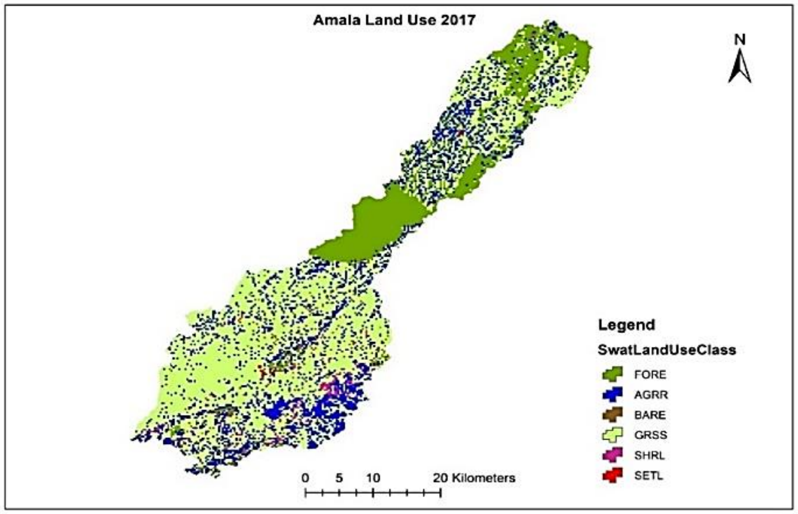


Figure 3.7. *Land Use Map Amala 2017*

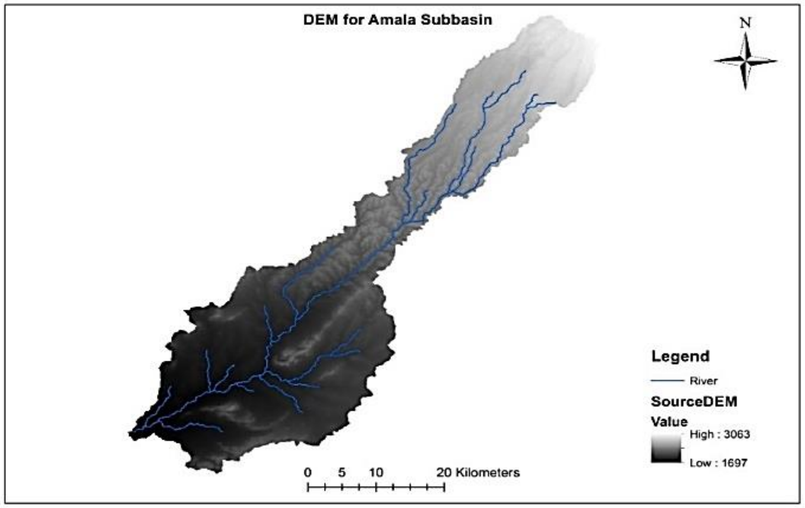


Figure 3.8. *DEM Map Amala*

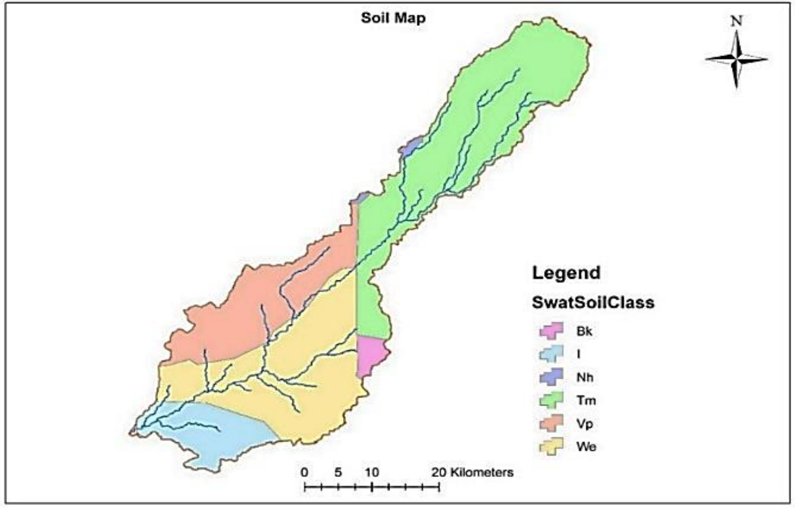


Figure 3.9. Slope Map Amala

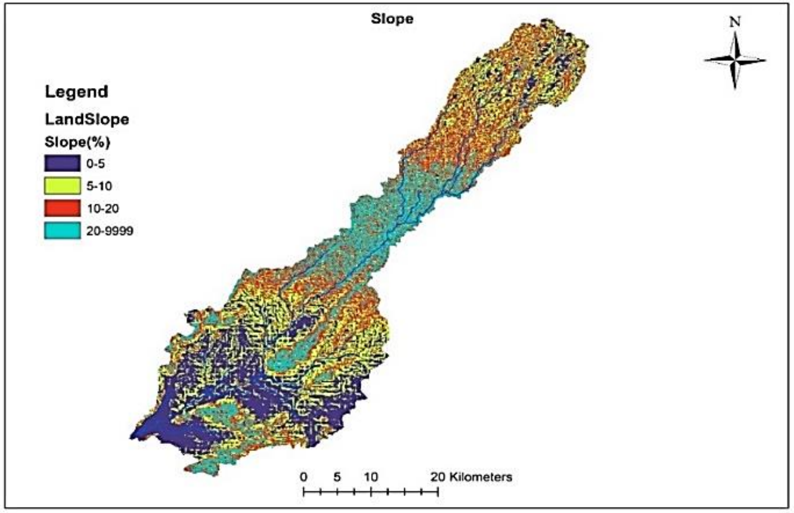


Figure 3.10. *Soil Map Amala*

3.5.5. Forecasting future pattern of the land cover changes

The comparison of the land cover statistics assisted in identifying the percentage change, trend and rate of change between 1987, 1997, 2007 and 2017. The first task was to develop a table showing the area in hectares and the percentage change for each of the 10 years (1987, 1997 and 2017) measured against each land use land cover type. Percentage change to determine the trend of change was then calculated by dividing observed change by sum of changes multiplied by 100 (Zubair, 2006).

$$\text{(Trend) Percentage change} = \frac{\text{observed change x 100}}{\text{sum of change}}$$

In obtaining annual rate of change, the percentage change was divided by 100 and multiplied by the number of study year 1987 – 1997 (10 years) 1987 – 2007 (20 years) and 2007-2017 (30 years).

Markov Chain model analysis

According to Hua (2017), the Markov chain model was presented by a Russian mathematician named Andrei A. Markov in 1970. Burnham was the first to use this model for land use modeling (Mishra and Rai, 2016; Parsa *et al.*, 2016). Markov chains are stochastic processes (Halmy *et al.*, 2015) and the matrices to show changes between land use categories (based on the basic core principle of continuation of historical development. Markov chains were used to obtain the percentage and probability for each category of land cover converted. Using the Markov model, the distribution of each land cover category was projected based on the transition probability p_{ij} between two land cover categories (i and j). P_{ij} was determined over a specific period, from time t to time t+1, as follows:

$$\boldsymbol{P_{ij} = \mathrm{P}[\mathrm{x}_{n+1} = \mathrm{j} | \mathrm{x}_n = i] \ldots [t\ t + 1]} \qquad \textbf{(eq. 2)}$$

Let $\boldsymbol{P = P_{ij}}$ denote the (possibly infinite) transition matrix of the one-step transition probabilities

Where:

P = the Markov transition matrix P

i, *j* = the land type of the first and second time period

P_{ij} = the probability from land type i to land type j

t t+1 = time

The estimate of Markov chain is the relative frequency of transitions observed over the entire time period. The result of the estimation was used for prediction. In practice, based on the map algebra principle, the class of land type utilizes the equation below to calculate the transfer map of land cover change under the ERDAS Modeler module.

$C_{ij} = A^{t}{}_{ij}X10 + A^{t+1}{}_{ij}$

$$\boldsymbol{C_{IJ} = A^{t}_{ij}X^{10} + A^{t+1}_{ij}} \qquad \text{(eq. 3)}$$

Where:

$\boldsymbol{A^{t}_{ij}}$, $\boldsymbol{A^{t+1}_{ij}}$ = the land use map of the first and second time period, respectively

t, t +1 = the first and the second time period

i, j = the land type of the first and second time period

C_{ij} = the class of land type i to land type j

1. Applying the Markov chain analysis to the 2007 and 2017 developed maps for calculating transition matrices;
2. Calculating land cover change transition potential maps; and
3. Predicting the land cover change for 2027 by using Markov CA model to develop transition matrices and then developing transition potential maps for all four sub-basins.

To understand decadal land cover dynamics, the periods between 1987 - 1997; 1997 - 2007 and 2007 – 2017, were used to produce land cover dynamics for each sub-basin. These dynamics helped to highlight changes to different land cover categories (what gained and lost and from which land cover category to another). The 2007 and 2017 land cover maps were then used to predict the changes likely to occur in land cover by 2027 for each sub-basin.

3.5.6. Analysis of the Household Socio-Economic Survey Data

Data obtained through the household survey was coded and analyzed descriptively using the Statistical Package for Social Sciences (SPSS) version 20 (SPSS Inc. 2008). Descriptive statistics such as cross tabulation, frequencies, and percentages were used to summarize data on land cover change and socio-economic variables. To establish the main drivers of land cover change in the four sub-catchments, a Generalized Linear Model was used.

All FGD recordings were transcribed verbatim from Maasai, Kalenjin or Kiswahili to English. The transcriptions were verified by two independent researchers knowledgeable in the local languages. Content analysis was used to analyze qualitative data, whereby the discussions from the focus group and key informants were objectively and subjectively analyzed and narrated. Text analysis of the transcriptions and the notes taken during the FGDs was conducted by NVivo 10® software (QSR International Pty. Ltd., Melbourne, Australia, 2008), which allowed for data classification and sorting, and exploration of relationships and trends. Three investigators, each working independently, coded the major themes that emerged from each topic using an inductive approach. They discussed any differences until consensus was reached.

3.6. Quality Assurance and Quality Control

The precision of procedure and data collection was established by collecting and comparing data from different sources. The selection of the software that was applied in this study was based on software precision that have been used for similar (Sathees *et al.*, 2014; Edgar *et al.*, 2018). Regarding the satellite images, 30mx30m was used for land cover classification and the images with cloud cover 5% or less were used. This enabled the researcher to visualise and classify land cover properly. Where necessary, the data was cross checked or compared with on ground data/ information. Precision was acceptable only if the replicate values yielded a relative standard deviation of less than 20%.

3.7. Ethical Issues

The protocol to initiate this study was developed by the researcher and approved by the School of Graduate Studies (SGS), Maseno University, Kenya. An official letter addressed to the relevant institution was drafted to obtain required data. Data in the websites that needed special permission were requested for and downloaded once the permission was granted. Informed consents were obtained from household heads during the household survey. Permission to conduct the study in the various sampling blocks (clusters) and to interview land owners was obtained from relevant administrators among them District Officers (DOs), Chiefs, Assistant Chiefs and Village Heads. To uphold confidentiality, personal data was not shared with anybody and was at all times kept safely by the principal investigator.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Correlation between rainfall and temperature patterns (trend) and land cover changes (forest, grass, shrub, bare land, crop and built up areas from 1987 and 2017 in Amala, Nyangores, Talek and Sand river sub-catchments of the Mara River tributaries, Kenya

The present study results of 30 years (1987 to 2017) demonstrated the existence of long term rainfall and temperature variability in the study area. Through Mann-Kendall trend test, all computed p-values of both rainfall and temperature in all four sub-catchments were lower than the significance level alpha=0.05, thus null hypothesis has been rejected. Therefore, long term rainfall and temperature variability have influenced land cover changes (forest, shrub, grass, human settlement, water bodies, agriculture and bare land) in Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River tributaries, Kenya. Similar results were observed in different regions globally (Mishra and Herath, 2012). Understanding the feedback mechanism between climate variability and land-cover changes is therefore important for planning climate mitigation and adaptation measures at the local scales.

4.1.1. Inter-annual rainfall variation over the study period (1987-2017) in the four sub-catchments

The present study results of 30 years (1987 to 2017) generally established annual rainfall trend variation (Figure 4.1a). Mann-Kendall trend test /Two-tailed test showed Amala sub-catchment with Kendall's tau=1, S'=12.000, Var(S')=12.000, p-value (Two-tailed)=0.001, alpha=0.050 and variation coefficient of 13.4%. ; Nyangores with Kendall's tau=1, S=465.000, Var(S)=3461.667, p-value (Two-tailed) =<0.0001, alpha=0.050 and variation coefficient of 15.3%.; Sand with

Kendall's tau=1, S=465.000,Var(S) =3461.667, p-value (Two-tailed)=<0.0001, alpha=0.050 and variation coefficient of 21.1%; and Talek with Kendall's tau=1, S =465.000, Var(S)=3461.667, p-value (Two-tailed) <0.0001, alpha=0.050 and Variation coefficient of 17.5%. Sand showed the highest annual average rainfall variation, followed by Talek, Nyangores and Amala sub-catchments (Figures 4.1b).

The results are in line with the findings Enete, and Alabi, 2012; Falahatkar, Hosseini and Soffianian., 2011; Oluwatola, and Abegunde, 2015), who revealed that land use and cover greatly affects the land surface temperature of a locality.

Average annual rainfall decreased over the 1987-2017 period with a steady decline recorded from 1987 to 1996 except for sand sub-catchment. In 1997 compared to 1987 to 1996, sharper and severer drop of rainfall was noted in all sub-catchments up to from 1998 to 2009. From 2011, the rainfall severely decreased and continued to drop up to 2017. According to the Intergovernmental Panel on Climate Change (IPCC, 2014) and World Meteorological Organisation (WMO, 2019), this phenomenon is called climate variation. Results of the present study suggest that climate variation became more evident in all four sub-catchments between 1997 and 2017 except in 2010 with changes being observed in rainfall variability and intensity.

Further analysis of the rainfall data revealed an inconsistent increase in rainfall variation with two distinct patterns emerging in 2001; one involved the upper sub-catchment tributaries (Amala and Nyangores) and the other involved the lower sub-catchment tributaries (Talek and Sand river) (Figure 4.1a). From Figures 4.1b, it is clear that, the climate variability has caused prolonged dry (droughts) and sometimes wet (floods) years. In comparison with the 30 years mean annual rainfall line in Figure 4.1b, in Amala the rainfall below mean rainfall was noted in year 1991, 1993/1994 and 1995, 1997/1998, 2000/2001, 2004, 2014 and 2017; in Nyangores was noted in 1989, 1991, 1994 and 1995, 1997/98, 2000/2001, 2004 and 2017; in Sand was noted in 1987, 1996, 2002, 2004, 2016and 2017; and in Talek was noted in 1987 to 1989, 1991, 1996/1997, 1998, 2001, 2002, 2003, 2005 to 2017. These years below mean line were the dry and driest years noted by key informants.

The stand deviation (SD) within 30 years (1987 to 2017) found, was 136.56 for Amala, 167.52 for Nyangores, for Sand 152.19 and 145.02 for Talek sub catchments. For 20 years (1987 to 2007) the SD was lower than for the 30 years (1987-2017) which were 96.34 for Amala, 139.43 for Nyangores, 141.54 for Sand; and 126.51 for Talek. For 10 years (1987-1997) the SD 74.98 for Amala, 137.74 for Nyangores, 139.63 for Sand, and 66.309 for Talek was smallest compared to 1987-2007, and 1987-2017. This result showed that rainfall variation was noted mostly from 1997 to 2017.

The above result is in line with Mara River Basin Monograph Final Report (NELSAP, 2008), which found three years 1983/84, 1991/92 and 1996/97 as dry years with the 1983/84 being the driest year following the failed Masika (March-May, MAM) rains of 1984. This variation is linked to the land cover changes particularly forest, shrub lands and grass lands that occurred over the same period as well as increase in surface temperatures, which mostly affect land cover negatively. Consistent with the present study findings, Gundula *et al.* (2018) opined that the recent severe droughts in the Mara could be attributed to the increasing temperatures.

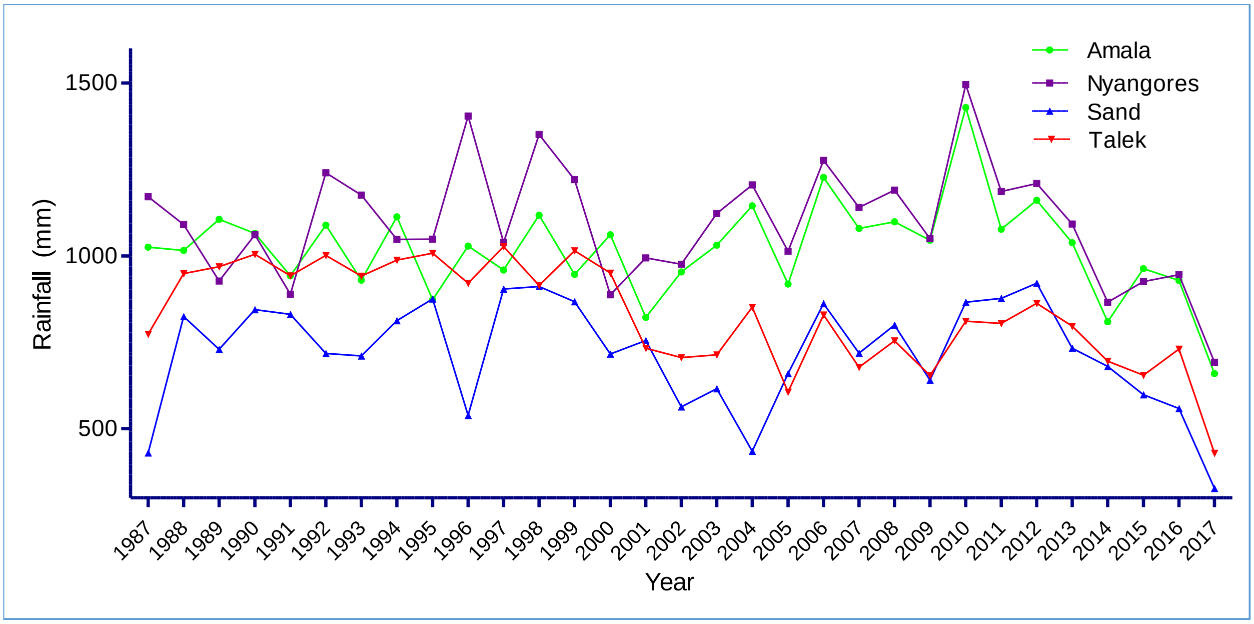


Figure 4.1a. *Total annual rainfall (1987-2017) across all sub-catchments*

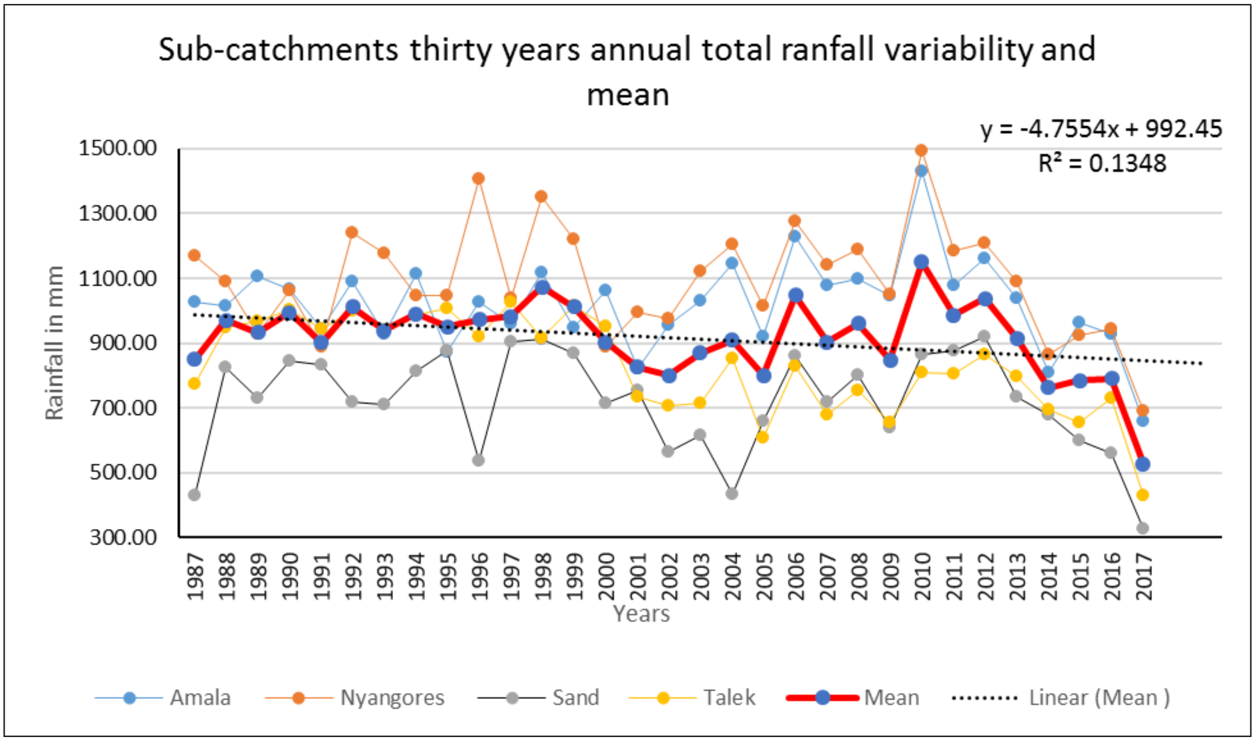


Figure 4.1b. *Total annual rainfall (1987-2017) across all sub-catchments compared with 30 years' rainfall mean.*

A socio-economic household survey conducted within the study area established that there have been some variation in climate with 96.4% of the 418 respondents across the four sub-catchments having noticed some changes in rainfall patterns. The most commonly cited indicator was unpredictable rainfall pattern (43.1%). Others included shifts in rainfall pattern, too little rainfall leading to prolonged droughts and disappearing of some species of vegetation, accounting for 28.3%, 17.5% and 11.2%, respectively. The observed changes were significantly different in the four sub-catchments ($\chi^2 = 11.587$, df = 3, $P < 0.008939$). Deforestation (46.2%), change of weather pattern (28%) and altitude (14%) were the three commonly perceived cause of change in rainfall patterns.

A study conducted by Fidelis *et al.* (2014) in Mara River basin concurs with the current study findings on increasing of rainfall variation in recent times. Rainfall gauging stations; Baraget and Olenguruone in the upper part of the Mara River basin catchment had significant decreasing trend in rainfall at both the 95% and 99% confidence levels. The current findings are also consistent with a study by Ministry of Natural Resources and Environmental Affairs (MoNRE, 2011) which established a general decrease in mean monthly rainfall over time. Earlier studies by Ritchie *et al.* (2008), however, reported a decrease in the total annual and wet season rainfall during 1960 - 2001 but an increase in the dry season rainfall in the Serengeti during 1913–2001 period. In contrast, Ogutu *et al.* (2008) reported a decrease in the dry season rainfall in the Maasai Mara Reserve (Mara Reserve) during 1975 - 2003. Cuni-Sanchez *et al.* (2018) studied climate change and pastoralists’ perceptions and adaptation over the 1920 - 2015 period and established a statistically insignificant decrease in annual rainfall over the past three decades. These contrasting findings demonstrate considerable uncertainty inherent in trends and variation in the past and anticipated future rainfall scenarios in the Maasai Mara region (McSweeney and Jones, 2013), athough majority of the past finding were based on short time data collection.

4.1.1.1. Decadal rainfall variation in driest (October) and wettest (April) month in the four sub-catchments

The month of October in Mara River basin has been documented by many authors including McClain *et al.*, (2014) and Melesse (2008) as the driest month. Consistent with earlier investigators, the month of October exhibited a gradual decrease in rainfall amount across all sub-catchments over the 30-year period, with Sand river recording the lowest decadal mean rainfall throughout the three decades while Nyangores sub-catchment recorded the highest (Figure 4.2).

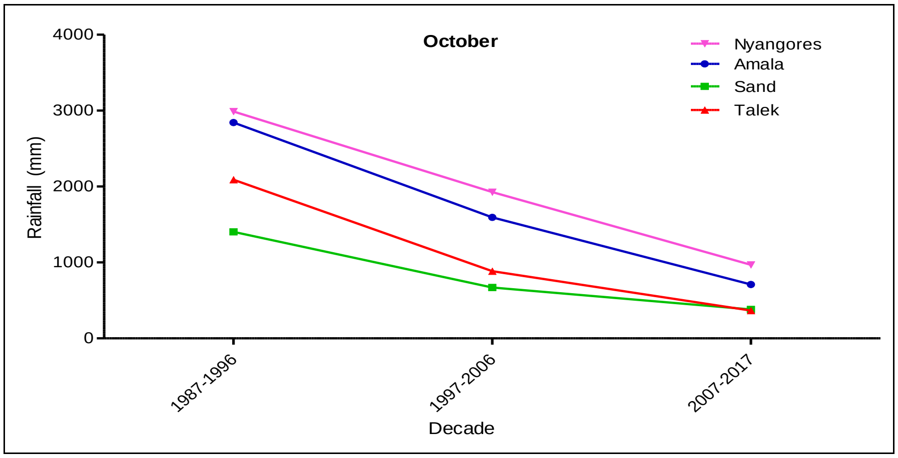


Figure 4. 1. *Decadal rainfall variation over the 30-year period in the four sub-catchments*

Similarly, the documented wettest month of April (McClain *et al.* 2014; Melesse, 2008; Gichana *et al.*, 2014; Melesse *et al.*, 2008; Omonge *et al.*, 2016, and Oruma *et al.*, 2017) in the Mara River basin showed gradual variation in rainfall over the three decades under study, with total rainfall amounts declining sharply from slightly over 3,000 mm on average to less than 1,000 mm between 1987 and 2017 across all the four sub-catchments (Figure 4.3).

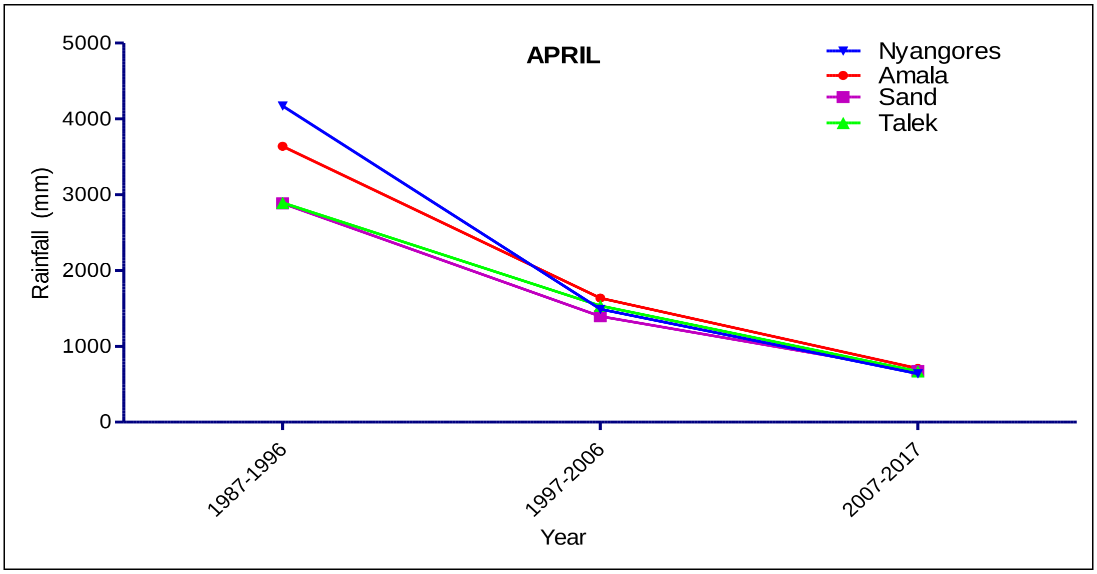


Figure 4. 2a. *Decadal rainfall variation recorded in April from 1987 to 2017*

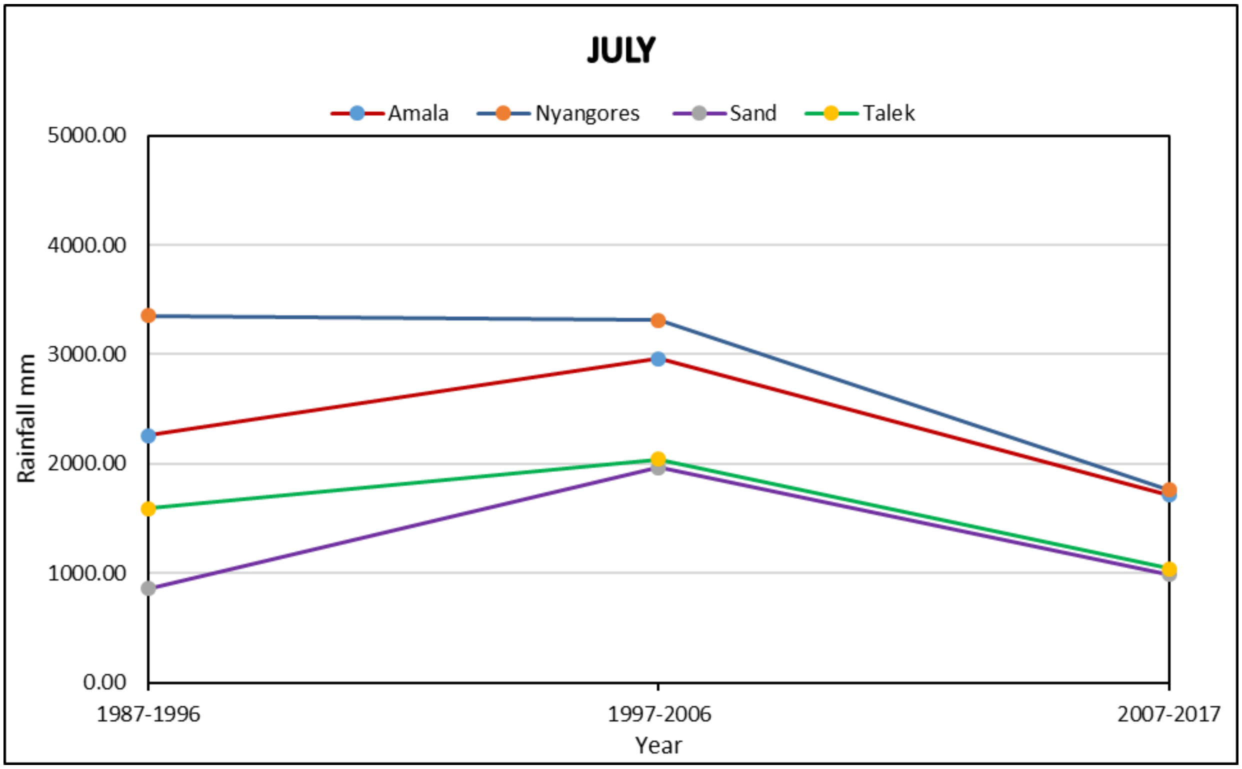


Figure 4. 3b. *Decadal rainfall variation recorded in Jully from 1987 to 2017*

The October and April decadal rainfall decrease confirmed that both dry and wet decadal rainfall months decreased from 1987 to 2017 in all sub-catchments. The July decadal rains data were analysed and the results show the rainfall was inceasing from from 1987 up to 2006; the droped up to 2017. The increase was more in Amala than Nyangores, and least was noted in sand-sub-catchments. Again Sand and Talek sub-catchments were affected to a greater extent compared to Amala and Nyangores sub-catchments.

Decadal results are explained by stand deviation (SD), the higher the SD value the higher the variation from mean. Specifically, annual rainfall standard deviation (SD) within 30 years (1987 to 2017) was found to be highest with 167.52 SD for Nyangores, followed by 152.19 for Sand, 145.02 for Talek and 136.56 for Amala sub catchments. Moreover, for 20 years (1987 to 2007) period SD was lower compared with SD found in 30 years (1987 to 2017). 20 years SD were highest in sand with 141.54 SD, followed by 139.43 for Nyangores, 126.51 for Talek and 96.34 for Amala sub-catchment. For 10 years (1987 to 1997) SD was lowest compare to 20 and 30 years SD. SD was found highest in 139.63 for Sand, followed by 137.74 for Nyangores, 74.98 for Amala, and 66.309 for Talek sub-catchment. Generally, results showed gradual increased SD from 1987 to 2017 and hence increased rainfall variation in all sub-catchments in the same period.

Current findings are consistent with study by Melesse, *et al.*, (2008), in which hydro-metrological rainfall data in Kiptunga Forest station in MRB showed continuous declined in total decadal annual rainfall from 1961 to 2003 by 14%. Mulinya, (2017) also reported decline in annual rainfall by 5 mm for 1960 to 2010 decades in Marsabit Forest Reserve (MFR) Kenya, though the decline was insignificant. Study result is consistent with study results conducted in East African region and found that, region has recently experienced series of devastating droughts which for “long rains” season [March, April and May (MAM)], are manifestation of long-term decline in rainfall totals (Viste, *et al.*,2013; and Liebmann, *et al.*,2014). Study result is also consistent with study conducted in eastern and south-west Ethiopia since 1982 and study conducted from 1965 to 2002 period (Seleshi, and Zanke, 2004; and Cheung, *et al.*, 2008,). Jury, and Funk, (2013) also reported downward trend in rainfall of -0.4 mm month per year over southwestern Ethiopia from 1948 to 2006 period.

From above results, it is clear that, this study found decadal rainfall variations in all four sub-catchments, and therefore study results suggest that, these decadal rainfall variations could be linked to natural and manmade activities demonstrated in decadal land cover variation results in section 4.1.4 and responses/results obtained from household survey conducted by this study.

4.1.1.2. Monthly average rainfall variation in the four sub-catchments

Fidelis *et al.* (2014) reported the wet seasons in Mara River to be March, April and May (MAM), and dry seasons December, January and February (DJF) and June, July and August (JJA). As noted above by the McClain *et al.* 2014; Melesse, 2008; Gichana *et al.*, 2014; Melesse *et al.*, 2008; Omonge *et al.*, 2016, and Oruma *et al.*, 2017 the April is the wettest. On the contrary, the present study established a gradual shift in the once known wettest month from April to July, with the toral highest monthly rainfall amounts in the 30-year period occurring in the month of July in Amala and Nyangores sub-catchments within the upper Mara River basin. This result is demonstrated by figure 4.2b, that Julys rainfall was inceasing from from 1987 up to 2006; the droped up to 2017, while the April rainfall was decreasing from 1987 to 2017. The increase was more in Amala than Nyangores, and least was noted in sand-sub-catchments.

However, April remains the wettest month in Talek and Sand River sub-catchments. Lowest rainfall amount was recorded in the month of September across all the 4 sub-catchments (Figure 4.4a and 4.4b).

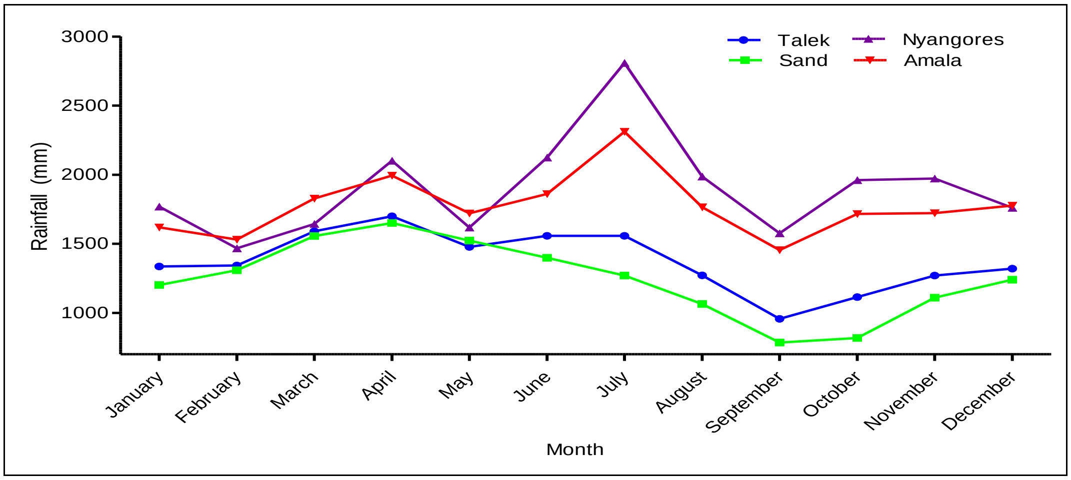


Figure 4.4a. *Monthly average rainfall received over a 30-year period (1987 – 2017)*

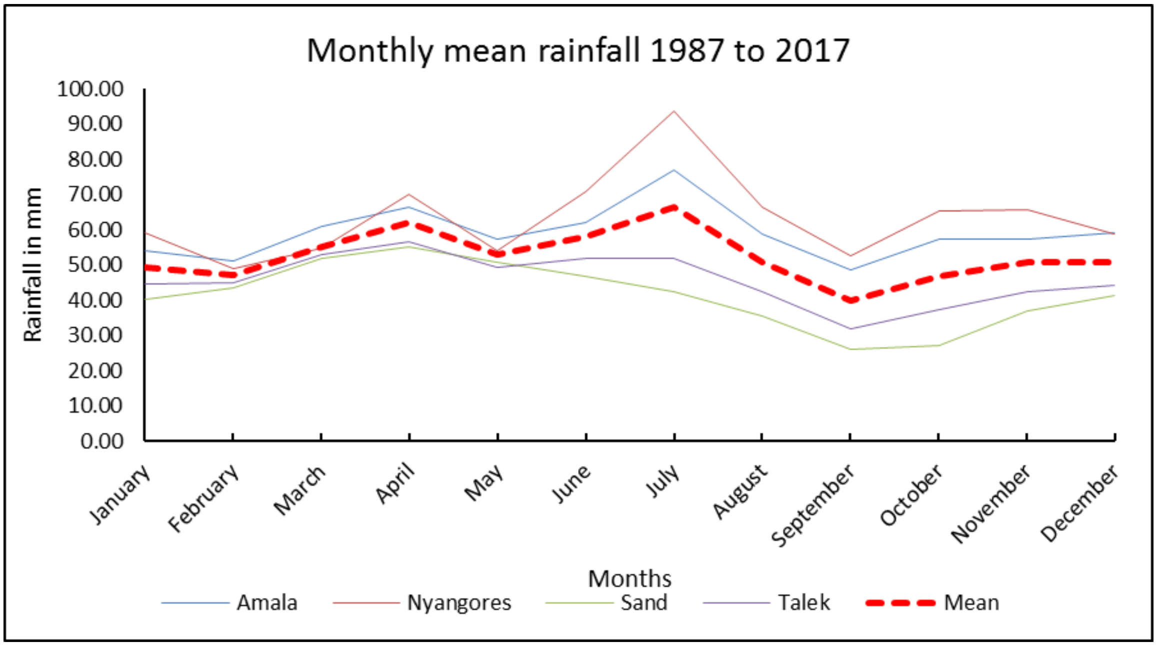


Figure 14.4b *Monthly mean rainfall compared with 30 years' monthly mean rainfall*

This study also suggests the driest month to be September and not October as it was. However, this study shows (Figure 4.4b), the month of July in Amala had the highest monthly rainfall variation followed by June compared with 30 years mean; while the month of February and April had lowest rainfall variability. The month of July in Nyangores had the highest monthly rainfall variation followed by April compared with mean; while the month of March and May had lowest rainfall variability. In Sand and Talek had highest monthly rainfall variation in April followed by March; and lowest in September compared with mean. This emphasise the great rainfall variation noted from 1997 to 2009 in Figures 4.1a and 4.1b). The variation in rainfall within the Mara River basin in the present study is consistent with findings of the Leadership and Assessments (USAID ATLAS, 2019), which noted reduced rainfall leading to droughts in Mara River basin, that previously occurred every 10 years, now occur every 2 to 3 years in the Nyangores sub-catchment, with farmers noting the years 1999–2000, 2004 and 2016–2017 as the most severe.

Respondents from Focus Group Discussion (FGD) in the present study noted that, rainfall period were predictable in the past, which is not the case currently. The discussants also reported experiencing long cold months which initially happened only around July. These variations in climate have resulted in alteration of the planting season in the area. According to FGD discussants, maize planting used to take place in February in anticipation of the heavy rains in March and April, while harvesting would occur between May and July. Indeed, it was reported that the month of June used to be a celebration month for farmers and livestock keepers because of fattening of livestock due to sufficient rains the previous months of March and April, which is not the case anymore.

A study conducted by McClain *et al.* (2014), reported similar result noting that the mean monthly flows remain relatively high during June–August, whereas the lowest flows occurred in the period from October to April. A study conducted in Ghana reported similar findings noting a delay in the wet season onset at several locations throughout the country and lengthening of rainless periods during wet season (Lacombe *et al.*, 2012). This change of rainfall variation was also predicted by Fernanda *et al* (2019), in which extreme climatic events were likely to increase in frequency and intensity, with a significant shift in rainfall patterns. The present study highlights the possible shift in wet month (heavy rains season) from April to July in Nyangores and Amala, while April remain wettest month in Sand river and Talek sub-catchments. This information is critical to land users among them farmers and land use planners. It is thus necessary to research more on the identified shift in the wettest month from April to July in Nyangores and Amala sub-catchments to affirm the shift and provide dependable information to farmers.

4.1.2. Average annual temperature variation (1987-2017) across the four sub-catchments

Generally, the mean temperatures ranged between 16 – 20 °C over the 30-years period in the present study. The present study results of 30 years (1987 to 2017) generally established annual average temperature trend variation (figure 4.5a). Mann-Kendall trend test / Two-tailed test showed Amala sub-catchment with Kendall's tau=1, S=465.000, Var(S) =3461.667, p-value (Two-tailed) =<0.0001, alpha=0.050 and Variation coefficient=3.3%; Nyangores with Kendall's tau=1, S=465.000, Var(S) =3461.667, p-value (Two-tailed) =<0.0001, alpha=0.050 and Variation coefficient =3.03%; sand with Kendall's tau=1, S=465.000, Var(S) =3461.667, p-value (Two-tailed) =<0.0001, alpha=0.050 and variation coefficient =38.7%; and Talek with Kendall's tau=1, S=465.000, Var(S) =3461.667, p-value (Two-tailed) =<0.0001, alpha=0.050

and variation coefficient=38.7. Sand and Talek showed the highest annual average temperature variation, followed by Nyangores and Amala sub-catchments (Figure4.5b).

Although average annual temperature fluctuated between years, a gradual increase was evident over the 1987-2017 period, rising steeply between 2013 and 2017 with a slight dip in 2016 across all sub-catchments. On average, Nyangores sub-catchment recorded the lowest average temperatures compared to the other three sub-catchments, throughout the 30-year period (Figure 4.5a). Between 1987 to 2000 Nyangores sub-catchment showed the great variation in annual average temperature compared to Amala, Sand and Talek sub-catchments. This difference of surface annual average temperature could be linked to the fact that, Nyangores sub-catchment from 1987 to 1997 had large tracts of land under forest cover while the rest changed from forest land to other land covers which is likely to have changed and affected the respective microclimates at the sub-catchment level. Between 2000 and 2017, the variation in annual average temperature between Nyangores and other sub-catchments narrowed and increased sharply from 2017.

In Amala higher mean temperatures were noted in year 1994, 1999, 2000, 2015 and 2016; in Nyangores were noted in 2000, 2005, 2009, 2015 and 2017; in Sand and Talek the were noted in 1999 and 2000, 2009, 2016 and 2017. The stand deviation (SD) within 30 years (1987 to 2017) found was to be 0.6 for Amala, 0.5 for Nyangores, for Sand 0.4 and 0.4 for Talek sub catchments. Therefore, the higher average annual temperature variation is was fond in Amala followed by Nyangores; and sand and Talek have similar variation. Within 20 years (1987-2007) the SD were 0.5 for Amala, 0.5 for Nyangores, 0.4 for Sand; and 0.4 for Talek which showed smaller variation in temperature than of 30 years (1987-2017). For 10 years (1987-1997) the SD were 0.4 for Amala, 0.3 for Nyangores, 0.3 for Sand, and 0.3 for Talek which showed the smallest temperature variation compared to 20 years (1987-2007), and 30 years (1987-2017).

The study shows July, August and September are cold months while December, January and February or sometimes March are hot months (Figure 4.5c).

This could have been linked into change of dominant forest cover to crop land within the Nyangores sub-catchment thus influencing the microclimate. Majority (94.5%, n = 398) of the respondents in the socio-economic household survey in the current study noticed changes in temperature variation over the past 30 years, with most respondents (49.3%) reporting that some months had become cooler than others, while 46.2% noted that some months had become hotter than normal. At the sub-catchments level, respondents from Amala (P = 0.003), Nyangores (P < 0.001), Talek (P = 0.02), and Sand River (P = 0.04) were all in concurrence that temperature had significantly increased (Fisher's exact test). With regard to seasonal temperature variation, 55% of the respondents concurred with historical data and model results that, the dry period which used to occur in June and July had shifted to October and November. The present study findings are consistent with the findings by Niang *et al.* (2014) indicating that temperatures have risen in recent decades in most parts of the Eastern African region.

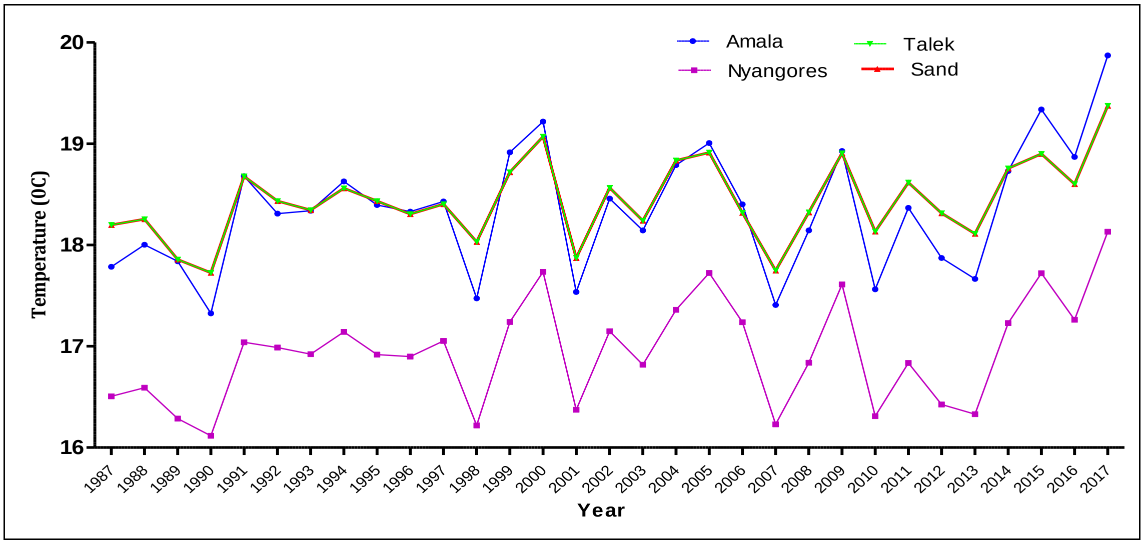


Figure 4.5a. *Annual average temp over the 30-year period across the four sub-catchments*

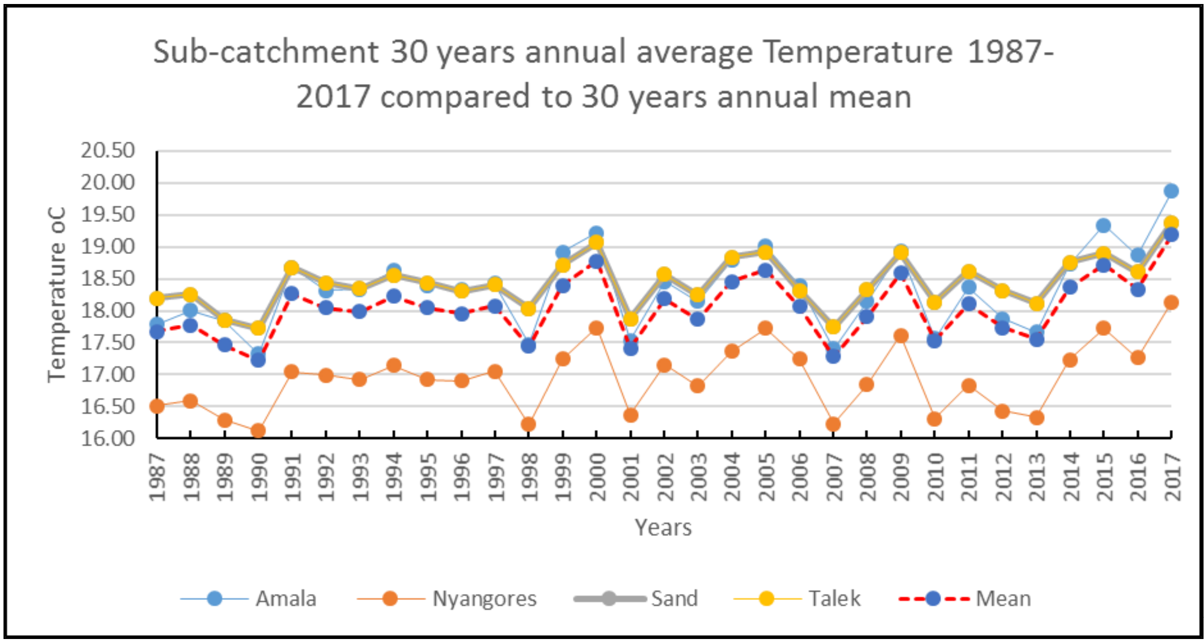


Figure 4.5b. *30 years' annual average temperature (1987-2017) across all sub-catchments compared with 30 years' annual temperature mean.*

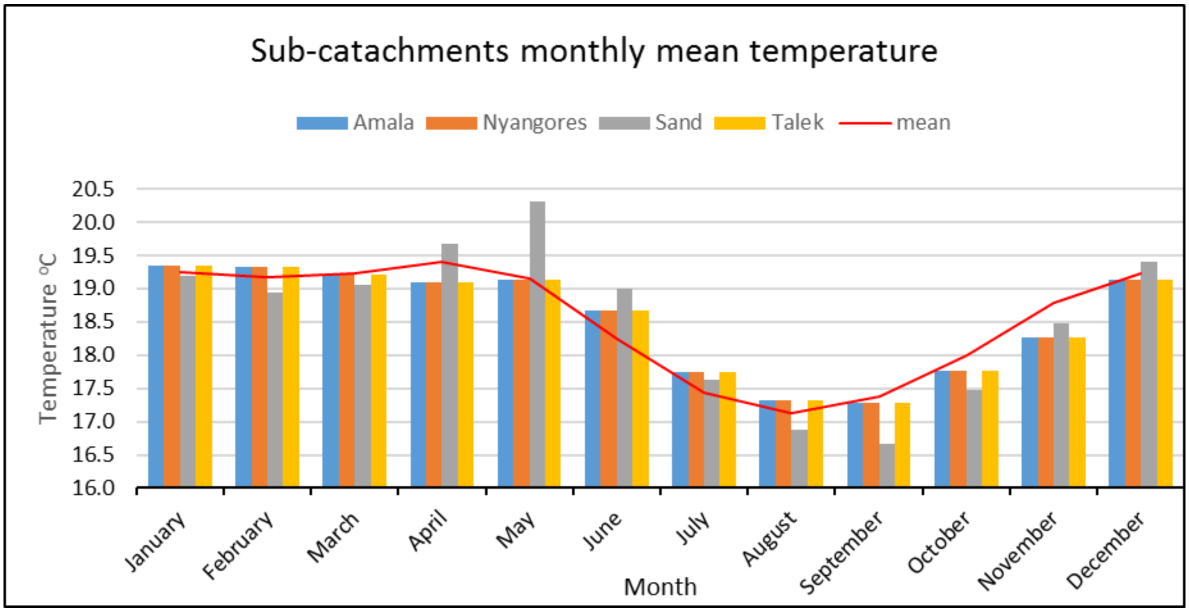


Figure 4.5c. *Sub-catchment monthly 30 years mean temperature*

4.1.3. Decadal temperature variation over the four sub-catchments

With respect to decadal time frames, the most recent decade (2007-2017) recorded a sharp variation in increase in mean temperature across all the four sub-catchments, with Amala sub-catchment recording the sharpest increase and Nyangores sub-catchment recording the lowest although both are in the upper Mara river Basin catchment. The preceding decade 1997-2007 and 1987-1997 recorded a sharp drop and increase in temperature, respectively, across all four sub-catchments with Talek –sub-catchment recording the highest (Figure 4.6a). The decadal annual average temperature confirms the temperature increased for the aforesaid reasons.

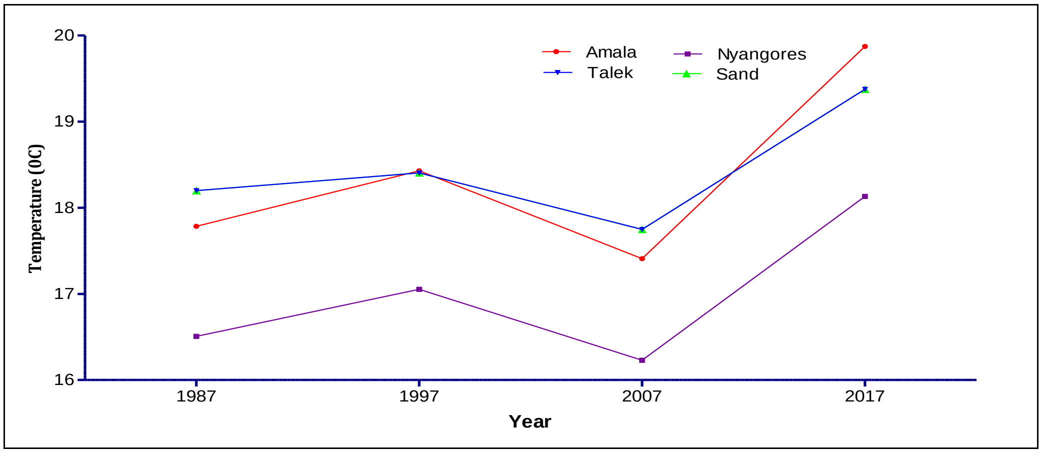


Figure 4.6a. *Average decadal temperature variation over the 30-year period across all sub-catchments*

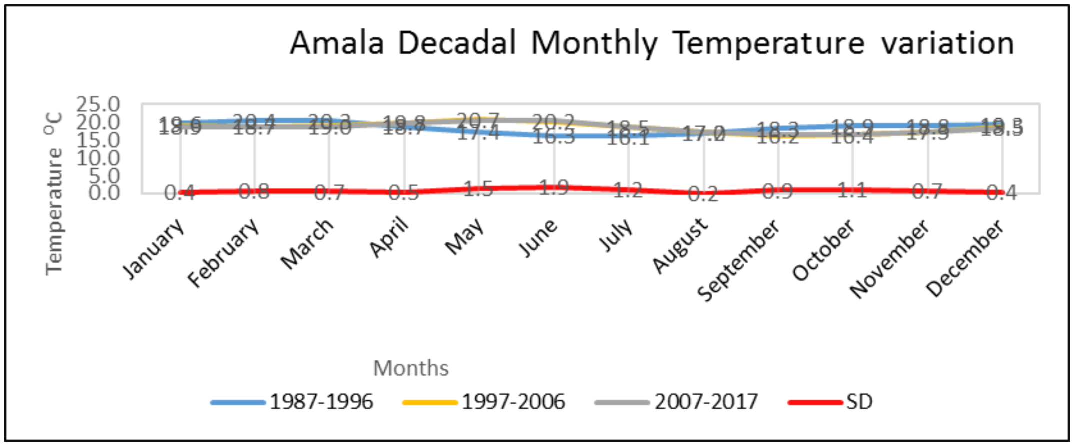


Figure 4.6b. *Decadal monthly temperature variation*

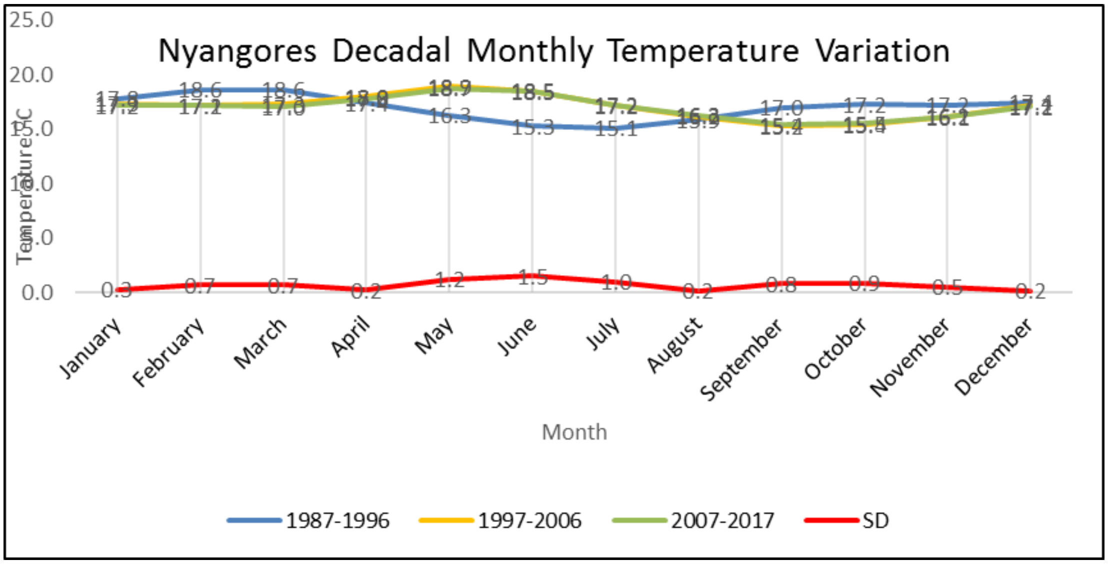


Figure 4.6c. *Decadal monthly temperature variation*

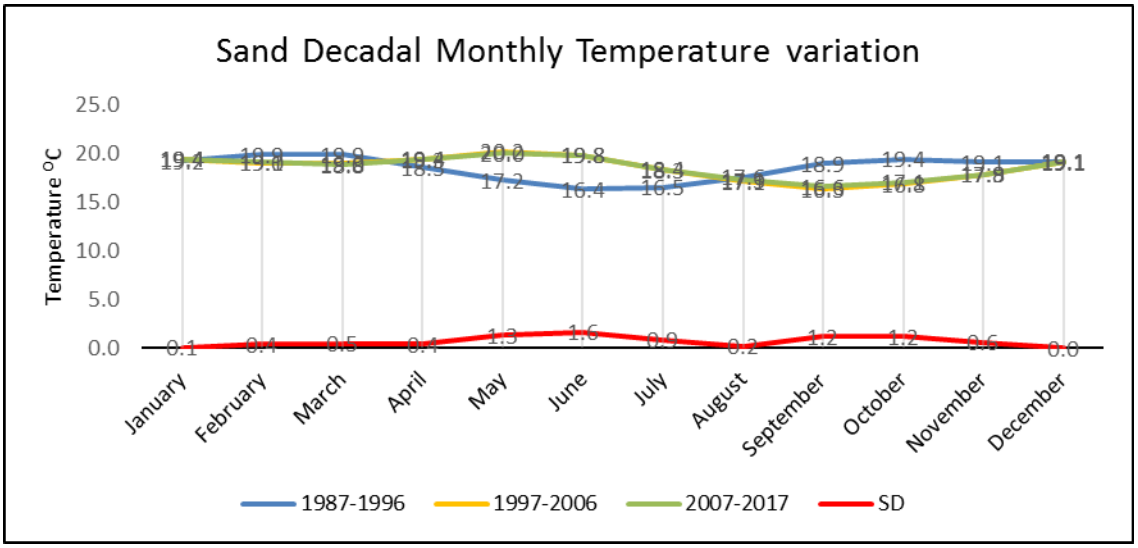


Figure 4.6d. *Decadal monthly temperature variation*

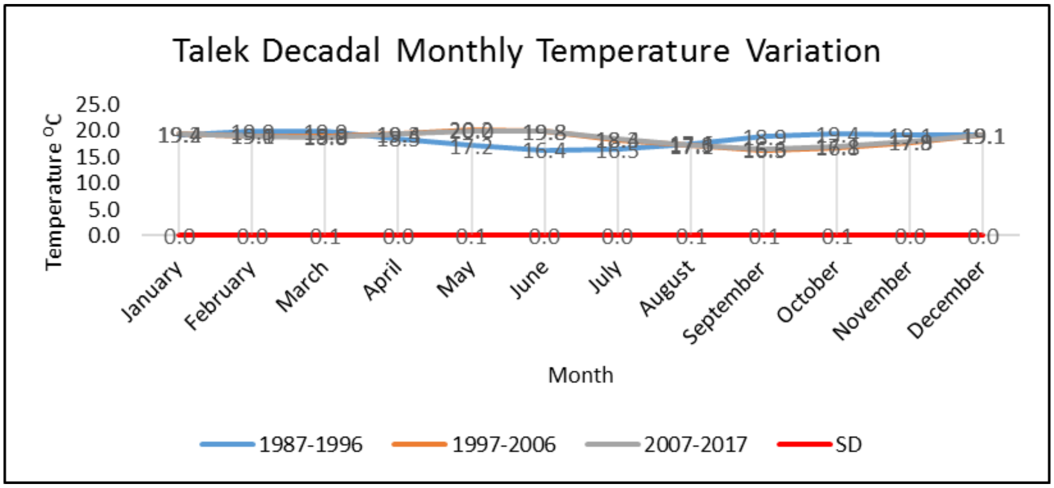


Figure 4.6e. *Decadal monthly temperature variation*

The month of June in Amala had the highest decadal monthly temperature Standard deviation of 1.9°C and therefore showed the highest decadal monthly temperature variation followed by May and July. The month of August had lowest decadal monthly temperature Standard deviation of 0.2°C, followed by January and December (Figure 4.6b). The month of June in Nyangores had the highest decadal monthly temperature Standard deviation of 1.5°C and therefore with highest decadal monthly temperature variation followed by May, and July. The month of April, August and December had lowest decadal monthly temperature Standard deviation of 0.2°C, followed by January and November (Figure 4.6c).

The month of June in Sand had the highest decadal monthly temperature Standard deviation of 1.6°C and therefore with highest decadal monthly temperature variation followed by May, September and October. The month of December and January had lowest decadal monthly temperature Standard deviation of 0 to 0.1°C, followed by August (Figure 4.6d). In Talek the decadal monthly temperature Standard deviation to all month is between 0 to 0.1°C (Figure

4.6e). Study respondents in the socio-economic survey perceived deforestation (40.4%), wind direction (15.6%), altitude (14.1%), increase in human settlements (12.4%), afforestation, (9.8%) and general change in weather patterns (5%) as causes of observed temperature variation. These observations were consistent with the rise in temperature projected by the Global Circulation Models (GCMs) for the East African Region, Kenya included (Gebrechorkos *et al.*, 2018). Consistent with empirical evidence, focus group discussants in the present study cited an increase in temperature in the Mara River basin region with some months reportedly being extremely hot and others being quite cold. Similar observations were made in Malawi where the rapidly warming temperature was regarded as the most visible impacts of climate variation by villagers in a participatory rural appraisal (PRA) study (Magrath and Sukali, 2009).

A number of other studies acknowledge that temperature is steadily increasing in East Africa region, though they differ on the rate of temperature rise (Omondi *et al.*, 2014; Omumbo *et al.*, 2011). For instance, a study conducted by United Nations Development Programme (UNDP) established that vast regions in Kenya experienced an average increase in temperature of 0.21°C per decade between 1960 and 2006 (UNDP, 2010), while a report by the Government of Kenya (2010) indicated an average annual increase in temperature of 1 °C between 1960 and 2003. Consistent with the present study, Mengistu *et al.* (2014) established a significantly increasing trend of temperature over the upper Blue Nile River basin of Ethiopia. Though these studies differ in rates of temperature increase, they both attribute the rise to global warming and climate change.

4.1.4. Dominant Land cover types across the four sub-catchments (1987-2017)

Six key land cover categories were identified in the present study including forest land, grass land, shrub land, crop land, bare land and built-up areas (Table 4.1 and Figure 4.7). Of these, forest and grass lands accounted for over 70% of all land cover types in Amala and Nyangores sub-catchments during the driest month (October) in 1987. Specifically, forest land and grass land accounted for 40% and 31%, respectively, in Amala sub-catchment and 43.7% and 29.48%, respectively, in Nyangores sub-catchment. Other land cover types such as crop land, shrub land, bare land and limited built-up areas were also recorded in the two sub-catchments over the same time period. However, after 1997, that is 1997, 2007 and 2017, crop land replaced forest land as the dominant land cover in Amala sub-catchment by 39.5%, 51.5% and 53.2% of the total land cover respectively; while in Nyangores sub-catchment, forest land remained the dominant land cover for two decades (1987 - 2007), accounting for between 43.6-43.8% of the total land cover respectively. The results indicated that although Amala and Nyangores are situated adjacent to each other in the upper part of the Mara River basin, deforestation happened more in Amala than Nyangores sub-catchment between 1987 and 2007, Table 4.1.

Table 4.1. *Land cover classes for 1987, 1997, 2007 and 2017 classified imageries*

Sub-catchment	Category	1987 Area (Ha)	1997 Area (Ha)	2007 Area (Ha)	2017 Area (Ha)
Amala	Forest land	56609 (**39.8**%)	34830 (24.4%)	25798 (18.2%)	29784 (**21.0**%)
	Grass land	44269 (31.1%)	46186 (32.3%)	36625 (25.8%)	31550 (22.2%)
	Shrub Land	6418 (4.5%)	3477 (2.4%)	2738 (1.9%)	2495 (1.8%)
	Cropland	29828 (**21.0%)**	56415 (39.5%)	73168 (51.5%)	75574 (**53.2%)**
	Bare Land	5068 (3.6%)	1894 (1.3%)	3691 (2.6%)	2615 (1.8%)
	Built up areas	34 (0.02%)	44 (0.03%)	65 (0.05%)	80 (0.06%)
Nyangores	Forest land	41031 (**43.7**%)	40897 (43.8%)	40510 (43.6%)	30164 (**32.3**%)
	Grass land	27681 (29.5%)	23817 (25.5%)	21712 (23.3%)	15997 (17.1%)
	Shrub Land	1014 (1.1%)	1598 (1.7%)	1070 (1.2%)	789 (0.8%)
	Cropland	21835 (**23.3**%)	24572 (26.3%)	26983 (29.0%)	42690 (**45.7**%)
	Bare Land	2279 (2.4%)	2455 (2.6%)	2663 (2.9%)	3721.6 (4.0%)
	Built up areas	47.4 (0.01%)	65.53 (0.1%)	80.5 (0.1%)	105.9 (0.1%)
Talek	Forest land	12357 (7.0%)	15138 (8.6%)	7673 (4.4%)	4939 (2.8%)
	Grass land	92493 (**52.8**%)	82989 (47.2%)	85005 (48.4%)	62708 (**35.7**%)
	Shrub Land	62757 (**35.8**%)	74286 (42.2%)	79786 (45.4%)	98079 (**55.9**%)
	Cropland	0 (0.0%)	0 (0.0%)	0 (0.0%)	5607 (3.2%)
	Bare Land	7723 (4.4%)	3472 (2.0%)	3166 (1.8%)	4244 (2.4%)
Sand	Forest land	13955 (7.6%)	9991 (5.5%)	8184 (4.5%)	7986 (4.4%)
	Grass land	87106 (**47.4%)**	86467 (47.2%)	81804 (44.7%)	79884 (**43.6%)**
	Shrub Land	80217 (**43.6%)**	78847 (43.1%)	76801 (42.0%)	72183 (**39.4%)**
	Bare Land	2510 (**1.4**%)	7785 (4.3%)	16257 (8.9%)	22977 (**12.6%)**

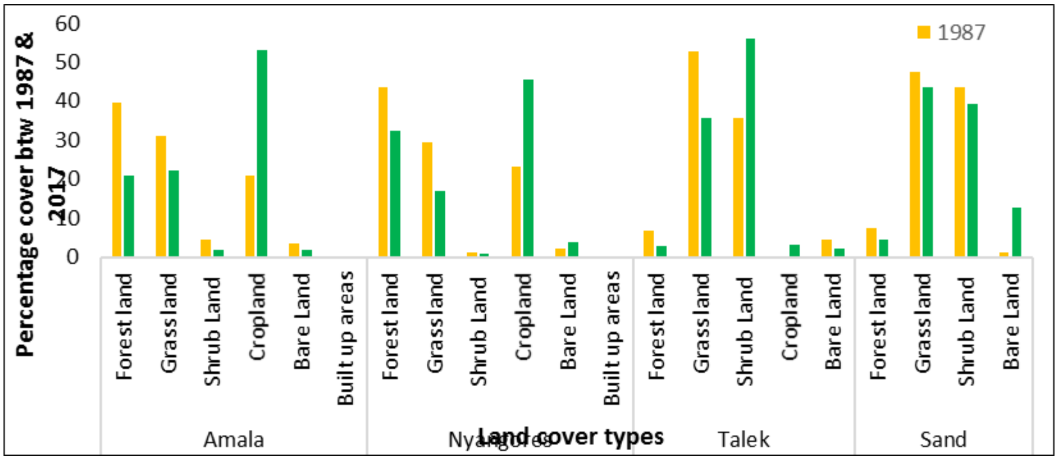
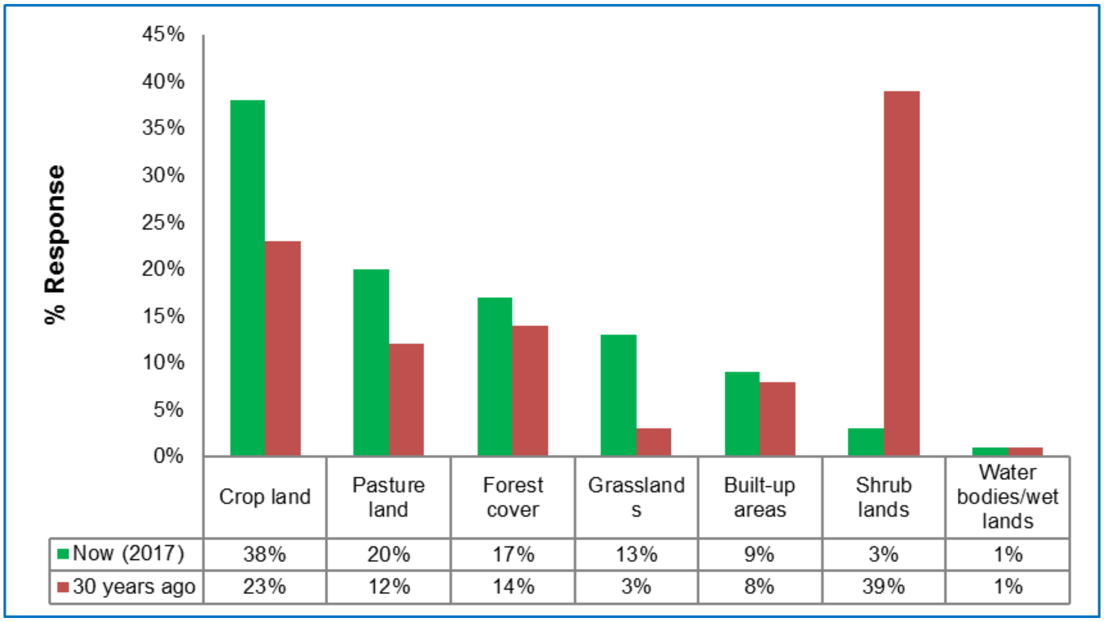


Figure 4.7. *Percentage land cover change between 1987 and 2017 across all sub-catchments*

In the last decade leading up to the year 2017, hectares under forest cover in the two sub-catchments decreased while those under crop land increased significantly from 29,828 (21.0%) to 75,574 (53.2%) hectares in Amala sub-catchment and from 21,835 (23.3%) to 42,690 (45.7%) hectares in Nyangores sub-catchment. Built-up areas occupied only a small fraction; ranging between 0.02 – 0.1%, in the two sub-catchments. On the contrary, grass land and shrub land were the dominant land cover types in Talek and Sand River sub-catchments in 1987. Specifically, grass land and shrub land covered 47.39% and 43.65%, respectively of land surface in Sand River sub-catchment, and 52.72% and 35.79%, respectively, in Talek sub-catchment in 1987. This has been the case for the 30-year period in Sand River sub-catchment, probably because big part of Sand sub-catchment is within protected Masai Mara national game reserve and conservancies as compared to Talek sub-catchment. Whereas shrub land replaced grass land after 2007 in Talek sub-catchment, though percentage dominance has been decreasing steadily due to overgrazing as presented by respondents during socio-economic survey.

Forest land accounted for only 7.6% and 7.05% in Sand River and Talek sub-catchments, respectively, in 1987. From the ground verification/truthing during the socio-economic survey, scattered crop land and built up areas in Sand and Talek sub-catchments were noted but were not visible in the satellite images (due to satellite images resolution used) therefore were not classified within the 1987 image. However, the area under crop land in Talek sub-catchment rose from 0% to 3.2%, while bare land increased from 1.4-12.6% between 1987 and 2017 within Sand sub-catchment (Figure 4.7).

Generally, forest cover showed a steady decrease from 1987 through to 2017 across all sub-catchments, while crop land increased steadily over the same period, especially for Amala and Nyangores sub-catchments. Unlike in 1987, crop land was the dominant land cover type in Amala and Nyangores, while grass land and shrub land dominated Sand and Talek sub-catchments, respectively by 2017. The land cover changes witnessed across the study area were significant with the socio-economic survey conducted in this study confirming the changes in which respondents reported observing an increase in crop land at the expense of other land cover types (Figure 4.8).



	Crop land	Pasture land	Forest cover	Grasslands	Built-up areas	Shrub lands	Water bodies/wet lands
🟩 Now (2017)	38%	20%	17%	13%	9%	3%	1%
🟥 30 years ago	23%	12%	14%	3%	8%	39%	1%

Figure 4.8. *Dominant land cover types in 1987 and 2017 as reported by respondents*

Based on the socio-economic survey results, the dominant life forms 30 years ago as reported by respondents across the study area were forest cover, shrubs lands, and grass lands. Majority of households (89.7%) reported having noticed changes in natural land cover in their surroundings in the past 30 years. However, 4.9% of the households did not notice any changes while 5.9% did not respond. For those who noticed changes in land cover, diminishing vegetation cover was the most common change according to 28.5% of the respondents.

Other changes cited include conversion of forests to cropland (16.5%), stunted vegetation growth (12.2 5%), conversion of forest land to bare land (11.7%), increased weeds on agriculture lands (9.3%), conversion of forests to human settlements (7.4%), conversion of forests to pasture lands (7.2%), selling of forest land to newcomers (3.6%) and conversion of rain fed cropland to irrigated cropland (1.9%). These changes observed over the 30-year period were statistically significant ($\chi^2 = 12.41$, df = 11, $P \leq 0.001$) (Table 4.2).

Table 4.2. *Observed changes in land cover over the 30-year period*

	Number	**% Response**
Diminishing vegetation cover	119	28.5
Conversion of forests to croplands	69	16.5
Stunted vegetation growth	50	12.0
Conversion of forestland/bush land/grassland to bare land	49	11.7
Increase in weeds in agricultural lands	39	9.3
Conversion of forestland to human settlements	31	7.4
Conversion of forestland/ bush land to pasture lands	30	7.2
Conversion of forest/ bush land/grassland to bare land	15	3.6
Conversion of rain fed cropland to irrigated crop land	8	1.9
Increase in vegetation cover	6	1.4
Covers ion of forestland / bush land to pasture land	1	0.2
Other changes	1	0.2
Total	**418**	**100**

The general changes observed after the 30-year period (1987-2017), point to a rapid reduction in forest land, shrub land and natural grassland, and a corresponding increase in crop land, built-up areas and bare land within the study area. Consistent with the current study results, change in land cover over time has also been reported in other basins as was evident in Nepal (Uddin *et al.*, 2015) and in the transboundary Gandaki River Basin of Central Himalayas (Rai *et al.,* 2018). Both studies suggested that land use and land cover changes were largely driven by pressure for increased food production, human settlements, infrastructure development, and tourism activities among other anthropogenic activities coupled with the effect of a rapidly changing climate. In the current study, respondents drawn from all the four sub-catchments (Talek, Sand River, Amala and Nyangores) confirmed that land cover had indeed changed and the change was likely triggered by a number of factors, among them climatic, human and biophysical forces.

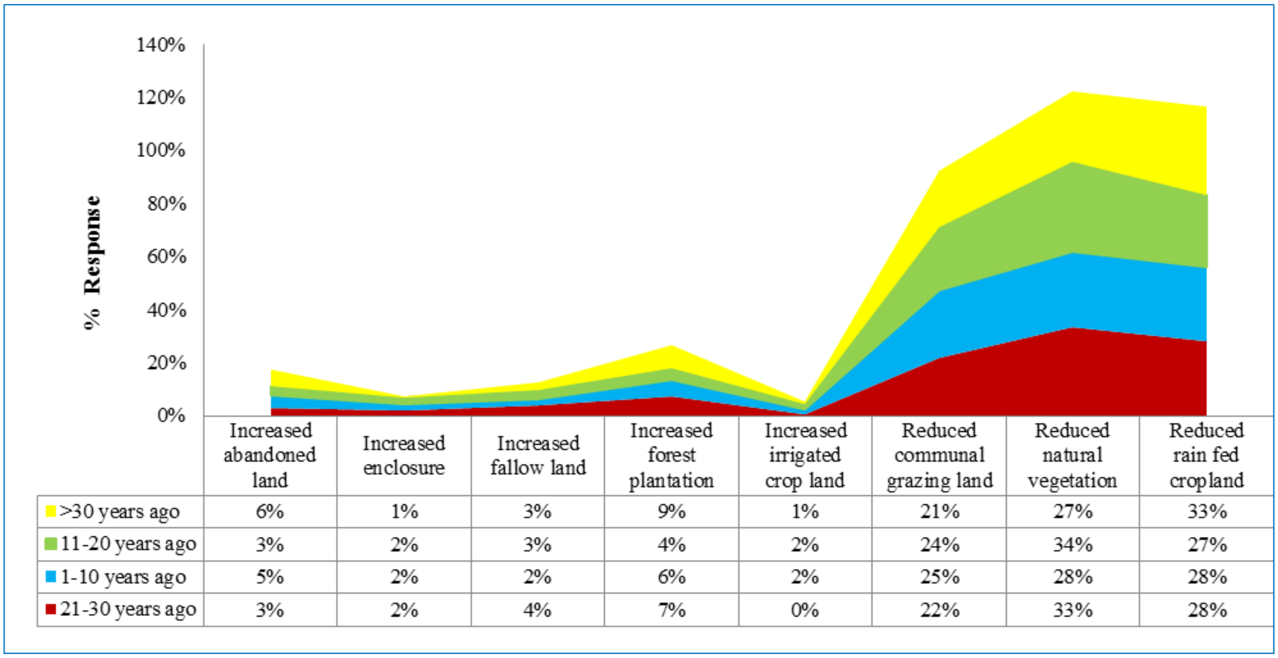
Likewise, human settlement patterns, policy shifts, household size, wild animal abundance and climate variability were identified as key drivers of land cover change in the four sub-catchments. Indirect factors like population growth and density were also identified as critical drivers of land cover change through the ever-increasing need for more food production that can only be achieved by increased farming and livestock keeping activities. Further analysis of the present findings revealed that average temperature had a positive but moderate correlation with built up area and extent of bare land percentages. This suggests that the higher the percentage of built up areas, the higher the likelihood of an elevated average temperature. Just as was reported in the household survey that rainfall patterns had changed, analysis of climate and land cover data showed a negative correlation between average rainfall and bare land as well as built up areas. This has implication by proxy, indicating that as more forested areas area cleared, its' impact is felt in the change of temperature and rainfall.

These findings are consistent with those reported by Matata *et al.* (2019) in semi-arid areas of Tanzania, Gwate *et al.* (2018), Palmer *et al.* (2017), Lei *et al.* (2016) and Forkel *et al.* (2013) in other parts of the globe. Although the drivers of land cover change are numerous and could include human influences, biophysical drivers and natural processes, the most commonly mentioned by the respondents in the current study were the human influence drivers. Common livelihood activities such as subsistence rain-fed farming, livestock keeping and pastoralism practiced by communities residing within the study area were singled out as key drivers of land cover change in the Mara River Basin of Kenya.

Pressure to produce more food for the ever-rising population had caused expansion of crop lands into areas previously forested and those covered with grass lands especially within Amala and Nyangores sub-catchments, thus contributing greatly to land cover change in the two sub-catchments over the 30-year study period. The change detection analysis based on remotely sensed data showed that large acres of grass, forest land and shrub lands got diminished at the expense of crop land and built-up areas between 1987 and 2017 and while forest cover dominated large tracts of land within Amala and Nyangores sub-catchments in 1987, the same recorded significant reduction over the 30-year period at the expense of crop lands and built-up areas albeit to a smaller extent.

Consistent with the current study findings, Temesgen *et al.* (2014) also noted that that land cover change; more so crop farming is among the driving force for vegetation cover loss and land degradation in Ethiopia. For the Talek and Sand River sub-catchments where pastoralism was the predominant household livelihood economic activity and a way of life for many households, livestock keeping was reported to be the main driver of land cover change. The fact that communities in Talek and Sand River take pride in the sizes of herds that they keep at the household level, had pushed the livestock population beyond the land's carrying capacity causing overgrazing.

Rain-fed cropland, natural vegetation and communal grazing land were identified by respondents as having contributed most to change in land cover over the 30-year period. Figure 4.9 depicts shifts in land cover over the 30-year period as reported by study respondents.



	Increased abandoned land	Increased enclosure	Increased fallow land	Increased forest plantation	Increased irrigated crop land	Reduced communal grazing land	Reduced natural vegetation	Reduced rain fed cropland
🟨 >30 years ago	6%	1%	3%	9%	1%	21%	27%	33%
🟩 11-20 years ago	3%	2%	3%	4%	2%	24%	34%	27%
🟦 1-10 years ago	5%	2%	2%	6%	2%	25%	28%	28%
🟥 21-30 years ago	3%	2%	4%	7%	0%	22%	33%	28%

Figure 4.9. *Markers of land cover change over the 30-year period (1987 and 2017)*

A GLM model of drivers of land cover change showed that increased temperature and human settlements were negatively correlated with land cover change ($P < 0.001$), whereas type of trees planted, household size, education level of household head, wild animals and change in rainfall patterns were positively correlated to land cover change ($P < 0.001$), and thus considered significant predictors of change in land cover. However, the relationship between land cover change and livestock keeping, weak land laws and tourism was not statistically significant (P > 0.05) (Table 4.3).

“This study showed a higher level of participation of households participation in land cover protection such as proper listock keeping, in the decision-making due to their increased dependency LC. This is consistent with the findings of other studies (Apipoonyanon *et al.*, 2020)”.

Table 4.3: *Generalized Linear Model (GLM) of land cover change against the identified drivers.*

Predictor variable	Estimate	Std. Error	z-value	P-value
Intercept	4.809	0.020	229.061	<0.001
Types of trees planted	0.076	0.013	5.899	<0.001
Level of education	0.131	0.011	11.906	<0.001
Livestock keeping	−0.030	0.024	−0.422	0.5013
Weak land laws	−0.066	0.027	−0.226	0.8212
Household size	0.155	0.011	4.880	0.0024
Human settlement	−0.066	0.014	−4.592	<0.001
Wild animals	0.059	0.024	2.527	0.0115
Tourist activities	0.005	0.028	0.176	0.8606
Change in rainfall pattern	0.324	0.019	3.003	<0.001
Increased temperature	−0.209	0.010	−20.822	<0.001

“Land cover change has been shown to have environmental change drivers plays an important role in modulating the local microclimate including land surface temperature (Deng *et al.,* 2018). Ameliorating extreme temperatures is an issue of increasing concern for urban areas worldwide, just as it has been observed in the current study (Turner, 2016). projected increasing temperature and drought frequency at varying global warming levels (GWL) mark these sub-catchments as being highly vulnerable (Nkemelang, New and Zaroug, 2018)”

Climatic factors and their effect on land cover change

Majority (94.5%, n = 398) of the respondents had noticed changes in temperature patterns, while 5.5% did not observed any changes over the last 30 years. With regard to seasonal temperature changes, 55% of the respondents stated that the dry period which used to occur in June and July had shifted to October and November. On changes observed in temperature over the 30 year period, 49.3% of the respondents felt that some months had became cooler than others, 46.2% noted that some months had became hotter than normal, while 4.5% did not respond to the question or did not observe any change. At the sub-catchments level, respondents from Amala ($P = 0.003$), Nyangores ($P < 0.001$), Talek ($P = 0.02$), and Sand River ($P = 0.04$) concurred that temperature had significantly increased (Fisher’s exact test). The perceived causes of the changes observed in temperature and rainfall were deforestation (40.4%), wind direction (15.6%), altitude (14.1%), increase in human settlements (12.4%) afforestation (9.8%) and general change in weather patterns (5%) (Table 4.4).

To contrast the community’s perception and responses concerning changes in climate over the Mara Region, a trend analysis was performed on climate data i.e. temperature and rainfall- spanning 30 years back (1987-2017) and it showed a significant decreasing trend in precipitation and increasing temperature trend over the study duration across all the four sub-catchments.

Respondents in all four sub-catchments felt that grassland, shrub land, tree cover and water sources had diminished significantly due to temperature ($\chi2 = 8.551$, P = 0.0359, $\chi2 = 14.669$, P = 0.002122, $\chi2 = 31.299$, $P < 0.001$ and $\chi2 = 8.8681$, P = 0.0311, respectively). However, there was no significant difference between those who thought that overgrazing and drying of crops were as a result of temperature change ($P \geq 0.05$).

In addition, those who reported noticing changes in temperature patterns singled out diminishing grasslands, diminishing pasture, diminishing shrub land, diminishing tree cover, diminishing water resources (rivers, springs and dams) and drying of crops

(Table 4.3) as some of the effects of temperature changes (standardized residual ≥ 1.5, Likelihood ratio test = 172.725, df = 16, $P > 0.001$).

Table 4.4: *Perceived cause of changes in rainfall and temperature in the study area.*

Variable	**Number**	**% Response**
Changes in weather pattern	21	5.0
Afforestation	41	9.8
Increased settlements	52	12.4
Altitude	60	14.4
Wind direction	65	15.6
Deforestation	169	40.4
Don’t know	3	0.7
Other factors	7	1.7
Total	**418**	**100**

With a chi-square test statistic ($\chi^2 = 408.753$) being P = 00034 and therefore less than the alpha level of significance of 0.05, the z-score of those who reported diminishing tree cover, shrub land and grass lands were (3.5), (2.8) and (2.6), respectively, which was higher than the critical Z value (1.96). This supported the observation by the surveyed households who noticed changes in rainfall and its effects on land cover (Table 6). From the results, fewer survey households than expected (standardized residual = −3.4) stated that deforestation affected temperature change and increased river flow. However, a good proportion of them indicated that increase in observed temperature affected rivers mainly due to changes in weather pattern (1.9) and deforestation (1.2). This therefore supports the argument that deforestation actually affected river flow (Table 4.4).

A host of studies have shown the cause-and-effect mechanism between changes in global land cover and climatic factors such as rainfall and temperature. The variation in urban-rural minimum temperature patterns in in the sub-catchments could be attributed to the differences in LC patterns (Jonsson, 2004). Measures to reduce deforestation and exposure of bare soils are needed.

Implication of changes in rainfall on land cover

With regard to rainfall, 96.4% of the 418 respondents across the four sub-cat- chments reported noticing some changes in rainfall patterns. The most commonly cited indicator was unpredictable rainfall pattern (43.1%). Others included shifts in rainfall pattern, too little rainfall leading to prolonged droughts and disappearing of some species of vegetation, accounting for 28.3%, 17.5% and 11.2%, respectively. The observed changes were significantly different across the four sub-catchments ($\chi2 = 11.587$, df = 3, $P < 0.008939$). On the perceived cause of changes in rainfall pattern, 46.2% of respondents cited deforestation, 28% cited change of weather pattern and 14% cited altitude as the main cause of change in rainfall patterns. Almost all (96.9%) respondents reported that changes in rainfall patterns had an effect on land cover, while 7.2% felt that change in rainfall patterns increased vegetation cover. Most respondents were in agreement that cutting down of trees was worsening the rainfall patterns in the area. Responses on impact of changes in rainfall patterns on water resources are shown in Table 4.5.

Table 4.5: *Effect of temperature change on different land cover types in the four sub-catchments.*

	Amala	**Nyangores**	**Sand river**	**Talek**	**χ^2 test (df = 3)**	**Total**
Diminishing grassland	30 (38.9%)	25 (32.5%)	8 (10.4%)	14 (18.2%)	8.551, P = 0.0359	77
Diminishing pasture	23 (31.1%)	19 (25.7%)	14 (18.9%)	18 (24.3%)	1.475, P = 0.688	74
Diminishing shrub-land	16 (28.6%)	24 (42.9%)	5 (8.9%)	11 (19.6%)	14.669, P = 0.0021	56
Diminishing tree cover	42 (39.3%)	47 (43.9%)	5 (4.7%)	13 (12.1%)	31.299, P < 0.001	107
Diminishing water resources	21 (36.8%)	19 (33.3%)	5 (8.8%)	12 (21.1%)	8.8681, P < 0.031	57
Drying crops	20 (42.6%)	23 (48.9%)	2 (4.3%)	2 (4.3%)	0.1315, P = 0.5816	47
Total	**152**	**157**	**39**	**70**		**418**

4.1.5. Decadal sub-catchment land cover changes between 1987 to 2017 in all sub-catchments

4.1.5.1. Decadal Amala sub-catchment land cover change (1987-2017)

In Amala sub-catchment, significant changes were observed in land cover over the 30-year period (1987-2017). While some land cover types increased, others reduced over the 30-year period. In the 1987 – 1997 decade, bare land, shrub land and forest land decreased by -62.63%, -45.82% and -38.47%, respectively. However, crop land, built-up areas and grass land increased by 89.13%, 47.73% and 4.33%, respectively, over the same period. Over the 1997-2007 decade, forest land, shrub land and grassland decreased by -25.93%, -21.25% and -20.70%, respectively, while bare land, built up areas and crop land increased by 94.88%, 29.41% and 29.70%, respectively. Over the 2007 – 2017 decade, bare land decreased by -29.15%, grass land by -13.86% and shrub land by -8.88%.

On the contrary, built-up areas increased by 23.08%, forest cover by 15.45%; and crop land by 3.29%. Cumulative changes over the 30-year period within Amala sub-catchment showed an increase in crop land (153.37%) and in build-up areas (135.29%) and a decrease in shrub land, bare land, forest land and grass land by: -61.12%, -48.40%, -47.39% and -28.73%, respectively. The Spatio-temporal maps below show decadal changes in land cover during the driest month (October) over the 30-year period (1987 – 2017) within Amala Sub-catchment (Table 4.6, Figure 4.10, 4.11, 4.12 and 4.13). Decadal land cover change has confirmed when the major land cover change happened and the reason of change are the same as mentioned in 4.1.3 above.

The results are consistent with the study conducted in Mara river basin which revealed that, shrub land decreased while cropland and built-up area increased from 1984 to 2016 (Ayuyo *et al.*, (2020).

Table 4.6. *Decadal land cover change trend (1987-2017) in Amala Sub-catchment*

Sub-catchment	**Category**	**1987 – 1997 % Change**	**1997 – 2007 % Change**	**2007 – 2017 % Change**	**1987-2017 Overall % change**
Amala	Forest land	-38.47	-25.93	15.45	**-47.39**
	Grass land	4.33	-20.70	-13.86	**-28.73**
	Shrub Land	-45.82	-21.25	-8.88	**-61.12**
	Cropland	89.13	29.70	3.29	**153.37**
	Bare Land	-62.63	94.88	-29.15	**-48.40**
	Built up areas	29.41	47.73	23.08	**135.29**

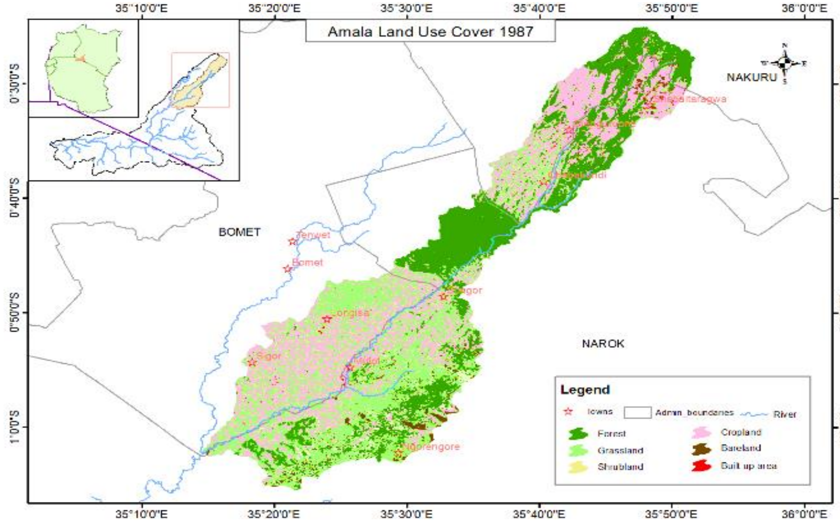


Figure 4.10. *Land cover of Amala sub-catchment 1987*

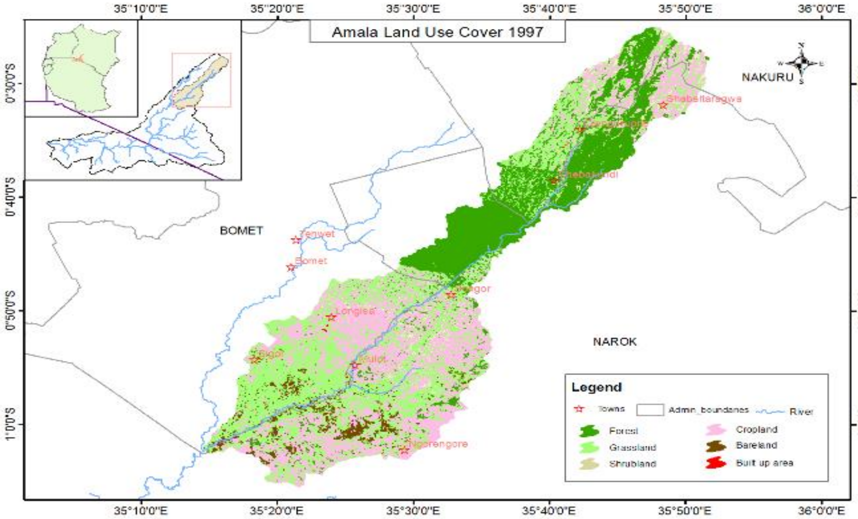


Figure 4.11. *Land cover of Amala sub-catchment 1997*

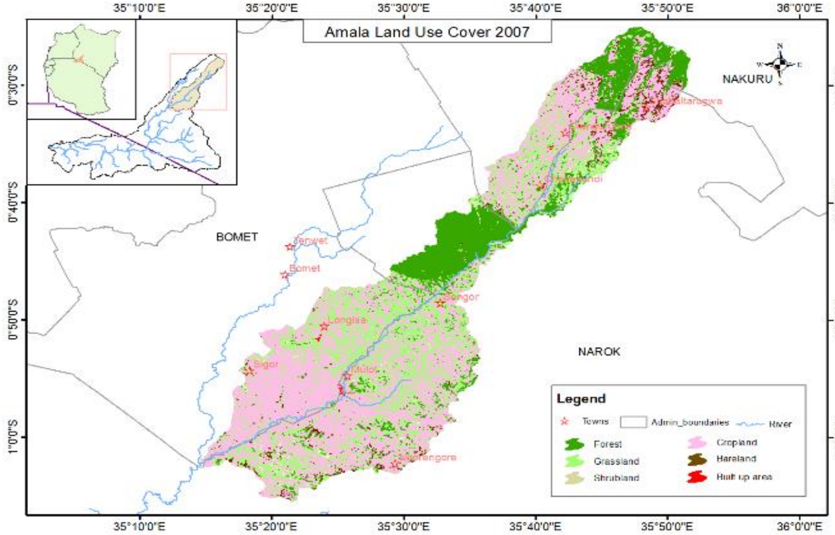


Figure 4.12. *Land cover of Amala sub-catchment 2007*

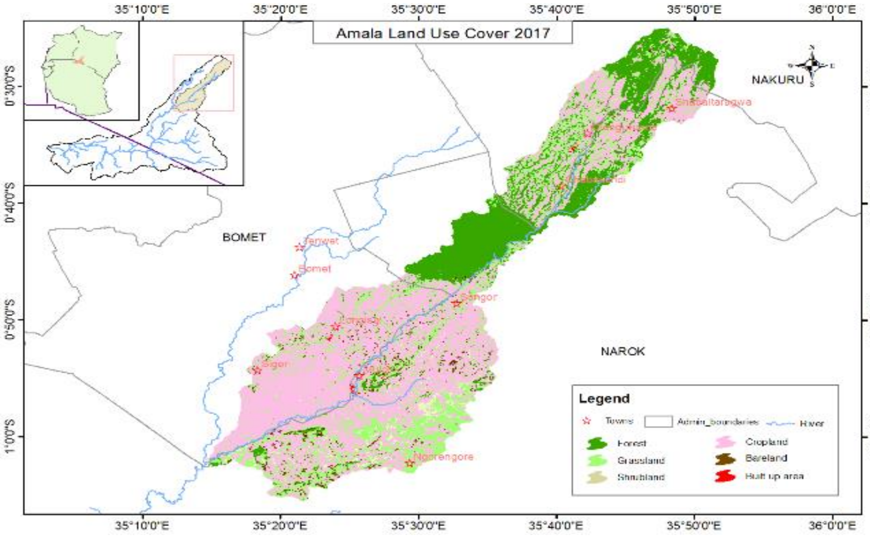


Figure 4.13. *Land cover of Amala sub-catchment 2017*

4.1.5.2. Decadal Nyangores sub-catchment land cover change (1987-2017)

In the 1987-1997 decade, grass land and forest land decreased by -13.96% and -0.33%, respectively, while all other land cover types among them; shrub land, built-up areas, crop land and bare land increased by 57.60%, 38.25%, 12.53% and 7.73%, respectively. A similar trend was evident in the subsequent decade (1997 – 2007) whereby shrub land, grass land, and forest land decreased by -33.04%, -8.84%, and -0.95%, respectively, while build up, crop land and bare land increased by 22.85%, 9.81% and 8.47%, respectively. However, in the 2007-2017 decade, grass land, shrub land and forest land decreased by -26.32%, -26.26% and -25.54%, respectively, while crop land, bare land and built up area increased by 58.21%, 39.75% and 31.55%, respectively.

Cumulatively, a significant increase in crop land by 153.37% and build up areas by 135.29% was observed within Nyangores tributaries at the expense of shrub land (-61.12%), bare land (-48.40%), forest cover (-47.39%) and grass land (-28.73%). The results further showed that the greatest degradation of forest, shrub and grass lands occurred between 1987 and 2007 (Table 4.7, Figure 4.14, 4.15, 4.16 and 4.17). Decadal land cover change has confirmed when the major land cover change happened and the reason of change are the same as mentioned in 4.1.3 above.

This result is consistent with study conducted to determine fPAR and leaf area index of several land cover classes in the Pot River and Tsitsa River catchments of the Eastern Cape, South Africa where similar land cover trend was noted (Palmer, *et al* (2017).

Table 4.7. *Decadal trend of land cover change (1987-2017) in Nyangores Sub-catchment*

Sub-catchment	**Category**	**1987 – 1997** **% Change**	**1997 – 2007** **% Change**	**2007 – 2017** **% Change**	**1987-2017** **Overall % change**
Nyangores	Forest land	-0.33	-0.95	-25.54	**-26.48**
	Grass land	-13.96	-8.84	-26.32	**-42.21**
	Shrub Land	57.59	-33.04	-26.26	**-22.19**
	Cropland	12.53	9.81	58.21	**95.51**
	Bare Land	7.73	8.47	39.75	**63.31**
	Built up areas	38.25	22.84	31.55	**123.42**

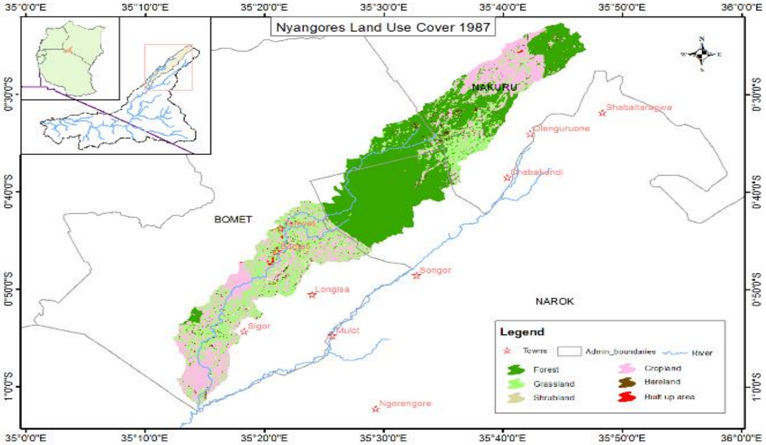


Figure 4.14. *Land cover of Nyangores sub-catchment 1987*

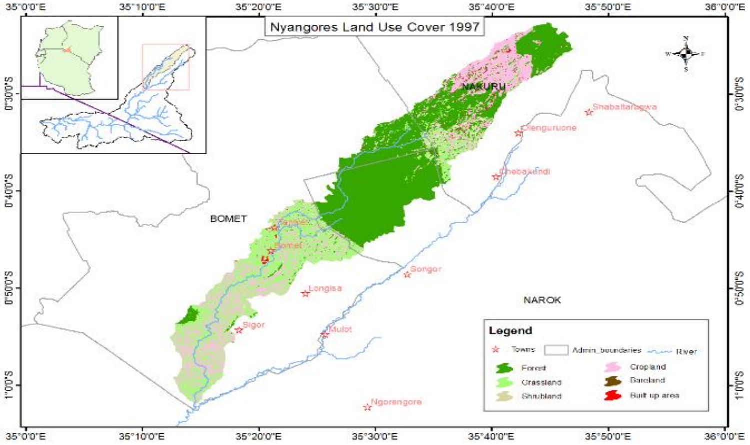


Figure 4.15. *Land cover of Nyangores sub-catchment 1997*

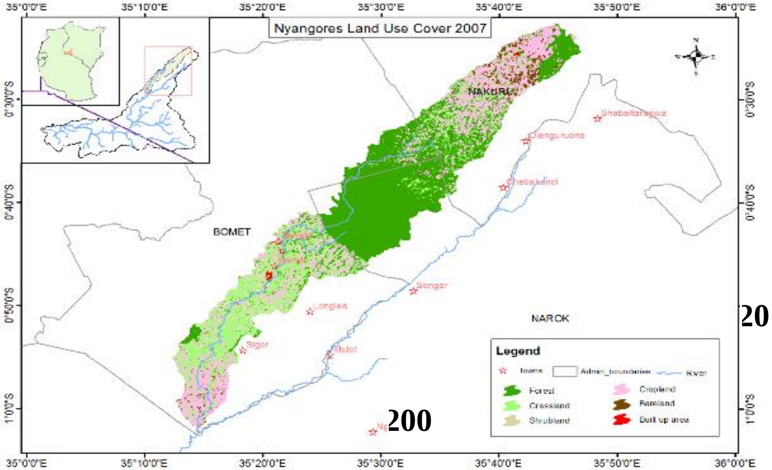


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Figure 4.16. *Land cover of Nyangores sub-catchment 2007*

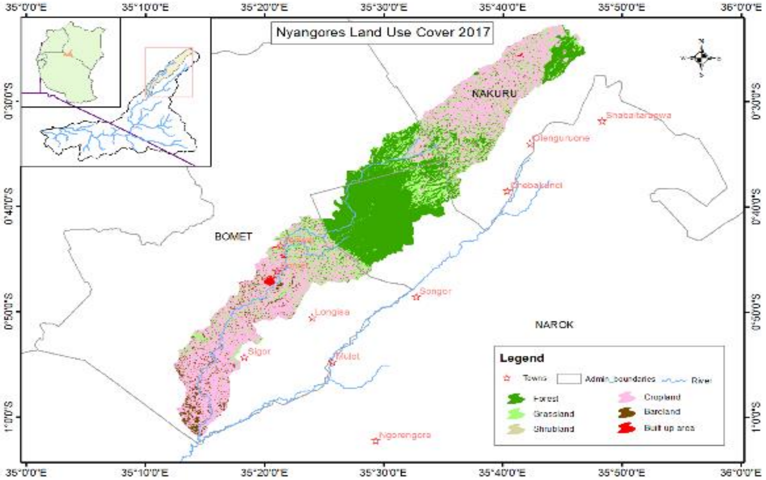

Figure 4.17. *Land cover of Nyangores sub-catchment 2017*

4.1.5.3 Decadal Sand sub-catchment land cover change (1987-2017)

Significant land cover changes were observed within Sand River sub-catchment over the 30-year period. In the 1987 and 1997 decade, forest land, shrub land and grass land decreased by -28.41%, -1.71% and -0.73%, respectively. However, bare land increased by a massive 210.16%. A similar trend was observed in the following decade (1997-2007) in which forest land, grass land and shrub land decreased by -18.09%, -5.39% and -2.59%, respectively, while bare land increased by 108.82%. Likewise, in the 2007-2017 decade, shrub-land, forest land and grass land decreased by -6.01%, -2.42% and -2.35%, respectively, while bare land increased by 41.34%.

Generally, bare land increased significantly throughout the three decades to a cumulative value of 815.42% or 22,977 ha in 2017 from just 2,510 ha in 1987 at the expense of grass land, forest and shrub land. The highest decline in forest land was witnessed between 1987 and 1997, while the highest decline in grass land and shrub land occurred between 1997 and 2017 (Table 4.8; Figure 4.18, 4.19, 4.20 and 4.21). Decadal land cover change has confirmed when the major land cover change happened and the reason of change are the same as mentioned in 4.1.3 above.

The above results are consistent with study by Matata *et al.* (2019) in Serengeti semi-arid areas of Tanzania, Mati *et al.* (2005) in Mara river basin, Gwate *et al.* (2018), Lei *et al.* (2016) and Forkel *et al.* (2013) in other parts of the globe on how land cover have been changing overtime.

Table 4.8. *Decadal trend land cover change (1987-2017) in Sand Sub-catchment*

Sub-catchment	**Category**	**1987 – 1997 % Change**	**1997 – 2007 % Change**	**2007 – 2017 % Change**	**1987-2017 Overall % change**
Sand	Forest land	-28.41	-18.09	-2.42	**-42.77**
	Grass land	-0.73	-5.39	-2.35	**-8.29**
	Shrub Land	-1.71	-2.59	-6.01	**-10.02**
	Bare Land	210.16	108.82	41.34	**815.42**

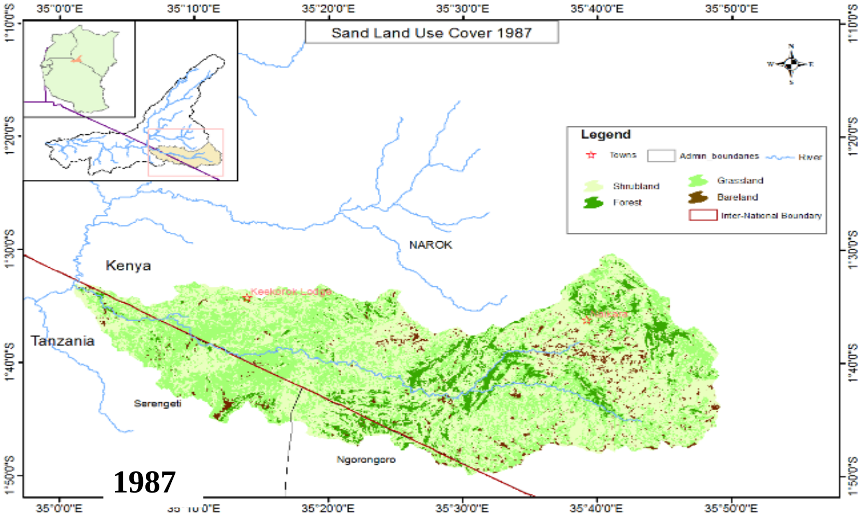

Figure 4.18. *Land cover of Sand sub-catchment 1987*

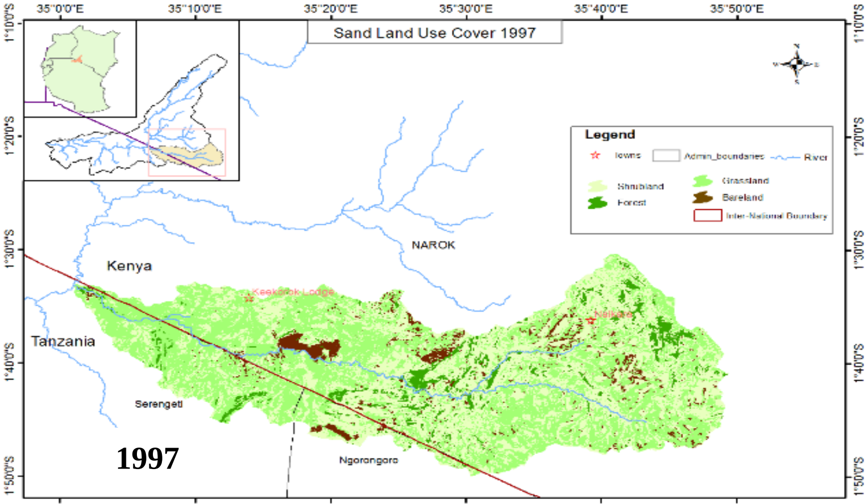

Figure 4.19. *Land cover of Sand sub-catchment 1997*

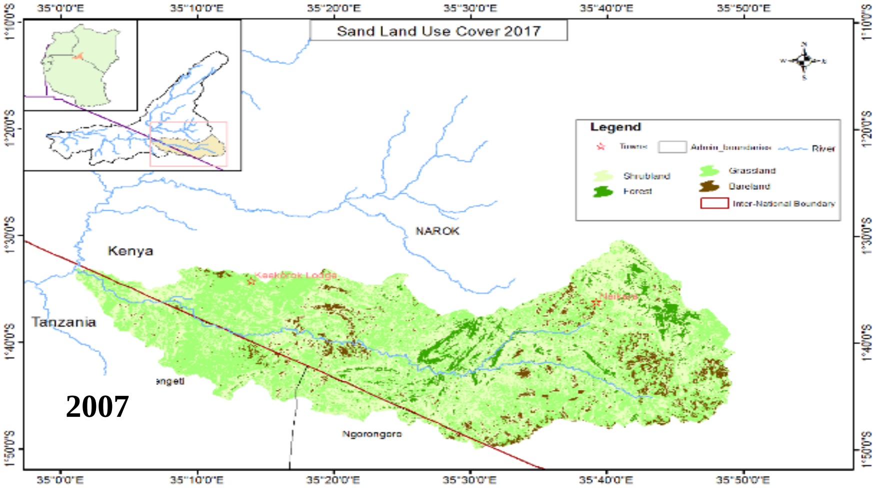

Figure 4.20. *Land cover of Sand sub-catchment 2007*

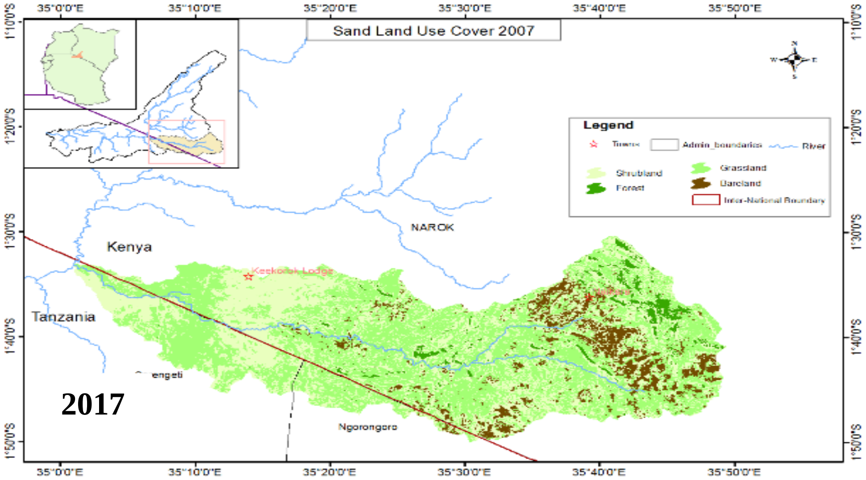

Figure 4.21. *Land cover of Sand sub-catchment 2017*

4.1.5.4. Decadal Talek sub-catchment land cover change (1987-2017)

Like in the other three sub-catchments, Talek sub-catchment exhibited significant changes in land cover over the last 30 years (1987-2017). Precisely in the 1987 and 1997 decade, bare land and grass land decreased by -55.04% and -10.28%, respectively, while forest land and shrub land increased by 22.51% and 18.37%, respectively. A slightly different trend was observed in the 1997 – 2007 decade, whereby forest land and bare land decreased by -49.31% and -8.81%, respectively, while shrub land and grass land increased by 7.04% and 2.43%, respectively. A further decrease in forest land (-35.63%) was also recorded in the 2007 – 2017 decade, as did grass land (-26.23%). However, bare land and shrub land increased by 34.06% and 22.93%, respectively.

Cumulatively, shrub lands exhibited the largest change over the 30-year period; increasing by 56.28%. In addition, the greatest degradation of forest land, grass land and shrub lands occurred between 1987 and 2007 (Table 4.9, Figure 4.22, 4.23, 4.24 and 4.25). Decadal land cover change has confirmed when the major land cover change happened and the reason of change are the same as mentioned in 4.1.3 above.

The result is consistent with study conducted in mapping Kenyan Grassland Heights Across Large Spatial Scales with Combined Optical and Radar Satellite Imagery which found that, communities of Talek and N'Tipiliguani, which lie immediately north of the Masai Mara National game reserve, had developed rapidly, lead to a fivefold increase in illegal livestock grazing in the park between 2008 and 2015. Results are also in line with the study conducted by Mati *et al.* (2005) and Olivia S.B *et al.* (2020) which noted potential causes of land cover types and changes over time due to seasonal changes in precipitation, seasonal movements of large herds of resident and migratory ungulates, fires, and livestock grazing.

Table 4.9. *Trend and magnitude of land cover change (1987-2017) in four Sub-catchments*

Sub-catchment	Category	1987 – 1997 % Change	1997 – 2007 % Change	2007 – 2017 % Change	1987-2017 Overall % change
Talek	Forest land	22.51	-49.31	-35.63	**-60.03**
	Grass land	-10.28	2.43	-26.23	**-32.20**
	Shrub Land	18.37	7.40	22.93	**56.28**
	Cropland	0	0	0	**100**
	Bare Land	-55.04	-8.81	34.06	**-45.04**

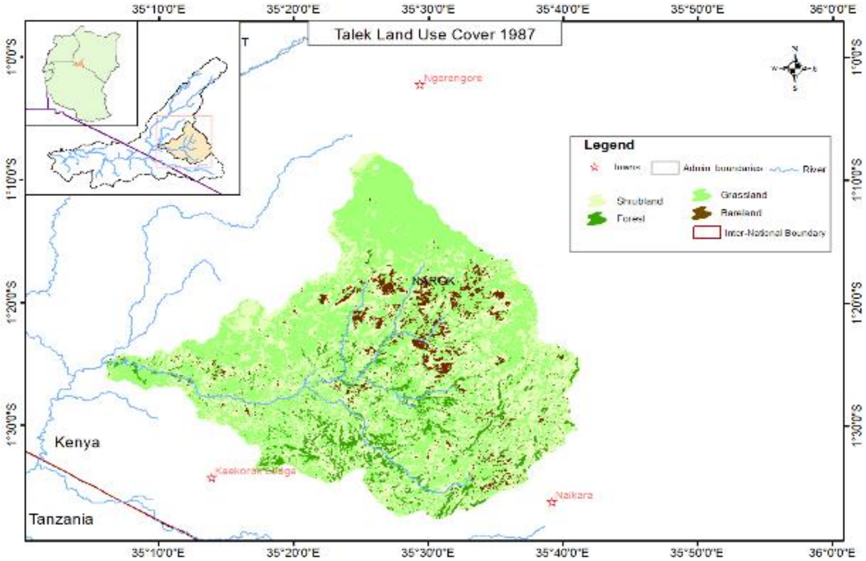

Figure 4.22. *Land cover of Talek sub-catchment 1987*

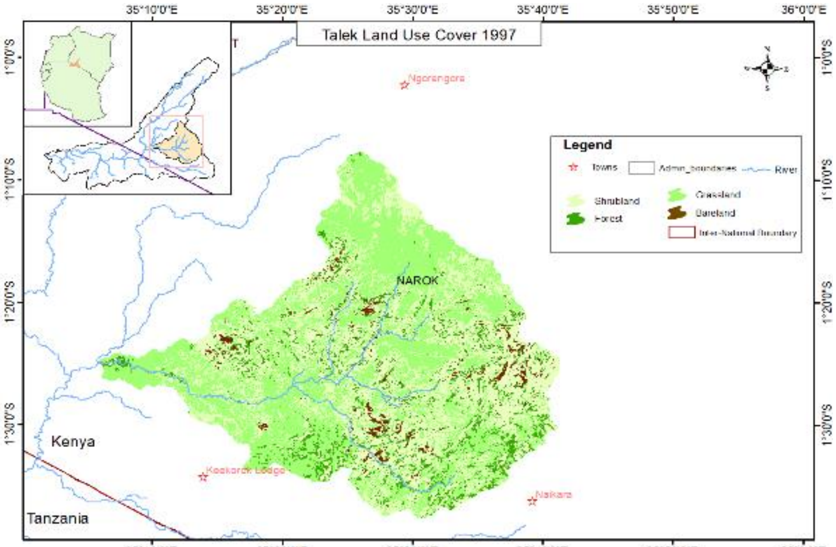

Figure 4.23. *Land cover of Talek sub-catchment 1997*

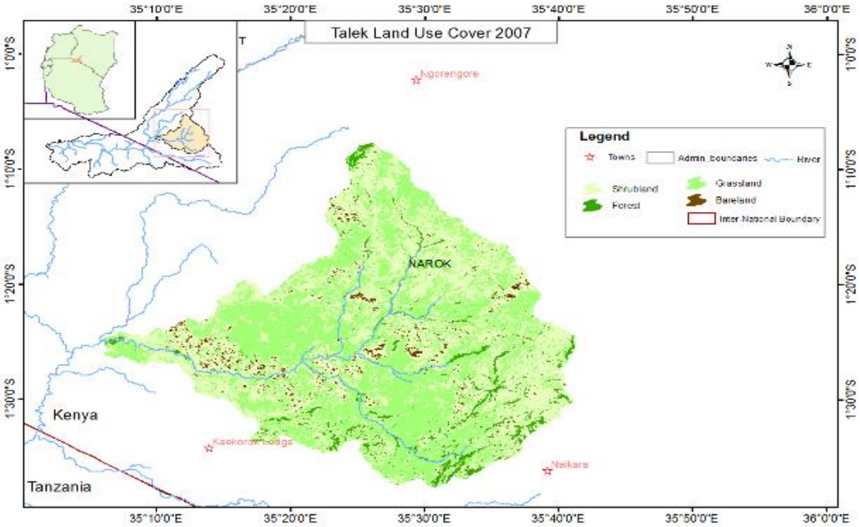

Figure 4.24. *Land cover of Talek sub-catchment 2007*

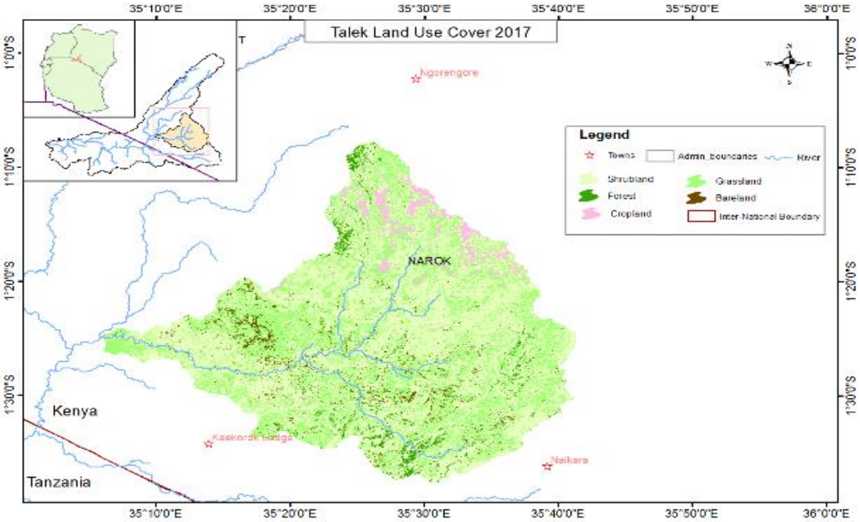

Figure 4.25. *Land cover of Talek sub-catchment 2017*

4.1.6. Land cover dynamics/ conversions (from-to) 1987-2017

4.1.6.1. Amala sub-catchment land cover dynamics/ conversions (from-to) 1987-2017

The greatest change experienced in the Amala sub-catchment between 1987 and 1997 was the conversion from grass land to crop land and the conversion from forest to crop lands in the upper portion of the sub-catchment. Other significant “from-to” changes observed within Amala sub-catchment included conversion from shrub land to forest land, grass land to forest land among others.

A large portion of the mid Amala sub-catchment however remained unchanged over the 1987-1997 period (Figure 4.26). Between 1997 and 2007, a large portion of the lower Amala sub-catchment transformed from grassland to crop land, while the upper part transformed from forest land to crop land and forest land to shrub-land. Over the 2007-2017 period, part of crop land was converted to grass land. In addition, bare land that was dominant between 1997 and 2007 had reduced significantly by 2017 (Figure 4.26, 4.27, 4.28 and 4.29).

The land cover change dynamics results from this study is consistent with the study conducted in Mara river basin which revealed status of the from and to land cover change dynamics from 1984 to 2016 (Ayuyo *et al.*, (2020). The same was noted by the study conducted by Gashaw *et al.*, (2018) in modeling the hydrological impacts of land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia.

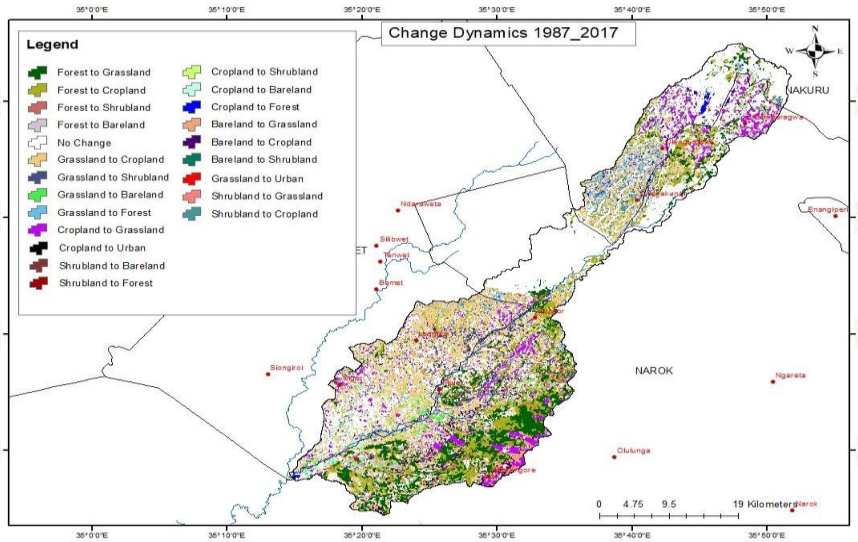

Figure 4.26. *Dynamics of land cover in Amala (1987-1997)*

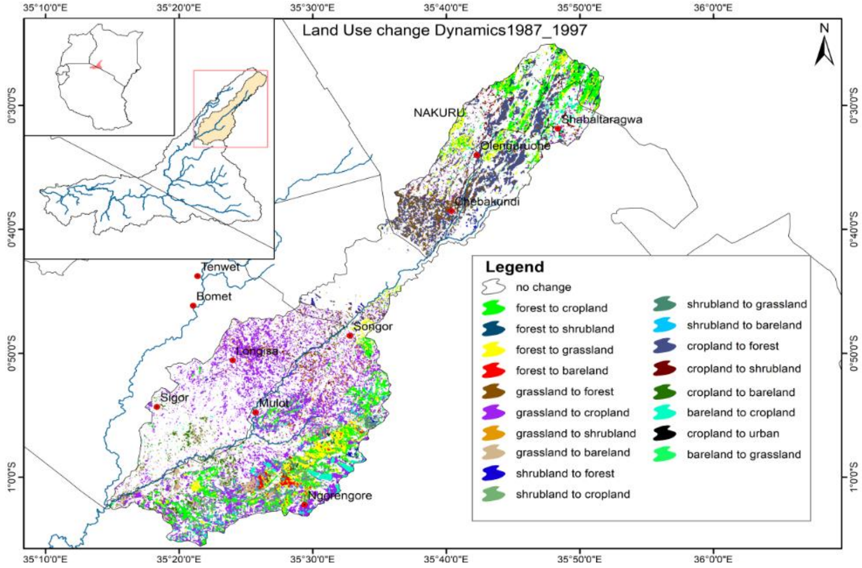

Figure 4.27. *Dynamics of land cover in Amala (1997-2007)*

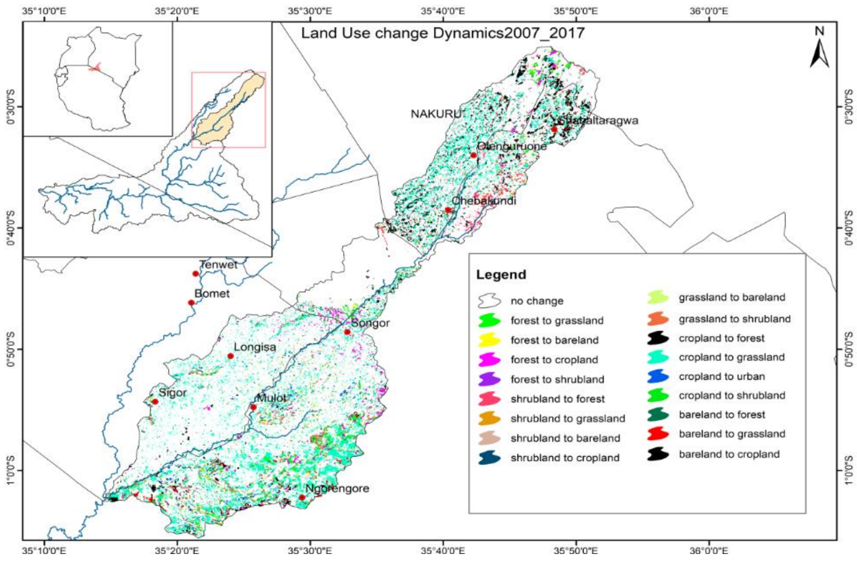

Figure 4.28. *Dynamics of land cover in Amala (2007-2017)*

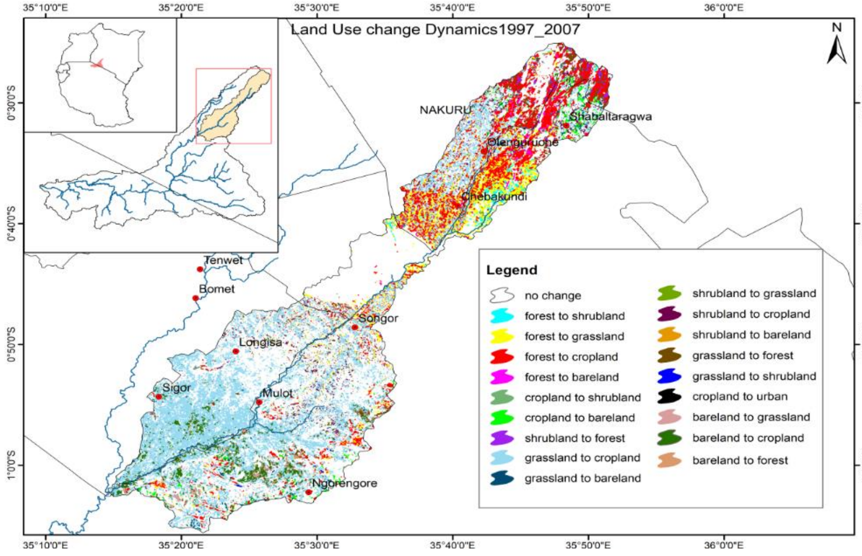

Figure 4.29. Dynamics of land cover in Amala (1987-2017)

4.1.6.2. Nyangores sub-catchment land cover dynamics/ conversions (from-to) 1987-2017

Between 1987 and 1997 considerable changes from largely grass land to crop land both in the upper and lower parts of Nyangores sub-catchment were evident. Other land cover changes were also observed though to a smaller scale. Between 1997 and 2007, a large portion of the lower Nyangores sub-catchment was converted to crop land from grass land, while large sections of forest were converted into crop land, bare land and grass land.

Between 2007 and 2017, a large portion of the lower Nyangores sub-catchment showed a change from grass land to crop land while a few other patches in the lowermost part of the sub-catchment were transformed from grass land to forest land and also to bare land from crop land. However, in the upper part of the sub-catchment, a large portion had been converted from forest to crop lands and grass land. The mid-section of the Nyangores sub-catchment however remained unchanged throughout the 30-year period (Figure 4.30, 4.31, 4.32 and 4.33).

The land cover change dynamics results from this study is consistent with the study conducted in Mara river basin which revealed status of land cover change dynamics from 1984 to 2016 (Ayuyo *et al.*, (2020). This land cover change dynamics results is also consistent with study compared the effects of dynamic versus static representations of land use change in hydrologic impact assessments (Wagner *et al.*, 2017).

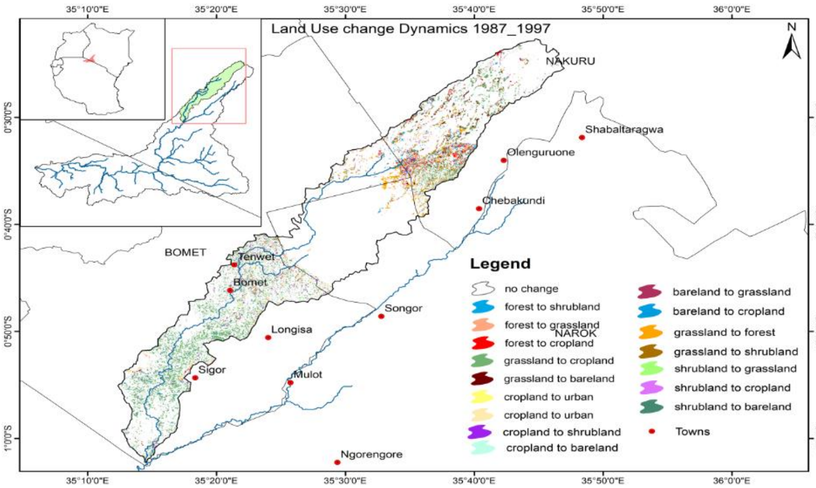

Figure 4.30. *Dynamics of land cover in Nyangores (1987-1997)*

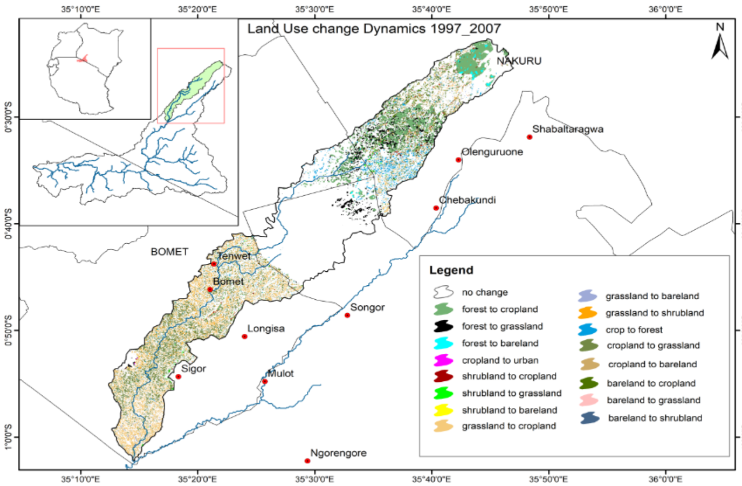

Figure 4.31. *Dynamics of land cover in Nyangores (1997-2007)*

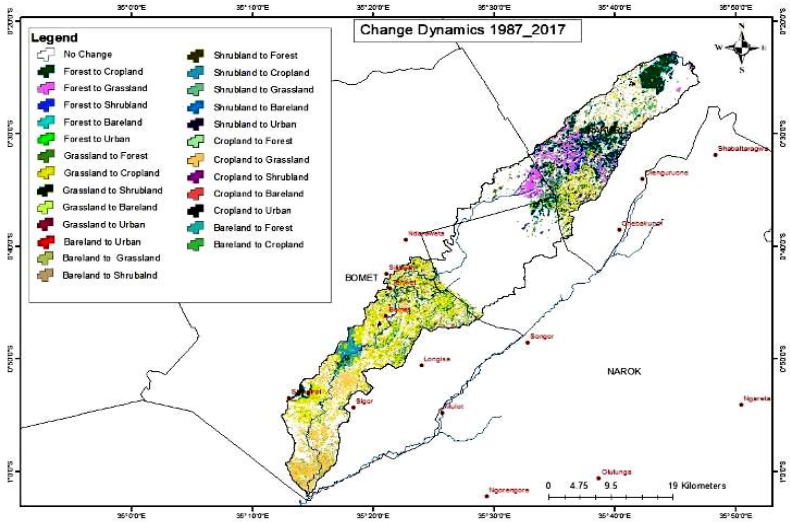

Figure 4.32. *Dynamics of land cover in Nyangores (2007-2017)*

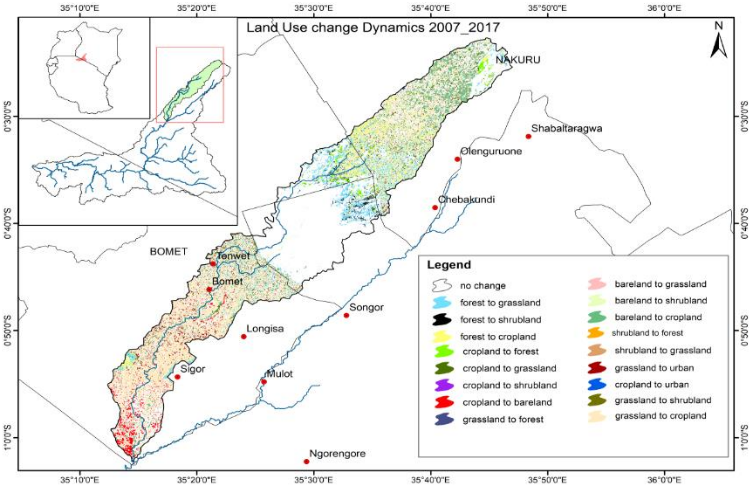

Figure 4.33. *Dynamics of land cover in Nyangores (1987-2017)*

4.1.6.3. Sand sub-catchment land cover dynamics/ conversions (from-to) 1987-2017

The most common land cover changes recorded between 1987 and 1997 was the conversion of shrub land to grass land, and forest/woodland to shrub land. Other changes also occurred though in patches such as the conversion of forest/woodland, grass land and shrub land to bare land.

Between 1997 and 2007, the most pronounced change was the conversion of shrub land to grass land. Nevertheless, a significant portion of the Sand river sub-catchment remained unchanged in the 1997-2007 period. A large portion changed from shrub land to grass land between 2007 and 2017among other changes (Figure 4.34, 4.35, 4.36 and 4.37).

This study is consistent with study conducted in Monitoring and Predicting Land Use Change in Beijing Using Remote Sensing and GIS (Wu. 2006). The land cover change dynamics results from this study is also consistent with the study conducted in Mara river basin which revealed status of land cover change dynamics from 1984 to 2016 (Ayuyo *et al.*, (2020).

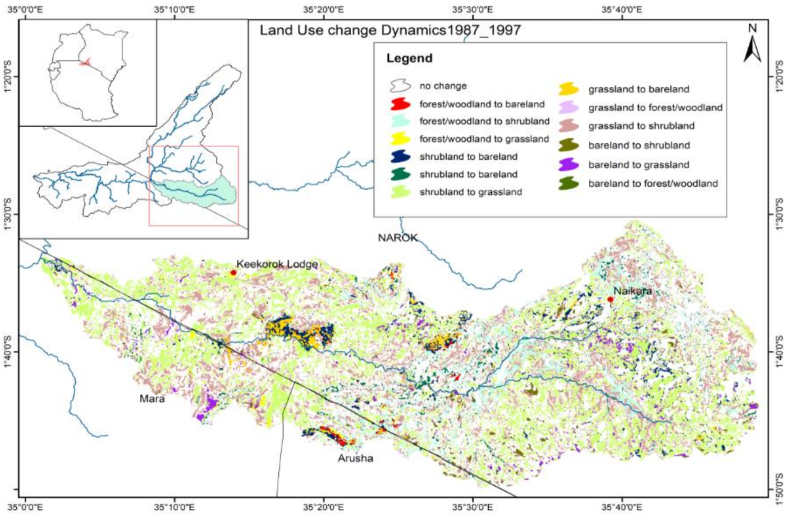

Figure 4.4. *Dynamics of land cover in Sand river (1987-1997)*

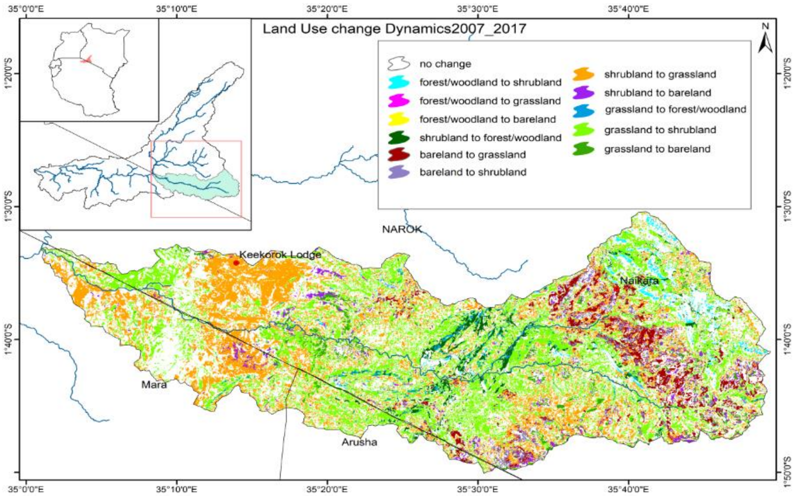

Figure 4.5. *Dynamics of land cover in Sand river (1997-2007)*

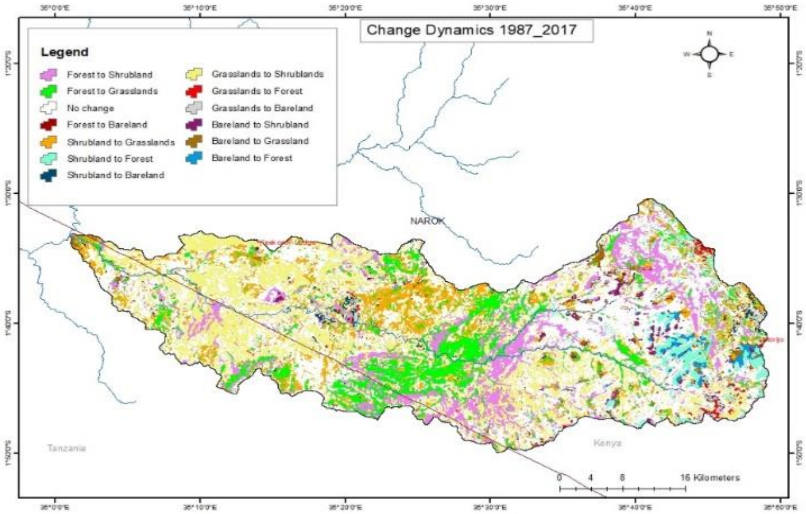

Figure 4.6. *Dynamics of land cover in Sand river (2007-2017)*

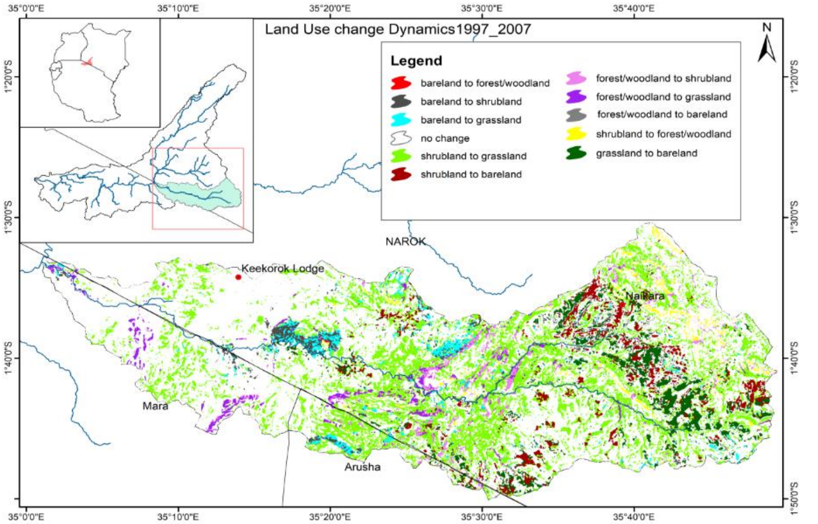

Figure 4.7. *Dynamics of land cover in Sand river (1987-2017)*

4.1.6.4. Talek sub-basin land cover dynamics/conversions (from-to) (1987-2017)

Within Talek sub-catchment, the most conspicuous land cover change between 1987 and 1997 was the conversion between grass land and shrub land. Others changes like conversion of shrub land to forest/woodland, forest/woodland to grass land, forest/woodland to crop land and bare land to shrub land also occurred within the period.

Between 1997 and 2007 as well as between 2007 and 2017, a large portion of Talek sub-catchment experienced conversions between shrub lands and grasslands. Conversions from grass land to bare land, forest/woodland to shrub land and crop land, bare land to grass land among others were also recorded albeit in smaller patches over that period. From the pictorial maps of the 30-year duration, it is evident that most of the changes within Talek sub-catchment occurred on the southeastern part of the sub-catchment (Figure 4.38, 4.39, 4.40 and 4.41).

The land cover change dynamics results from this study is consistent with the study conducted in Mara river basin which revealed status of land cover change dynamics from 1984 to 2016 (Ayuyo *et al.*, (2020). The result is also consistent with studies conducted by Remondi *et al.*, 2016 which explored the hydrological impact of increasing urbanisation on a tropical river catchment of the metropolitan Jakarta, Indonesia. The study found land cover changes were associated with rapid urbanization and deforestation.

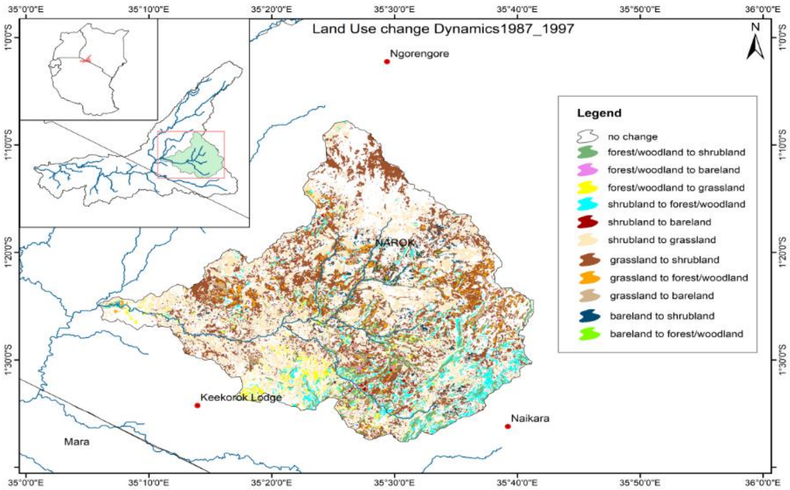

Figure 4.8. *Dynamics of land cover in Talek (1987-1997)*

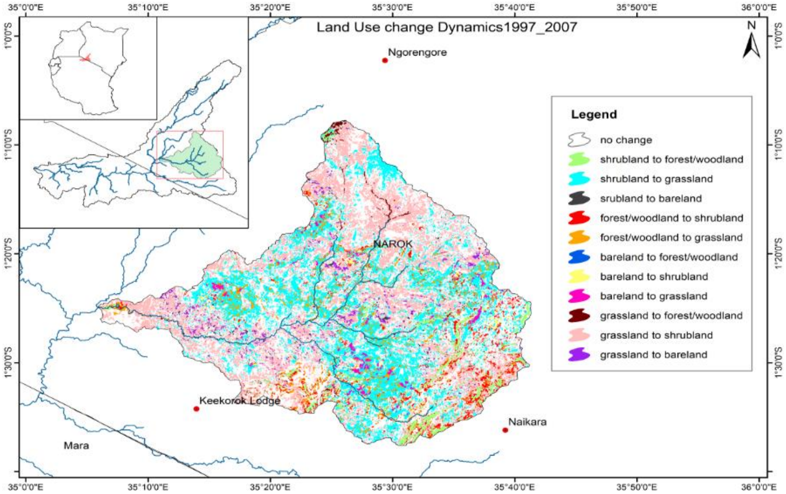

Figure 4.9. *Dynamics of land cover in Talek (1997-2007)*

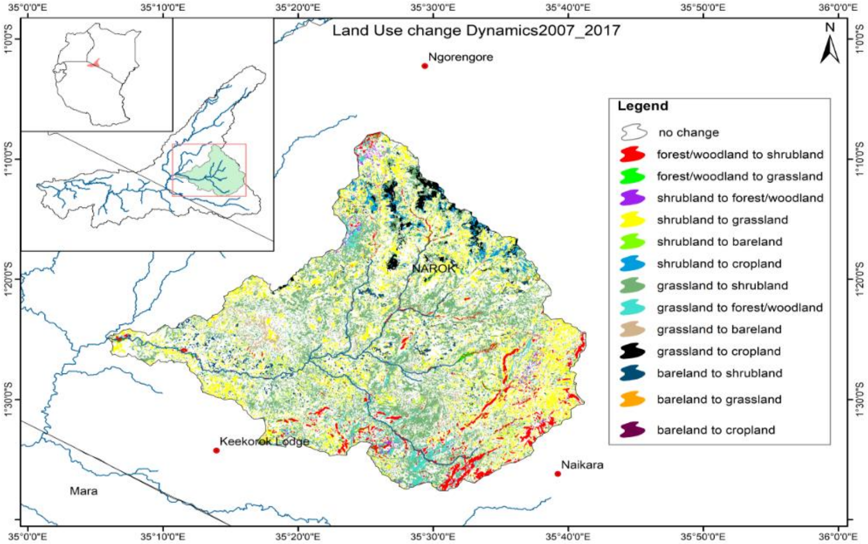

Figure 4.10. *Dynamics of land cover in Talek (2007-2017)*

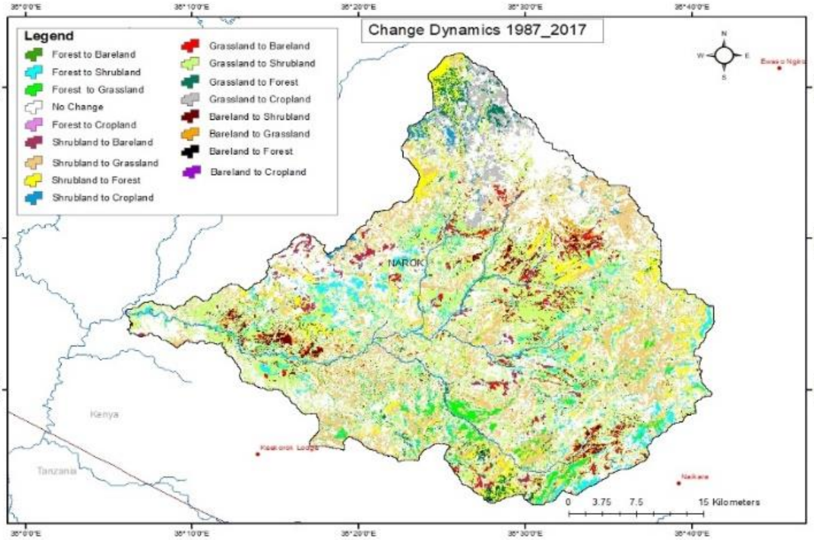

Figure 4.41. *Dynamics of land cover in Talek (1987-2017)*

4.1.7. Correlation between climate variation (rainfall and temperature) and different land cover changes in the sub-catchments

Correlation analysis between Normalized Difference Vegetation Index (NDVI) and climate variables were conducted to all sub-catchments to understand the effects of rainfall and Temperature variability on land cover categories. Many studies have used NDVI to understand the influence of climatic variables on the land cover because of ability of NDVI to probe ecosystem function response to global climate change (Chuai *et al.*, 2012; Schnur *et al.*, 2010; Chuai *et al.*, 2013; Guo *et al.*, 2008; Rasmusen, 1998 and Ichii *et al.*, 2002). From great powerful and ability of NDVI to respond to the climate variability, this study adopted the same method.

Overall, the correlation analysis results (table 4.8) showed both strong and weak coefficient of determination (R^2). The correlation analysis proved that the LC classes were correlated with temperature and rainfall in different ranges from $R^2 = 0.23$ to 0.99. Temperature showed a strong correlation with built-up areas ($R^2 = 0.99$), while the weakest correlation was observed in grassland ($R^2 = 0.23$). With regrads to rainfall, the strongest correlation was found in bare land ($R^2 = 0.98$), while the weakest correlation was found in grasslands ($R^2 = 0.024$).

4.1.7.1. Amala sub-catchment correlation between climatic variability and different land cover change (1987-2017)

In Amala, the present study revealed that, climatic variability (temperature and rainfall) and land cover change overtime are correlated but in differenge degrees. Generally, mean total rainfall decreased from as high as 1033.95 mm in 1987 to as low as 660.01 mm in 2017 a decrease of -373.94 mm (-36.17%); while maximum mean annual temperature increased from 24.13 °C in 1987 to 26.96 °C in 2017 - an increase of 2.83°C or 11.73% (Table 4.10).

Table 4. 10: *Rainfall and temperature variability trend*

YEAR	1987	1997	% change btw 1987 & 1997	2007	% change btw 1997 & 2007	2017	% change btw 2007 & 2017	Change btw 1987 & 2017	% change btw 1987 & 2017
Rainfall annual mean	1033.9	1098.9	6.28	1079.6	-1.75	660.0	-38.87	-373.94	-36.17
TEMP max annual mean	24.13	25.05	3.81	23.35	-6.79	26.96	15.46	2.83	11.728

In Amala sub-catachment, results (Table 4.8) showed a strong and weak coefficient of determination between Rainfall and land cover categories NDVIs. The rainfall in Amala sub-catchment was correlated with shrubland (R^2=0.93), followed by grassland (R^2=0.81), forestland and bareland both (R^2=0.66); and low coefficient of determination in built upareas (R^2=0.49) and cropland (R^2=0.47). Results implied that, health of shrub, grassland, forest is highly correlated and can be detrmined with rainfall variation. Correlation between rainfall with bareland and cropland is low, and therefore, areas under bareland and cropland cannot be determined by rainfall variation only.

A strong coefficient of determination between Temperature and land cover categories NDVIs were found to be higher on grassland (R^2=0.99), followed by bareland (R^2=0.98), forestland (R^2=0.95), built up areas (R^2=0.92), Cropland (R^2=0.88), and shrubland (R^2=0.87). Results suggests that, temperature variation determines the status of the grassland, bareland, forestland, builtup areas, cropland and shrubs, Table 4.11.

Table 4.11. *Coefficient of determination between temperature, rainfall and change of NDVI of different land cover categories btw 1987-2017 in Amala sub-catchment*

Year	Total Annual Rainfall	Mean annual max Temp	Forest land NDVI	Shrub land NDVI	Built up are NDVI	Crop land NDVI	Bare land NDVI	Grass land NDVI
1987	1033.95	24.13	0.58	0.43	0.31	0.44	0.35	0.45
1997	1098.85	25.05	0.53	0.48	0.27	0.35	0.26	0.41
2007	1079.61	23.35	0.74	0.57	0.35	0.62	0.38	0.52
2017	660.01	26.96	0.36	0.13	0.24	0.25	0.16	0.25
Coefficient of determination for Rainfall and land cover categories (R2)			0.6609596	0.93453983	0.48849833	0.46817873	0.66165851	0.81472762
Coefficient of determination for Temperature and land cover categories (R2)			0.94981596	0.87123399	0.91879086	0.87661169	0.981642	0.98972303

Above results are demostrated by the facr that, under high mean annual temperature 26.96°C and low mean total annual rainfall 660.01mm, NDVIs of all land cover types were lowest as exhibited in the year 2017. During periods of high rainfall and low mean maximum temperatures, the NDVIs of all land cover categories were highest and vice versa (Figure 4.42 and 4.43).

This result is in agreement with study conducted in Inner Mongolia, China by Chuai et al (2013) which showed that the effects of precipitation and temperature on NDVI varied among different vegetation types and seasons. In summer, NDVI correlated with temperature negatively and precipitation positively for cultivated vegetation, shrubs, steppes, meadows and desert vegetation. According to study conducted by Ting er al., (2018) NDVI demonstrated that HSCI can provide more detailed quantitative observations of diverse anthropogenic activities across human settlements. At the local scale, HSCI distinguished and separated non-artificial land covers (e.g., water bodies, vegetated lands, and bare areas), which can be affected originally by the over-glow effect of nighttime radiances from human settlements, and hence, obtained a clear image of the spatial distribution of diverse human activities.

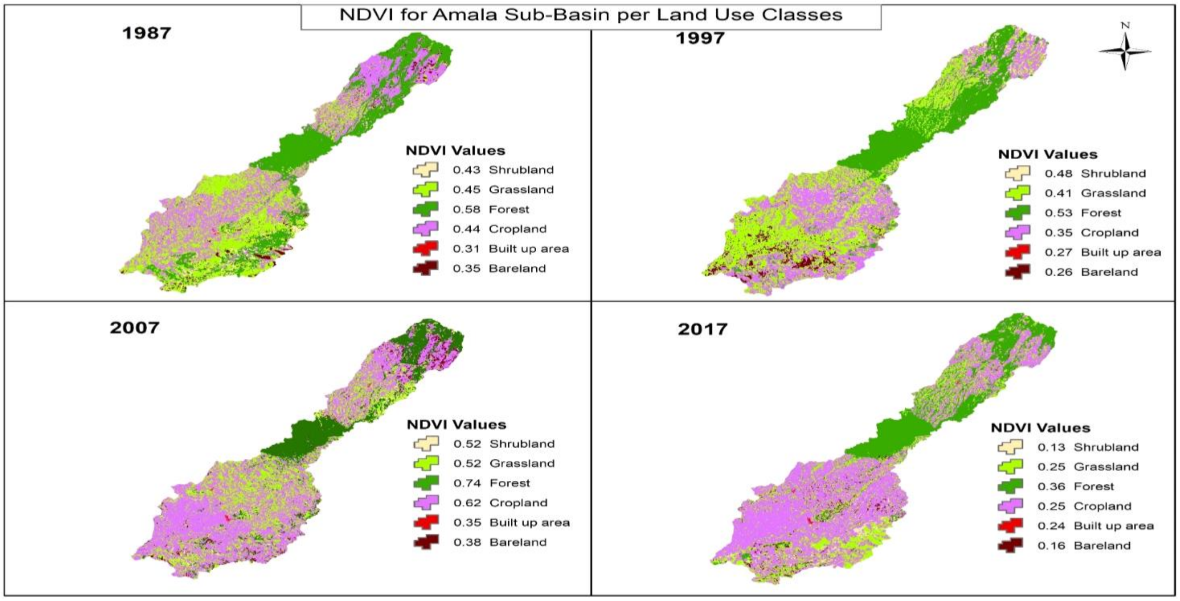

Figure 4.42. *October land cover categories NDVI for 1987, 1997, 2007 and 2017 in Amala sub-catchment*

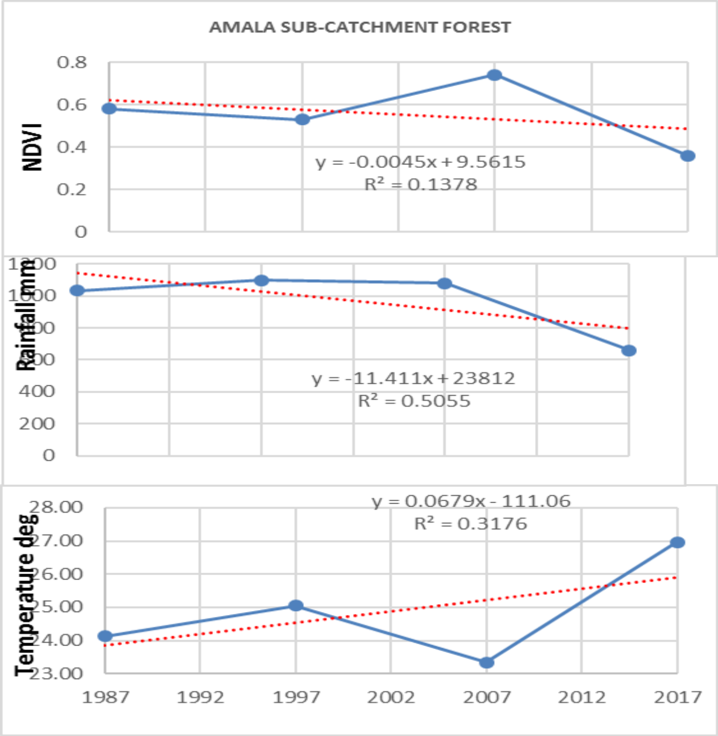

Figure 4.43. *Temperature and Rainfall variability and changes in NDVI, in Amala sub-catchment (Blue and Red lines shows trend and linear regression, respectively of NDVI, Temperature and Rainfall)*

4.1.7.2. Nyangores sub-catchment correlation between climatic variability and different land cover change (1987-2017)

In Nyangores, generally, between 1987 and 2017 mean total annual rainfall decreased from 1171mm to 692.4mm a -478.6mm decrease translating to -40.87%, while maximum mean annual temperature increased from 22.54°C in 1987 to 26.96 °C in 2017; a difference of 2.23 °C which translates to a 9.89% increase (Table 4.9). Temperature variation trend also showed relative low change in mean R^2 =0.32 while rainfall showed greater R^2 =0.62, Table 4.12.

Table 4. 12. *Trend of rainfall and temperature in Nyangores sub-catchment*

Year	**1987**	**1997**	**Change btw 1987 & 1997**	**2007**	**Change btw 1997 & 2007**	**2017**	**Change btw 2007 & 2017**	**Change btw 1987 & 2017**
Rainfall annual mean (mm)	1171	1038.6	-132.4	1139.6	101	692.4	-447.2	-478.6
TEMP max annual mean (°C)	22.54	23.48	0.94	22.03	-1.45	24.77	2.74	2.23

In Nyangores sub-catachment, results (Table 4.10) showed a strong coefficient of determination between Rainfall and land cover categories NDVIs. Rainfall was found to be correlated with Bareland (R^2=0.99), followed by builtup area (R^2=0.81), forestland (R^2=0.67), grassland (R^2=0.64); and low coefficient of determination in shrubland (R^2=0.51) and cropland (R^2=0.27). Results implied that, rainfall variation in Nyangores determines the status of bareland, builtup areas, forestland, grassland; however, its determination on the status of shrublands and crop land is low or limited.

A strong coefficient of determination between Temperature and land cover categories NDVIs were found on Built-up areas (R^2=0.99), followed by bareland (R^2=0.95), forestland (R^2=0.91), grassland (R^2=0.87), shrubland (R^2=0.82), and low in cropland (R^2=0.59). Results reveales that, temperature variation determines the status of the builtup areas, bareland, forestland, grassland and shrubland; while its ability to cropland status is limited, Table 4.13.

Year	**PPT annual mean (mm)**	**TEMP max annual mean (°C)**	**Built-up areas NDVI**	**Forest land NDVI**	**Crop land NDVI**	**Bare land NDVI**	**Grass land NDVI**	**Shrub land NDVI**
1987	1171	22.54	0.4	0.6	0.46	0.39	0.56	0.48
1997	1038.6	23.48	0.34	0.53	0.35	0.33	0.42	0.41
2007	1139.6	22.03	0.44	0.75	0.6	0.4	0.59	0.57
2017	692.4	24.77	0.25	0.42	0.39	0.19	0.4	0.39
Coefficient of determination for Rainfall and land cover categories (R2)			**0.88578602**	**0.67340838**	**0.26538157**	**0.98522278**	**0.64131202**	**0.5104117**
Coefficient of determination for Temperature and land cover categories (R2)			**0.99925752**	**0.9140852**	**0.58835001**	**0.95403869**	**0.86699702**	**0.81791208**

Table 4.13. *Coefficient of determination between temperature, rainfall and change of NDVI of different land cover categories btw 1987-2017 in Nyangores sub-catchment*

The above results are revealed by the fact that, during periods of high rainfall and low mean maximum temperatures, the NDVIs of all land cover categories was highest and vice versa (see year 2017) (Figure 4.44 and 4.45).

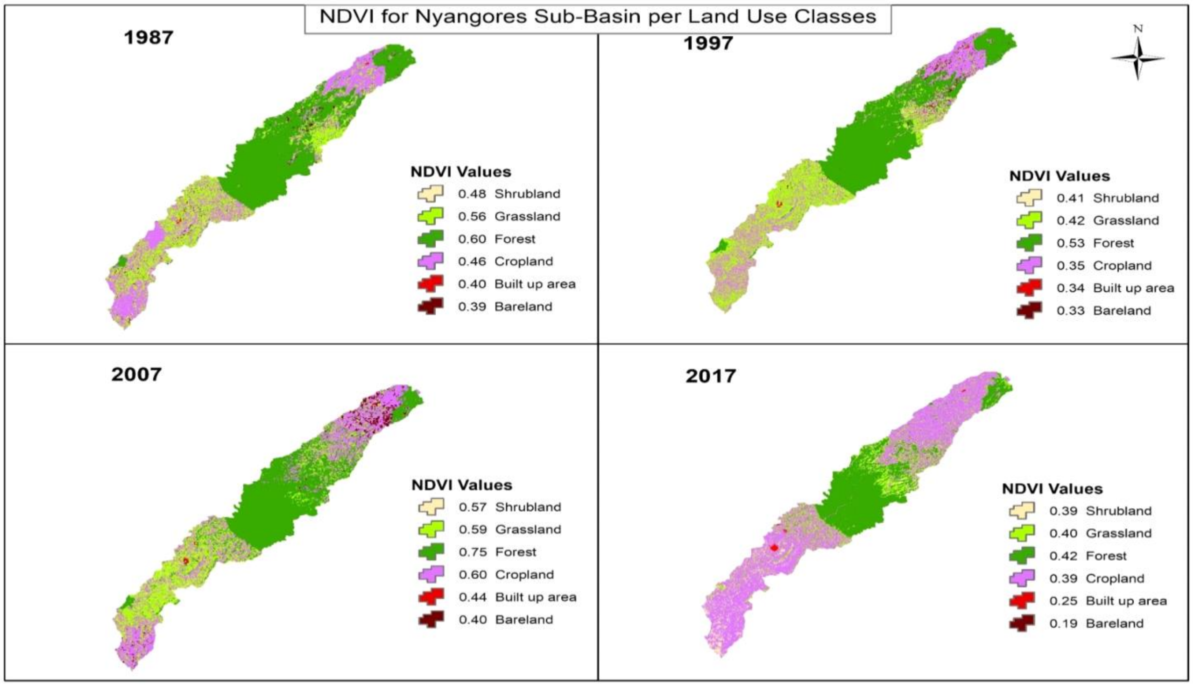

Figure 4.44 *NDVI for Nyangores Sub-catchment October for 1987, 1997, 2007 and 2017*

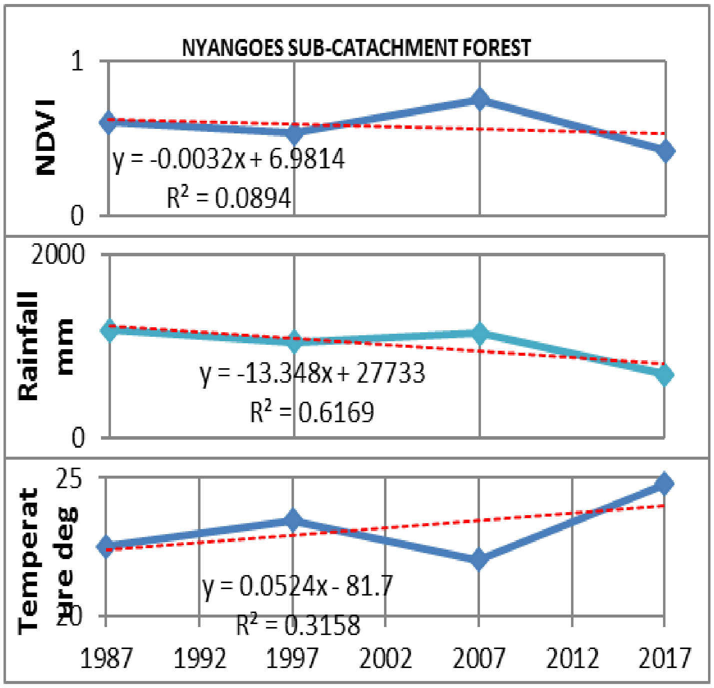

Figure 4.45. *Nyangores changes in NDVI, Temperature and Rainfall (Blue and Red lines show trend and linear regression of NDVI, Temperature and Rainfall respectively)*

4.1.7.3. Sand sub-catchment influence of climate variability on land cover change (1987-2017)

Generally, from 1987 to 2017 mean total annual rainfall decreased from 430.09 mm to 327.59 mm, a negative decrease of -102.5mm which translates to -23.83%. Over the same period, maximum mean annual temperature increased by 1.66◦C from 24.25ºC to 25.91ºC; which translates to a 6.85% increase (Table 4.14). However, both temperature and rainfall showed relative low change in their means R^2 =0.22, R^2 =0.06, respectively, Table 4.14.

Table 4.34. *Rainfall and temperature variability trend of 1987-2017 in Sand sub-catchment*

YEAR	1987	1997	% change btw 1987 & 1997	2007	% change btw 1997 to 2007	2017	% change btw 2007 to 2017	Change btw 1987 to 2017	% change btw 1987 to 2017
Rainfall annual mean (mm)	430.1	904.3	110.27	718.4	-20.6	327.6	-54.4	-102.5	-23.83
TEMP max annual mean (ºC)	24.3	24.4	0.70	23.3	-4.4	25.9	11.0	1.66	6.85

In Sand sub-catachment, results (Table 4.15) showed a strong coefficient of determination between Rainfall and land cover categories NDVIs. Resuts suggest that, Rainfall variability is ascetically determine status of bareland (R^2=0.63), followed by grassland (R^2=0.61), and low on shrubland (R^2=0.58), and Forest (R^2=0.57).

A strong coefficient of determination between Temperature and land cover categories NDVIs were found on grassland (R2=0.94), followed by forestland (R2=0.93), shrubland (R2=0.91), and bareland (R2=0.76). Results reveales that, temperature variation determines the status of the grassland, forestland, shrubland, and bareland.

Table 4.15. *Coefficient of determination between temperature, rainfall and change of NDVI of different land cover categories btw 1987-2017 in Sand sub-catchment*

Year	**Rainfall annual mean (mm)**	**TEMP max annual mean (^{0}C)**	**Forest land NDVI**	**Bare land NDVI**	**Shrub land NDVI**	**Grass land NDVI**
1987	430.09	24.25	0.37	0.23	0.29	0.28
1997	904.34	24.42	0.39	0.25	0.31	0.31
2007	718.43	23.34	0.42	0.24	0.33	0.35
2017	327.59	25.91	0.25	0.15	0.18	0.19
Coefficient of determination for Rainfall and land cover categories (R2)			0.56530941	0.63140406	0.58195233	0.60607313
Coefficient of determination for Temperature and land cover categories (R2)			0.931167	0.75576553	0.90897221	0.93721433

The above results are explained by the fact that, when mean total annual rainfall was high and maximum mean annual temperature was low, the NDVId of all land cover categories was high and when maximum mean annual temperature was high and mean total annual rainfall was low then NDVIs of all land cover categories were low [see year 2017] (Figure 4.46 and 4.47).

The present results are consistent with a studies conducted by Yuhong et al 2012 and Akira *et al*, (2001), on the rainfall and climate variability impacts to land cover types. All studies noted the influence of rainfall and temperature variability to the different land covers either positively or negatively depends on the locality.

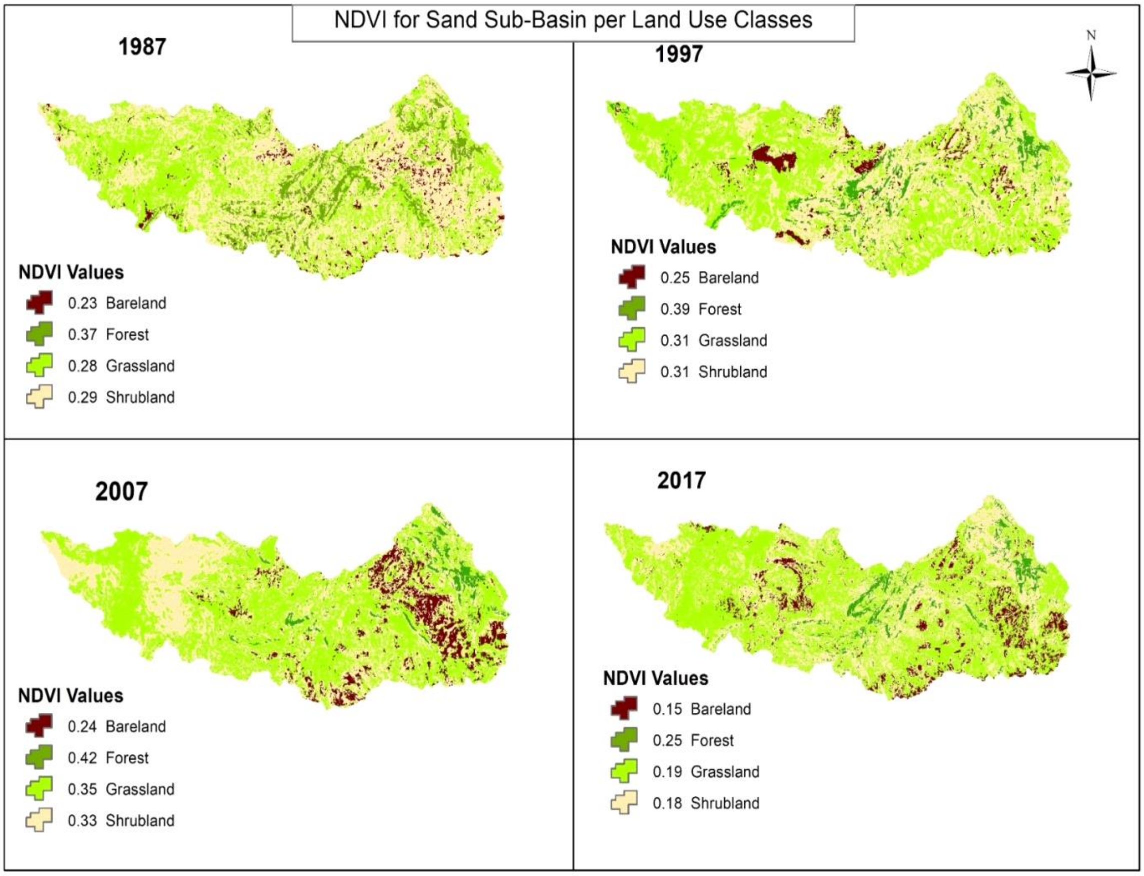

Figure 4.46. *October land cover categories NDVI trend from 1987 to 2017 in Sand sub-catchment*

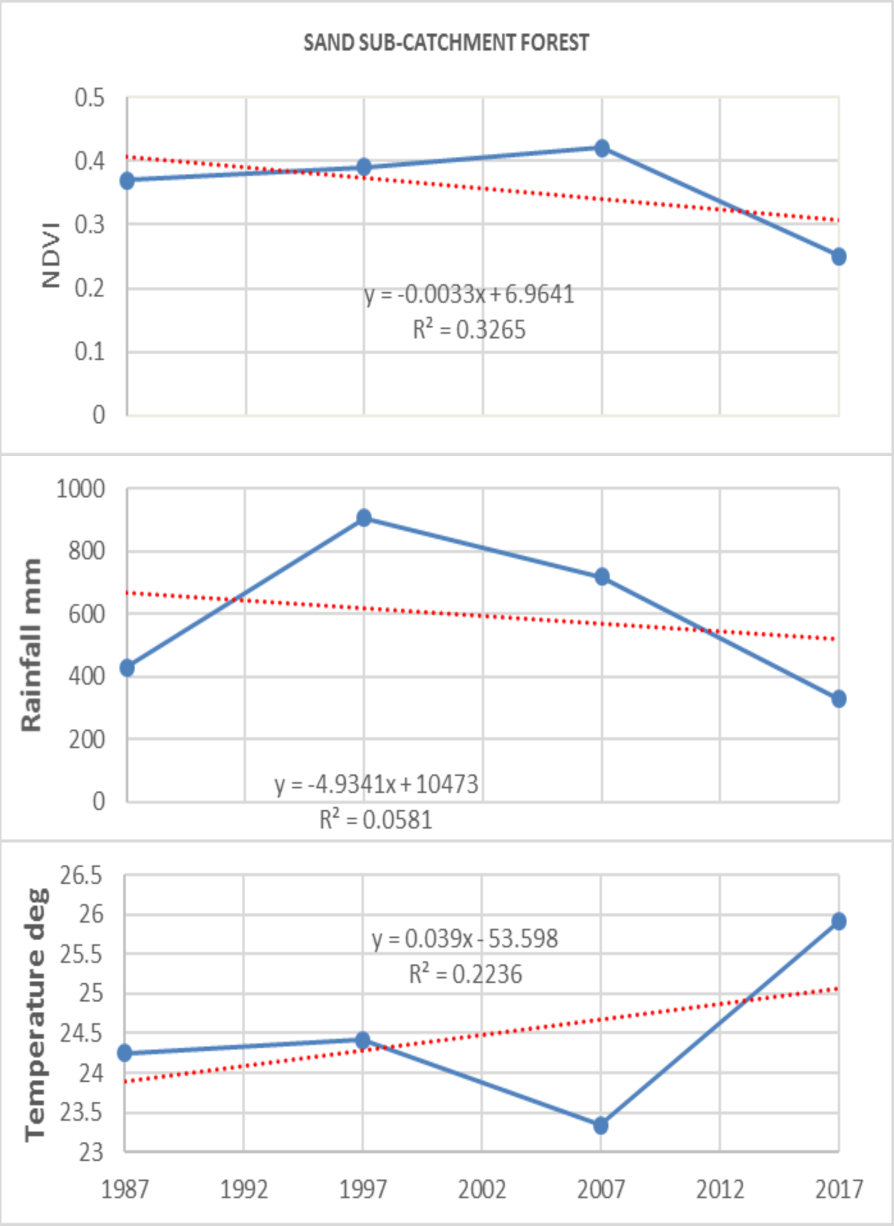

Figure 4.47. *Sand sub-catchment changes in NDVI, Temperature and Rainfall (Blue and Red lines show trend and linear regression of NDVI, Temperature and Rainfall respectively)*

4.1.7.4. Talek sub-catchment effect of climatic factors on land cover change (1987-2017)

In Talek sub-catchment, mean total annual rainfall decreased by -343.96mm from 773.24mm to 429.28mm; which translates to -44.48%, while maximum annual mean temperature increased by 1.66 ^{o}C from 24.25 ^{o}C to 25.91 ^{o}C; which translates to 6.85% between 1987 and 2017 (Table 4.16).

Table 4.46. *Trend of rainfall and temperature within Talek Sub-catchment 1987-2017*

Year	1987	1997	% change btw 1987 & 1997	2007	% change btw 1997 & 2007	2017	% Change btw 2007 & 2017	Change btw 1987 & 2017	% change btw1987 & 2017
Rainfall annual mean (mm)	773.24	1027.1	32.83	678.1	-33.99	429.28	-36.69	-343.96	-44.48
TEMP max annual mean (^{o}C)	24.25	24.42	0.70	23.4	-4.18	25.91	10.73	1.66	6.85

In Talek sub-catachment, results (Table 4.17) showed a weak coefficient of determination between Rainfall and land cover categories NDVIs. Results suggest that, rainfall variation in Talek has very limited influencies on cropland (R^2=0.64), and low on forestland (R^2=0.45), shrubland (R^2=0.24), grassland (R^2=0.24), and bareland (R^2=0.17). However, temperature variation in Talek, has strong coefficient of determination with land cover categories NDVIs.

Temperature variation determine the status of bareland (R^2=0.84), cropland (R^2=0.82), forestland (R^2=0.64), grassland (R2=0.62), and very limited influence on shrubland (R2=0.23).

Table 4.17. *Coefficient of determination between temperature, rainfall and change of NDVI of different land cover categories btw 1987-2017 in Talek Sub-catchment*

Year	**PPT annual mean (mm)**	**max annual mean temp (◦C)**	**Forest land NDVI**	**Crop land NDVI**	**Bare land NDVI**	**Grass land NDVI**	**Shrub land NDVI**
1987	773.24	24.25	0.37	0	0.29	0.31	0.21
1997	1027.12	24.42	0.65	0	0.28	0.5	0.5
2007	678.05	23.4	0.68	0	0.29	0.59	0.48
2017	429.28	25.91	0.25	0.23	0.27	0.27	0.28
Coefficient of determination for Rainfall and land cover categories (R2)			**0.44685519**	**0.64461471**	**0.17279872**	**0.23848147**	**0.24483125**
Coefficient of determination for Temperature and land cover categories (R2)			**0.6438361**	**0.81717632**	**0.8448404**	**0.62411008**	**0.23284998**

Generally, temperature showed slightly less variation (R^2 = 0.24) compared to rainfall (R^2 = 0.5). In general, when mean total annual rainfall was high and maximum mean annual temperature was low, the NDVI of all land cover categories was high; and when maximum mean annual temperature was high and mean total annual rainfall was low, NDVI of all land cover categories was low (see year 2017), (Figure 4.48 and 4.49).

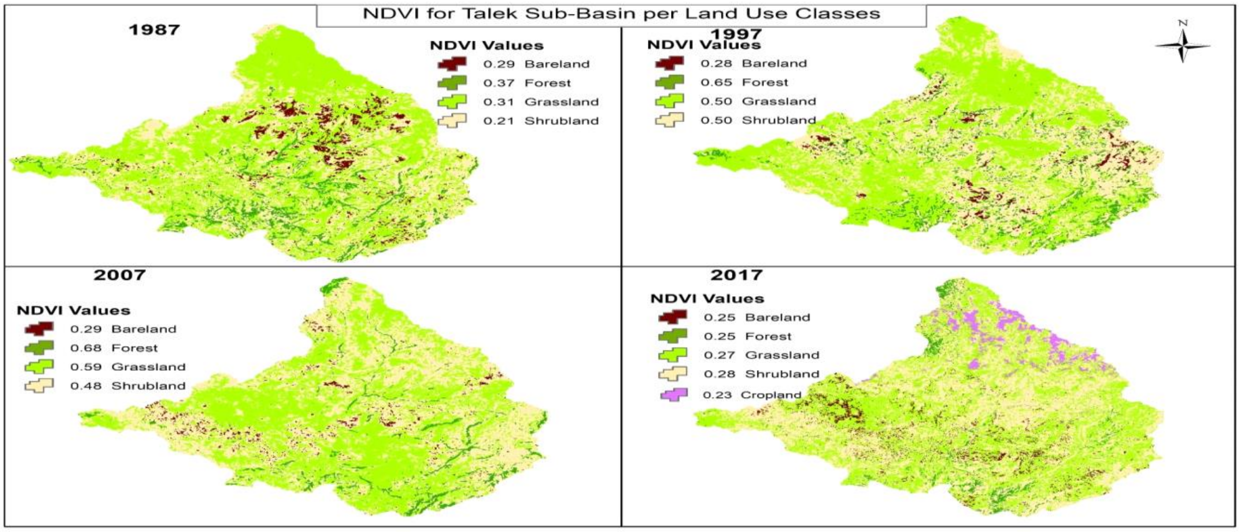

Figure 4.48. *October land cover categories NDVI trend 1987 - 2017 in Talek sub-catchment*

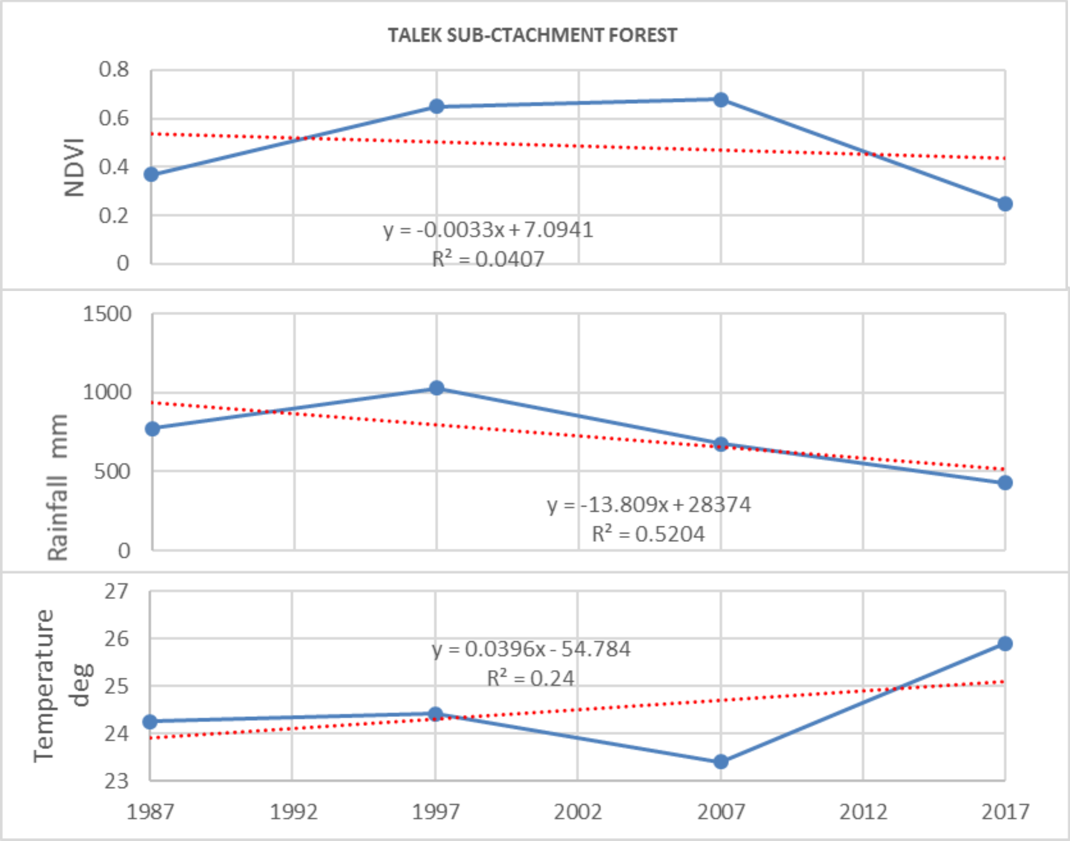

Figure 4.49. *Changes in NDVI, temp and rainfall in Talek sub-catchment (Blue and Red lines show trend and linear regression of NDVI, temp and rainfall, respectively)*

From the above results, significant changes in land cover is evident across the studied area. These findings suggest that there exists a correlation between climatic variability and land cover types. A clear trend was evident, in which rainfall tended to affect NDVI positively, while temperature affected NDVI negatively. During periods of high rainfall and low mean maximum temperatures, the NDVI of all land cover categories was highest and vice versa. Almost all (96.9%) respondents in the socio-economic survey reported that changes in rainfall patterns had an effect on land cover, with a small proportion (7.2%) reporting that change in rainfall patterns increased vegetation cover. Further analysis of the respondents' findings revealed that average temperature had a positive but moderate correlation ($R^2 = 0.53$) with built up area and extent of bare land percentages. This suggests that the higher the percentage of built up areas, the higher the average temperature.

The present findings are consistent with a study conducted by Ibrahim *et al.* (2016) on the land surface temperature impact to land cover types in Klang Valley in Malaysia. Respondents in all four sub-catchments felt that grass land, shrub land, forest/tree cover and water sources had diminished significantly due to temperature ($\chi^2 = 8.551$, $P = 0.0359$; χ 2 = 14.669, $P = 0.002122$; $\chi^2 = 31.299$, $P < 0.001$ and $\chi^2 = 8.8681$, $P = 0.0311$, respectively). However, there was no significant difference between those who thought that overgrazing and drying of crops were as a result of temperature change ($P \geq 0.05$). In addition, those who reported noticing changes in temperature patterns singled out diminishing grasslands, diminishing pasture, diminishing shrub land, diminishing tree cover, diminishing water resources (rivers, springs and dams) and drying of crops as some of the effects of temperature changes (standardized residual ≥ 1.5, Likelihood ratio test = 172.725, df = 16, $P > 0.001$).

4.2. Impacts of land cover changes on the stream flows of Nyangores and Amala sub-catchments over time

The Soil and Water Assessment Tool (SWAT) and SWAT CUP models were used to determine the long term impacts of land cover dynamics on stream flows in Nyangores and Amala sub-catchments of the Mara River Basin, Kenya. The Nash-Sutcliffe Efficiency (NSE) was 0.94, Coefficient of Determination (R^2) was 0.94 and Percent of Bias (PBOAS) was -1. P-factor was 0.96 and R-factor 0.8. Results demonstrated good strength of the model prediction. To understand impact of land cover changes on the stream flows of Nyangores and Amala sub-catchments over time, different analysis was done among observed stream flows and simulated stream flows; rainfall, percolation and total water yield; total water yield and different land cover categories; and land cover changes on simulated annual mean flows in Nyangores and Amala sub-catchments. A Coefficient of determination analysis was used to show the results. Since simulated mean annual water flows produced by models and observed mean annual flows were highly correlated, the models were found capable of analysing the land cover change dynamics impacts in stream flows of Amala and Nyangores tributaries. Results showed, whereas both sub-catchments are located in the upper Mara River basin and are adjacent to each other, the impacts of land cover categories on the flow of Nyangores and Amala are not the same. The following are the results.

4.2.1. Correlation between rainfall, percolation and total water yield

The results of the model showed that in Nyangores sub-catchment, rainfall amount recorded was higher than amount of water percolation and total water yield in that order (Figure 4.50). This implies that, more rainfall percolated in the soil as compared to total water yield flowing in the tributary. Nevertheless, the present findings showed a strong Coefficient of determination (R^2=0.92) between rainfall and total water yield and between rainfall and percolation (R^2=0.83) within Nyangores sub-catchment. Implying that as rainfall increased the water percolation and water yield also increased. This was also evident in the peak rainfall, water percolation and total yield observed in 2010 and the dip observed in all parameters in 2017.

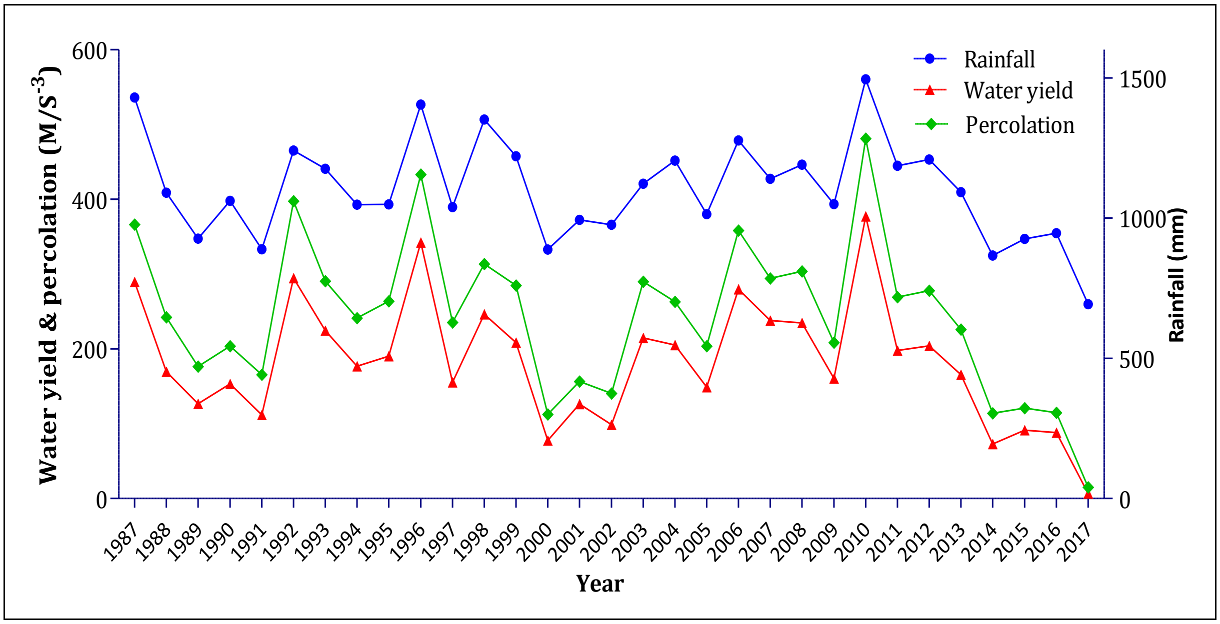

Figure 4.50. *Trends of rainfall, percolation and water yield in Nyangores sub-catchment (1987-2017)*

In Amala sub-catchment, however, rainfall amount recorded was higher followed by total water yield then percolation, in that order. This implies that, less rainfall amount percolated and more rainfall was converted into surface runoff (Figure 4.51). Unlike in Nyangores sub-catchment, Amala sub-catchment rainfall showed a lower (compared to Nyangores) strong Coefficient of determination with total water yield (R^2=0.72) as well as water percolation into the soil (R^2=0.63).

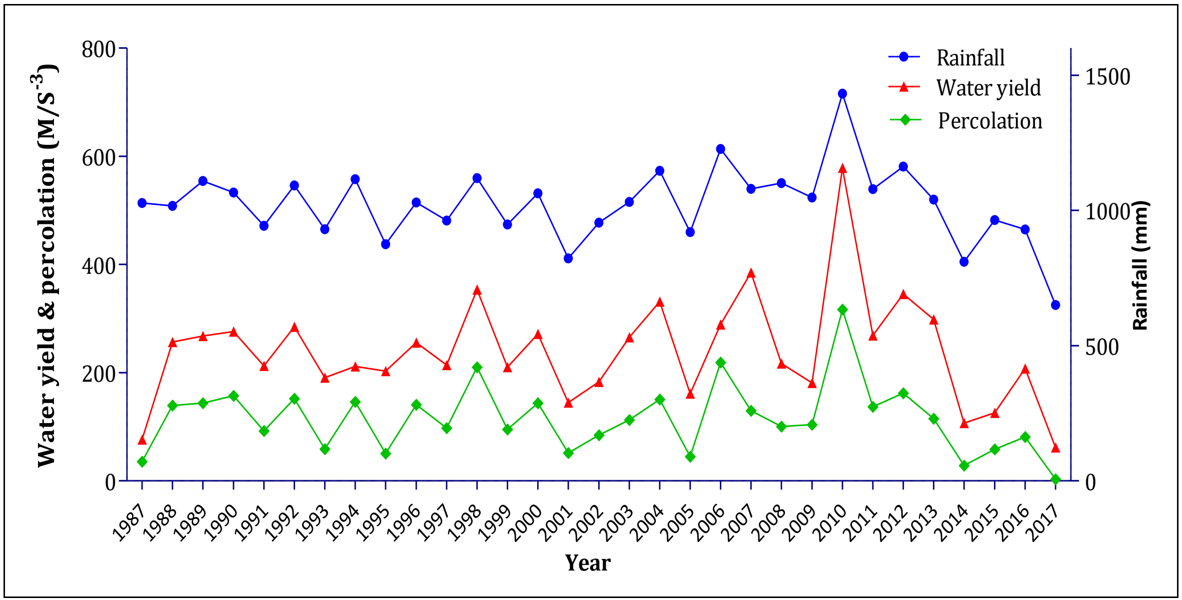

Figure 4.51. *Trends of rainfall, percolation and water yield within Amala sub-catchment*

The higher surface runoff compared to water percolation demonstrated by Amala sub-catchment could have been caused by higher conversion of forest, grass and shrub lands to crop land and built up area. Some factors governing the increase of water percolation/infiltration rate include the infiltration capacity for a given area, which is a measure of the spatial variability of soils and vegetation of that area (Stone *et al.* 2015). The results emphasize the greater role that grasslands and forests play in boosting rainfall percolation and by extension stream flow, which is important during dry seasons.

This result is supported by the study conducted and found land cover changes have transformed most of the planet's land surface (Foley *et al.*, 2011), with a great deal of land conversion being witnessed at the expense of forests (Lambin and Meyfroidt, 2011). These changes have an implication on water resources (Vörösmarty *et al.*, 2015; D'Almeida *et al.*, 2007; Dessie *et al.*, 2013). However, while the positive effects of forest restoration on water quality have repeatedly been highlighted (Neary *et al.,* 2009), the impacts of forest cover expansion on water quantity are at best still unclear (Ellison *et al.,* 2012) and therefore the analysis done by this study at sub-catchment level to understand its' dynamics and inform decision making at sub-catchment accordingly is exquisite.

Similar results were found in the study of flow Regime Changes in two Watersheds of North-eastern Tibetan Plateau, the trends of precipitation and runoff decreased from 1980 to 1995 and increased from 1996 to 2010 in both watersheds (Linshan *et al.,* 2017).

4.2.2. Correlation between total water yield and different land cover categories in Nyangores and Amala sub-catchments

Generally, total water yield decreased across all decades in Nyangores sub-catchment as areas of crop land and bare land increased at the expense of grass land and forest land (Figure 4.52). In Nyangores sub-catchment, water yield was contributed by all six land cover categories (forests, cropland, bare land, built-up area, shrub lands, grassland) to varying degrees. Water yield had strong coefficient of determination with bareland (R^2=0.99), followed by cropland (R^2=0.99), Built up areas (R^2=0.98), forestland (R^2=0.96), grassland (R^2=0.94), and lowest was shrubland (R^2=0.57).

Similar results were found and changes had an implication on water resources (Vörösmarty *et al.,* 2015; D'Almeida *et al.,* 2007; Dessie *et al.,* 2013).

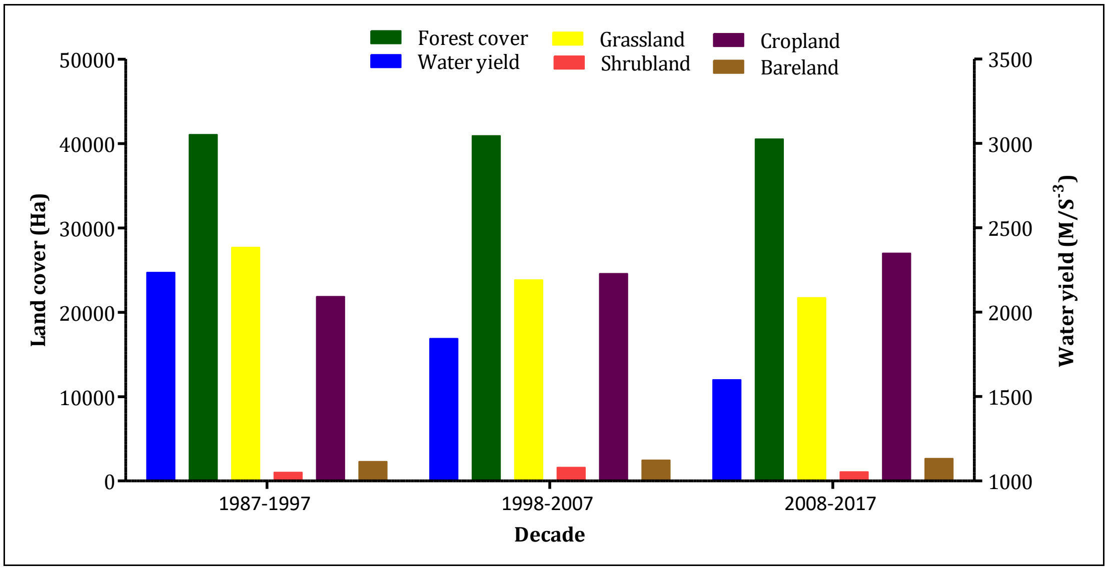

Figure 4.52. *Water yield against different land cover categories in Nyangores sub-catchment*

In Amala sub-catchment, total water yield increased between 1987-1997 and 1998-2007 decades before decreasing in the last decade (2008-2017), while grass land increased between 1987-1997 and also between 1998-2007 decades, but decreased between 2008-2017 decade. However, forest land decreased across the three decades (Figure 4.53). Similarly, in Amala sub-catchment, total water yield had strong coefficient of determination with bareland (R^2 =0.99), followed by cropland (R^2=0.97), built up areas (R^2=0.94), forestland (R^2=0.83), grassland (R^2=0.76), and Shrubland (R^2=0.68). Since total water yield includes both surface runoff and underground flows, the results indicate how bareland contributes to more water runoff. High water yield in the cropland is contributed by the fact that, most of the croplands are monoculture and after haresting land is left with limited vegetation to reduce speed of water runoff and hence more runoff is noted. Forestland, grassland and shrubland have lower R^2 compared to bareland and cropland beacuse they reduce water runoff and therefore less water yield is noted; while increased water percolation in the soil is noted. This phenomenor is seen in Amala sub-catchment due to very high deforestation happened from 1997 to 2007.

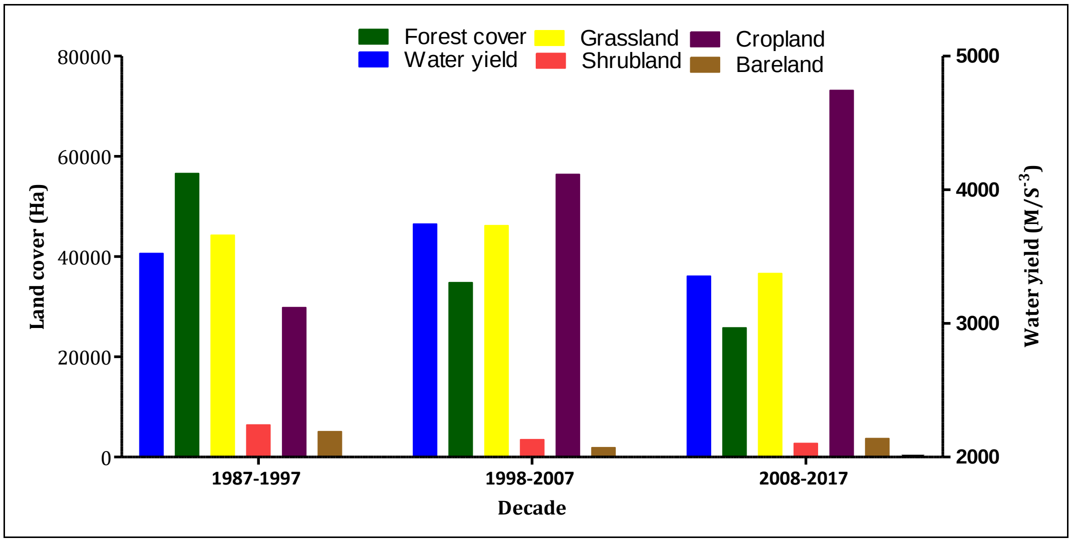

Figure 4.53. *Land cover on water yield in Amala sub-catchment*

For both Amala and Nyangores sub-catchments, crop land showed a steady increase over all decades at the expense of forest land, grass land and shrub land, which declined steadily over the same period. The effect of land cover on total yield was however more pronounced in Amala sub-catchment.

These results are consistent with Melesse *et al.* (2008) study which forecasted a decrease in base flow leading to low flows during dry seasons due to declining forest cover in Mara River basin headwaters from 2010 to 2030. The current study findings are also consistent with those of Khalid *et al.* (2017) in which land use/land cover affected streamflow in both the Dinder and the Rahad lower sub-basins of the Blue Nile River basin. The same study noted that, woodland and shrub land had high porosity and hence delayed the release of water to the catchment outlet.

Woodland removal implied less infiltration due to a decrease in soil permeability caused by livestock grazing, less interception of rainfall by the tree canopies and thus more runoff and high flow peaks noted in the areas. Different evapo-transpiration rates of forest, grass and shrubs have also been reported to influence total water yield in river basins (Abel *et al.*, 2020). Soil types and topography of the area have also been singled out as contributing factors influencing the impacts of land cover on total water yield (Dishon *et al.*, 2015).

4.2.3. Correlation between observed and simulated water flows

In Nyangores sub-catchment, the retrospective observed and simulated mean annual stream flows were closely similar with a Coefficient of determination (R^2=0.94) being recorded. Both observed and simulated mean annual stream flows peaked and dipped between 1987 and 2014, with slight differences being witnessed.

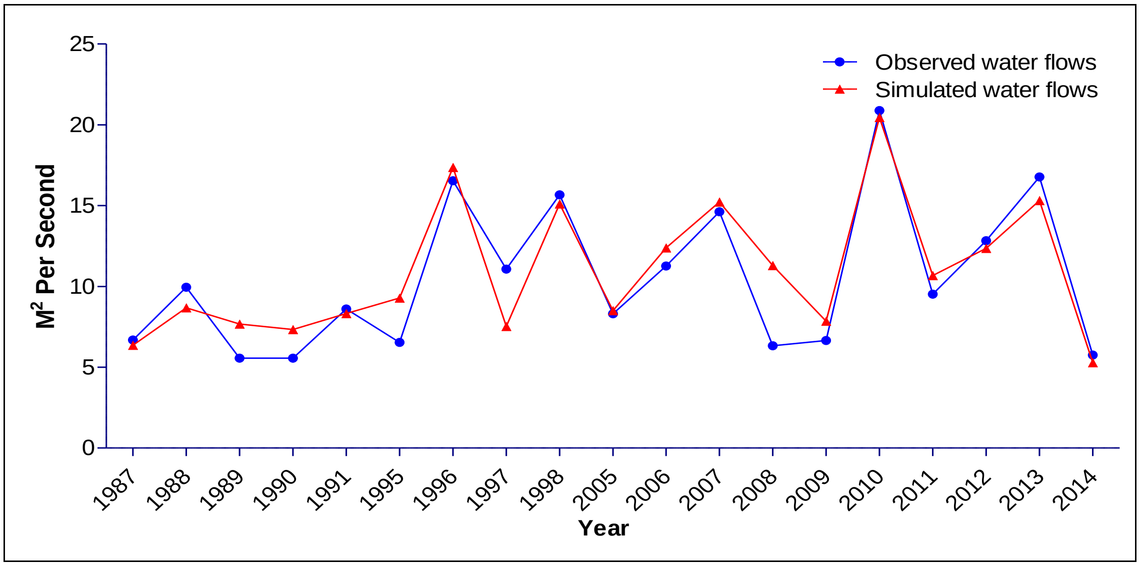

Figure 4.54. *Observed and simulated water flows along Nyangores tributary*

In Amala sub-catchment the observed and simulated mean annual stream flows were also closely similar, both peaking and dipping between 1988 and 2003, with slight differences in magnitude being observed between 2004 and 2017 (Figure 4.55). An equally high Coefficient of determination of R^2=0.94 was also noted between the observed and simulated mean annual stream flow along Amala tributary. These results were used to aid in the validation of the SWAT model. Melesse *et al.* (2007) posted similar results in the Nyangores and Amala tributaries indicating that the calibrated model performed equally well at replicating the peaks in most cases.

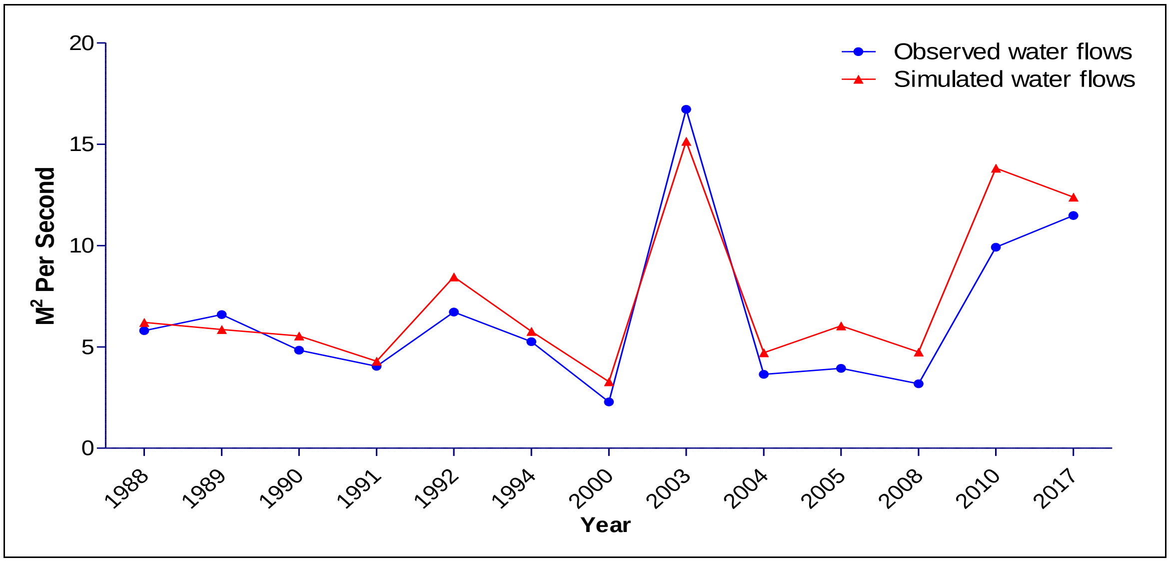

Figure 4.55. *Observed and simulated flow along Amala sub-catchment (1988-2017)*

From the results the retrospective observed and simulated mean annual stream flows in both Nyangores and Amala sub-catchments are similar and hence model was well calibrated.

4.2.4. Impacts of land cover changes on simulated annual mean flows

In Nyangores sub-catachment, results (Table 4.15) showed a strong coefficient of determination between simulated annual mean flows and land cover categotoes. Shrubland showed hghest correlation of (R^2=0.76), followed by grassland (R^2=0.61), forestland (R^2=0.60), and low on bareland (R^2=0.21), cropland (R^2=0.12) and builtup areas (R^2=0.13). In Nyangores therefore shrubland contributes most to annual mean flows compard with other land covers; while builtup areas is the least contributor beause the more the built upareas the higher the water surface runoff and hence reduced percollation and stream flows. This implies that when forest land, shrubland and grassland increased, the simulated annual mean water flow increased; and when cropland, bareland and built up areas increased, simulated annual mean water flows along the Nyangores tributary reduced (Table 4.15).

A number of assessments of the impact of forest cover expansion on the water balance of watersheds have reported reductions in annual runoff especially in drier regions and in areas where forests have replaced grasslands or shrub lands (Liang *et al.*, 2015; Trabucco *et al.*, 2008). The same result was found by Mezgebu (2021), that between 1989 to 2000, total surface runoff and stream flows were inceased due to effect of land cover and climate variation in Hayke Lake basin in Ethiopia, Table 4.18.\

Table 4. 18. ***Coefficient of determination between between simulated mean flows and Land cover changes of Nyangores sub-catachmnt btw 1987-2017***

Years	Simulated mean annual water flows	Forest	Grassland	Shrub-land	Crop land	Bare land	Built-up area
1987-1997	9.78	41031	27681	1014	21835	2279	47.4
1998-2007	10.41	40897	23817	1598	24572	2455	65.53
2008-2017	9.33	40510	21712	1070	26983	2663	80.5
Coefficient of determination (R2) between Water Flows and Land cover categories		0.60201708	0.6056657	0.75768846	0.14533485	0.20976439	0.13252803

This points to the greater role that grasslands and forests play in boosting water yield and by extension to stream flow. In Amala sub-catachment, results (Table 4.16) showed a strong coefficient of determination between simulated annual mean flows and land cover categotoes. Builtup area contributes most to annual mean flows (R^2=0.99), followed by cropland (R^2=0.89), forestland (R^2=0.82), grassland (R^2=0.76), shrubland (R^2=0.74) and low bareland (R^2=0.06). This phenomana in Amala shows how builtup areas can contribute most in annual mean flows as built up areas contribute water as local catchments and direct water to steams. This occurs in the sub-catachments where a lot of deforestation happended; and hence changes hydrology regeme of the area.

The findings of the present study are consistent with those reported by Foley *et al.* (2011), that, land use/land cover changes have the capacity to transform most of the planet’s land surface including hydrology with a great deal of land conversion being witnessed at the expense of forests, Table 4.19.

Table 4.59. ***Coefficient of determination between between simulated mean flows and Land cover changes of Amala sub-catachmnt btw 1987-2017***

Years	Simulated annual mean water flows	Forest land	Grass land	Shrub land	Crop land	Bare Land	Builtup areas
1987-1997	76.58	56609	44269	6418	29828	5068	34
1998-2007	74.73	34830	46186	3477	56415	1894	44
2008-2017	70.84	25798	36625	2738	73168	3691	65
Coefficient of determination (R2) between Water Flows and Land cover categories		0.82099905	0.76009584	0.7400498	0.89337037	0.05881821	0.9999999

These findings imply that as grass land increased, the simulated annual mean water flow increased and when bare land increased, simulated annual mean water flows reduced. The phenomenal changes in land cover observed between 1987 and 2017 in Amala sub-catchment could be the cause of the correlations noted between simulated annual mean water flow and land cover change in Amala sub-catchment. Similar results were obtained by Khalid *et al.* (2017) where the results of one degraded sub-catchment showed annual streamflow increased by 75% between 1972 and 1986, followed by a decrease of 45% between 1986 and 1998. It was reported that the increase in streamflow was the result of a decrease in woodland by 60% between 1972 and 1986 which was associated with an increase in cropland and grassland.

Indeed, the findings emanating from the current study concur with these findings in which a correlation analysis established that stream flows had a strong positive correlation with grasslands followed by forests in both Amala and Nyangores sub-catchments. This implies that grasslands contributed much more to stream flows compared to other land cover types like forest cover and shrub-lands.

Consistent with current study findings, Hudson *et al.* (1997) concur that trees have the ability to use more water than most other types of vegetation, while Kirby *et al.* (1991) reported that forested catchments used larger amounts of water than grasslands.

Likewise, percolation, which contributed to high water yield and stream flows, also showed a strong positive correlation with grass lands and forest cover in both Amala and Nyangores sub-catchments than other land cover types. This implies that an increase in grasslands and forest cover resulted to an increase in percolation and subsequent increase in water yield and stream flows, while an increase in crop land, bare land or built-up areas resulted to a reduction in percolation and by extension the water yield and stream flows. Nevertheless, given the many other benefits of forest restoration, improving the communities' understanding of why forest restoration is important to the community and to the species can lead to recovery of water yields and is therefore crucial to help improve positive outcomes and prevent unintended consequences (Filoso *et al.*, 2017). Based on the foregoing, water catchment managers, forestry, and agriculture experts among others can now locate and advise on which areas, if well managed, can increase stream flows due to the nature of the area by having higher soil water availability, water percolation, and water yields; as well as where to plant appropriate grasses and tree species.

Study conducted in Mara River basin by Hosea *et al.* (2016), noted that future watershed response of low flows after deforestation depends on the balance between reduced evapotranspiration and the expected decrease in water infiltration/percolation due to degradation. If land degradation reaches a point where water infiltration is reduced to the extent that the quick flows exceeds the gain in baseflow associated with reduced evapotranspiration after forest removal, then the dry season flows would decline. Mwetu (2019) noted decrease trend of annual discharge that were corespended to inceased deforestation.

4.3. Forecasting future pattern of the land cover changes by 2027 in the four sub-catchments

The CA-Markov model was used to predict land cover change trends into the future (2027) to gain an understanding of the future ten years' land cover dynamics at sub-catchment level (Nyangores, Amala, Sand and Talek) in the Mara River Basin of Kenya to form the Forest, Agriculture, water and other land management to ensure increased sub-catchments stream flows managers. However, the complex processes of future land cover change are not easy to capture using just variables, and model in algorithms, since they are often shaped by dynamic, non-linear human-nature interactions (Camacho *et al.*, 2015).

The present study projected land cover change in all four sub-catchments by 2027 to guide sub-catchments land cover management planning and aid in developing strategies to increase forest cover, shrub and grass lands which were identified by this study as major factors that influence stream flows. Münch *et al.* (2017) observed that land cover classification is fraught with uncertainties and these uncertainties are propagated through errors in historic change quantification and indeed future scenario mapping too. It is therefore important to take cognizance of this limitation and any interpretation of results should be done with these accuracies in mind. Knowing the limitation, ground truthing was conducted to ascertain the accuracy of model results on transitional probability and land cover prediction status made from 2007 to 2017. The ground truthing results was very good which guaranteed the use of model to predict for 2027. Studies indicated that the use of CA-Markov model on land cover dynamics is likely to influence the direction and magnitude of changes that are likely to occur in the future (Singh *et al.*, 2014).

4.3.1. Sub-catchments land cover change transitional probability

To assess where direction and magnitude of land cover changes is expected to occur by 2027, transition probability matrices were derived from Markov chain analysis and predicted land cover maps were generated through CA-Markov model. The MMULT in EXCEL function was used and through multi-step operation, the transition probability matrix Pij was obtained and used to simulate the changes for the future. Table 4.17, 4.18, 4.19, and 4.20 show the simulated change trends of land cover types in all sub-catchments from 2007 to 2027 (next 10 years). The simulation is well-defined, when the value of indicators is equal to 1 and unsatisfactory when it is equal to 0 (Singh *et al.,* 2015). Eastman *et al.* (2006) stated that 0.80 is acceptable accuracy rate to make plausible future predictions. The following are the results delivered from Markov chain analysis.

4.3.1.1. Sub-catchments transitional probability matrix

The results show in all sub-catchments the simulation is well-defined, and the value of indicators are between 0.99 and 1 which is acceptable and Validation Kappa indices for each map were above 0.8 that is 0.901 for Amala, 0.898 for Nyangores, 0.938 for sand and 0.963 for Talek

(Tables 4.17 to 4.20). The results from Nyangores sub-catchment indicated that grassland and shrub lands had the highest potential of changing from 2007 to 2017 into crop land by 73% each, forest land to crop land by 17% (0.17), forest land to grass land by 14% (0.14); while built up areas to all land cover except into shrub land. The likelihood/probability of grass land changing to crop land in the next 10 years was 73% (0.73), shrub land to crop land was 73% (0.73), bare land to crop land was 76% (0.76); while the likelihood of forest land to remain forest land was 66% (0.66), and crop land to remain crop land was 82% (0.82) (Table 4.20).

Table 4.20:. *Transitional probability matrix for Nyangores sub-catchment (2017-2027)*

Land cover type	**Probability of changing by the year 2027 from 2007**						**Total**	**Loss**
	Forest land	**Grass land**	**Shrub land**	**Crop land**	**Bare land**	**Built-up area**		
Forest land	0.656541	0.144	0.01908	0.17016	0.01007	0.00016	**1.00**	**0.34**
Grass land	0.044171	0.11888	0.00494	0.72793	0.10201	0.00207	**1.00**	**0.88**
Shrub land	0.030252	0.14238	0.00059	0.73067	0.08688	0.00395	**0.99**	**0.99**
Crop land	0.041294	0.08228	0.00247	0.82219	0.05177	0	**1.00**	**0.18**
Bare land	0.002294	0.0971	0	0.76147	0.13685	0.00023	**1.00**	**0.86**
Built-up areas	0.00813	0.04472	0	0.18293	0.01626	0.74797	**1.00**	**0.25**
Total	**0.782682**	**0.62934**	**0.027083**	**3.395338**	**0.403834**	**0.754382**	**6.0**	
Gain	**0.126141**	**0.510464**	**0.026488**	**2.57315**	**0.266984**	**0.006415**		

In Amala sub-catchment, shrub land and bare land had the highest potential of changing into crop land by 53% (0.53) and 68% (0.68) respectively, in the next 10 years, while built up areas were not likely to change into any other land cover category (1%). The likelihood/probability of grass land changing to forest land was 45% (0.45), grass land to crop land was 20%, shrub land to grass land was 29%, crop land grass land was 23%; grassland to forest land was 45%; while the likelihood of forest land to remain forest land is 80%, cropland to remain cropland is 69% (Table 4.21).

Table 4.21:. *Transition Probability Matrix for Amala sub-catchment (2007-2017)*

Land cover type	**Probability of changing by the year 2027 from 2017**						**Total**	**Los s**
	Forest land	**Grass land**	**Shrub land**	**Crop land**	**Bare land**	**Built-up areas**		
Forest land	0.809	0.090	0.013	0.081	0.009	0.000	1.00	0.19
Grass land	0.453074	0.26037	0.07237	0.198	0.016	0	1.00	0.74
Shrub land	0.125763	0.28834	0.02904	0.53287	0.024	0	1.00	0.97
Crop land	0.038497	0.23328	0.01366	0.69706	0.018	0	1.00	0.30
Bare land	0.054522	0.2367	0.00876	0.68097	0.019	0	1.00	0.98
Built-up areas	0	0	0	0	0	1	1.00	0.00
Total	**1.480**	**1.108**	**0.137**	**2.189**	**0.086**	**1.000**	**6.00**	
Gain	**0.672**	**0.848**	**0.108**	**1.492**	**0.067**	**0.000**		

In the Sand sub-catchment, the highest transition probability was expected to change from grass land to shrub land 53% (0.53), with the likelihood /probability of changing from bare land to shrub-land being 48% (0.48), while the likelihood/probability of forest to remaining as forest was 57% (0.57), forest land to change to grassland was 38% (0.38), shrubland to change to grassland was 41% (0.41), shrub land to remain shrub land was 53%(0.53); and bare land to change to grassland was 22% (0.22), and bare land to remain bareland is 30%(0.30); (Table 4.22).

Table 4.22:. *Transition probability matrix for Sand River sub-catchment based on 2017-2027*

Land cover type	**Probability of changing by the year 2027 from 2017**				**Total**	**Loss**
	Forest land	**Grass land**	**Shrub land**	**Bare land**		
Forest land	0.571987	0.37674	0.05018	0.00109	**1.00**	**0.43**
Grassland	0.043466	0.37	0.53	0.06	**1.00**	**0.63**
Shrub land	0.017485	0.40707	0.53481	0.04064	**1.00**	**0.47**
Bare land	0	0.22183	0.47852	0.29965	**1.00**	**0.70**
Total	**0.632938**	**1.375731**	**1.593308**	**0.398022**	**4.00**	
Gain	**0.060951**	**1.01**	**1.058498**	**0.09837**		

In Talek sub-catchment, the highest transition probability was a change from bare land to forest land 72% (0.72), grass land to forest land at 55% (0.55), shrub-land to forest land at 37% (0.37) and grass land to shrub land was at 37% (0.37) (Table 4.23).

Table 4.23. *Transition potential matrix for Talek Sub-catchment based on the 2017-2027 changes*

Land cover type	**Probability of changing by the year 2027 from 2017**				**Total**	**Loss**
	Forest land	**Grassland**	**Shrub land**	**Bare land**		
Forest land	0.755453	0.09977	0.14403	0.00074	**1.00**	**0.24**
Grass land	0.546455	0.01769	0.37169	0.06417	**1.00**	**0.98**
Shrub land	0.372432	0.03793	0.50166	0.08798	**1.00**	**0.50**
Bare land	0.717363	0.00026	0.22891	0.05347	**1.00**	**0.95**
Total	**2.391703**	**0.155649**	**1.246294**	**0.206346**	**4.00**	
Gain	**1.63625**	**0.137964**	**0.501656**	**0.152881**		

4.3.2. Sub-catchments forecasted land cover change by 2027

The simulated results based on a CA-Markov model indicates the projected changes likely to be observed in the various sub-catchments.

4.3.2.1 Nyangores forecasted land cover by 2027

In Nyangores sub-catchment, shrub land is predicted to increase the most with a percentage change of 122.10% followed by built up areas (73.37%), grass land (29.0%) and forest land (8.37%) within Nyangores tributary by 2027. However, crop land and bare land are expected to reduce by -18.57% and -5.32% (Table 4.24, and Figures 4.56 and 4.57).

Table 4.24. *Forecasted land cover by 2027 in Nyangores sub-catchment*

Land cover category	1987 Area (Ha) and % of total area	1997 Area (Ha) and % of total area	2007 Area (Ha) and % of total area	2017 Area (Ha) and % of total area	Projected land cover by 2027 area (Ha)	% change btw 2017 to 2027 (10 yrs.)
Forest	41031 (43.7%)	40897 (43.8%)	40510 (43.6%)	30164 (32.3%)	32688.6	8.37%
Grassland	27681 (29.5%)	23817 (25.5%)	21712 (23.3%)	15997 (17.1%)	20636.13	29.00%
Shrub Land	1014 (1.1%)	1598 (1.7%)	1070 (1.2%)	789 (0.8%)	1673.5	112.10%
Cropland	21835 (23.3%)	24572 (26.3%)	26983 (29.0%)	42690 (45.7%)	34761.97	-18.57%
Bare Land	2279 (2.4%)	2455 (2.6%)	2663 (2.9%)	3721.6 (4.0%)	3523.6	-5.32%
Built up areas	47.4 (0.01%)	65.53 (0.1%)	80.5 (0.1%)	105.9 (0.1%)	183.6	73.37%

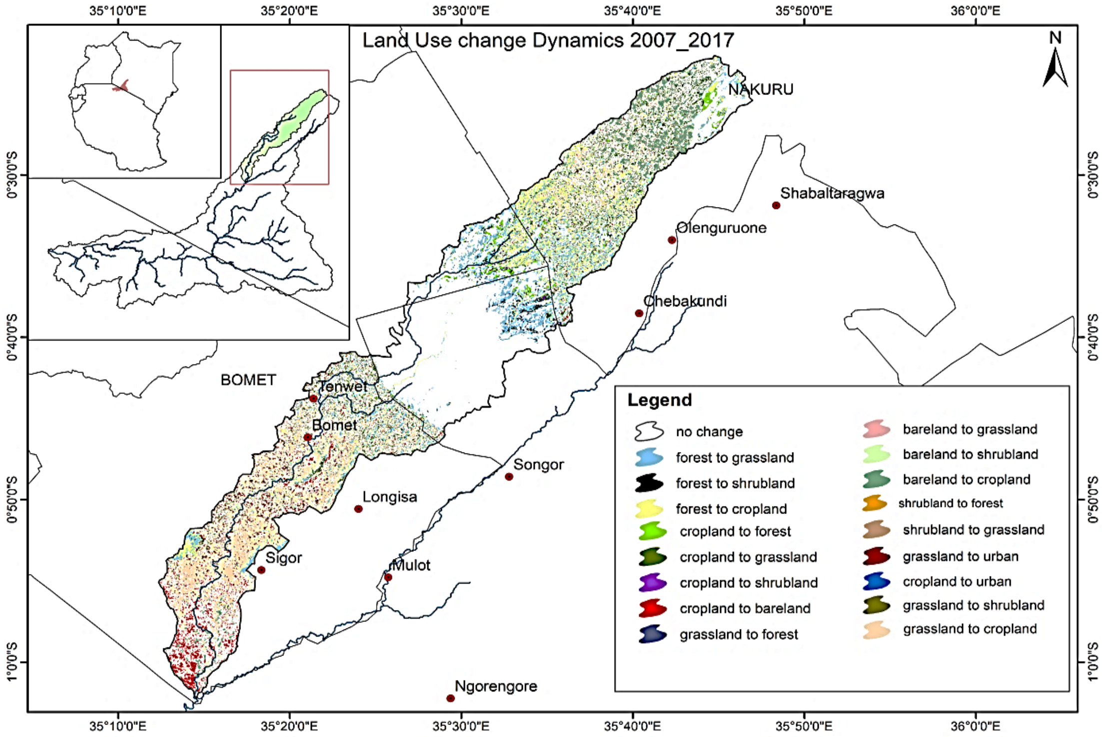

Figure 4.56. *Land dynamics 2007-2017 Nyangores*

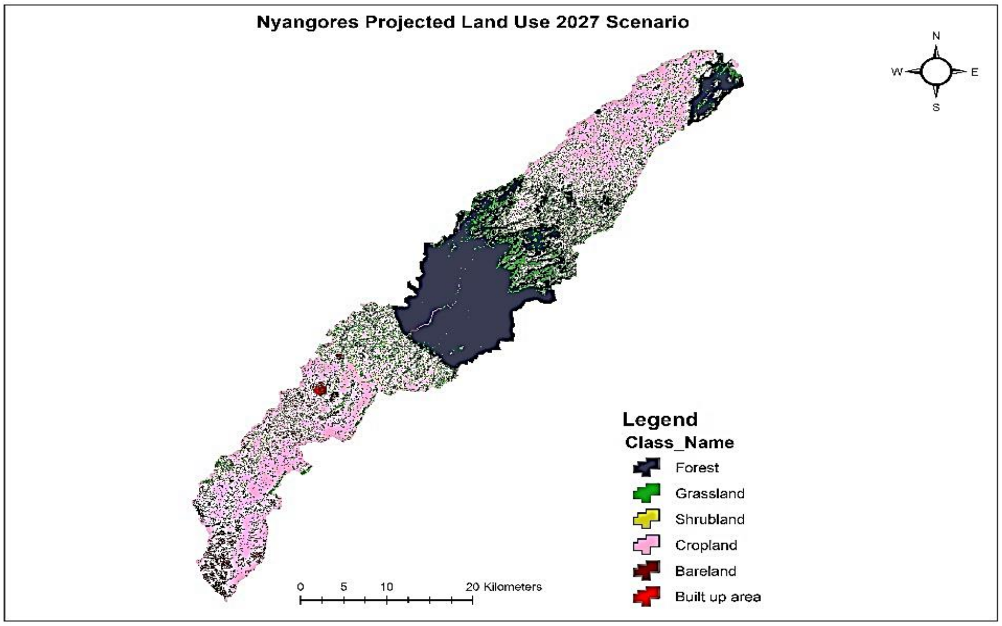

Figure 4.57. *Land cover change 2027 Nyangores*

4.3.2.2. Amala forecasted land cover by 2027

In Amala sub-catchment, it is predicted that shrub-land, grassland and forest land are likely to increase by 22.86%, 13.31% and 5.95%, respectively, while crop lands and bare land are likely to reduce by -8.50% and -6.05%, respectively. Built up areas was predicated to increase by 45.63% (Table 4.25 and Figure 4.58 and 4.59).

Table 4.25: *Projected land cover from 2017 to 2027 within Amala sub-catchment*

Category	1987 Area (Ha)	1997 Area (Ha)	2007 Area (Ha)	2017 Area (Ha)	Projected land cover by 2027 Area (Ha)	% change between 2017 to 2027 (10 years)
Forest	56609 (39.8%)	34830 (24.4%)	25798 (18.2%)	29784 (21.0%)	31556	5.95
Grassland	44269 (31.1%)	46186 (32.3%)	36625 (25.8%)	31550 (22.2%)	35750.7	13.31
Shrub Land	6418 (4.5%)	3477 (2.4%)	2738 (1.9%)	2495 (1.8%)	3065.4	22.86
Cropland	29828 (21.0%)	56415 (39.5%)	73168 (51.5%)	75574 (53.2%)	69152.7	-8.50
Bare Land	5068 (3.6%)	1894 (1.3%)	3691 (2.6%)	2615 (1.8%)	2456.7	-6.05
Built up areas	34 (0.02%)	44 (0.03%)	65 (0.05%)	80 (0.06%)	116.5	45.63

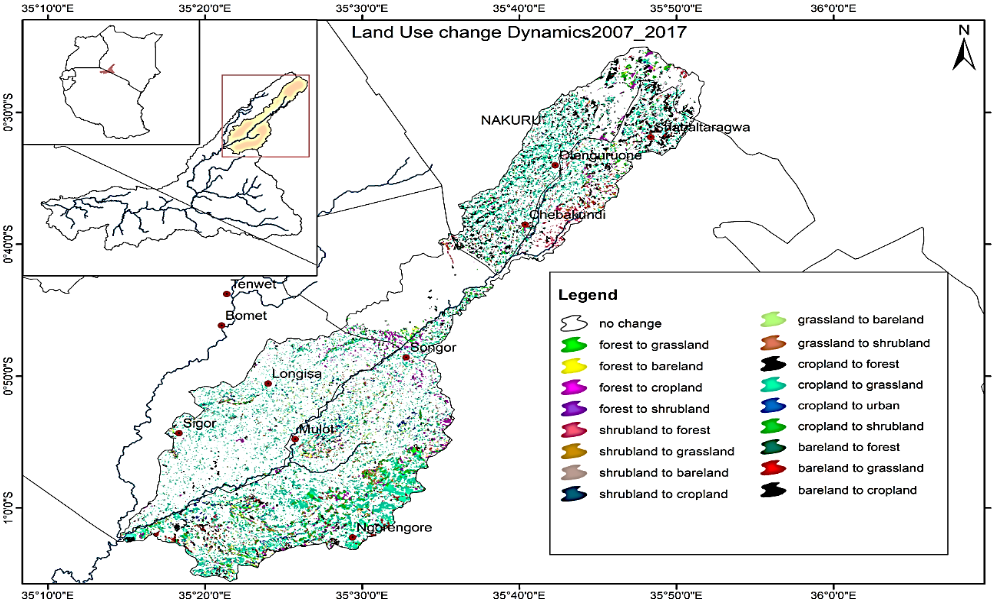

Figure 4.58. *Land dynamics 2007-2017 Amala*

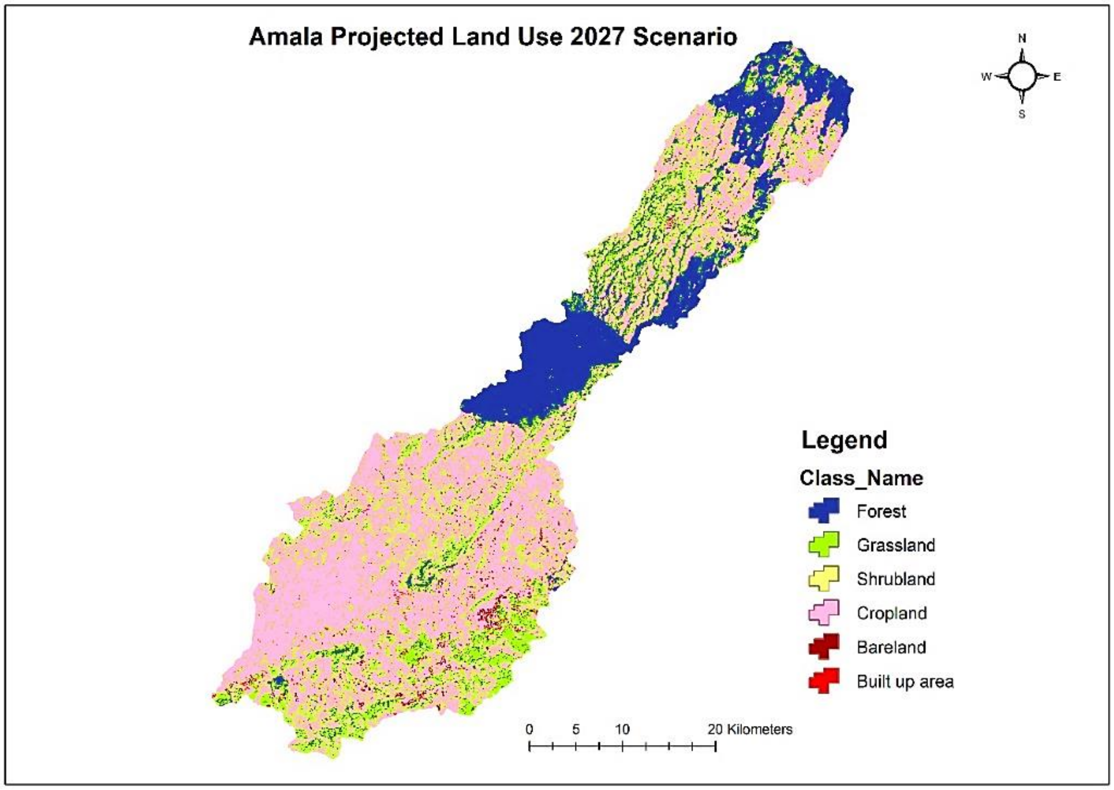

Figure 4.59. *Land cover change 2027 Amala*

4.3.2.3. Sand River sub-catchment forecasted land cover by 2027

In Sand river sub-catchment, it is predicted that the greatest projected land cover change by 2027 is likely to be a reduction in bare land by -55.70%, while grass land, forest land and shrub-land are likely to increase slightly by 10%, 6% and 6%, respectively, (Table 4.26, and Figure 4.60 and 4.61).

Table 4.26. *Forecasted land cover from 2017 to 2027 in Sand River sub-catchment*

Category	1987 Area (Ha)	1997 Area (Ha)	2007 Area (Ha)	2017 Area (Ha)	Projected land cover by 2027 Area (Ha)	% change btw 2017 to 2027 (10 yrs.)
Forest	13955 (7.6%)	9991 (5.5%)	8184 (4.5%)	7986 (4.4%)	8465.16	6
Grassland	87106 (47.4%)	86467 (47.2%)	81804 (44.7%)	79884 (43.6%)	87872.4	10
Shrub land	80217 (43.6%)	78847 (43.1%)	76801 (42.0%)	72183 (39.4%)	76513.98	6
Bare land	2510 (1.4%)	7785 (4.3%)	16257 (8.9%)	22977 (12.6%)	10178.5	-55.70

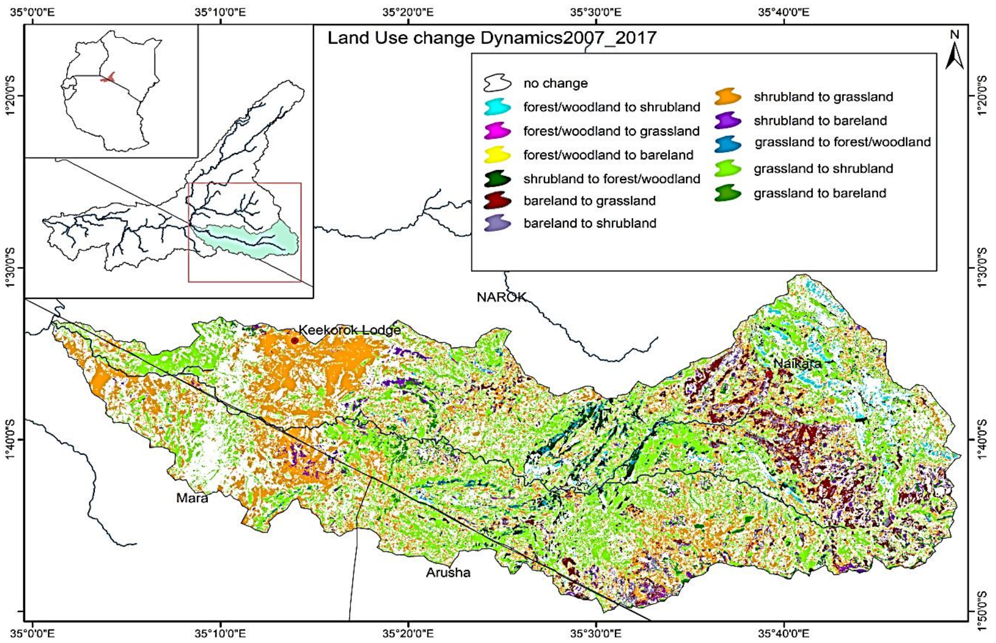

Figure 4.60. *Land dynamics 2007-2017 Sand*

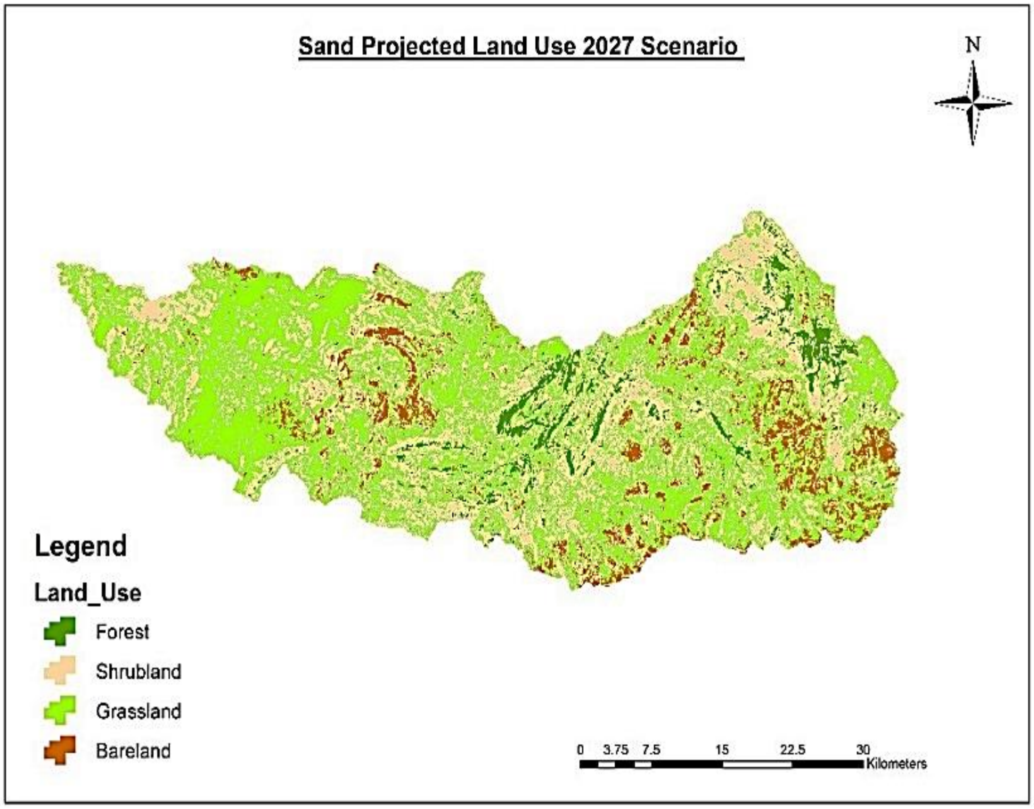

Figure 4.61. *Land cover change 2027 Sand Sub-catchment*

4.3.2.4. Talek sub-catchment forecasted land cover by 2027

In Talek sub-catchment, the greatest projected land cover change by 2027 is in crop land and bare land both at negative -40.0%. However, slight positive changes are expected in forest land (4.0%), grass land (3.5%) and shrub land (2.0%) by 2027 (Table 4.27, and Figure 4.62 and 4.63).

Table 4.27. *Forecasted land cover from 2017 to 2027 in Talek River sub-catchment*

Category	1987 Area (Ha)	1997 Area (Ha)	2007 Area (Ha)	2017 Area (Ha)	Projected land cover 2027 (Ha)	% change btw 2017 & 2027 (10 yrs.)
Forest	12357 (7.0%)	15138 (8.6%)	7673 (4.4%)	4939 (2.8%)	5136.56	4.0
Grassland	92493 (52.8%)	82989 (47.2%)	85005 (48.4%)	62708 (35.7%)	64902.78	3.5
Shrub land	62757 (35.8%)	74286 (42.2%)	79786 (45.4%)	98079 (55.9%)	100040.58	2.0
Cropland	0 (0.0%)	0 (0.0%)	0 (0.0%)	5607 (3.2%)	3364.2	-40.0
Bare land	7723 (4.4%)	3472 (2.0%)	3166 (1.8%)	4244 (2.4%)	2546.676	-40.0

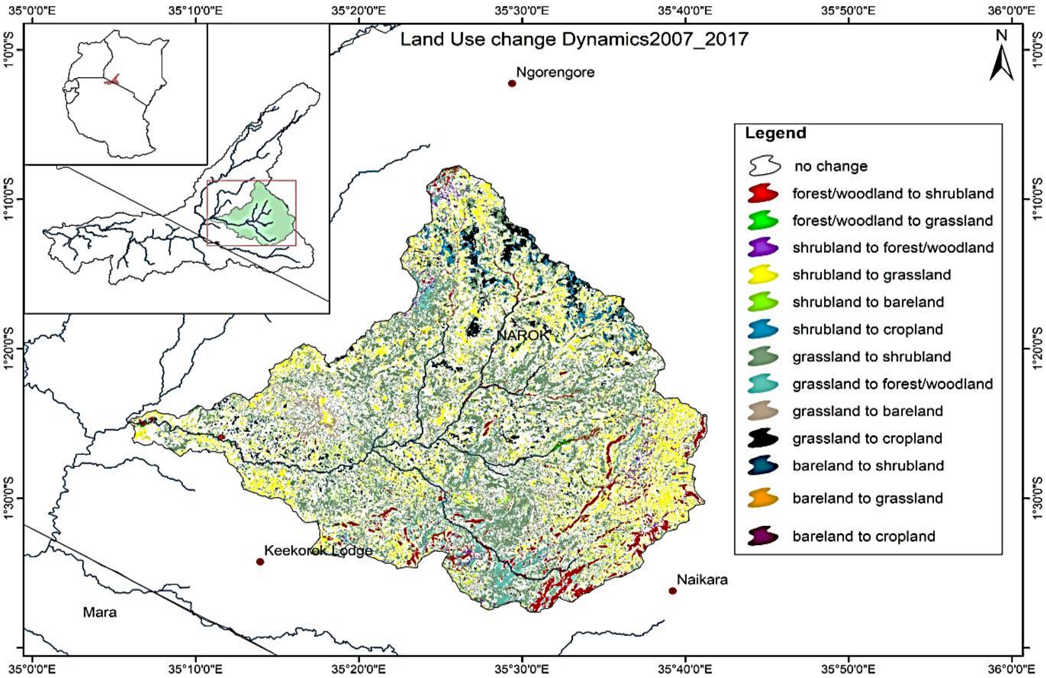

Figure 4.62. *Land dynamics 2007-2017 Talek Sub-catchment*

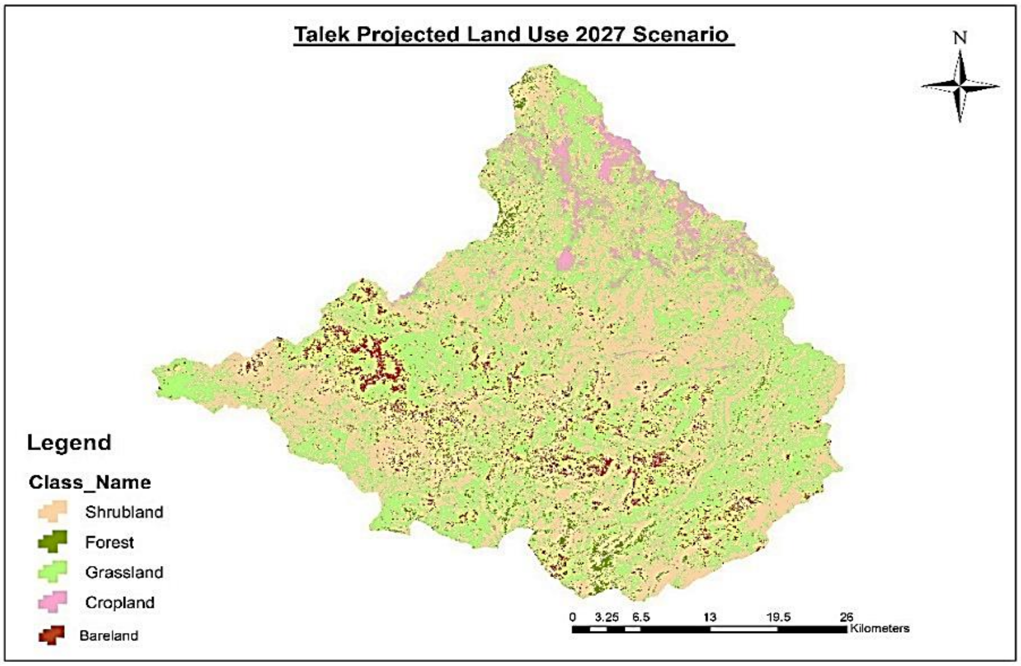

Figure 4.63. *Land cover change 2027 Talek Sub-catchment*

Restoration of the Mara River ecosystem by the Government of Kenya and other partners since 2006 could have contributed to the prediction of an increased forest cover among other land use types by 2027. Respondents in household survey were aware of the importance of conservation and protection of natural resources. Restoration of a section of the Nyangores sub-catchment following the Kenya government's restoration programme led to the re-establishment of forest cover in an area whose forest cover had almost been wiped out (GoK, 2007). This is classical proof that with the right policies and good will, restoration of destroyed forests is indeed possible.

This present study provides evidence of effects of the Mara river basin restoration that has been spearheaded by the Government of Kenya and the county governments of Narok and Bomet, alongside other partners like World Wide Funds for Nature (WWF) funded by the government of Norway, United States Agency for International Development (USAID) East Africa office, Federal Ministry of Economic Cooperation and Development (BMZ), Lake Victoria Basin Commission funded by USAID East Africa; World Vision; and Community effort within the basin.

The restoration efforts included reforestation of degraded Mau and Mara River basin riverine ecosystem, implementation of soil and water conservation initiatives in the farmlands to reduce erosion and improve soil fertility, establishment of sub-catchment community based water resources management through established registered Water Resources Users Associations (WRUAs) as well as advocating for transboundary Mara river Basin initiatives to jointly manage water resources within Mara River basin. The other effort was to act on the Mau forest encroachments which allowed big part of Masai Mau the source of Amala sub-catchment to regenerate from crop to grass, then to shrub and forest lands. The results moreover suggest that, with proper interventions therefore, forest, grassland, shrub, built up lands are likely to increase, while crop land and bare lands are likely to decrease by 2027. The little successes imply that with proper interventions, it is possible to restore Mara River basin sub-catchments and the whole Mara River basin health if government of Kenya and other partners commit to it and continue with their efforts. Besides highlighting the potential serious environmental consequences, these findings have important implications for the management and development of water resources within the Mara River basin as well as all those dependent on the basin.

4. 4. Socio – economic impacts of land cover change on the sub-catchments' inhabitants

The socio-economic study conducted for this study revealed the following impacts.

4.4.1. Household socio-demographic characteristics

Most respondents (272, 65.1%) were males whereas females constituted 34.9% (n = 146). Up to 89.2% of the respondents were aged between 35 - 65 years, while 5.1% were between the ages of 25 and 34 years, and 5.7% were above 65 years. The number of family members per household ranged from 1 to 7 persons, with the average family size being 5.4 persons. The number persons in the economically dependent age groups (0 - 14) and elderly (65 and above) varied from family to family, with 66.1% of the households having a dependency ratio of between 0.0 and 0.5, while 33.9% had a dependency ratio of between 0.5 and 3. Almost half the household heads (49.8%) had high school level of education or above, while 38.7% had primary level of education. However, 11.5% of the respondents were illiterate. Most (60.3%) of the surveyed households engaged in mixed farming, while 39.7% engaged either in some form of business, informal labour.

4.4.2. Impacts of Land Cover Change on Socio-Economic Wellbeing

4.4.2.1. Impact of land cover change on livestock production

Livestock is an important sector of the rural economy in the four sub-catchments studied. Results showed that 95% of the households kept some livestock. Responses on the effect of land cover change on livestock production varied among respondents. Whilst 43.9% believed that changes in land cover affected livestock in their region, 19.6% thought otherwise, while 0.2% did not know and 4.1% did not respond to the question. Another 32.8% felt that the question was not applicable to them. Nevertheless, there was a general consensus that decreased levels of rainfall and prolonged droughts in recent times had impacted on livestock production. Respondents mentioned diminishing grasslands (29.7%), diminishing pasture (20.3%), diminishing shrub land (14.8%), diminishing tree cover (17%), diminishing water resources (11.7%), among others as some of the effects of livestock production and climatic factors on land cover (Table 4.28).

Table 4.28. *Impact of climatic factors and livestock production on land cover*

	Number	% Response
Diminishing grasslands	124	29.7
Diminishing pasture due to overgrazing	85	20.3
Diminishing tree cover	71	17.0
Diminishing shrub land	62	14.8
Diminishing water resources	49	11.7
Improved grasslands	8	1.9
Improved pasture	8	1.9
Improved water sources	6	1.4
Improved tree cover	3	0.7
Improved shrub land	1	0.2
Other changes	1	0.2
Total	**418**	**100.0**

The socio-economic survey results are consistent with the results from applied software/models of this study that, crop land increased at the expense of grass, shrub and forest lands. The same was reported in Nepal by Uddin *et al.* (2015) and in the transboundary Gandaki River Basin of Central Himalayas by Rai *et al.* (2018). Both studies suggested that land use and land cover changes were largely driven by pressure for increased food production, human settlements, infrastructure development, and tourism activities among other anthropogenic activities coupled with the effect of a rapidly changing climate.

The diminishing grasslands and drying up of water pans in the region are key pointers to livestock production in Talek and Sand River sub-catchments. Reid *et al.* (2014) also reported that climate change, range land fragmentation and rangeland degradation, coupled with settlement schemes often interfere with pasture land creating resources and mobility constraints for pastoralists who are increasingly dependent on livestock mobility. As a result, shortage of water and pasture are increasingly becoming more common triggering farmer-herder conflicts in some areas and human-wildlife conflicts in other areas (Korf *et al.*, 2015; Brottem, 2016).

Demand for trees and their products (fuel and construction wood) also encourage deforestation which exposes the soil to erosion that affects pasture. In the current study, deforestation and increased land fragmentation in the basin were cited as causes of increased soil erosion affecting land cover including grass and shrub as source of livestock fodder. This consequently affects the level of water quality in the nearby rivers and livestock. Consistent with the current findings, Geist *et al.* (2006) concluded that land cover conversions due to demographic pressure are more serious particularly to aquatic ecosystems in tropical regions. The land cover conditions of the

Mara River sub-catchments have also been modified or significantly transformed by the rapidly increasing population pressure. Human population in the basins continues to grow at the expense of limited land resources forcing the inhabitants to encroach on surrounding forests, grass and shrub lands in a bid to produce more food, and hence reduce pasture land.

About 92% of the respondents in the present study reported noticing nomadic movements in the region due to shortage of pasture and water. More than half (53%) the respondents however felt that these nomadic movements had severely degraded pastures, while others associated loss of some vegetation species to overgrazing. Of the 3.6% of respondents who did not keep livestock, 35% of them cited lack of water, 26% lack of pasture land and 22% unfavourable climate as the key reasons for not keeping livestock (Figure 4.64).

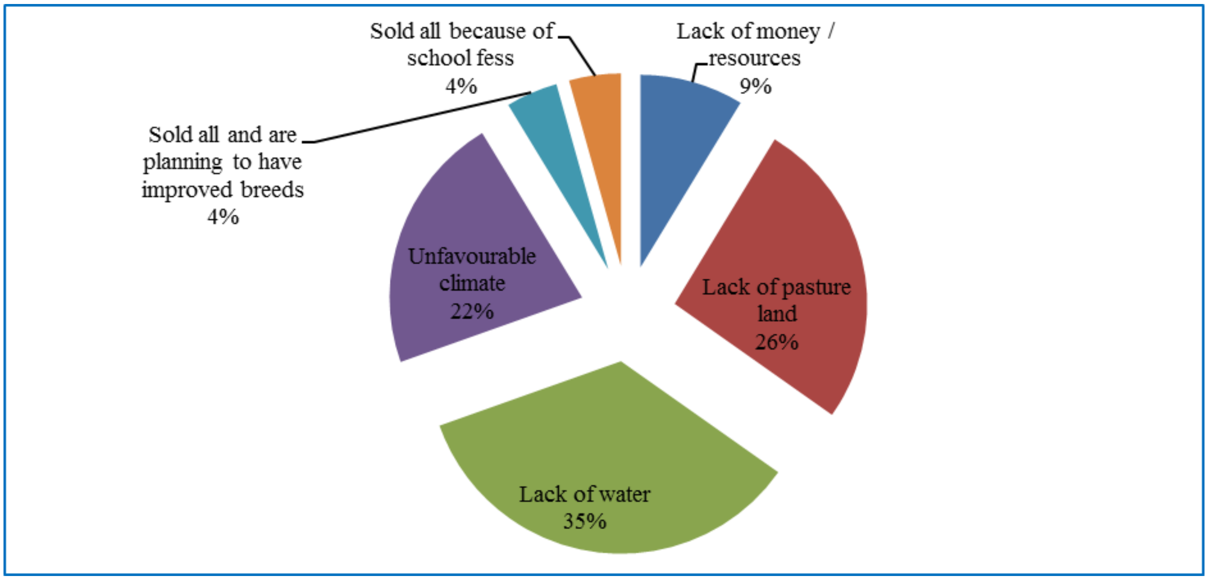

Figure 4.64. *Reason given for not keeping livestock*

A large proportion (95.5%) of respondents believed that changes in land cover affected livestock production. Additional factors attributed to changes in livestock production besides changes in land cover were lack of water (26.6%), prolonged drought (33.5%), and increase in diseases (33.3%) and frequent flooding (4.5%). Most households (90.7%) believe that animal production had considerable effect on land cover change. Over half (54%) of the respondents reported having been affected negatively, while 21% were affected positively (Figure 4.65).

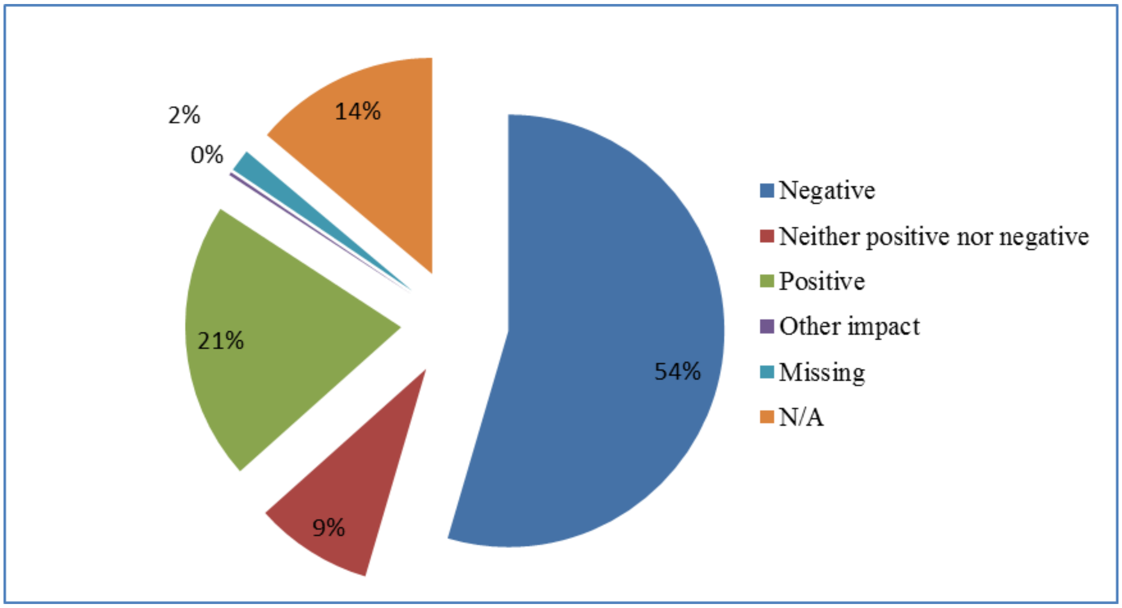

Figure 4.65. *Impact of livestock production on community member's livelihood*

4.4.2.2. Impact of climate and land cover change on crop production

Vegetables, cereals, legumes, tubers, fruits and cash crops were some of the crops grown within the study area. Of these, vegetables were the most commonly stated type of crop accounting for 37.8% of the responses followed by cereals and legumes each at 18.7% and 15.1%, respectively (Table 4.29).

Table 4.29. *Crops grown within the study area*

Variables	Number	% Response
Vegetables	158	37.8
Cereals	78	18.7
Legumes	63	15.1
Tubers	51	12.2
Fruits	41	9.8
Cash crops	24	5.7
No response	3	0.7
Total	418	100.0

Low and declining rainfall, land and soil degradation, over grazing, cultivation without rest periods and poor traditional land tenure systems, were cited as major constraints to crop production in the studied sub-catchments. Most (79.4%) respondents reported witnessing insufficient crop yields over the last 30 years, largely because of rainfall variability, land degradation and a lack of extension services.

Pearson correlation coefficients for annual rainfall Coefficient of Variation (CV) against crop yield for the period 1987-2017 revealed negative correlations for most common basic food crops: i.e. maize ($r = -0.587$), beans ($r = -0.5459$), sorghum ($r = -0.351$), cow peas ($r = -0.544$), and pigeon peas ($r = -0.337$). Shifts in seasons (35.3%), deforestation (30.7%), loss of fertility (13.0), increase in pests and weeds (12.7%) and drought (5.6%) were among the reasons cited for the reduction in crop production (Figure 4.66).

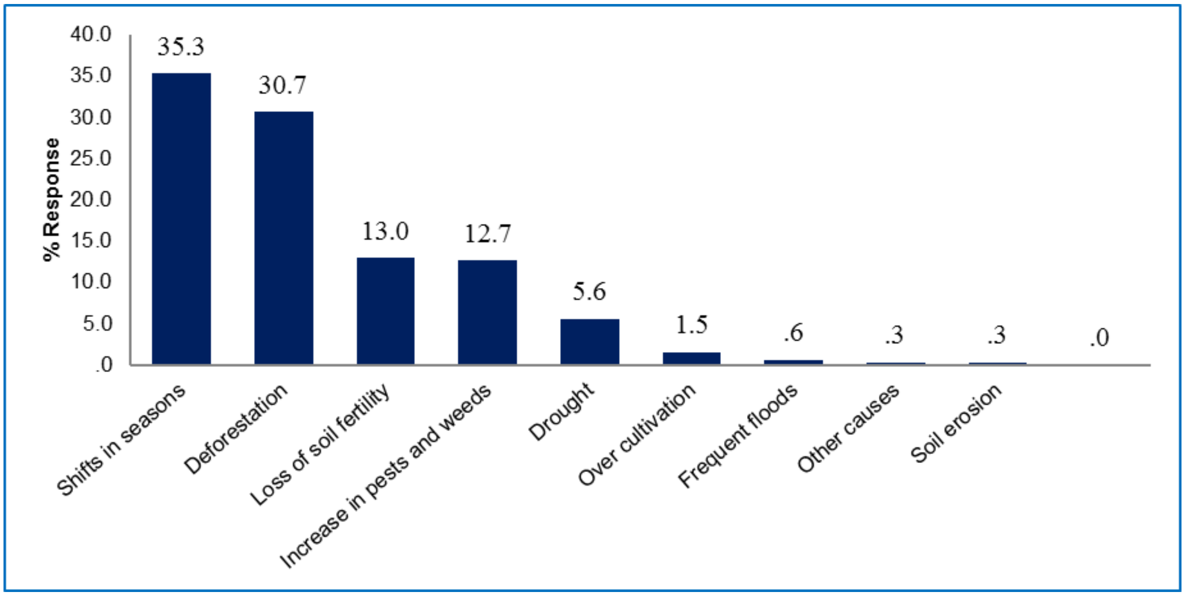

Figure 4.66: *Causes of decrease in crop production within the study area*

On further investigation to establish whether respondents attributed the decrease in crop production to land cover change, 35.1% of households stated that deforestation exposes soil, making it easily erodible, 27.4% stated diminishing vegetation cover exacerbates droughts, 23.5% reported increase in weeds that chock food crops and 11.9% reported excessive uptake of water by alien plant species which dries up the area (Figure 4.67).

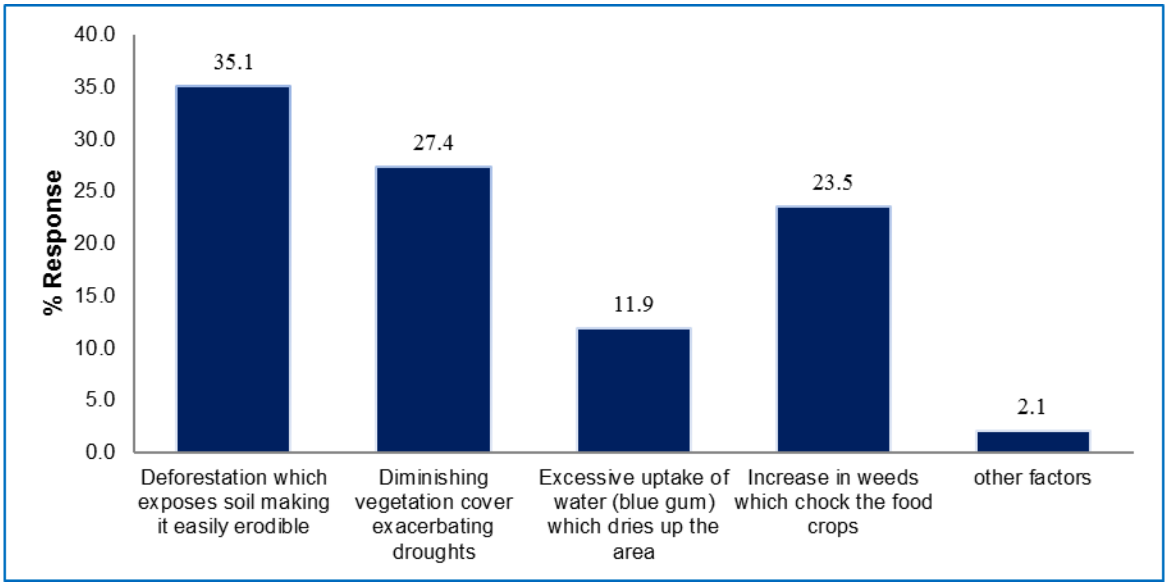

Figure 4.67. *Land cover changes and climatic factors affecting crop production*

4.4.2.3. Impact of climatic factors and land cover change on water resources

Reduction in the availability of water was apparent in all the sub-catchments going by the responses received. Obtaining clean water for drinking from nearby streams and rivers was cited as among the biggest challenge facing water resources accessibility. According to respondents, the main cause of water reduction was lack of rainfall as a result of the cutting down of trees. Almost all (96.4%) respondents associated decrease in river flow to increase in temperature. High temperatures were responsible for decrease in river flow (36.4%), drying up of water pans and drying up of rivers and their tributaries ($\chi^2 = 40.685$, df = 3, $P \leq 0.001$) (Table 4.30).

Table 4.30. *Changes observed in water resources availability over the 30-year period*

Variable	**Number**	**% response**
Drying up of tributaries	67	16.0
Drying up of water pans	86	20.6
Drying up of rivers	113	27.0
Decrease in river flow	152	36.4
Total	418	100
χ^2 test	P<0.001	

Change in rainfall patterns was reported to affect water resources by 98.1% of the respondents. Of these, 38.8% cited decreased water quantity, 33.3% reported increased pollution into rivers, while the rest mentioned increase in respiratory diseases. A large proportion of household respondents (78.1%) cited declining rainfall (32.3%) as the major contributor to water shortages whilst 43% attributed water shortage to disappearance of forest cover. Over 68.2% of respondents mentioned animal deaths as major consequences to decreasing rainfall.

4.4.2.4. Other socio-economic implications of climatic and land cover change

Results showed that some respondents believed that changes in rainfall increased cost of water treatment (25.8%) and decreased crop yields resulting in low household income (16%). Few respondents (9.8%) cited increased yield resulting in high income and decrease in diseases (7.2%). There were varied responses on indicators of changes in rainfall pattern. For instance, 34.2% (n = 40) of respondents in Amala sub-catchment, 45.3% (n = 53) in Nyangores, 12.8% (n = 15) in Sand River and 16.2% (n = 19) in Talek sub-catchment mentioned unpredictable rainfall as a major indicator of change in rainfall patterns. Other indicators mentioned include disappearance of some species of vegetation, heavy rains leading to flooding, too little rainfall leading to prolonged droughts and shift in rainfall seasons (Table 4.31). A chi-square test statistic (n = 418, df = 5, χ 2 = 408.753, P = 00034) supported the notion among the surveyed respondents on the changes that they had noticed concerning changes in rainfall pattern in the four sub catchments.

Table 4.31. *Effect of changes in rainfall on land cover and socio-economic well being*

	Amala	**Nyangores**	**Sand River**	**Talek**	**Total**
Disappearance of some vegetation species	19 (35.2%)	18 (33.3%)	4 (7.4%)	13 (20.1%)	54
High frequency of rains leading to floods	13 (52.0%)	7 (28.0%)	1 (4.0%)	4 (16.0%)	25
Too little rains leading to prolonged droughts	29 (39.7%)	22 (30.1%)	7 (9.6%)	15 (20.5%)	73
Unpredictable rainfall patterns	50 (36.2%)	57 (41.3%)	12 (8.7%)	19 (13.8%)	138
Shift in rainfall seasons	40 (34.2%)	53 (45.3%)	15 (12.8%)	19 (16.2%)	117
Other indicators	1 (100%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1
Total	**152**	**157**	**39**	**70**	**418**

4.4.2.5. Effect of climate and land cover change on human health

Change in land cover has an impact on human health as reported by 84.2% of the respondents. On the contrary, 14.6% stated that the changes did not have any human health implications. Majority (68.2%) of the respondents reported an increase in malaria fever and malnutrition due to land cover change while 15.3% reported a decrease in malnutrition and malaria incidences as a result of changes in land cover. Up to 43% of respondents were of the opinion that new ailments such as high blood pressure, cancer and diabetes had also emerged with onset of climate change, resulting in high cost of health care. Skin rash, toothaches, headaches and flu were other ailments mentioned as occurring due to climate-related changes.

4.4.2.6. Human-wildlife conflicts resulting from land cover change

Results showed that 87% of the households had experienced some form of human-wildlife conflict over the study duration. Of the households who had experienced some form of human wildlife conflict, death or injury by wildlife and destruction of crops accounted for 58.11% and 40.54% of the responses, respectively. Insecurity within the community accounted for 50% of responses on the consequences of human-wildlife conflicts. Increased hospital bills for those injured and court fines resulting from killing of wildlife both accounted for 19%, whereas reduced working hours during crop production accounted for 13% of the responses on consequences of human-wildlife conflicts (Figure 4.68).

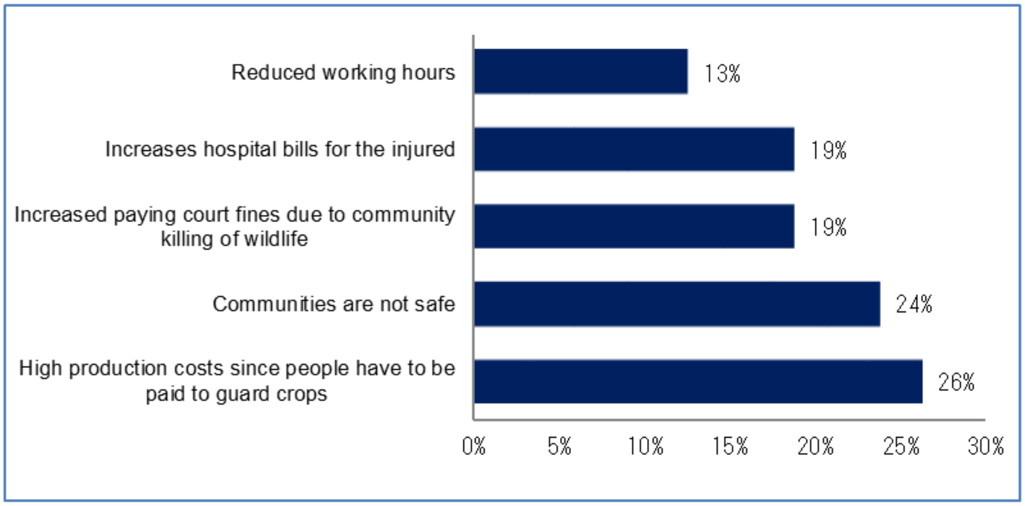

Figure 4.11. *Consequences of human – wildlife conflict on human wellbeing*

Only 19.9% of respondents practiced wildlife co-management, compared to 70.8% who did not and 9.3% who did not respond to the question. With regard to effect of land cover change on wildlife, only 36.6% of the respondents responded, out of whom 12.9% noted that low wildlife population leads to reduction in tourism in the region, 10.5% cited reduced income from tourism while 10% cited reduced crop yields resulting from wildlife destruction of crop farms.

4.4.2.7. Effects of land cover change on household income

Monthly household income was dependent on the effects of changes in rainfall and temperature patterns on household's wellbeing ($\chi^2 = 35.531$, $P = 0.039$). Even within the farming community, climatic changes are contributing to the widening of this income gap, because the adverse effects of climatic changes (Alam *et al.* 2011) affect poor farmers more. The Even within the farming community, climatic changes are contributing to the widening of this income gap, because the adverse effects of climatic changes (Alam *et al.* 2011) affect poor farmers more. The results were also supported by the fact that fewer households that reported decrease of diseases earned between KES 10,000 and 30,000, with a z-score of −2.2 which was smaller than

1.96 (Table 4.32), suggesting those with lower income were adversely affected by the weather. This is important because z statistic tables can then be used to estimate the probability of the particular value occurring (Kroenke *et al.*, 1996).

Table 4.32. ***Effects of land cover change on household income***

Monthly HH Income		Decrease of diseases	Decreased yield resulting in high HH income	Increase in diseases resulting in high cost of health care	High yield resulting in high HH income	Increased cost of water treatment	Total
Other HH Income	Count	0	2	2	1	0	6
	Expected Count	0.4	1	2.3	0.6	1.6	6
	Residual	-0.4	1	-0.3	0.4	-1.6	
	Std. Residual	-0.7	1.1	-0.2	0.5	-1.2	
Less than 10,000	Count	21	27	68	12	51	182
	Expected Count	13.1	29.2	71	17.9	47	182
	Residual	7.9	-2.2	-3	-5.9	4	
	Std. Residual	2.2	-0.4	-0.4	-1.4	0.6	
10,000-30,000	Count	4	30	58	20	41	157
	Expected Count	11.3	25.2	61.2	15.4	40.6	157
	Residual	-7.3	4.8	-3.2	4.6	0.4	
	Std. Residual	-2.2	1	-0.4	1.2	0.1	
30,001-50,000	Count	2	5	27	6	14	55
	Expected Count	3.9	8.8	21.4	5.4	14.2	55
	Residual	-1.9	-3.8	5.6	0.6	-0.2	
	Std. Residual	-1	-1.3	1.2	0.3	-0.1	
More than 50,000	Count	3	3	8	2	2	18
	Expected Count	1.3	2.9	7	1.8	4.7	18
	Residual	1.7	0.1	1	0.2	-2.7	
	Std. Residual	1.5	0.1	0.4	0.2	-1.2	
Total	Expected Count	30	67	163	41	108	418

These factors are very important for sustainability of small farmers, poverty reduction and reduce income inequality (Alam *et al.* 2010, 2011). Government's attention to these factors will help increase overall productivity to gain self-sufficiency, or close to self-sufficiency, and to ensure food security. Government's supports for technological adaptation to climate change are very important to deal with the climatic problems in the end. Moreover, they need to take income stabilization programs, such as portfolio of investment, saving scheme, minimum income protection by government or insurance to reduce the risk of income loss due to changing climatic conditions and variability.

4.4.2.8 Discussion of qualitative findings

Knowledge of the impact of climate on land cover.

Most FGD participants were aware of climate change and its impacts on the land cover having reported observing changes in climate in recent times. Participants noted that long ago, rainfall patterns were predictable, which is not the case currently. They lamented that this unpredictability has affected vegetation cover, crop and animal production which according to them had become more severe than in the past. Some of the changes mentioned included drying up of trees and other vegetation, increase in crop diseases and pests, increase in malaria cases which was not the case previously and "colored rainfall" attributed to increased pollutants in the atmosphere. The FGD participants also reported noticing a reduction in crop productivity; particularly maize and beans in their farms. Land cover change in the region was mainly attributed to deforestation of indigenous forests. Participants observed that wild fruits and most indigenous fruits that were abundant in the past had also disappeared due to climate change, with only man made forests dotting the region. Some of their views are captured in the following excerpts:

Masendeke (2008) submitted that although people in rural areas in some instances concede that they can no longer rely solely on their traditional knowledge, indigenous knowledge relating to climate change, whether it concerns agricultural techniques, biodiversity, indicators of change or weather prediction and response, provides the basis for many successful and cost-effective adaptation measures. Indigenous knowledge transmission is threatened by social, cultural and environmental drivers, including climate change, resulting in erosion of the knowledge base and its potential to respond to climate change (UNESCO 2013).

"There has been an increase in temperature with some months being extremely hot. We experience long cold months which initially happened only around July and these changes have resulted in alteration of the planting seasons" (FGD discussant—Nyangores sub-catchment).

According to the sentiments submitted by the respondents, they are saddled with confusion as to which knowledge is viable because the predictions from the Kenya Department of Metrological Services are not reliable as they contrast with the change in climate. Previous stuies indicate that communities believe that scientific forecasts are made at very low spatial resolution, while indigenous forecasts tend to be local in focus (Speranza *et al.,* 2010). Thus, they tend to rely on indigenous forecasts, mostly derived from local experiences, communicated in local languages, and trusted by the communities. These sometime mislead them due to lack reliability, or capacity to interpret meteorological forecasts.

"Maize planting used to take place in February so as to benefit from the heavy rains, while harvesting would occur in May. This pattern has now changed because the seasons have become increasingly erratic and unpredictable. The month of June used to be a celebration month for farmers and livestock keepers because of fattening of livestock due to sufficient rains but this is not the case anymore. The changes in climate started becoming evident around 30 years ago in this region." (FGD discussant—Amala sub-catchment).

Consistent with the current study findings, the demand for land for agricultural activities and biomass as a source of fuel and construction materials to meet the rising demands for the ever increasing population has also been reported in many other regions across the world by Badege (2001), Woldeamlak (2002), and Hurni *et al.* (2005). This is clear evidence in favor of the Malthusian and Neo-Malthusian theoretical premise and the stand of political ecologist school of thought regarding population dynamics, land system change and resource degradation (Malthus, 1798; Panayotou, 2000; Andersson *et al.*, 2011).

Additional causes of land cover change as cited by the participants included soil erosion, which was attributed to increased construction of local roads. Soil fertility loss also came up strongly among the FGD discussants especially from Amala and Nyangores sub-catchments who felt that soil fertility had reduced considerably forcing them to use fertilizers and manure unlike in the past. The excerpts below capture some of their views:

"The use of fertilizer started about 15 years ago, prior to that, we just used to plant crops without any fertilizer or manure. Potatoes which used to grow well in this region do not grow anymore. Nowadays, farmers cannot plan because of the increased unpredictability of the

weather patterns. Farming has now become like betting due to increased unpredictability of the rainy season" (FGD discussant—Amala sub-catchment).

The above perspective is in line with Hohenthal *et al.* (2017), in recognizing the complexity of local resource management and empowering the farmers from the narrative in which their lack of knowledge of farm and land management practices is the main constraint on technology adoption to improve their production. This may further contribute to imagining alternative intervention strategies that are based on dialogue building between state actors and farmers (Hohenthal *et al.*, 2018).

"Vegetation has reduced significantly and as a result, livestock grazing has been extended into wild animal habitats. We have seen majority of people here encroaching into forests and bushes cutting them down and turning forests into human settlements, and this has increased erosion. Some tree species have become extinct—e.g. cedar, among others" (FGD discussant—Nyangores sub-catchment).

With regard to water resources, respondents reported that the main cause of water pollution was increased human activities such as bathing, washing, cleaning, and swimming along the river. Participants observed that rainfall patterns had changed significantly due to climate change. They reported that rainfall used to be uniform and predictable in the past, but had become increasingly unpredictable with the rainy season appearing to have been reduced to short rains only. In all the discussions, climate change was frequently mentioned, but its linkage with human activities was not well comprehended by the discussants. Only one lady appeared knowledgeable of the link between human activities and climate change, citing activities like burning of forests, burning of waste, deforestation, and emission of gases from green houses as contributing to climate change. On the contrary, some discussants were of the opinion that climate change was a result of supernatural forces, while one male discussant mentioned "God's punishment" as one of the causes.

Studies have shown that changes in climate affect animal production and human health directly through the principal weather factors: temperature, rainfall, humidity, solar radiation and airflow and indirectly through alteration of their nutritional environment and changes in the epidemiology and dynamics of human (Dida *et al.*, 2018) and livestock disease pathogens, pests and vectors (Baylis and Githeko, 006).

Most participants did state clearly the real causes of climate change and were able to link the observed land cover change to various proximate factors. For instance, change in land cover was described as bare land due to drought, or drying of shrubs and trees due to prolonged dry season. The predominantly maize cultivators expressed concerns in particular about declining soil fertility, and also attacks by pests, plant diseases and parasitic weeds. The pastoralists also, expressed concerns on the impacts of land cover degradation to the quality of pasture and the value of livestock and their products, as exemplified in the following excerpt:

"In the past, two cows could provide a bucket of milk, but now, even 10 cows cannot fill a cup with milk, and yet, they [cows] eat grass in sufficient quantity"

(Male discussant—Talek sub-catchment).

Drought has substantial impacts upon societal and economic priorities, including increased budgeting for fresh water, reduction of crop yields, losses from businesses, families, and government (Descroix *et al.,* 2013). Depletion of soil nutrients has been singled out as the key biophysical cause of declining per capita food production in SubSaharan Africa 12 (Sanchez et al 1997). To combat these ills, extension workers and farmers require practical knowledge on better land management practices.

All focus group discussants were in agreement that rains have decreased in recent times. In addition, they noted that rainfall has become irregular while there have been changes in the onset of the rainy and dry seasons, the duration of these seasons, and the occurrence of intermittent dry spells. When the causes of the perceived changes in rainfall patterns were discussed, the causes were not directly attributed to a changing climate; although it was attributed to other climatic parameters, such as wind in some focus groups, and more typically, either in passing or explicitly, to divine intervention as exemplified in the following excerpts:
"*Nowadays we leave it to God. You do what you can, without knowing what you will collect. It is God who decides"* (Female discussant—Talek sub-catchment).

"With the hot weather of this year, minds are open to believe that the season will be good. But, only God knows" (Male discussant—Amala sub-catchment). The current study findings thus suggest that climate has a non-linear relationship with crops and this without forsen intervention may worsen their feelings and make them resort to supernatural for guidance, which is consistent with the findings of Fezzi and Bateman (2015).

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. Summary

Land cover change is fast changing the face of Mara river basin sub-catchments mainly through agriculture and human settlements. These has been some of the primary modes for human modification of the environment. As evident, there has been a significant land cover changes in the sub-catchment In Amala sub-catchment, a positive correlation between annual mean rainfall and forest, shrub, built-up areas, cropland, bare land were observed. While, In Nyangores sub-catchment, a correlation was observed between annual mean rainfalls and built-up, forestland, cropland, bare land, grassland and shrub land. In Sand sub-catchment, annual mean rainfall showed a strong positive correlation with different land cover categories *i.e*. forestland, bare land, shrub land and grassland. However, maximum mean temperature showed a negative correlation with different land cover categories *i.e.* forest cover, bare land, shrub land and grassland. In Talek sub-catchment, maximum mean temperature showed a strong negative correlation with forestland, bare land, grassland and shrub land, and a strong positive correlation with cropland. However, annual mean rainfall showed a positive correlation with forest, cropland, bare land, grass land and shrub land. These changes have been attributed to the expansion and intensification of agriculture, human settlement, and deforestation and water resources in the sub-catchment to satisfy demands of increasing population. For instance, forest cover showed a steady decrease from 1987 through to 2017 across all sub-catchments, while crop land increased steadily over the same period, especially for Amala and Nyangores sub-catchments. Unlike in 1987, crop land was the dominant land cover type in Amala and Nyangores, while grass land and shrub land dominated Sand and Talek sub-catchments, respectively by 2017. The process of LC in the sub-catchments has involved substantial conversion of vegetation cover from higher forms to lower forms. For example, it was noted that between 1987 – 1997 decade, bare land, shrub land and forestland decreased by -62.63%, -45.82% and -38.47%, respectively. However, crop land, built-up areas and grassland increased by 89.13%, 47.73% and 4.33%, respectively, over the same period. Over the 1997-2007 decade, forest land, shrub land and grassland decreased by -25.93%, -21.25% and -20.70%, respectively, while bare land, built up areas and crop land increased by 94.88%, 29.41% and 29.70%, respectively. Over the 2007 – 2017 decade, bare land decreased by -29.15%, grass land by -13.86% and shrub land by -8.88%. The study also revealed that haphazard development which is caused by human settlement and demographic factors is one of the major factors contributing to land cover changes in the sub catchments. Other major factors included, climate variability and socio-economic factors. During the study period, it was found that the number of occurrences of high and low flows is decreasing over time. The trend analysis of the peak discharge values and low flow values was done. The 30-year average discharge hydrograph showed a decrease in peak flow over the period. In Nyagores sub-catchment, rainfall amount recorded was higher than amount of water percolation and total water yield in that order. This implies that, more rainfall percolated in the soil as compared to total water yield flowing in the tributary. Nevertheless, the present findings showed a strong Coefficient of determination (R^2=0.92) between rainfall and total water yield and between rainfall and percolation (R^2=0.83) within Nyangores sub-catchment. Implying that as rainfall increased the water percolation and water yield also increased. This was also evident in the peak rainfall, water percolation and total yield observed in 2010 and the dip observed in all parameters in 2017. Future LC projection showed significant increase in grassland and reduced cropland. Types of trees planted, irregular rain pattern and increased temperature were the drivers of LC change. The study recommends adaptation to temperature and rainfall variability; a multidisciplinary approach towards the hydrologic processes that maintain ecological health and communities' livelihood, suitable land use practices to improve future land cover, and an integrated plan to address the drivers of LC changes.

5.2. The Contribution to Knowledge

The study results contribute knowledge to water resources managers, forests managers, decision and policy makers that is crucial in making informed and timely decisions to address water resources management challenges caused by change of climate variability and land cover. The following are contribution of this study to the knowledge:

i) Most of the previous studies related to climate varibility, land cover and water resources were conducted in perennial sub-catchments; Nyangores and Amala tributaries, either separately or together and not together with seasonal sub-catchments of Sand and Talek. The present study focused on all four sub-catchments on the Kenyan portion of the Mara River basin and established that, although Nyangores, Amala, Sand and Talek Sub-catchments contribute to the entire transboundary Mara river basin ecosystem services, they are not homogenous. Therefore, this study contributes to sub-catchment specific information, strategies, plans and approaches necessary for managing the different sub-catchments owing to their heterogeneous nature.

ii) Due to limited observed rainfall and temperature data from existing few weather stations in Nyangores and Amala sub-catchments, many studies conducted in Mara River basin relied on existing data with a lot of gaps and also covered just a few years in their analysis of climate varibility impacts. This study is relied on long term climate data obtained from reliable sources and calibrated models to understand and ascertain the long term impacts of climate variability and land cover changes on stream flow in Mara River basin;

iii) This study suggests climate variability in Mara River basin is real and provides information on how climate variability is correlated with different land cover categories and its resulting implications. This is important knowledge to water and forest managers in the Mara River basin as it can aid in informing development and implementation of effective land cover and water resources management plans, strategies and initiatives necessary to address land cover and water resources challenges.

iv) The study has demonstrated the effectiveness of a holistic approach in the determination of the impact of both climate and land cover change on stream flows overtime and their resulting socio-economic impacts on communities residing within the Mara River Basin;

v) Two manuscripts drawn from this thesis, (a) Land Cover Change and its Socio-Economic Impact on the Residents of the Mara River, Kenya; and (b) Impacts of Temperature and Rainfall Patterns on Land Cover Change Overtime and Future Projections in the Mara River Basin Kenya, have been published in peer-reviewed journals contributing greatly to knowledge with a number of authors citing them.

5.3. Conclusion

Objective 1: To determine the correlation between land cover changes (forest, grass, shrub, bare land, crop and built up areas from 1987 and 2017 and rainfall and temperature patterns (trend) in Amala, Nyangores, Talek and Sand river sub-catchments of the Mara River tributaries, Kenya..

The findings point to a close correlation between climatic factors (temperature and rainfall) and land cover change with an increase in rainfall affecting NDVI positively while increased temperature affected NDVI negatively. The general increase in temperature and decline in rainfall that is now evident in the Mara River basin is therefore likely to have had influenced on different land-cover types in the region. Besides climatic factors, human activities also influenced the seasonal and gradual changes in land cover. This result nullifies the null hypothesis that, 'Long term changes in rainfall and temperature patterns have no impacts on land cover in the Amala, Nyangores, Talek and Sand river sub-catchments of the Mara River tributaries, Kenya'.

Objective 2: To evaluate the effects of land cover changes (forest, grass, shrub, crop, bare and built up areas) on stream flow of the Amala and Nyangores tributaries of the Mara River, Kenya from 1987 and 2017The present study established that land cover change dynamics impacted simulated mean annual water flows in Nyangores and Amala tributaries. Since simulated mean annual water flows and retrospective observed mean annual flows are highly correlated, the results also suggest that the land cover change dynamics also affect steam flows of Amala and Nyangores tributaries in different ways. However, even though both tributaries are in the upper Mara River basin and are adjacent to each other, the impact of and cover on the tributaries is not the same. While in Nyangores sub-catchment, an increase in forest land, shrubland and grassland increased the mean annual water flow, in Amala sub-catchment, it is the increase in crop land, bare land and built up areas that increased mean annual water flow.

Besides land cover, stream flow was also found to be a function of other environmental factors including, surface runoff, evapotranspiration (ET), infiltration/percolation, soil characteristics/soil water availability, subsurface flow, and rainfall interception. Nevertheless, rainfall was found to be a key driver of stream flows. These findings nullify the null hypothesis that, ‘Land cover (forest, shrub, water bodies, grass, settlement, agriculture and bare land) dynamics have no impacts on stream flows in Amala and Nyangores tributaries of the Mara River, Kenya.

Objective 3: To forecast future changes in forest, grass, shrub, crop, bare and built up land cover type from 2017 to 2027 for the Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya

The simulated results based on a CA-Markov model indicated that in the upper Mara Basin sub-catchments (Nyangores and Amala), shrub land, forest land, built-up land and grasslands are likely to increase though to varying degrees while crop land and bare land are likely to decrease by 2027. However, in Sand river sub-catchment, grass land, forest land and shrub-land are likely to increase while bare land is likely to decrease by the greatest margin. In Talek, the greatest projected land cover change is likely to be crop land and bare land with slight increase expected in forest land, grass land and shrub land. This result nullifies the null hypothesis that, ‘there are no expected changes in future patterns of land cover of the Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya’

Objective 4: To assess the effects of land cover change "(forest, grass, shrub, crop, bare and built up areas and their socio-economic impact on the residents of Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya.

Results show that, socio-economic consequences of climate variability and change are most extremely felt by communities in the livestock production sector with other spheres of production and livelihoods such as crop production, water resources, human health, human wildlife conflicts, and households' income also being affected. Diminishing grasslands shrub, tree cover and water resources for livestock production were some of the effects of land cover change on livestock production cited. Impact of land cover change on crop production was linked to a change in climate resulting from land cover change Besides, reduction in the availability of water was apparent in all the sub-catchments going by the responses received with accessibility of clean water being the biggest challenge facing water resources accessibility, whose severity was blamed on deforestation of the water towers. Other consequences of land cover change cited include an increase in diseases and an increase in human-wildlife conflict. These findings nullify the null hypothesis that, 'Change in land cover has no impact on the socio-economic wellbeing of communities living within the Amala, Nyangores, Talek and the Sand river sub-catchments of the Mara River, Kenya'.

Efforts by the Government of Kenya (GOK, 2007), to restore the Mau Forest seen to have achieved the desired effect as exhibited by a rise in forest cover around 2007 implying that with strict regulations and government commitment, accelerated land cover change within the basin can be curbed.

5.4. Recommendations

Objective 1: To determine the correlation between land cover changes (forest, grass, shrub, bare land, crop and built up areas from 1987 and 2017 and rainfall and temperature patterns (trend) in Amala, Nyangores, Talek and Sand river sub-catchments of the Mara River tributaries, Kenya.

Due to climate variability, the impacts of rainfall and temperature on land cover change is now localised and affect communities at sub-catchments level differently. Nyangores and Amala sub-catchments are almost in the same altitude but due to land cover change dynamics the two sub-catchments experiences different rainfall and temperature pattern and intensities. The study recommends monitoring temperature, rainfall and land cover change at the sub-catchment levels to ensure that climate information and prediction products are generated in a consistent manner and at the local scale. The study recommends establishment of weather stations at the sub-catchment levels to ascertain the real local changes. There is also need for the government and other stakeholders to develop and implement sub-catchment comprehensive adaptive and mitigation strategies and plans to increase the resilience of communities towards impacts of climate variability at the sub-catchment level.

Objective 2: To evaluate the effects of land cover changes (forest, grass, shrub, crop, bare and built up areas) on stream flow of the Amala and Nyangores tributaries of the Mara River, Kenya from 1987 and 2017

Impacts of land cover dynamics on stream flows has been ascertained by this study and many other studies. Different land cover types affected streamflow differently with grass land and forest land appearing to have more positive impact on stream flows compared to other land cover types. This study recommends incorporation and increase in land area under grass and forest cover to boost and increase stream flows at sub-catchments level. Nevertheless, the study also noted higher evapotranspiration rates in forested areas compared to other land cover types necessitating more studies to ascertain this.

Objective 3: To forecast future changes in forest, grass, shrub, crop, bare and built up land cover type from 2017 to 2027 for the Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya

Due to efforts made by government of Kenya to restore forest land from 2006, the study forecasted forest, grass, shrub, built up lands are likely to increase, while crop land and bare lands to decrease by 2027. This study revealed that it is possible to restore Mara River basin and therefore recommends to the government of Kenya and other partners to scale – up the restoration efforts of the Mara River basin forest land, grass land and shrub land as well as improve water and soil conservation initiatives to achieve increased water percolation, yields and stream flows at sub-catchment levels. Study has demonstrated the future land cover status where crop land will be reduced not only to increased stream flows but also sustainable management of environment. Due to climate variability noted by this study, there is need to use seed which are climate resilient and apply smart agriculture to improve security.

Objective 4: To assess the effects of land cover change "(forest, grass, shrub, crop, bare and built up areas and their socio-economic impact on the residents of Amala, Nyangores, Talek and Sand River sub-catchments of the Mara River, Kenya.

Study recommends that the impact of both climate and land cover change on stream flows overtime should be studied holistically alongside their resulting socio-economic impacts on communities residing within the affected basins.

5.5. Areas for Further Research

a) Mara River being a transboundary river shared by the republics of Kenya and Tanzania, similar studies should be extended to the Tanzania side of the basin incorporating Somonche, Tighite and Tobora sub-catchments to generate sub-catchment specific information on the effects of inter-annual climate variability on land cover and stream flow.

b) While it was established that land cover types have different impacts on stream flows, with grass land and forest land having more positive impact on stream flows compared to other land cover types, the high evapotranspiration rates by forest land compared to other land use types and resulting water loss needs further investigations. Detailed study on the impacts of evapotranspiration from grassland, shrub land and forest lands on stream flows in the sub-catchments is recommended to ascertain how much each land cover contributes to the stream flows.

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APPENDICES

Appendix I: Publications from the Current Study

1. Mngube, F.M., Anyona, D.N., Abuom, P.O., Matano, A.-S. and Kapiyo, R.A. (2019) Land Cover Change and Its Socio-Economic Impact on the Residents of the Mara River, Kenya. American Journal of Climate Change, 8,404-438. https://doi.org/10.4236/ajcc.2019.83022;

2. Mngube, F.M., Kapiyo, R., Aboum, P., Anyona, D. and Dida, G.O. (2020) Subtle Impacts of Temperature and Rainfall Patterns on Land Cover Change Overtime and Future Projections in the Mara River Basin, Kenya. Open Journal of Soil Science, 10, 327-358. https://doi.org/10.4236/ojss.2020.109018

Appendix II: Survey Questionnaire

Respondent or Interviewee Informed consent

Good morning/afternoon. My name is Fredrick Mngube. I am a PhD student at Maseno University and I am conducting a study titled: *"Impact of Climate and Land Cover Changes on Stream Flows of Nyangores, Amala, Talek and Sand River Tributaries of the Mara River, Kenya".* In order to obtain information on this topic, I am conducting a survey of households in this area. Your household is among those that have been selected by random sampling of all houses in this locality so as to participate in the study. I would like to ask you some questions relating to the impacts of climate and land cover changes on stream flows of Mara River tributaries and their socio-economic impacts on community members.

The information you provide will be useful for future planning, implementation and mitigating the impacts of climate and land cover changes on stream flows of Mara River tributaries.

Your participation in the survey is voluntary and you can choose not to take part. All the information including your name you give will be treated with confidentiality and will only be used for academic purposes.

If you have any questions about the survey, feel free to ask me. At this time do you have any questions about the survey?

Respondent agreed to be interviewed	Yes..............................	No...............................
Signature of Interviewer:	Signature of respondent:	

Code of Respondent...

SECTION 1. HOUSEHOLD IDENTIFICATION

This section is to be completed for each household visited

1.1. Date of interview: Day…………… Month…..............…. Year...............................
1.2. Name of Sub-catchment..
1.3. County ………...…...….….…
1.4. Sub-county ………..……..
1.5. Location..
1.6. Village..
1.7. GPS Coordinates: Longitude................................... Latitude..............................
1.8. Alt...

SECTION 2. HOUSEHOLD CHARACTERISTICS

The table below contains Q. 201 to Q 209. (Fill the questions below as appropriate)

	201.	**202.**	**203.**	**204.**	**205.**	**206.**
Question	Respondents age	Gender of respondent	Position in the Household	Total number of family members	Number of males	Number of females
Response code	Age (in years) 1. 30-40 years 2. 41-50 years 3. 51-60 years 4. >60 years	1. Male 2. Female	1. Household head 2. Spouse 3. Son 4. Daughter	Give exact number	Give exact number	Give exact number
Response	....	....	....	....	....	....

207 What is the occupation of household head? (put ✓ in the selected response)

1. Salaried employee [ ]
2. Casual labourer [ ]
3. Business man [ ]
4. Farmer [ ]
5. Livestock keeper [ ]
6. Fisherman [ ]
7. Jobless [ ]
8. Other (specify)...

207. . What is your main source of livelihoods? (put ✓ in the selected response)

1. Agriculture (farming) [ ]
2. Livestock [ ]
3. Business [ ]
4. Fishing [ ]
5. Employment [ ]
6. Mining [ ]
7. Others [ ]

208. . What is the level of education (completed) of the household head? (put ✓ in the selected response)

1. None [ ]
2. Primary [ ]
3. Secondary [ ]
4. Mid level college [ ]
5. University [ ]
6. Other (specify)...

SECTION 3: SOCIO-ECONOMIC IMPLICATION OF LAND COVER CHANGE ON LAND RESOURCES

301. How long have you lived in this community? (Write number of years_____________________)

302. Does your household own any land? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

303. If yes, how did you acquire the land that you own? (put ✓ in the selected response)

1. Inherited from parents [ ]
2. Bought [ ]
3. Gift [ ]
4. Other (Please specify)……………………………………

304. What is total size of your land as a household? (put ✓in the selected response)

1. 1-3 acres [ ]
2. 3.1-5 acres [ ]
3. 5.1-7 acres [ ]
4. 7.1-10 acres [ ]
5. >10 acres [ ]

305. Of the total acreage that you own, what size (in acres) of land is/was under different land uses (fill table below by putting ✓ as appropriate)?

Type of land cover	**Approximate Size (In acres)**					Underlying Reasons where applicable
	Now	1-10 yrs ago	11-20 yrs. ago	21-30 yrs. ago	> 30 yrs ago	
a) Irrigated cropland						
b) Rain-fed cropland						
c) Wetland						
d) Private grazing/grass land						
e) Communal grazing land						
f) Closed area /hill						
g) Abandoned land						
h) Gully / eroded land						
i) Forest/shrub land						
j) Rocky surface						
k) Water body						
l) Settlement						
m) Other (specify)………………….						

**refers to amount of land owned by the interviewed household during the time of interview*

What is/was the dominant life forms on your land (Fill table below as appropriate by putting ✓)

Dominant land cover	**Now**	**1-10 yrs ago**	**11-20 yrs. ago**	**21-30 yrs. ago**	**> 30 yrs ago**	**Underlying Reasons**
a) Trees/forest cover						
b) Shrubs lands						
c) Grasslands						
d) Water bodies/wetlands						
e) Human settlement						
f) Grazing lands						
g) Agricultural crops						
h) Others (specify)………						

306. Have you noticed any changes in natural land cover on your land or surrounding areas within the last 30 years? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

307.. If yes, what changes have you observed in land cover? *(*? (put ✓ in the selected response; *Multiple responses allowed*)

a) Diminishing vegetation cover (trees, shrubs and grasses) [ ]
b) Increased vegetation cover (grasses, shrubs and tree) [ ]
c) Stunted vegetation growth [ ]
d) Increase in weeds in agricultural lands [ ]
e) Conversion of forests to crop lands [ ]
f) Conversion of rain fed cropland to irrigated crop land [ ]
g) Conversion of forestland to human settlements [ ]
h) Conversion of forestland/bushland to pasture lands [ ]
i) Conversion of forest/bushland/grassland to bare land [ ]
j) Others (please specify)..

308. What do you attribute these changes to? (put ✓ in the selected response; *Multiple responses allowed*)

a) Inadequate rainfall [ ]
b) Frequent floods [ ]
c) Prolonged droughts [ ]
d) Increased temperatures [ ]
e) Failure to protect rivers [ ]

f) Destruction of catchment areas [ ]
g) Change of ownership [ ]
h) Land sub-divisions [ ]
i) Don't know [ ]
j) Others (please specify) ………………………………

309. On a Richter scale, how would you rate trends in land degradation over time in terms of (put 1, or, 2,or 3,or4, or 5 as appropriate in the selected response)

	Land degradation trends	**Now**	**1-10 yrs ago**	**11-20 yrs. Ago**	**21-30 yrs. Ago**	**> 30 yrs ago**
a)	Severity of land degradation? (1: light; 2: moderate; 3: severe; 4: very severe; 5: none)					
b)	Extent of land degradation? (1: absent; 2: present on vulnerable land units; 3: widespread everywhere)					
c)	Sign of land degradation? (1: soil erosion; 2: gully formation; 3: vegetation degradation; 4: soil fertility degradation; 5: water stress; 6: others)					

310. What major shifts in land cover have occurred on your land or in your locality over the last 30 years? (Respond with: 1. Positive; 2. Negative; 3. No change; in the appropriate box in the table)

		1-10 yrs ago	**11-20 yrs. Ago**	**21-30 yrs. Ago**	**> 30 yrs ago**
a)	Rain-fed cropland				
b)	Irrigated crop land				
c)	Communal grazing land				
d)	Natural vegetation				
e)	Plantation forest				
f)	Fallow land				
g)	Enclosure				
h)	Abandoned land				

311. Are there differences in shifts in land cover between the dry, wet and normal years? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

312.. Has your household or your community lost any land in the last 30 years? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

313. If yes, what was the MAIN cause of loss of land? (put ✓ in the selected response; *Multiple responses allowed*)

a) Land inundation following persistent floods [ ]
b) Drying of land due to prolonged droughts [ ]
c) Loss of soil fertility [ ]
d) High levels of erosion [ ]
e) Human settlement or urban development [ ]
f) Weed infestation [ ]
g) Others (please specify)..

314.. Has your household or community gained any land over the last 30 years? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

315. If yes, what was the MAIN factor associated with the gain? (put ✓ in the selected response)

1. Reclaimed wetland [ ]
2. Improved soil fertility [ ]
3. Irrigation of dry areas [ ]
4. Others (please specify)..

316.. Are there external factors related to major land cover changes that are out of your control? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

317.. If yes, which ones? (put ✓ in the selected response; *Multiple responses allowed*)

a) Increase in flooding events [ ]
b) Prolonged droughts [ ]
c) Unpredictable weather patterns [ ]
d) Increase in weeds and pests [ ]
e) Other (please specify)..

318. What are the most pressing issues related to land resources management in your locality that needs intervention? (put ✓ in the selected response; *Multiple responses allowed*)

a) Increased rates of soil erosion [ ]
b) Increased land sub-division reducing their potential [ ]
c) Reduced soil fertility [ ]
d) Increased deforestation [ ]
e) Drying up of land [ ]
f) Other (please specify)..

319. What are major land management initiatives practiced in your locality (put ✓ in the selected response; *Multiple responses allowed*)

a) Afforestation [ ]
b) Agroforestry [ ]
c) Soil and water conservation [ ]
d) Zero grazing [ ]
e) Land reclamation [ ]
f) River bank and water catchments conservation [ ]
g) Other (please specify)..

320.. Are there organizations working towards management of various land-management initiatives above in your locality? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

321. If yes, which ones? (put ✓ in the selected response; *Multiple responses allowed*)

a) Government institutions [ ]
b) Community based institutions [ ]
c) Non-governmental organisations [ ]
d) Private organisations [ ]
e) Local women groups [ ]
f) Local youth groups [ ]
g) Other (please specify)...

322. How can you rate the efforts of these/this organisation? (put ✓ in the selected response)

1. Successful [ ]
2. Un successful [ ]
3. Neither successful nor unsuccessful [ ]
4. Don’t know [ ]

SECTION 4: SOCIO-ECONOMIC IMPLICATION OF LAND COVER CHANGE ON CROP PRODUCTION

401.. Which are the major vegetation life forms found in your locality that are socio-economically important (put ✓ in the selected response; *Multiple responses allowed*)

a) Trees [ ]
b) Shrubs [ ]
c) Grass [ ]
d) Herbs [ ]
e) Others (specify)..

402.. What are the common and local names of the most prominent vegetation life forms in your locality? (Provide your responses in the columns as appropriate)

	Vegetation life forms	**Common Name**	**Local Name**
a)	Trees		
b)	Shrubs		
c)	Grass		
d)	Herbs		
e)	Others		

403. What are the main uses of the common vegetation life forms identified above? (Pick all that apply from the 7 options provided; *Multiple responses allowed*)

	Vegetation life forms	Main uses: (1: construction; 2: firewood; 3: fodder; 4: shelter; 5: fruits; 6: conservation; 7: Religious activities) *Choose all that apply*
1	Trees	
2	Shrubs	
3	Grass	
4	Herbs	

404.. Do you grow any crops on your land? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

405.. If yes, which crops do you grow? (put ✓ in the selected response; *Multiple responses allowed*)

a) Cereals [ ]
b) Legumes [ ]
c) Vegetables [ ]
d) Tubers [ ]
e) Fruits [ ]
f) Cash crops [ ]
g) Other (please specify) ………………………….………

406.. Have you noticed any changes in crop productivity over the last 30 years? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

407.. If yes, through which indicator(s) have you noticed the changes in crop productivity? (put ✓ in the selected response; *Multiple responses allowed*)

a) Reduced yields [ ]
b) Increased yields [ ]
c) Stunted growth [ ]
d) Others (specify)………………………………………..

408.. What do you perceive to be the **MAIN** cause of crop productivity change? (put ✓ in the selected response)

1. Increase in pests and weeds [ ]
2. Increased rainfall amounts [ ]
3. Soil erosion [ ]
4. Frequent floods [ ]
5. Prolonged drought [ ]
6. Over cultivation [ ]
7. Deforestation [ ]
8. Loss of soil fertility [ ]
9. Increase in soil fertility [ ]
10. Shifts in seasons [ ]
11. Others (specify)…………………………………………

409.. Can you attribute the change in crop productivity to general changes in land cover? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

410.. If yes, through which factors can you attribute the changes in crop productivity to land cover changes? (put ✓ in the selected response)

1. Deforestation which exposes soil making it easily erodible [ ]
2. Diminishing vegetation cover exacerbating droughts [ ]
3. Increase in weeds which chock the food crops [ ]
4. Excessive uptake of water (blue gum) which dries up the area[ ]
5. Others (please specify)..

411.. Has your household been affected directly by the change of crop yield over the last 30 years? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

412.. If yes, what impact did it have on your household livelihood? (put ✓ in the selected response)

1. Positive [ ]
2. Negative [ ]
3. Neither positive nor negative [ ]
4. Others (please specify)……………………………..

SECTION 5: SOCIO-ECONOMIC IMPLICATIONS OF LAND COVER CHANGE ON LIVESTOCK PRODUCTION

501.. Do you keep livestock on your farm? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

502. If yes, give the type and number of each (Fill the table below as appropriate)

a) Which type of livestock do you have? (check as appropriate)	b) How many of each type do you own? For bees number of colonized hives)	**c)** What are the main reason for keeping animals (1=Food; 2=Sale; 3 Farm power; 4= Other (specify)
a. Cattle		
b. Goats		
c. Sheep		
d. Pig		
e. Chicken		
f. Camels		
g. Rabbits		
h. Bees		
i. Donkeys		
j. Ducks		
k. Other (specify) ____		

503 . What are the key factors that determine productivity of livestock in your locality? (put ✓ in the selected response; *Multiple responses are allowed*)

1. Water availability [ ]
2. Pasture availability [ ]
3. Favourable temperatures [ ]
4. Absence of diseases [ ]
5. Keeping superior livestock breeds [ ]
6. Others (please specify)..

503.. Have you noticed any changes in animal production in your area? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

504.. If yes, through which indicator(s) have you noticed the changes in animal productivity? (put ✓ in the selected response; *Multiple responses allowed*)

a) Reduced production (milk, eggs, honey etc) [ ]
b) Increased prevalence of livestock diseases [ ]
c) Livestock wasting away [ ]
d) Livestock deaths [ ]
e) Others (specify)……………………………………………………………..

505.. Do you think changes in land cover have an effect on animal production in your area? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

506.. If yes, how does land cover changes influence animal production? (put ✓ in the selected response; *Multiple responses allowed*)

a) Diminishing grasslands [ ]
b) Diminishing tree cover [ ]
c) Diminishing shrub land [ ]
d) Diminishing pasture due to overgrazing [ ]
e) Diminishing water resources [ ]
f) Other (please specify)………………………………….

507. What other factors result in changes in animal productivity? (put ✓ in the selected response; *Multiple responses allowed*)

a) Prolonged drought [ ]
b) Frequent flooding [ ]
c) Lack of water [ ]
d) Increased diseases [ ]
e) Other (please specify)…………………………………..

SECTION 6: SOCIO-ECONOMIC IMPLICATION OF LAND COVER CHANGE ON WATER RESOURCES

601.: What were the main sources of water for your household? (put ✓ against the selected response; *Multiple responses allowed*)

	Main source of water	**1987-1997 (10yrs ago)**	**1998-2008 (20yrs ago)**
a)	Piped water		
b)	Public tap		
c)	Well in dwelling place		
d)	Open or protected public well		
e)	Spring / river / stream		
f)	Pond / dam		
g)	Rainwater		
h)	Tanker truck		
i)	Bottled water		
j)	Other (please specify)		

602. What is the time taken to fetch water from house/yard/plot in the past? (put ✓in the selected response)

	Time taken	**1987-1997 (10yrs ago)**	**1998-2008 (20yrs ago)**
1	Less than 30 minutes walk		
2	30 – 60 minutes walk		
3	More than 60 minutes walk		
4	Water is piped into the house		
5	Don’t know / No answer		

603.. What are the one **main** sources of water for your household currently (from 2009 to 2017)? (put ✓ in the selected response; *Multiple responses allowed*)

	Main source of water	**2009 to 2017**
a)	Piped water	
b)	Public tap	
c)	Well in dwelling place	
d)	Open or protected public well	
e)	Spring / river / stream	
f)	Pond / dam	
g)	Rainwater	
h)	Tanker truck	
i)	Bottled water	
j)	Other (please specify)…….	

604 What is the time taken to fetch water from house/yard/plot currently (2009 to 2017)? (put ✓in the selected response)

	Time taken to fetch water from the house/yard/plot and back	**2009 to 2017**
1	Less than 30 minutes walk	
2	30 – 60 minutes walk	
3	More than 60 minutes walk	
4	Water is piped into the house	
5	Don't know / No answer	

604.. Have you noticed any changes in availability and accessibility of water in the last 30 years? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

605.. If yes, what changes have occurred in relation to availability of water sources in the last 30 years? (put ✓ in the selected response; *Multiple responses allowed*)

a) 1. Drying up of rivers [ ]
b) 2. Drying up of dams [ ]
c) 3. Flooding of water sources [ ]
d) 4. Drying up of springs [ ]
e) Others (Specify) ________________________________

606.. What problems do you encounter in accessing water resources currently? (put ✓ in the the selected response; *Multiple responses allowed*)

a) Long distance [ ]
b) Contaminated water [ ]

c) Water scarcity [ ]
d) High cost of water [ ]
e) Conflict with neighbours [ ]
f) Conflict with wild animals [ ]
g) Non [ ]
h) Other (Specify) ____

607.. What do you attribute these problems to? (put ✓ in the selected response; *Multiple responses allowed*)

a) Changes in rainfall patterns [ ]
b) Prolonged droughts [ ]
c) Increase in temperatures [ ]
d) Failure to protect rivers [ ]
e) Destruction of catchment areas [ ]
f) Increase in human population [ ]
g) Others (Specify)..

608.. Have you noticed any change in water quantity in the last 30 years? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

609. Do you think change in land cover has an effect on water quantity? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

610. If yes, how does land cover change influence water resources? (put ✓ in the selected response; *Multiple responses allowed*)

a) Deforestation leading to reduced water resources [ ]
b) Increased trees leads to improved hydrologic cycle [ ]
c) Loss of vegetation reduces water infiltration affecting ground water [ ]
d) Loss of vegetation cover increased soil erosion / water pollution [ ]
e) Other (please specify)..

611. What are the major problems associated with water resources in your locality? (put ✓ in the selected response; *Multiple responses allowed*)

a) General water scarcity [ ]
b) Water pollution [ ]
c) Water sources are far away [ ]
d) Drying up of water pans [ ]
e) Drying up of rivers [ ]
f) Other (please specify)...

612. Which water conservation practices exists in your locality? (put ✓ in the selected response; *Multiple responses allowed*)

a) Protection of water sources such as springs [ ]
b) Planting of suitable trees in water sheds [ ]
c) Protecting existing forest cover [ ]
d) Ensuring proper agricultural practices to curb soil erosion [ ]
e) Ensuring the vegetation cover is protected to curb soil erosion [ ]
f) Curbing pollutant load into aquatic ecosystems [ ]
g) Others (please specify)..

613. According to you, which one of these is most effective in conserving water resources? (put ✓ in the selected response)

a) Protection of water sources such as springs [ ]
b) Planting of suitable trees in water sheds [ ]
c) Protecting existing forest cover [ ]
d) Ensuring proper agricultural practices to curb soil erosion [ ]
e) Ensuring the vegetation cover is protected to curb soil erosion [ ]
f) Curbing pollutant load into aquatic ecosystems [ ]
g) Others (please specify)..

614. What is the effect of polluted waters on your livelihoods? (put ✓ in the selected response; *Multiple responses allowed*)

a) Increased water borne diseases [ ]
b) Increased cost of treatment from illnesses [ ]
c) Wastage of time fetching water from far off places [ ]
d) High cost of obtaining water from vendors [ ]
e) Increased cost of treating available water [ ]
f) Other (please specify)..

615. Do you think change in rainfall pattern has an effect on vegetation cover? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

616. If yes, how does rainfall pattern effects vegetation cover? (put ✓ in the selected response; *Multiple responses allowed*)

a) Increased vegetation cover [ ]
b) decreased vegetation cover [ ]
c) changes from trees to shrubs [ ]
d) Changes of Shrubs to Trees [ ]
e) Change of tress to shrubs; and to grasses [ ]
f) Other (please specify)..

SECTION 7: SOCIO-ECONOMIC IMPLICATION OF TEMPERATURE ON LAND COVER CHANGE AND WATER RESOURCES

701.. Have you noticed any changes in temperatures in your area? (put ✓ in the selected response)

1. Yes [ ]
3. No [ ]

702.. If yes, through which indicator(s) have you noticed the changes in temperature? (put ✓ in the selected response; *Multiple responses allowed*)

a) Some months become hotter than normal [ ]
b) Some months become cooler than normal [ ]
c) Others (specify)………………………………………..

703. What factors influence changes in temperature in your area? (put ✓ in the selected response; *Multiple responses allowed*)

a) Deforestation [ ]
b) Afforestation [ ]
c) Wind direction [ ]
d) Altitude [ ]
e) Increased settlements [ ]
f) Other (please specify………………………………………………

704.. Do you think changes in temperature affects land cover in your area? (put ✓ in the selected response)

1. Yes [ ]
2. No [ ]

705.. If yes, how does temperature changes influence land cover? (put ✓ in the selected response; *Multiple responses allowed*)

g) Diminishing grasslands [ ]
h) Diminishing tree cover [ ]
i) Diminishing shrub land [ ]
j) Diminishing pasture due to overgrazing [ ]
k) Diminishing water resources [ ]
l) Drying of crops [ ]
m) Other (please specify)………………………………

Appendix III. Key Informant Interview Guide

1. Identification

1.1	Name of interviewee	
1.2	Interview venue	
1.3	Occupation	
1.4	Village / place of work	
1.5	Date of interview	
1.6	Name of interviewer	

2. Thematic areas

General knowledge

i) What climate markers (Temperature and Rainfall) have changed in this region (Mara river Basin) over time?
ii) What climatic changes have occurred in this region over the last 30 years?
iii) What are the dominant land cover types in this area?
iv) What changes in land cover have you experienced in this locality over the last several years?
v) How does change in climate markers affect land cover in this region?
vi) How do community members perceive changes in land cover in this area in terms of its impacts on crop production, livestock production and water resources availability?
vii) What are the possible impacts of land cover change on stream flow as well as on household livelihoods in this area?
viii) How do climate change markers affect stream flow in this area?
ix) Are there any interventions by the national government, county governments, non-governmental organizations or community based organizations operating in this region that are aimed at combating the changing climate, land cover and changes in stream flows?
x) What are the impacts of the national government, county governments, non-governmental organizations or community based organizations operating in this region on combating the changing climate, land cover and stream flows?
xi) What strategies do you propose to reduce the impact of changing climate, land cover and stream flows in this region?

Appendix IV. Focus Group Discussion Guide

1. Discussants Identification

1.1	Description of Group: N/B: Group should have the same character	
1.2	Interview venue	
1.3	No. of participants	
1.4	Date	
1.5	Time of the day	
1.6	Person(s) conducting interview	1 2

2. Thematic Areas

i) What climatic changes have occurred in this region over the last 30 years?

ii) What are some of the dominant land cover types in this area?

iii) What changes in land cover have you experienced in this locality over the last several years?

iv) According to you, what do you think are the causes of land cover changes in this region?

v) How do community members perceive changes in land cover in this area in terms of its impacts on crop production, livestock production and water resources availability?

vi) What are the negative impacts of climate change on land cover within your locality?

vii) What are the possible impacts of land cover change on stream flow as well as on household livelihoods in this area?

viii) What are the positive outcomes of improved stream flow on health, social well being and income and savings by community members?

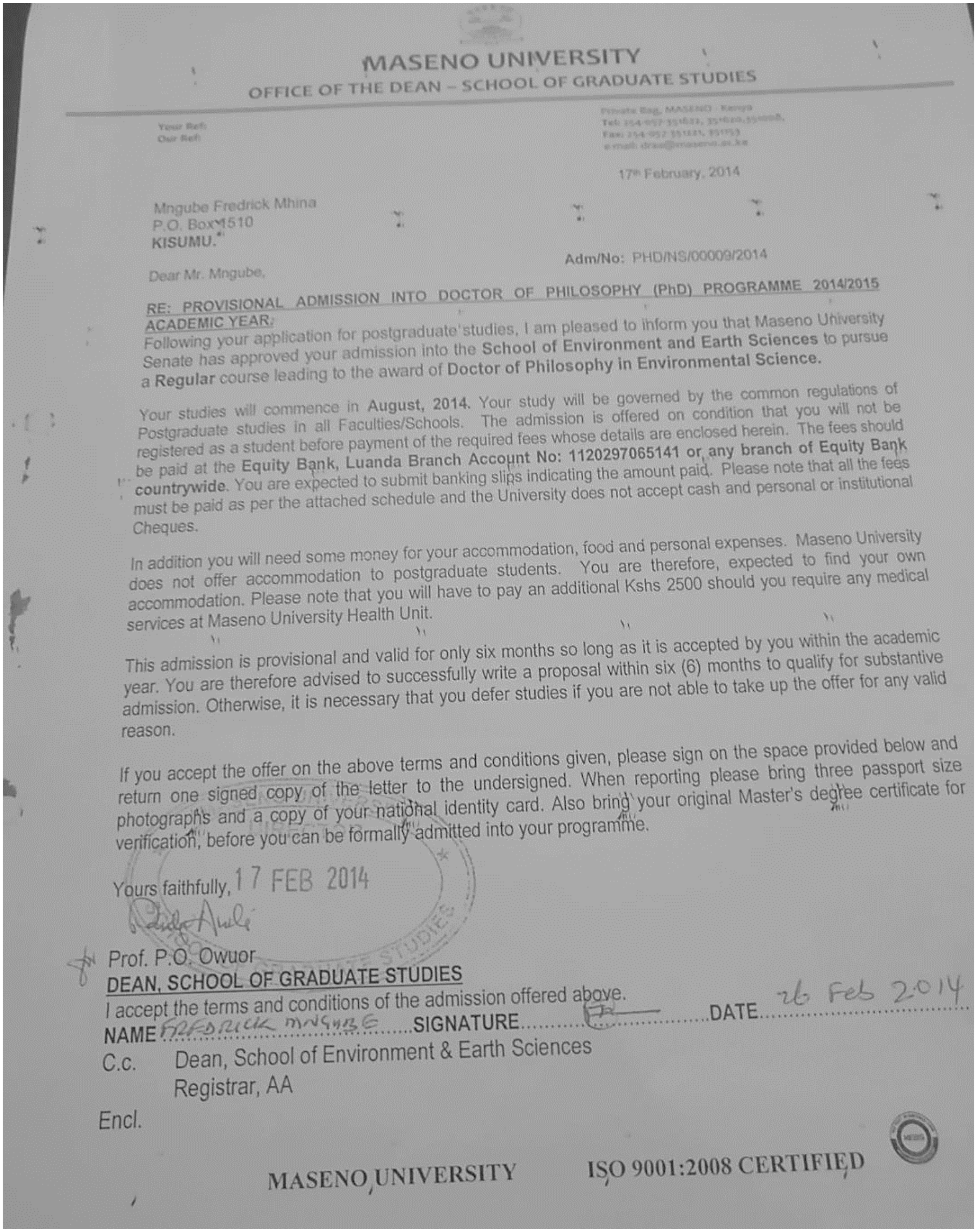
ix) Are there any interventions by the national government, county governments, non-governmental organizations or community based organizations operating in this region aimed at combating the changing land cover?

x) As community members, are you aware of the impact of climate changes on land cover and how this impacts on your socio-economic well being? If yes, please explain.

xi) What can you as communities do to improve stream flow in your locality?

Thank You Very Much

Appendix V: Admission Letter for Doctorate Programme



MASENO UNIVERSITY
OFFICE OF THE DEAN – SCHOOL OF GRADUATE STUDIES

Your Ref:
Our Ref:

Private Bag, MASENO - Kenya

17th February, 2014

Mngube Fredrick Mhina
P.O. Box 1510
KISUMU.

Adm/No: PHD/NS/00009/2014

Dear Mr. Mngube,

RE: PROVISIONAL ADMISSION INTO DOCTOR OF PHILOSOPHY (PhD) PROGRAMME 2014/2015 ACADEMIC YEAR.

Following your application for postgraduate studies, I am pleased to inform you that Maseno University Senate has approved your admission into the **School of Environment and Earth Sciences** to pursue a **Regular** course leading to the award of **Doctor of Philosophy in Environmental Science.**

Your studies will commence in **August, 2014.** Your study will be governed by the common regulations of Postgraduate studies in all Faculties/Schools. The admission is offered on condition that you will not be registered as a student before payment of the required fees whose details are enclosed herein. The fees should be paid at the **Equity Bank, Luanda Branch Account No: 1120297065141 or any branch of Equity Bank countrywide.** You are expected to submit banking slips indicating the amount paid. Please note that all the fees must be paid as per the attached schedule and the University does not accept cash and personal or institutional Cheques.

In addition you will need some money for your accommodation, food and personal expenses. Maseno University does not offer accommodation to postgraduate students. You are therefore, expected to find your own accommodation. Please note that you will have to pay an additional Kshs 2500 should you require any medical services at Maseno University Health Unit.

This admission is provisional and valid for only six months so long as it is accepted by you within the academic year. You are therefore advised to successfully write a proposal within six (6) months to qualify for substantive admission. Otherwise, it is necessary that you defer studies if you are not able to take up the offer for any valid reason.

If you accept the offer on the above terms and conditions given, please sign on the space provided below and return one signed copy of the letter to the undersigned. When reporting please bring three passport size photographs and a copy of your national identity card. Also bring your original Master's degree certificate for verification, before you can be formally admitted into your programme.

Yours faithfully, 17 FEB 2014

Prof. P.O. Owuor
DEAN, SCHOOL OF GRADUATE STUDIES

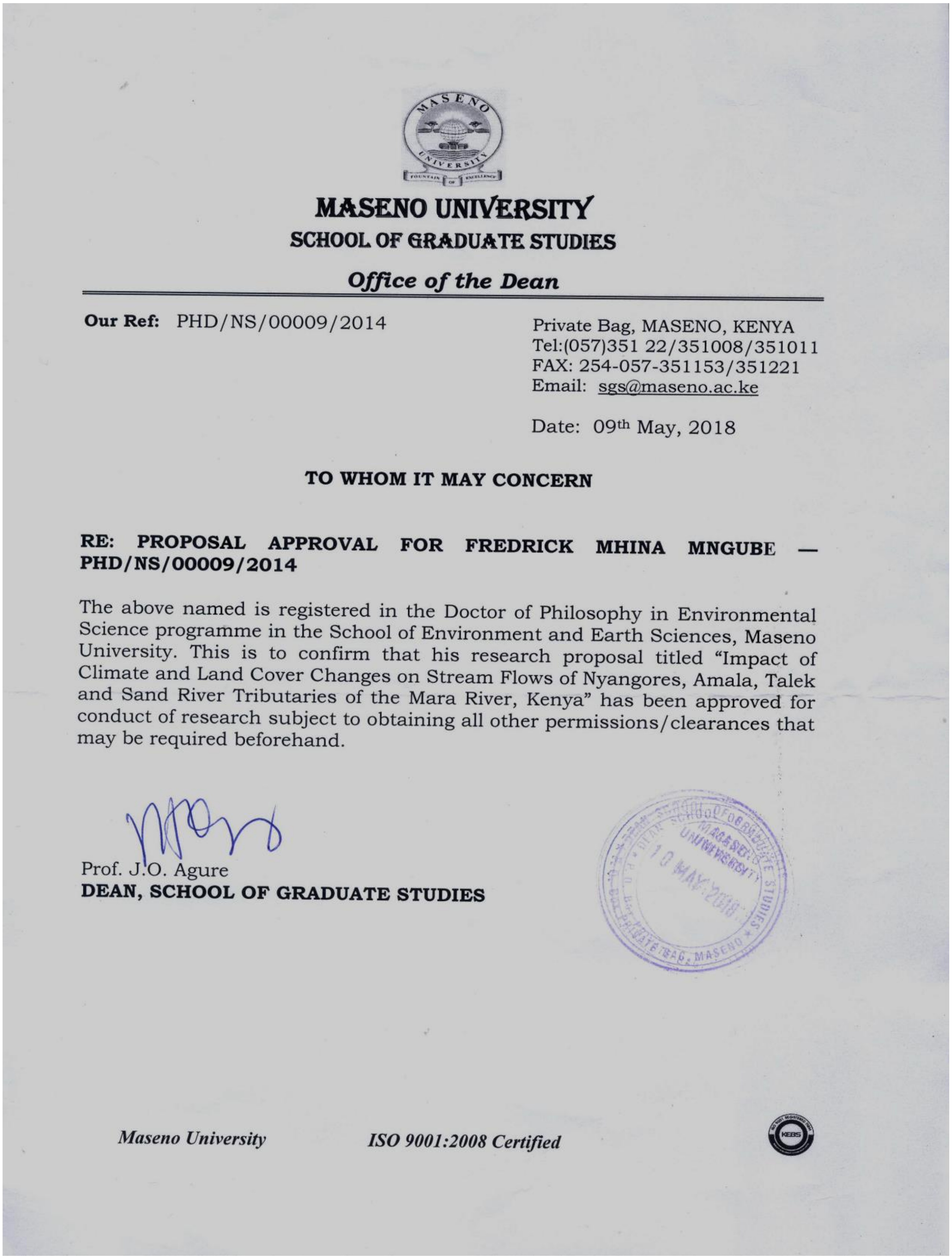
I accept the terms and conditions of the admission offered above.
NAME FREDRICK MNGUBE ....SIGNATURE..........................DATE 26 Feb 2014

C.c. Dean, School of Environment & Earth Sciences
Registrar, AA

Encl.

MASENO UNIVERSITY ISO 9001:2008 CERTIFIED

Appendix VI. Proposal Approval Letter from School of Graduate Study



MASENO UNIVERSITY
SCHOOL OF GRADUATE STUDIES
Office of the Dean

Our Ref: PHD/NS/00009/2014

Private Bag, MASENO, KENYA
Tel:(057)351 22/351008/351011
FAX: 254-057-351153/351221
Email: sgs@maseno.ac.ke

Date: 09th May, 2018

TO WHOM IT MAY CONCERN

RE: PROPOSAL APPROVAL FOR FREDRICK MHINA MNGUBE — PHD/NS/00009/2014

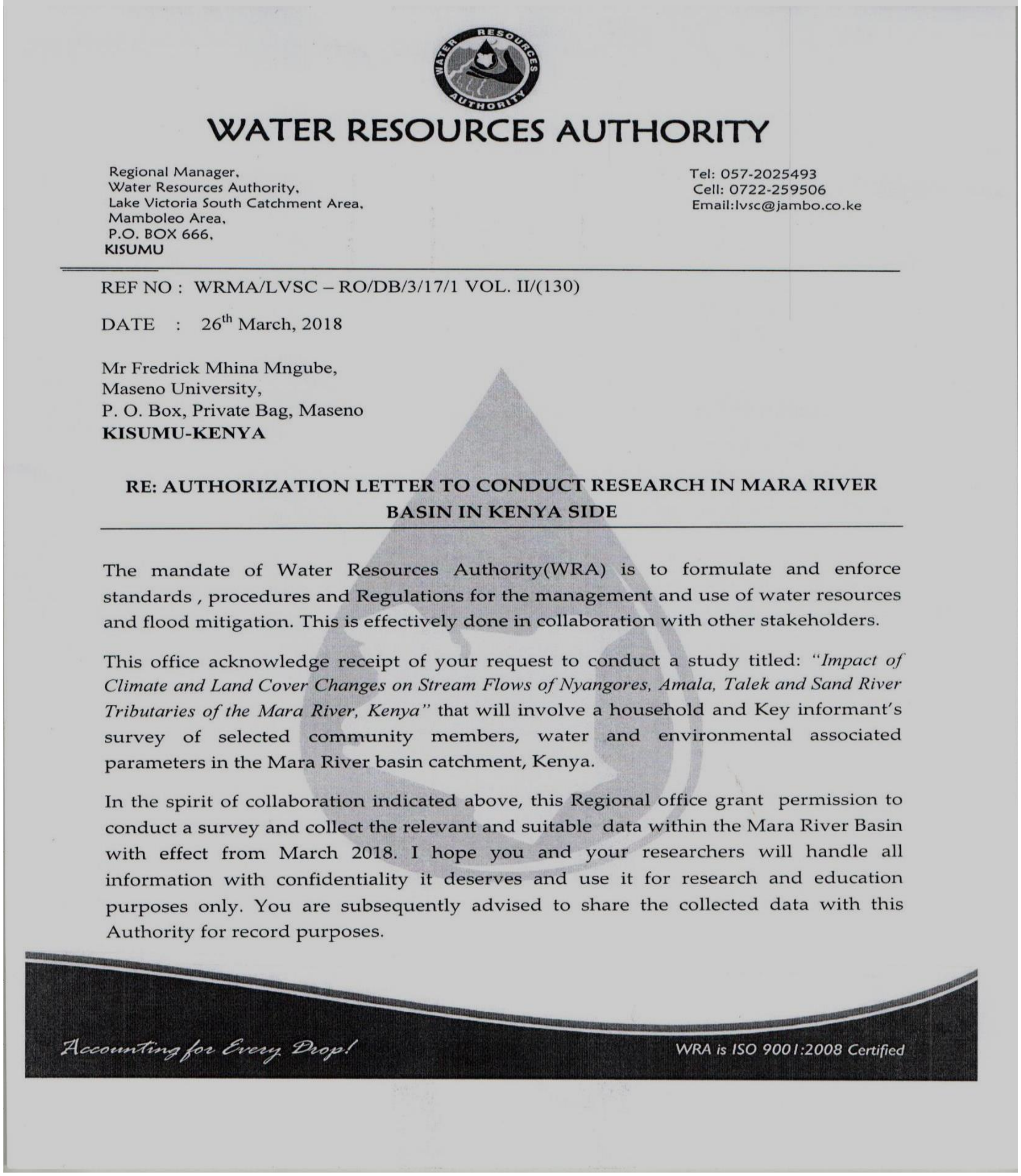
The above named is registered in the Doctor of Philosophy in Environmental Science programme in the School of Environment and Earth Sciences, Maseno University. This is to confirm that his research proposal titled "Impact of Climate and Land Cover Changes on Stream Flows of Nyangores, Amala, Talek and Sand River Tributaries of the Mara River, Kenya" has been approved for conduct of research subject to obtaining all other permissions/clearances that may be required beforehand.

Prof. J.O. Agure
DEAN, SCHOOL OF GRADUATE STUDIES

10 MAY 2018

Maseno University *ISO 9001:2008 Certified*

Appendix VII. Approval from WARMA to Conduct the Study within Mara River Basin



WATER RESOURCES AUTHORITY

Regional Manager,
Water Resources Authority,
Lake Victoria South Catchment Area,
Mamboleo Area,
P.O. BOX 666,
KISUMU

Tel: 057-2025493
Cell: 0722-259506
Email:lvsc@jambo.co.ke

REF NO : WRMA/LVSC – RO/DB/3/17/1 VOL. II/(130)

DATE : 26th March, 2018

Mr Fredrick Mhina Mngube,
Maseno University,
P. O. Box, Private Bag, Maseno
KISUMU-KENYA

RE: AUTHORIZATION LETTER TO CONDUCT RESEARCH IN MARA RIVER BASIN IN KENYA SIDE

The mandate of Water Resources Authority(WRA) is to formulate and enforce standards , procedures and Regulations for the management and use of water resources and flood mitigation. This is effectively done in collaboration with other stakeholders.

This office acknowledge receipt of your request to conduct a study titled: *"Impact of Climate and Land Cover Changes on Stream Flows of Nyangores, Amala, Talek and Sand River Tributaries of the Mara River, Kenya"* that will involve a household and Key informant's survey of selected community members, water and environmental associated parameters in the Mara River basin catchment, Kenya.

In the spirit of collaboration indicated above, this Regional office grant permission to conduct a survey and collect the relevant and suitable data within the Mara River Basin with effect from March 2018. I hope you and your researchers will handle all information with confidentiality it deserves and use it for research and education purposes only. You are subsequently advised to share the collected data with this Authority for record purposes.

Accounting for Every Drop!

WRA is ISO 9001:2008 Certified

Appendix VII. Climate and Hydrological Data Sets

a) Nyangores monthly average Discharge data computed from daily data from WRMA-Kisumu Office

Months/Year	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
January	1.320262	1.522424	0.579299	0.579299	9.825104	2.197068		1.985431	1.742912	1.742912	1.629782
February	3.875569	1.168337	0.511699	0.511699	1.412449	0.640575		12.82108	2.234388	2.234388	0.60631
March	1.044273	1.104154	0.45229	0.45229	7.053456	0.540323	0.358247	2.632168	1.803851	1.803851	0.376252
April	6.811093	31.02318	5.165446	5.165446	46.44536	3.160589	1.872646	0.639178	7.038361	7.038361	5.453805
May	14.48768	41.26218	8.20801	8.20801	18.74815	7.469706	4.592453	2.657549	7.985333	7.985333	19.51076
June	36.83229	11.76077	2.936321	2.936321	4.954894	11.97503	6.697345		7.855938	7.855938	6.470243
July	3.499989	4.65337	2.964857	2.964857	2.621623	3.879508	9.356805		6.457853	6.457853	9.667012
Aug	2.78879	5.186471	10.92262	10.92262	4.37113	3.983702	8.319689		5.683834	5.683834	7.581626
Sept	3.266044	6.376115	14.01532	14.01532	3.686347	3.561654	12.58419		24.09358	24.09358	5.145682
Oct	1.957502	12.55057	7.580219	7.580219	1.564327		7.243183		5.505884	5.505884	2.468154
Nov	4.177273	1.894601	3.993347	3.993347	1.438254	0.891313	3.062357		3.826877	3.826877	26.52194
Dec	0.089672	0.916043	9.430367	9.430367	1.043317		1.784465		4.21937	4.21937	47.37202

Months/Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
January	65.55594	1.697167	1.631955	17.11753	5.015467	16.33157		3.151384	18.60218	33.96783
February	10.51353	0.930301	1.229596	10.19752	2.432852	2.817919		1.330326	0.585758	17.48552
March	5.127149	1.810197	0.987759	3.515756	3.473278	1.564997		1.590408	3.604721	5.090061
April	10.54167	7.90583		15.83236	6.875517	12.91328	10.17727	4.483928	17.50925	10.84158
May	31.88842	13.38836	1.570542	28.68188	42.66523		33.07118	13.95753	24.55895	14.02396
June	18.51504		1.696361	15.21826	4.742073	18.75702	4.642203	12.6462	5.475421	20.39833
July	27.89801		3.793063	15.87608	4.071653	7.914169	4.969835	6.559263	4.901252	9.741628
Aug	9.680956		4.216957	12.69544	10.23343	18.62898	7.027138	17.69898	7.786712	25.55328
Sept	8.717788	15.34679	5.515805	7.136934	8.469782	21.62834	5.788554	24.08813	7.614668	22.20441
Oct	13.02293	7.982861	5.503102	5.935262	3.172209	7.59925	6.855624	7.502893	4.823542	9.116402
Nov	7.827376	3.910619	7.067861	24.91398	5.931213	3.714737	5.432917	4.494852	8.314532	4.562672
Dec	2.793915	2.96043	5.826114	6.406807		2.060197	3.327849	2.255964	31.31367	2.454341

Months/Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
January	1.658791	2.263938	2.971278	3.089103	7.863976	10.08442	3.147162	3.529696	17.6273	1.692861
February	1.249114	1.272808	8.094752	2.845408	3.271716	4.007927	2.438906	2.096594	5.553698	1.256686
March	1.469642	1.190626	19.02979	3.555143	3.503203	6.873037	2.482146	1.27642	2.402452	1.011344
April	5.520034	2.809958	4.497058	3.559468	29.41864	58.93728	2.993406	2.171646	4.434308	1.000343
May	7.158341	6.562927	4.158816	5.57461	58.65604	62.84797	2.349507	20.07293	51.65997	3.729808
June	8.960664	4.282236	6.004767	5.269825	13.81609	5.482147	8.249493	32.50534	9.640542	3.093435
July	6.42797	1.591455	7.899132	5.259644	21.60562	6.463144	4.818065	5.904492	9.580531	5.219237
Aug	8.514413	3.299744	4.897505	5.151338	13.13428	12.86282	7.73972		7.763701	
Sept	6.307938	2.057906	9.139004	18.84821	29.20974	13.78167	9.251529		5.925805	14.89739
Oct	11.89182	2.16037	24.16576	8.044595	11.76753	10.53294	10.12777		18.3751	7.008955
Nov	11.75536	2.134496	10.96979	15.15136	26.53739	5.340281	9.010835		4.168644	8.063955
Dec	5.073429	2.276956	4.891684	38.06002	7.20264	4.133431	6.430363	12.62156	2.789834	4.354337

b) Amala monthly average Discharge data computed from daily data from WRMA-Kisumu Office

Months/Year	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
January	0.987625	1.293367		6.713133	0.399679	1.231613	3.881953	0.977712	0.339755		0.864544
Febuary	0.568741	0.69698	0.842361	1.47245	0.363399	0.332011	11.61026	0.579182	2.20419		0.470346
March	1.927872	0.909052	0.900286	3.187097	0.416561	0.254688	2.581058	0.936708	6.799649		0.194693
April	3.586953		8.26717	20.72161	1.881221	2.027696		1.164217	0.49333		6.824727
May	7.279867	5.656562		11.04307	3.149421	5.172395		5.807301			10.90655
June	12.1451	6.816233	3.362287	2.74115	15.40044	7.442783	7.451944	12.77634			3.226666
July	3.912565	7.19564	4.874423	1.605441	4.773403	12.89192	6.638358	7.427448			8.565308
Aug	2.326746	13.74518	13.50004	4.314898	11.75739	16.80743	6.551276	11.99963	3.333503		
Sept	2.523009	11.45351	12.76861	3.048716	6.199621	19.75423	6.172026	12.40985	4.689248		
Oct	1.434097	12.4626	14.78133	1.274333	2.217926	8.100658	2.316867	2.135096	5.514057	4.326315	2.131947
Nov	2.924552	2.433009	4.201659	1.363905	1.243213	4.509506	1.704332	3.132973	3.786844	1.906648	8.219429
Dec	2.356867	1.490266	2.374972	0.577385	0.677299	2.104648	1.285125	3.65813		2.933973	47.36588

Months/Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	2007
January	43.75859		1.498212	3.156798	7.84367	36.23048	0.548061	0.50988	0.131521	22.46084585
Febuary	9.490142		0.221058	0.454592	1.401931	0.683995	0.457537	0.550506	1.118325	
March	2.996062		0.27629		3.022849	1.967028	0.261296	0.213536	9.597406	2.070406422
April	8.631791		0.240272		3.518008	3.540713	4.679769	1.234759	32.2088	4.986001005
May	17.6426		0.555486		23.9731	81.23349	19.64471	2.775155	22.53478	4.94205231
June	14.45324	2.323785	0.886375		1.911884	30.05357	1.968697	2.816672		14.91359646
July	7.242442	2.521686	1.740461	5.703686	2.087621	12.76511	1.534625	3.388182	16.79716	8.454802612
Aug	5.020734		2.957121	10.75625	4.517436	11.87494	4.045525	13.53538		25.68473845
Sept	5.480419		3.5399	2.412832	4.706974	14.01083	3.84783	14.72807	4.669777	17.60402069
Oct		2.013663	6.273533	9.858806	0.873272	5.789603	4.364598	4.902183	1.821627	22.70828686
Nov		2.056495	5.136068	15.26878	1.89973	1.738439	1.492499	2.266229		1.545406136
Dec		4.084718	4.01324	0.884522	3.120455	0.787896	0.796884	0.345233	18.16777	2007

Months/Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
January	0.15407	0.322757	9.038002	0.604905		3.016399	5.020316		17.60235	5.075592
Febuary	0.050935		3.738849				1.941579		5.62613	3.650218
March	0.331179		15.39213	0.542702			0.723229		1.15262	3.307777
April	1.28577		12.92605	0.628818			4.405108			2.388805
May	2.444329	5.239236	19.10587	2.078903	28.23183	29.28558				7.197586
June	1.307646	1.7638	3.424953	6.621053	9.091069	6.156752			7.746243	5.550359
July	2.488852	0.597501	5.518784	6.67964	10.17502	6.525314			7.159212	14.53569
Aug	6.711015	0.832114	8.156092	14.61803	10.10904	9.121156		5.66025	6.543988	16.09606
Sept	8.458764	1.033525	18.94085	20.53153	17.9401	10.30126		7.595904	7.037687	31.87762
Oct	7.107211	1.32802	12.87946	4.76139	4.185211	7.90466	12.13679	1.42516	30.76876	15.91623
Nov	6.192932	1.12993	6.941552		5.023408	4.834737	5.334656	35.89852	4.277388	17.32398
Dec	1.686606	3.025465	2.817844		0.944022	6.469413	3.23308	36.13174		14.8348

c) Amala, Nyangores, Sand and Talek annual total rainfall and mean annual rainfall 1987 to 2017 computed from daily rainfall data from NASA Giovanni website.

Year	Amala	Nyangores	Sand	Talek	Mean annual rainfall
1987	1025.5	1171	430.09	773.24	849.96
1988	1015.66	1090.5	824.47	948.94	969.89
1989	1105.58	927	729.88	968.56	932.76
1990	1064.89	1061	844.23	1004.25	993.59
1991	942.04	889	831.22	942.4	901.17
1992	1089.27	1240.3	718.12	1001.16	1012.21
1993	929.72	1176.1	710.85	941.71	939.60
1994	1112.9	1047.3	812.44	988.06	990.18
1995	873.27	1048.4	875.13	1007.67	951.12
1996	1028.47	1404.8	538.24	920.91	973.11
1997	959.24	1038.6	904.34	1027.11	982.32
1998	1117.66	1350.8	911.24	914.69	1073.60
1999	946.69	1220.7	867.57	1014.75	1012.43
2000	1061.28	887.3	715.99	950	903.64
2001	822.09	993.9	755.21	732.88	826.02
2002	953.71	975.9	563.18	705.49	799.57
2003	1030.87	1122.3	615.72	713.49	870.60
2004	1144.73	1205.3	434.92	851.38	909.08
2005	918.37	1013.7	659.62	606.49	799.55
2006	1227.06	1276.5	861.69	829.06	1048.58
2007	1079.61	1139.6	718.43	678.04	903.92
2008	1098.43	1190.1	799.66	754.57	960.69
2009	1045.46	1050	640.89	653.93	847.57
2010	1429.4	1495.1	866.06	811.19	1150.44
2011	1076.86	1186.3	876.76	804.61	986.13
2012	1161.02	1208.9	920.65	862.87	1038.36
2013	1037.72	1092	732.6	796.43	914.69
2014	809.72	866.2	680.23	695.25	762.85
2015	963.02	925.9	597.98	654.87	785.44
2016	928.92	945.5	558.74	730.33	790.87
2017	660.02	692.4	327.59	429.26	527.32

d) Standard Deviation and Mean/Average of Total annual rainfall (1987-2017) across all sub-catchments in Millimetres

STDEV-P Average and average of Total annual rainfall (1987-2017) across all sub-catchments	**Amala 1987 to 2017**	**Nyangores 1987 to 2017**	**Sand 1987 to 2017**	**Talek 1987 to 2017**
STDEV-P 30years	136.5575	167.5228	152.1922	145.0216
Average	1021.264	1094.594	720.1206	829.4706
STDEV-P and average of Total annual rainfall (1987-2007) across all sub-catchments	Amala 1987 to 2017	Nyangores 1987 to 2017	Sand 1987 to 2017	Talek 1987 to 2017
STDEV-P 20 years 1987-2007	96.34006	139.4324	141.5376	126.514
Average	1021.362	1108.571	729.6467	881.9181
STDEV-P and average of Total annual rainfall (1987-1997) across all sub-catchments	Amala 1987 to 2017	Nyangores 1987 to 2017	Sand 1987 to 2017	Talek 1987 to 2017
STDEV-P 10 years 1987-1997	74.98348	137.7373	139.6262	66.29494
Average	1013.322	1099.455	747.1827	956.7282

e) Annual average Temperature computed from daily maximum and minimum rainfall data from NASA Giovanni website (in Centigrade)

Year	**Amala Annual Average Temperature**	**Nyangores Annual Average Temperature**	**Sand Annual average temperature**	**Talek Annual average temperature**
1987	17.8	16.5	18.2	18.2
1988	18.0	16.6	18.3	18.3
1989	17.8	16.3	17.9	17.9
1990	17.3	16.1	17.7	17.7
1991	18.7	17.0	18.7	18.7
1992	18.3	17.0	18.4	18.4
1993	18.3	16.9	18.3	18.3
1994	18.6	17.1	18.6	18.6
1995	18.4	16.9	18.4	18.4
1996	18.3	16.9	18.3	18.3
1997	18.4	17.1	18.4	18.4
1998	17.5	16.2	18.0	18.0
1999	18.9	17.2	18.7	18.7
2000	19.2	17.7	19.1	19.1
2001	17.5	16.4	17.9	17.9
2002	18.5	17.1	18.6	18.6
2003	18.1	16.8	18.2	18.2
2004	18.8	17.4	18.8	18.8
2005	19.0	17.7	18.9	18.9
2006	18.4	17.2	18.3	18.3
2007	17.4	16.2	17.7	17.7
2008	18.1	16.8	18.3	18.3
2009	18.9	17.6	18.9	18.9
2010	17.6	16.3	18.1	18.1
2011	18.4	16.8	18.6	18.6
2012	17.9	16.4	18.3	18.3
2013	17.7	16.3	18.1	18.1
2014	18.7	17.2	18.8	18.8
2015	19.3	17.7	18.9	18.9
2016	18.9	17.3	18.6	18.6
2017	19.9	18.1	19.4	19.4

f) Average annual temperature (1987-2017) across all sub-catchments compared with 30 years average annual temperature mean (in Centigrade).

	Amala	Nyangores	Sand	Talek	Mean
1987	17.79	16.51	18.20	18.20	17.67
1988	18.00	16.59	18.25	18.25	17.78
1989	17.84	16.29	17.86	17.86	17.46
1990	17.33	16.12	17.73	17.73	17.22
1991	18.68	17.04	18.68	18.68	18.27
1992	18.31	16.99	18.43	18.43	18.04
1993	18.34	16.92	18.35	18.35	17.99
1994	18.63	17.14	18.56	18.56	18.22
1995	18.40	16.92	18.43	18.43	18.05
1996	18.33	16.90	18.31	18.31	17.96
1997	18.43	17.05	18.40	18.40	18.07
1998	17.47	16.22	18.03	18.03	17.44
1999	18.92	17.24	18.72	18.72	18.40
2000	19.22	17.74	19.07	19.07	18.77
2001	17.54	16.37	17.87	17.87	17.41
2002	18.46	17.15	18.56	18.56	18.18
2003	18.14	16.82	18.24	18.24	17.86
2004	18.79	17.36	18.84	18.84	18.46
2005	19.01	17.72	18.91	18.91	18.64
2006	18.40	17.24	18.32	18.32	18.07
2007	17.41	16.23	17.75	17.75	17.28
2008	18.14	16.84	18.32	18.32	17.91
2009	18.93	17.61	18.91	18.91	18.59
2010	17.56	16.31	18.13	18.13	17.54
2011	18.37	16.83	18.62	18.62	18.11
2012	17.87	16.43	18.31	18.31	17.73
2013	17.67	16.33	18.11	18.11	17.55
2014	18.73	17.23	18.76	18.76	18.37
2015	19.34	17.72	18.90	18.90	18.72
2016	18.87	17.26	18.60	18.60	18.33
2017	19.87	18.13	19.38	19.38	19.19

g) Decadal mean temperature in Centigrade

Month	**1987-1996**	**1997-2006**	**2007-2017**	**1997-2017**
January	19.2	19.4	19.4	19.4
February	19.9	19.0	19.1	19.3
March	19.9	19.0	18.8	19.2
April	18.5	19.4	19.3	19.1
May	17.2	20.2	20.0	19.1
June	16.4	19.8	19.8	18.7
July	16.5	18.3	18.4	17.7
August	17.6	17.1	17.3	17.3
September	18.9	16.3	16.6	17.3
October	19.4	16.8	17.1	17.8
November	19.1	17.8	17.9	18.3
December	19.1	19.1	19.1	19.1

h) RAINFALL MANN-KENDALL TREND TEST

1. Amala Sub-catchment Rainfall Mann Kendall trend test Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Rainfall	31	0	31	660.020	1429.400	1021.264	138.815

Seasonal Mann-Kendall Test / Period = 12 / Serial independence / Two-tailed test (Var1):

Kendall's tau	1
S'	12.000
Var(S')	12.000
p-value (Two-tailed)	0.001
alpha	0.050
An approximation has been used to compute the p-value.	

Test interpretation:

H0: There is no trend in the series

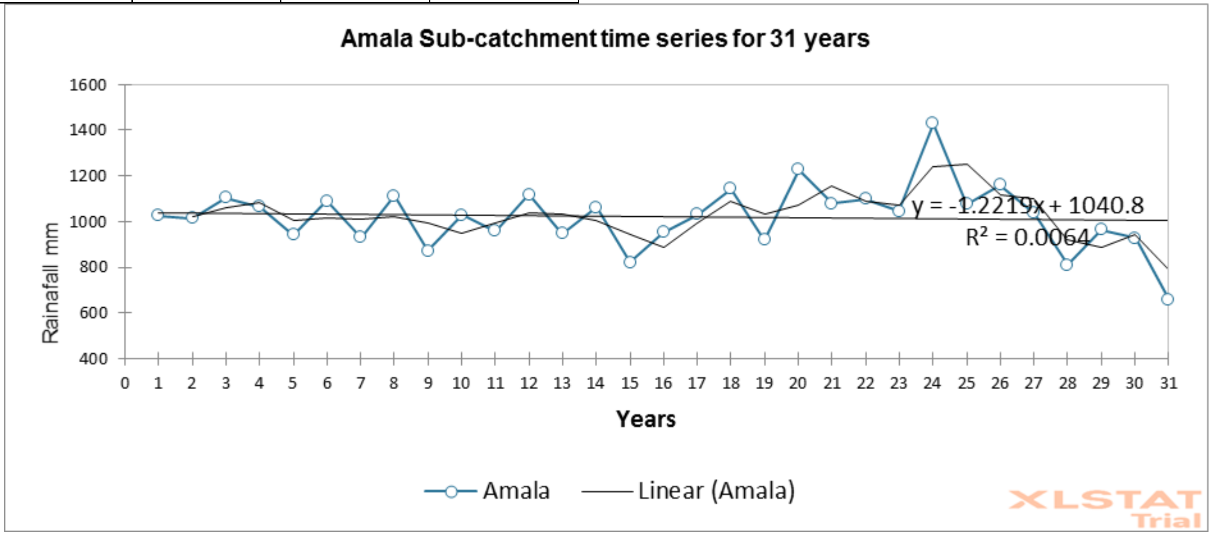
Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.000	1.000	1.000
Intercept	1986.000	1986.000	1986.000



2. Nyangores Sub-catchment Rainfall Mann Kendall trend test Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Rainfall	31	0	31	692.400	1495.100	1094.594	170.292

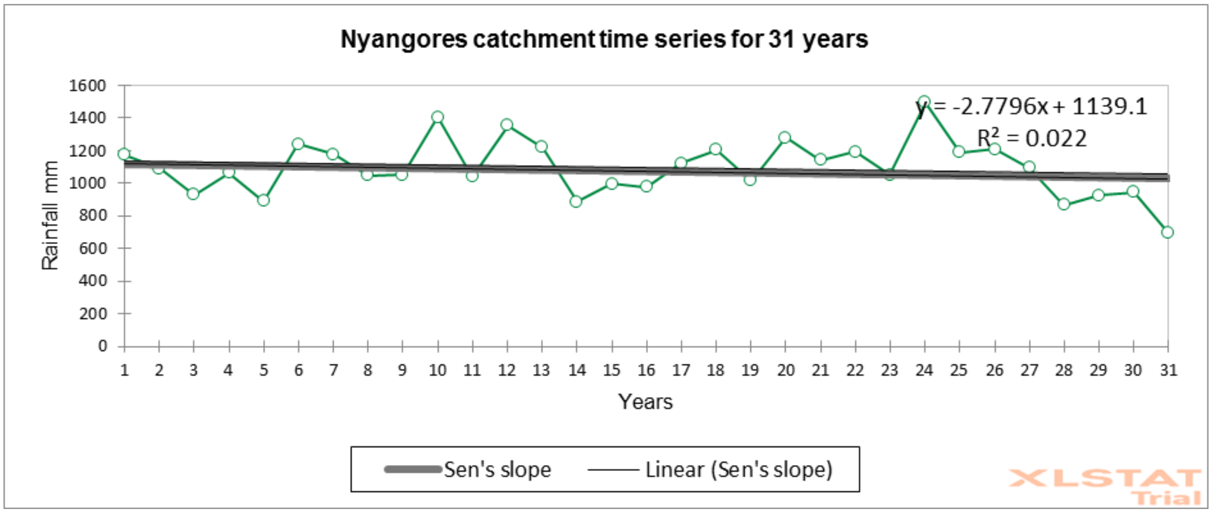
Mann-Kendall trend test / Two-tailed test (Var1):

Kendall's tau	1
S	465.000
Var(S)	3461.667
p-value (Two-tailed)	<0.0001
alpha	0.050
An approximation has been used to compute the p-value.	

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.000	1.000	1.000
Intercept	1986.000	1986.000	1986.000



3. Sand Sub-catchment Rainfall Mann Kendall trend test Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Rainfall	31	0	31	327.590	920.650	720.121	154.708

Mann-Kendall trend test / Two-tailed test (Var1):

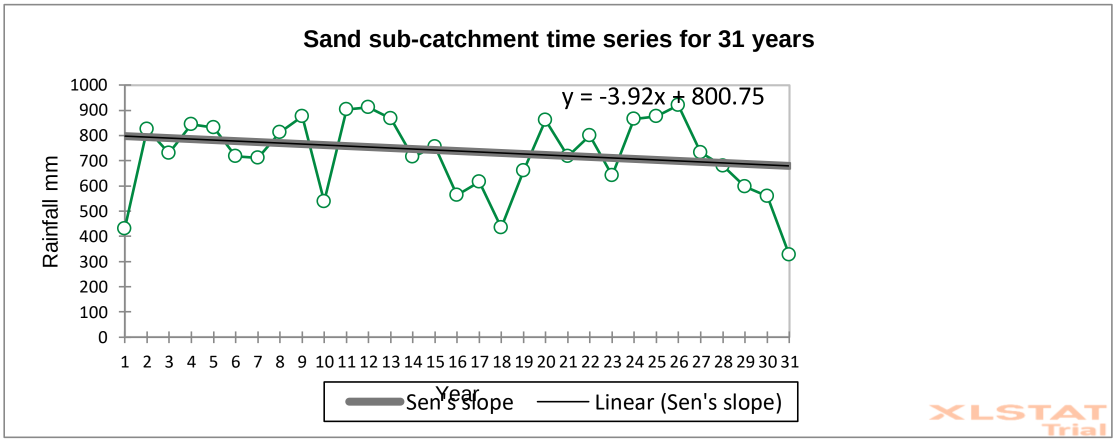
Kendall's tau	1
S	465.000
Var(S)	3461.667
p-value (Two-tailed)	<0.0001
alpha	0.050
An approximation has been used to compute the p-value.	

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.000	1.000	1.000
Intercept	1986.000	1986.000	1986.000



4. Talek Sub-catchment Rainfall Mann Kendall trend test Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Rainfall	31	0	31	429.260	1027.110	829.471	147.419

Mann-Kendall trend test / Two-tailed test (Var1):

Kendall's tau	1
S	465.000
Var(S)	3461.667
p-value (Two-tailed)	<0.0001
alpha	0.050
An approximation has been used to compute the p-value.	

Test interpretation:

H0: There is no trend in the series

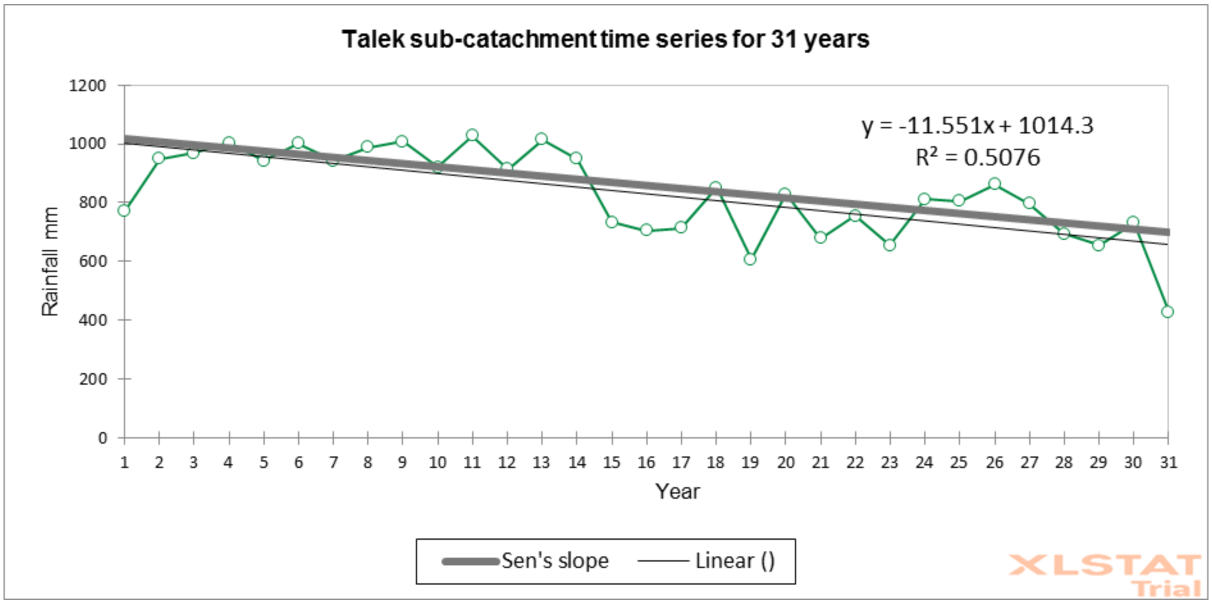
Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.000	1.000	1.000
Intercept	1986.000	1986.000	1986.000



i) TEMPERATURE MANN-KENDALL TREND TEST

1. Amala Sub-catchment Temperature Mann Kendall trend test Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Temperature	31	0	31	17.326	19.873	18.348	0.617

Mann-Kendall trend test / Two-tailed test (Var1):

Kendall's tau	1
S	465.000
Var(S)	3461.667
p-value (Two-tailed)	<0.0001
alpha	0.050
An approximation has been used to compute the p-value.	

Test interpretation:

H0: There is no trend in the series

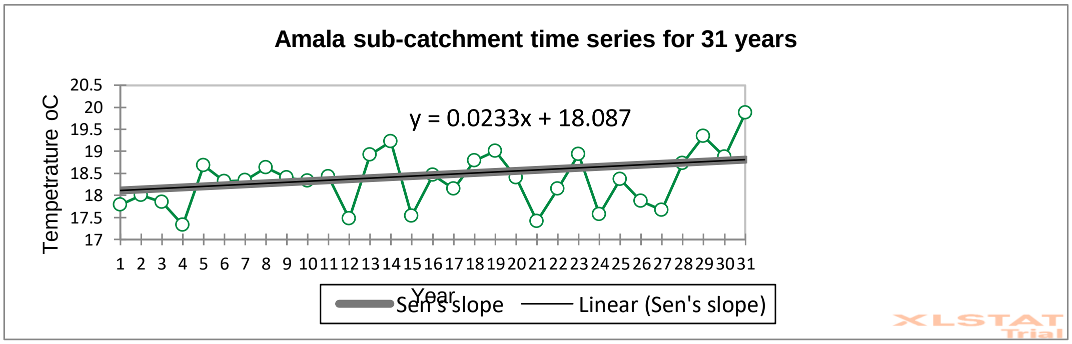
Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.000	1.000	1.000
Intercept	1986.000	1986.000	1986.000



2. Nyangores Sub-catchment Temperature Mann Kendall trend test Summary statistics:

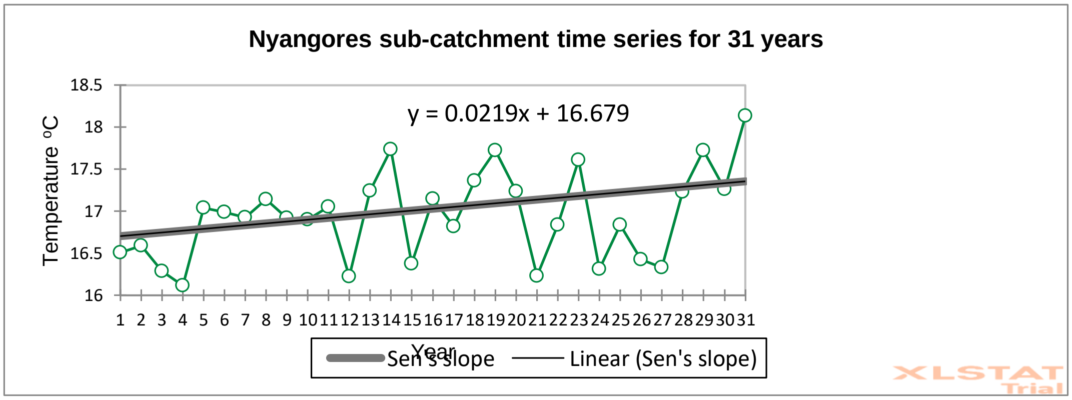
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Temperature	31	0	31	16.117	18.132	16.944	0.523

Mann-Kendall trend test / Two-tailed test (Var1):

Kendall's tau	1
S	465.000
Var(S)	3461.667
p-value (Two-tailed)	<0.0001
alpha	0.050
An approximation has been used to compute the p-value.	

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The continuity correction has been applied.
Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.000	1.000	1.000
Intercept	1986.000	1986.000	1986.000



3. Sand Sub-catchment Temperature Mann Kendall trend test Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Temperature	31	0	31	17.727	19.376	18.438	0.393

Mann-Kendall trend test / Two-tailed test (Var1):

Kendall's tau	1
S	465.000
Var(S)	3461.667
p-value (Two-tailed)	<0.0001
alpha	0.050
An approximation has been used to compute the p-value.	

Test interpretation:

H0: There is no trend in the series

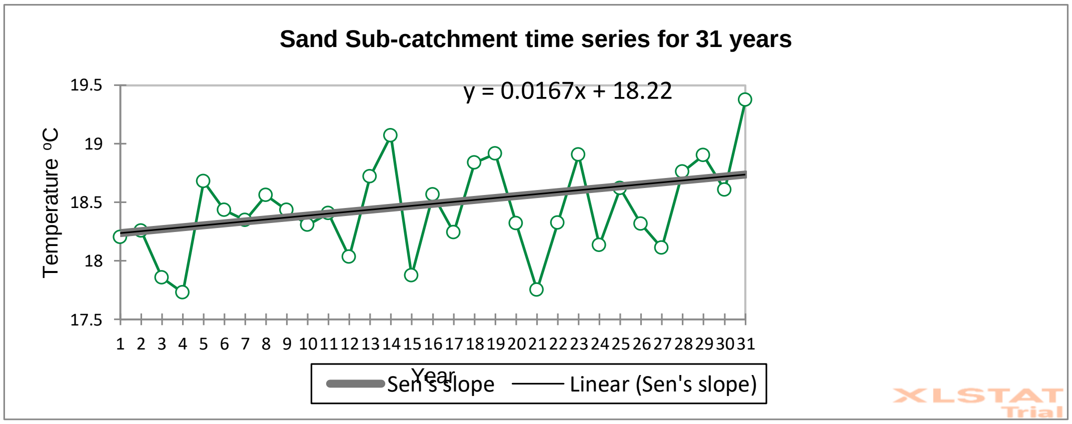
Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The continuity correction has been applied.

Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.000	1.000	1.000
Intercept	1986.000	1986.000	1986.000



4. Talek Sub-catchment Temperature Mann Kendall trend test Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Talek	31	0	31	17.727	19.376	18.438	0.393

Mann-Kendall trend test / Two-tailed test (Var1):

Kendall's tau	1
S	465.000
Var(S)	3461.667
p-value (Two-tailed)	<0.0001
alpha	0.050
An approximation has been used to compute the p-value.	

Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The continuity correction has been applied.
Sen's slope:

	Value	Lower bound (95%)	Upper bound (95%)
Slope	1.000	1.000	1.000
Intercept	1986.000	1986.000	1986.000

Appendix VIII. Relationship between Total water yield and surface runoff

SWAT model revealed that, the lower part of the Nyangores sub-catchment contributed most of the total water yield (figure 1) and part of it is surface runoff (figure 2). Figure 1 to 4 illustrate additional SWAT model outputs on surface runoff as part of total water yield.

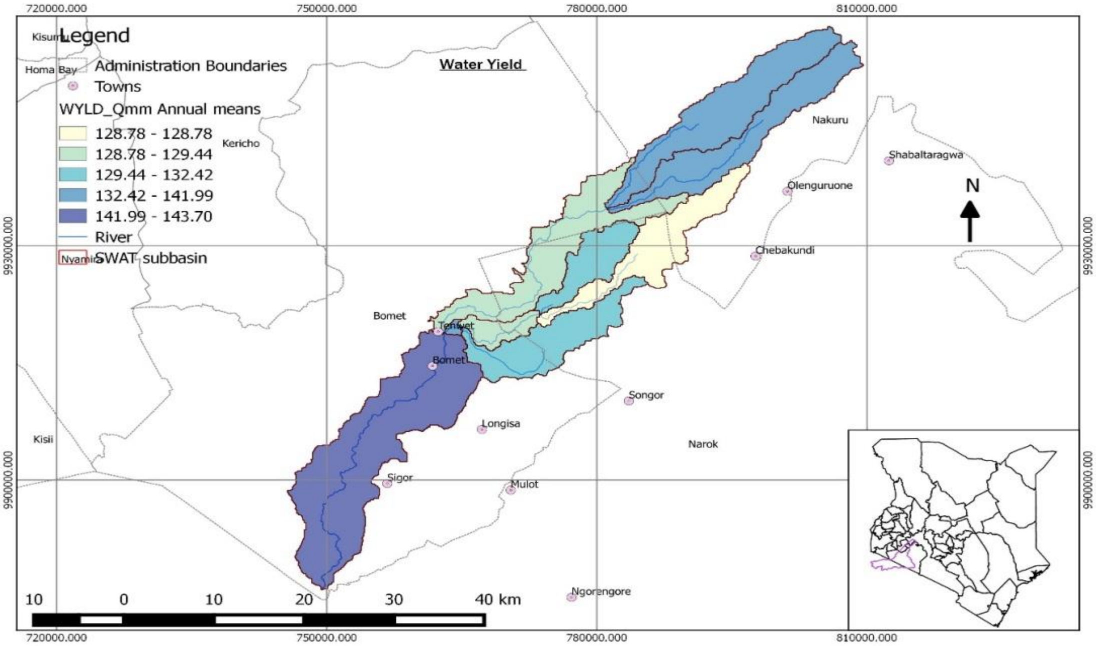


Figure 1. Total water yield (WYLD) in Nyangores

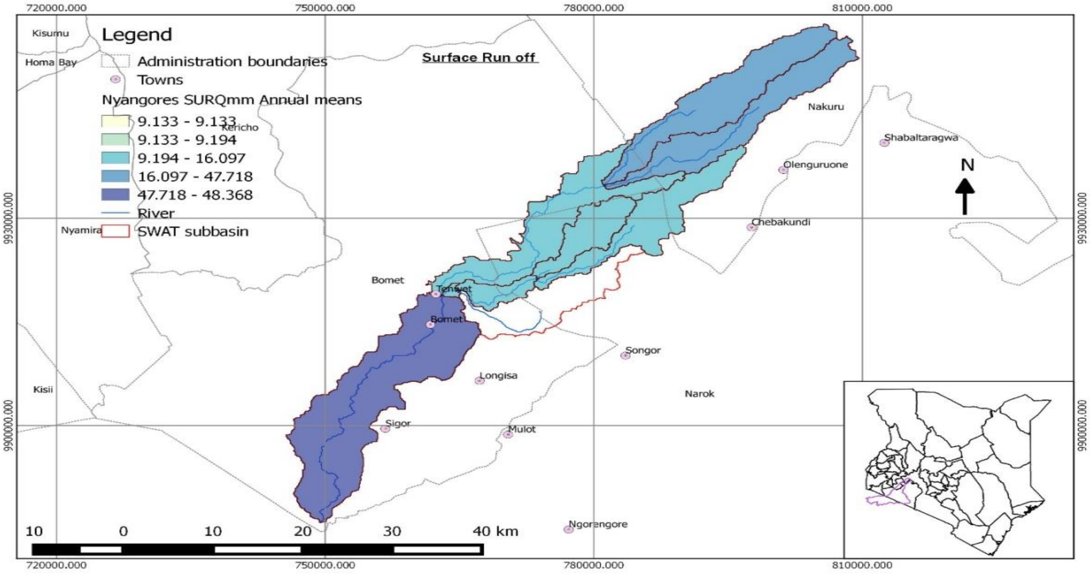


Figure 2. Surface runoff in Nyangores

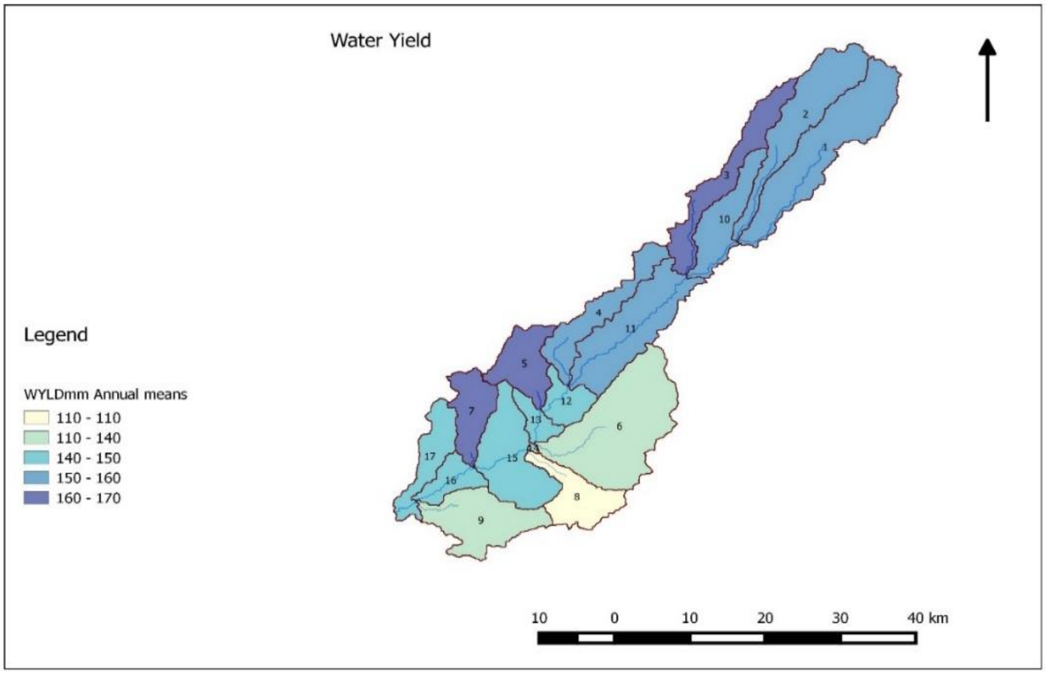


Figure 3. Total Water yield within the Amala sub-catchment

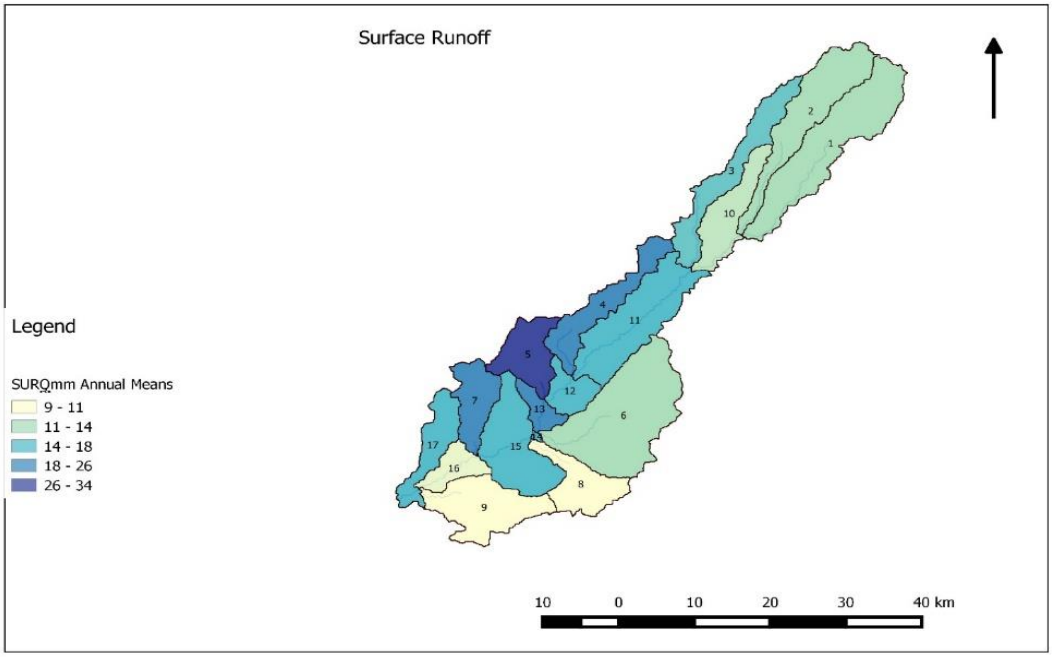


Figure 4. Surface runoff within the Amala sub-catchment

Appendix IX. Relationship between Soil water availability and soil classes/types

Soil water availability is the capacity of a soil to hold water that is available for plant and other uses. Figure 1 to 4 illustrate additional SWAT model outputs on soil factors.

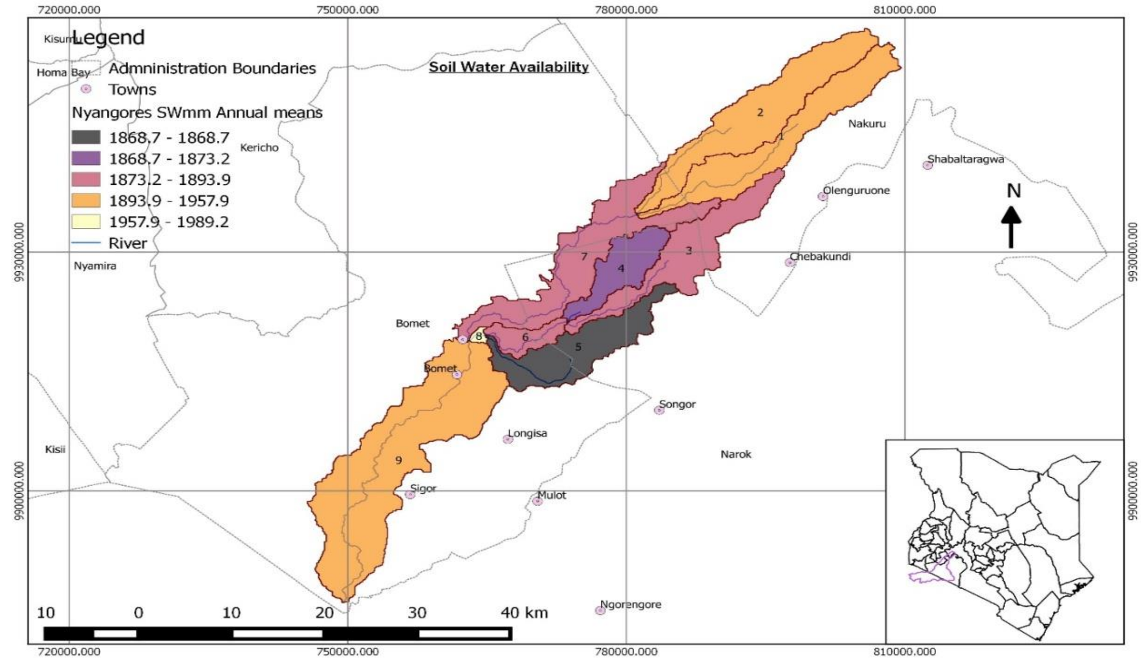


Figure 1. Soil water availability Nyangores

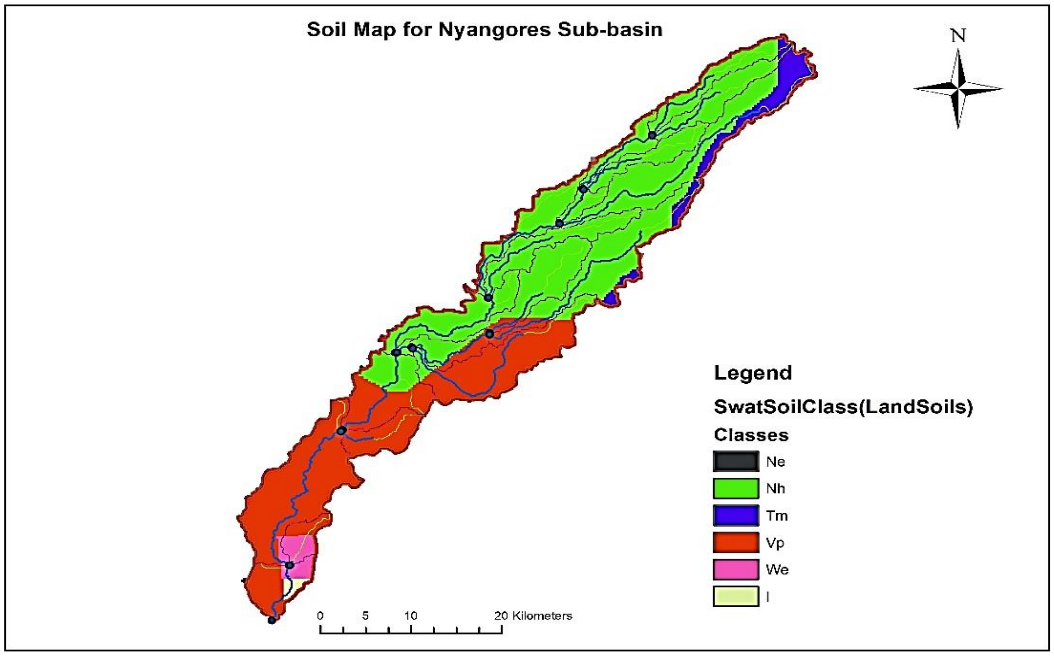


Figure 2. Soil SWAT classes in Nyangores

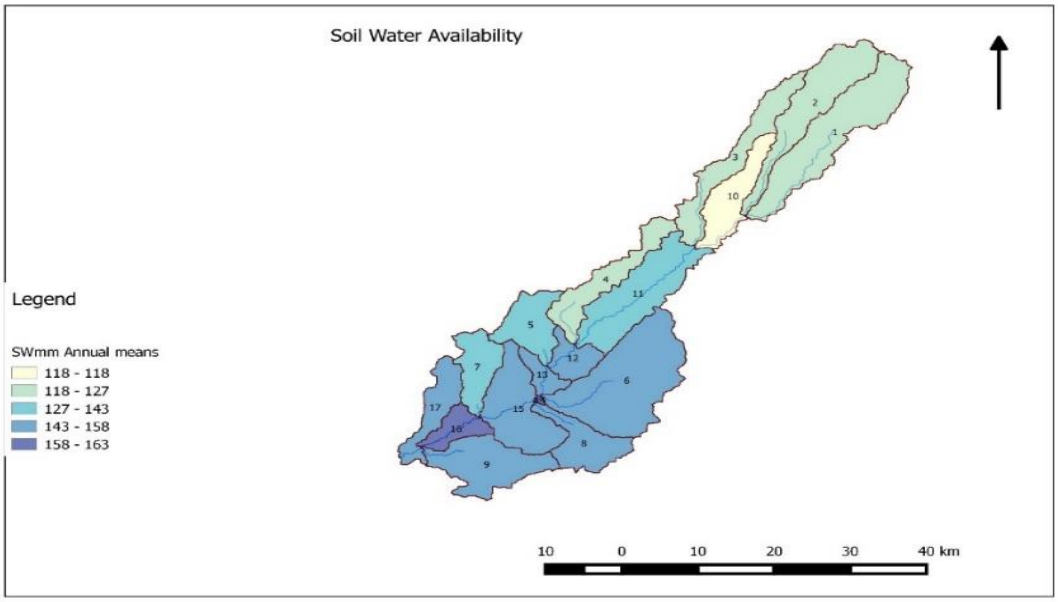


Figure 3. Soil water availability within the Amala sub-catchment

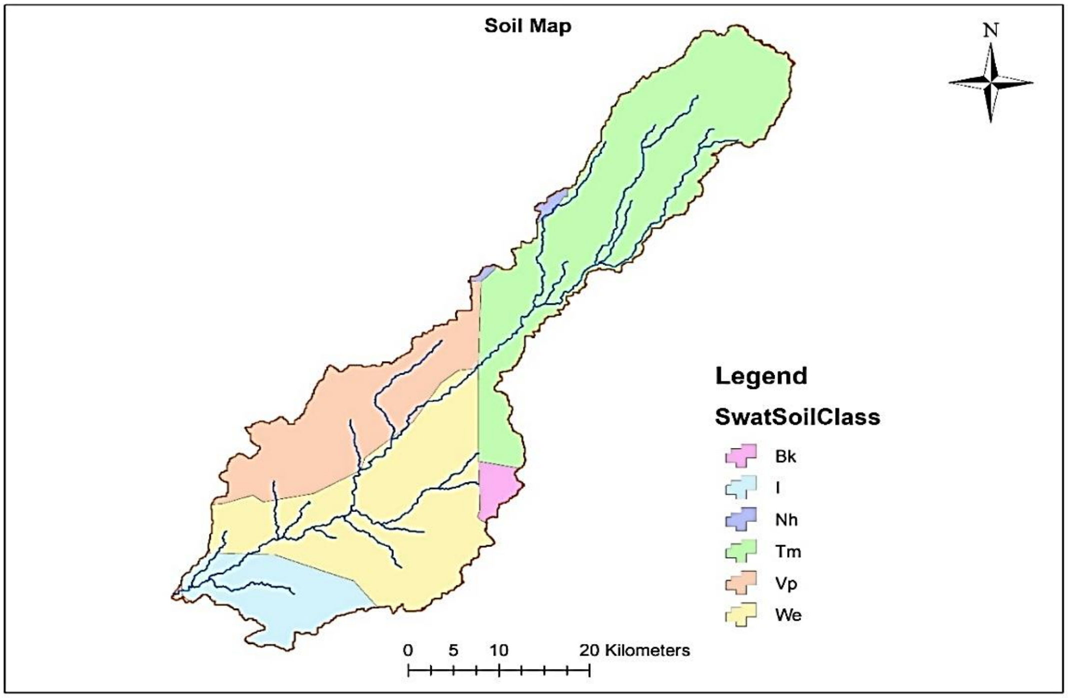


Figure 4. Total soil SWAT classes in Amala

Appendix X. Relationship between Evapotranspiration and water percolation

In Nyangores, evapotranspiration was lowest in the lower section and highest in the mid-section of the basin (Figure 1) where crop and forest lands existed respectively. Figure 1 to 4 illustrate additional SWAT model outputs.

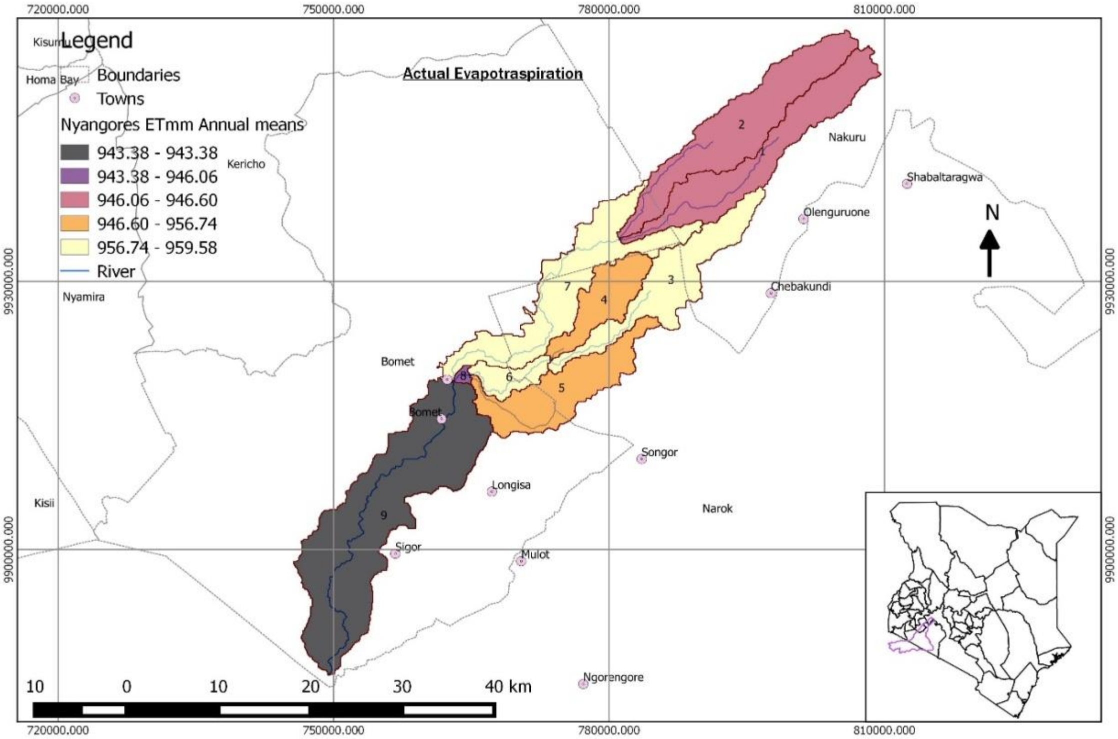


Figure 1. Evapotranspiration in Nyangores

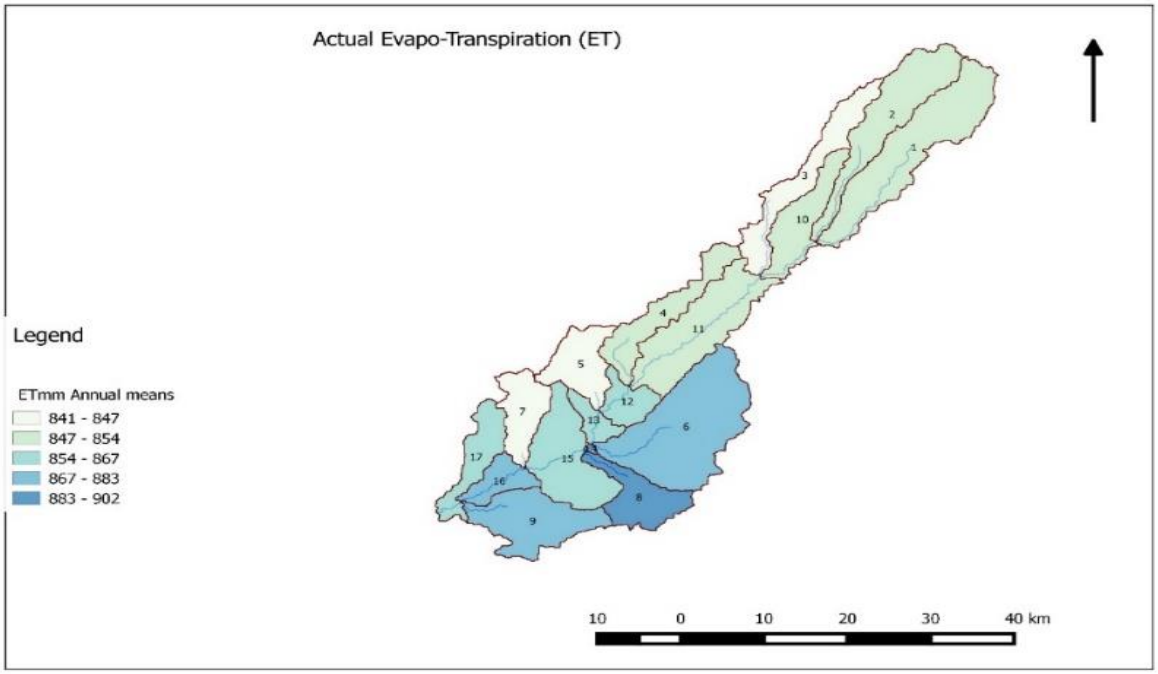


Figure 2. Evapotranspiration within the Amala sub-catchment

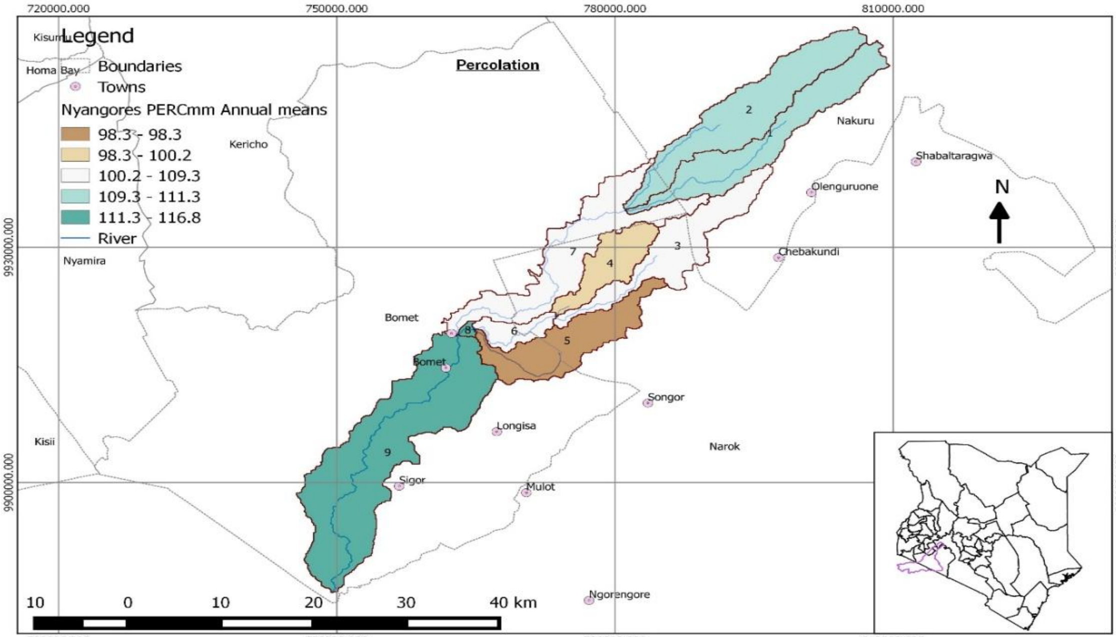


Figure 3. Water percolation in Nyangores

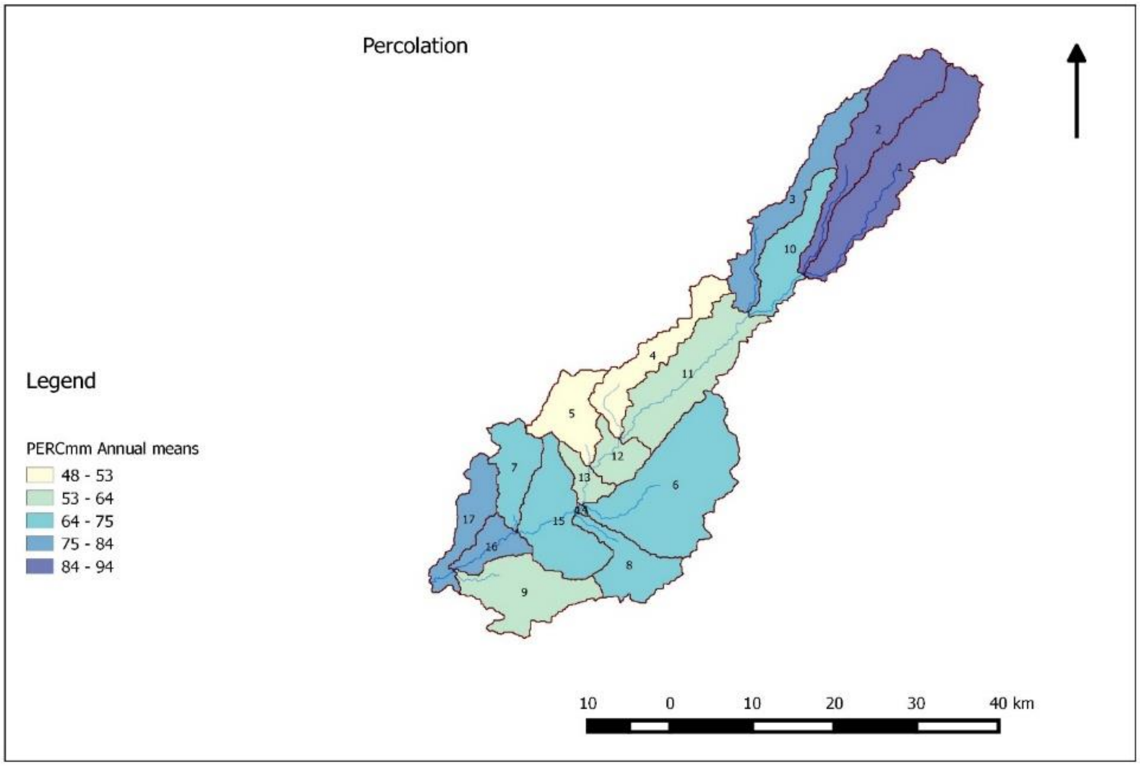


Figure 4. Water percolation within the Amala sub-catchment