IMPACT OF LAND USE AND LAND COVER CHANGE ON
STREAM FLOW IN NYANGORES SUB-CATCHMENT MARA
RIVER, KENYA

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Environmental Studies of

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DECLARATION

I declare that this is my original research and has not been presented in any other institution of higher learning or any other award.

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Reg: No. N50/CTY/PT/22734/2012

Signature

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DEDICATION

I wish to dedicate this work to my parents, Mr. Julius Cheruiyot and Mrs. Elizabeth Cheruiyot for educating me up to this far.
ACKNOWLEDGEMENT

I wish to thank the Almighty God for giving me the chance and strength to carry out the research and to write this thesis. I sincerely appreciate my supervisors Dr. Geoffrey Macharia of Department of Environmental Science, Kenyatta University and Dr. Luke Olang’ of Department of Biosystems and Environmental Engineering Technical University of Kenya for support, positive criticism and assistance. I am thankful to my colleague, a friend and fellow MSc. Student Mr. Paul Omonge at the Department of Environmental Science, Kenyatta University whose encouragement assisted me in many ways, I won’t forget the memorable moments we had together. I am also great full to my friend Sospeter Wakesa for helping me to understand and to shape up my GIS skills.

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Last but not least, I thank my family for their encouragement, sacrifice and support, I truly appreciate. THANK YOU ALL and May God bless you abundantly.
### ACRONYMS AND ABBREVIATIONS

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<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer</td>
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<td>DEM</td>
<td>Digital Elevation Model</td>
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<tr>
<td>DMC</td>
<td>Double Mass Curve</td>
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<tr>
<td>EOS</td>
<td>Earth Observation Systems</td>
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<td>ERTS</td>
<td>Earth Resource Technology Satellite</td>
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<tr>
<td>ECA</td>
<td>Economic Commission for Africa</td>
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<td>ETM+</td>
<td>Enhanced Thematic Mapper Plus</td>
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<td>Equ</td>
<td>Equation</td>
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<tr>
<td>FAO</td>
<td>Food and Agricultural Organization</td>
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<td>GIS</td>
<td>Geographic Information Systems</td>
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<td>GLCN</td>
<td>Global Land Cover Network</td>
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<td>GPS</td>
<td>Geographical Positioning System</td>
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<td>GWP</td>
<td>Global Water Partnership</td>
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<td>HSG</td>
<td>Hydrologic Soil Group</td>
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<td>ITCZ</td>
<td>Inter-Tropical Convergence Zone</td>
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<tr>
<td>LCC</td>
<td>Land Cover Change</td>
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<td>LCCS</td>
<td>Land Cover Classifications System</td>
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<td>KSS</td>
<td>Kenya Soil Survey</td>
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<td>MEA</td>
<td>Millennium Ecosystem Assessment</td>
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<tr>
<td>Mm$^3$</td>
<td>Million Cubic Meter</td>
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<td>MODIS</td>
<td>Moderate Resolution Imaging Spectrometer</td>
</tr>
<tr>
<td>MSS</td>
<td>Multispectral Scanner</td>
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<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration-</td>
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<tr>
<td>NGO</td>
<td>Non-Governmental Organization</td>
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<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<td>Acronym</td>
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<tr>
<td>OLI</td>
<td>Operational Land Imager</td>
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<td>PA</td>
<td>Producer Accuracy</td>
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<td>SCS</td>
<td>Soil Conservation Curve</td>
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<tr>
<td>SRTM</td>
<td>Shuttle Radar Topographic Mission</td>
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<tr>
<td>SWIR</td>
<td>Shortwave Infrared</td>
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<tr>
<td>SPOT</td>
<td>Satellite Probitoire'd Observation De La Terre</td>
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<tr>
<td>TIR</td>
<td>Thermal Infrared</td>
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<tr>
<td>TM</td>
<td>Thematic Mapper</td>
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<td>UA</td>
<td>User Accuracy</td>
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<td>USGS</td>
<td>United States Geological Survey</td>
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<tr>
<td>WEAP</td>
<td>Water Evaluation and Planning Model</td>
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<tr>
<td>WRM</td>
<td>Water Resource Management</td>
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<td>WRMA</td>
<td>Water Resource Management Authority</td>
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<td>WRUA</td>
<td>Water Resource Users Association</td>
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ABSTRACT

The Nyangores sub-catchment of the transboundary Mara Basin of Kenya and Tanzania is an important upstream area due to its ecological composition. Like many other sub-catchments in Kenya, Nyangores sub-catchment has undergone significant land cover changes arising from various socio-economic reasons. In the Nyangores sub-catchment, these changes are believed to be amplifying stream flows through increased runoff rates during rainfall seasons. Over the years, land use changes have been observed and have contributed to environmental changes which has led to reduction in vegetation cover in the upper catchements hence impacting on the river flow. Hydrological models have proved to be efficient evaluating the effects of land cover changes on stream flow characteristics. These models require high resolution spatio-temporal land cover information which defines the change statistics and directions. The aim of this study was; (i) To determine the physical sub-catchment characteristics. (ii) To assess the spatial and temporal land cover change (1995-2010). (iii) To assess the effects of land use land cover changes on the stream flow in Nyangores sub-catchment. The morphometric characteristics were assessed from a Digital Elevation Model (DEM) based on standard and automated procedures available within ArcGIS to determine physically based catchment characteristics. The land cover changes were obtained through classification of Landsat images for 1995 (Landsat TM) and 2010 (Landsat ETM+) based on a supervised classification methodology employing the Maximum Likelihood Function. The images were classified into four major classes namely, farmlands, tree plantation, natural forest and Shrub lands. The WEAP model was calibrated and validated using observed monthly streamflow data and later used to simulate the land cover change effects on stream flow between 1995 and 2010. From the morphometric analysis, the sub-catchment covers an area of about 933km². Nyangores River was found to be a 4th order stream with a mean bifurcation ratio of 1.4. Land cover classification reveals that tree plantation declined by about 9.4%, farmland expanded by about 8.7%, Shrub lands increased by about 1.9% while forest declined by 1.2%. After calibration and validation, the simulation results indicated that stream flow increased by 3% in the whole sub catchment. The statistical analysis shows that the increase of streamflow and farmland expansion demonstrates a very strong and positive relationship. Land use change in the study area have contributed to environmental degradation, erosion and deforestation. The analysis of stream flow indicates predominantly low dry season flows and peak wet season flows between the 1995 and 2010. These changes could be attributed to spatial decrease in natural forest and tree plantation land areas that occupied upper sub-catchment over the study period. This situation has strong implications to water resources management in Nyangores sub-catchment where conflicts related to periodic water scarcity are increasing. The results will go a long way providing a useful
information to support land-use planning and management. The study therefore calls for a multidisciplinary approach with a comprehensive view towards land use that maintains ecological health and human requirements. This study provides valuable information for sub-catchment management in the efforts to mitigate streamflow impact caused by LULC change in this critical watershed

**Key words:** GIS, Land Cover, WEAP, Nyangores sub-catchment
CHAPTER ONE: INTRODUCTION

1.1 Background to the study

The global environmental modifications and the resulting problems are greatly influence by the LULC (Olang, 2009; Aboud, 2002). LULC anthropogenic modifications has adversely lead to deforestation, loss of biodiversity, flooding, changes in global climate due to global warming, and land degradation disrupting the ecological balance as well as environmental set up. Changes in forest cover have become an issue of global concern due to its role in causing malfunctioning of carbon cycle (Aboud, 2002). Remote sensing using satellite has for long been used in monitoring of LULC on the basis of spatial and temporal remotely sensed data all over the world.

Global water use has been increasing with population growth and it will continue to increase rapidly as industrial, agricultural and domestic demands for water rises (UNDP, 2006; GWP, 2004). The soaring global demand for water has become an environmental cost with some rivers no longer reaching the lakes and sea due to loss in river basins and wetlands (GWP, 2004). With over 42% of the world’s population living in sub-catchment basins, there is real cause for concern on the likely effects of human induced activities on the river basins (MEA, 2005).

In developing countries mainly in the Sub-Saharan Africa, increase in population growth rates correlates with low productivity and environmental degradation (Lambin and Geist, 2003). In Kenya, various
land use processes that have led to the natural land cover changes include; urbanization, conversion of forests to crop land, conversion of grasslands to crop land, changing of crops on the existing cropland, as well as the intensification of croplands (Lambin and Geist, 2003).

Kenya with a population estimated at 40 million, faces a complex water resources crisis because of its rainfall variability and distribution, deforestation of water catchment areas, degradation of water resources and changing national land-use policies (Government of Kenya, 2006). Ninety percent of the population living in rural areas derives its livelihood directly from land use (Government of Kenya, 2008). The increase in population, declining land area available for cultivation due to land sub-divisions coupled with unsustainable land management practices affect land productivity, forcing communities to intensify cultivation into catchment areas in search of more land which, ultimately affect the catchment water functions (Campbell et al., 2003).

Most communities generate their goods and service from land with is a vital resources and form the input of land use (Campbell et al., 2003). According to De Fries et al., 2007, Human land-use is at the center of some of the most complicated and pressing problems facing resource managers and land users in balancing trade-offs between human needs and the environment.

Domestic water sources in rural settings include streams, springs, ponds, small dams, shallow wells and small piped systems (Government of
Kenya, 2007b). Such sources are very susceptible to encroachment and pollution through land-use activities because they are open and often not protected (Masiyandima, 2007). The impacts of land-use activities have been of primary concern because of their ability of the natural ecosystem to provide both for the human and ecological needs (Reid et al., 2004).

1.2 Problem statement

The Nyangores River is of critical importance to the natural habitats of the Maasai Mara ecosystem, as well as other land users in the sub-catchment. Major environmental changes related to land-use changes have been observed in recent years. The river is threatened by an accelerated reduction in vegetation cover in the upper catchments, and consequent land degradation, which impacts the river flows and the ecosystem (Aboud, 2002; Mati et al., 2005). Increased agricultural activities in the Nyangores river sub-catchment over the last decade have resulted in the opening of large forest plantations for the cultivation of seasonal crops, thereby reducing the natural perennial vegetation. This situation has been accelerated by a rapid population growth and high immigration rates. Forests and savannah grasslands have been cleared and converted into agricultural lands (IUCN 2000; Machiwa, 2002), while grazing resources have dwindled. The Ndorobo Forest in the Mau escarpment, for example, was reduced from 75200 ha in 1973, to 49300 ha in 2000 (Gereta, et al., 2001). Therefore, an intervention to
study extend at which Nyangores land cover is changing over time was necessary.

Land-use and land cover change is an important characteristic in the hydrological processes that affects infiltration, run-off and evapotranspiration. These changes have caused severe stress on land and water resources in Nyangores Sub-catchment. Due to rapid development in the sub-catchment, land-use land cover is subjected to changes causing the area to form impervious surfaces. Deforestation, farming, and other land use activities can significantly alter the hydrological components of the sub-catchment (Kilonzo, 2013).

Although land-use changes in the area are a current phenomenon, the severity of their effects in land cover and hydrology of Nyangores Sub-catchment might pose serious concern on the future functioning of this fragile resource if urgent action is not taken into consideration (Kilonzo, 2013). There was therefore, a need to assess the spatial and temporal changes in Nyangores sub-catchment and their effects on the hydrological components, which this study addressed.

1.3 Research Question

The research aimed at addressing the following questions;

i. What are the physical features of Nyangores sub-catchment?

ii. To what extent has the spatial and temporal land cover change in the sub-catchment occurred?
iii. How does the land use land cover change affects the stream flow of Nyangores River?

1.4 Research Hypotheses

H1: There is land cover change in the Nyangores sub-catchment.

H2: The change in land cover affects the streamflow of Nyangores River.

1.5 Objectives

The general objective was to assess the impact of land use and land cover change on stream flow in Nyangores sub catchment Mara River, Kenya. The specific objectives of the research were:

i. To determine the physical sub-catchment characteristics. (Linear aspects, Relief aspects and Aerial aspects).

ii. To assess the spatial and temporal land cover change (1995-2010).

iii. To assess the effects of land use land cover changes on the stream flow in Nyangores sub-catchment.

1.6 Justification of the Study

This study examined the land-use and land cover change and its effects on the stream flow of Nyangores Sub-catchment. The reasons for conducting this study were as follows.
First, the Nyangores sub-catchment is the most affected among the Mara River Basin sub-catchments (Kilonzo, 2013). This is due to threats of land-use and land-cover changes and the weak land and water conservation measures, resulting in more adverse effects on water and land resources than expected.

Secondly, the population in the sub-catchment has been growing very rapidly, which has escalated the land use and land cover changes. The intensification of farming in the Sub-catchment have ensured that soils are increasingly eroded, which directly affects its water retention capabilities and increase run-off (Kilonzo, 2013).

Thirdly, the trend of land-use change between 1995 and 2010 was used simply because during that time the effects of land-use change in Mau complex forest had been severed prompting the government to carry out massive eviction from the forest. In addition, during that period the area had successive and prolong droughts for example the one in 2009 which led to flow reduction causing massive water scarcity for both domestic and wildlife in the expansive Maasai Mara and Serengeti game reserves.

1.7 Significance of the Study

Land-use and land-cover changes in Kenya are extremely rapid, and their direction of change is not clear (IUCN, 2000). With rapid developments, water resources become an important commodity that every sector is competing for.
The problem of siltation, erosion and dry season flow reduction can only be approached from a whole sub-catchment perspective with improved water management tools based on sound scientific principles and efficient technologies. Developing an approach for assessing land-use changes and their effects on the hydrological components at the sub-catchment level is essential in land-use and water resource planning and management. Understanding the consequences of land-use change for hydrologic processes, and integrating this understanding into the emerging focus on land-use change science (Turner et al., 2003), are major needs for the future.

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 findings of this study will also enable planners to formulate policies to minimize the undesirable effects of future land-use cover changes in the sub-catchment.

1.8 Conceptual framework

The land use in the sub-catchment, such as farming, human settlement, cultivation on the riparian area and illegal logging are the driving forces in the system. The hydrology in the sub-catchment is based on the sub-catchment recharge from the precipitation and runoff to the river. The status of the land cover change in turn influence the introduction or
The pressure on the land use comes from among other things, the population pressure, soil erosion, deforestation and industrialization; this in turn affects the state of land cover. The decision variables which are in form of policies, by-laws, modelling in WEAP, afforestation and reafforestation are used to impose control and regulation of land usage. The decisions made from the various constraints affect both the state of land cover and the hydrology in the sub-catchment.

The land use and hydrological data variables are then modeled in WEAP to simulate various scenarios. Such comprise “what if” scenarios and include; What if there is 5% human population increase in the...
catchment? What if a reafforestation plan is introduced? What if there is a 50% increase in land area under farming? These scenarios are then entered into the model and repeated through a cyclic loop from the modeling results until a specific objective is met.
CHAPTER TWO: LITERATURE REVIEW

This chapter deals with reviewing of literature for water resources, land use change and geographical information systems, hydrological modelling, WEAP model and Landsat imagery. The chapter capitalized mostly on books, journals, and any other relevant publication. The purpose of literature review is to get a clear picture of what has been done elsewhere by other scholars or researchers in relation to land use land cover change and hydrological components.

2.1 Water Resources

There is growing global recognition that, functionally intact and biologically complex freshwater ecosystems provide economically valuable commodities and services to society beyond direct water supply (Flint, 2004; GWP, 2006). Water resources are an integral part of the ecosystem, a social and economic good, and a scarce resource (Shisanya, 2005).

Degradation of water resources in Kenya has been caused by poor land management, mostly destruction of natural vegetation in the catchment areas through activities such as farming, encroachment and illegal logging of forests (Government of Kenya, 2007a; 2007b). 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 has 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 (Terer, 2004).

Semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater. Many of these areas will suffer a decrease in water resources due to climate change. Efforts to offset declining surface water availability due to increasing precipitation variability will be hampered by the fact that groundwater recharge will decrease considerably in some already water-stressed regions, where vulnerability is often exacerbated by the rapid increase in population and water demand (IPCC, 2007).

Climate change is strongly associated with increased water scarcity and stress. The IPCC predicted that major effects of climate change on African water systems would be through changes in the hydrological cycle, the balance of temperature, and rainfall (IPCC, 2007). Today, the changes in temperature, precipitation and sea levels have had varying consequences on the availability of freshwater in the region. The temperature rise has led to greater water loss through evaporation. Regardless of changes in rainfall, this situation is placing additional stress on water resources (Akotsi, 2006).
2.2 Land-Use and Land Cover Change

Land-use changes are complex processes that arise from modifications in land-cover to land conversion process (Aboud, 2002). 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 (Olang’, 2009). 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 (Gereta et al. 2001) 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 (Akotsi et al., 2006). 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 land use/cover changes between 1995 and 2010 in Nyangores Sub-catchment.

2.3 WEAP model

WEAP applications include several steps: First, the study definition sets up the time frame, spatial boundary, system components and configuration of the problem. Secondly, the current account, which is viewed as a calibration step in the development of an application, provide a snapshot of actual water demand, pollution loads, resources and supplies for the system. Key assumptions may be built into the current accounts to represent policies, costs and factors that affect demand, supply and hydrology. Thirdly, scenarios build on the current accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (Sieber and Purkey, 2011).

The design of WEAP is guided by a comprehensive planning framework it includes a hydrological model and links to the groundwater model MODFLOW and the water quality model QUAL2K (Yates et al., 2005).

With WEAP, current accounts are first created of the water system under study. Then, based on a variety of economic, demographic, hydrological, and technological trends, a "reference" or "business - as -
usual" scenario projection is established, referred to as a Reference Scenario. One can then develop one or more policy scenarios with alternative assumptions about future developments. These scenarios may be viewed simultaneously in the results for easy comparison of their effects on the water system (Sieber and Purkey, 2011). In addition, WEAP is unique in its capability of representing the effects of demand management on water systems per demand site thus priorities for allocating water for particular demands or from particular sources may be specified by the user.

2.3.1 Case Study: WEAP in Kenya

WEAP model was calibrated and validated as a tool for water allocation in Ruiru, Thiririka and Ndaru sub-basins and used to simulate effect of future water use change scenarios in Ruiru, Thiririka and Ndaru sub-basins and propose water use management strategy. The study modeled 5 scenarios namely; High population growth rate, area under irrigation is reduced by a half, a reservoir is added along the river, Environmental flow requirement and Irrigation water quality constraint. The study projected the water demand in the study will grow from 75.1 Million M³ in 2010 to 96.3 Million M³ and 129.2 Million M³ in 2020 and 2030 respectively. The unmet demand was 0 Million M³ in 2010 and 0.6 Million M³ and 7.2 Million M³ in 2020 and 2030 respectively with the surface water storage strategy (Thubu, 2010).
2.4 Remote Sensing and GIS

Generally, a Geographical Information Systems (GIS) provides an environment to acquire, store, process and map spatial datasets (Singh and Fiorentino, 1996). Many GIS tools are today available for specialized purposes in data management. Remote sensing data and geographic information system are increasingly becoming important tools in hydrology and land-use and land cover analysis. This is due to the fact that most of the data required for hydrological and land-use/cover analysis can easily be obtained from remotely sensed images. Remote sensing has the capability to acquire spectral signatures instantaneously over large areas. The signatures allow for the extraction of information pertaining to land-use and land cover, emissivity, surface temperature and energy flux (Gumindonga, 2010). Land-use and land cover changes can be analysed over a period of time using Landsat Multi Scanner (MSS) data and Landsat Thematic Mapper (TM) data by image classification techniques (Gumindonga, 2010). Using independent validation data, error matrix (also known as a confusion matrix) is calculated to determine the accuracy of the classification and to identify where misclassification occurs.

In studying land use and land cover changes, Geographical information systems (GIS) and remote sensing techniques are important tools in monitoring and assessment of their dynamics. This is determined by production of geospatial components for land features and natural
resources based on time series imagery. Variation in temporal distribution of land cover due to land use practices helps in monitoring and assessment of environmental degradation (Veldkamp and Kok, 2001).

2.4.1 Image classification

The selection of image classification scheme is to ensure that it represent the features as in true ground brightness value of each pixel. Visual and statistical examination of the images is used to assess the contamination of the scenes by factors such as clouds and other atmospheric conditions. Reducing and eliminating these factors can be costly in terms of time and therefore money and can result in the removal of useful image information. Some of the preferred selection classification include per pixel and object based classification (Jensen, 2005).

2.4.2 Supervised Classification

Supervised classification procedure classifies an image based on a predefined land cover types. This involves identifying and delineating regions in the satellite image to be used as training sites. The sites should have the same spectral information of the land cover types to be used to calculate the classification algorithm. This uses multivariate statistics of the training areas to assign a specific code to every pixel in the image. Some of the techniques used in supervised classification include: selection of training areas, selection of feature space and classification
algorithm and parallelepiped classifier. The parallelepiped classifier was widely involved in this study.

2.4.3 Parallelepiped Classifiers

This classification rule is based on Boolean “and/or” logic. The pixel brightness value of each pixel in each band and class in a multispectral imagery is used to create an $n$-dimensional mean measurement vector for all the possible classes. For each class, the mean vector is represented using Equation 3 (Olang’, 2009)

$$M_f = \frac{1}{n} \sum_{k=1}^{n} f_k, \quad f_2, \quad f_3, \ldots, \quad f_k$$  \hspace{1cm} (1)

Where $M_f$ is the mean measurement vector for class $f$ (e.g. forest), $f_k$ is the mean value of the training data for class $f$ in band $k$ out of all possible classes.

The parallelepiped algorithm considers the brightness value of each class, $f$ within the low and high decision boundaries only if equation (4) is valid (Olang’, 2009).

$$f_f f_k B V_{f_k} f_f f_k f_k$$  \hspace{1cm} (2)

Where the low decision boundary is defined by $f_f f_k f_k$ and the high decision boundary by $f_f f_k f_k$. $f_k$ is the standard deviation of the
training data for class $f$ in band $k$ out of all possible classes. $BV_{ijk}$ is the brightness value of the $i^{th}$ row, $j^{th}$ column and $k^{th}$ band.

Parallelepiped classifiers are widely used and computationally efficient image classifiers. Nonetheless, because some parallelepiped may overlap, there is a possibility of some unknown pixels meeting the conditions of more than one class and hence wrongly assigned. As such, it is usually a good practice to use this classifier with another algorithm such as the minimum distance to assign the unknown pixels based on proximity.

### 2.4.4 Preprocessing

In order to analyze remotely sensed images, the different images representing different bands must be stacked. This allows for different combinations of Red Green Blue (RGB) to be shown in the view. Landsat images from TM and ETM+ are in 8 bands. Layer stacking was performed to combine all the image bands minus the thermal bands. The study area spanned several image files. Image mosaicking which involved the combination of the two TM and ETM+ was performed to create one large file for each study period (1995 and 2010).

An Arcview shapefile for the watershed, geo-referenced to the same coordinate system as the mosaiced image, was used to get a subset of the images for the catchment. Sub-setting not only eliminates the extraneous data in the file, but it speeds up processing due to the smaller
amount of data to process, which is important when dealing with multiband data (Arcgis 10.1). The extracted subset (Appendixes III) for 1995 and 2010 were used in the classification procedures of the images. Unsupervised classification followed by supervised classification was used. According to (Arcgis 10.1), combining supervised and unsupervised classification may yield optimum results, especially with large data sets.

2.5 Assessment of the Accuracies

Assessing the accuracy of classified images is an important step in evaluating the classification results before subsequent use in any decision making process (Lu et al., 2002). Accuracy assessment is accomplished by comparing the classified image(s) and the reference dataset(s) using an error matrix, also called contingency table. An error matrix relates the classified image and the reference data using four main measures namely the overall accuracy (OA), producer’s accuracy (PA), user’s accuracy (UA) and Kappa coefficient, $\kappa$ (Congalton, 1991).

Table 2.1 below illustrates a typical error matrix for assessing the accuracy of land cover classes, say $q$ based on N ground reference test samples (Olang’, 2009).
Table 2.1: Typical error matrix used for accuracy assessment (Olang’, 2009)

<table>
<thead>
<tr>
<th>Image Data</th>
<th>Reference Data</th>
<th>Class</th>
<th>1</th>
<th>2</th>
<th>…</th>
<th>Q</th>
<th>Total (row)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>$x_{1,1}$</td>
<td>$x_{1,2}$</td>
<td>…</td>
<td>$x_{1,q}$</td>
<td>$x_{1,q+1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>$x_{2,1}$</td>
<td>$x_{2,2}$</td>
<td>…</td>
<td>$x_{2,q}$</td>
<td>$x_{2,q+1}$</td>
</tr>
<tr>
<td>…</td>
<td></td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>Q</td>
<td></td>
<td>Q</td>
<td>$x_{q,1}$</td>
<td>$x_{q,2}$</td>
<td>…</td>
<td>$x_{q,q}$</td>
<td>$x_{q,q+1}$</td>
</tr>
<tr>
<td>Total (column)</td>
<td></td>
<td></td>
<td>$x_{-1}$</td>
<td>$x_{+1}$</td>
<td>…</td>
<td>$x_{+q}$</td>
<td>$N$</td>
</tr>
</tbody>
</table>

The diagonal values ($x_{1,1}$, $x_{2,2}$, … $x_{q,q}$) in the table above defines the image pixels assigned to the right classes when the classified image and the reference data are compared. The ratio of the sum of the rightly classified pixels to the total reference samples, $N$ is called the OA (Equation 1) (Olang’, 2009).

2.6 GIS and Interpolation

There are various forms of interpolation method such as, IDW (Inverse Distance Weight), ordinary Kriging, linear regression, Nearest Neighbor, Thiessen polygon method among others. The choice of interpolation method is considered when interpolating the precipitation to a regular grid. The interpolation task, the climate variable and the topographical settings of the region for which the interpolation is done should also be considered.

In this study ordinary Kriging was used because it predicts the results in the form of a linear combination of measured values, whose weights
depend on the spatial correlation between them (Yumei, 2010). The mathematical function of ordinary kriging is as follows:

\[
\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)
\]

Where:

- \(Z(s_i)\) = the measured value at the \(i\)th location
- \(\lambda_i\) = an unknown weight for the measured value at the \(i\)th location
- \(s_0\) = the prediction location

\(N\) = the number of measured values

In kriging method, the weights, \(\lambda_i\), are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in ordinary kriging, the weight, \(\lambda_i\), depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.
The assumption of this method is that the spatial process must be assumed as intrinsic stationary, which means the raw data will not change with time or space. The process to transform the raw data to intrinsic stationary is usually referred as detrending (http://en.wikipedia.org/wiki/Stationary_process).

2.6.1 Runoff generation mechanism

Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall event for example, intensity, duration and distribution. It’s the portion of rainfall that turns into stream flow during and after a storm event. There are many other factors that influence the runoff generation (Bronstert et al. 2002).

When rainfall falls on the land surface depending on the intensity of the rainfall and the permeability and wetness of the soils (Watts, 1996), some of the rainfall infiltrates into the ground, and the remainder becomes runoff and flows overland to reach the nearest stream channel, thus contributing to river flow or stream flow.

Runoff flow is a very important aspect of the water cycle. It can be generated under two different physical mechanisms. The infiltration excess overland flow or Hortonian overland flow mechanism (Figure 2.1), is formed when the rainfall intensity exceeds the soil infiltration capacity in an area (Liu et al., 2004). Then water accumulates on the soil and starts moving down slope, due to gravity towards the hydrographic
network. The second mechanism occurs when the soil saturation exceeds its maximum level due to groundwater uplifting, base flow, and lateral subsurface water discharges, resulting in the appearance of saturation excess overland flow (Beven, 2001).

Figure 2.1: Hydrograph illustrated the Hortonian flow mechanism (Kirkby, 1985).

The Hortonian idea is that we can separate total stream flow $R$ into quick flow $R_Q$ and base flow $R_B$. Quick flow $R_Q$ is the portion of runoff that is “prompt” or rapid after the rain, and base flow $R_B$ is the difference between $R$ and $R_Q$, i.e.,
\[ R = R_Q + R_B \quad \text{or} \quad R_B = R - R_Q \]

The classical theory of Horton is based on two basic assumptions:

\[ R_B = \text{groundwater flow} \]

\[ R_Q = \text{overland flow} \]

Overland flow is generated by “infiltration excess”. Horton defines the infiltration capacity \( f^* \) as the maximum rate at which rain can be absorbed by the soil in a given condition. When the rainfall intensity \( p \) falling on the ground is less than \( f^* \), then all of the rain infiltrates (Figure 2.2). When \( p > f^* \), then only \( f^* \) infiltrates, and the excess of \( p \) over \( f^* \) becomes overland flow. This can be stated mathematically as follows:

\[ p - f = \frac{q}{s} \]

Figure 2.2: Hortonian Concept of Runoff Generation

Let \( f \) be the actual rate of infiltration during rain. Then,

\[ f = p \quad \text{if} \quad p < f^* \]

\[ = f^* \quad \text{if} \quad p > f^* \]
Correspondingly, denoting the rate of runoff generation (overland flow) by \( q_s \), we can then state equivalently:

\[
q_s = 0 \quad \text{if } p < f^* \\
= p - f^* \quad \text{if } p > f^*
\]

Hortonian mechanism of runoff generation occurs at those points on the land where rainfall intensity exceeds the infiltration capacity. The generation of runoff therefore influenced by the rainfall intensity and permeability of the soils controls the infiltration capacity.

Hortonian mechanism and saturation excess mechanisms generate runoff that accumulates over the soil surface. Surface depressions stores water and when surface storage is filled, the water begin to overflow (Figure 2.3), forming what is now the actual runoff.
The presence of bedrock and groundwater table at shallow depths limits the storage capacity. When rainfall prolongs, then through infiltration all of the storage capacity is filled and the surface begins to pond, hence surface runoff is generated.
CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter focuses on the description of the study, data and tools used. It is sub-divided into three parts based on the objectives of the study. The procedure and the general methodology on how the data were processed using various datasets and tools is clearly outlined.

3.1.1 Description of the study area

The Nyangores sub catchment of study is part of the larger Mara basin, located in the upstream part of the basin. The sub catchment covers an area of approximately 933 km², between 35°52’E and 1°13’S (Figure 3.1). The study area falls within three counties, namely of Bomet, Nakuru and Narok. The basin is drained by the Nyangores River, which has two main tributaries. The main tributaries, the Nyangores and Ngetunyek originates from the Mau Forest (Mati et.al. 2005). The area is characterized by bimodal rainfall ranging from 900mm in the lower areas to 1400 mm in the mid and upper sections. The elevation changes from the flat tropical savanna plains at 1600 m above sea level to the high mountainous Mau escarpments at 3000m. (Kilonzo, 2013).

The study area was chosen for this study due to its ecological significant that is more recently being negatively influenced by anthropogenic activities consequent of population increases. The Mara River Basin is an important ecosystem with several land uses, including the Maasai
Mara and Serengeti national parks. It also has a strong and competitive water resource uses due to agricultural activities, wildlife ecosystems, industrial activities and domestic consumption. The sub catchment is one of the most affected water catchments in Mara River Basin due to threats of land-use and land-cover changes and the weak land and water conservation measures, resulting in more adverse effects on water and land resources than expected. Also the population in the sub-catchment has been growing very rapidly, which has escalated the land use and land-cover changes. The intensification of farming in the Sub-catchment have ensured that soils are increasingly eroded, which directly affects its water retention capabilities and increase run-off (Kilonzo, 2013).

Figure 3.1: Map of the study area (Source: Author, 2016)
3.1.2 Topography

The upper part of Nyangores sub-catchment is mountainous and hilly characterized by undulating topography and the lower part consist of gently sloping plains. The altitudes within sub-catchment range between 2970m above the sea level around the sources in the Mau Escarpment to 1695m above the sea level downstream in Kaboson.

3.1.3 Climate

The amount of precipitation varies according to the altitudes. The Mau Escarpment receives most rainfall with a mean annual rainfall between 1,000 and 1,400 mm. The rainfall seasons are bi-modal, with the long rains starting in mid-March to June with a peak in April, while the short rains occur between September and December. The average mean temperature is about 18°C in the highlands and 25°C in the lowland. The mean annual potential evapotranspiration is 1500mm in upper Mara basin of Nyangores sub-catchment and above 1700mm in lowlands (Gathenya, 2011).

3.1.4 Population

Nyangores sub catchment is part of the Mara Basin which is home to 1.1 million people who are mostly engaged in agricultural and pastoral activities. Bomet town is the main urban centre within the sub-catchment with about 95,000 residents. Other urban centers include Silibwet Township, Sigor, Merigi, Keringet and Kiptagich trading
centers which are also rapidly growing into towns. The rest of the population lives in rural areas, with a very high percentage (up to 64%) being below the poverty line. Nyangores sub catchment covers Bomet, Nakuru and Narok counties. The populations of the nineteen wards in the three Counties that overlap the catchment area were recorded in the 2009 Census to have a combined population of 566,153 with an average density of 625 persons per Square Kilometre (Total population therefore is 245,955 for the Nyangores basin). Based on an assumed growth rate of 2.8 % (National census, 2009), the current total population of the residents within Nyangores drainage basin is estimated to be approximately 290,278 persons.

3.1.5 Economic Activities

Crop farming remains the dominant economic activity to the majority of the population despite the diversity in spatial extent and land use. Tea is the main cash crop in the upper part of the catchment and many tea processing factories are located. In the lower part, maize is a dominant crop for both commercial and consumption purposes. About 62% of the households are smallholder farmers (Aboud et al., 2002), with livestock rearing being a second dominant activity, yet agriculture occupies about 28% of the available arable land. The main crops are tea, maize, potatoes, beans, coffee and onions.
3.2 Spatial Datasets and Tools

3.2.1 Land cover datasets

The land cover datasets were obtained from the Global Land Cover Network (GLCN) and was produced due to the need by the international community for a standardized global land cover database (http://www.glcn.org). The dataset is provided through the FAO - Land Cover Classifications System (LCCS) at a scale of 1:20000. The dataset contains digital geo-referenced databases with geodetic homogeneous referential, topography, roads and hydrograph data, which has greatly reinforced national and sub regional capacities for the establishment, updating and use of land cover maps and spatial data bases (http://www.glcn.org). For use in this study, analyzing this dataset was important in correctly referencing the land cover classification and supporting hydrological studies using the WEAP model.

3.2.2 Soil Datasets

The soil datasets was acquired from Global Environment Facility (http://www.isric.org). For Kenya, the data is available at a scale of 1:1M. The soil units correspond to soil components selected by national soil experts as being representative for these units. The associated soil analytical data have been derived from soil survey reports. Gaps in the measured soil profile data have been filled using a step-wise procedure, which involved collating additional measured soil data were available,
filling in gaps using expert knowledge; and fill the remaining gaps using a scheme of pedo-transfer functions. In this study, a reclassification and analysis of the dataset was important for derivation of developing soil characteristics and parameters that influence the hydrology of the study region (Muchena et al. 1988).

### 3.2.3 Terrain Surface Data

To understand the terrain of the study area and surface water movement, a Digital Elevation Model (DEM) was selected. The elevation model was developed by the Shuttle Radar Topographic Mission (SRTM), an international project spearheaded by the National Geospatial-Intelligence Agency and NASA (http://srtm.csi.cgiar.org). The DEM provides a representation of a terrain surface through raster grids of elevation values that are arrayed in series of south-north profiles.

For this study, the processed seamless SRTM DEM with a spatial resolution of 3-arc seconds, approximately 90m, was downloaded in GeoTiff file formats. Four tiles of the file, namely (43-11, 43-12, 44-11 and 44-12) were downloaded for further processing since the basin cuts across the tiles. Generally, resolution of the SRTM data obtained is consistent for most regions of the globe, and sufficiently allows for quantification of landscape features influencing hydrological processes (Olang’, 2009).
3.3 Satellite Images

To discriminate land cover changes in the sub catchment over the study period, Landsat satellite data was used. The use of Landsat imagery was mainly because of its longest history of service with good resolution of the spatial data sufficient for the study. The Nyangores sub-catchment is covered by two Landsat images (scenes) of paths 169 row 060 and path 169 row 061 for Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) (Figure 3.2). Selected orthorectified images for the years 1995 and 2010 were acquired from the global Landsat web portal available at: (www.earthexplorer.usgs.gov).
Table 3.1: characteristic of selected TM and ETM+

<table>
<thead>
<tr>
<th>Date</th>
<th>Landsat /Sensor</th>
<th>path/row</th>
<th>spatial resolution</th>
<th>cloud cover</th>
<th>climatic condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>21/01/1995</td>
<td>TM</td>
<td>169/060</td>
<td>30</td>
<td>0</td>
<td>dry</td>
</tr>
<tr>
<td>21/01/1995</td>
<td>TM</td>
<td>169/061</td>
<td>30</td>
<td>0</td>
<td>dry</td>
</tr>
<tr>
<td>30/01/2010</td>
<td>ETM+</td>
<td>169/060</td>
<td>30</td>
<td>0</td>
<td>dry</td>
</tr>
<tr>
<td>30/01/2010</td>
<td>ETM+</td>
<td>169/061</td>
<td>30</td>
<td>2</td>
<td>dry</td>
</tr>
</tbody>
</table>
3.4 Soft Wares and Tool Used

3.4.1 ArcGIS Version 10.1

In this study, ArcGIS version 10.1 was acquired and used to process the data. Generally, the datasets of this study were projected to UTM-WGS 1984 coordinate system, Zone 35°S for the Nyangores sub-catchment. This coordinate system was selected because it preserves areas in regions around the equator i.e. it is an equal area conformal projection.

3.4.2 WEAP model

The hydrologic model used in this study is the WEAP model, which was developed by the Stockholm Environment Institute (SEI). The water system in WEAP is represented in terms of supply sources which include: stream flow and run off (SEI 2013).

3.5 Processing of the Land Cover Data

The land cover data acquired for this study used the FAO-LCCS, which is a prior classification scheme that describes land cover types with a set of pre-selected independent diagnostic attributes called classifiers (ArcGis manual 10.1). Dataset for Kenya was downloaded and subset to an area encompassing the study area. Such a procedure was important in order to reduce the rigorous work of classifying the whole datasets. In order to reclassify the land cover types into local classes for subsequent modeling using WEAP, the classes were accessed by
querying and selecting specific land characteristics based on citation defined in the table 3.2 below.

Table 3.2: Criteria for Land cover classes (Source: Author, 2016)

<table>
<thead>
<tr>
<th>WEAP classes</th>
<th>Land cover</th>
<th>Defined Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural forest</td>
<td></td>
<td>Medium to tall tree with thick underground cover</td>
</tr>
<tr>
<td>Herbaceous crops</td>
<td></td>
<td>Herbaceous plants like bean, maize, vegetables shrubs with grass, herbs and herbaceous plants</td>
</tr>
<tr>
<td>Shrub cropland</td>
<td></td>
<td>Broadleaved trees planted in rows and tea plantation</td>
</tr>
<tr>
<td>Tree plantation</td>
<td></td>
<td>Areas dominated by grass with vegetation cover that are highly scattered</td>
</tr>
<tr>
<td>Grassland</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Generally, the FAO-LCCS in the acquired datasets provide the capability to incorporate various land cover classes. For instance, land covers in the classification, includes major land cover classes such as close woody vegetation, grassland, shrub land, shrub savannah, tree savannah and Forests. These classification were further reclassified, the shrub-land covers for instance are further reclassified into sub-classes such shrub cropland. Considering that in FAO-LCCS, land cover classes are too general and could not sufficiently take into account the subtle differences of land cover classes existing in reality in the study basin, reclassification was therefore necessary. Using ArcGIS extension the land cover attributes table was accessed and a new column on WEAP land cover classes created for the reclassification. The reclassified FAO-LCCS was accessed, carefully examined and subsequently reclassified,
as per the defined criteria, with the new classes recorded in the new column of the attribute table. Generally, areas without vegetation cover or with highly scattered vegetation were classified as the bare grounds.

In this classification Bomet town and human settlement were not classified because the study aims to investigate the relationships between land cover and 3 hydrological components namely the evapotranspiration, infiltration and runoff. In this context therefore, classification of towns and human settlement were left out because there is no direct relationship with evapotranspiration which was one of the hydrological component investigated.

3.6 Processing of the Soil Data

The soil data acquired for this study used the KenSOTER soil classification system, which is a prior classification system that describes soil types for Kenya. Dataset for Kenya was downloaded and subset to an area encompassing the study area. Such a procedure was important in order to reduce the rigorous work of classifying the whole datasets. In order to reclassify the soil types into local classes for subsequent modeling using WEAP, the classes were accessed by querying and selecting specific soil characteristics based on citation defined in Table 3.4.

The Global Environment Facility in the acquired datasets provides the capability to incorporate various soil classes. The column with the
criteria above was created in ArcGis 10.1 and used as the WEAP soil classes. This criterion provides distinct soil characteristic that can be incorporated in WEAP model.

Table 3.3: Criteria for soil classes (Source: Author, 2016)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loam sandy</td>
<td>Moderately drain Consist of silt and sand</td>
</tr>
<tr>
<td>Clay light</td>
<td>Moderately drain and very fertile</td>
</tr>
<tr>
<td>Clay loam</td>
<td>Moderately drain and Consist of clay and high amount of silt</td>
</tr>
<tr>
<td>Loam</td>
<td>Moderately drain and Consist of mostly sand, silt and small amount of clay</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>Moderately have high concentration of sand with gritty feel Poor drain</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>Poorly drain with fine particles, holds water and have poor aeration</td>
</tr>
<tr>
<td>Silt</td>
<td>Poorly drain with fine particles and poor aeration</td>
</tr>
<tr>
<td>Silty clay</td>
<td>Poorly drain with small amount of clay</td>
</tr>
</tbody>
</table>

3.7 Land cover Classification and Change Detection

Data collected were first pre-processed before any quantitative and qualitative analysis. A quality control helped checking their accurateness, reliability and relevance to the study. Quantitative data analysis in this study essentially involved time series analysis and change detection analysis. To analyze remotely sensed images, the different images representing different bands were stacked. This allowed for different combinations of RGB to be shown in the view. This process was done using ArcGis imagine classifier tool.
Supervised classification was used in analysis of land-use/cover changes because it allows the user to define the training data set (or signature) that indicated the type of software and pixels to be selected for land-cover categories (Jensen, 1995). Details about the area, knowledge about ground truth and experience in image interpretation permit pixels with specific characteristics to be selected for a better classification of the image (Coppin & Bauer, 1996). After identifying the signatures, the pixels of the image were sorted into classes based on the signatures by using a classification decision rule. According to Coppin & Bauer (1996), the decision rule is a mathematical algorithm that, using data contained in the signature, performs the actual sorting of pixels into distinct class values.

After sub-setting the image, the training data sets were created from the satellite image with the help of aerial photographic interpretation and ground truth data. The photographic interpretation information was used as a guide for defining the feature classes in the satellite images. The classes identified in this way were farm land, Tree plantation, Natural forest and shrub land. These classes were sampled from the satellite image by using the polygon method. The polygon method simply allows drawing a polygon that defines the location of the pixels which represent the particular spectral class (Jensen, 1995). Once the base training sets were established, each training set was stored in signature editor and assigned the colour desired for the particular feature
class. The training data sets were used to generate class signatures and classify the rest of the image into meaningful information classes.

3.7.1 Accuracy Assessment of Image Classification

The accuracy assessment of an image classification was done by creating the classification error matrix. In this confusion matrix, classification results were compared to ground truth data obtained during fieldwork. This was done by selecting the menu item (classifier accuracy assessment tool), then importing the ground coordinates of the ground truth samples.

According to Coppin & Bauer (1996), whatever the algorithm used, the spectral image classification always results in accuracies which range between 50% and 75%, depending on the number of available image registrations, the quality of the ground truth and the number of considered change classes.

The land-use and land cover change detection was done by involving the images of (1995 and 2010) using confusion matrix. This is due to the fact that the matrix operation from the ArcGIS analysis allows two thematic images or vector files of different years to be compared. By comparing two classified sets of data, the matrix operation was able to show all the changes from one class to another (Jensen, 1995).

The total number of sampling points required for the assessment was established using the binomial distribution equation. Ideally, this equation
required a total of 112 sampling points to be used for assessing the accuracies. But, based on visual analysis of the distribution and location of these sampling points in the study area and heterogeneous nature of the sub-catchment, it was necessary to add more points where there was not clear distinction between different land cover classes.

Figure 3.3: Ground control points (GCPs) used for the ground truthing

This procedure resulted into a total of a total of 113 and 140 auxiliary points for Landsat TM (1995) and ETM+ (2010) (Table 3.4 and 3.5) respectively. These error matrices were derived from the equations in assessment of accuracy in chapter two (2.6).
3.8 Methodology for Hydrological Processes

3.8.1 WEAP21 modelling process

WEAP21 is structured as a set of five different "views" onto the working Area: Schematic, Data, Results, Overview and Notes. These views are listed as graphical icons on the View Bar. The Current Accounts represents the basic definition of the water system as it
currently exists, and forms the foundation of all scenarios analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. The comparison of these alternative scenarios proves to be a useful guide to development policy for water systems from local to regional scales (Vogel et al., 2007).

The main screen of the WEAP21 system consists of the View Bar and a main menu at the top providing access to the most important functions of the program. WEAP21 calculates a water quantity and pollution mass balance for every node and link in the system on a monthly time step. Water is dispatched to meet in stream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints.

3.8.2 Parameters Determination in WEAP

Arc Hydro tools compatible with ARCGIS 10.1 was used to process DEM to delineate the watershed boundary for Nyangores sub-catchment. Land cover classes were as result of the classification of Landsat imageries for 1995 and 2010. Hydrometrological data was obtain from the Water Resource Management Authority (WRMA).

Missing rainfall and stream flow data were fill using the Normal Ratio Method (NRM) and the Arithmetic Mean Method (AMM). The Double
Mass Curve (DMC) was applied to check inconsistency of rainfall and stream flow data.

In this study, (8) rainfall stations were selected for interpolation. The choice of these stations was based on the availability and consistence of the data. This is because some of the stations have a lot of missing data gaps of up to 24% of missing data. Ordinary Kriging was used in this study because it predicts the results in the form of a linear combination of measured values, whose weights depend on the spatial correlation between them (Olang’ 2009). Rainfall interpolation in this study was necessary because the sub-catchment is highly ungauged and there was need to quantify the amount of precipitation in each of four land cover classes.

The reference evapotranspiration (ET₀) and crop coefficient (Kc) were computed from a set of climatic variables using Penman Monteith equation provided in WEAP version 21.

3.8.3 Calibration and Validation of the Model

To calibrate the watershed model, observed monthly stream flow at the outlet of watershed was compared with simulated monthly stream flow during 1998-2002 ($R^2 = 0.73$) and 2005 2010 ($R^2 = 0.78$) for the land use map in 1995 and 2010, respectively. The estimation of stream flow using WEAP is included erroneous result because of (1) limited and unevenly distributed gauge stations with varies time series length and (2) the lack
of data on soil moisture and deep aquifer percolation which are considered for calibration and validation in WEAP model.

3.8.4 Simulation of the Runoff for Nyangores sub-catchment

To understand the hydrological cycle change and associated potential of runoff, this study applied WEAP model to evaluate the surface runoff in the upper Mara river basin. WEAP is hydrological model which continuously simulate time model and operates on an annual time step at basin scale. In watershed scale, all of a range in climatic, soils, topographic, and land use condition are input data. Normally, WEAP is applied to determine hydrology element, agricultural management, and stream routing (Sieber and Purkey, 2013. However, this study focuses only on hydrology element that is surface runoff.

Since the study area is included the large scale spatial heterogeneity, considering information from the elevation map (DEM), the soil and land use map, is divided into sub-basins and each sub-basin is discriminated into a series of hydrologic response units or HRUs, which are unique soil and land use. Moreover, each sub-basin is consisted of slope, reach dimensions, and climate data. For climate data, the station nearest to the centroid of each sub-basin is considered. The routing through the river system is concerned using the variable storage or Muskingum method (Mutiga et al. 2010).
To compute surface runoff, the concept of water balance is concerned using the elements of hydrology cycle. Evapotranspiration is computed using Penman-Monteith equation (Akivaga et al. 2010). The function of potential evapotranspiration and leaf area index are applied to estimate potential soil water evaporation while the exponential function of soil depth and water content is concerned to calculate actual soil evaporation. Plant water evaporation is simulated using the linear function of potential evapotranspiration, leaf area index, and root depth (Abrishamchi et al., 2007). The SCS curve method based on land use, soil type, and antecedent moisture condition is applied in WEAP model to calculate surface runoff from daily rainfall (Mutiga et al. 2010). Moreover, soil profile, subdivided into multilayer, is considered to support the process of infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. To estimate flow to soil layer in root zone, the soil percolation is concerned using the method of water storage capacity. The percolation to lower layers occurs when field capacity of soil layer is exceeded and layer below is not saturated. The simulation of daily average soil temperature is based on the function of maximum and minimum air temperature. There is not percolation to lower layer when temperature in soil layer is less than or equal 0°C. Groundwater flow contribution to total stream flow is simulated by routing a shallow aquifer storage component to the stream (Akivaga et al. 2010) ;( Mutiga et al. 2010).
Since the weather station network in the upper Mara river basin is not very dense and data duration is quite short, to simulate missing data. The Double Mass Curve (DMC) is used to fill data gap or extends time series of daily data based on monthly statistics (Akivaga et al. 2010). Thereafter, water balance is applied in everything that occurs in the watershed. To accurately computation water balance, there are two major division of hydrologic cycle for the watershed. Firstly, the land phase of the hydrologic cycle is concerned to control the amount of water loading to the main channel in each sub-watershed. Secondary, the water phase of the hydrologic cycle is considered for the movement of water through the channel network of the watershed to the outlet.

3.8.5 Interpolation

In this study, (8) rainfall stations were selected for interpolation. The choice of these stations was based on the availability and consistence of the data. This is because some of the stations have a lot of missing data gaps of up to 24% of missing data.

Ordinary Kriging was used in this study because it predicts the results in the form of a linear combination of measured values, whose weights depend on the spatial correlation between them (Yumei, 2010). This was found to be necessary since the sub-catchment was highly ungauged with only six rainfall stations located in the sub-catchment. Simulating runoff and infiltration processes requires matching data of rainfall in order to determine the amount of runoff and infiltration produced from a given
storm. It is important that measurements of runoff at the river gauge station correlate with the rainfall events that produced them. To understand this rainfall, runoff and infiltration relationships in the sub catchments of Nyangores, interpolation was necessary more so for areas that did not have hydrometrological data within the sub-catchment. The assessment of rainfall was necessary in order to determine the annual amount of rainfall in each of the five land cover classes. The amount of rainfall in the area ranges from 1467.7 to 808.1 mm/yr. The annual average rainfall between 1995 and 2010 was used in this study. Areas around the protected Nyangores forest receives significantly high rainfall. The lower part of the sub-catchment receives low rainfall amount compared to upper part of the sub-catchment. On the upper part of the sub-catchment, areas around Kiptagich and Keringet had a mean annual average of 1120 mm/yr. The middle part around Bomet town and Tenwek was 1260mm/yr, whereas the lower part around Kaboson had a mean annual average of 960mm/yr.
Figure 3.4: Spatial rainfall distribution in the Nyangores sub-catchment

(Source: Author, 2016)
CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Catchment characteristics using spatial datasets for the river basin

The aim of this objective was to acquire, analyze and present the spatial datasets required to support land cover classification process and subsequent hydrologic modeling. A Geographical Information System was used to achieve this, first by building a geo-database of the spatial datasets and subsequently by analysis using standard and automated procedures important to reveal the physically based catchment characteristics of the study basin in accordance with the requirement of the hydrologic model of choice.

4.1 Land cover Map

Figure 4.1 below shows the FAO 2008 land cover map obtained after GIS processing of the acquired land cover data. From the map, it can be seen that a majority of the study basin is dominated by forested land cover (Figure 4.1). The major forest is located in the middle area in an area known as Kenon in Bomet county and extend upwards to Kiptagich in Nakuru county This forest is part of the larger Mau forest which covers at least four counties namely Kericho, Nakuru, Bomet and Narok.. From field truthing, the natural forest in Nyangores sub-catchment can be classified as a mixed forest.
The forest is mainly dominated by the *Tabernamontana – Allophylus – Drypetes* forest formations (Kinyanjui, 2009). The main herbaceous crops in the sub-catchment are bean, maize, peas, onions, vegetables potatoes among others. Farming is done throughout the year mainly through household labor, mainly for food production and as an alternative source of income.

Figure 4.1: FAO 2008 land cover map

Tree plantation in the sub-catchment covers an area of 95.5km² and practiced mainly for reafforestation activity. It is normally carried out in areas that have been deforested through timber harvesting and illegal
logging and charcoal production. The most dominant tree species are pine, *grevilearobusta* and eucalyptus.

Tree plantation is also practiced as agro forestry whereby farmers plant tree along the edges of their farms to act as the windbreakers. This plantation is also carried out on areas that are perceived to be less or non-productive. However with high economic value of eucalyptus species, farmers have started planting these trees on productive land and along the river banks.

Shrub crops are mainly located on areas that were once forested or covered by herbaceous crops but have since been degraded through poor farming methods that leads to erosion of top fertile soils or deforested lands that exposed the top soils to erosion through run-off.

### Table 4.1: Area of the selected land covers classes

<table>
<thead>
<tr>
<th>WEAP classes</th>
<th>Area(KM²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>346.6</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>306.1</td>
</tr>
<tr>
<td>Shrub crops</td>
<td>177.5</td>
</tr>
<tr>
<td>Tree plantations</td>
<td>95.5</td>
</tr>
<tr>
<td>Grass land</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td><strong>933</strong></td>
</tr>
</tbody>
</table>

#### 4.2 Soil data

Nyangores sub-catchment consists of nine (9) soil classes. The clay light was found to be the dominant soil group in the upper part of the sub-catchment and covered approximately 62.4%. While silt and silt clay
dominated the lower part and covering 14.7% and 2.9% respectively.

The clay light soil is found on high deforested region around Bararget, Keriget and Kiptagich and also in forested part of the sub-catchment. Areas around Tenwek, Silibwet and part of Bomet town are also dominated by loam and sandy loam.

Figure 4.2: Soil cover (Source: Author, 2016)
Clay light are soils with moderate infiltration rates when completely wet. These soils have moderately fine to moderately coarse textures. These properties that include the relatively tiny size of particles allow air passage through the spores give a good aeration of the soil. Due to its moderate drainage, leaching of fertile top soil is minimal hence holds on the plant nutrients thus making it rich in plant’s food. These properties make the soil fertile and conducive for farming activities.

The lower part of the sub-catchment consist of silt and silt clay soils. These soils retain water longer, leading to poor aeration. Silt clay soils have high swelling potential. The poor drainage also contributes to flood during high rainfall. However, these soils are fertile but not good for farming and growing of crops due to water logging and poor aeration.

### 4.3 Land cover classification

Figures 4.3 and 4.4 depict land cover maps for 1995 and 2010 obtained after the classification exercise. A visual assessment of the figures
reveals significant deforestation in the sub-catchment over the 15 years of the study. Farm land on the other side can be seen to have expanded in the sub-catchment over the same time period (Table 4.3). The classifications also revealed the existence of shrub lands in some areas formally occupied by forest.
Figure 4.3: Classified Landsat TM 1995

Figure 4.4: Classified Landsat ETM+2010
Table 4.3: Lands cover change statistics

<table>
<thead>
<tr>
<th>Description</th>
<th>1995 image</th>
<th>2010 image</th>
<th>Relative Change 1995-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shape Area (KM²)</td>
<td>Shape Area (KM²)</td>
<td>% (%)</td>
</tr>
<tr>
<td>Tree plantations</td>
<td>199.2</td>
<td>110.8</td>
<td>-9.4%</td>
</tr>
<tr>
<td>Farm lands</td>
<td>280.4</td>
<td>362.2</td>
<td>8.7%</td>
</tr>
<tr>
<td>shrub lands</td>
<td>191.9</td>
<td>210.2</td>
<td>1.9%</td>
</tr>
<tr>
<td>Forest</td>
<td>261.5</td>
<td>249.8</td>
<td>-1.2%</td>
</tr>
<tr>
<td>Total</td>
<td><strong>933</strong></td>
<td><strong>933</strong></td>
<td></td>
</tr>
</tbody>
</table>

From the Table 4.3 above, Noticeable changes were observed in Farm land where it increased by 8.7%. The area covered by tree plantations decreased by -9.4% in the period of 1995 to 2010. This translates to an area of about -88.4 km². Between 1995 and 2010, Shrub lands increased by about 1.9 % or 18.3 km². The area covered by forest decrease by -1.2% during the same period. The planting of tree along the edges of tea plantations may have also contributed to the small percentage changes. Increase in eucalyptus tree plantations along the river banks also contributed to the small changes in the tree plantation cover. This is evident in areas around Tenwek, Silibwet, Ndarawet and Kenon where the local community has embraced agro forestry in their farms.

The increase in farmland cover by +8.7% is due to an increase in population in the area, resulting in a higher demand for land under farming to produce food. Other factors that could have led to an increase in farmland are the increase in tea plantations in the area, specifically around Tegat, Tenwek, Kapkoros and Tirgaga.
This area receives significantly high rainfall that favours tea plantation. During the same period, Shrub land cover class increased by 1.9%. This increase was more so in the regions formerly occupied by natural vegetation cover, highlighting the degeneration of the forests into shrubs through logging and re-growths. The results obtained shows that farm land have increased significantly and tree plantations reduced between the 15 years period.

As mentioned above, the changes indicated are contributed by many factors such as, farm land expansion and commercialization of tree products mostly timbers. This is evident in Bararget forest where tree logging is rampant. Poor law enforcement in the region also allows illegal logging and harvesting of charcoal to take place. Land fragmentation which is known to begin at family level, where land is sub divided into small pieces to provide space for farming for the rapidly growing families. These land pieces are constantly under intensive cultivation and lead to land conversion in terms of their natural status. The high population growth rate in the sub-catchment leads to small sub divisions of pieces of land becoming incapable in sustaining the socioeconomic demands of the population leading to encroachment into the nearby natural vegetated land. This nature of farming is caused by the search of fertile land. The practice is dominant due to lack of proper land management regulations and guidelines. These factors therefore have led to drastic land cover conversions and modifications in the sub-catchment.
The factors for land-use land cover change comprises of anthropogenic activities. These include increase in human population in the area and the increasing demand for more land for farming. This resulted in encroachment of the natural vegetated land and lead to clearing of bushes in their fields to pave way for farming. The increase in land under tea plantation has contributed to increased Farm land class and decrease Forest land. Illegal logging and harvesting for wood fuel has also contributed to reduced Forest land and Farm land expansion to meet the food demand of many home states. Land degradation as a result of bush fire for land preparation for farming is also a dominant practice in the sub-catchment. This has led to reduction vegetation cover exposing the top soil to water erosion. Other human activities such as human settlement and urbanization have also been witnessed in the sub-catchment (Kilonzo, 2013).

The rapid urbanization of formerly small trading centers into major towns has contributed to urban-rural migration. This has resulted in changes in the ecological zonation of the sub-catchment, where areas that were formerly farmland have been converted to urban areas (Kilonzo, 2013). The high population growth rate has increased the demand for land, translating in an increase in human settlements and increase farmlands. The human settlement has led to encroachment of forested areas hence reduced forest cover.

The classified Landsat images of 1995 and 2010 indicates that the sub-catchment has undergone numerous land-use and land cover changes. The assessment of the
Landsat images show significant reduction in Tree plantation in the sub-catchment between the period 1995 and 2010. Farmland has experienced a drastic expansion over the same period. From the observation in Figure 4.3 above, it is evident that farm land is encroaching into the Forest lands and more so from the upper part of the sub-catchment.

4.3.1 Transitional matrix

Post classification method was used to get the land cover change difference in temporal and spatial scale over the study. The importance of using the post classification method is because it has the ability to show the direction of change from one land cover class to another one. The land cover matrix for 1995-2010 can give an account for variables at different times. The conversion matrix is therefore used to estimate and understand the trend in which the land cover classes are changing from one class to the other for example from closed tree plantation to farmland and vice versa.

Table 4.4: Transition matrix in km² for 1995-2010

<table>
<thead>
<tr>
<th></th>
<th>From 1995</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Total 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tree plant</td>
<td>Farmlands</td>
<td>shrub land</td>
<td>Forest</td>
<td>Total 1995</td>
<td></td>
</tr>
<tr>
<td>Tree plant</td>
<td>55.4</td>
<td>14.5</td>
<td>7.8</td>
<td>33.1</td>
<td>199.2</td>
<td></td>
</tr>
<tr>
<td>Farmlands</td>
<td>87.3</td>
<td>141.3</td>
<td>70.7</td>
<td>62.9</td>
<td>362.2</td>
<td></td>
</tr>
<tr>
<td>Shrub land</td>
<td>12.7</td>
<td>31.4</td>
<td>94.9</td>
<td>71.2</td>
<td>210.2</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>43.8</td>
<td>93.2</td>
<td>18.5</td>
<td>94.3</td>
<td>249.8</td>
<td></td>
</tr>
<tr>
<td>Total 1995</td>
<td>199.2</td>
<td>280.4</td>
<td>191.9</td>
<td>261.5</td>
<td>933</td>
<td></td>
</tr>
</tbody>
</table>
The conversion matrix above shows that the majority of land cover was converted to farmland. A total of 87.3km$^2$ of tree plantation was converted to farm land during the period of 1995 and 2010. During the same time, 14.5km$^2$ of farmland and 7.8km$^2$ of shrub crop land cover were converted to tree plantation.

It should be noted that some of the land cover conversions are as a result of the normal land cover conversions. For example the conversion of forest to scrub land can be as a result of land cover modification processes that modify one land cover to another one.

During the classification process, errors that might have occurred during data processing can contribute to changes in statistical values for land cover. For example, the conversion of other land cover classification back to Tree plantation and Forest classes look unrealistic due to the fact that Farm land is increasing to provide land for food production. But based on the nature of the sub-catchment, the period between 1995 and 2010 can lead to such land cover changes. For instance, the introduction of eucalyptus tree species has converted much of the Farm lands to Tree plantation land. Also the planting of *grevillea robusta* along the edges of tea plantation have contributed to significant increase in Tree plantation, they act as windbreakers and source of timber for construction and wood fuel. The degraded and abandoned lands may allow re-growth of natural vegetation. Therefore, the area that might have been classified in 1995 as Farm land has been classified in 2010 as Tree plantation.
4.3.2 Accuracy assessment of image classification

The comparison between the classified Landsat TM and the general land cover data were relatively good. This was attributed to producers’ accuracy and secondary information in the reference dataset used to generate the error matrix.

Table 4.5: accuracy assessment of TM and ETM+

<table>
<thead>
<tr>
<th>Land cover classes</th>
<th>TM 1995</th>
<th>ETM+</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PA%</td>
<td>UA%</td>
</tr>
<tr>
<td>Tree plantations</td>
<td>82</td>
<td>67</td>
</tr>
<tr>
<td>Farm lands</td>
<td>54</td>
<td>83</td>
</tr>
<tr>
<td>Forest</td>
<td>74</td>
<td>59</td>
</tr>
<tr>
<td>Shrub lands</td>
<td>68</td>
<td>51</td>
</tr>
<tr>
<td>Overall accuracy (%)</td>
<td><strong>67%</strong></td>
<td></td>
</tr>
</tbody>
</table>

The classified Landsat ETM+ image produced acceptable accuracies of 74% when compared with the digitized datasets (Table 4.5). This shows that there was a good correlation between the images and the reference data in all the land cover classes.

It was noted that the Farm land produced the lowest accuracies in the two study periods. This was attributed to close spectral boundary between Farm land and Shrub land cover classes.

4.4 Hydrometeorlogical Data Analysis

Daily rainfall data for 8 stations located in and within the sub-catchment (Figure 4.5), were obtained from Kenya meteorological department (Table 4.6). The daily stream flow data for Nyangores River was obtained from WRMA regional office
in Kericho. The data range from 1963 to 2013. It should be noted that there is only one river gauging station in the sub-catchment located at Bomet Bridge.

Table 4.6: Acquired rainfall data (Source: Author, 2016)

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Lat</th>
<th>Long</th>
<th>Annual (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9035079</td>
<td>Tenwek hospital</td>
<td>-0.753</td>
<td>35.343</td>
<td>1356.6</td>
</tr>
<tr>
<td>9035227</td>
<td>Bomet DC</td>
<td>-0.781</td>
<td>35.331</td>
<td>1283.7</td>
</tr>
<tr>
<td>9035302</td>
<td>Nyangores forest</td>
<td>-0.701</td>
<td>35.432</td>
<td>1468.3</td>
</tr>
<tr>
<td>9035265</td>
<td>Bomet water supply</td>
<td>-0.781</td>
<td>35.353</td>
<td>1251.4</td>
</tr>
<tr>
<td>9035241</td>
<td>Baraget</td>
<td>-0.41667</td>
<td>35.733</td>
<td>1121.9</td>
</tr>
<tr>
<td>9035324</td>
<td>Kirengat forest</td>
<td>-0.48333</td>
<td>35.801</td>
<td>1184.5</td>
</tr>
<tr>
<td>9035228</td>
<td>Kiptungat forest</td>
<td>-0.45</td>
<td>35.233</td>
<td>906.5</td>
</tr>
</tbody>
</table>

Figure 4.5: Showing spatial location for rainfall station and river gauging stations (Source: Author, 2016)
Figure 4.6 shows time series plot of stream flow for Bomet gauging station located along Nyangores River. The station had daily discharge data from 1963 to 2013 with relatively small data gaps of 13%. A hydrographic plot for the station shows that the highest discharge of 21 m$^3$/s, recorded on the 18th of May, 1985 with an average mean flow of 20.4 m$^3$/s. The general trends in the mean base flow indicated an overtime decrease from 4.5 m$^3$/s in 2000 to 3.0 m$^3$/s in 2010.

![Figure 4.6: Hydrograph for Nyangores River stream flow.](image)

**4.4.1 Simulated effects of LULC on stream flow**

In this study, the WEAP model was used to simulate annual average runoff from annual rainfall data. This was used to determine the fraction of total precipitation that infiltrates into the soil and the fraction that runs off to surface water or streams. Figure 4.7 below shows the simulated annual average stream flow using the WEAP model form 1995 to 2010.
From the simulated results obtained, stream flow have been highly affected by land use practices over the study period (1995-2010). From the four land cover classes, Farm land had experienced the high runoff of 10 mm$^3$. In Tree plantation the runoff increased by 5 mm$^3$ and 2.1 mm$^3$ in Shrub land while in Forest cover it increased by 0.2 mm$^3$.

The high runoff in farm land could be attributed to farming pattern, where during land preparation much of the vegetation is cleared hence decreasing the canopy interception allowing water to drain off. Also poor farming methods like cultivation on a slope or hilly areas. This is because cultivation reduces the soil compaction hence allowing more water to drain as surface runoff. The increased in runoff in Tree plantation cover is due to deforestation which leads to reduced rainfall interception. The deforestation is brought about by illegal logging for commercial production of timber. In Forest cover, run off increased is also attributed to decrease
vegetation cover due to charcoal burning and encroachment of human settlement. These have led to large tracks of forest cover being cleared to pave way for farming activities hence contributing to increase in run off. The increase in run-offs contributes significantly to high peak flows during rainy seasons and low peaks in dry seasons. This is because there is less water infiltrating into the groundwater which are responsible for recharge of streams. Therefore the high peak flows will only last as long as there is rainfall.

4.4.2 Changes to the hydrological regimes

The simulated monthly stream flow was obtain from January 1963 to December 2010, the mean monthly stream flow during January 1995 to December 2010 is overlaid in all the land cover classes. For 1995, the stream maximum mean monthly flow is in October and equal to 101.31 m$^3$/s while the stream minimum mean monthly flow is in March and equal to 5.79 m$^3$/s. The mean annual stream flow is 51.60 m$^3$/s. The relation of calculated mean monthly stream flow shown in Figure 4.8 is based on the polynomial equation ($y = 0.663x^2 + 15.738x - 16.115; R^2 = 0.7069$).
4.7: Mean Monthly Steam flow Using LULC Map 1995

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean Monthly Stream flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>18.79</td>
</tr>
<tr>
<td>February</td>
<td>6.22</td>
</tr>
<tr>
<td>March</td>
<td>5.79</td>
</tr>
<tr>
<td>April</td>
<td>39.44</td>
</tr>
<tr>
<td>May</td>
<td>42.78</td>
</tr>
<tr>
<td>June</td>
<td>50.62</td>
</tr>
<tr>
<td>July</td>
<td>51.27</td>
</tr>
<tr>
<td>August</td>
<td>57.26</td>
</tr>
<tr>
<td>September</td>
<td>95.08</td>
</tr>
<tr>
<td>October</td>
<td>101.36</td>
</tr>
<tr>
<td>November</td>
<td>86.67</td>
</tr>
<tr>
<td>December</td>
<td>47.94</td>
</tr>
</tbody>
</table>

Figure 4.8: Mean monthly stream flow in 1995
In 2010, the mean monthly stream flow in every month is higher than that in 1995. The maximum mean monthly stream flow is in October and equal to 112.66 m$^3$/s while the minimum mean monthly stream flow is in February and equal to 8.04 m$^3$/s. The relation of calculated mean monthly stream flow shown in Figure 4.9 is based on the polynomial equation ($y = -0.9152x^2 + 19.818x - 20.2; R^2 = 0.7333$).

![Figure 4.9 Mean monthly stream flow in 2010](image)
The simulation results in this study shows that significant changes in the stream flow in the Nyangores River have occurred. The simulated stream flow hydrographs shows a higher flow peaks for the 2010 land-use cover datasets than the 1995 land-use cover datasets. The monthly stream flow reveal that the discharge at the river gauging station have increased during the study period. The shift in peak flows between the study periods indicates the potential effects of LULC on the stream flow in the Nyangores River. The high peak flow in 2010 datasets indicates that for every rainfall event in the sub-catchment, rain water flows faster as surface runoff from the catchment to the stream. Such scenarios indicate that water interception in the sub-catchment is low and therefore less time for infiltration. This is caused by a decrease in Forest cover, decrease in Tree plantation and increase in Farmlands therefore reducing rain water interceptions leading to increase in surface run offs in the sub-catchment (Olang’, 2009)

Table 4.8: Mean Monthly Stream flow Using LULC Map 2010

<table>
<thead>
<tr>
<th>Month</th>
<th>Mean Monthly Stream flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>22.67</td>
</tr>
<tr>
<td>February</td>
<td>8.04</td>
</tr>
<tr>
<td>March</td>
<td>8.2</td>
</tr>
<tr>
<td>April</td>
<td>43.72</td>
</tr>
<tr>
<td>May</td>
<td>54.37</td>
</tr>
<tr>
<td>June</td>
<td>62.56</td>
</tr>
<tr>
<td>July</td>
<td>63.53</td>
</tr>
<tr>
<td>August</td>
<td>72.65</td>
</tr>
<tr>
<td>September</td>
<td>107.94</td>
</tr>
<tr>
<td>October</td>
<td>112.66</td>
</tr>
<tr>
<td>November</td>
<td>97.64</td>
</tr>
<tr>
<td>December</td>
<td>54.56</td>
</tr>
</tbody>
</table>
The field work study revealed the potential effects of land use land cover changes in the sub-catchment. The transition matrix indicates that more land have been converted from Tree plantation to Farm lands. From previous studies; (Aboud, 2002), the area around Kiptagich Tea Plantations was once Forested area but have since been converted to Farmlands. Bararget forest has been deforested for timber production and illegal burning of charcoal. The encroachment and allocation of Mau forest to individuals has led to massive deforestation to pave way for farming. The deforestation and degradation of the forested upstream areas has led to increase run off downstream leading to increase in siltation (Mati et al., 2005). The building up of silt at Tenwek dam is an indication that soil erosion is taking place upstream (Kilonzo, 2013). The siltation therefore could have contributed to the increased in the peak flows in 2010 datasets than in 1995 datasets. This shows that sub-catchment is experiencing intensive land use land cover change that affects the Nyangores river stream flow (Mati et al., 2005).
CHAPTER FIVE: SUMMARY OF THE FINDINGS, CONCLUSION AND RECOMMENDATION

5.0 Summary of the Study

This study aimed at examining the land-use and land cover changes and their effects on the hydrological components of Nyangores sub-catchment. The specific objectives were:

i. To determine the physical sub-catchment characteristics.

ii. To detect the spatial and temporal land cover change 1995-2010.

iii. To assess the effects of land use land cover changes on the hydrological components in Nyangores sub-catchment.

Quantitative and qualitative research techniques were both employed in this study. Morphometric analysis, Time series analysis and change detection were used. GIS classification extensions, integration of remote sensing techniques were well employed in assessing the change in land cover. WEAP model was used to simulate the effects of land cover change on the hydrological components.

5.1 Conclusions

Conversion of land to Farm land was one of the primary mode of human modification of the environment. It was evident that there has been a significant
land-use and land cover change in the sub-catchment where the Farm land covered 30.1% in 1995, increased to 38.89% in 2010. However, the area occupied by tree plantation decreased from 21.3% in 1995 to 11.9% in 2010. There was also a decrease in forest land from 28.0% in 1995 to 26.8% in 2010. These changes have been attributed to the expansion and intensification of farming, harvesting of timber and illegal logging.

The conversion matrix revealed that the majority of lands cover was converted to farmland. A total of 87.3km$^2$ of tree plantation was converted to farm land during the period of 1995 and 2010. During the same time, 14.5km$^2$ of farmland and 7.8km$^2$ of shrub crop land cover were converted to tree plantation. It should be noted that some of the land cover conversions are as a result of the normal Land cover conversions or modification. For example the conversion of forest to scrub land can be as a result of land cover modification processes that modify one land cover to another one.

The clearing of close tree plantation and the increase in farm has resulted in severe soil erosion in the basin. This is evident by increase sediment deposition over the years in Nyangores River reducing its aerial extent.

During the classification process, errors that might have occurred during data processing can be contributes to changes in statistical values for land cover. For example, the conversion of other land cover classification back to tree plantation and forest classes look unrealistic due to the fact that farm land is increasing to
provide land for food production. But based on the nature of the sub-catchment, the period between 1995 and 2010 can lead to such land cover changes. The introduction of eucalyptus tree species has converted much of the farmlands to tree plantation land due to their economic value. Also the planting of *grevillea robusta* along the edges of tea plantation have contributed to significant increase in forest land, they act as windbreakers and source of timber for construction and wood fuel. The degraded and abandoned lands may allow re-growth of natural vegetation. Therefore, the area that might have been classified in 1995 as farm land has been classified in 2010 as natural forest or a close tree plantation.

The research developed an integrated approach for combining hydrological modeling with remote sensing classification to assess the long-term impacts of LULC change on runoff. In particular, the WEAP model, calibrated and validated using observed stream flow data in 2010, was integrated with the detailed LULC record classified using Landsat images to simulate the long-term hydrological impacts. Simulation results indicated an overall 3% stream flow increase for the whole watershed in 1995-2010. The increase in runoff is probably caused by farm expansion and degradation of natural forest.

The findings and conclusions can provide useful information to assist decision making efforts of land use planning and water resource management. In addition, the integrated approach developed in this study can also be applied to other catchments, particularly those that have experienced rapid LULC change.
5.2 Recommendations

The long history and wealth of data currently available from remote sensing should be applied to monitor land cover changes in all the watersheds. This will go a long way in managing and conserving the water resources from degradation and pollution.

The use of hydrological models such as WEAP in data scarce and data poor catchments is a big challenge. Methods of calibration and validation of these models using non-statistical objective functions and performance criteria need to be evaluated to quantify the skill of models to fit to hydrological components in such catchments.

5.3 Areas for Further Research

The study recommends that future studies should pay particular attention to the following research topics in Nyangores Sub-catchment:

i. An assessment of climate variability and climate change in the sub-catchment for the period of last 30 years or so, this may help to understand the real cause of the land degradation of the sub-catchment.

ii. The need to develop land-use scenarios to analyze the impact of land use change on the stream flow using hydrological models basing on the future scenarios.

iii. The use high resolution satellite images to assess the spatio-temporal land cover change and also develop land cover change scenario.
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Appendixes

Appendixes I: Landsat 1 Satellite Data produced using a thematic mapper in 1995
Appendix II: upper Mara River Basin indicating forest and agriculture