ANTHROPOGENIC IMPACTS OF LAND USE AND LAND COVER CHANGES ON MAI MAHIU ECOSYSTEM, NAKURU COUNTY, KENYA

By

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Thesis Submitted in Fulfillment of the Requirements
For the Award of the
Degree of Doctor of Philosophy (Environmental Science)
School of Environmental Studies
Kenyatta University, Nairobi (KENYA)

JULY 2020

DECLARATIONS

Declaration by Candidate:

This thesis is my original work and has not been presented for any degree or award in any university.

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DEDICATION

To my beloved family; loving wife Gladys Kwamboka; daughter Reyna-Nyanami and sons – Ray-Basweti, Rodney-Nyangoto and Reagan-Nyachieo.

and

In memory of my late beloved parents – Priscillah Nyanami and Benson Basweti Mobe

ACKNOWLEDGEMENT

I am very thankful to my supervisor Prof. Shyam Manohar for his invaluable advice on methodology and consistent support in corrections of thesis drafts and encouragement from the conception of the research ideas throughout the study duration. He devoted his time and attention from his own hectic schedules to read the corrections and see that this study must have successful completion till defence. I extend my deepest gratitude to my other supervisor, Dr Samuel Otor for sharing his experience.

I appreciate the help of Mr Stephen Gichugu Muturi for information on local knowledge about the study area and untiring helping hand during field surveys. I am thankful to the technical staff of Kenyatta University led by Benjamin (Environmental Sciences Laboratory) and Stanly Kariuki (Chemistry Laboratory) for their support in laboratory analysis.

I am thankful to friends and relatives led by Prof. Zablon Oonge, Dr. Naphtali Agata, Creck Buyonge and Prof. Evans Basweti for their generous financial support in raising tuition fees for this study.

Finally, I thank my wife, Gladys Kwamboka and our loving children; Ray Basweti, Rodney Nyangoto, Reagan Nyachieo and Reyna Nyanami for being part of my life and source of inspiration, support and encouragement throughout the study period.

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ABBREVIATIONS AND ACRONYMS

ANOVA:	Analysis of Variance
APHA:	American Public Health Association
CBD:	Convention on Conservation of Biodiversity
EU:	European Union
FAO:	Food and Agriculture Organization of United Nations
GPS:	Global Positioning System
KEBS:	Kenya Bureau of Standards
USDA:	United States Department of Agriculture
UN:	United Nations
UNEP:	United Nations Environmental Programme
WHO:	World Health Organization
WMO:	World Meteorological Organization
WRI:	World Resources Institute

OPERATIONAL DEFINITION OF TERMS

Bulk density (Soil): The density of undisturbed soil.

Ecosystem: A system defined by the interaction of a community of organisms with their physical environment.

Ecosystem resilience: The ability of an ecosystem to recover from disturbance.

Land-use: The total of arrangements, activities, and inputs that people undertake in a certain land cover type.

Land-use change: Conversion of natural ecosystems such as forests, natural grasslands, savannahs and wetlands into other land-use practices and vice versa. Simply, it is the change in land cover

Land-cover conversion: The complete replacement of one cover type by another for example forest to cropland.

Land-cover modification: A change that take place within one land-use or land-cover category which change the characteristics of the land as a result of natural processes or actions and reactions within that ecosystem.

pH: The negative logarithm of the hydrogen ion. A measure of the acidity or alkalinity of a substance as ranked on a scale from 1.0 to 14.0.

Plant community: A natural aggregate of different species of organisms existing in the same environment.

Riparian Buffer: Trees and shrubs growing parallel to a stream or shoreline that reduce the intrusion into the top bank area by humans, animals, and machinery. This vegetation also retards surface runoff down the bank slope and provides a root system which binds soil particles together.

ABSTRACT

Land-use changes are the main cause of human and environmental problems especially in many developing countries in Africa and Asia. Study was conducted in Mai Mahiu, Nakuru County, Kenya whose aim was to assess the impacts of land-use and cover changes on the ecosystem functioning and human environment. Specific objectives were: (i) to understand the nature of land use practices (ii) to monitor impacts on soil quality; (iii) impacts on vegetation composition and structure; (iv) to examine the level of variation in the physico-chemical parameters of rivers; and (v) to assess the effect of land-use change on climatic variability. GIS technology was used to establish land-use/cover changes from 1985 to 2015. Soil samples were collected for physical and chemical analyses from five land-use practice namely; undisturbed forest, disturbed forest dominated by *Croton spp.*, disturbed forest dominated by *Tarchonanthus camphoranthus*, cropland and severely grazed grassland while Transect method was used for vegetation survey. Water was sampled at four sampling stations (A, B, C and D) which are sites where the river passes through the above mentioned land-use practices and analyzed for physico-chemical parameters while climate data was used in climatic variability analysis. Analysis of variance, regressions and mean separation at 0.05 significance level were excuted on the data using GenStat 14th edition. Results showed a remarkable land-use and land-cover change between 1985 and 2015. Cropland significantly increased by 135% from 27.3 km^2 in 1985 to 64.2 km^2 2015 at the expense natural forest. Built-up area and roads coverage had increased by almost three times from 9.8 to 29.9 km^2. Soil quality deteriorated significantly with land conversions. There were significant changes in soil bulk density ($p<0.001$) that ranged from 0.93 g/cm^3 in undisturbed forest to 1.27 g/cm^3 in severely grazed grassland, soil pH ($p=0.002$), soil organic carbon ($p=0.008$) with losses of up to 63%, and total nitrogen ($p=0.005$) that ranged from 0.15 to 034%. Vegetation was stratified into three layers with shrub stratum being dominant replacing the tree layer that was dominant in 1985. Physico-chemical characteristics of river water deteriorated along sampling stations, A to D in both dry and wet seasons. Water pH, temperature, turbidity and conductivity increased along sampling stations A to D ($p<0.001$) while flow velocity and dissolved oxygen decreased significantly ($p<0.001$). Chlorides, sulphates, nitrates, phosphates calcium, iron, magnesium, potassium and sodium were significantly higher ($p<0.001$) at stations C and D compared to stations A and B. There was no significant difference in long-term annual rainfall variability ($p=0.685$). Intra-annual rainfall variability was noticed in the months of March, April, May and November ($p>0.001$). The study concluded that land use change and modifications in Mai Mahiu have negatively affected the state of the Mai Mahiu ecosystem. For the sake of the present and future generation in the region, the study recommends restoration and rehabilitation through landscape based land-use practices, enforcement of laws and implementation of policies relevant this type of ecosystem.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Land-use and land-cover changes are the most emerging issues of local and global environment change.The changes have compromised the natural ecosystems and earth system functions that support the primary ecosystem services (Keesstra *et al.,* 2016) which supports and secures wellbeing of the human and animal population through production of food, fibre, feed, fresh water, clean air, energy, climate stability and maintaining biodiversity on this planet.

The main driver for land-use and land-cover change is the rapidly growing population (Lambin *et al*., 2001) and its movement that has made human modify and continuously reduce and/or disturb natural habitats including forested areas (FAO, 2001b), native grasslands and wetlands (FAO, 2001a) for farming, ranching, resource extraction, infrastructure development and human settlements.

Globally, land use has led to alteration of 70% of ice free land (FAO, 2015; IPCC, 2018) through various practices in effort to satisfy human needs (Lambin *et al.,* 2006; Ellis, 2010). The world's forests are distributed unevenly with almost being found in the tropics (45% of total area), about one third in boreal (31%) while smaller amounts in temperate (16%) and subtropical (8%) regions (FAO, 2015). The highest rate of forest conversion to other land uses in both periods was in South America, followed by Africa and Asia.

In 1990 the world had 4128 million ha of forest; by 2015 this area has decreased to 3999 million hectares which is a change from 31.6 percent of global land area in 1990 to 30.6 percent in 2015 representing an annual rate of negative 0.13 percent (FAO, 2015).

Studies show that between 2010 and 2015, annual forest loss of 3.3 million ha of forest area per year (FAO, 2015). However, some natural forests were converted to forest plantations and the gains in forest cover arose from afforestation. Between 2010 and 2015 there was an annual loss of 7.6 million hectares and an annual gain of 4.3 million hectares per year, resulting in a net annual decrease in forest area of 3.3 million hectares per year (FAO, 2015).

These changes in forest cover vary from region to region with western Europe and eastern North America resulting to the net global decrease in forest area to 9.4 million hectares per year from 1990 to 2000 (FAO, 2001b). While total net forest change for the temperate regions was positive, it was negative for the tropical regions. The tropical regions lost 15.2 million hectares of forests per year during the 1990s (FAO, 2001b) with a loss of 5.8 million hectares of humid tropical forest each year between 1990 and 1997 (Achard *et al*., 2002). Forest re-growth accounted for 1.0 million hectares with an annual rate of net cover change in humid tropical forest was 0.43% during that period. A further 2.3 million hectares of forest were visibly degraded (Achard *et al*. 2002). Southeast Asia has experienced the highest rate of net cover change of 0.71% per year, whereas Africa and Latin America have lower rates of 0.36% and 0.33% respectively during the 1990–1997 time periods (Achard *et al.*, 2002).

The changes in permanent cropland at a global scale during the last 300 years has increased globally from an estimated 300–400 million hectares in 1700 to 1500–1800 million hectares in 1990 which is a 4.5 to 5 times increase in three centuries and a 50% net increase just in the twentieth century (Ramankutty and Foley, 1999; Goldewijk, 2001). Since 1850, the global total cultivated land has increased by more than 425%, with the most rapid changes occurring in tropical and subtropical regions especially after 1950s (Houghton *et al.*, 1999). In the period from 1961 to 1996, world food production increased by 1.97-fold due to expansion of cropland and irrigated agriculture (Tilman, 1999). By year 2000, 271 million ha were irrigated (FAO, 2001a). Global cropland area per capita decreased by more than half in the twentieth century, from around 0.75 hectares per person in 1900 to only 0.35 hectare per person in 1990 (Ramankutty *et al.*, 2002).

Pasture-land increased from 500 million hectares in 1700 to around 3100 million hectares in 1990 (Goldewijk and Ramankutty, 2004). These increases led to the clearing of forests and the transformation of natural grasslands, steppes, and savannas. In this period, forest area decreased from 5000–6200 million hectares in 1700 to 4300–5300 million ha in 1990 while the Steppes, savannas, and grasslands decline, that was also rapid was from around 3200 million hectares in 1700 to 1800–2700 million ha in 1990 (Ramankutty and Foley, 1999; Goldewijk, 2001). Most pastures are located in Asia (33%) and Africa (28%), with only a small portion of 7% being located in Europe and North America (FAO, 2001a).

In regards to human habitation and urbanization, urbanization affects land in rural areas through the consumption of prime agricultural land in peri-urban areas for residential, infrastructure, and amenity uses (Folke *et al.*, 1997). By 2000, towns and cities sheltered more than 2.9 billion people which are nearly half of the world population (UN, 2002). Urban population has been growing more rapidly than rural population worldwide; particularly in developing countries where 1 to 2 million hectares of cropland are being taken out of production every year to meet the land demand for housing, industry, infrastructure, and recreation (Doos, 2002). Built-up or paved-over areas are estimated to occupy from 2% to 3% of the earth's land surface (Young, 1999). The cities experiencing the most rapid change in urban population between 1990 and 2000 are mostly located in developing countries (Deichmann *et al.*, 2001).

Unsustainable land-use and land-cover practices have led to occurrence of unpleasant impacts on terrestrial ecosystem (Bahn *et al.*, 2006) because vital components of ecosystems and earth system have been compromised through changes in landscape configuration making it loose the ability to withstand d shocks. The impacts have become serious issues in the under-developing tropical and sub-tropical nations of Africa, Asia, Latin America and the Caribbean where desertification and degradation of the landscape has led to capital assets loss which influences knowledge, systems, human cultures, religions, and social interactions (Renaud *et al.*, 2013). The consequences of human modification and alterations of Earth's terrestrial surface are complex and diverse. Decrease in terrestrial biological resources and their habitats are the serious challenge today in most of the countries. They have influenced the structure, function, and dynamics of ecosystems significantly affecting key ecological functions (de Chazal and Rounsevell, 2009) and environmental integrity thereby causing alteration of global biosphere-climate system (Goldewijk, 2001; Turner *et al.*, 2007) and environmental change (Lambin *et al.*, 2001). Other consequences include deterioration in the physical and chemical properties of soil causing degradation of the land (Lal, 2003; Symeonakis *et al.*, 2007; Onur *et al*., 2009; Ries, 2010), loss of biodiversity (Baan *et al.*, 2012) that supports human life (Sala *et al.*, 2000). Others include: hydrological cycles (Eltahir and Brass, 1996), landscape patterns (Feng *et al.*, 2011), and human life (Maitima *et al.*, 2009). It also influences CO_2 enrichment in the atmosphere (Lal, 2003) and other greenhouse gas (GHG) emissions which directly alter atmospheric composition and radiative forcing properties (Marland *et al.*, 2003; World Meteorological Organization, 2005) which is the main driving force of regional and global climate change (Vitousek 1997; Foley *et al.*, 2005)

In the sub-Saharan Africa, land-use and land-cover changes have led to soil and land degradation (Lal, 2003; Symeonakis *et al.,* 2007; Onur *et al*., 2009; Ries, 2010) which is a critical problem that has affected environment and agricultural productivity. This has led to poor crop yields due to decrease in soil fertility (Bationo *et al.,* 2004) thereby affecting economic growth and increasing poverty levels because agriculture contributes more than 25% of the Gross Domestic Product (GDP), employs more people and is a source of income. Decline and loss of biological diversity, land productivity, water quality and quantity, climatic variability, droughts, floods, crop failure, hunger are due to malfunctioning of an ecosystem.

In Kenya, the main driver for land-use and land-cover change is the rapidly growing population and their movements to satisfy socio-economic needs without regard to environmental impacts despite existence of laws that promote sustainable activities on the environment. Examples of such laws include Environmental and Management Act (EMCA), (1999) whose focus is on protection, improvement and utilization of environmental components; Water Act, 2002 for the management, conservation, use and control of water resources and Forests Act, 2005 that focuses on sustainable management, conservation and rational utilization of forest resources.

The effect of unsustainable human-induced land-use activities in Kenya is land degradation which is in the forms of soil erosion, soil nutrient depletion, salinity, acidity, compaction, organic matter loss and pollution (Lang, 2004). It has become an important problem because of its adverse impacts on agronomic and ecosystem productivity thereby affecting quality of life (Eswaran *et al.,* 2001). These have made the country get subjected to environment-related stresses that put sustainable development at risk. Recent studies (Manohar, 2018; UN-Water, 2018; Kitur, 2009) show that human activities have rapidly deteriorated water quality in aquatic systems. Other consequences include alteration of landscape patterns (Feng *et al.,* 2011), biosphere-climate system (Goldewijk, 2001; Turner *et al.,* 2007) environmental change (Lambin *et al.,* 2001), biodiversity distribution, decline and loss (Baan *et al.,* 2012; McCain and Colwell, 2011; Hansen *et al.,* 2012; Thomas *et al.*, 2004). Land-use practices have also affected hydrological cycles (Eltahir and Brass, 1996), CO_2 enrichment in the atmosphere (Lal, 2003; Marland *et al.*, 2003; WMO, 2005) which is the main driving force of climate change (Foley *et al.*, 2005) especially high temperatures and low precipitation (McCain and Colwell, 2011; Ge *et al.*, 2014).

Impacts of land-use and land-cover changes have become a serious issue in sustainable development therefore requiring integrated assessment of the environment in order to understand the nature and extent of problems and come up with mitigation measures. There is a growing international concern on themes that are central to understanding land-use and land-cover change as a major driver of environmental change (Braimoh and Osaki, 2010). On the global scale, there is synergy at the global and regional scales such as the Convention on Conservation of Biodiversity (CBD), Kyoto Protocol, United

Nations Climate change Conference (UNCCC) Framework, Paris Agreement and the Intra-ACP Climate Change Alliance Plus (GCCA+) to promote sustainable human-environment interactions for human well-being and environmental sustainability. Global Land Project (GLP), jointly established by the International Human Dimensions Program on Global Environmental Change (IHDP) and the International Geosphere Biosphere Program (IGBP), is the foremost international global change project promoting land change science (LCS) for environmental sustainability seeking to integrate a range of research questions towards an improved understanding of the dynamics of land change, the causes and consequences of land change, and assessment of system outcomes, notably vulnerability and resilience of land systems (Turner *et al.,* 2007).

To address challenges associated with land-use and land-cover changes and achieve sustainable development, timely and precise information about land-use and land-cover change is extremely important (Lambin and Geist, 2007; Anil *et al.,* 2011). Accurate and up-to-date land cover change information is necessary to understand and assess the environmental consequences of such changes (Lambin and Geist, 2007) and addressed through observation, assessing and monitoring; understanding the coupled system—causes, impacts, and consequences; modeling; and synthesis issues (Lambin *et al.,* 2006; Turner *et al.,* 2007).

1.2 Problem Statement

The Mai Mahiu ecosystem is a fragile and an important ecological area since it consists of great portion of the Upper Ewaso Kedong water catchment that supports many livelihoods and drains into ecologically sensitive Lake Magadi. Before independent Kenya, Mai Mahiu was a ranching zone under European settlement that traversed from

Mai Mahiu to Longonot that supported large herds of cattle, sheep and goats. After independence in the late 1960s and early 1970s a population that was regarded as landless got moved from then Central Province of Kenya to Mai Mahiu where they formed land-buying companies notably Ereri, Nyakinywa and Utheri wa Lari which bought a large area which they distributed to members. Later, these companies fragmented the land into smaller pieces of 5-acre plots without to natural features such as slopes and drainage lines. Before 1990, the study area was forested with a number of wild animals notably the giraffe, buffalo, antelopes and snakes. Main rivers which are Mai Mahiu, Naisaia, Kambogo and Mutathia were perennial then with lots of water and good climate that supported farming and wildlife. Over the last forty years, the area has experienced rapid population growth which is associated with in-migration influenced by social and economic factors including its location long a major transportation route, land resources and government policies to settle people in that area. Between 1969 and 2009, Naivasha sub-county had its population increase from 43867 to 158679 which is 422.9% while Mai Mahiu recorded an increase of 216.8%. Livestock population has also increased tremendously. This increase in human and animal population was believed to have exerted pressure on available land and its resources through land fragmentation, resources extraction and consumption, settlement and various socio-economic practices.

The unsustainable land-use practices were believed to have brought ecological imbalances and harmful impacts soil erosion that is caused by deforestation, poor tillage and agricultural practices and overgrazing. It is believed that this has led to land degradation and fertility loss, changes in vegetation cover and structure, sedimentation of rivers and enhanced flooding. All these were compromising the resilience and productivity of Mai Mahiu ecosystem and quality of life. This study attempted to give an explanation on the current environmental situation through the investigation of long-term spatial and temporal variations in aspects of soil quality, vegetation, physico-chemistry of rivers and climatic variations of Mai Mahiu ecosystem that have been linked to land-use and land-cover changes. Degradation was envisaged to have had negative effects on soil productivity, vegetation distribution, and water resources. In addition, a detailed phytosociological analysis of the Mai Mahiu region does not exist. Though low vegetation cover, abundance and species diversity observed in an area might be associated with the prevailing natural conditions, structural changes in vegetation distribution through increased human activities could be linked to soil quality deterioration, water quality and quantity changes in these rivers and climatic variations experienced in the area. There was need to examine the role of anthropogenic land use and land cover change in initiating and accelerating natural vegetation depletion within this ecosystem. Also, physico-chemical characteristics and water level fluctuations in flowing rivers have become of concern.

1.3 Justification of the Study

The degradation of this ecosystem has threatened agronomic productivity, natural vegetation, and continued supply of quality water to the Mai Mahiu inhabitants and Upper Ewaso Kedong catchment. Despite of this, the decline of environmental quality in the area has not been clearly documented and addressed by past studies thereby making the development of effective approaches for conservation difficulty. There is need to know what impacts have been induced by human activities with respect to soil quality, vegetation, water quality and quantity characteristics of some of the rivers and climatic variations. Baseline information is vital in understanding of ecosystem dynamics and detection of undesirable changes in soil, vegetation, water and climatic variability due to human activities. It is against this background that this study was carried out whose purpose was to assess and determine the impacts of anthropogenic activities on Mai Mahiu ecosystem. To date, no study has been done focusing on impacts of human-induced land-use and land-cover changes upon soil quality, vegetation, natural rivers, water quality of rivers and climatic variability. It aimed to fill the existing knowledge gaps whose findings will emerge useful in the restoration, conservation and protection of the degraded but vital ecosystem for its continued productivity for present and future generations.

1.4 Objectives of the Study

The general objective was to investigate the impacts of land use and land cover changes on Mai Mahiu ecosystem in Nakuru County, Kenya.

1.4.1 Specific objectives

These objectives were as follows:

(i) To analyze and map out land-use and land-cover changes for the period of 30 years (1985-2015) in the Mai Mahiu ecosystem,

(ii) To determine the effects of land-use and land-cover changes on soil properties of the Mai Mahiu ecosystem in the study period,

(iii) To evaluate the long term impacts of land-use and land-cover changes on natural vegetation composition and characteristics in the study area,

(iv) To analyze the effect of land-use and cover-changes on water quality and quantity of rivers within the area under study,

(v) To quantify the effect of land-use and land-cover changes on climatic variability in Mai Mahiu.

1.5 Research Hypotheses

The following hypotheses were tested after the analysis of data:

(i) There is no significant changes in land use land cover on Mai Mahiu ecosystem in the past 30 years (1985-2015);

(ii) Land use land cover changes have not affected soil properties within the Mai Mahiu ecosystem in the study period;

(iii) Natural vegetation composition and characteristics in the study area have not been modified by land-use and land-cover changes;

(iv) That there is no negative impacts of land use land cover changes on water quality and quantity of rivers within Mai Mahiu region; and

(v) Changes in land use practices for the last 30 years are not the cause of climatic variability within the study area.

1.6 Scope of the Study

Due to complexity of land use land cover change subject, the study was limited to assessment of the impacts on the ecosystem components that play crucial roles in the functions of healthy ecosystem as influenced by land use land-cover change.

1.7 Conceptual Framework

Conceptual framework (Figure 1.1) explains the analysis of impacts of land-use and land-cover changes within the study area. Land-use and land-cover changes are driven by demographic and socio-economic developments in the area. The demand to satisfy the needs such as food, energy, shelter and infrastructure development for the rapidly growing population may have led to unsustainable practices that have exerted pressure on the available land leading to the adverse changes the environment. These changes may include soil degradation, changes in vegetation composition and structure, water quality and variable climate. The degraded state negatively impacts on ecosystem functions and services provisioning such as habitat destruction, soil fertility decline, biodiversity loss/decline and poor water quality and / or shortage. The negative impacts calls for responses that can mitigate, adapt or reverse the adverse impacts through various interventions which include conservation and rehabilitation measures, policy implementation and law enforcement, awareness campaigns among others. Successful intervention measures require congruent understanding of the causes, nature, extent and consequences of land-use and land-cover changes in the ecosystem through impacts assessment.

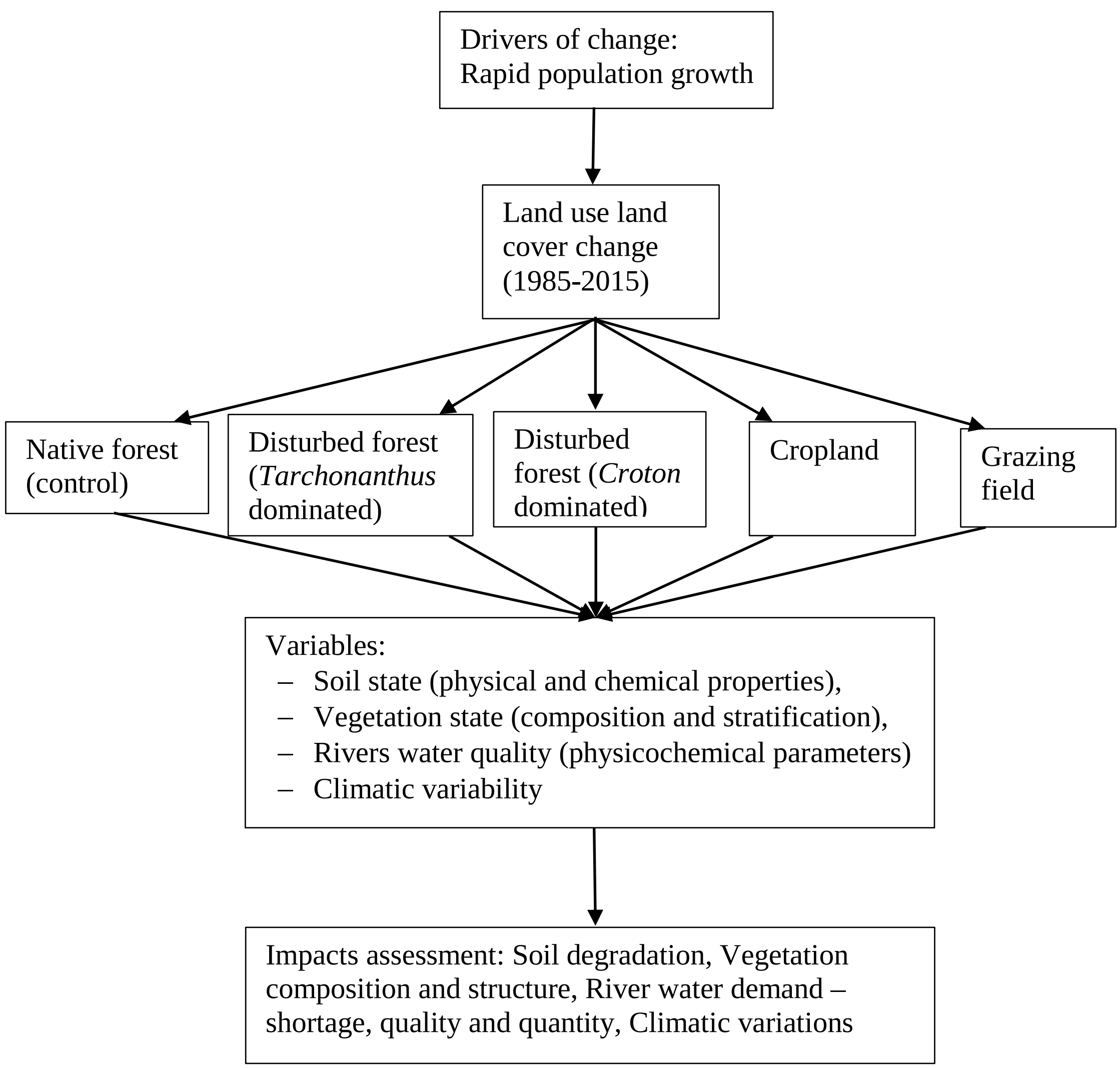

Figure 1.1: Conceptual framework representing the interactions associated with land-use and land-cover changes in Mai Mahiu ecosystem.

1.8 Limitations of the Study

The nature of such studies requires considerable time, money and logistic support that were not at disposal of the researcher. However, the information collected was effective to meet the objectives of the study since it well represented the study area.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The chapter reviews trends and consequences of land use land cover changes on ecosystem at global, regional and local levels and identify research gaps to be addressed as proposed by this study.

2.2 Land-use and Land-cover Change

Human exploitation of the Earth's ecosystems has increased tremendously (Foley *et al.*, 2005; Ellis and Ramankutty, 2008). Anthropogenic land-cover modifications and interactions are mainly through various exploitative land use practices in effort to satisfy human needs from land (Lambin *et al.*, 2006; Ellis, 2010) namely food, fibre, energy, housing and infrastructural developments. These modifications, in most instances, have resulted to occurrences of unpleasant impacts on terrestrial ecosystem (Bahn *et al.*, 2006) because vital components of ecosystems and earth system have been disrupted through changes in landscape configuration. The consequences include disruption of flow of energy and cycling of nutrients, climate change (Foley *et al.*, 2005) through alteration of the global biosphere-climate system (Goldewijk, 2001; Turner *et al*., 2007) that has significantly affected ecological functions (de Chazal and Rounsevell, 2009). Human-induced ecological degradation is diverse and it varies from one region to another (Foley *et al.*, 2005). Effects include land degradation (Lal, 2003; Symeonakis *et al*., 2007); decline and/or loss of biodiversity (Baan *et al*., 2012) that supports human life (Sala *et al*., 2000) through provisioning of goods and services from the ecosystem (DeFries and Bounoua, 2004) such as water quality (Wohl *et al.*, 2012), hydrological cycles (Eltahir and Brass, 1996), landscape patterns and human life (Feng *et al*., 2011). Other impacts include CO_2 enrichment in the atmosphere (Lal, 2003) and other greenhouse gases (GHG) that are responsible for the changes in composition and radiative forcing properties of the atmosphere (Marland *et al.*, 2003; WMO, 2005).

2.3 Global Perspective of Land-use Land-cover Changes

According to IPCC (2018), global uses of ice free land include forests which include plantation forests and managed forests for timber and other land uses, unfrosted ecosystem, and primary forests and other land including barren and rock (28%), cropland; irrigated and non-irrigated (12%), pastureland; intensive pasture, used savanna and shrubland and extensive pasture (37%), infrastructure (1%).

The largest forest cover is found in the tropics (45% of total area) followed by the boreal (31%), temperate (16%) and subtropical regions having 8% (FAO, 2015). Highest rate of forest conversion into other land-use practices is in South America followed by Africa and Asia (FAO, 2015). The reduction of forest cover is due to development of civilizations, economies and rapid population increase with associated increased demand for food and fibre that has made agriculture to expand into natural vegetation in every corner of the world (FAO, 2001a). By 1990 the global forest cover was 4128 million ha which reduced to 3999 million ha in 2015 which is a change from 31.6% in 1990 global land area to 30.6% in 2015 that represent a decrease of annual deforestation rate of 0.13% (FAO, 2015). This notwithstanding, there was natural forests conversion to forest plantations that made gains in forest cover through afforestation. In the 2010 and 2015 period, annual forest loss was 7.6 million ha and a gain of 4.3 million ha per year, translating to a net annual loss of 3.3 million ha of forest area per year (FAO, 2015). Net positive change in forest cover is in the temperate region while negative for the tropical regions.

Global total cultivated land has increased by more than 425% since 1850 with a vast increase experienced after 1950s in the tropical and subtropical regions (Houghton *et al.*, 1999). In the 1961 to 1996 period, food production in the world increased by 1.97 times because of expansion of cropland and irrigated agriculture (Tilman, 1999). Land expansion for cultivation is increasingly occurring into more marginal and fragile land (Turner and Benjamin, 1991)

Pasture-land increased to around 3100 million ha from 500 million ha in 1700 by 1990 (Goldewijk and Ramankutty, 2004). In this period, area covered by forest decreased from 5000 to 6200 million ha in 1700 to between 4300 million ha and 5300 million ha in 1990 (Ramankutty and Foley, 1999; Goldewijk, 2001). Most of pastureland is found in Asia with (33%) and Africa with (28%) while a small proportion of 7% is in Europe and North America (FAO, 2001a).

Infrastructural development including human habitation and urbanization is due to conversion of native land to land residential, infrastructural and amenity use (Folke *et al.*, 1997) which is as a result of increased human population especially in the urban areas. By year 2000, nearly half of the world population (2.9 billion people) was living in towns and cities (UN, 2002). This has increased housing, infrastructure and recreation demand leading to between one and two million hectares of cultivated land taken out to meet this demand (Doos, 2002) especially in the developing countries in Africa, Asia and Latin America including Caribbean (Deichmann *et al.*, 2001).

2.4 Land-use and land-cover changes in USA and South America

Gradual cropland expansion in North America started in nineteenth century with dramatic increases in the second half of 20th century (Ramankutty *et al.,* 2002) especially in the Corn Belt and Prairie Provinces in Corn Belt in the United States and Canada, respectively. The grassland regions in Argentina and Brazil have also had rapid cropland expansion early in the twentieth century. Rapid expansion into cropland led to rapid land degradation in this region. Rapid industrialization is also responsible for the decline of forests, soil erosion and biodiversity loss in the United States (World Resources Institute, 2006). Main reasons for deforestation are to get timber for business, road construction, industrialization and paper consumption (Butler, 2007). Soil degradation from agriculture contributes to 66% of the soil loss in United States (FAO, 2004).

2.5 Land-use and land-cover changes in Europe

Europe is one of the most intensively used continents with up to 80% of land used for settlement, agriculture, forestry and infrastructure. The drivers of land-use are food and fibre production, energy and biomass, industry, carbon storage and settlement (European Environment Agency, 2008). The greater part of farmland is in the Eastern part of Europe which has more than 50% of its land area under crop (Ramankutty *et al.,* 2002). High level of industrialization in Europe has led to pollution problem because of use of fossil fuel in power plants and transportation. This pollution disrupts natural ecosystem functions by affecting food chains and decreasing production on farmlands by poisoning the soil especially in the former Soviet Union, and Southern and Central Europe (UNEP, 1999).

2.6 Land-use and land-cover changes in Asia

Asia continent's crop expansion was experienced in the Indo-Gangetic Plain, and eastern China. Before 1850, a gradual expansion of cropland occurred in Southeast Asia with a dramatic increase during the second half of the twentieth (Ramankutty *et al.*, 2002). The major consequence of land use change in this region is land degradation especially in Central Asian countries where there is severe loss of soil fertility, salinization, water logging; degradation of pastures and forests (Mikhalev and Reimov, 2008).

2.7 Land-use and land-cover changes in Africa

The land-use change in Africa is mainly conversion of native forest into agricultural land particularly in the sub-Saharan Africa where it accounts for 60% of land-use change (FAO, 2015). Main practices include clearing trees for practices that support more food, feed, fibre, energy and infrastructural developments for rapidly growing population in all the zones. These changes have negative consequences especially when practiced in the vast dry lands of Africa which is about 2.1 billion hectares. The consequence includes land degradation that has become a major concern that threatens lives in the continent (Bationo *et al.*, 2004). Overgrazing and uncontrolled fires have become key factor of land degradation in the humid lands of Africa. In the dry lands, in addition to overgrazing, unsustainable agriculture and overexploitation of natural resources that are key factors of degradation which has resulted to desertification in the dry Sub-humid and dryland regions (Blay *et al.*, 2004).

2.8 Land-use and land-cover changes in East Africa

East Africa's land use changes are a transformation of natural vegetation into croplands, graze lands, infrastructural development, settlements and urbanization. The transformations have drastically reduced forest cover, biodiversity decline or loss and degradation of land (Maitima *et al.,* 2009). Land expansion especially for planted pasture and cultivation for ever-growing demand for food and income generation has transformed natural land cover into agro-ecosystems (Maitima *et al.,* 2009). The rate of conversion to agriculture has indeed become more than the proportional growth of human population in recent times (Lambin *et al.,* 2003) because these countries depend heavily on agricultural sector with national Gross Domestic Product (GDP) ranging between 30 and 40%. The agricultural sector is the source for 80% of employment and earns more than 50% of export earnings (Kimaru and Jama, 2005).

In Uganda, land fragmentation, cultivation of marginal land is attributed to population growth which has increased and unsustainable use of arable lands, (Birungi, 2007) that has resulted to land degradation from depletion of soil nutrient and soil erosion.

In Tanzania, land use changes have led to land degradation which has become a major environmental problem (Mongi, 2008) with soil erosion observed at 61% of the entire land. Degradation in Tanzania is caused by deforestation, overgrazing, slope cultivation and wild fires especially in the central, Lake Victoria zone and parts of Northern parts. In some parts of the country such as Dodoma, Shinyanga, Mwanza, Arusha and Tabora, land degradation has gone beyond the natural regeneration (Anderson and Slunge, 2005).

2.9 Land-use and land-cover changes in Kenya

Kenya’s land area is about 582,646 km^2 with a huge proportion of almost 80% of total area being arid and semi-arid lands which are predominantly pastoral (Kenya National Bureau of Statistics (KNBS), 2009). Agricultural land covers 48.5% (276300 km^2) of the total land area while forest cover is 7.8% (World Bank, 2016). Kenya's forests provide goods and services to approximately 70 per cent of households adjacent to forests (World Resources Institute (WRI), 2007).

The major cause spatial and temporal of changes in land use in Kenya is natural attributed to climatic variability and human activities (Kiage *et al.,* 2007). Human-induced activities have made the country undergo rapid transformations in land use and land cover due to increased demands from rapidly growing population and political, social-cultural and economic factors (WRI, 2007; Maitima *et al.,* 2009).

The effect of unsustainable human-induced land use activities in Kenya is land degradation (WRI, 2007). Studies show that the extent of land degradation in Kenya and it affects is slightly over 20% of cultivated areas, 30% of forests and 10% of grassland (Muchena, 2008). Forms of land degradation include; soil erosion, depletion of soil nutrients, salinity and acidity, soil compaction, loss of organic matter and pollution (Lang, 2004), has become an important problem because of its adverse impacts on agronomic and ecosystem productivity (Eswaran *et al.,* 2001). On study on land use change on water resources of River Njoro catchment, Baker and Miller (2013) notes that land conversions had affected soil properties, nutrient losses and fluxes, and vegetation cover and composition. These changes can affect important processes such as rainfall interception, soil infiltrability, groundwater recharge and evapotranspiration that leads to changes in amount of runoff consequently affecting hydrology of the watershed (Baker and Miller, 2013; Kitheka *et al.,* 2019). In a study in Gucha catchment, Kathumo (2011) observes that increase in human activities in this catchment have caused continuous change in land cover and increased pressure on natural resources in this region. Kioko and Okello (2010) notes that increased activities into marginal land in the semi-arid rangelands of Southern Kenya have affected rangeland health through the removal of natural vegetation and overgrazing (Gathaara, 2010). Studies in Kijabe–Longonot catchment (Mwehia, 2015) while Kiage *et al.* (2007) argues that and use change deforestation due to increased human and livestock population in Lake Baringo catchment is the main cause of degradation and in sediment yield in the lake and lake surface area reduction. Land use change has been cited as the cause of flash floods occurances in some part of Kenya. Barasa and Perera (2018) observe that deforestation and expansion of farmland from 15.3% in 1975 to 75.2% in 2013 and urbanization increase from 0.4% to 10% had increased river peak discharge in the Sosian River basin of the Rift Valley from 167 m^3/s in 1970 to 233 m^3/s in 2013.

Degradation has made the country get subjected to environment-related stresses that put sustainable development at risk and recovery from adverse loss of ecosystem productivity needs interventions (Bai *et al*., 2008). Interventions that strike a balance between balance between economic development and environmental conservation requires availability of detailed and reliable information on land cover and its impacts.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This chapter presents a detailed description of the study area, research designs, data collection and analysis.

3.2 Study Area

3.2.1 Location

Study was conducted in Mai Mahiu ecosystem that covers the area 354.9 km^2 in Naivasha sub-county, Nakuru County, Kenya. It is located between latitude 1^o 2' S and 0^o 56' S and between longitude 36^o 30' E and 36^o 36' E, and altitude between 1520 and 1890 m above the sea level. It is about 60 km northwest of Nairobi, the capital city of Kenya along Nairobi-Narok road (Figure 3.1, Plate 3.1).

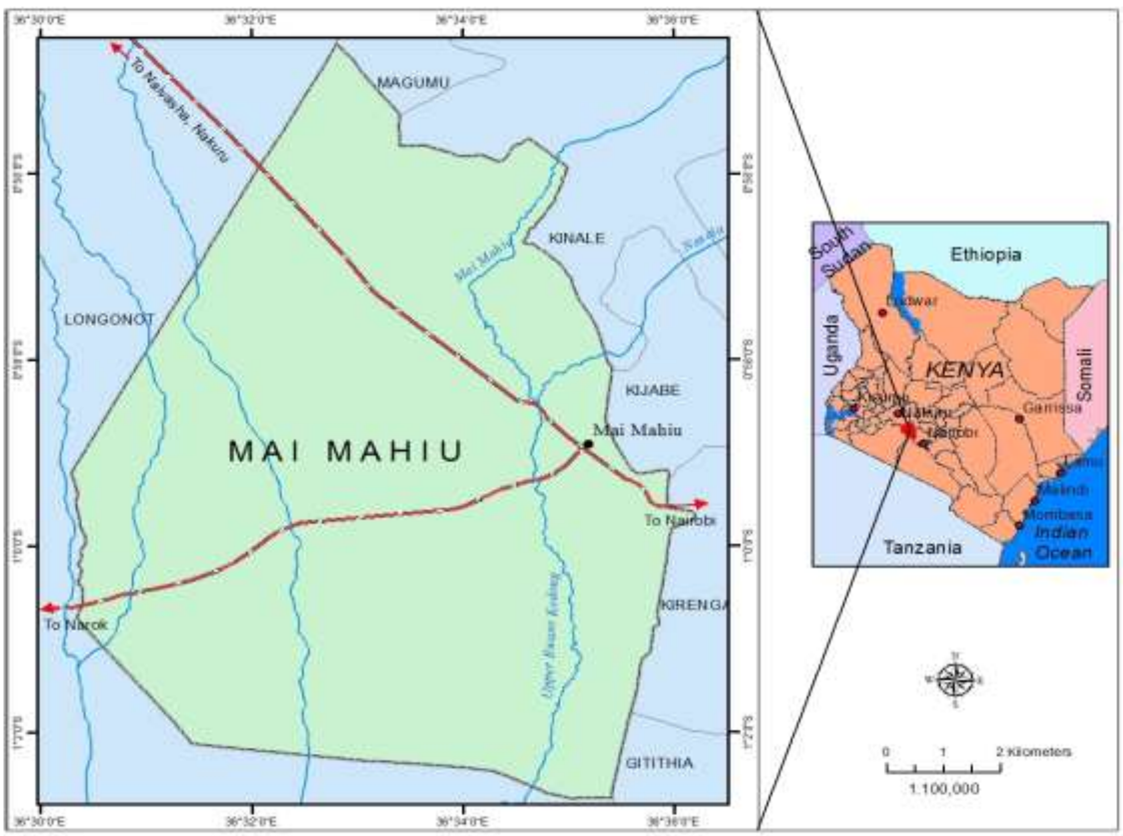

Figure 3.1: Map of Kenya shows Mai Mahiu division within Nakuru County, Kenya.

Plate 3.1: Satellite image of the study area. (Source: Google map, 2019)

3.2.2 Climate

The climate of Mai Mahiu is warm and rainy that is influenced by the Equatorial Monsoon with two rain periods; long and short rain seasons. Long rain season starts in March and ends in May while the short rain season is from October to December. The average annual rainfall is between 443–939 mm/year with an average of 608 mm. The annual temperature ranges between 15.9 and 29.3 ^{o}C with a mean of 22.6 ^{o}C with the highest temperature recorded in months of January and February. Relative humidity is 75%. Evaporation rate is between 1700mm and 1000mm per year. Mean monthly potential evaporation at the region exceeds rainfall by a factor of 2–8 for every month, except April in the wettest years. Most of the wind blows from the south-west with a few cases when it flows from north-west. Because of its locality in the rift valley, colder winds blow from colder upper region and enters the valley with increased velocity between 13 km/hour and 30 km/hour during the day. The monthly average wind velocities are strongest in the months of May and June.

3.2.3 Geology and soils

Geologically, all rocks and structures were formed during the past 4 million years during episodes of volcanic activity and faulting (reference). The area has Lacustrine sediments which are very porous. Soils are influenced by intensive variation in topography, climate, volcanic activities and underlying rocks. The soils are predominantly Nitosols with mixture of Andosols, Cambisols and the Regosols formed from weathered volcanic and basement rock systems.

3.2.4 Flora and fauna

Main vegetation type is savannah which is characterized by open grasslands with isolated trees. Common trees species are A*cacia xanthophloea, Euphorbia inaequilatera, Euphorbia candelabrum, Felicia muricata, Tarchonanthus camphorantus, Croton spp., Acacia drepanalobium* and *Rhus natalensis* within the study area. Large part of the natural vegetation has been cut and replaced by agriculture and pasture. The remaining vegetation has been partly disturbed by clearing including areas which are forest reserves. Initially the area had a number of wild animals that included birds, giraffes, buffalo, Impala and Zebra that have since declined or disappeared.

3.2.5 Hydrology and drainage

Mai Mahiu drainage is mainly internal. Surface water drainage is from fault blocks that extend for a short distance then infiltrates rapidly to the thick cover of soil and alluvium.

Ground water is recharged laterally from the high rifts and axially along the floor southwards. The area forms part of Ewaso Kedong catchment that drains its water into Lake Magadi (Figure 3.2).

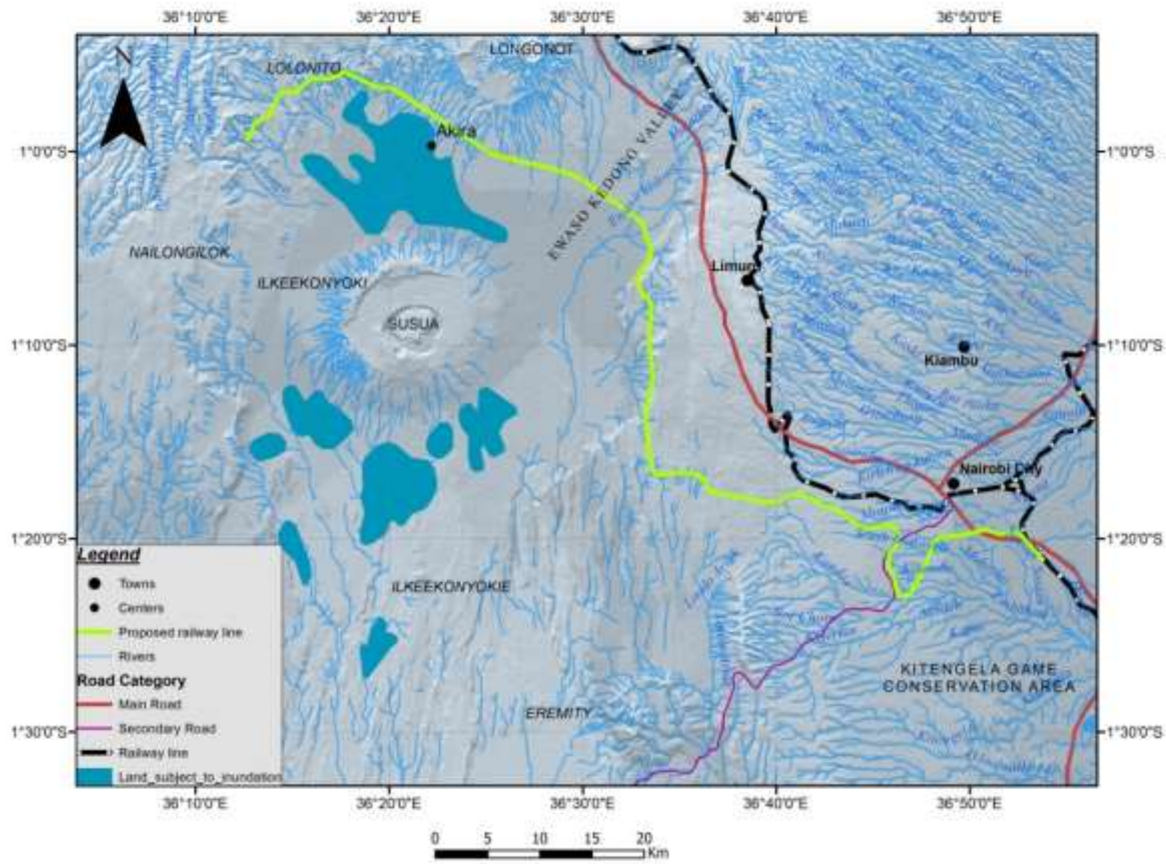

Figure 3.2: Satellite image shows hydrology within the study region

3.2.6 Social-economic activities

Human population of the study area is 38546 with a population density of 66 people per square kilometre and 9661 households. The main economic activities are mining of building materials mainly sand and stones, agricultural activities with 240746 sheep, 139501 cattle, 115363 goats, 19375 donkeys, 6390 pigs, 67 camels and 222,316 chicken (KNBS, 2009). Urban self-employment stands at 23% while rural self-employment is at 8%, wage employment at 19% and other sectors 2%. An average family in Mai Mahiu earns Ksh.5,000 per month with a great struggle. The area is surrounded by diverse habitats that also act as tourist sites that include Mt. Longonot, Mt. Suswa, Hell's Gate and Lake Naivasha. With a good road network, Mai Mahiu urban centre is rapidly growing.

3.3 Data Collection and Analyses

This section entails how the data were collected for every objective of the study including designs, methods of data collection, sample handling and analyses.

3.3.1 Objective 1: Land uses and land cover changes from 1985 to 2015

3.3.1.1 Data acquisition

The Landsat archive was utilized in the land cover land use change analysis. Images were acquired the images from the Global visualization Viewer (Glovis) archive which is managed by the USGS. Images were downloaded at 15 years interval for 1985, 2000 to 2015 (Table 3.1). Clouds usually block the view from the sensor to the object on the earth surface thus minimizing the observations that can be made on the image. The cloud cover for the images acquired for this study ranged from 0.34 to 5%. This left the 95% of pixels in the majority of the scenes usable for further procedures.

Table 3.1: Dates and scene ID of the Landsat Images used over the study period.

Year	Day and Month	Path/Row	Entity Id
1985	18/Jan	168/061	LT05_L1TP_168061_19850118_20170219_01_T1
2000	21/Feb	168/061	LE71680612000052EDC00
2015	03/Feb	168/061	LC08_L1TP_168061_20150203_20170426_01_T1

All satellite images were geometrically corrected to the universal Transverse Mercator coordinate system (zone 37S). Image pan sharpening was utilized in resampling the images from 30 m to 15 m spatial resolution. The images were taken after every 16 days in different rows and columns to determine changes and the observable characteristics of the data captured within this period. Sampling points which act as the ground truth sites were captured from the field by GPS system. These points were also applied in accuracy assessment on image classification.

3.3.1.2 Image classification and land-cover clustering

Land-use and land-cover maps were developed using satellite images by defining spectral classes. Multi-temporal Landsat data processing was done using ENVI 4.7 Software (ESRI, 2009). The Maximum Likelihood Classification, under the category of supervised classification, which is pixel-based method, was applied to capture the spectral information of land cover classes of interest (Table 3.2). Minimum distance classification methods were used to classify the images (ESRI, 2009). Eight land use and land cover types were classified as forests, deciduous trees, cropland, bare-lands, grasslands, water bodies, scrubs and built area.

Table 3.2: Description of land-use and land-cover clusters in the study area.

	Land Cover	**Description**
1.	Forest	The areas with evergreen trees mainly growing naturally in the reserved land, along the rivers and on hills
2.	Deciduous trees	Trees planted on farms, homesteads and reserved areas
3.	Crop land	Land which is mainly used for growing food crops such as vegetables, maize and fruits.
4.	Bare-land	Land left without vegetation cover. This results from abandoned crop land, eroded land from land degradation and weathered road surface
5.	Grassland	Land where grass is the main dominant vegetation cover.
6.	Water bodies	The flowing rivers, fish ponds, water pans and lakes in the area.
7.	Scrubs	Uncultivated land covered with shrubs, or other natural vegetation.
8.	Built-up area	Land covered with buildings. The tarmac roads and concrete structures area also put in this class.

3.3.1.3 Change detection and analysis

ENVI EX software was used to compute thematic changes for classified land use and land cover types. Images comparison from two different time periods (1985 and 2000 images, 2000 and 2015 images) was done at a time. Different land uses and cover area of lands were used to calculate percentage change in LULCC using Excel. Also, the overall change in land use and land cover from 1985 to 2015 was calculated.

3.3.2 Objective 2: Impacts of land uses and land cover changes on soil quality

3.3.2.1 Research design and soil sampling

Five common land-use and land cover types were identified and selected for soil sampling. They were: (i) undisturbed forest, (ii) disturbed forest dominated by *Tarchonanthus camphoranthus* (iii) disturbed forest dominated by *Croton spp.* (iv) cropland and (v) grassland. The criteria used in the selection of the sampling sites were their link to nearby undisturbed Kijabe and Kinale forest reserves from which the conversions occured.

From each land-use/cover practice, plots measuring 20 m x 20 m were laid out and soil sampled from the corners and centre by use of samplers (196 cm^3) and augers to the depth of 15 cm. From each plot, sub-samples were pooled to form a composite sample while three individual cores were left un-bulked for undisturbed soil analyzes (Plate 3.2).

Plate 3.2. Researcher (left) and Supervisor during soil sampling exercise in the study area in Mai Mahiu, Nakuru County.

All sample points were georeferenced by a Geographical Positioning Satellite (GPS) gadget. Samples were transported in a cooler box to the National Agricultural Laboratories in Kabete for soil analyses. The soils were processed by air-drying for four days, thoroughly mixed and sieved through 2 mm sieve for removal of plant roots and other non-soil matter before it was analyzed.

3.3.2.2 Particle size determination

Soil particle size composition was analyzed by the Hydrometer Method (Bouyoucos, 1962). The samples were treated with peroxide (H_2O_2) to kill the organic matter, while dilute hydrochloric acid (HCl) was used to remove alkaline earth carbonates on an electric soil dispersion stirrer. This was followed by adding sodium Hexametaphosphate (with sufficient Na_2CO_3 to give pH of about 8.5 in 10% solution) to disperse the particles and the volume of dispersed solution adjusted to 1 L in a measuring cylinder. This solution was passed through 0.2 mm sieve to separate coarse sand while fine sand determined by beaker method. Silt and clay fractions were determined by pipette from upper 10 cm depth. From calculated percent particle composition, textural triangle was used to assign soil texture classes according to the USDA particle size classes which Sand (2.0–0.05 mm), Silt (0.05–0.002 mm) and Clay (<0.002 mm).

3.3.2.3 Bulk density analysis

This was determined by the core method according to Blake (1965). In this method, soil in cores were placed in weighing tin and weighed. With known weight (W_1) of weighing tin and that of core cylinder (W_2), the samples were dried in an oven at 105 ^oC for 24 hours and weighed (W_3). These values were used to determine bulk density (BD) as follows:

$$BD = \{W_3 - (W_2+W_1)/Volume\ of\ cylinder\} \qquad (3.1)$$

Where: BD = soil bulk density;

W_3 = weight of weighing tin + core cylinder + soil;

W_2 = weight of core cylinder and

W_1 = weight of weighing tin.

3.3.2.4 Water content determination

Soil water content was established by use of pressure plate at pF 0, 2.3 and 4.2 (Blake and Hartge, 1986).

3.3.2.5 pH determination

Soil pH was measured in water (1:2.5 soil:water) using a standard pH electrode. Here, 10 g soil was transferred into a 50 ml beaker in which 25 ml of distilled water was added. The mixture was stirred by using a horizontal mechanical shaker for 15 minutes and left to stand for another 15 minutes. pH meter electrode was inserted into the supernatant for pH reading.

3.3.2.6 Organic carbon determination

Organic carbon of the soil was determined by the volumetric method (Allison, 1965). Here, 1 gm of prepared soil sample was taken in a 500 ml conical flask. To it, 10 ml of 1N potassium dichromate ($K_2Cr_2O_7$) solution and 20 ml concentrated sulphuric acid (H_2SO_4) containing 0.125 g Ag_2SO_4 were added. These were mixed thoroughly and the reaction was allowed to complete for 30 min. The reaction mixture was diluted with 200 ml water and 10 ml H_3PO_4. To this, 2 ml of diphenyl-amine indicator was added. The solution was titrated with standard $FeSO_4$ solution to a brilliant green colour. A blank without soil was run simultaneously. Organic carbon in soil was determined by the following equations:

$$\textit{Percent Organic Carbon} = (10/S)(S-T) \times 0.003 \times 100 \qquad (3.2)$$

Where: S = ml $FeSO_4$ solution required for blank,

T = ml $FeSO_4$ solution required for the sample.

3.3.2.7 Total nitrogen determination

Total nitrogen was determined by Kjeldahl method (Bremner, 1996). Here, 10 g air-dry sample was transferred in a round bottom Pyrex Kjeldahl flask and added 30 ml concentrated sulphuric acid (H_2SO_4**)** followed by addition of 10 ml of salicylic acid and the reaction allowed to take place for half an hour with occasional stirring. After which 5 g of sodium thiosulphate and a mixture of 8 g of potassium sulphate and 0.2 g of selinium were poured to hasten the reaction under gentle heating in a fume chamber. Heating was continued until the content of the flask become colourless or pale straw. The flask was cooled and 150 ml water was added to prevent crystallisation of sulphate. After digestion, the digested material was transferred to 1000 ml Pyrex flask for distillation. 100 ml 10 N NaOH was poured to make the content alkaline. Distillation was done, receiving ammonia in a known volume of N/10 sulphuric acid (20ml). The excess of the acid was titrated with N/10 NaOH, using methyl red indicator. The blank was carried out in the same way without the sample. Percentage of nitrogen was calculated by the following formula (Piper, 1944):

$$\% N = (B-T) \times N \times 0.01 / A \quad (3.3)$$

Where: B = Blank titration reading,

T = Actual titration reading,

N = Normality of standard alkali.

A = soil sample weight (g)

3.3.2.8 Available phosphorous

Available phosphorus of the soil was estimated by Olsen's method (Olsen *et al.,* 1954). Here, 2.5 g of the prepared soil sample was taken into a 100 ml conical flask; 50 ml of the bicarbonate extractant and 1g of activated carbon was added to it. The suspension was shaken for 30 minutes on a mechanical shaker and filtered after which 5 ml of the extractant was taken in a 50 ml flask to which 5 ml molybdate reagent and 1 ml dilute $SnCl_2$ solution was added and stirred well. Then the volume was made up with adequate amount of distilled water. The blue colour was read after 10 min. on the photoelectric colorimeter, using red filter. Blank set was prepared in the same way without the soil. The amount of available phosphorus, parts per million (ppm) was calculated from the standard curve of known concentration. The standard curve was prepared in the same way with known amount of phosphate samples.

3.3.2.9 Potassium

Potassium (K_2O) was estimated by the flame photometer method (Toth and Prince, 1949). Here, 5 g of the prepared soil sample was taken into a 100 ml conical flask; 25 ml of amnonium acetate extractant was delivered into it with a multiple dispenser, stirred vigorously for 5 min. and filtered. Two drops of butyl alcohol were added to the filtrate and potash content was determined with flame photometer by comparing emissions with those of standard extractants containing 0–5 ppm potassium.

3.3.2.10 Calcium and magnesium

Calcium and magnesium were detamined by complexometric titration method (Tucker and Kurtz, 1961). The ammonium acetate (NH_4OAc) leachate was titrated with 0.01 M EDTA, a sequestening agent which forms unionized complexes with Ca and Mg ions. First the total concentration of Ca and Mg was obtained by titrating to eriochrome black T dye as indicator and a buffer to get a pH of 10.0. The NH_4Cl buffer was prepared by dissolving 7.0 g ammonium chloride in 57 ml concentrated ammonia after which it was diluted to 100 ml with distilled water to give pH of 10.0. In a separate aliquot, Calcium was determined with EDTA using murexide as an indicator after precipitating Mg as $Mg(OH)_2$ by adding 4 N NaOH solution to increase the pH to 12. The titration was performed immediately after alkali addition. Magnesium was calculated from the difference between the above two titrations.

3.3.3 Objective 3: Impacts of land use and land cover changes on vegetation composition and structure

3.3.3.1 Vegetation sampling and analysis

Random stratified design was used for vegetation survey with vegetation sampling method being quadrat method according to Mueller–Dombois and Ellenberg (1974). Ten transects (Figure 3.3 and Plate 3.3) which were 100 m long and 50 m apart were bisected parallel to the environmental gradient. In each transect, 3 x 3 m quadrats were placed at an interval of 10 m that gave rise to 10 quadrats per transect. The following vegetation attributes are monitored: vegetation cover, density and frequency.

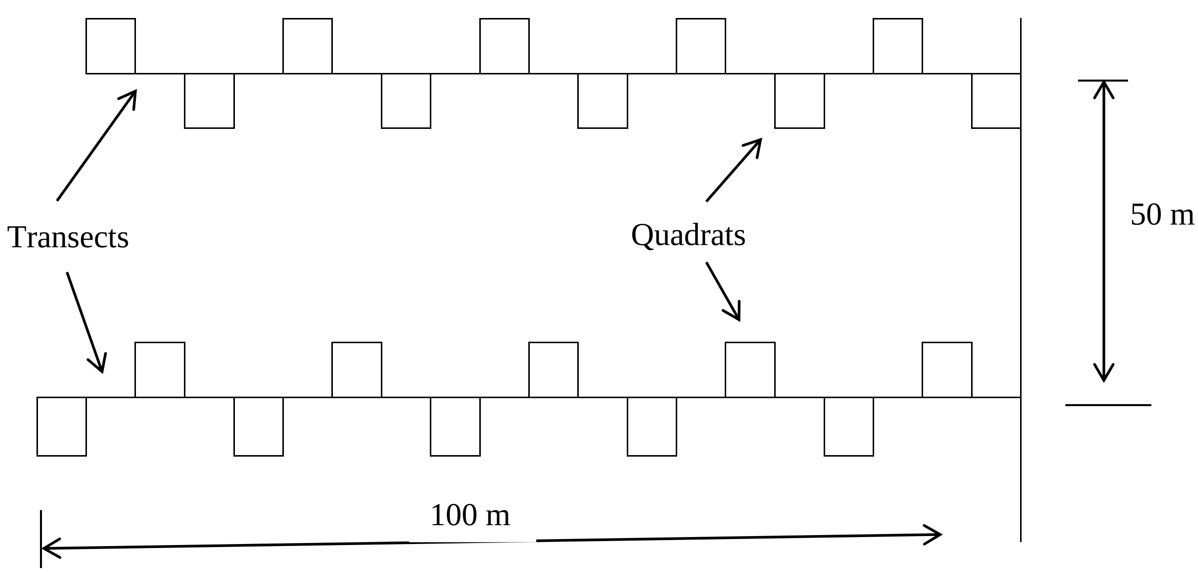

Figure 3.3: Transect study layout for the vegetation survey in this study.

Plate 3.3: Vegetation cover measurement along a transect within degraded study area.

3.3.3.2 Vegetation cover

Percent cover of a plant species was determined by measuring the distance covered by each of plant species along transect. Both coverage and relative cover were calculated as follows:

$$\% \ Cover = (total \ lengths \ for \ one \ species \ / \ length \ of \ transect) \times 100 \qquad (3.4)$$

Relative cover was calculated from the plant cover as:

$$Relative \ cover \ (RC_i) = (Cover \ of \ species \ i / \ Total \ plant \ cover) \times 100 \qquad (3.5)$$

3.3.3.3 Vegetation frequency

Vegetation frequency was estimated by the number of times a species occurs in a given number of repeatedly placed quadrats. In each placement, the species were recorded without regard to their quantity or number of individuals. Frequency was calculated using the following equation:

Frequency, f (%) = (No. of quadrats with presence of a species/Total no. of quadrats sampled) x 100 *(3.6)*

For comparison across communities, frequency for each species was expressed as a fraction of the total frequency and expressed as a percentage which is known as frequency percentage or frequency index. It was calculated as follows:

$$\text{Relative frequency } (RF_i) = (F_i \,/\, \text{Total frequency}) \times 100 \qquad (3.7)$$

3.3.3.4 Vegetation density

Density is the number of individuals per unit area. Every plant species in each quadrat was counted then divided by the total area as shown as:

$$\text{Density } (D_i) = \text{No. of individuals of species } i \,/\, \text{total area } (A) \qquad (3.8)$$

Relative density was calculated from the density as:

$$\text{Relative density } (RDi) = (Di \,/\, \text{Total plant density}) \times 100 \qquad (3.9)$$

3.3.3.5 Importance value of species

Importance value (IV) was used for the assessment of the distribution of species abundance and the overall plant species influence in this community. It was calculated by summing the relative cover, relative density and relative frequency of each species according to Curtis and McIntosh (1951) as:

$$IV = RC_i + RF_i + RDi \quad (3.10)$$

These values ranged from 0–300 since it combines relative cover, density and frequency. Dominant species considered as to be the species with highest importance value. Plant community was named based on dominant species.

3.3.3.6 Unidentified plant species

Plant specimens of species that were not possible to be identified in the field were collected and pressed in plant press according to Bridson and Forman (1998) as shown on Plate 3.4 for further study and confirmation of species names by the National Museums of Kenya.

Plate 3.4: Unidentified plant species collections in a plant press for further identification.

3.3.4 Objective 4: Impacts of land uses and land cover changes on river's water quality

3.3.4.1 Research design and site selection

Four water sampling stations (A, B, C and D) were selected along rivers Naisaia, Mai Mahiu and Ewaso that passed through different land-use practices (Figure 3.4). Rivers Naisaia and Mai Mahiu join together to form Ewaso River. Sampling stations A and B were up-stream of Naisaia and Mai Mahiu rivers, respectively within disturbed Kijabe and Kinale forests at an altitude of 2000 m above sea level. Sampling stations C and D were from Ewaso River at the down-stream at elevation of 1820 and 1809 above sea level, respectively. The dominant land-use activities practiced around sampling station C were agricultural activities mainly cultivation of maize and vegetables (onions, cabbage, kales, and chilli), over-grazed fields, lorry and container washing and a school (Ngeya primary school). Sampling station D geo-positioned at latitude -0.9792689, longitude 36.5785729 and altitude of 1816.5 m above sea level was dominantly surrounded by urban settlement of Mai Mahiu town, grazing and acted as watering point for livestock.

3.3.4.2 Water sampling

Systematic sampling method was used to collect water samples every month during wet and dry seasons from December 2016 to February 2018 and analyzed for physical and chemical characteristics according to APHA (2005). Sampling was done in the morning between 7 and 10 am to 20 cm depth by using a water scooper and transferred to 500 ml plastic bottles that had been cleaned with 10% nitric acid and rinsed with distilled water. They were then rinsed three times with the river waters at the time of sampling. Collected water samples were fixed using 0.2 M H_2SO_4, labelled and tightly closed before taken to

Kenyatta University laboratory for chemical analyses within 24 hours.

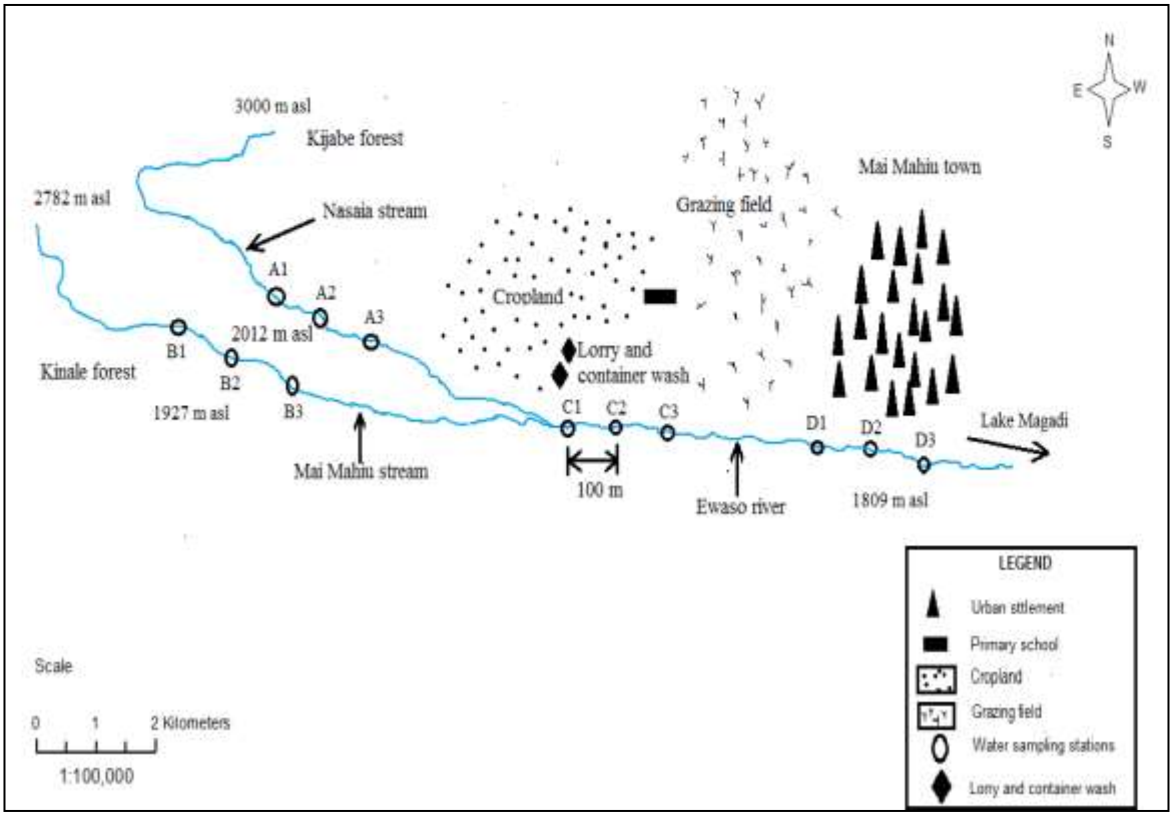

Figure 3.4: Water sampling stations within the study area (Mai Mahiu)

3.3.4.3 Physical parameters

Physical parameters analyzed were: pH, temperature, turbidity, electrical conductivity, dissolved oxygen and flow velocity were done in the field.

3.3.4.3.1 Water pH

Water pH was measured by use of a pH meter (Model: HI 8314 HANNA instruments, Romania). The pH probe was lowered to a depth of about 30 cm where it was allowed to stabilize before reading the value.

3.3.4.3.2 Water temperature

It was determined by using temperature sensor of a dissolved oxygen probe (Model: DO 5510M.R.C). At each sampling station, the probe was immersed in the river water to 30 cm depth and allowed to stabilize before readings were done in degrees Celsius (^{o}C).

3.3.4.3.3 Turbidity

The turbidity of water in all sampling stations was determined by use of a turbidity meter (Model: 2100P, Hach Company, USA). The measurements were read in Nephelometric Turbidity Units (NTU).

3.3.4.3.4 Electrical conductivity

A multi-range conductivity meter (Model: HI 9033 HANNA instruments, Romania) was used to measure electrical conductivity (EC) of surface water in all sampling sites. The meter was lowered into river water at various sampling stations to a depth of 30 cm. After stabilization, the conductivity readings were taken in μS/cm.

3.3.4.3.5 Dissolved oxygen

Dissolved oxygen was determined by using Oxygen meter (Model: DO-5510M.R.C) with automatic temperature compensation to 25 ^{o}C. Meter's probe was immersed into the river water to 30 cm depth and water was gently stirred with the probe to a point where readings got stabilized and taken in mg/L.

3.3.4.3.6 Water flow

River water flow was determined by float method (FAO, 1993). A wooden floater was placed on the water surface between a 40 m distance and measured the time taken for a floating disk to travel from one point to the other downstream. This was repeated four times with average time taken calculated. Velocity was calculated as distance over time.

3.3.4.4 Chemical parameters

Laboratory analyses are carried out in the laboratory for water chemical parameters characterization. These analyses were done according to APHA (2005).

3.3.4.4.1 Total nitrogen

Total nitrogen determination was by following sodium salicylate procedure (APHA, 2005). Samples were oxidized to PO_4-P by autoclaving the samples at 120 ^{o}C at 15 psi for 40 minutes with ammonium persulfate as an oxidizing agent. The nitrate nitrogen concentration of the oxidized sample was determined calorimetrically using UV/VIS spectroscopy machine T80+. Also, the standards of known NO_3-N concentration underwent same treatment as the samples and their readings used to calculate the total nitrogen concentration of water samples.

3.3.4.4.2 Total phosphorus

Total phosphorus determination was by following sodium salicylate procedure (APHA, 2005). Samples were oxidized to PO_4-P by autoclaving the samples at 120 ^{o}C at 15 psi for 40 minutes with an oxidizing agent being ammonium persulfate. Concentrations of the oxidized sample were determined calorimetrically using UV/VIS spectroscopy machine T80+. Standards of known PO_4-P phosphate concentration readings underwent same treatment as the samples and their readings used to calculate the total phosphorus concentration of water samples.

3.3.4.4.3 Chloride and carbonates

Carbonates and Chlorides were determined by titration method according to APHA (2005). Carbonates were determined using 0.02 N sulphuric acid and mixed bromocressol green indicator and calculated as mg/L $CaCO_3$.

3.3.4.4.4 Potassium, calcium and iron

Flame photometry was used for determination of potassium, calcium and iron irons as described by APHA (2005).

3.3.4.4.5 Total dissolved solids (TDS)

Total dissolved solids were measured by gravimetric method according to APHA (2005). Here, 10 g water was passed through a Whatman 934AH glass fibre filter, and then passed through vacuum filtration and dried at 105 °C, measured and expressed in g/l.

3.3.5 Objective 5: Meteorological data acquisition and analysis

3.3.5.1 Data acquisition

Long-term meteorological data from 1985 to 2014 (30 years) for temperature, precipitation and evaporation for Mai Mahiu area as sourced from Kenya Meteorological Services Department.

3.4 Statistical Analysis

Data from soil and water were analyzed in Genstat 14th Edition. Analysis of Variance (ANOVA) was used to detect whether there was statistical differences across sampled land-use practices/stations while Least significant difference (LSD) were used for mean separation at 0.05 significance level. Pearson linear correlation was used to establish relationships among soil variables and water parameters. Changes of soil and water attributes from the ecosystems due to land use change were evaluated and linked with changing vegetation, land degradation and water quality of natural rivers. Long-term climatic trend were expressed in ombrothermic diagrams. Long-term monthly average of precipitation and temperature interactions and water deficiency months were developed using Emberger *et al.,* (1963) technique. Mean monthly temperature (^{o}C) and monthly precipitation (mm) were plotted on the same axis, Y1-axis (primary) and Y2-axis (secondary) respectively with precipitation data scale at twice that of the temperature data. The temperature and precipitation data were plotted against an axis of time, X-axis. This resulted to climate diagram known as ombrothermic diagram or Walter Lieth diagram. The diagram establishes the relationship between temperature and precipitation and determines general monthly trends thereby identifying months with conditions (un)favorable for plant growth as dry, wet and extreme wet period. The interpretation of this diagram is that if the precipitation curve falls below the temperature curve that is a dry period, if the curve of precipitation runs above the curve of temperature that period is wet, and if the precipitation curve runs above 100mm that is an excess water period. Descriptive statistics was used to understand characteristics and variability of monthly, annual and seasonal rainfall and temperature. Computed statistics were the mean, range, standard deviation (SD), variance and coefficient of variation according to (Nyatuame *et al.,* 2014).

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CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the findings of land use and land cover changes during the period of 30 years from 1985 to 2015, soil properties, quantitative analysis of vegetation, physical parameters, physico-chemical properties of the river's water and long-term climatic variability.

4.2 Population growth dynamics in Mai Mahiu

Human demographic data spanning from 1969 to 2009 population census were collated from the Kenya National Bureau of Statistics (KNBS) of the Republic of Kenya. This was compared to the land use and land cover change data to establish if there was any relationship between land use change and human population trends. The study results strongly show that the population in this area has increased from 1969 to 2009 (Figure 4.1) with a drastic increase since 1990s. Population increased to 42000 persons with population density of 60 persons per square kilometer. The motivating factors of increase can be explained by the proximity of the area to major towns such as Nairobi, good road network, available natural resources and the social-political factors that forced people move from certain parts of the country to settle there. The study results strongly show that the rapid population increase is exerting pressure on available resources in the study area. The main causes of this can be explained by the parameters of population pressure such as population growth, land-hold and income contribution from various land-use practices. Increase in population growth and population density has caused unsustainable pressure on available land resources because this increase comes with the need for food and income for families leading to unsustainable use of forest resources and intense economic activities and settlement. Furthermore, the range of average agricultural land-hold was between 0.10 ha to 1.00 ha and it was not enough for farmers to fulfill the basic need of their family. Drigo (1999) notes that population growth and density are main factors that lead to clearing the forest area for agricultural activities in a region.

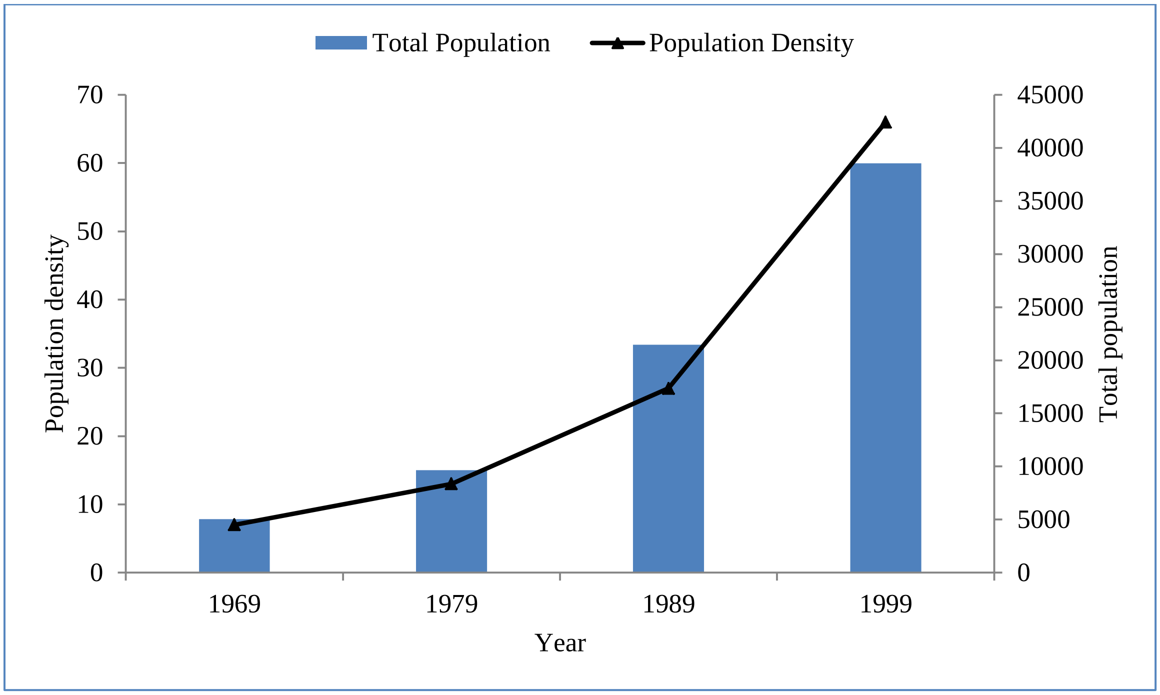

Figure 4.1: Human population growth dynamics in Mai Mahiu from 1969 to 2009. (Source: Kenya National Bureau of Statistics).

4.3 Objective 1: Land use and land cover changes in Mai Mahiu from year 1985 to 2015.

4.3.1 Land use and land cover changes in 1985

The land-use and land-cover clusters in 1985 showed thorny shrubs covering an area of 120.3 km^2 (34%) and heathland which covered an area of 68.2 km^2 (19%) while the evergreen trees occupied 35 km^2 (10%) of the study area. The least land coverage was observed on the cropland (8%), deciduous trees (4%) and the built-up area (3%). The results shown in Table 4.1 shows that the natural vegetation had not been cleared in 1985.

The human activities were minimal in the study area which most likely explains the reason why there is relatively minimal land coverage of built-up areas, disturbed soils, roads, croplands, and bare-land.

Table 4.1: Spatial distribution of land-use and land-cover changes in Mai Mahiu from 1985 to 2015.

Land-use/cover types	**1985**		**2000**		**2015**	
	Area (km^2)	**Area (%)**	**Area (km^2)**	**Area (%)**	**Area (km^2)**	**Area (%)**
Deciduous trees	15.7	4%	20.9	6%	25.3	7%
Grassland	49.6	14%	35.1	10%	30.9	9%
Bare land	29.0	8%	53.7	15%	34.1	10%
Roads/Built-up/soils	9.8	3%	19.9	6%	29.9	8%
Evergreen Trees	35.0	10%	28.2	8%	48.8	14%
Thorny Shrubs	120.3	34%	79.6	22%	67.0	19%
Heathland	68.2	19%	37.9	11%	54.8	15%
Cropland	27.3	8%	79.6	22%	64.2	18%
Total Area (km^2)	**354.9**	**100%**	**354.9**	**100%**	**354.9**	**100%**

The map shown below is an indication of the results shown in Table 4.1 which is summary of the land-use and land-cover distribution in Mai Mahiu in 1985. The major part is covered with thorny shrubs and heathland which stretch from Mt. Longonot in the north-western part to south respectively (Figure 4.2). Croplands and also the built-up areas are not pronounced.

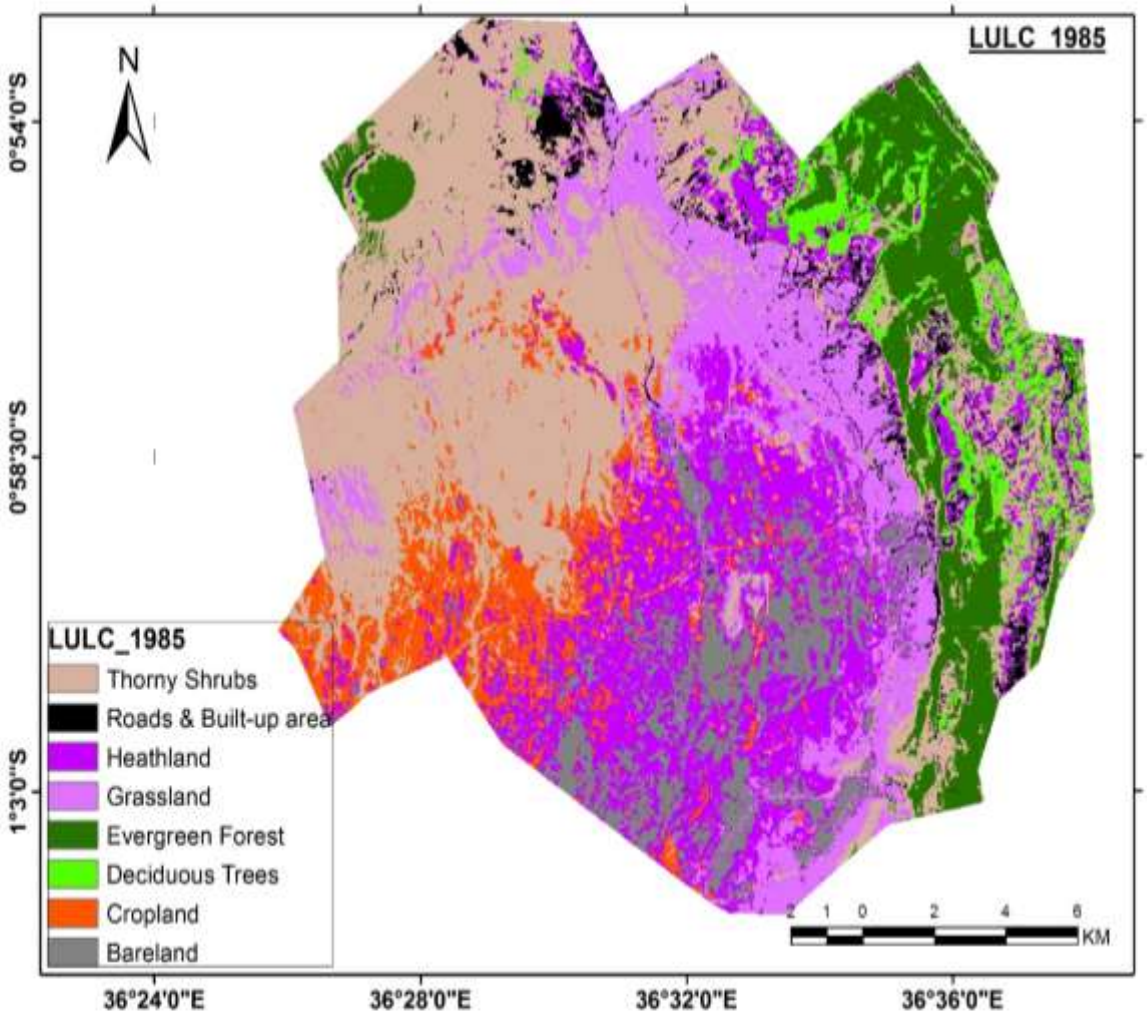

Figure 4.2: Satellite image of land-use and land-cover in Mai Mahiu are during the year 1985.

4.3.2 Land use and land cover changes in 2000

Year 2000, land-use and land-cover clusters are almost equally distributed (Figure 4.3). There was equal area coverage of cropland and thorny shrubs (22%) in the study area. The bare-land covered an area of 53.7 km^2 which is 15% while the grassland coverage was 35.1 km^2 (10%). The evergreen trees covered 28.2 km^2 (8%) while the roads and built-up area was 6% (19.9km^2). The land covered with grassland and heathlands are almost equal in size (10%) while the minimal land coverage is observed with built-up areas and deciduous trees. The cropland extends from north to south in widely distributed areas. During this year, the population in the study area was likely to have increased that is why more land is being used as cropland.

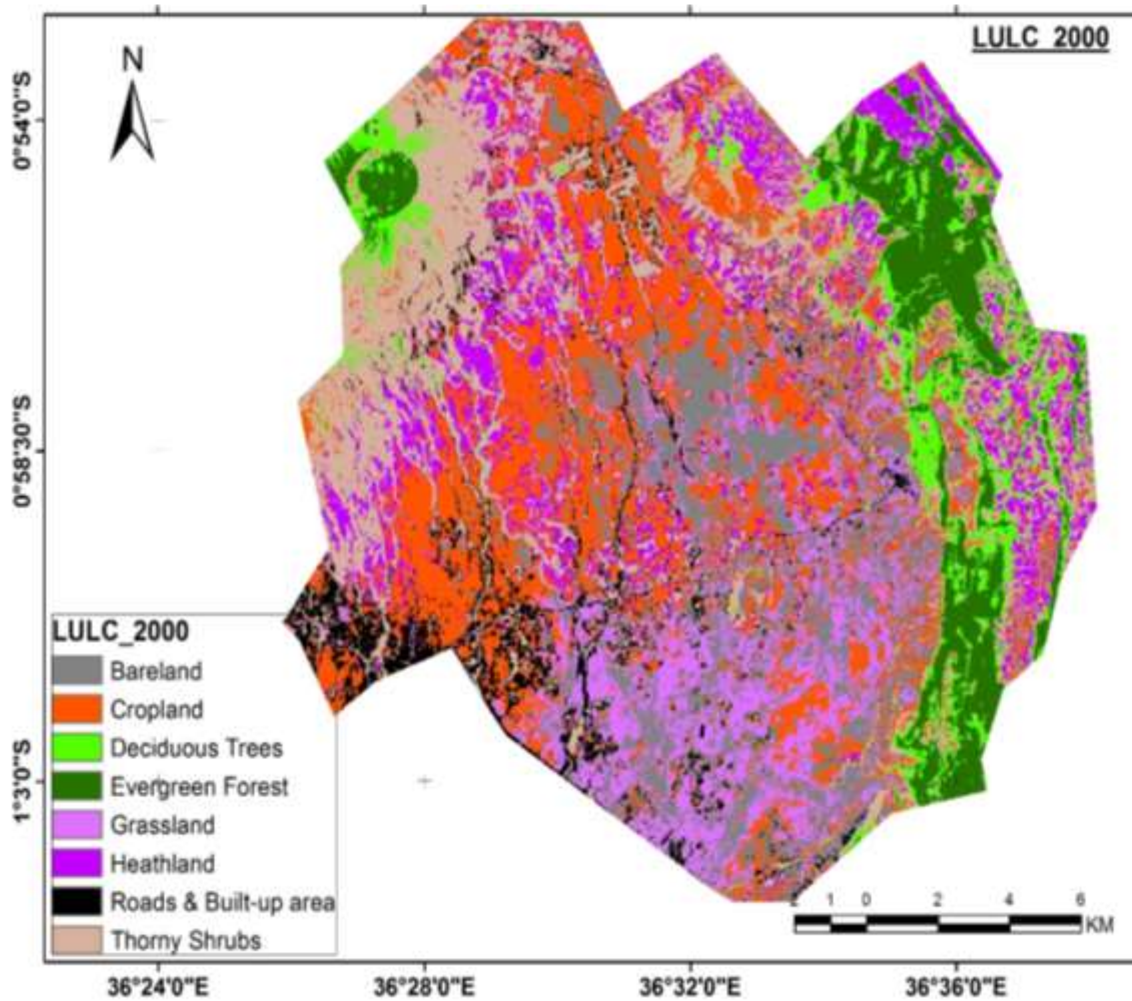

Figure 4.3: Satellite image of land-use and land-cover in Mai Mahiu are during the year 2000.

4.3.3 Land use and land cover changes in 2015

In year 2015 the land-use and land-cover map shows a decrease in the active cropland which covered 64.2 km^2 (18%) and an increase in the heathland covering 54.8 km^2 (15%). The built-up area and the bare-land covered an area of 29.9 km^2 and 34.1 km^2, respectively (Figure 4.4). The increase in the heathland is attributed to the decrease in the active cropland. The coverage of the shrubs and cropland was relatively equal while the minimal land coverage was observed on the areas with deciduous trees, grassland and built-up area. The evergreen trees and deciduous trees are well observed on the eastern margin of the area which is approximately 16% of land in the study area. The heathland and cropland are observed mainly within the central region of the study area. Mt. Longonot which lies at the north western part of the area is dominated by the evergreen trees especially at the crater area and thorny shrubs on the hillslopes. The built-up area and the exposed soils are observed in dark patches.

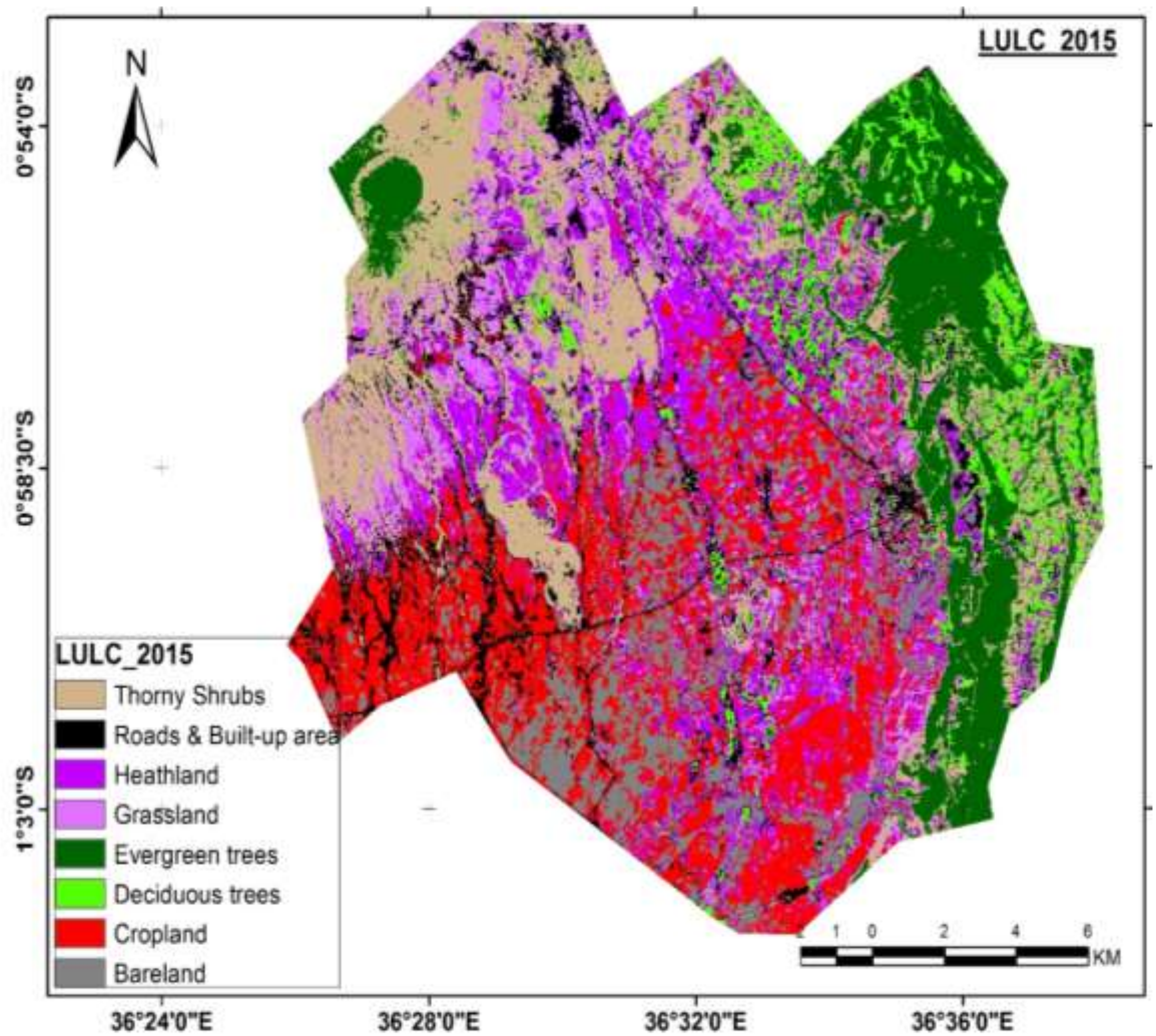

Figure 4.4: Satellite image of land-use and land-cover in Mai Mahiu are during the year 2015.

4.3.4 Land use and land cover changes detection for the period 1985 to 2015

Table 4.2 below shows the transitioning area coverage in square kilometers of the classified LULC categories from the year 1985 through to 2015. The land-cover and land-use clusters that showed significant changes are highlighted in the table whereby the decreased coverage is indicated with negative value while the increased coverage is indicated with a positive value. For example the cropland shows a significant increase from 27.3 km^2 to 79.6 km^2 between 1985 and 2000. In the same year the area used as built-up area and roads in 2000 was almost double the same type of LULC in 1985 with a 104% increase. The bare land increased by 85% between 1985 and 2000. In 2015, the evergreen trees showed a tremendous increase by 73% from 1985.

Table 4.2: Land-use and land-cover changes detection for the period 1985 – 2015

Land-use/cover type	**1985**	**2000**	**Change (km^2)**	**% change**	**2000**	**2015**	**Change (km^2)**	**% change**	**1985**	**2015**	**Change (km^2)**	**% change**
Deciduous trees	15.7	20.9	5.2	33%	20.9	25.3	4.4	21%	15.7	25.3	9.6	61%
Grassland	49.6	35.1	-14.4	-29%	35.1	30.9	-4.2	-12%	49.6	30.9	-18.6	-38%
Bare-land	29.0	53.7	24.7	85%	53.7	34.1	-19.7	-37%	29.0	34.1	5.0	17%
Roads/Built-up/soils	9.8	19.9	10.2	104%	19.9	29.9	10.0	50%	9.8	29.9	20.1	206%
Evergreen Trees	35.0	28.2	-6.8	-19%	28.2	48.8	20.6	73%	35.0	48.8	13.8	39%
Thorny Shrubs	120.3	79.6	-40.8	-34%	79.6	67.0	-12.6	-16%	120.3	67.0	-53.3	-44%
Heathland	68.2	37.9	-30.4	-45%	37.9	54.8	17.0	45%	68.2	54.8	-13.4	-20%
Cropland	27.3	79.6	52.3	192%	79.6	64.2	-15.4	-19%	27.3	64.2	36.9	135%
Grand Total	**354.9**	**354.9**	**0.0**	**0%**	**354.9**	**354.9**	**0.0**	**0%**	**354.9**	**354.9**	**0.0**	**0%**

The heathland increased by almost a half (45%) between 2000 and 2015. This observation was corresponding to the decrease of the bare-land by -19.7 km^2 (-37%) in the same period. In a period of 15 years the land used as built-up area and roads coverage had increased by almost three times from 9.8–29.9 km^2 between 1985 and 2015. The cropland significantly increased by 135% covering an area of 27.3–64.2 km^2 in 1985 and 2015, respectively.

Detailed analysis (Table 4.3, 4.4 and 4.5) show the detailed analysis on the specific conversions of the various land-use and land-cover clusters defined in Mai Mahiu. The changes are presented in terms of area coverage in square kilometers. Area which never changed during the specified period is shown in the highlighted values in the diagonals. For example, Table 4.3 shows the changes in the various land-use and land-cover categories whereby the land that was covered with deciduous tree in 1985 and remained the same in 2000 was 4.4 km^2 while 5.4 km^2 of land remained as grassland, 12.1 km^2 bare-land, 0.2 km^2 as built-up areas and roads, 23.5 km^2 as evergreen trees, 52.7 km^2 as thorny shrubs, 5.4 km^2 as heathland and 11.4 km^2 remained as cropland.

The other observed changes were on the land that was converted from grassland to other types of land-use and land-cover. The results show that 14.8 km^2 which was grassland in 1985 resulted to be bare-land in 2000. In the same period 13.7 km^2 of grassland was converted to be cropland in 2000. A significant area coverage that was bare-land in 1985 (10.9 km^2) was converted to grassland in 2000. Heathland was changed to grassland (15.6 km^2) and bare-land (17 km^2) and some areas were used as cropland (18.9 km^2) in 2000. Shrubs area covering 26.3 km^2 was cleared to be used as cropland in 2000.

Table 4.3: Land-use and land-cover changes between years 1985 and 2000 in Mai Mahiu.

Land use and land cover in 1985 (km^2)	Land use and land cover in 2000 (km^2)								
	Deciduous trees	Grass-land	Bare-land	Roads/ Built-up and soils	Evergreen trees	Thorny Shrubs	Heathland	Cropland	Grand Total
Deciduous trees	4.4	0.0	0.3	0.0	1.7	5.1	2.5	1.6	15.7
Grassland	0.1	5.4	14.8	2.5	0.0	8.0	5.2	13.7	49.6
Bare-land	0.0	10.9	12.1	1.4	0.0	0.7	0.4	3.6	29.0
Roads/Built-up/soils	0.2	0.4	2.0	0.2	0.1	1.9	1.1	3.9	9.8
Evergreen Trees	6.4	0.0	0.0		23.5	2.0	2.9	0.1	35.0
Thorny Shrubs	9.2	0.9	4.4	5.0	2.8	52.7	19.1	26.3	120.3
Heathland	0.7	15.6	17.0	3.6	0.2	6.9	5.4	18.9	68.2
Cropland	0.0	1.9	3.2	7.2	0.0	2.2	1.4	11.4	27.3
Grand Total	20.9	35.1	53.7	19.9	28.2	79.6	37.9	79.6	354.9

For the period between 2000 and 2015 large portion of the land remained as evergreen trees with an area coverage of 27 km^2, 39.3 km^2 remained as shrubs and 21.9 km^2 remained as cropland (Table 4.4). Within a period of 15 years, the amount of land that was converted from grassland to bare-land was 10.4 km^2 while 13.3 km^2 of land that was bare-land in 2000 was covered with heathland and 14.5 km^2 used as cropland in 2015. The total land size of land converted from cropland to built-up area during the period 2000 – 2015 was 6.5 km^2 while 0.7 km^2 was observed with evergreen trees.

Table 4.4: Land-use and land-cover changes between years 2000 and 2015 in Mai Mahiu.

		Land use and land cover in 2015 (km^2)								
		Deciduous trees	Grass-land	Bare-land	Roads/ Built-up and soils	Evergreen trees	Thorny Shrubs	Heathland	Cropland	Grand Total
Land use and land cover in 2000 (km^2)	Deciduous trees	2.5	0.1	0.0	0.1	12.9	5.1	0.2	0.0	20.9
	Grassland	0.7	1.6	10.4	2.4	0.0	0.3	7.2	12.7	35.1
	Bare land	2.4	4.1	13.0	4.8	0.2	1.6	13.3	14.5	53.8
	Roads/Built -up/soils	0.2	1.2	1.3	5.2	0.0	1.4	1.5	9.1	19.9
	Evergreen Trees	0.5	0.0		0.0	27.0	0.6	0.0		28.2
	Thorny Shrubs	8.6	8.5	0.4	8.4	4.9	39.3	6.5	2.9	79.6
	Heathland	5.5	6.4	0.9	2.5	3.0	8.4	8.0	3.2	37.9
	Cropland	4.8	9.1	8.1	6.5	0.7	10.3	18.1	21.9	79.6
	Grand Total	25.3	30.9	34.1	29.9	48.8	67.0	54.8	64.2	355.0

For a period of 30 years (1985–2015), significant land-use and land-cover changes were observed as highlighted in Table 4.5. During that period, 0.6 km^2 which was covered with deciduous trees in 1985 was used as built-up area by 2015. Other changes show that 5.1 km^2 of grassland, 2.2 km^2 of bare land, 0.1 km^2 of evergreen trees, 11.9 km^2 of shrubs and 4.1 km^2 of heathland were all converted to built-up areas by 2015. Shrubs land was cleared and resulted to 15.8 km^2 of grassland, 17.7 km^2 turned to be heathland and 7.8 km^2 used as cropland in 2015. The evergreen trees seems less disturbed but the shrub land was the most affected and cleared to pave way for settlements, cropland and other parts left as bare-land among other changes.

Table 4.5: Land-use and land-cover changes between years 1985 and 2015 in Mai Mahiu.

	Land use and land cover in 2015 (km^2)									
	Land-use and Land-cover type	Deciduous trees	Grass-land	Bare-land	Roads/ Built-up and soils	Evergreen trees	Thorny Shrubs	Heathland	Cropland	Grand Total
Land use and land cover in 1985	Deciduous trees	5.0	0.2	0.0	0.6	5.8	2.8	1.1	0.1	15.7
	Grassland	3.7	7.1	4.2	5.1	0.3	4.3	14.5	10.4	49.6
	Bare-land	0.9	1.6	10.3	2.2	0.0	0.3	6.3	7.3	29.0
	Roads/Built-up/soils	1.7	1.6	0.2	1.9	0.4	1.5	2.2	0.2	9.8
	Evergreen Trees	1.9	0.0	0.0	0.1	31.3	1.4	0.1	0.0	35.0
	Thorny Shrubs	6.0	15.8	1.0	11.9	9.4	50.9	17.7	7.8	120.3
	Heathland	5.7	3.8	15.0	4.1	1.6	4.6	10.7	22.8	68.2
	Cropland	0.3	0.8	3.3	3.9	0.0	1.2	2.2	15.5	27.3
	Grand Total	25.3	30.9	34.1	29.9	48.8	67.0	54.8	64.2	354.9

The observed changes in land uses can be associated with rapid population growth. The motivating factors of the increase in population can be explained by the proximity of the area to major towns such as Nairobi, good road network, available natural resources and the social-political factors that forced people to move from certain parts of the country to settle there. Increase in population growth has caused unsustainable pressure on available land resources because of the need for food, income and settlement for families (Plate 4.1). The discovery of natural resources especially building materials such as building stones and sand have led to the land use change because of higher economic returns. Improved road network and connectivity between the study area and major commercial towns such as Naivasha, Nairobi and Narok has increased urban formal and informal settlement in the area. With continued increase in population and income will lead to changes in resources consumption patterns leading to demand for food, feed, fibre and energy.

Plate 4.1: Various land-use practices in Mahi Mahiu: (a) open grassland in background with croton species, other indigenous trees were deforested for poles, wood and charcoal; (b) quarry to collect rocks/stone blocks for building and construction; (c) human settlement; (d) vegetable cultivation; (e) forage cultivation; and (f) severely grazed landscape

These changes will exert more pressure on land through changes in land practices that reduce vegetation cover and expansion of agriculture and other land use practices that lead to ecosystem degradation with implications on decrease in below- and above-ground biodiversity, food insecurity, water quality and scarcity, climatic variability and overall increase in poverty. This finding agrees with studies by Geist and Lambin (2002), Alejandro *et al.* (2007) and Kathumo (2011) who indicated that expansion of agriculture is the main cause of deforestation in the developing world especially Asia, Africa and Latin America. The findings confirm according to IPCC (2018) that expected increase in population will lead to land use changes that leads to ecosystem degradation that results in exposing populations to various risks associated with climate change including water stress, drought intensity particularly in semi-arid environments.

4.4 Objective 2: Impacts of land use and land cover changes on soil quality

4.4.1 Bulk density

There was significant difference ($p<0.001$) in the bulk density between undisturbed forest and disturbed forest, cropland and disturbed grassland. Lower bulk density values (0.93 g/cm^3) were recorded in undisturbed forest soil compared to intermediate values of 1.07 g/cm^3 in disturbed forest where croton *spp.* was the dominant, and 1.16 g/cm^3 where *Tarchonathus sp*. was the dominant vegetation. High bulk density values of 1.23 g/cm^3 and 1.27 g/cm^3 for cultivated and disturbed grassland fields, respectively were observed (Table 4.6). The increase in bulk density with land-use change ranged between 12 and 25%.

Table 4.6: Soil physical analysis under different land-use and land-cover types within Mai Mahiu area.

Soil property	Land-use and Land-cover type					
	Undisturbed forest	Disturbed forest (*Croton*-dominated)	Disturbed forest (*Tarchonanthus*-dominated)	Cropland	Disturbed grassland	p-value
Bulk density	0.93±0.02[a]	1.07±0.04[b]	1.16±0.01[bc]	1.23±0.03[c]	1.27±0.02[c]	<0.001
Clay (%)	19±0.58[a]	17.65±0.88[a]	31±0.58[b]	38.33±1.86[b]	30±4.16[b]	<0.001
Sand (%)	50.33±0.33[a]	47±0.58[a]	53±0.58[a]	43.67±4.33[a]	48.67±2.91[a]	0.142

Bulk density is one of the important soil physical indices used to know about the state and transport of matter such as water movement and storage, aeration and thermal conductivity in the soil system. This index is promoted by soil aggregation which is affected by a number of factors including soil organic matter and compaction. The increase of bulk density in disturbed forest, cropland and grassland as compared to undisturbed forest indicates deterioration of soil quality and natural habitat through compaction and loss of organic matter due to deforestation, forest disturbance, overgrazing (Plate 4.2) and poor cultivation practices. Soil compaction disrupts soil structure while organic matter enhances soil aggregation and the subsequent soil structure improvement. Improved soil structure influences important soil processes such as aggregate stability, aeration, water retention and movement. Poor soil structure promotes soil erosion during high precipitation events. Eroded sediments were deposited in the river valley with subsequent implication on water quality and poor water quality of Ewaso River. This finding agreed with that of Hajabbasi *et al.* (1997) which indicated that deforestation and poor tillage practices increased bulk density by 20% and a decrease in soil organic matter (SOM) by 50% for soils cultivated for more than 20 years in Zagrous Mountain in Iran. The study also concurs with that of Çelik (2005) who noted that the conversion of forest into cropland and other forms of land use deteriorates important soil physical attributes resulting in land degradation through soil erosion.

Plate 4.2: Large deforested hilly area in background and forefront under uncontrolled overgrazing practices by local residents of Mai Mahiu.

4.4.2 Sand and clay content

There was no significant difference in sand content across land-use practices ($p = 0.142$). Sand content were as follows: undisturbed forest soil was 50.33%, disturbed forest-*croton* dominated field 47%, *Tarchonathus*-dominated field (53%), cropland 43.67% and disturbed grassland 48.67%. Clay content increased with land-use conversion and modification ($p < 0.001$). It ranged between 28 and 30% in forest soils, between 16 and 19% in croton-dominated soils, between 30 and 32% in *Tarchonanthus*-dominated field, between 33 and 48% in cropland and between 24 and 38% in disturbed grassland land. Since sand content is affected by soil erosion, the content can be used as an indicator for evaluating soil degradation. Lack of statistical difference in sand content can be attributed to severely degradation from poor land-use practices without conservation practices (Plate 4.3). This had led to collapse of soil structure and selective removal of the loose clay particles by erosion and deposited at the foothills where crop growing is practiced thereby increasing clay content there. Since there is no much movement of soil particles in the foothill and being an area of deposition, there was no much sand loss there thus making sand content be at relatively equal proportion. Ayoubi *et al.* (2011) showed that sand content increase while soil organic matter decrease with conversion of forest land to cultivation.

Plate 4.3: Evidence of severe land degradation and soil erosion in Mai Mahiu landscape (study area).

4.4.3 Water holding capacity

Water holding capacity is significantly higher in undisturbed forest soils as compared to other land use changes and modifications. Mean values at field capacity (pF 2.3) are as: forest soil (26.57%), disturbed forest (22.99%), cultivated soils (22.94%) and disturbed grassland (20.95%). There is a negative correlation between water holding capacity and bulk density (R^2 = -0.789) and a positive one with soil organic carbon (R^2 = 0.824). Negative correlation can be attributed to disruption of soil structure with land use conversion from forest to other uses. The positive correlation is attributed to soil aggregation due to organic matter especially in the forest soils and the subsequent influence on bulk density and porosity. Soil organic carbon enhances soil aggregation that in turn favour pore space increment. Land degradation increases bulk densities subsequently lowering water holding capacity.

4.4.4 Soil temperature

Soil temperature at 20 cm depth is significantly higher (T = 4.53) than air temperature both in the morning and afternoon hours. Soil temperature range between 22 and 31 ^{o}C in the morning and 32 and 41 ^{o}C in the afternoon while air temperature is on average 16.2 ^{o}C in the morning and 22.4 ^{o}C in the afternoon. The observed temperature gradient between the soil and air temperatures indicates that there is loss of water from the soil system into the atmosphere through the process of evaporation. The water deficits in the soil system can worsen if there is no vegetation cover which is evident from land-use modifications and changes in objective number one of this study. As illustrated in Figure 4.5 on water budget, higher soil temperature coupled with high mean monthly evaporation than mean monthly rainfall has rendered the soil system in the study area to experience moisture deficits in the whole year except during long rain season (March–May) when the area experiences moisture surplus.

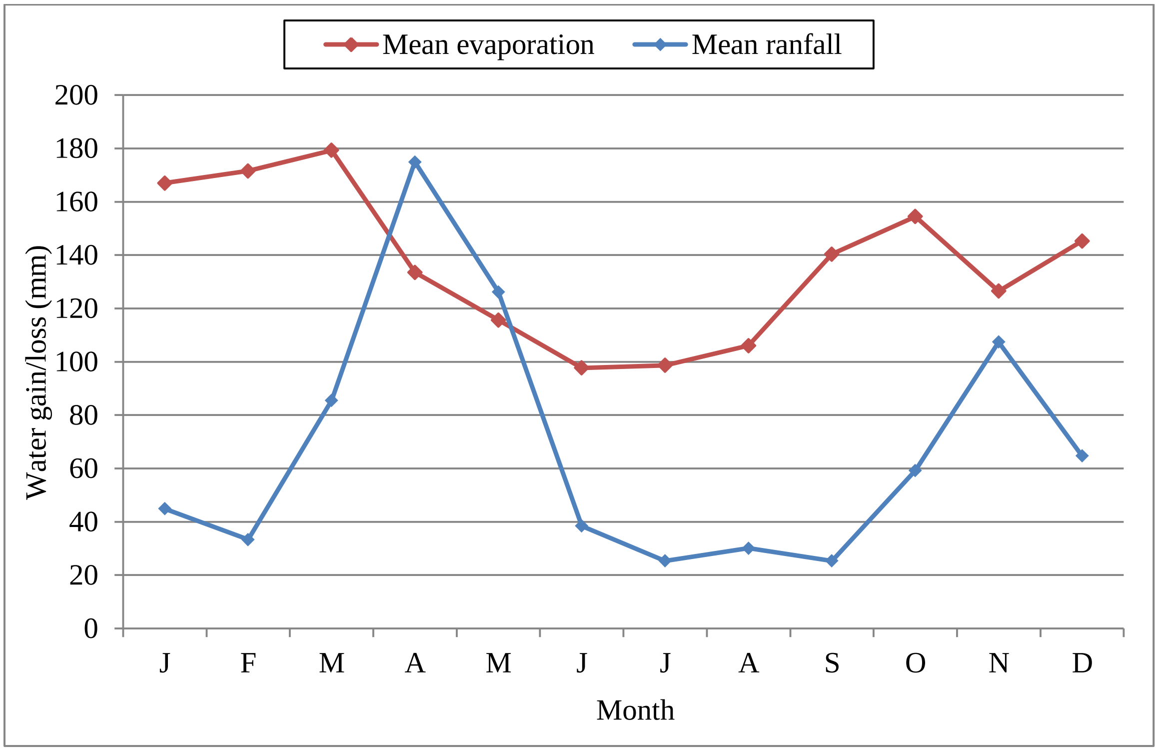

Figure 4.5: 30-year (1985–2014) water balance relationship between precipitation and potential evapotranspiration in Mai Mahiu.

High soil temperature can affect water storage and availability that can have detrimental effect on biota and ecosystem performance and productivity. It can also alter important soil processes such as oxidation or decomposition of soil organic matter and mineralization of various organic materials. Under unsustainable land-use change and practices, the products of decomposition and mineralization will get dissipated or lost through erosion. Increase in soil temperature in this area is associated with loss of vegetation cover due to deforestation, overgrazing and poor land cultivation that leaves the soil bare. Vegetation cover can insulate soil from excessive temperature and make soil microclimate favourable for biota and ecosystem productivity since soil will be neither too hot nor too cold in hot and cold seasons respectively. Soil thermal conductivity is one of the important physical properties that influence other important soil processes that promote vegetation growth (Onwuka and Mang, 2018). Enhanced temperatures affect important biological processes in the soil such as the rate of organic matter decomposition and the mineralization of different organic materials (Davidson and Janssens, 2006) and governs chemical and biological processes necessary for plant growth (Onwuka and Mang, 2018). Vegetation cover insulates land surface from excessive temperature (Nwankwo and Ogugurue, 2012; Jamenoz *et al.*, 2007).

4.4.5 Soil pH

Soil pH values decreased with land use conversions (Figure 4.5). The values range from 7.18 to 6.19 across land-use practices. Forest and croton-dominated soils recorded slightly alkaline conditions with mean pH values of 7.18 and 7.09, respectively compared to acidic characteristics recorded in soils collected from *Tarchonanthus*-dominated, cropland and disturbed grassland fields that show an average pH values of 6.82, 6.51 and 6.19, respectively. Analysis of variance showed significant difference ($p = 0.002$) in pH values across land-use practices.

Higher pH values in the forest soils can be attributed to high decomposition of organic materials with the release basic cations into soil. The acidic nature of soils dominated by *Tarchonanthus* vegetation can be attributed to acidic elements concentration in its floral parts. *Tarchonanthus comphratus* has high sulphur concentrations in the leaf tissues that decrease soil pH upon their decomposition. Low pH values in cropland and disturbed grassland can be attributed to loss of basic cations due to erosion and continuous crop harvesting without return of organic materials into the soil and the eventual build-up of acidic cations with degradation.

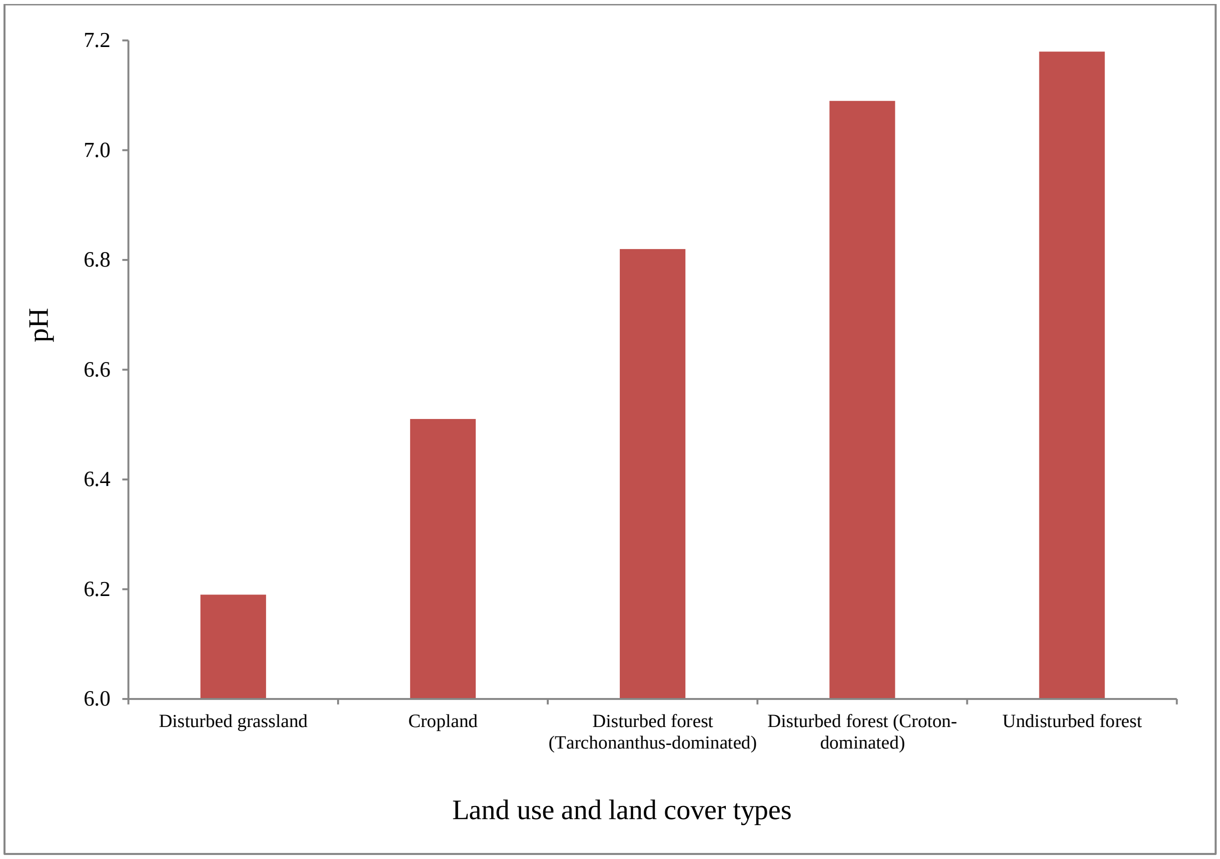

Figure 4.5: Soil pH distribution from soil samples collected from various land use and land cover types within Mai Mahiu, study area.

Another possible explanation could be the use of acidic fertilizers such as diammonium phosphate and calcium ammonium nitrate which have increased hydrogen ion concentration in the cropland. Soil pH is a general indicator and integrator of the nutrient release environment and soil contamination. These values are within the range of those reported by Solomon *et al.* (2007) for tropical soils that have undergone long term land use modifications.

4.4.6 Total carbon and nitrogen

Total carbon concentrations are high in undisturbed forest soil (3.55%) followed by disturbed forest–*croton* dominated (3.47%), disturbed forest–*Tarchonanthus* dominated

(2.65%), cropland (1.79%), and disturbed grassland (1.59) in forest soils and least of 1.5% in disturbed grassland soils. Conversion of the forest to cropland represented 63% soil organic carbon decrease in disturbed grassland lands, 57% in cultivated fields, 35% in *Tarchonanthus*-dominated and 17% in croton-dominated vegetation. Analysis of variance shows a significant difference in organic carbon concentrations (p = 0.001) between land-use practices (Table 4.7).

Table 4.7: Chemical analysis of soil samples collected from different land-use and land-cover types within Mai Mahiu area, Nakuru County, Kenya.

Soil chemical parameter	Land-use and Land-cover change types					
	Disturbed grassland	Cropland	Disturbed forest (*Tarchonanthus*-dominated)	Disturbed forest (*Croton*-dominated)	Undisturbed Forest	p value
pH	6.19 ± 0.14^{a}	6.51 ± 0.08^{ab}	6.82 ± 0.12^{bc}	7.09 ± 0.18^{bc}	7.18 ± 0.12^{c}	0.002
Total N (%)	0.15 ± 0.01^{a}	0.17 ± 0.01^{a}	0.27 ± 0.04^{ab}	0.33 ± 0.02^{b}	0.34 ± 0.06^{b}	0.005
Total SOC (%)	1.59 ± 0.12^{a}	1.79 ± 0.23^{a}	2.65 ± 0.37^{ab}	3.47 ± 0.32^{b}	3.55 ± 0.58^{b}	0.008
C/N ratio	10.61 ± 0.08	10.44 ± 0.79	10.05 ± 0.31	10.37 ± 0.45	10.33 ± 0.01	0.919
Phosphorus (ppm)	5.00 ± 0.00^{a}	5.00 ± 0.00^{a}	21.67 ± 8.33^{a}	9.67 ± 7.67^{a}	5.67 ± 0.33^{a}	0.174
Potassium (me%)	1.76 ± 0.36^{a}	1.79 ± 0.25^{a}	1.72 ± 0.42^{a}	2.33 ± 0.27^{a}	2.87 ± 0.08^{a}	0.082
Calcium (me%)	7.53 ± 1.73^{a}	9.27 ± 1.35^{a}	13.67 ± 2.33^{a}	12.33 ± 2.13^{a}	11.7 ± 0.6^{a}	0.17
Magnesium (me%)	1.16 ± 0.16^{a}	1.25 ± 0.09^{a}	3.32 ± 0.96^{a}	2.41 ± 0.62^{a}	1.40 ± 0.01^{a}	0.059
Manganese (me%)	0.52 ± 0.08^{a}	0.65 ± 0.07^{a}	0.78 ± 0.09^{ab}	0.72 ± 0.08^{ab}	1.06 ± 0.03^{b}	0.005
Sodium (me%)	0.81 ± 0.21^{a}	1.04 ± 0.21^{a}	0.81 ± 0.01^{a}	1.08 ± 0.06^{a}	1.19 ± 0.10^{a}	0.285
Copper (ppm)	1.34 ± 0.03^{a}	1.38 ± 0.33^{a}	1.19 ± 0.14^{a}	1.02 ± 0.02^{a}	1.55 ± 0.01^{a}	0.17
Iron (ppm)	153 ± 4.67^{a}	119.3 ± 0.33^{a}	100.9 ± 20.57^{a}	91.7 ± 13.33^{a}	123 ± 3.00^{a}	0.241
Zinc (ppm)	1.53 ± 0.32^{a}	7.05 ± 0.90^{a}	19.75 ± 7.15^{a}	12.13 ± 3.53^{a}	13.33 ± 0.97^{a}	0.118

* small alphabets a, b, c,… indicate significant differences at p< 0.05)

Total nitrogen concentrations vary widely across land-use practices. There is a significant difference (p = 0.005) in nitrogen concentration across land-use practices with forest soils recording higher mean value of 0.34% followed by croton-dominated and

Tarchonanthus-dominated soils with 0.33 and 0.27%, respectively. Lower values of 0.17 and 0.15% are recorded in cropland and disturbed grassland soils, respectively. Nitrogen losses observed in disturbed grassland and cultivated soils fields represented 55.9 and 50.0% of the original stock respectively.

Depletion of organic carbon and nitrogen may be associated with soil disturbances that enhanced oxidation/decomposition and biological mineralization by microorganisms as a result of improved soil aeration from tillage practices, reduction in input of organic materials or residues into the soil by farmers and increased erosion and leaching in cultivated soils and disturbed grassland.

The notable decrease in carbon and nitrogen with land-use changes in Mai Mahiu is a manifestation of a degraded ecosystem (Plate 4.4) can be attributed to growing population with increasing demand for secure livelihoods and income source. Over-cultivation and poor soil conservation measures have led to observed decline in soil fertility with subsequent abandonment. Income and wealth associated with large herds has also contributed to the pressure on the land leading to soil erosion problem.

Plate 4.4: Disturbed hill slope, evidence showing land degradation due to unsustainable land-use practices in the Mai Mahiu region

Carbon and nitrogen contents obtained in soils from the study site are in agreement with those reported by Solomon *et al*. (2007) and Basweti (2009) for tropical soils that are derived from forest from Kenya. Solomon *et al*. (2007) observes that land-use change may lead to losses of up to 58% of the initial organic carbon pools especially in the tropical soils where 32% of global soil carbon stocks are stored. Soil organic carbon is vital for enhancing and promoting of soil fertility for agricultural production that is sustainable and carbon storage and climate change resilience (Luo *et al*., 2019). Poor land use practice leads to land degradation affecting the status of soil health through depletion of soil organic matter, nutrients, erosion (Six *et al.*, 1999; Lal, 2003; Solomon *et al*., 2007) and physical habitat. Montanarella (2015) notes growing population with increasing dietary preferences towards livestock products is leading to overstocking and putting pressure on fertile soils and enhancing soil erosion problem.

Carbon:nitrogen (C:N) ratio was found not to have been significantly influenced by land-use practices. The ratios lacked a consistent trend and mean values ranged between 10.05 and 10.61 with no significant difference ($p = 0.919$). Lack of statistical significance could be attributed to a similar organic carbon and nitrogen loss kinetics that lead to a positive correlation ($r = 0.978$) between the losses of organic carbon and nitrogen with time. C/N ratios were similar to average values reported for agricultural soils (Solomon *et al*., 2007).

4.4.7 Exchangeable cations

There were no significant differences in calcium (Ca), potassium (K), sodium (Na) and magnesium (Mg) in soils from land uses under study. There were no significant difference ($P>0.05$) on concentrations of micro-nutrients– iron, copper and zinc across sites.

4.5 Objective 3: Impacts of land-use and land-cover changes on vegetation composition and structure

4.5.1 Species composition and growth forms

There are 22 families and 33 genera identified in the area. As shown in Table 4.8 below, vegetation is stratified into three strata or layers as follows: the upper stratum or tree layer; middle stratum or shrub layer and the lower stratum, herb layer. The vegetation is dominantly comprised of the shrub layer (63.64%) while remaining proportion was shared equally between tree and herb layers.

Table 4.8: Floristic structure of plant species within the study area.

Family	**Generic name**	**Growth-forms**
1. Acanthaceae	i. *Justicia gendarussa* (Burm .f)	S
2. Amaranthaceae	i. *Achyranthus aspera* (L.)	S
3. Asteraceae	i. *Aspelia Africana* (Pers.) C. D. Adams	S
	ii. *Tarchonanthus camphorantus* (L.)	S
4. Asparagaceae	i. *Dracaena aletriformis* (Haw.)	S
5. Cactaceae	i. *Opuntia ficus-indica*	S
6. Celastraceae	i. *Gymnosporia heterophylla* (Eckl. & Zeyh.) Loes.	S
7. Combretaceae	i. *Combretum molle* (R. Br. Ex G. Don)	T
8. Compositae	i. *Vernonia amygdalina* (Del)	S
9. Dracaenaceae	i. *Sansevieria ehrenbergii* (Chweinf. Ex Baker)	H
10. Euphorbiaceae	i. *Croton matourensis* (Aubl.)	S
	ii. *Croton bathianus* (Leandri)	S
	iii. *Euphorbia candelebrum* (Kotschy)	T
11. Fabaceae	i. *Tephrosia candida* (DC.)	S
	ii. *Tipunea tipa*	S
12. Flacourtiaceae	i. *Dovyalis caffra* (Hook.f. & Harv.) Hook.f.	S
13. Labiateae	i. *Oscimum gratissimum* (L.)	S
	ii. *Fuerstia Africana* (T.C.E.Fr.)	S
14. Lythraceae	i. *Lawsonia inermis* (L.)	H
15. Malvaceae	i. *Sida cordata* (Burm. f.)	S
	ii. *Hibiscus acicularis* (Standl.)	S
	iii. *Thespesia garckeana* (F.Hoffm.)	S
16. Mimosaceae	i. *Acacia xanthophloea* (Benth.)	T
	ii. *Acacia mearnsii* (D. Wild)	T
17. Moraceae	i. *Ficus sycomorus* (L.)	T
18. Poaceae	i. *Hyperrhenia filipendula* (Hochst.) Stapf	H
	ii. *Themeda triandra* (Forssk.)	H
	iii. *Panicum repens* (L.)	H
	iv. *Cynodon dactylon* (L.) Pers.	H
19. Rubiaceae	i. *Vangueria infausta* (Burch.)	T
20. Sapindaceae	i. *Dodonea angustifolia* (L.f.)	S
21. Solanaceae	i. *Solanum incunum*	S
22. Tiliaceae	i. *Grewia villosa* (Willd.)	S

Key: T = Tree; **S** = Shrub; **H** = Herb

Tree layer if severely cut down for the provision of firewood, charcoal, constructions poles among other uses. Some of the trees are characterized by stumps with small sized trees indicate the stage of secondary regeneration (Plate 4.5). The herb layer and undergrowth species is mainly *Themeda triandra, Hyperhenia filipendula, Panicum repens* and *Cynodon dactylon.* The families with highest number of species are *Poaceae* (4) followed by *Malvaceae (3), Euphorbiaceae* (3), *Asteraceae* (2), *Fabaceae* (2), *Labiateae* (2), *Lamiaceae* (2) and *Mimosaceae* (2). In most of the area, the canopy is open due to the history of human and animal's disturbance.

Plate 4.5: Severely cut trees undergoing secondary regeneration in Mai Mahiu.

4.5.2 Vegetation cover, density and frequency

The Mai Mahiu landscape is dominantly covered by C*roton bathianus* with a relative cover of 16.36% (Table 4.9) followed by *Justicia gendarussa* (15.10%), *Oscimum gratissimum* (12.27%), *Aspilia africana* (7.85%), *Croton natoulensis (4.51%) and Tarchonanthus camphoratus (4.03%)*. In regards to stem count, species *Justicia gendarussa* has highest stem count representing 18.47% of the total density followed by *Croton natoulensis* (17.63%), *Hyperhenia filipendula* (12.97%), Themeda *triandra* (10.10%) and *Panicum repens* (9.33%). Plant species in the families of *Cactaceae* and *Mimosaceae* have the lowest density of less than one percent. Abundant species are *Croton matourensis* with frequency of 78%, *Justicia gendarussa* (Frequency of 66%), *Croton bathianus* (52%) and *Hyperhenia filipendula* (36%). Les abundant species which are species with frequency of less than 10% include: *Ficus sycomorus*, *Gymnosporia heterophylla*, *Euphobia canderubrum*, *Tipunea tipa*, *Tephrosia candida* and *Thespesia garckeana.*

4.5.3 Importance value index

Quantitative analysis (Table 4.9) shows five dominant species are *Justicia gendarussa* with IV index of 44.78, *Croton matourensis* (35.38), *Croton bathianus* (29.93), *Hyperhenia filipendula* (19.53) and *Oscimum gratissimum* (15.79). Rare species included *Tipunea tipa*, *Euphobia canderubrum, Hibiscus acicularis, Vernonia amygdalina* and *Acacia mearnsii* with IV index of 0.46, 0.61, 0.93, 1.04 and 1.39, respectively.

Table 4.9: Quantitative analysis of plant species studied within study area.

Generic name	Cover	Density (plants/ha)	Frequency	Relative cover (RC)	Relative density (RD)	Relative frequency (RF)	Importance value (IV)
Acacia mearnsii	0.33	51.93	5	0.83	0.04	0.85	1.72
Acacia xanthophloea	0.57	66.77	6	1.44	0.06	1.02	2.52
Achyranthus aspera	0.29	6528.19	25	0.73	5.48	4.24	10.45
Aspilia africana	3.12	890.21	24	7.85	0.75	4.07	12.67
Combretum molle	0.12	356.08	24	0.3	0.3	4.07	4.67
Croton bathianus	6.5	5652.82	52	16.36	4.74	8.83	29.93
Croton matourensis	1.79	21023.74	78	4.51	17.63	13.24	35.38
Cynodon dactylon	0.33	10445.1	19	0.83	8.76	3.23	12.82
Dodonea angustifolia	0.1	370.92	10	0.25	0.31	1.70	2.26
Dovyalis caffra	1.33	37.09	2	3.35	0.03	0.34	3.72
Dracaena aletriformis	1.46	74.18	10	3.68	0.06	1.70	5.44
Euphobia candelabrum	0.23	14.84	2	0.58	0.01	0.34	0.93
Ficus sycomorus	1.53	14.84	1	3.85	0.01	0.17	4.03
Fuerstia africana	1.1	764.09	12	2.77	0.64	2.04	5.45
Grewia villosa	1.23	1112.76	32	3.09	0.93	5.43	9.45
Gymnosporia heterophylla	1.22	22.26	2	3.08	0.02	0.34	3.44
Hibiscus acicularis	0.18	96.44	3	0.45	0.08	0.51	1.04
Hyperhenia filipendula	0.18	15467.36	36	0.45	12.97	6.11	19.53
Justicia gendarussa	6	22017.8	66	15.1	18.47	11.21	44.78
Lawsonia inermis	0.68	4525.22	34	1.72	3.8	5.77	11.29
Opuntia ficus-indica	0.14	148.37	10	0.35	0.12	1.70	2.17
Oscimum gratissimum	4.87	1557.86	13	12.27	1.31	2.21	15.79
Panicum repens	0.24	11120.18	19	0.61	9.33	3.23	13.17
Sansevieria ehrenbergii	0.41	979.23	12	1.03	0.82	2.04	3.89
Sida cordata	0.73	74.18	10	1.84	0.06	1.70	3.60
Solanum incunum	1.48	1632.05	20	3.74	1.37	3.40	8.51
Tarchonanthus camphoratus	1.6	252.23	22	4.03	0.21	3.74	7.98
Tephrosia candida	0.38	1557.86	10	0.96	1.31	1.70	3.97
Themeda triandra	0.52	12040.06	16	1.31	10.1	2.72	14.13
Thespesia garckeana	0.1	133.53	2	0.01	0.11	0.34	0.46
Tipunea tipa	0.1	22.26	2	0.25	0.02	0.34	0.61
Vangueria infausta	0.68	170.62	6	1.72	0.14	1.02	2.88
Vernonia amygdalina	0.26	66.77	4	0.65	0.06	0.68	1.39
TOTAL	39.7	119288	589	100	100	100	300

As observed from Landsat imagery and soil tests from different land-use practices, the main anthropogenic factors which influenced the Mai Mahiu vegetation and habitat were improper land-use practices that were in the form of deforestation, poor cultivation practices and overgrazing. The cropland significantly increased by 135% from 1985 to 2015 covering an area of 27.3 and 64.2 km^2 respectively. This and other land-use changes have compromised natural processes between edaphic, climatic and topographic factors leading to interference with species composition and vegetation pattern. These alterations make plant community to undergo changes as a result of their own interactions that might result in micro-gradients shift (Hanson and Churchill, 1965). An example is *Tarchonanthus camphorantus* which was found to be mostly thriving in acidic soils due to degradation.

The vegetation attributes are used to inform about the distribution of species in a plant community and changes in vegetation composition over time as a result of disturbance. Uncontrolled grazing, over-grazing and over-browsing of livestock mainly goats, sheep, cows and donkeys (Plate 4.6) were found to have brought ecological problems in the study area. They have inhibited the development and growth of woody vegetation, modified original vegetation and changed community composition in this ecosystem. Overgrazing had also enhanced soil erosion due to compaction and loss of soil structure as evidenced in higher soil bulk densities in overgrazed fields as reported in objective two of this study. Seligman and Perevolotsky (1994) reported that grazing stress can reverse the course of vegetation succession in such disturbed ecosystems. Other studies have indicated that grazing may determine the dynamic relationships between herbaceous and woody vegetation (Sher *et al*., 2010) such as opening niches for woody seedling establishment because it reduce competition from herbaceous vegetation (Mitchell and Kibry, 1990). Grazing can determine the community composition (Rajwanshi *et al.*, 1985) or modify the original vegetation pattern. Soil erosion is a side effect of the ill managed grazing (Hussain *et al.*, 1997). These findings were in agreement with Kapur and Sarin (1985), Hussain and Ilahi, (1991) and Hruska (1991) who note that anthropogenic interference upsets the natural interaction between climatic, edaphic and topographic factors that influence growth and occurrence of plant species leading to unpredictable vegetation distribution pattern.

Plate 4.6: Overgrazing and cleared vegetation cover inhibiting the growth and development and of herbaceous and woody plant species in the study area of Mai Mahiu.

Another important factor that has affected vegetation in Mai Mahiu is deforestation. Deforestation has led to degradation of Kijabe forest through changes in cover, density and structure of the trees, plants biomass, among others. Vegetation cover is very sensitive to biotic and edaphic forces thus making it an important vegetation and hydrologic characteristic that shows the contribution of each species to a plant community after disturbance and/or land-use change. The main reasons for deforestation in this area were mainly extraction of firewood and poles, charcoal burning, land for settlement and cultivation to satisfy socio-economic needs of its population. Some of the affected vegetation included *Wambugia ugadensis, Juniperus procera, Ficus thonningii, Olea europaea, Rhus vulgaris, Combretum molle* and *Vangueria madagascariensis.* As population grows, more land is required for intense agricultural use, which results in necessity for new areas to be deforested for agriculture and urbanization with negative impacts on tree diversity (Sala *et al.,* 2000) including increased species endangerment and extinctions (Czech and Krausman, 1997; Wilcove *et al*., 1998). Daubenmire (1959) notes that continuous cultivation makes land become susceptible to water and wind erosion that reduces the fertility and vegetation cover of given area.

In an ecosystem, some plant species act as indicator species that show the state and function of that ecosystem upon disturbance. In this study, *Ficus sycomorus* and *Dracaena aletriformis* (Plate 4.7) are clear indicators of an ecosystem that had undergone disturbance whose impacts were negative. The presence of *Dracaena aletriformis,* as one of the remaining alpine species in the area indicated that in the past decades, the Mahi Mahiu region was experiencing high amount of rainfall. With human disturbance and associated increase in climatic variability, this species was disappearing at alarming rate as evidenced by old stumps and poor secondary vegetation or regrowths. *Ficus sycomorus* was distinctively standing along river valleys indicating presence of underground water flow along the river valley. Seasonality and underground water flow may be associated with disturbance especially deforestation that led to opening up of the canopy, increased river valley erosion, siltation and lowering of water table.

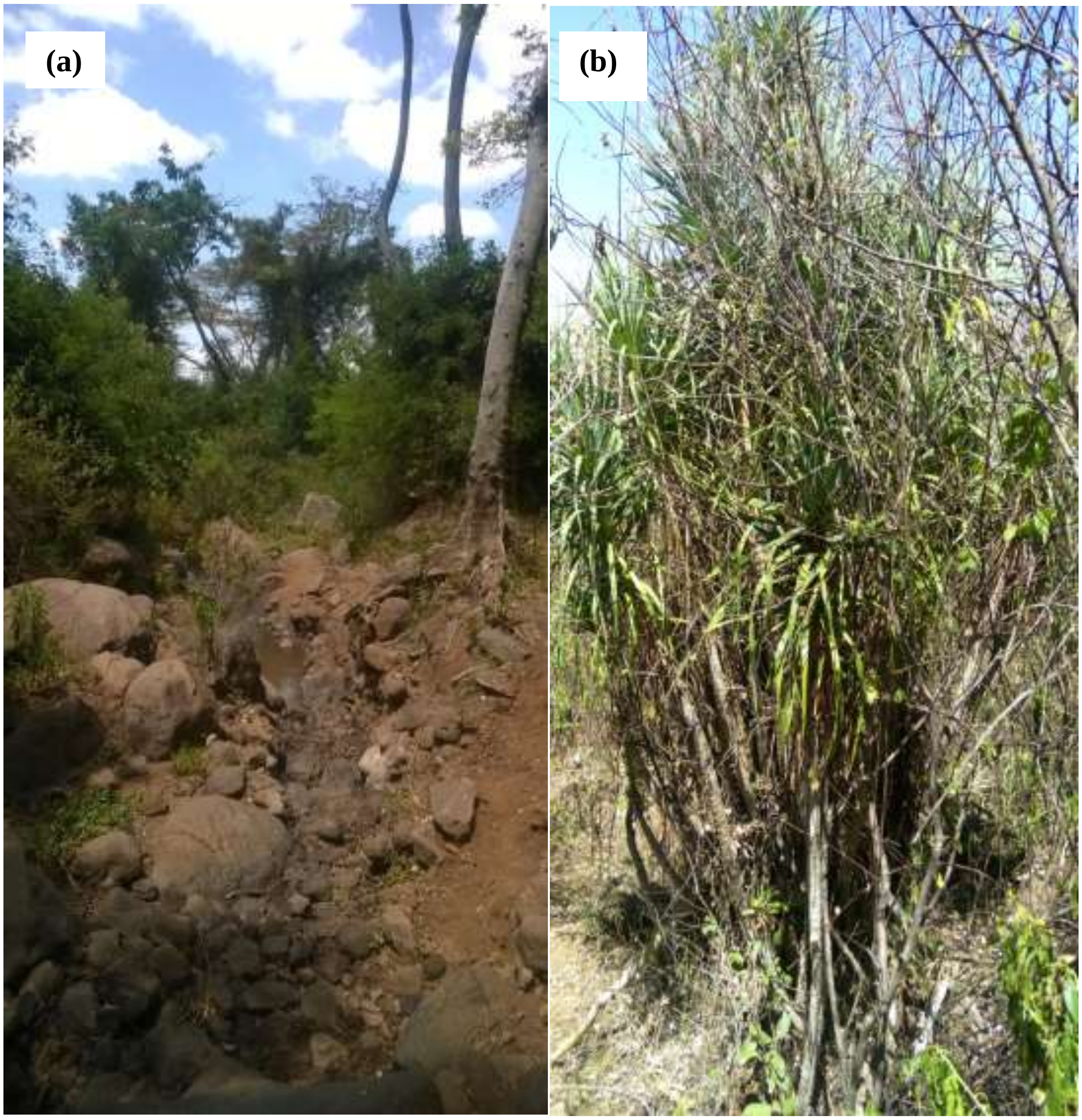

Plate 4.7: Plant species as an indicator of disturbed environment: *Ficus sycomorus* (a) and *Dracaena aletriformis* (b) in Mai Mahiu study area.

Vegetation is one of the factors that influence soil erosion. It plays an important role in reducing the energy of eroding agent and on the other hand enhances infiltration and recharge of the catchment. Cutting down of vegetation in the area increased overland flow whose high energy had scoured stream banks leaving behind exposed roots and rocks. Lowering of water table and drying of streams was attributed to variable climate and increased evaporation. Climate analysis showed a highly variable rainfall and increased evaporation.

The occurrence of a species in an area indicates the availability of optimal balance of conditions for its survival. The plant community distribution and abundance therefore, indicates the gradient of vital growth factors that are physical, chemical, edaphic and interaction with other species found in the locality (Spellerberg, 1992). Spatial distribution of species will follow optimal abundance of resources which include food, shelter and minimal competition of resources. It is also determined by innate capacity of each species to access resources and to tolerate gradients of deficiency or excesses of the environmental stress which is termed as its adaptation. With growth in population and urbanization, vital growth factors and abundance of resources are at the imbalanced state through habitat fragmentation, destruction and degradation. This has put biodiversity under multiple pressures from land degradation and water pollution.

4.5.4 Vegetation community

Each community was derived from species with highest index of importance value in each vegetation layer. Based on vegetation cover, two broad plant associations were identified:

4.5.4.1 Justicia-Oscimum-Aspilia association

Occupying the disturbed (Kijabe) forest belts across the upper parts of Mai Mahiu, this formation is predominantly visible on an ill grazed ecosystem. Some of the species found here include *Justicia*, *Occimum* and *Aspilia* constituting dominant tree species. They are more tolerant to human stress and drier conditions. Main grass species are *Cynodon dactylon* and *Panicum repens.*

4.5.4.2 Croton-Tarchonanthus-Themeda triandra association

This formation is restricted to a narrow belt along Kijabe hills to the upper part of the study area and *Achyranthes aspera* constitute the undergrowth. Lying at approximately 1900 m above sea level, the soils of this belt show higher proportions of sands. Because of overgrazing and fuel-wood cutting by local residents, this woodland has been converted into a shrubland dominated by *Croton bathianus* and *Tarchonanthus camphoratus*.

4.6 Objective 4: Impacts of land use and cover changes on rivers water quality

4.6.1 Physico-chemical parameters during dry season

4.6.1.1 Water pH

The pH values show a wide variation that range from 7.17 to 9.98 along all sampling stations (Tables 4.10, 4.11 and 4.12). At sampling station (A), pH values range from 7.17 to 7.82 with a mean of 7.51±0.19, station (B) between 7.31 and 7.92 and mean of 7.61±0.18, station (C) values range between 8.34 and 8.96 with a mean of 8.67±0.18 while sampling station (D) range from 8.85 to 9.98 with a mean of 9.23±0.39. There is a significant difference ($p<0.001$) on mean values between sampling sites (Table 4.12). High pH values recorded at sampling station (C) and (D) is due to erosion of soil materials accumulated with salts especially carbonates and sulphates from surrounding degraded agricultural land and detergents from washing activities that go on at this point (Plate 4.8).

Table 4.10: Average values of selected physicochemical parameters of water samples collected along upstream sampling stations (A) and (B) during dry season within the study area of Mai Mahiu from Dec. 2016–Feb. 2018.

Physical parameters	Sampling stations along upstream rivers							
	Sampling sites along Nasaia river (A1, A2 and A3)				Sampling sites along River Mai Mahiu (B1, B2 and B3)			
	A1	A2	A3	Mean	B1	B2	B3	Mean
pH	7.17	7.53	7.82	7.51	7.31	7.59	7.92	7.61
Temperature (^{o}C)	15.0	15.8	16.2	15.67	15.2	16.1	16.3	15.87
Turbidity (NTU)	7.91	8.79	8.92	8.54	7.68	8.04	8.72	8.15
Conductivity (µS/cm)	414.91	482.02	489.98	462.30	423	487	499	469.67
Flow (km/h)	10.3	9.1	6.4	8.60	10.5	8.3	5.8	8.20
Dissolved oxygen (mg/L)	6.82	6.23	5.31	6.12	6.78	6.42	5.38	6.19
Chemical parameters								
Chlorides (mg/L)	3.01	3.89	3.98	3.63	3.11	3.92	3.98	3.67
Carbonates (mg/L)	6.56	7.34	8.52	7.47	6.67	7.84	9.26	7.92
Total Phosphates (mg/L)	3.43	3.64	3.78	3.62	3.16	3.57	3.62	3.45
Nitrates (mg/L)	2.98	3.12	3.35	3.15	2.93	2.96	3.41	3.10
Sulphates (mg/L)	2.73	2.92	3.36	3.00	3.89	3.93	3.99	3.94
Potassium (ppm)	5.37	5.95	5.68	5.67	5.27	5.92	5.93	5.71
Calcium (ppm)	5.02	5.61	5.63	5.42	5.13	5.68	5.74	5.52
Iron (ppm)	3.24	3.25	3.24	3.24	3.17	3.19	3.20	3.19
Sodium (ppm)	301.0	305.61	306.69	304.43	304.1	306.5	306.9	305.83
Total dissolved solids (mg/L)	235.01	350.00	411.98	332.33	237.00	367.10	432.40	345.50

Table 4.11: Average values of selected physicochemical parameters of water samples collected along upstream sampling stations (C) and (D) during dry season within the study area from Dec. 2016–Feb. 2018.

	Sampling stations along downstream rivers							
Physical parameters	Sampling sites along River Ewaso (C1, C2 and C3)				Sampling sites along River Ewaso (D1, D2 and D3)			
	C1	C2	C3	Mean	D1	D2	D3	Mean
pH	8.34	8.71	8.96	8.67	8.65	9.05	9.98	9.23
Temperature (^{o}C)	25.5	26	26.8	26.10	26.9	27.2	27.6	27.23
Turbdity (NTU)	77.6	108.03	151.99	112.54	133.98	148.00	151.02	144.33
Conductivity (µS/cm)	512.04	533.97	552.01	532.67	548.00	560.97	582.04	563.67
Flow velocity (km/h)	4.23	3.4	2.3	3.31	2.23	1.94	1.82	2.00
Dissolved oxygen (mg/L)	4.21	3.62	3.59	3.81	3.54	3.44	3.38	3.45
Chemical parameters								
Chlorides (mg/L)	4.78	5.35	5.98	5.37	5.12	5.64	6.21	5.66
Carbonates (mg/L)	8.85	9.54	9.78	9.39	8.95	9.96	11.64	10.18
Total Phosphates (mg/L)	5.27	5.38	5.48	5.38	6.76	6.86	6.95	6.86
Nitrates (mg/L)	15.57	18.56	19.58	17.90	16.24	17.12	20.91	18.09
Sulphates (mg/L)	5.77	5.87	5.89	5.84	6.45	6.54	6.87	6.62
Potassium (ppm)	13.82	13.88	14.1	13.93	14.42	14.46	14.54	14.47
Calcium (ppm)	6.21	6.32	6.41	6.31	6.52	6.58	6.61	6.57
Iron (ppm)	4.4	4.5	4.49	4.46	6.15	6.16	6.17	6.16
Sodium (ppm)	389.1	390.51	420.99	400.20	430.12	425.2	411.02	422.11
Total dissolved solids (mg/L)	782.02	839.99	890.54	837.52	821	870.01	932.1	874.37

Table 4.12: Average values of selected physicochemical parameters of water samples along upstream sampling stations (A) and (B) (Rivers Nasaia and Mai Mahiu) and downstream stations (C) and (D) (River Ewaso) within the study area during dry period from Dec. 2016–Feb 2018.

Physical parameters	**Mean concentration levels along sampling stations**				
	Station (A)	Station (B)	Station (C)	Station (D)	p-value
pH	7.51± 0.19[a]	7.61±0.18[a]	8.67±0.18[b]	9.23±0.39[c]	<.001
Temperature (^{o}C)	15.67±0.35[a]	15.87±0.34[a]	26.1±0.38[b]	27.23±0.20[c]	<.001
Turbdity (NTU)	8.54±0.32a	8.12±0.32[a]	112.5±21.59[b]	144.3±5.25[b]	<.001
Conductivity (μS/cm)	462.3±23.81[a]	469.7±23.59[a]	532.7±11.56[ab]	563.7±9.92[b]	0.011
Flow velocity (km/h)	8.6±1.15[a]	8.2±1.36[a]	3.31±0.56[b]	2.00±0.12[b]	<.001
Dissolved oxygen (mg/L)	6.12±0.44[a]	6.20±0.42[a]	3.81±0.20[b]	3.45±0.047[b]	<.001
Chemical parameters					
Chlorides (mg/L)	3.63±0.31[a]	3.67±0.21[a]	5.37±0.35[b]	5.66±0.32[b]	<.001
Carbonates (mg/L)	7.47±0.57[a]	7.92±0.75[a]	9.39±0.28[b]	10.18±0.79[b]	<.001
Total Phosphates (mg/L)	3.62±0.10[a]	3.45±0.15[a]	5.38±0.06[b]	6.86±0.06[b]	<0.001
Nitrates (mg/L)	3.15±0.12[a]	3.1±0.16[a]	17.90±1.20[b]	18.09±1.43[b]	<.001
Sulphates (mg/L)	3.00±0.19[a]	3.94±0.03[a]	5.84±0.04 [b]	6.62±0.12[c]	<0.001
Potassium (ppm)	5.67±0.19[a]	5.71±0.22[a]	13.93±0.09[b]	14.47±0.04[c]	<.001
Calcium (ppm)	5.42±0.20[a]	5.52±0.19[a]	6.31±0.06[b]	6.57±0.03[b]	<.001
Iron (ppm)	3.24±0.00[a]	3.19±0.01[a]	4.46±0.03[b]	6.16±0.01[c]	<.001
Sodium (ppm)	304.4±1.75[a]	305.8±0.87[a]	400.2±10.40[b]	422.1±5.73[b]	<.001
Total dissolved solids (mg/L)	332.3±51.85[a]	345.5±57.43[a]	837.5±31.35[b]	874.4±32.15[b]	<.001

*Means values with different alphabetical superscripts (a, b, ab and c) are statistically different ($p < 0.05$ levels).

Plate 4.8: Water volume in Ewaso River has declined due to climate variations associated with land use and land cover changes in the study area.

4.6.1.2 Water Temperature

Water temperatures are low in sampling stations (A) and (B) compared with sampling stations (C) and (D). Temperature values at sampling station (A) range between 15.0 and 16.2 ^{o}C with a mean value of 15.7±0.35 ^{o}C and sampling station (B) the range is between 15.2 and 16.3 ^{o}C with mean of 15.87±0.32 ^{o}C, while sampling station (C) is between 25.5 and 26.8 ^{o}C with a mean of 26.1±0.38 ^{o}C and sampling station (D) values range between 26.9 and 27.6 ^{o}C with a mean value of 27.2±0.20 ^{o}C (Table 4.10). Analysis of variance show a significant difference ($p<0.001$) in mean water temperature values between sampling stations. High water temperatures are recorded in the downstream sampling stations (C) and (D) where flow velocity is lower. There is a negative correlation (R^2= -0.996) between temperature and water flow along the sampling stations (Figure 4.6).

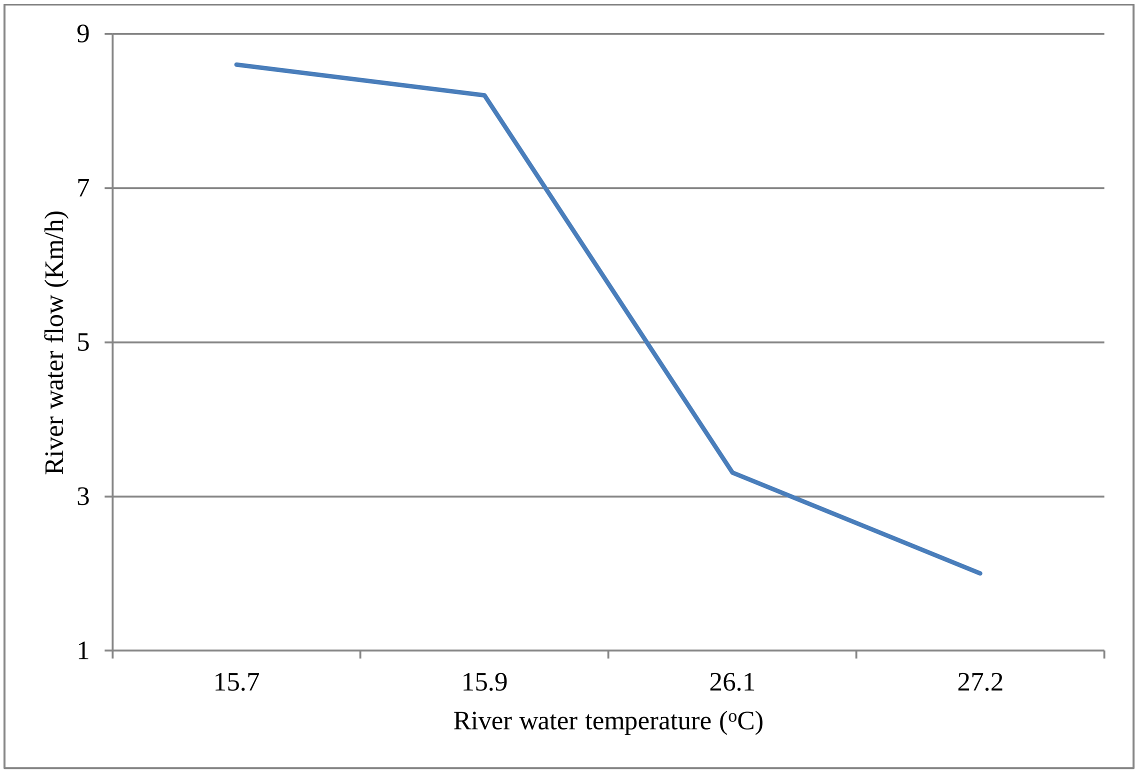

Figure 4.6: Relationship between water velocity and temperature in river within Mai Mahiu area.

Low water temperatures at upstream sampling stations (A and B) can be associated with high elevation, presence of vegetation cover along the river valley and high water velocity. This finding concur with Solomon and Sambrook (2004), Webb and Crisp (2006) and Subehi and Fakhrudin (2011) who explains that variations in water temperatures are influenced by land use changes, slow flow velocity, intensity and duration of solar radiation and fluctuations in precipitation.

4.6.1.3 Turbidity

Turbidity values (NTU) vary widely between sampling stations. Measured values in sampling station (A) range between 7.91 and 8.92 NTU with a mean of 8.54±0.32 NTU, station (B) between 7.68 and 8.72 NTU with a mean of 8.15±0.31 NTU, station (C) between 77.6 and 151.99 NTU with a mean value of 112.53±21.60 NTU while station (D) values range between 133.98 and 151.02 NTU with a mean of 144.33±5.24 NTU. Analysis of variance shows that turbidity values are highly significant ($p<0.001$) with mean separation showing higher turbidity values at downstream sampling stations (C) and (D) compared with values at upstream sampling stations A and B (Figure 4.7). There was no significant difference on turbidity values between the upstream stations. High levels of turbidity at downstream stations (C) and (D) was due to intense water mixing from human activities that take place there. These include car and container washing, livestock watering points, soil erosion from adjacent poorly cultivated land and river valley sedimentation. This finding concurs with Pringle and Benstead (2001) on logging effect on river ecosystems of the tropics where it is concluded that poor deforestation, cultivation practices and soil erosion lead to increased turbidity in river water sources.

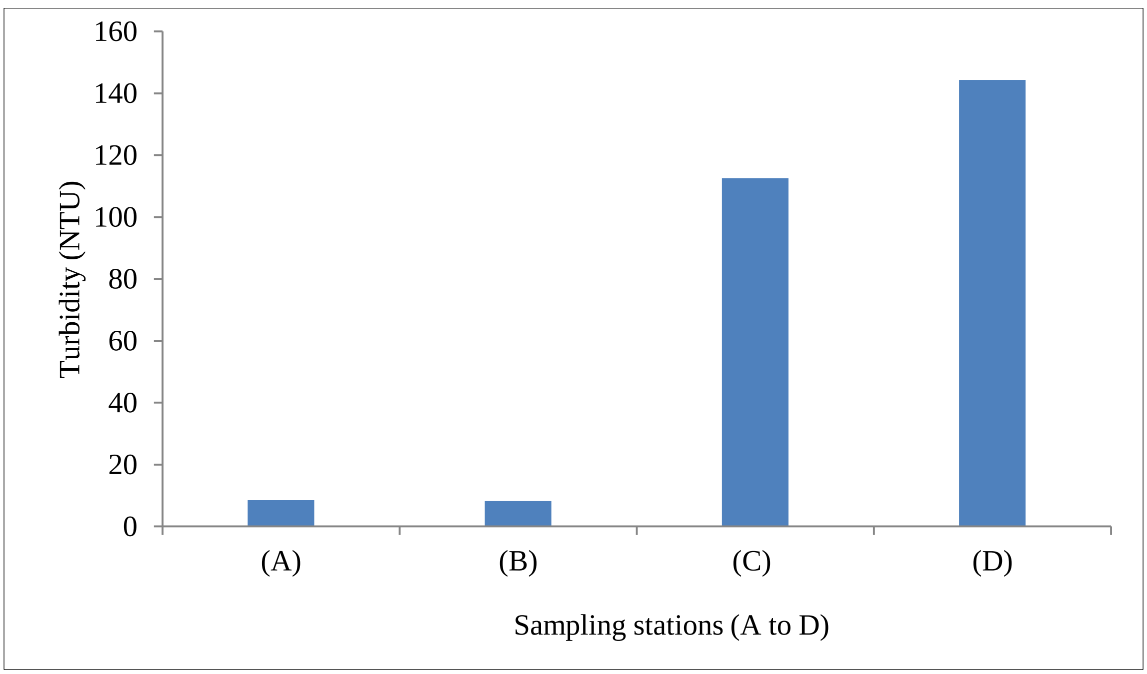

Figure 4.7: Variations in turbidity values of water collected along sampling stations (A), (B), (C) and (D) in the study area, Mai Mahiu, Nakuru County.

4.6.1.4 Electrical conductivity

Electrical conductivity (EC) increased with changes in land-use practices. At sampling station (A), EC values range between 414.91 and 489.98 μS/cm with a mean value of 462.33±23.78 μS/cm. Values at sampling station (B) ranges between 423 and 499 with a mean value of 469.7±23.59 μS/cm, sampling station (C) ranges between 512.04 and 552.01 with a mean value of 532.67±11.57 μS/cm while at sampling station (D) had values that ranges between 548.00 and 582.04 μS/cm and a mean value of 563.67±9.91 μS/cm. Test of significance show a significant difference ($p<0.011$) in electrical conductivity between stations with stations (C) and (D) having significantly higher values compared with sampling stations (A) and (B).

Level of electrical conductivity in water is influenced by total dissolved chemicals and suspended solids. Higher values observed in sampling stations (C) and (D) can be attributed to high chloride, phosphate and nitrate rich soils eroded from nearby agricultural farms, discharge of organic and inorganic wastes from built-up environment of Mai Mahiu town. Other sources include washing of cars, trucks, tankers, containers of various chemicals and petroleum products that constitute daily activities within these sampling stations (Plate 4.9 and 4.10) with subsequent pollution downstream. Mai Mahiu being an urban centre, there are many pollutants that are washed off from impervious surfaces at the parking lots, roads and paths into sampling stations (C) and (D) without undergoing infiltration and purification effects of the soil. Study findings are in agreement with Sainato *et al.* (2012) and Acosta *et al.* (2011) that erosion of agrochemicals from agricultural farms can influence electrical conductivity in water.

Plate 4.9: Dirty vehicles and containers (a) getting washed next to Ewaso River at sampling station (C) and dirty effluent (b) heading into the river along the main road to Naivasha.

Plate 4.10: Uneven landscape forming gullies and loose soil getting eroded to and / or along river Ewaso due to anthropogenic activities in the region of Mai Mahiu.

4.6.1.5 River water flow

Flow of water in the rivers is high at sampling station (A) and (B) compared to sampling stations (C) and (D). At sampling station (A), flow varied between 6.4 and 10.3 km/h with a mean of 8.60±1.15 km/h while station (B) range was between 5.8 and 10.5 km/h with a mean of 8.20±1.36 km/h. Flow at sampling station (C) ranges between 2.3 and 4.2 km/h with a mean of 3.31±0.56 km/h. Lowest flow is at sampling station (D) with values ranging between 1.82 and 2.23 km/h with a mean of 2.00±0.12 km/h. There is a significant difference ($p<0.001$) in water velocity between the sampling stations. Water at upstream sampling stations (A) and (B) flow with high velocity compared to downstream sampling stations (C) and (D). This is associated with higher elevation at stations (A) and (B). Low flow velocity at stations (C) and (D) is due to siltation due to destruction of forest cover, unsustainable crop cultivation and overgrazing which have enhanced soil erosion; low water volume due evaporation resulting from increased surface-atmosphere energy exchange due to loss of vegetation cover. The finding concurs with Manohar *et al.,* (2017) who reports that flow velocity depends on angle of slope/land surface and intensity, quantity of rainfall within the region.

4.6.1.6 Dissolved oxygen

Dissolved oxygen varies widely with a decreasing trend from stations (A) to (D). In sampling station (A) the concentration levels range from 5.31 to 6.82 mg/L with mean of 6.12±0.44 mg/L, station (B) between 5.38 and 6.78 mg/L with mean of 6.13±0.28 mg/L while station (C) between 3.59 and 4.21 mg/L with mean of 3.81±0.20 mg/L and finally station (D) range is between 3.38 and 3.54 mg/L with mean of 3.45±0.05 mg/L. Analysis of variance showed significant difference in dissolved oxygen between sampled sites

($p<0.001$). Dissolved oxygen concentration is high in points with high water velocity ($r = 0.996$) at stations A and B and lower at station C and D where velocity is low. Dissolved oxygen decreased with an increase in water temperature ($r = -0.999$).

Dissolved oxygen concentration is good indicator of water quality and state of aquatic life. Lower values of dissolved oxygen in water recorded at stations (C) and (D) can be attributed increased temperatures that enhance active biological activities that utilize dissolved oxygen, decaying organic matter brought into these rivers as runoff from agricultural farms, faecal matter from built-up environment (nearby school and Mai Mahiu urban centre) and oily and petroleum products from washing of lorries and containers near the river that severely suppress dissolved oxygen levels when they get into the river. This finding concur with Manohar (2018) that reports that slow flow velocity, low turbulence and longer exposure to solar radiation can lead to low dissolved oxygen levels in water sources.

4.6.1.7 Chlorides

Chlorides level varies considerably across sampling stations (A) to (D) (Table 4.13, 4.14 and 4.15). Concentrations at station (A) range between 3.01 and 3.98 mg/L with a mean of 3.63±0.31 mg/L, station (B) is between 3.11 and 3.98 mg/L with a mean of 3.67±0.21 mg/L, station (C) between 4.78 and 5.98 mg/L with a mean of 5.37±0.35mg/L and station (D) between 5.12 and 6.21 with a mean of 5.66±0.32 mg/L. Analysis of variance show a significant difference in chloride levels between different sites ($p = 0.001$). Mean separation showed high chloride concentration in sampling station (C) and (D) compared to sampling stations (A) and (B). Increased levels of chloride in water are as a result of fertilizer, municipal and domestic sewage (Sunkad, 2013; Stamenkovic *et al.*, 2009). It is also observed that water softeners, animal feed additives, pesticides, concentration and dissolution of salts from irrigation with deep groundwater can contribute to increase in chloride levels of surface water (WHO, 2004; Grimsson *et al.*, 2014). Sewage water and industrial effluents are rich in chlorides and discharge of these wastes result in high chloride levels in fresh water bodies (Hasalam, 1991).

4.6.1.8 Carbonates

Carbonates concentration were higher in the upstream compared to down-stream points. Concentration ranged from 6.56 mg/L to 8.52 mg/L in sampling station (A), 6.67 mg/L to 9.26 mg/L in sampling station (B), 8.85 mg/L to 9.78 mg/L in sampling station (C) and 8.95 mg/L to 11.64 mg/L in sampling station (D). Mean values were 7.47±0.57, 7.92±0.75, 9.39±0.28 and 10.18±0.79 mg/L for sampling stations (A), (B), (C) and (D), respectively. Analysis of variance shows a significant difference in chloride levels between sampling sites ($p = 0.001$). Tukey-test for mean comparison showed significant difference in carbonates concentration between sampling stations with sampling stations A and B recording lower values than stations (C) and (D). The different concentration levels between upstream and downstream can be associated with organic matter decomposition and subsequent release of carbonates and parent materials decomposition and mineral leaching. The results agrees with (Kitur, 2009) who reports that levels of carbonates in water depend on weathering process in catchments while (Mustapha, 2008) notes that organic matter decomposition can be the source of high carbonate levels in water.

4.6.1.9 Total phosphates

Phosphates level varies from 3.43 mg/L and 3.78 mg/L at sampling station (A); 3.16 mg/L and 3.62 mg/L at station (B); and 5.27 mg/L and 5.48 mg/L at station (C) and 6.76 and 6.95 at station (D). Mean values are 3.62±0.10, 3.45±0.15, 5.38±0.06 and 6.86±0.06 mg/L for sampling stations (A), (B), (C) and (D), respectively. Analysis of variance shows a significant difference ($P<0.001$) in phosphate levels between sampling stations. There are high phosphates in water at sampling stations (C) and (D) compared to sampling stations (A) and (B) which is attributed to land conversions to agricultural farms and grazing fields. This has increased run-off from agricultural farms. The findings concur with the findings of Pontivs (1990), and Ator and Ferrari (1997) who reports that Phosphates in surface water arise from run-off from agricultural activities while Melakua *et al.* (2007) and Mustapha (2008) notes that municipal sewage is the source of phosphate as a result of domestic detergent and silage effluents.

4.6.1.10 Nitrates

Nitrates level shows a wide variation that range from 2.98 to 3.35 mg/L in sampling station (A) with mean of 3.15±0.12; 3.11 to 3.98 mg/L in sampling station (B) with mean of 3.10±0.16; 15.57 to 19.58 mg/L in sampling station (C) with mean of 17.90±1.20 and 16.24 to 20.91 mg/L in sampling station (D) with mean of 18.09±1.43. Analysis of variance shows significant difference in mean concentration of nitrates across sampling ($p<0.001$). Low total nitrates concentration in the upstream sampling stations (A) and (B) can be explained by low anthropogenic inputs and high retention of nutrients since the stations are within Kijabe and Kinale forests, respectively. On the other hand, high mean concentration in sampling stations (C) and (D) could be attributed to low retention and loss of nutrients from poorly cultivated and grazed fields. Other possible causes include nitrogen release from eroded faecal matter/dung from livestock grazing fields, excretory organic products from pit latrines of neighbouring Ngeya primary school, dung from livestock drinking water at these points. These results concur with WHO, (2011) who notes that agricultural activities increases levels of nitrate in water. Excretory products and decaying organic matter can be source of nitrate increase in water (Deshmukh and Urkude, 2014). In another study, Gardner and McGlynn (2009) reports that forested land use generally acts as a nutrient detention zone as nutrients move down stream that suggests strong biological nutrient retention. Rapid growth of Mai Mahiu urban centre has increased impervious areas that have led to increased storm flow plus pollutant loadings. Waters *et al.* (2014) studied differential carbon and nitrogen controls of denitrification in riparian zones and streams along an urban to exurban gradient and concludes that urbanization expand impervious areas, that lead to faster storm flows and greater runoff volumes that washes all types of pollutants both non-point source and point source pollutants into rivers, which increases concentrations of nutrients and other pollutants in surface waters (White and Greer 2006).

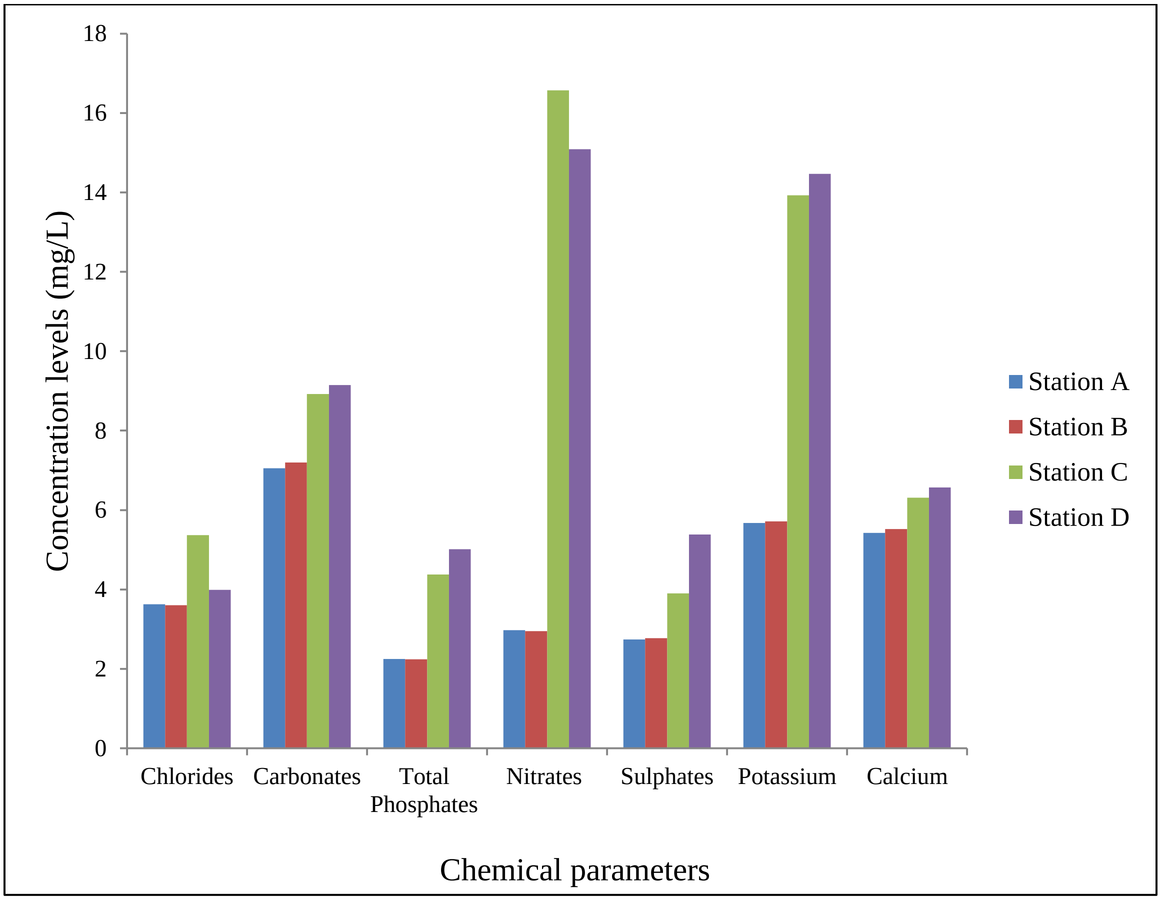

Figure 4.8: Concentration levels of chemical parameters within the water collected from sampling stations (A), (B), (C) and (D) during the dry season from December 2016 to February 2018.

4.6.1.11 Sulphates

Sulphates level range from 2.73 mg/L to 3.36 mg/L in sampling station (A); 3.89 mg/L to 3.99 mg/L in sampling station (B); 5.77 mg/L to 5.89 mg/L in sampling station (C) and 6.45 mg/L to 6.87 mg/L in sampling station (D). Mean values are 3.00±0.19, 3.94±0.03, 5.84±0.04 and 6.62±0.12 mg/L for sampling stations (A), (B), (C) and (D), respectively. The analysis of variance results showed that there was significant difference $p < 0.001$ in sulphates levels between sampling area (A), (B), (C) and (D). Sources of sulphate in water include leaching from soil, industrial discharge, decaying animal and plant matter and chemical products including ammonium sulphate fertilizers (WHO, 2004). The mean concentration of sulphates at different sites showed significant difference between sites ($p < 0.001$). Increased overland low of water through various sources of sulphate such as soil, decaying animal and plant matter, chemical products such as ammonium sulphate fertilizers (WHO, 2004) is the cause of the observed levels. Discharge of industrial wastes, surface runoff and domestic sewage tend to increase sulphate concentration in surface water (Tiwari and Manzoor, 1988).

4.6.1.12 Potassium

Potassium concentration levels vary widely across values at sampling stations. They range from 5.37 to 5.95 ppm with mean value of 5.67±0.17 ppm at sampling station (A) compared to 5.27 to 5.93 ppm with mean of 5.71±0.22 ppm at sampling station (B), 13.82 to 14.10 ppm with mean of 13.93±0.09 ppm at sampling station (C) and 14.42 to 14.54 ppm with mean of 14.47±0.04 ppm at sampling station (D). Analysis of variance shows a significant difference ($p<0.001$) in concentration levels across sites with sampling stations (C) and (D) have higher values compared to sampling stations (A) and (B). High values at (C) and (D) can be due to erosion of nutrients and potassium salts from nearby agricultural land and Mai Mahiu town. Brainwood *et al.* (2004) and Blanchard and Lerch (2000) states that potassium concentrations increase in water bodies because of salts and nutrients leached to the water table.

4.6.1.13 Calcium

Calcium concentration levels vary widely between upstream stations (A) and (B) and downstream sampling stations (C) and (D). High values were recorded in the down-stream sites compared to upstream sampling sites. Values ranged from 5.02 mg/L to 5.63

mg/L with a mean of 5.42±0.20 mg/L in sampling station (A), 5.13 mg/L to 5.74 mg/L with a mean of 5.52±0.19 mg/L in sampling station (B), 6.21 mg/L to 6.41 mg/L with a mean of 6.31±0.20 mg/L in sampling station (C) and 6.52 mg/L to 6.61 mg/L with a mean of 6.57±0.02 mg/L in sampling station (D). Analysis of variance shows a significant difference ($p < 0.001$) in calcium levels between sampling sites. The significant difference in concentration levels between upstream and downstream sites is associated with dissolution of calcium carbonates organic compounds contaminated with wastewater and leaching of minerals at sampling stations (C) and (D). The calcium concentration in the study area are slightly similar to those reported by Kitur (2009) who notes that levels of calcium in water depend on weathering process in catchments in water. Galczynska *et al.* (2013) reports that calcium levels in surface water are influenced by the carbonate balance in the area under study.

4.6.1.14 Iron

Iron levels are higher in downstream compared to upstream sampling points. The ranges are from 3.24 mg/L to 3.25 mg/L with a mean of 3.24±0.003 mg/L in sampling station (A), 3.17 mg/L to 3.20 mg/L with a mean of 3.19±0.01 mg/L in sampling station (B), 4.4 mg/L to 4.50 mg/L with a mean of 4.46±0.03 mg/L in sampling station (C) and 6.15 mg/L to 6.17 mg/L with a mean of 6.16±0.01 mg/L in sampling station (D). Analysis of variance test showed there was significant difference ($p < 0.001$) in iron levels between sampled sites. Mean comparison shows significant difference in iron concentration across sampling stations with sampling stations (C) and (D) recording higher values compared to stations (A) and (B).

4.6.1.15 Sodium

Sodium levels are high in the downstream compared to upstream points. The ranges are from 301.00 mg/L to 306.69 mg/L in sampling station (A), 304.10 mg/L to 306.90 mg/L in sampling station (B), 389.10 mg/L to 420.99 mg/L in sampling station (C) and 411.02 mg/L to 430.12 mg/L in (D). Analysis of variance show significant difference ($P < 0.001$) sodium levels between sites with higher values at sampling station (C) (400.22±10.46 mg/L) and sampling station (D) (422.10±5.73 mg/L) compared with sampling station (A) (304.43±1.75 mg/L) and station (B) (305.8±0.87 mg/L). Enhanced concentration of sodium in this water can be attributed to erosion and deposition of sodium salts from agricultural farms.

4.6.1.16 Total dissolved solids

Total dissolved solids levels are high in the downstream sampling stations (C) and (D) compared to upstream sampling station (A) and (B). The ranges were from 235.01 mg/L to 411.98 mg/L in sampling station (A), 237.0 mg/L to 432.4. mg/L in sampling station (B), 782.02 mg/L to 812.00 mg/L in sampling station (C) and 812.10 mg/L to 821.00 mg/L in (D). Analysis of variance shows a significant difference in mean values ($p<0.001$) between sampling stations. Mean separation shows high concentrations at sampling station (C) (837.5±31.35 mg/L) and sampling station (D) (874.4±32.15 mg/L) when compared with sampling stations (A) (332.33±51.85 mg/L) and (B) (345.5±57.43). Changes in TDS is due to erosion from agricultural and grazing fields, washing activities that take place around sampling stations (B) and (C) and pollutants from roads and parking lots and garages at Mai Mahiu town.

4.6.2 Physico-chemical parameters during wet season

4.6.2.1 Water pH

The pH values during wet season are low compared with dry season with an increasing trend along downstream stations. At sampling station (A) values range from 6.96 to 7.00 with a mean of 6.98±0.01, station (B) between 6.98 and 7.01 with mean of 6.99±0.01, station (C) between 7.56 and 7.62 with a mean of 7.59±0.02 while sampling station (D) range is between 8.31 and 8.45 with a mean of 8.37±0.04. There is a significant difference ($p < 0.001$) in mean values between sampling sites. High pH values recorded at sampling station (C) and (D) compared to sampling stations (A) and (B) is attributed to erosion of salt accumulated soil materials especially carbonates and sulphates from surrounding agricultural land and detergents from washing activities going on at this point. Lower pH values in wet season compared to dry season are mainly due to dilution from enhanced water volume in the rivers during rainy season.

4.6.2.2 Water temperature

Mean water temperature is low in wet season compared to dry season with an increasing trend from sampling station (A) to (D). Temperature values at sampling station (A) range between 14.98 and 15.9 ^{o}C with a mean of 15.43±0.27 °C, sampling station (B) between 14.78 and 15.72 °C and mean of 15.39±0.31 °C while that in sampling station (C) was from 23.43 to 25.56 °C with a mean of 24.44±0.62 °C. Sampling station (D) range was between 25.54 and 26.53 °C with a mean value of 26.17±0.32 °C. Analysis of variance shows a significant difference ($p<0.001$) in mean water temperature values between sampling stations. There was a negative correlation (R^2= -0.995) between temperature and flow velocity along the sampling stations signifying that water temperature increased with reduction in flow velocity. The reduction in water temperature in wet season is attributed to high water volume in the rivers and cooling enhanced from water mixing as it flows downstream. Other possible reasons for this difference may be due to high elevation at stations (A) and (B) compared to stations (C) and (D), high solar radiation at station (C) and (D) due to lack of vegetation cover along the river and high sediment load from deposition of eroded soil materials that reduce water volume at stations (C) and (D). This finding concur with Solomon and Sambrook (2004), Webb and Crisp (2006) and Subehi and Fakhrudin (2011) who explain that variations in water temperatures are influenced by land use changes, slow flow velocity, intensity and duration of solar radiation and fluctuations in precipitation.

4.6.2.3 Turbidity

Turbidity values vary widely between sampling stations with high values in wet season compared to dry season. Measured turbidity values (NTU) in sampling station (A) range between 9.79 and 9.89 NTU with mean value of 9.85±0.03 NTU, station (B) between 8.56 and 8.82 NTU with mean value of 8.72±0.08 NTU, sampling station (C) between 123.00 and 156.00 NTU with mean value of 137.67±9.70 NTU. Sampling station (D) values range between 201.00 and 209.00 NTU with mean value of 205.67±2.40 NTU. Analysis of variance shows a significant difference ($p<0.001$) in turbidity values across sampling stations with sampling stations (C) and (D) recording higher values compared with values sampling stations (A) and (B). Mean separation showed that there was no significant difference on turbidity values at the upstream stations, (A) and (B). The high levels of turbidity at sites (C) and (D) may be attributed to intense water mixing from activities such as car and container washing, trampling by livestock when taking water, and slower water movement and soil erosion from adjacent poor cultivation practices and loss of vegetation cover due to deforestation. Pringle and Benstead (2001) on effects of logging on tropical river ecosystems notes that poor cultivation practices, deforestation and soil erosion are main factors that lead to increased turbidity and sediment loads in water sources.

4.6.2.4 Electrical conductivity

Electrical conductivity (EC) values are low in wet season compared with dry season with an increase along sampling stations (A) to (D). At sampling station (A), EC values range between 349 and 392.33 μS/cm with a mean value of 369.33±12.47 μS/cm, sampling station (B) range is between 412 and 426 μS/cm with a mean value of 419.67±23.59 μS/cm. Values at sampling station (C) range between 498.04 and 514.00 μS/cm with a mean value of 507.33±4.57 μS/cm while at sampling station (D) it is between 514.00 and 525 μS/cm and a mean value of 520.33±3.28 μS/cm. Analysis of variance shows significant difference ($p<0.001$) in electrical conductivity across sampling stations. Values at sampling stations (C) and (D) were high compared to sampling stations (A) and (B). Electrical conductivity levels in water bodies are influenced by total dissolved chemicals and suspended solids from various land uses. Lower values in wet season are attributed to dilution of water due to more rainfall and underground recharge. Higher values observed in sampling stations (C) and (D) can be attributed to high chloride, phosphate and nitrate contents associated with erosion from agricultural farms, discharging of wastes from built-up environment, washing of vehicles and containers of chemicals, petroleum, milk, meat, cooking oils which is a daily routine along these sampling points. Mai Mahiu as an urban centre, pollutants are usually deposited on impervious surfaces at the parking lots and roads whereby they are washed off into sampling stations (C) and (D) without any chance for infiltration into the soil. The findings of the study agrees with the findings of Sainato *et al.* (2012) and Acosta *et al.* (2011) reports that electrical conductivity in water is due to erosion of agrochemicals from agricultural farms.

4.6.2.5 Water flow

Water flow of the rivers increases during wet season compared with dry season. Water flow is high at sampling station (A) and (B) compared to sampling stations (C) and (D). At sampling station (A), water flow vary between 7.6 and 11.2 km/h with a mean of 9.53±1.05 km/h; sampling station (B) range is between 6.7 and 11.4 km/h with a mean of 9.17±1.36 km/h. Sampling station (C) values range between 3.4 and 5.4 km/h with a mean of 4.40±0.58 km/h. Sampling station (D) experiences low flow with values that range between 2.1 and 3.3 km/h and a mean of 2.53±0.38 km/h. Analysis of variance shows a significant difference ($p<0.001$) in water flow between sampling stations with sampling stations (A) and (B) having a high flow compared to stations (C) and (D). This is because of elevated topography in sampling stations (A) and (B) compared with sampling stations (C) and (D).

Another reason for low water flow at stations (C) and (D) is destruction of vegetation cover along the river valley. Coupled with strong solar radiation, there is increased rate of evaporation at these points thus reducing volume of water and its flow. Poor cultivation practices and overgrazing have affected soil physical properties and increase in soil erosion and sediment deposition thereby affecting water flow and volume at sampling stations (C) and (D). This finding is in agreement with Manohar *et al.* (2017) who reports that water flow in rivers depends on angle of slope / land surface, gravity; frequency, intensity, quantity of rain and its volume within the region.

4.6.2.6 Dissolved oxygen

Dissolved oxygen concentrations are high in wet season compared to dry season (Table 4.14). Values vary widely with decreasing trend from stations (A) to (D). In station (A) the concentration levels range from 5.11 to 5.86 mg/L with a mean of 5.40±0.23 mg/L, station (B) between 5.03 and 5.67 mg/L with mean of 5.31±0.19 mg/L while station (C) has a range between 3.05 and 4.14 mg/L with a mean of 3.45±0.35 mg/L and station (D) between 3.04 and 3.17 mg/L with a mean of 3.11±0.02 mg/L. Analysis of variance shows there is a significant difference in dissolved oxygen values between stations ($p < 0.001$). Dissolved oxygen concentration is high in points with high flow velocity ($r = 0.99$) and decreased with an increase in water temperature ($r = -0.98$). High dissolved oxygen concentration during wet season is attributed to high water volumes and increased flow and mixing water as it flows. Low levels of dissolved oxygen in the water at stations (C) and (D) are due to high concentrations of decaying organic matter as runoff from farms, faecal matter from built-up environment and oily and petroleum products from washing of lorries and containers near the river that severely depress dissolved oxygen levels through oxidation processes. This finding concur with Manohar (2018) who reports that slow flow velocity, low turbulence with low aeration and longer exposure to solar radiation can lead to low dissolved oxygen levels in water sources.

4.6.2.7 Chlorides

Chlorides levels decreased during the wet season compared to dry season and varied considerably across sampling stations. Concentrations in sampling station (A) ranged between 3.45 and 4.88 mg/L with a mean of 4.02±0.11 mg/L, between 3.34 and 3.65 mg/L with a mean of 3.47±0.09 mg/L in station (B), between 4.78 and 5.98 mg/L with a mean of 5.10±0.23 mg/L in station (C) and between 4.12 and 4.21 with a mean of 4.16±0.03 mg/L in station (D) (Table 4.13 and 4.14). Analysis of variance shows significant difference ($p < 0.001$) in chloride levels across sampling sites. Mean separation showed high chloride concentration in sampling station (C) and (D) compared to sampling stations (A) and (B). Decreased concentration of chlorides during wet season is because increased water volume in the river which diluted chloride levels. Levels of chloride in water are as a result of fertilizer, municipal and domestic sewage (Sunkad, 2013; Stamenkovic *et al.,* 2009). Grimsson *et al.* (2014) also observes that water softeners, animal feed additives, pesticides, concentration and dissolution of salts from irrigation with deep groundwater can contribute to increase in chloride levels of surface water.

4.6.2.8 Carbonates

Carbonates concentrations varied widely across sampling stations with high values in sampling stations (C) and (D) compared to sampling stations (A) and (B). Concentration levels were lower in wet season compared with dry season. The ranges were from 6.56 mg/L to 6.75 mg/L in sampling station (A), 6.67 mg/L to 6.99 mg/L in sampling station (B), 7.78 mg/L to 8.28 mg/L in sampling station (C) and 7.92 mg/L to 8.45 mg/L in sampling station (D). Mean values were 6.65±0.06, 6.85±0.10, 8.04±0.2 and 8.27±0.10 mg/L for sampling stations (A), (B), (C) and (D) respectively. Analysis of variance shows a significant difference ($p < 0.001$) in carbonate concentrations across sampling points. Mean comparison shows significant difference in carbonates concentration between sampling stations (A) and (B) and (C) and (D). Lower concentration levels during wet season can be attributed to dilution associated with increase in water volume in rivers as a result of rainfall in this period. Levels of carbonates in water depend on weathering process in catchments (Kitur, 2009) and organic decomposition (Mustapha, 2008) in water. Calcium levels in surface water are also influenced by the carbonate balance (Galczynska *et al.,* 2013) and organic compounds contaminated with waste water (Kolanek and Kowalski, 2002) which enter water sources through mineral leaching.

4.6.2.9 Total phosphates

Phosphates levels are low in wet season than dry season and varies from 2.04 mg/L to 2.43 mg/L at sampling station (A); 4.04 mg/L and 2.51 mg/L at station (B); 4.28 mg/L and 4.50 mg/L at station (C) and 4.51 mg/L and 5.70 mg/L at station (D). Mean values were 2.25±0.11, 2.24±0.14, 4.38±0.07 and 5.01±0.36 mg/L for sampling stations (A), (B), (C) and (D), respectively. Analysis of variance shows a significant difference ($p < 0.001$) in phosphate concentration levels between sampling stations with sampling stations (C) and (D) having high levels than stations (A) and (B). High phosphates in surface water at sampling stations (C) and (D) arise from run-off from agricultural farms, domestic detergent and effluents from washing of clothes, vehicles and containers that take place at these points. The findings concur with the findings of Pontivs (1990), and Ator and Ferrari (1997) who reports that Phosphates in surface water arise from run-off from agricultural activities while Melakua *et al.* (2007) and Mustapha (2008) note that municipal sewage is the source of phosphate as a result of domestic detergent and silage effluents.

4.6.2.10 Nitrates

Nitrate concentration levels are lower during wet season than in dry season. Levels show wide variation during study period and range from 2.11 to 2.18 mg/L in sampling station (A) with mean of 2.15±0.02 mg/L; 2.43 to 2.49 mg/L in sampling station (B) with mean of 2.46±0.02 mg/L; 13.57 to 14.58 mg/L in sampling station (C) with mean of 14.24±0.34 mg/L and 14.36 to 14.58 mg/L in sampling station (D) with mean of 14.47±0.06 mg/L (Table 4.15). Analysis of variance of nitrate concentrations show significant difference ($p<0.001$) between sampling sites. Low total nitrate concentration in sampling station (A) and (B) (upstream) can be explained by low anthropogenic inputs and a high retention of nutrients in Kijabe and Kinale forests respectively. High mean concentration in sampling stations (C) and (D) may be attributed to low retention of nutrients in degraded and eroded cultivated fields and grazing fields. Other possible causes are eroded faecal matter/dung from livestock grazing fields, excretory organic products from pit latrines of neighbouring Ngeya primary school. The finding is in agreement with other studies which report that levels of nitrate in water are caused by discharge of sewerage (Sunkad, 2013), agricultural activities (WHO, 2011), metabolic waste, excretory products and decaying organic matter (Deshmukh and Urkude, 2014). In another study, Gardner and McGlynn (2009) reports that forested land use generally acts as a nutrient detention zone as nutrients move down stream that suggests strong biological nutrient retention. Rapid growth of Mai Mahiu urban centre has increased impervious areas that have led to increased storm flow plus pollutant loadings. Waters *et al.* (2014) studied differential carbon and nitrogen controls of denitrification in riparian zones and streams along an urban to exurban gradient and concludes that urbanization expand impervious areas, that lead to faster storm flows and greater runoff volumes that washes all types of pollutants both non-point source and point source pollutants into rivers, which increases concentrations of nutrients and other pollutants in surface waters (White and Greer, 2006).

4.6.2.11 Sulphates

Sulphates levels are low during wet season compared to dry period and increases from sampling stations (A) to (D). Sulphates levels range from 2.87 mg/L to 2.95 mg/L with mean of 2.92±0.02 mg/L in sampling station (A); 2.74 mg/L to 2.98 mg/L with mean of 2.85±0.07 mg/L in sampling station (B), 3.91 mg/L to 4.98 mg/L with mean of 4.44±0.31 mg/L in sampling station (C) and 4.93 mg/L to 6.54 mg/L with mean of 5.69±0.47 mg/L in sampling station (D). Analysis of variance shows a significant difference ($p<0.001$) in sulphates concentration levels between sampling stations (A), (B), (C) and (D) with downstream stations (C) and (D) recording higher mean values than upstream counterparts, (A) and (B). Point sources of sulphate in water at sampling sites (C) and (D) can be attributed to the intense human activities taking place around this area. The activities include agricultural practices and subsequent erosional loss sulphates on fertilizer material used in the surrounding farms, waste discharge from Mai Mahiu town and decaying animal wastes left by livestock while water at these points. Sources of sulphate in water include leaching from soil, decaying animal and plant matter, chemical products such as ammonium sulphate fertilizers (WHO, 2004), discharge of industrial wastes, surface runoff and domestic sewage increases sulphate concentration in surface water (Tiwari and Manzoor, 1988).

4.6.2.12 Potassium

Potassium levels are low in wet season than during dry period. Potassium values at sampling station ranged from 4.38 to 4.48 ppm with mean value of 4.43±0.03 ppm at sampling station (A) compared to 4.75 to 4.85 ppm with mean of 4.79±0.03 ppm at sampling station (B), 12.67 to 12.84 ppm with mean of 12.75±0.05 ppm at sampling station (C) and 13.34 to 13.53 ppm with mean of 13.44±0.06 ppm at sampling station (D). Mean values across sites showed significant difference ($p<0.001$) with sampling (C) and (D) recording highest values. High concentration values at sampling stations (C) and (D) is attributed to erosion of nutrients and salts from cropland and urban centre within the study area. The results agrees with Brainwood *et al.*(2004) and Blanchard and Lerch (2000) who state that potassium concentrations increase in water bodies because of salts and nutrients leached to the water table.

4.6.2.13 Calcium

Calcium levels are low in wet season than during dry period. Calcium concentrations were higher in the upstream compared to down-stream points. The ranges were from 5.14 mg/L to 5.39 mg/L with a mean of 5.29±0.08 mg/L in sampling station (A), 5.45 mg/L to 5.53 mg/ L with a mean of 5.50±0.03 mg/L in sampling Station (B), 6.01 mg/L to 6.11 mg/ L with a mean of 6.07±0.03 mg/L in sampling Station (C) and 6.16 mg/L to 6.24 mg/L with a mean of 6.20±0.02 mg/L in sampling station (D). Analysis of variance shows there is significant difference ($p<0.001$) in chloride levels across sampling sites. Higher calcium concentrations in sampling stations (C) and (D) can be attributed to erosion of calcium rich sediments from fertilized surrounding agricultural land and carbonates from Mai Mahiu town that have been deposited into these points. Study by

Kitur (2009) notes that levels of calcium in water depend on weathering process in the catchment. Calcium levels in surface water are also influenced by the carbonate balance (Galczynska *et al.*, 2013) and organic compounds contaminated with waste water (Kolanek and Kowalski, 2002) which enter water sources through mineral leaching.

4.6.2.14 Iron

Iron levels are low in wet season compared to dry season across sampling stations. The ranges are as follows: from 2.52 mg/L to 2.57 mg/L with a mean of 2.54±0.02 mg/L in sampling station (A), 2.87 mg/L to 2.94 mg/L with a mean of 2.90±0.02 mg/L in sampling station (B), 3.56 mg/L to 3.64 mg/L with a mean of 3.59±0.02 mg/L in sampling station (C) and 4.98 mg/L to 5.16 mg/L with a mean of 5.09±0.06 mg/L in sampling station (D). Analysis of variance showed significant difference in mean chloride levels between different sites ($p < 0.001$).

4.6.2.15 Sodium

Sodium levels are low during wet season compared with dry season. There is an increasing trend in concentration levels from sampling stations (A) to (D). The range are from 255.0 mg/L to 256.7 mg/L in sampling station (A), 267.8 mg/L to 275.2 mg/L in sampling station (B), 345.3 mg/L to 349.4 mg/L in sampling station (C) and 378.4 mg/L to 382.2 mg/L in sampling station (D). Analysis of variance show there is significant difference ($P<0.001$) in sodium levels across sampling sites. Mean values were high at sampling station (C) (400.22±10.46 mg/L) and sampling station (D) (422.10±5.73 mg/L) when compared with sampling station (A) (304.43±1.75 mg/L) and station (B)

(305.8±0.87). Low values recorded during wet season is because of high water volumes in rivers which diluted the salt levels.

4.6.2.16 Total dissolved solids

Total dissolved solids levels are higher in the sampling stations (C) and (D) compared to sampling stations (A) and (B). The ranges were from 335.4 mg/L to 349.6 mg/L in sampling station (A), 354.0 mg/L to 362.3 mg/L in sampling station (B), 812.0 mg/L to 853.7 mg/L in sampling station (C) and 887.4 mg/L to 893.7 mg/L in (D). Analysis of variance shows significant difference ($p<0.001$) in dissolved solids levels across sampling stations. Mean separation shows high values at sampling station (C) (837.00±12.73 mg/L) and sampling station (D) (890.30±1.84 mg/L) when compared with sampling station (A) (343.37±4.19 mg/L) and station (B) (357.30±2.54). Changes in TDS is due to erosion from agricultural and grazing fields, washing activities that take place around sampling stations (B) and (C) and pollutants from roads and parking lots and garages at Mai Mahiu town.

Table 4.13: Average values of selected physicochemical parameters of water samples collected along upstream sampling stations (A) and (B) during wet season within the study area of Mai Mahiu from Dec. 2016–Feb. 2018.

Physical Parameters	Sampling stations along upstream rivers							
	Sampling sites along Nasaia river (A1, A2 and A3)				Sampling sites along River Mai Mahiu (B1, B2 and B3)			
	A1	A2	A3	Mean	B1	B2	B3	Mean
pH	7.00	6.96	6.98	6.98	6.98	6.99	7.01	6.99
Temperature (^oC)	14.98	15.40	15.90	15.43	14.78	15.67	15.72	15.39
Turbdity (NTU)	9.79	9.87	9.89	9.85	8.56	8.78	8.82	8.72
Conductivity (µS/cm)	349.00	367.00	392.00	369.33	412.00	421.00	426.00	419.67
Flow velocity (km/h)	11.20	9.80	7.60	9.53	11.4	9.4	6.70	9.17
Dissolved oxygen (mg/L)	5.86	5.23	5.11	5.40	5.67	5.23	5.03	5.31
Chemical Parameters								
Chlorides (mg/L)	3.45	3.74	4.88	4.02	3.34	3.43	3.65	3.47
Carbonates (mg/L)	6.56	6.63	6.75	6.65	6.67	6.89	6.99	6.85
Total Phosphates (mg/L)	2.29	2.43	2.04	2.25	2.16	2.51	2.04	2.24
Nitrates (mg/L)	2.11	2.17	2.18	2.15	2.43	2.47	2.49	2.46
Sulphates (mg/L)	2.87	2.93	2.95	2.92	2.74	2.83	2.98	2.85
Potassium (ppm)	4.38	4.43	4.48	4.43	4.75	4.78	4.85	4.79
Calcium (ppm)	5.14	5.33	5.39	5.29	5.45	5.52	5.53	5.50
Iron (ppm)	2.52	2.54	2.57	2.54	2.87	2.89	2.94	2.90
Sodium (ppm)	255.00	256.20	256.70	255.97	267.8	274.0	275.2	272.33
Total dissolved solids (mg/L)	335.40	345.10	349.60	343.37	354.00	355.60	362.30	357.30

Table 4.14: Average values of selected physicochemical parameters of water samples collected along downstream sampling stations (C) and (D) during wet season within the study area of Mai Mahiu from Dec. 2016–Feb. 2018.

	Sampling stations along downstream River Ewaso							
Physical Parameters	Sampling sites along River Ewaso (C1, C2 and C3)				Sampling sites along River Ewaso (D1, D2 and D3)			
	C1	C2	C3	Mean	D1	D2	D3	Mean
pH	7.56	7.58	7.62	7.59	8.31	8.35	8.45	8.37
Temperature (^{o}C)	23.43	24.32	25.56	24.44	25.54	26.43	26.53	26.17
Turbdity (NTU)	123.0	134.0	156.0	137.7	201.0	207.0	209.0	205.7
Conductivity (µS/cm)	498.0	510.0	514.0	507.3	514.0	522.0	525.0	520.3
Flow velocity (km/h)	5.4	4.4	3.4	4.4	3.3	2.2	2.1	2.53
Dissolved oxygen (mg/L)	4.14	3.17	3.05	3.45	3.17	3.12	3.04	3.11
Chemical parameters								
Chlorides (mg/L)	4.78	4.98	5.54	5.10	4.12	4.15	4.21	4.16
Carbonates (mg/L)	7.88	7.97	8.28	8.04	7.92	8.43	8.45	8.27
Total Phosphates (mg/L)	4.28	4.35	4.50	4.38	4.51	4.81	5.70	5.01
Nitrates (mg/L)	13.57	14.56	14.58	14.24	14.36	14.47	14.58	14.47
Sulphates (mg/L)	3.91	4.43	4.98	4.44	4.93	5.60	6.54	5.69
Potassium (ppm)	12.67	12.75	12.84	12.75	13.34	13.45	13.53	13.44
Calcium (ppm)	6.01	6.08	6.11	6.07	6.16	6.21	6.24	6.20
Iron (ppm)	3.56	3.58	3.64	3.59	4.98	5.12	5.16	5.09
Sodium (ppm)	345.3	347.6	349.4	347.4	378.4	379.7	382.2	380.1
Total dissolved solids (mg/L)	812.0	845.3	853.7	837.0	887.4	889.8	893.7	890.3

Table 4.15: Average values of selected physicochemical parameters of water samples along upstream sampling stations (A) and (B) (Rivers Nasaia and Mai Mahiu) and downstream stations C and D (River Ewaso) within the study area during wet period from Dec. 2016–Feb 2018

Physical Parameters	**Mean concentration levels along sampling stations**				
	Station (A)	Station (B)	Station (C)	Station (D)	p-value
pH	6.98±0.01[a]	6.99±0.01[a]	8.37±0.04[b]	7.59±0.02[c]	<0.001
Temperature (^{o}C)	15.43±0.27[a]	15.39±0.31[a]	24.44±0.62 [b]	26.17±0.32[c]	<0.001
Turbdity (NTU)	9.85±0.03a	8.72±0.08[a]	137.67±9.70 [b]	205.67±2.40[b]	<0.001
Conductivity (µS/cm)	369.33±12.5[a]	419.67±4.1[a]	507.33±4.8 [b]	520.33±3.3[b]	<0.001
Flow velocity (km/h)	9.53±1.05[a]	9.17±1.36[a]	4.40±0.577 [b]	2.53±0.38[b]	<0.001
Dissolved oxygen (mg/L)	5.40±0.23[a]	5.31±0.19[a]	3.45±0.35 [b]	3.11±0.037 [b]	<0.001
Chemical Parameters					
Chlorides (mg/L)	3.59±0.10[a]	3.47±0.09[a]	5.10±0.23 [b]	4.16±0.03[b]	<0.001
Carbonates (mg/L)	6.65±0.06[a]	6.85±0.10[a]	8.04±0.12 [b]	8.27±0.10[b]	<0.001
Total Phosphates (mg/L)	2.25±0.11[a]	2.24±0.14[a]	4.38±0.07[b]	5.007±0.36[b]	<.001
Nitrates (mg/L)	2.15±0.02[a]	2.46±0.02[a]	14.24±0.34 [b]	14.47±0.06 [b]	<0.001
Sulphates (mg/L)	2.92±0.02[a]	2.85±0.07[a]	4.44±0.31[b]	5.69±0.47[c]	<.001
Potassium (ppm)	4.43±0.03[a]	4.79±0.03[a]	12.75±0.05 [b]	13.44±0.06[c]	<0.001
Calcium (ppm)	5.29±0.08[a]	5.50±0.03[a]	6.07±0.03 [b]	6.20±0.02[b]	<0.001
Iron (ppm)	2.54±0.02[a]	2.90±0.02[a]	3.59±0.02 [b]	5.09±0.06[b]	<0.001
Sodium (ppm)	255.97±0.50[a]	272.33±2.3[a]	347.43±1.2 [b]	380.10±1.1[c]	<0.001
Total dissolved solids (mg/L)	343.37±4.2[a]	357.30±2.5[a]	837.00±12.7 [b]	890.30±1.8[b]	<0.001

*Means values with superscripts (a, b, ab and c), statistically different (p<0.05 levels).

Table 4.16: Seasonal differences on selected physicochemical parameters of the river water samples along upstream (Nasaia and Mai Mahiu) and downstream (Ewaso River) within the study area from Dec. 2016–Feb. 2018.

Physical Parameters	**Mean concentration levels comparison during dry and wet period along sampling stations**											
	Station A (dry season)	Station A (wet season)	Seasonal difference	Station B (dry season)	Station B (wet season)	Seasonal difference	Station C (dry season)	Station C (wet season)	Seasonal difference	Station D (dry season)	Station D (wet season)	Seasonal difference
pH	7	6.98	0.02	7.03	6.99	0.04	8.82	8.37	0.45	7.91	7.59	0.32
Temperature (^{o}C)	15.7	15.4	0.3	15.9	15.4	0.5	26.1	24.4	1.7	27.2	26.2	1.0
Turbdity (NTU)	8.5	9.9	-1.4	8.2	8.7	-0.5	112.5	137.7	-25.2	144.3	205.7	-61.4
Conductivity (µS/cm)	462.3	5.4	456.9	469.7	5.3	464.4	532.7	3.5	529.2	563.7	3.1	560.6
Flow velocity (km/h)	8.6	9.53	-0.93	8.2	9.17	-0.97	3.31	4.4	-1.09	2	2.53	-0.53
Dissolved oxygen (mg/L)	6.12	5.4	0.72	6.13	5.31	0.82	3.81	3.45	0.36	3.45	3.11	0.34
Chemical Parameters												
Chlorides (mg/L)	3.63	3.59	0.04	3.6	3.47	0.13	5.37	5.1	0.27	3.99	4.16	-0.17
Carbonates (mg/L)	7.05	6.65	0.4	7.2	6.85	0.35	8.92	8.04	0.88	7.82	7.34	0.48
Total Phosphates (mg/L)	3.62	2.25	1.37	3.45	2.24	1.21	5.38	4.38	1	6.86	5.01	1.85
Nitrates (mg/L)	2.97	2.15	0.82	2.95	2.46	0.49	16.57	14.24	2.33	15.09	14.47	0.62
Sulphates (mg/L)	2.74	2.92	-0.18	3.94	2.77	1.17	5.84	3.9	1.94	6.62	5.38	1.24
Potassium (ppm)	5.67	4.43	1.24	5.71	4.79	0.92	13.93	12.75	1.18	14.47	13.44	1.03
Calcium (ppm)	5.42	5.29	0.13	6.58	5.5	1.08	6.31	6.07	0.24	6.55	6.2	0.35
Iron (ppm)	3.24	2.54	0.7	3.19	2.9	0.29	4.49	3.59	0.9	6.16	5.09	1.07
Sodium (ppm)	304.4	256.0	48.4	305.8	272.3	33.5	400.2	347.4	52.8	422.1	380.1	42.0
Total dissolved solids (mg/L)	332.3	343.4	-11.1	345.5	357.3	-11.8	794.7	837.0	-42.3	817.7	890.3	-72.6

Variation in physico-chemical parameters in both dry and wet seasons at sampling stations (C) and (D) when compared with international standards (Table 4.17), were found to have exceeded the acceptable limits.

Table 4.17: Comparison of water quality chemical levels of the present study with international standards

Parameter	**WHO, (2011)**	**EU, (1998)**	**KEBS (2007)**	**Water quality results (2017/2019)**			
				(A)	**(B)**	**(C)**	**(D)**
Chloride (mg/L)	2.50	2.50	2.50	3.63	3.67	5.37	5.66
Carbonates (mg/L)	(-)	(-)	(-)	7.47	7.92	9.39	10.18
Phosphate (mg/L)	0.3	5	(-)	2.25	2.24	4.38	5.01
Nitrate (mg/L)	10	50	10	2.97	2.95	16.57	15.09
Sulphate (mg/L)	2.50	2.50	4.00	3.00	3.94	5.84	6.62
Potassium (mg/L)	<50	10		5.67	5.71	13.93	14.47
Calcium (mg/L)	<1.00	(-)	1.50	5.42	5.52	6.31	6.57
Sodium (mg/L)	<200	200	200	304.43	305.8	400.22	422.1
Total Dissolved Solids (mg/L)	600	1000	2500	332.33	345.5	794.67	817.67
Iron (mg/L)	0.3	0.2	0.3	3.24	3.19	3.19	4.49

4.7 Objective 5: Impacts of land-use and land-cover changes on climatic variability

4.7.1 Impacts on rainfall

The total rainfall from 1985 to 2014 is 24462.5 mm with average annual rainfall of 815.4 mm, rainfall range of 743.3 mm and standard deviation of 188.86 mm. Long-term monthly ranged between 94.8 and 335.2 mm (Table 4.18).

Table 4.18: Statistical summary of long-term annual and monthly rainfall distribution in Mai Mahiu, Nakuru County.

Year	Month																			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Range	Min	Max	Sum	Mean	SD	Variance	cv
1985	4.9	75.7	113.9	266.7	108.4	40.8	35.0	18.7	20.3	50.8	109.6	64.9	261.8	4.9	266.7	909.5	75.8	70.8	5009	0.9
1986	14.9	6.4	65.6	235.8	191.0	35.0	10.1	10.7	14.0	48.9	138.5	80.6	229.4	6.4	235.8	851.6	71.0	77.4	5996	1.1
1987	29.2	22.5	31.9	151.0	119.9	77.2	18.3	34.9	11.1	12.6	136.6	15.2	139.9	11.1	151.0	660.4	55.0	52.1	2718	0.9
1988	64.4	14.4	104.1	355.1	164.9	52.4	29.3	46.0	41.0	32.6	105.8	84.9	340.7	14.4	355.1	1095.1	91.3	93.2	8677	1.0
1989	96.6	49.0	88.9	214.7	170.8	20.9	51.3	42.8	47.2	109.6	117.8	127.9	193.9	20.9	214.7	1137.4	94.8	57.6	3316	0.6
1990	44.3	63.9	213.0	233.1	161.3	16.2	21.1	24.3	20.0	95.9	103.4	65.1	216.8	16.2	233.1	1061.7	88.5	76.1	5788	0.9
1991	25.8	5.7	92.0	110.5	198.6	41.3	18.9	28.1	11.2	53.3	98.4	45.3	192.9	5.7	198.6	729.3	60.8	55.6	3097	0.9
1992	6.8	18.0	17.6	239.4	118.0	41.3	42.4	19.4	23.4	60.9	100.9	87.6	232.6	6.8	239.4	775.7	64.6	65.9	4342	1.0
1993	166.9	61.1	24.1	53.6	95.1	62.8	11.3	15.1	7.6	30.9	77.4	69.6	159.3	7.6	166.9	675.3	56.3	44.9	2018	0.8
1994	7.2	41.8	62.5	185.7	113.9	44.9	36.6	37.5	9.8	103.6	241.1	45.3	233.9	7.2	241.1	929.8	77.5	71.9	5169	0.9
1995	12.7	68.2	125.1	147.8	129.8	39.6	30.5	47.3	36.8	107.4	96.9	53.3	135.1	12.7	147.8	895.3	74.6	44.9	2019	0.6
1996	17.4	41.6	105.8	79.7	93.5	77.2	51.1	43.7	23.5	18.1	113.8	14.2	99.7	14.2	113.8	679.7	56.6	36.1	1305	0.6
1997	8.7	0.4	34.3	299.6	77.3	37.9	23.6	34.3	4.4	140.2	255.5	147.1	299.2	0.4	299.6	1063.3	88.6	101.1	10231	1.1
1998	234.4	129.1	74.8	151.3	247.4	63.7	25.2	31.2	24.4	22.7	59.7	8.8	238.7	8.8	247.4	1072.7	89.4	83.0	6896	0.9
1999	16.3	1.9	141.6	108.2	32.4	11.0	14.6	39.2	15.8	28.0	190.7	111.2	188.8	1.9	190.7	710.9	59.2	62.2	3871	1.1
2000	4.2	1.5	20.4	65.8	41.1	19.8	20.4	13.9	18.9	27.7	104.3	55.8	102.8	1.5	104.3	393.7	32.8	29.6	877	0.9
2001	209.5	11.1	125.3	132.8	49.1	28.8	22.0	22.5	21.0	42.9	110.4	24.3	198.3	11.1	209.5	799.7	66.6	62.8	3939	0.9
2002	52.9	18.3	112.3	219.2	149.6	11.1	15.1	20.1	22.4	77.5	114.8	133.2	208.2	11.1	219.2	946.5	78.9	67.2	4521	0.9
2003	27.3	8.1	43.4	157.3	261.7	40.6	13.2	64.7	25.8	61.5	73.8	24.6	253.7	8.1	261.7	802.1	66.8	73.1	5350	1.1
2004	31.0	33.8	71.6	243.6	89.1	7.6	6.9	7.3	21.8	52.1	77.3	41.7	236.8	6.9	243.6	683.8	57.0	65.1	4238	1.1
2005	29.9	19.0	50.7	131.2	166.2	32.2	30.8	22.6	39.2	37.6	50.8	4.3	161.9	4.3	166.2	614.6	51.2	47.9	2294	0.9
2006	13.0	24.5	90.9	217.8	220.4	31.0	29.9	44.3	48.4	61.0	208.2	143.9	207.4	13.0	220.4	1133.3	94.4	80.9	6542	0.9
2007	34.0	43.7	33.5	129.9	86.1	51.0	40.7	52.6	50.8	42.6	34.8	21.5	108.3	21.5	129.9	621.2	51.8	29.2	854	0.6
2008	34.1	26.1	131.0	124.8	24.9	9.5	32.2	20.1	41.1	106.4	91.1	5.5	125.5	5.5	131.0	646.6	53.9	45.9	2109	0.9
2009	28.7	15.2	26.9	78.9	93.1	19.3	8.4	13.6	17.1	99.2	74.9	103.2	94.8	8.4	103.2	578.6	48.2	37.9	1437	0.8
2010	72.2	80.0	168.2	147.8	199.9	34.3	22.8	0.0	0.0	0.0	0.0	41.4	199.9	0.0	199.9	766.5	63.9	71.4	5104	1.1
2011	8.6	31.9	103.2	65.5	92.6	51.5	28.2	57.5	55.0	136.7	170.5	97.4	161.9	8.6	170.5	898.7	74.9	47.0	2212	0.6
2012	0.8	23.7	8.5	288.7	171.9	56.6	10.1	0.0	0.0	19.7	47.8	65.7	288.7	0.0	288.7	693.4	57.8	87.3	7615	1.5
2013	35.6	4.8	175.7	340.1	48.1	29.4	28.1	42.8	43.9	18.9	117.2	108.0	335.2	4.8	340.1	992.8	82.7	95.0	9017	1.1
2014	14.6	58.0	108.2	71.4	70.6	68.0	32.9	46.6	44.5	78.7	0.0	49.8	108.2	0.0	108.2	643.2	53.6	29.2	855	0.5

The long-term (30-year) annual rainfall distribution in Mai Mahiu region shows a declining trend (Figure 4.9).

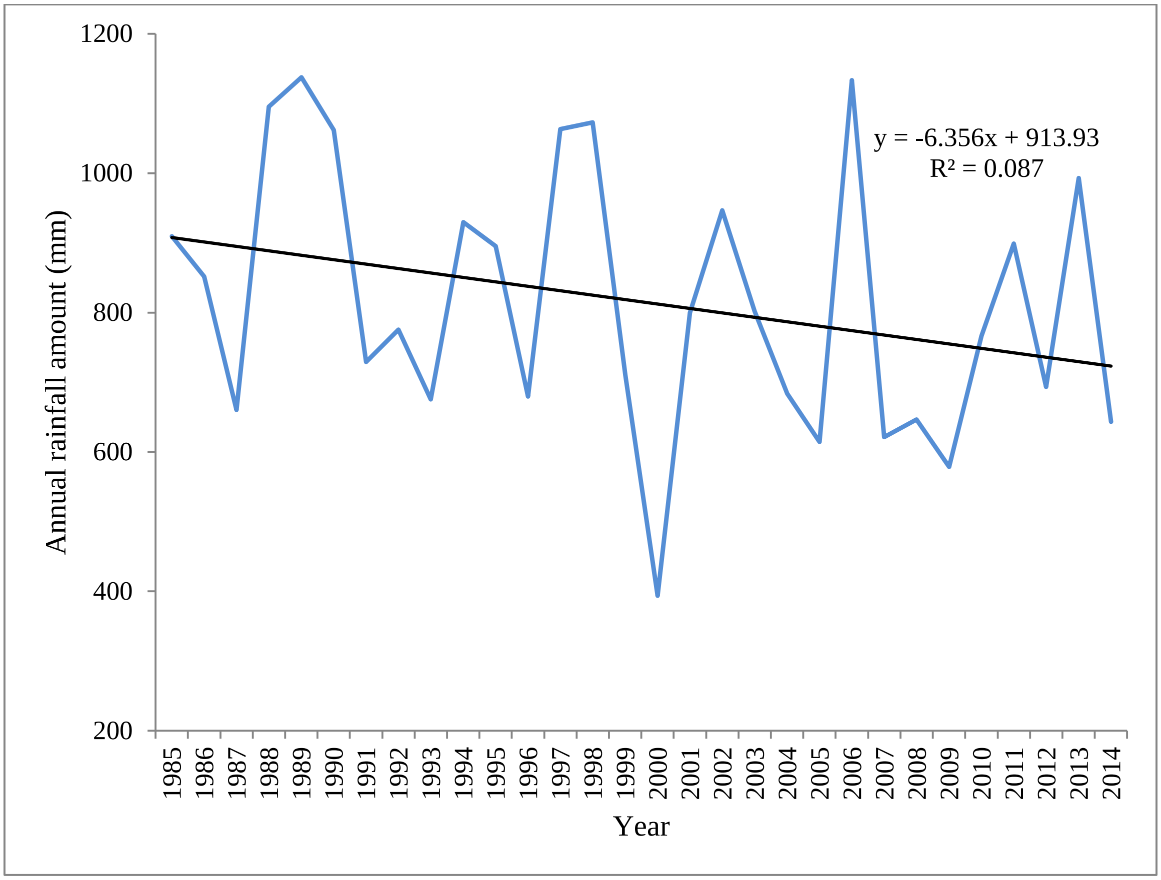

Figure 4.9: Annual rainfall distribution from 1985 to 2014 in Mai Mahiu

More rains were experienced in 1985–1994 with an average of 882.6 mm compared with 2005–2014 with average of 758.9 mm (Figure 4.10). The decrease in rainfall amounts in the last 20 years can be attributed to intense land-use change that took or taking place in this area as captured by Landsat imagery in objective one of this study.

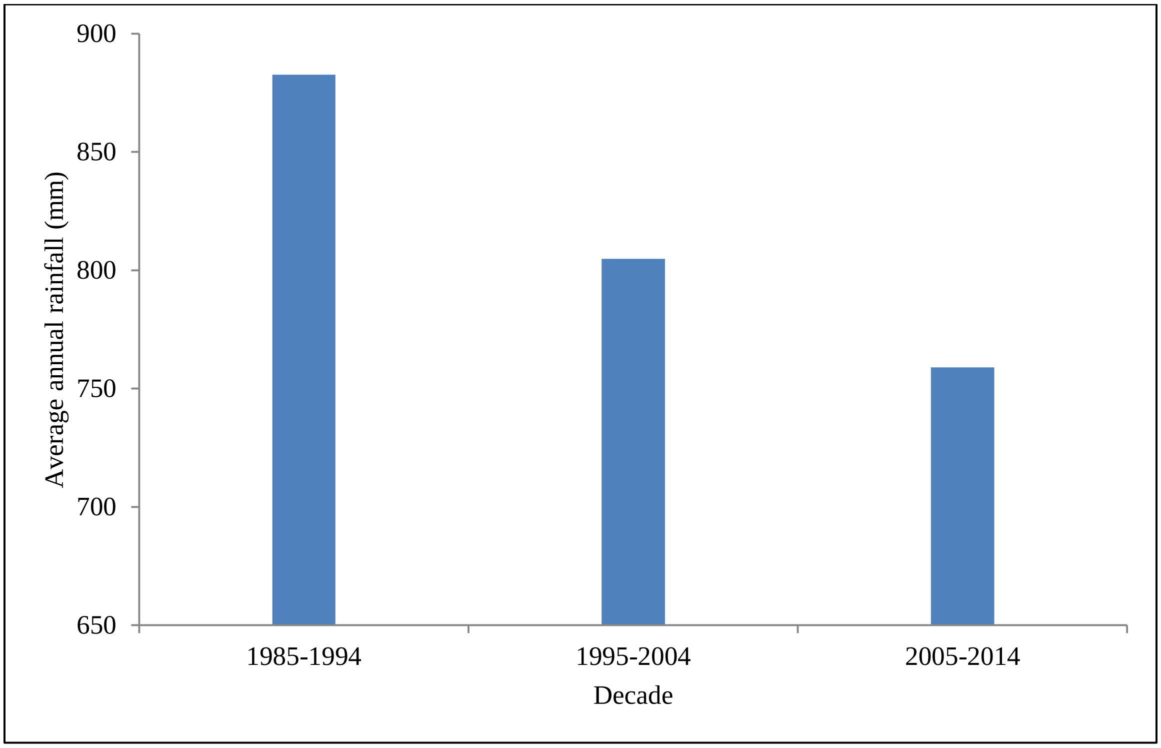

Figure 4.10: Rainfall distribution at ten-year interval for the last 30 years in Mai Mahiu area.

Long rain season receives the highest rainfall which is about 387 mm of rainfall contributing for 47.4% of the long-term average annual rainfall whereby the month of April recorded highest monthly precipitation of 174.9 mm. Short Rain season total precipitation received is 231.4 mm accounting for 28.4% of the total annual rainfall. Non-growing period of January to February and June to September recorded lesser precipitation of 78.2 mm and 119.2 mm respectively accounting for 10% and 14.6% of the average annual rainfall. The long-term mean annual rainfall for Mai Mahiu study area was 815.4 mm.

The long-term (30-year) rainfall analysis found that the long-term average monthly rainfall during rainy seasons of March–May and October–December was higher when compare with the study year seasons (Figure 4.11). There was slight increase in off-season months in year 2014 compared with the long-term average.

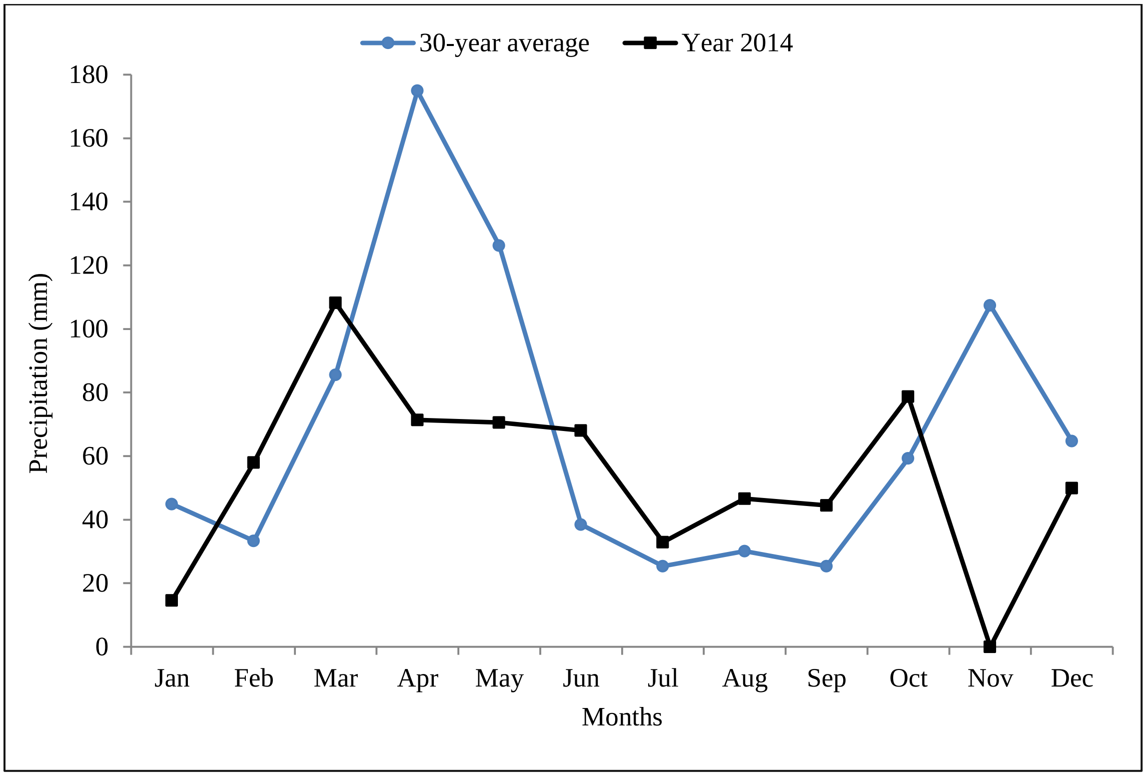

Figure 4.11: Comparison between long-term average precipitation (years 1985 – 2014) and year 2014 precipitation distribution in Mai Mahiu.

Below normal rainfall is defined as a period with precipitation amount of 75% or less of the long-term mean. Seven long rain seasons of year 1987, 1993, 2000, 2007, 2009, 2011 and 2014 experienced below normal rainfall of which 71.43% occurred in the last 20 years, from 1996 to 2014 (Table 4.19). For the case of the short rain seasons (October–December), 12 out of 30 seasons (40%) recorded below normal rainfall of which 83.33% occurring in the last 20 years (1996, 1998, 2001, 2003, 2004, 2005, 2007, 2010, 2012 and 2014). The increase in frequency of below normal rainfall in the last 20 years in both long and short rain seasons correlates positively with drastic increase in population and land use change and its associated poor land management. This is a clear indication that there an increase in aridity in the area within that last 20 years. In the case of above normal rainfall (precipitation amounts with 125% or more of the long-term mean - LTM), nine out of thirty long rain seasons and eight out of thirty short rain seasons experienced wet conditions due to receiving of above normal rainfall of which 88.9% of the long rain season and 87.5% of short rain season occurred in the last 20 years (1994–2014).

Table 4.19: Precipitation for total 30 year and growing season and percent of long-term mean (LTM) in Mai Mahiu (1985-2014).

Year	Total year		Long rain season (March-May)		Short rain season (October-December)	
	Precipitation (mm)	% of LTM	Precipitation (mm)	% of LTM	Precipitation (mm)	% of LTM
1985	909.52	103.05	488.90	113.67	225.24	89.56
1986	851.56	96.49	492.45	114.49	268.11	106.61
1987	660.38	74.82	302.83	70.41	164.38	65.36
1988	1095.14	124.08	624.16	145.12	223.36	88.81
1989	1137.45	128.88	474.49	110.32	355.23	141.25
1990	1061.67	120.29	607.39	141.22	264.43	105.14
1991	729.26	82.63	401.18	93.27	196.98	78.32
1992	775.66	87.89	375.05	87.20	249.36	99.15
1993	675.35	76.52	172.70	40.15	177.84	70.71
1994	929.77	105.35	361.99	84.16	390.04	155.09
Mean	**882.58**	**100.00**	**430.11**	**100.00**	**251.50**	**100.00**
1995	895.33	111.25	402.71	110.91	257.60	107.81
1996	679.71	84.46	279.05	76.85	146.10	61.15
1997	1063.25	132.12	411.18	113.24	542.82	227.18
1998	1072.68	133.29	473.61	130.43	91.18	38.16
1999	710.91	88.34	282.14	77.70	329.92	138.08
2000	393.74	48.93	127.39	35.08	187.73	78.57
2001	799.75	99.38	307.18	84.60	177.55	74.31
2002	946.49	117.61	481.11	132.50	325.58	136.26
2003	802.06	99.66	462.42	127.35	159.82	66.89
2004	683.82	84.97	404.31	111.35	171.09	71.60
Mean	**804.77**		**363.11**		**238.94**	
2005	614.58	80.98	348.11	94.94	92.76	45.54
2006	1133.27	149.33	529.14	144.31	413.08	202.81
2007	621.19	81.85	249.45	68.03	98.96	48.59
2008	646.62	85.21	280.62	76.53	202.97	99.65
2009	578.63	76.25	199.01	54.27	277.33	136.16
2010	766.53	101.01	515.87	140.69	41.37	20.31
2011	898.73	118.43	261.35	71.28	404.58	198.64
2012	693.43	91.37	469.11	127.94	133.16	65.38
2013	992.80	130.82	563.93	153.80	244.07	119.83
2014	643.22	84.76	250.15	68.22	128.50	63.09
Mean	**758.90**		**366.67**		**203.68**	

The consequences of excess and erratic and intense rainfall conditions coupled with reduced vegetation has led to severe degradation of Mai Mahiu ecosystem. Vegetation cover reduces the eroding power of the rain through dissipation of its kinetic energy and enhanced infiltration. Absence of vegetation cover enhances destruction of soil structure by raindrops and subsequent hindrance of infiltration and promotion of promote overland flow (Plate 4.11) that erodes away top soil into riverbeds and deposition at foot/toe slopes.

Plate 4.11: Image of severely degraded land as a result of variable climatic conditions in Mai Mahiu.

The pattern of change in rainfall variability in the last 30 years showed an increasing trend with coefficient of variation ranging between 0.5 and 1.1 (Figure 4.12). Regression analysis show a significant difference in monthly rainfall variability ($p<0.001$) with months of March, April, May and November being highly variable. No significant difference (p = 0.685) in the long-term annual variability (Figure 4.12). Average rainfall variability range in 1985-1994 period was 0.91 compared with 0.86 in 2005–2014. This is a manifestation that rainfall was decreasing and aridity increasing. Dryland areas may show a high inter-annual variability in their rainfall regime (Maestre *et al*., 2012). Inter-annual variability was found to be within bounds of that found in arid and semiarid regions. There is likelihood that inter-annual rainfall variability can influence the productivity, composition, structure, diversity of this ecosystem. It is reported that changes in the random seasonal patterns of precipitation might affect productivity of such ecosystem and cycling of nutrient (D'Odorico *et al.*, 2003).

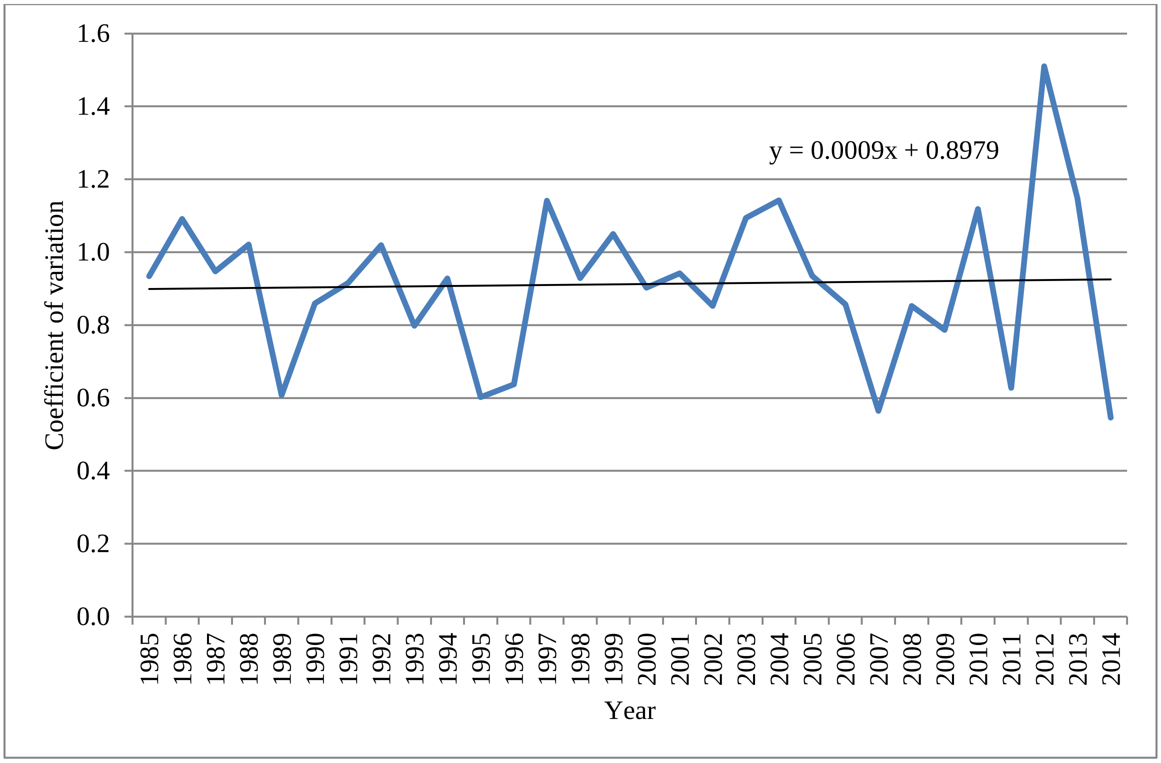

Figure 4.12: Rainfall variability from 1985 to 2014 in Mai Mahiu region

4.7.2 Impacts due to temperature fluctuations

Both mean annual maximum and minimum temperature showed an increasing trend from 1985 to 2014. Both minimum and maximum temperature was much lower in early years (1985–1994) compared with a drastic increase in recent years (2005–2014). Minimum temperature increased by 0.9 ^{o}C that is, from 11.8 ^{o}C in 1985–1994 to 12.7 ^{o}C in 2005–2014. Maximum temperature increased by 0.4 ^{o}C that is, from 23.8 ^{o}C in 1985–1994 to 24.2 ^{o}C in 2005–2014. This change is a manifestation that the local climate has become hotter and can be attributed to clearing of vegetation and settlement that has altered surface-atmosphere energy exchanges thereby having adverse effect on productivity of this ecosystem through increased evaporation and water balance.

Both decadal maximum and minimum temperature showed an increasing trend (Figure 4.13). Maximum temperature increased from a mean of 23.8 ^{o}C in the first decade to 24.2 ^{o}C in the last decade of study. This was at an increasing rate of 0.21 ^{o}C for every 10 years. Minimum temperature increased from a mean of 11.8 ^{o}C in the first decade to 12.7 ^{o}C in the last decade of study. This was at an increasing rate of 0.46 ^{o}C for every 10 years. Local climate has become hotter.

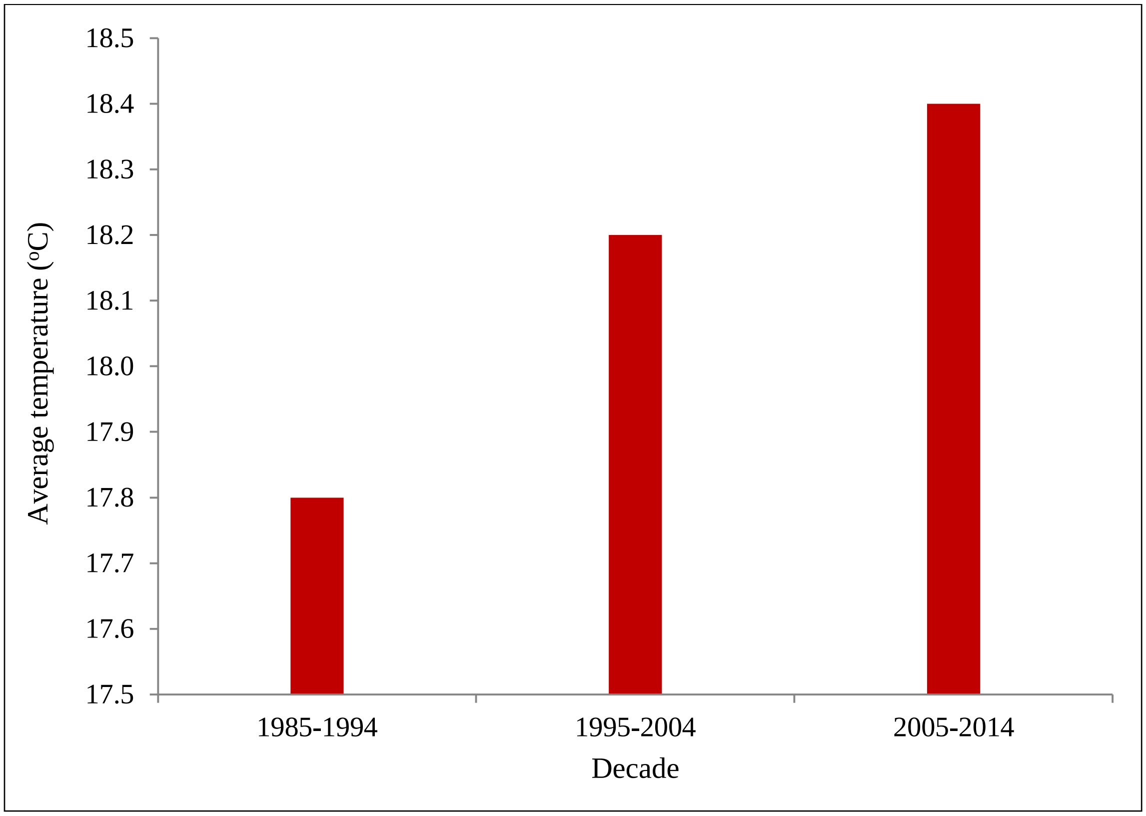

Figure 4.13: Decadal temperature distribution in Mai Mahiu for the last 30 years.

The long-term (30-year period) mean annual temperature was 18.1 °C. The highest temperature, in the day time was recorded in the months of February (26.6 °C) and March (26.2 °C). July was the coldest month, with a mean temperature of 16.2 and minimum temperature of 10.9 °C. Warmest months were found to be February, March and April with mean temperature range 19.1 °C to 19.6 °C. The observed increase in temperature in Mai Mahiu has led to increase in evapotranspiration leading to reduction of volume of water in rivers and water stress in crops and forage thereby affecting crop yields and reducing water and forage for livestock.

4.7.3 Rainfall and temperature interactions

To investigate the effect of land use on climate variability and the consequences on Mai Mahiu ecosystem productivity, thirty-year climate data was analyzed for in inter-annual precipitation and temperature interaction (ombrothermic relationship) to identify how this has affected the productivity of this ecosystem especially development of specific types of vegetation. Climatic conditions, especially the relationship between temperature and precipitation affects soil water balance and subsequently available water which crucial in plant productivity. Equally true that vegetation also feedback on climate.

Ombrothermic diagram drawn helps to identify the dry and wet months in a region with the help of monthly average temperature and average rainfall. In the diagram, the rainfall amount is plotted in the Y axis at the left side and the temperature is plotted on the right side of the Y axis while the months are plotted in the X axis. It is observed from the diagram that the months showing rainfall below the average temperature are identified as dry months and the months above the average temperature are considered to be as wet months. The ombrothermic relationship for Mai Mahiu is shown for each month from 1985 to 2014 is shown in Figure 4.14. From the diagram it is evident that only 25% or three out of 12 months of the year (April, May and November) are considered as wet months, because rainfall amount received fall above the mean temperature. The remaining months (75%) are dry or near-water deficient months as the rainfall received fall below the mean temperature and they include months of June to October and December to February.

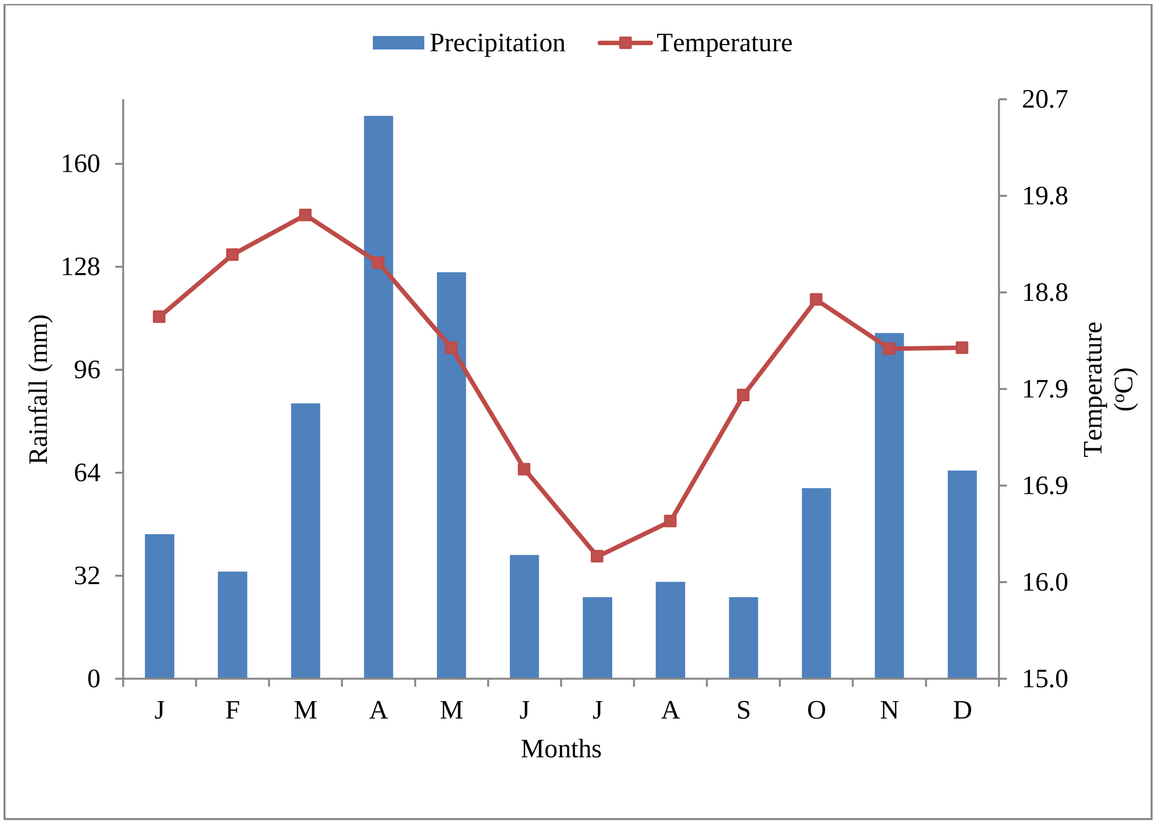

Figure 4.14: Ombrothermic diagram shows the impacts of temperature on precipitation within Mai Mahiu region since the year 1985 up to 2014.

The study found that decade-wise temperature-rainfall interactions were more favourable for plant growth during 1985–1994 period than subsequent periods of 1995–2004 and 2005–2014 (Figure 4.15a, b and c). In 1985–1994 decade, four months (April, May, July and November) of the year had enough soil moisture and slight soil moisture deficiency in the month of August. Difference was noticed in 1995–2004 period where three out of twelve months had favourable conditions for plant growth. These were April, May and November with the month of July being water deficient. Between 2005–2014, only two months of April and May showed favourable conditions while the rest of the year including the short rain season of October, November and December had negative water balance that was drastic. The pronounced changes in temperature-rainfall interaction during 1995–2004 and 2005–2014 manifests climatic variability which may be associated with intense land-use changes that has taken place in this area.

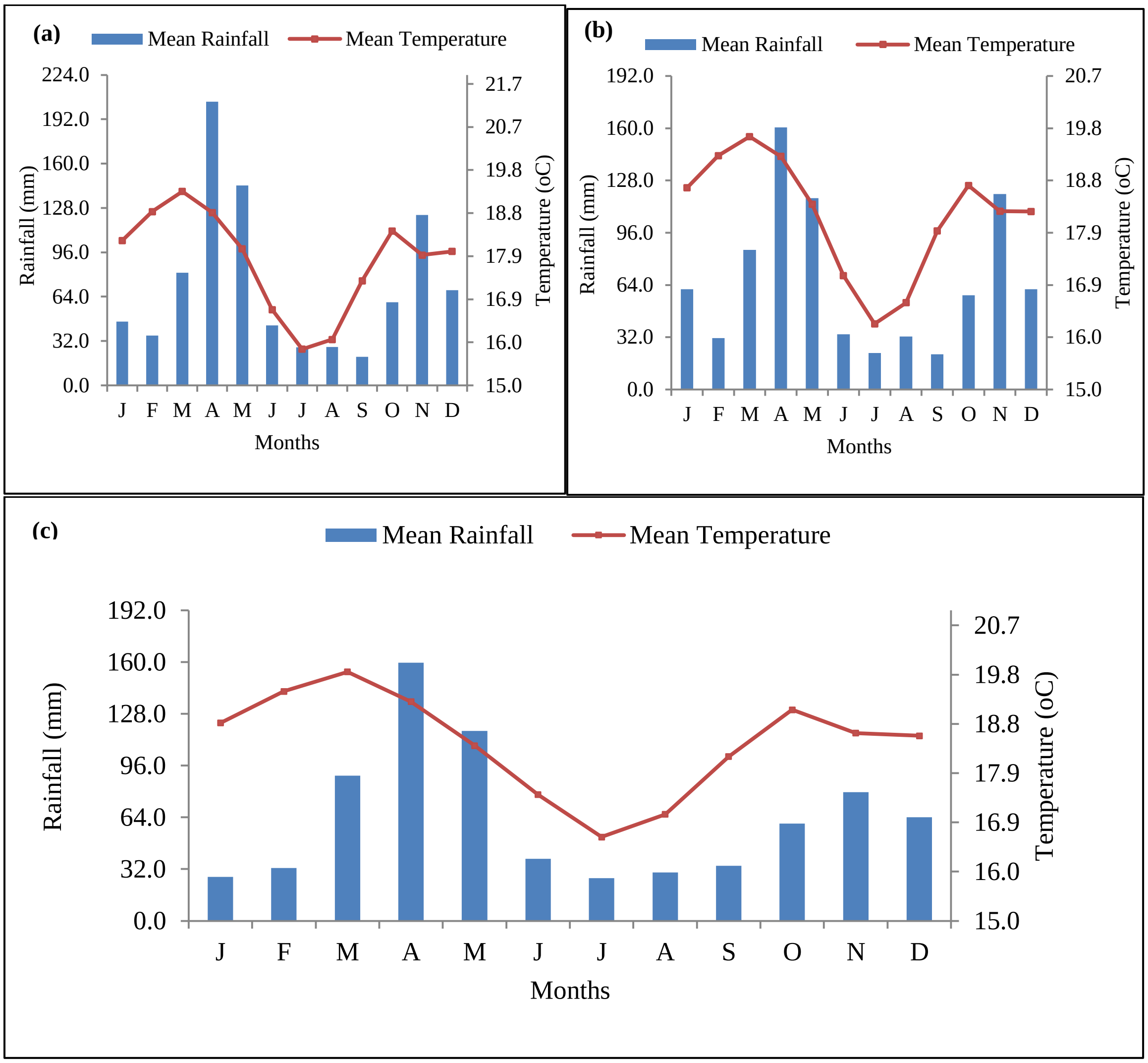

Figure 4.15: Decadal ombrothermic diagrams (a) 1985-1994, (b) 1995-2004 and (c) 2005-2014 shows progressive negative interactions in the months of July-December in Mai Mahiu.

Environmental gradients mainly temperature, precipitation and wind velocity play a major role in climate stability or variations in any region. If any of these three gradients have high fluctuations the area will experience some forms of drought or flood. Temperature and precipitation act together to affect the physiological and ecological status of plants. The biological situation of a plant at any time is determined by the balance between rainfall and potential evapotranspiration. One month with water deficiency conditions can cause plants to experience water stress severe enough to reduce herbage biomass production. When water gain is less than water loss, negative water balance occurs as shown in Figure 4.4. Negative water balance were pronounced in the later decades under study. The wet conditions show that soil has enough water for favorable soil water-plant relations to occur and plants are able to grow and accumulate biomass. Under water deficiency conditions, water stress develops and plants are unable to absorb adequate water to match their transpiration rate and maintain homeostasis. However, some plants develop mechanisms that help reduce the damage from water stress, but with some degree of reduction in herbage production. Increasing temperature has affected crop yields, forage production and water availability for livestock in the area. Under tropical climate conditions if any region will experience the temperature between 15 and 25 ^{o}C and with an average of 300 mm of rain throughout the year, it will give us a reasonable production of the forage as well as certain agricultural crops.

The findings of this study agrees with that of McCain and Colwell (2011) and Thomas *et al*. (2004) where it is noted that rapid shifts in temperature and precipitation in a changing climate is threat to biodiversity. Temperature changes and increases of extreme weather events (Hansen *et al*., 2012) are the cause of important changes in biodiversity around the globe and it is associated to the effects of land-use changes such as habitat loss (Lambin and Meyfroidt, 2011) and land-use intensification (Tscharntke *et al*., 2005). Climate and land-use change are, therefore, considered to be key drivers of biodiversity loss today and, particularly when combined, they can reduce suitable habitats for species and disrupt ecological interactions, potentially driving species to extinction (Fox *et al*., 2014). IPCC

(2018) notes that temperature rise may led to drought and water scarcity through enhanced evapotranspiration and reduction of surface and underground water. Also, increase in temperature may reduce forage and water in water bodies for livestock (Thornton *et al*., 2009)

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATIONS

Because of the rejection of the null hypotheses postulated in this study, alternative hypotheses are therefore accepted and stated as follows:

(i) That there is significant changes in land-use and land-cover changes on Mai Mahiu ecosystem in the past 30 years (1985-2015);

(ii) That land-use and land-cover changes have affected soil properties within the Mai Mahiu ecosystem in the study period;

(iii) That natural vegetation composition and characteristics in the study area have been modified by land-use and land-cover changes;

(iv) That there is negative impacts of land use land cover changes on water quality and quantity of rivers within Mai Mahiu region; and

(v) That changes in land-use and land-cover for the last 30 years are the cause of climatic variability within the study area.

Based on the accepted alternative hypotheses together with results of this study, summary, conclusion and recommendations are as follows:

5.1 SUMMARY

The following constitute summary of the study on the impacts of land-use and land-cover changes on Mai Mahiu ecosystem.

5.1.1 Land use and land cover changes from 1985 to 2015

Significant land-use and land-cover changes were observed for a period of 30 years (1985–2015). During that period, 0.6 km^2 covered with deciduous trees in 1985 was used as built-up area by 2015. Other changes show that 5.1 km^2 of grassland, 2.2 km^2 of bare land, 0.1 km^2 of evergreen trees, 11.9 km^2 of shrubs and 4.1 km^2 of heathland were all converted to built-up areas by 2015. Shrubs land was cleared and resulted to 15.8 km^2 of grassland, 17.7 km^2 turned to be heathland and 7.8 km^2 used as cropland in 2015.

5.1.2 Impacts of land use and land cover changes on soil properties

Soil attributes have been affected by land-use and land-cover changes. Bulk density increased between 12 and 25% with land use modifications and changes. Organic carbon losses of up to 63% was recorded while nitrogen levels dropped by 55.9% of the original stock.

5.1.3 Impacts of land use and land cover changes on vegetation

Mai Mahiu vegetation is composed of 21 families and 31 genera stratified in three layers namely upper (tree layer); middle (shrub layer) and the lower stratum (herb layer). Landscape was dominantly covered by C*roton bathianus, Justicia gendarussa, Oscimum gratissimum,Aspilia africana*, *Croton natoulensis and Tarchonanthus camphoratus.* There were two different plant associations namely *Justicia-Oscimum-Aspilia* association and *Croton-Tarchonanthus-Themeda triandra* association. These formations are in areas degraded by overgrazing and cut of trees for firewood and poles.

5.1.4 Impacts of land use and land cover changes on water quality of rivers

Land use and land cover changes have influenced physico-chemical characteristics of water of Ewaso River. There is high mineral and salt concentrations with electrical conductivity ranging between 512.04 and 563.67 μS/cm. There are high levels of chlorides, nitrates, phosphates, potassium, sulphates, calcium, iron, sodium and dissolved solids thus making this water unsuitable for drinking.

5.1.5 Climatic variability

Variations in rainfall amount and duration and temperature fluctuations are evident in the past 30 years; from 1985 up to 2015.

5.2 CONCLUSION

Based on the results, it is concluded that:

i. There is significant land-use changes with significant impacts on Mai Mahiu ecosystem within the period of 1985 to 2015,

ii. unsustainable land-use practices have led to soil degradation and loss of land productivity,

iii. Land-use changes have affected vegetation types and its composition, cover and productivity,

iv. Water quality of Ewaso River, especially the downstream is polluted by a number of human-induced factors therefore not good for human consumption, and

v. Land use and land cover changes are responsible for changing climatic conditions in the region thus affecting land management decisions.

5.3 RECOMMENDATIONS

The study revealed and concluded that the Mai Mahiu is a degraded ecosystem and if anthropogenic and other biotic interferences are not controlled or continue unabated in their current speed, the valuable resources and functions may be wasted or lost soon. There is need for attention by various actors including involvement of local people for protection, management, sustainable and improvement of this environment. To achieve that, the following recommendations are made:

- Environmental awareness must be enhanced nationwide

- Proper human settlement policies must be enforced to control further land degradation, provision of agricultural activities and infrastructural development for healthy human population and environment.
- Soil and water conservation policies must be practiced to manage the land and its cover for environmental management.
- Trained environmental officers must guide and assist the local people of Mai Maihu region for sustainable land use practices.
- Natural vegetation cover must be protected to control soil erosion / land degradation.
- Strong enforcement of environmental laws must be practiced in the area to protect the land, water bodies and natural vegetation for present and future generation.
- To avoid a serious threat to the health of stream ecosystem and local communities, pollutants should be controlled effectively through implementing proper management policies and actions.
- Based on World Standards, only water from sampling station A (Nasaia river) and B (Mai Mahiu River) should be used for domestic purposes.

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APPENDICES

Appendix 1: Mean monthly rainfall (mm) between years 1985 and 2014 in the study area.

Year	**Month**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	4.9	75.7	113.9	266.7	108.4	40.8	35.0	18.7	20.3	50.8	109.6	64.9
1986	14.9	6.4	65.6	235.8	191.0	35.0	10.1	10.7	14.0	48.9	138.5	80.6
1987	29.2	22.5	31.9	151.0	119.9	77.2	18.3	34.9	11.1	12.6	136.6	15.2
1988	64.4	14.4	104.1	355.1	164.9	52.4	29.3	46.0	41.0	32.6	105.8	84.9
1989	96.6	49.0	88.9	214.7	170.8	20.9	51.3	42.8	47.2	109.6	117.8	127.9
1990	44.3	63.9	213.0	233.1	161.3	16.2	21.1	24.3	20.0	95.9	103.4	65.1
1991	25.8	5.7	92.0	110.5	198.6	41.3	18.9	28.1	11.2	53.3	98.4	45.3
1992	6.8	18.0	17.6	239.4	118.0	41.3	42.4	19.4	23.4	60.9	100.9	87.6
1993	166.9	61.1	24.1	53.6	95.1	62.8	11.3	15.1	7.6	30.9	77.4	69.6
1994	7.2	41.8	62.5	185.7	113.9	44.9	36.6	37.5	9.8	103.6	241.1	45.3
1995	12.7	68.2	125.1	147.8	129.8	39.6	30.5	47.3	36.8	107.4	96.9	53.3
1996	17.4	41.6	105.8	79.7	93.5	77.2	51.1	43.7	23.5	18.1	113.8	14.2
1997	8.7	0.4	34.3	299.6	77.3	37.9	23.6	34.3	4.4	140.2	255.5	147.1
1998	234.4	129.1	74.8	151.3	247.4	63.7	25.2	31.2	24.4	22.7	59.7	8.8
1999	16.3	1.9	141.6	108.2	32.4	11.0	14.6	39.2	15.8	28.0	190.7	111.2
2000	4.2	1.5	20.4	65.8	41.1	19.8	20.4	13.9	18.9	27.7	104.3	55.8
2001	209.5	11.1	125.3	132.8	49.1	28.8	22.0	22.5	21.0	42.9	110.4	24.3
2002	52.9	18.3	112.3	219.2	149.6	11.1	15.1	20.1	22.4	77.5	114.8	133.2
2003	27.3	8.1	43.4	157.3	261.7	40.6	13.2	64.7	25.8	61.5	73.8	24.6
2004	31.0	33.8	71.6	243.6	89.1	7.6	6.9	7.3	21.8	52.1	77.3	41.7
2005	29.9	19.0	50.7	131.2	166.2	32.2	30.8	22.6	39.2	37.6	50.8	4.3
2006	13.0	24.5	90.9	217.8	220.4	31.0	29.9	44.3	48.4	61.0	208.2	143.9
2007	34.0	43.7	33.5	129.9	86.1	51.0	40.7	52.6	50.8	42.6	34.8	21.5
2008	34.1	26.1	131.0	124.8	24.9	9.5	32.2	20.1	41.1	106.4	91.1	5.5
2009	28.7	15.2	26.9	78.9	93.1	19.3	8.4	13.6	17.1	99.2	74.9	103.2
2010	72.2	80.0	168.2	147.8	199.9	34.3	22.8	0.0	0.0	0.0	0.0	41.4
2011	8.6	31.9	103.2	65.5	92.6	51.5	28.2	57.5	55.0	136.7	170.5	97.4
2012	0.8	23.7	8.5	288.7	171.9	56.6	10.1	0.0	0.0	19.7	47.8	65.7
2013	35.6	4.8	175.7	340.1	48.1	29.4	28.1	42.8	43.9	18.9	117.2	108.0
2014	14.6	58.0	108.2	71.4	70.6	68.0	32.9	46.6	44.5	78.7	0.0	49.8

Appendix 2: Mean monthly maximum temperature (^oC) between years 1985 and 2014 in the study area.

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	25.8	25.4	25.4	23.2	22.2	21.7	21.2	21.0	24.0	24.5	23.3	24.1
1986	26.3	28.2	26.8	24.1	22.3	21.0	21.4	23.2	23.9	25.7	23.7	23.9
1987	24.8	26.7	27.7	25.1	23.6	22.0	22.0	22.3	25.6	26.6	24.2	25.7
1988	26.0	27.0	26.6	23.9	22.5	21.7	21.2	21.4	23.0	24.8	23.0	23.2
1989	23.8	24.7	25.8	22.7	22.5	21.5	20.8	20.7	23.1	23.4	22.8	23.7
1990	24.2	25.6	23.8	23.4	23.3	22.1	21.7	21.1	24.3	24.6	23.1	23.2
1991	25.8	27.5	26.8	24.5	22.9	22.5	20.7	22.4	24.4	25.3	23.5	24.1
1992	25.3	27.0	27.2	24.7	22.9	21.9	20.6	20.3	23.2	24.5	23.2	23.3
1993	22.9	23.9	25.7	25.1	24.0	21.7	21.1	22.2	24.7	25.5	24.1	23.7
1994	26.0	26.7	26.3	24.4	22.4	22.0	20.9	21.1	23.7	24.8	23.0	23.8
1995	26.2	26.7	24.9	24.5	23.2	23.3	21.1	22.0	23.9	24.1	23.7	23.5
1996	25.4	26.5	26.1	24.6	23.1	21.1	20.6	22.1	24.3	25.6	23.3	24.9
1997	26.8	28.6	27.4	23.8	22.7	22.1	21.6	23.0	25.6	23.7	22.6	23.1
1998	23.5	25.6	25.6	25.1	23.6	22.2	20.0	20.4	23.7	25.3	23.7	25.6
1999	26.5	27.8	26.1	24.0	23.2	22.9	21.9	22.0	24.4	25.2	23.1	23.0
2000	25.7	27.6	27.2	25.4	24.2	22.5	22.2	22.6	24.4	25.8	24.1	24.3
2001	23.8	26.0	25.4	23.6	23.0	21.9	21.0	23.1	25.1	25.2	23.0	24.3
2002	25.4	26.9	25.5	24.3	23.1	22.2	22.8	21.6	24.6	24.9	23.8	23.8
2003	25.3	27.6	27.4	25.5	22.9	21.9	21.3	21.7	23.7	24.9	23.5	24.3
2004	25.1	25.2	25.9	23.7	23.3	21.5	22.9	22.7	25.0	24.4	23.5	24.5
2005	26.4	27.6	26.9	25.0	23.4	21.4	20.6	21.6	23.7	25.1	24.3	26.0
2006	26.3	27.7	26.0	23.7	23.2	22.8	20.9	23.1	23.6	25.5	22.8	23.5
2007	24.6	25.9	25.9	24.6	23.0	22.3	21.0	21.3	23.6	24.1	23.9	24.7
2008	25.7	25.8	26.0	23.7	23.3	22.3	21.5	22.7	25.2	24.6	24.3	25.5
2009	26.3	26.6	28.1	25.6	24.0	23.9	22.5	22.8	25.9	24.7	24.5	24.6
2010	24.7	25.7	24.7	24.5	23.6	22.2	21.6	22.0	24.1	25.2	23.6	24.9
2011	26.2	27.4	26.6	25.1	23.7	23.6	23.8	22.0	24.1	24.3	23.6	24.1
2012	26.6	27.2	27.8	24.5	23.2	21.8	21.3	22.8	24.5	25.0	24.1	23.7
2013	25.1	26.5	26.2	24.3	23.3	22.1	23.0	21.9	25.0	26.0	24.0	23.4
2014	25.6	24.9	24.7	23.4	21.9	22.5	22.0	22.9	23.2	24.8	23.7	23.9

Appendix 3: Mean monthly minimum temperature (^oC) in the study between years 1985 and 2014, Mai Mahiu.

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	10.4	12.1	12.3	13.6	12.9	11.0	10.4	10.2	10.9	11.5	12.4	11.9
1986	10.6	10.2	11.4	13.5	13.0	11.0	9.1	8.7	10.0	11.9	12.4	12.0
1987	11.7	11.2	12.4	13.2	13.5	11.7	10.2	11.1	11.0	11.9	13.1	11.4
1988	12.1	12.0	13.3	14.3	13.4	11.6	11.1	11.3	11.5	11.5	11.8	11.4
1989	12.0	10.5	11.9	13.0	12.8	11.0	10.7	10.7	11.2	11.8	12.4	12.6
1990	10.6	12.4	13.3	13.9	13.2	10.8	9.8	10.9	10.1	11.8	12.0	12.1
1991	10.9	11.1	12.3	13.0	13.8	12.2	10.9	10.1	9.7	11.6	11.8	11.8
1992	11.0	11.7	12.6	13.9	12.7	12.1	10.9	10.3	10.8	12.0	12.1	12.3
1993	12.2	11.4	11.2	12.8	13.0	12.1	10.2	10.2	10.0	12.1	12.4	12.8
1994	11.5	11.4	12.9	13.7	13.2	11.7	11.2	11.2	10.9	12.5	13.3	11.8
1995	11.2	11.4	12.8	13.7	13.6	11.8	11.1	10.9	11.5	12.7	12.6	11.6
1996	11.2	12.2	13.3	13.7	13.6	12.8	11.0	10.2	10.8	11.8	12.6	11.3
1997	11.4	10.7	13.0	13.9	13.1	12.4	11.1	10.9	10.8	13.4	14.0	13.9
1998	14.2	13.0	13.4	14.8	14.6	12.5	11.5	11.4	11.6	11.6	12.0	10.4
1999	11.2	10.6	13.5	13.7	12.9	11.5	11.0	11.6	10.9	12.1	12.8	12.4
2000	10.7	9.9	12.5	13.6	12.7	12.2	11.2	11.0	10.9	12.3	13.1	12.8
2001	13.0	12.3	12.7	14.0	13.5	11.8	10.7	10.7	11.4	12.7	13.1	12.2
2002	12.5	11.8	13.1	14.4	13.6	11.4	10.6	11.6	11.3	13.0	13.6	13.6
2003	11.6	11.5	12.5	14.0	14.2	12.5	11.0	11.4	11.8	12.4	13.4	12.2
2004	12.9	13.0	13.5	14.5	13.2	10.9	9.4	10.5	11.8	13.1	13.4	13.1
2005	11.9	11.9	13.7	14.0	14.1	12.6	11.1	11.5	11.9	12.7	12.7	11.4
2006	11.7	12.9	14.2	14.3	13.0	11.6	11.6	11.2	11.8	13.2	14.1	14.0
2007	12.9	12.6	12.6	13.9	13.2	12.7	11.7	12.2	11.9	12.8	12.8	11.9
2008	11.8	11.9	13.3	13.5	12.9	11.8	11.7	12.2	12.1	13.7	13.4	12.2
2009	11.9	12.4	13.2	14.3	14.1	12.5	10.5	11.8	12.5	13.7	13.5	13.5
2010	12.7	14.2	13.8	14.8	14.3	12.6	11.4	11.7	11.5	13.2	13.0	12.4
2011	11.5	11.6	13.2	13.9	13.8	12.8	11.1	12.2	12.6	13.4	13.9	13.0
2012	10.2	11.1	12.3	14.5	13.8	12.5	11.7	11.3	11.8	13.2	13.1	12.8
2013	12.5	11.9	13.8	14.4	12.9	12.0	10.9	11.6	12.1	12.5	13.6	13.3
2014	11.8	12.8	13.2	12.5	12.8	13.0	12.3	12.2	12.2	13.5	13.6	12.7

Appendix 4: Mean monthly evaporation (mm) between years 1985 and 2014 in the study area, Mai Mahiu.

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	196.9	147.9	177.5	117.5	121.4	110.0	113.5	119.1	148.4	162.2	127.0	155.9
1986	183.8	209.9	211.0	156.2	147.9	150.2	161.0	144.6	163.4	192.1	139.3	164.3
1987	161.5	177.3	205.5	155.0	118.5	93.6	103.8	115.9	157.4	184.3	133.3	180.0
1988	167.1	193.6	172.0	135.9	109.1	97.7	94.6	91.4	115.7	155.3	123.2	141.6
1989	138.9	159.2	173.9	124.3	119.2	98.5	85.6	87.2	126.5	133.0	125.5	129.4
1990	149.7	138.5	134.4	113.6	119.9	97.2	100.1	87.9	139.5	150.1	131.8	140.1
1991	168.1	179.4	187.5	133.5	105.8	87.9	84.0	101.8	143.1	158.0	127.6	140.3
1992	174.4	186.8	214.2	148.2	110.0	85.2	86.2	86.5	127.8	141.7	133.9	135.1
1993	124.8	133.0	172.8	143.6	127.6	87.8	94.1	120.5	160.3	172.6	141.6	146.2
1994	188.0	167.1	182.4	146.2	119.4	93.9	92.1	96.2	143.8	166.7	126.9	135.1
1995	166.6	159.9	155.8	131.9	107.6	103.2	80.2	112.0	132.6	134.9	126.1	137.4
1996	172.1	172.1	171.3	135.2	111.1	81.8	86.1	108.4	134.1	179.6	114.0	165.2
1997	193.8	222.7	219.5	134.0	123.6	101.5	98.2	114.5	173.6	139.1	107.8	120.2
1998	128.6	146.7	165.1	134.5	106.3	97.9	75.9	72.3	127.0	148.9	122.1	167.5
1999	174.2	196.2	167.7	130.8	122.3	109.3	108.9	104.6	144.9	157.5	119.0	124.9
2000	187.8	217.0	214.9	153.4	133.8	119.6	123.6	134.4	153.9	169.6	130.0	145.4
2001	120.5	160.1	162.6	119.4	109.0	90.9	84.2	114.6	144.2	147.8	108.2	136.9
2002	148.1	166.3	151.6	123.5	113.3	94.9	115.2	101.6	154.8	151.3	132.7	125.7
2003	163.8	180.8	203.0	148.4	105.8	92.5	97.8	97.5	129.1	152.1	131.3	160.6
2004	154.9	150.6	176.0	120.7	118.8	90.9	117.8	110.1	138.6	138.0	125.5	148.8
2005	184.3	196.1	186.3	139.0	116.0	83.3	83.3	94.3	124.3	148.1	143.2	187.7
2006	201.7	191.7	163.6	117.5	108.9	107.6	95.9	129.1	140.3	169.1	113.4	121.0
2007	139.6	143.8	168.0	128.5	112.2	92.4	83.2	100.0	132.0	147.9	137.3	154.5
2008	174.8	165.5	162.3	128.1	116.7	100.3	88.9	111.9	140.6	136.1	140.2	178.3
2009	187.2	176.3	218.2	145.7	117.0	118.1	114.4	121.8	165.1	141.7	138.6	133.2
2010	150.0	138.7	130.2	116.0	105.9	86.8	93.2	94.6	124.3	142.0	113.2	155.0
2011	188.9	178.0	182.2	142.7	108.3	100.2	115.6	91.6	125.1	138.7	106.6	137.4
2012	197.4	197.4	223.2	129.5	109.8	82.4	80.8	111.8	142.1	164.2	131.4	129.6
2013	151.6	165.0	164.9	114.6	107.9	82.4	104.2	91.0	128.8	167.6	118.4	121.5
2014	171.1	128.8	161.2	138.1	115.4	93.8	96.7	114.3	129.9	144.4	126.6	139.7

Appendix 5: Chemical analyses of soil samples collected from specific site around the root

system of plant species within the study area, Mai Mahiu.

Land use types	pH	Total Nitrogen (%)	Total Organic Carbon (%)	P (ppm)	K (me%)	Ca (me%)	Mg, (me%)	Mn, (me%)	Cu (ppm)	Fe (ppm)	Zi (ppm)	Na (me%)
Undisturbed Forest	7.30	0.41	4.13	6.01	2.95	12.3	1.43	1.10	1.55	122	14.54	1.29
Undisturbed Forest	7.05	0.43	4.38	5.28	2.84	11.8	1.39	1.07	1.52	129	11.41	1.02
Undisturbed Forest	6.99	0.40	4.24	5.12	2.78	10.5	1.37	1.12	1.55	124	13.43	1.17
Undisturbed Forest	7.35	0.42	4.15	6.01	2.85	12.4	1.41	1.09	1.56	120	14.32	1.31
Undisturbed Forest	7.06	0.44	4.39	5.23	2.79	11.5	1.34	1.08	1.54	126	11.71	1.31
Cropland (maize)	6.35	0.20	2.12	5.01	1.67	6.66	1.09	0.52	1.59	119	6.16	0.68
Cropland (maize)	6.38	0.19	2.03	5.04	1.69	6.87	1.14	0.56	1.58	122	6.18	0.69
Cropland (maize)	6.41	0.15	1.98	5.07	1.59	6.79	1.12	0.54	1.58	118	6.14	0.66
Cropland (maize)	6.36	0.18	2.14	5.03	1.70	6.60	1.09	0.53	1.60	117	6.15	0.62
Cropland (maize)	6.39	0.17	2.05	5.06	1.65	6.89	1.13	0.57	1.58	121	6.17	0.69
Cultivated (Maize)	6.63	0.16	1.35	5.07	1.45	10.17	1.36	0.73	0.74	119	6.13	1.23
Disturbed Forest (*Tarchonanthus*)	6.59	0.18	1.92	5.99	1.55	9.67	2.41	0.59	1.47	142	5.46	0.84
Disturbed Forest (*Tarchonanthus*)	6.89	0.23	2.92	5.98	1.48	9.85	3.14	0.79	1.23	134	5.49	0.82
Disturbed Forest (*Tarchonanthus*)	6.94	0.31	3.02	6.01	1.3	9.96	4.28	0.87	1.05	114.7	6.92	0.8
Grazing field	6.05	0.16	1.44	5.34	1.4	5.8	1.02	0.6	1.5	118	5.95	1.06
Grazing field	6.18	0.13	1.36	5.23	1.47	11.11	1.05	0.47	1.58	132	5.54	1.22
Grazing field	6.54	0.15	1.41	5.27	1.72	11.21	1.07	0.49	1.55	122	5.15	1.19
Grazing field	6.07	0.17	1.42	5.38	1.43	5.91	1.02	0.80	1.56	119	5.75	1.16
Disturbed Forest (*Croton spp*)	6.64	0.18	1.87	20.32	1.44	6.90	2.54	0.73	1.14	97.7	15.9	1.02
Disturbed Forest (Croton *spp*)	6.73	0.3	2.84	21.12	1.80	16.60	3.66	0.55	1.05	98.9	19.2	1.26
Disturbed Forest (Croton *spp*)	7.27	0.35	3.79	19.54	2.61	10.20	1.79	0.8	1.04	105	8.6	1.02
Disturbed Forest (Croton *spp*)	6.68	0.21	1.97	22.01	1.47	6.87	2.52	0.64	1.15	97.7	15.95	1.08

Appendix 6: Bulk density and particle size distribution for soil samples collected from the study area, Mai Mahiu.

Land use types	**Lab. No/2016**	**Bulk Density**	**%Sand**	**%Clay**	**%Silt**
Cropland	9339	1.27	48	37	15
Cropland	9340	1.18	48	36	16
Cropland	9341	1.15	34	33	33
Cropland	9342	1.30	32	48	20
Cropland	9343	1.23	35	42	23
Grazing field	9343	1.26	54	38	8
Grazing field	9344	1.31	44	24	32
Grazing field	9345	1.29	47	26	27
Grazing field	9346	1.32	43	23	34
Grazing field	9347	1.25	48	28	24
Disturbed forest (Croton	9348	1.12	48	19	33
Disturbed forest (Croton)	9349	1.00	47	16	37
Disturbed forest (Croton)	9350	1.01	40	19	41
Disturbed forest (Croton)	9351	1.04	51	21	28
Disturbed forest (Croton	9352	1.03	44	19	37
Disturbed forest (Tarchonanthus)	9353	1.18	54	30	16
Disturbed forest (Tarchonanthus)	9354	1.14	52	31	17
Disturbed forest (Tarchonanthus)	9355	1.16	53	32	15
Disturbed forest (Tarchonanthus)	9356	1.17	54	34	12
Disturbed forest (Tarchonanthus)	9357	1.16	52	31	17
Undisturbed forest	9334	0.97	50	28	22
Undisturbed forest	9335	0.89	50	30	20
Undisturbed forest	9336	0.92	51	29	20
Undisturbed forest	9337	0.90	52	31	17
Undisturbed forest	9338	0.93	48	32	20

Appendix 7: Vegetation Data Sheet

Vegetation Data Sheet																									
Study Area:							Date:								Examiner:										
Transect Number:									Number of Quadrats: 100																
	Quadrat Numbers																								
Plant Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Quadrat Number																								
Plant Species	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Appendix 8: Vegetation data collected from the study area, Mai Mahiu

Vegetation Data Sheet

Study Number: MMahiu/1/2016 | Date: 21/11/2016 – 10/12/2016 | Examiner: Caleb Basweti

Transcect Number: 1-10 | Number of Quadrats:

Species Name	Quadrat																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Croton matourensis	(-)	19	48	49	38	26	45	33	29	(-)	19	48	49	38	26	45	33	29	(-)	19	48	49	38	26	45
Oscimum gratissimum	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)
Aspilia africana	7	(-)	(-)	(-)	3	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	3	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	3	(-)	(-)
Achyranthes aspera	(-)	68	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	68	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	68	(-)	(-)	(-)	(-)	(-)
Justicia gendarussa	16	118	5	(-)	(-)	55	40	35	(-)	16	118	5	(-)	(-)	55	40	35	(-)	16	118	5	(-)	(-)	55	40
Solanum incunum	(-)	(-)	(-)	(-)	(-)	8			14	(-)	(-)	(-)	(-)	(-)	8	(-)	(-)	14	(-)	(-)	(-)	(-)	(-)	8	(-)
Sida cordata	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)
Croton bathianus	(-)	(-)	(-)	26	(-)	7	1	3	34	(-)	(-)	(-)	26	(-)	7	1	3	34	(-)	(-)	(-)	26	(-)	7	1
Grewia villosa	(-)	(-)	(-)	(-)	5	2	7	(-)	(-)	(-)	(-)	(-)	(-)	5	2	7	(-)	(-)	(-)	(-)	(-)	(-)	5	2	7
Gymnosporia heterophylla	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)
Dracaena aletriformis	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)
Tarchonanthus camphorantus	(-)	(-)	(-)	2	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	1	(-)
Euphobia candelabrum	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Lawsonia inermis	(-)	(-)	12	(-)	13	(-)	31	(-)	(-)	(-)	(-)	12	(-)	13	(-)	31	(-)	(-)	(-)	(-)	12	(-)	13	(-)	31
Opuntia ficus-indica	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	2
Dodonea angustifolia	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	5	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	5	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Tephrosia candida	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	21	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	21	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Combretum molle	(-)	1	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	3	(-)	(-)	(-)	(-)
Sansevieria ehrenbergii	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Vernonia amygdalina	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	3	(-)
Fuerstia africana	(-)	(-)	(-)	4	(-)	(-)	(-)	(-)	(-)	(-)	(-)	23	(-)	(-)	(-)	(-)	(-)	6	(-)	5	(-)	(-)	(-)	(-)	(-)
Thespesia garckeana	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	6	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	12	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Hibiscus acicularis	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Ficus sycomorus	(-)	2		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Panicum repens	36	(-)	75		212	(-)	(-)	(-)	42	(-)	(-)	112	(-)	(-)	(-)	(-)	(-)	(-)	23	(-)	(-)	(-)	(-)	136	(-)
Themeda triandra	(-)	56	(-)	(-)	(-)	(-)	65	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	78	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Hyperhenia filipendula	45	47	57	78	(-)	44	(-)	(-)	27	(-)	(-)	56	(-)	75	(-)	(-)	86	(-)	(-)	(-)	65	(-)	(-)	43	(-)
Cynodon dactylon	123		57	(-)	(-)	(-)	(-)	49	(-)	(-)	(-)	(-)	129	(-)	(-)	(-)	(-)	(-)	87	57	(-)	(-)	(-)	(-)	90
Vangueria infausta	(-)	(-)	5	(-)	(-)	(-)	7	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	6	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Acacia mearnsii	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)
Acacia xanthophloea	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Dovyalis caffra	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	3	(-)	(-)	(-)
Tipunea tipa	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Species Name	**Quadrat**																								
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Croton matourensis	33	29	(-)	19	48	49	38		45		29	(-)	19	48	(-)	38	(-)	45	33	29	(-)	19	48	49	(-)
Oscimum gratissimum	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)
Aspilia africana	(-)	(-)	7	(-)	(-)	(-)	3	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	3	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	3
Achyranthes aspera	1	(-)	(-)	68	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	68	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	68	(-)	(-)	(-)
Justicia gendarussa	35	(-)	16	118	5	(-)	(-)	55	40	35	(-)	16	118	5	(-)	(-)	55	40	35	(-)	16	118	5	(-)	(-)
Solanum incunum	(-)	14	(-)	(-)	(-)	(-)	(-)	8	(-)	(-)	14	(-)	(-)	(-)	(-)	(-)	8	(-)	(-)	14	(-)	(-)	(-)	(-)	(-)
Sida cordata	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Acacia xanthophloea	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Croton bathianus	3	34	(-)	(-)	(-)	26	(-)	7	1	3	34	(-)	(-)	(-)	26	(-)	7	1	3	34	(-)	(-)	(-)	26	(-)
Grewia villosa	(-)	(-)	(-)	(-)	(-)	(-)	5	2	7	(-)	(-)	(-)	(-)	(-)	(-)	5	2	7	(-)	(-)	(-)	(-)	(-)	(-)	5
Gymnosporia heterophylla	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Dracaena aletriformis	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Tarchonanthus camphoratus	(-)	(-)	(-)	(-)	(-)	2	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)
Euphobia candelabrum	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Lawsonia inermis	(-)	(-)	(-)	(-)	12	(-)	13	(-)	31	(-)	(-)	(-)	(-)	12	(-)	13	(-)	31	(-)	(-)	(-)	(-)	12	(-)	13
Opuntia ficus-indica	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

Dodonaea angustifolia	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	5	(-)	(-)	(-)	(-)	(-)
Tephrosia candida	(-)	21	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	21	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	21	(-)	(-)	(-)	(-)	(-)
Combretum molle	(-)	(-)	(-)	1	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	3	(-)	(-)
Sansevieria ehrenbergii	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)
Fuerstia africana	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	(-)	(-)	(-)
Vernonia amygdalina	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Fuerstia africana	(-)	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Thespesia garckeana	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Hibiscus acicularis	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	4
Acacia xanthophloea	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Acacia mearnsii	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Ficus sycomorus	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Panicum repens	(-)	(-)	(-)	(-)	(-)	53	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Themeda triandra	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Hyperhenia filipendula	(-)	(-)	(-)	(-)	(-)	(-)	(-)	71	(-)	(-)	(-)	(-)	(-)	(-)	(-)	23	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	41
Cynodon dactylon	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Vangueria infausta	(-)	42	(-)	(-)	(-)	(-)	(-)	(-)	(-)	67	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	57	(-)	(-)	(-)	(-)	(-)	(-)
Solanum incunum	(-)	(-)	(-)	(-)	(-)	(-)	(-)	9	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Species Name	**Quadrat**																								
	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Croton matourensis		19	48	49	38	26	45	33	29		19	48	49	38	26	45	33	29		19	48	49	38	26	45
Oscimum gratissimum	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)
Aspilia africana	7	(-)	(-)	(-)	3	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	3	(-)	(-)
Achyranthes aspera	(-)	68	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	68	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	68	(-)	(-)	(-)	(-)	(-)
Justicia gendarussa	16	118	5	(-)	(-)	55	40	35	(-)	16	118	5	(-)	(-)	55	40	35	(-)	16	118	5	(-)	(-)	55	(-)
Solanum incunum	(-)	(-)	(-)	(-)	(-)	8	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	8	(-)	(-)	14	(-)	(-)	(-)	(-)	(-)	8	(-)
Sida cordata	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)		(-)	(-)	(-)	(-)	(-)	1	(-)
Acacia xanthophloea	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Croton bathianus	(-)	(-)	(-)	26	(-)	7	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	7	1	(-)	(-)	(-)	(-)	(-)	26	(-)	7	1

Grewia villosa	(-)	(-)	(-)	(-)	5	2	7	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	5	2	7
Gymnosporia heterophylla	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Dracaena aletriformis	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)
Tarchonanthus camphorantus	(-)	(-)	(-)	2	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	1	(-)
Euphobia canderubrum	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Lawsonia inermis	(-)	(-)	12	(-)	13		31	(-)	(-)	(-)	(-)	12	(-)	13	(-)	31	(-)	(-)	(-)	(-)	12	(-)	13	(-)	31
Opuntia ficus-indica	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	(-)	(-)	(-)		(-)	(-)	(-)	2
Dodonaea angustifolia	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	5	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	5	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Tephrosia candida	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	21	(-)	(-)	(-)	(-)	(-)	(-)	(-)		21	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Combretum molle	(-)	1	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	3	(-)	(-)	(-)	(-)
Sansevieria ehrenbergii	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)
Fuerstia africana	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	12	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Vernonia amygdalina	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Fuerstia africana	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Thespesia garckeana	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Hibiscus acicularis	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Acacia xanthophloea	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Acacia mearnsii	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Ficus sycomorus	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Panicum repens	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	24	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Themeda triandra	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Hyperhenia filipendula	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Cynodon dactylon	(-)	(-)	(-)	(-)	(-)	(-)	(-)	12	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Vangueria infausta	(-)	(-)	(-)	84	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	53	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	58	(-)
Solanum incunum	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Dracaena aletriformis	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	26	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Species Name	**Quadrat**																								
	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Croton matourensis	(-)	(-)	(-)	(-)	(-)	(-)	38	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	38	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Oscimum gratissimum	(-)	(-)	11	(-)	(-)	(-)		(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	78	(-)	(-)	(-)	(-)	11	(-)	(-)	(-)	(-)

Aspilia africana	(-)	(-)	7	(-)	(-)	(-)	3	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	3	(-)	(-)	(-)	(-)	7	(-)	(-)	(-)	3
Achyranthes aspera	1	(-)	(-)	68	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	68	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	68	(-)	(-)	(-)
Justicia gendarussa	35	(-)	(-)	(-)	(-)	(-)	(-)	55	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	55	40	35	(-)	16	118	5	(-)	(-)
Solanum incunum	(-)	14	(-)	(-)	(-)	(-)	(-)	8	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	8	(-)	(-)	14	(-)	(-)	(-)	(-)	(-)
Sida cordata	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Acacia xanthophloea	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Croton bathianus	3	34	(-)	(-)	(-)	26	(-)	7	1	3	34	(-)	(-)	(-)	26	(-)	7	1	3	34	(-)	(-)	(-)	26	(-)
Grewia villosa	(-)	(-)	(-)	(-)	(-)	(-)	5	2	7	(-)	(-)	(-)	(-)	(-)	(-)	5	2	7	(-)	(-)	(-)	(-)	(-)	(-)	5
Gymnosporia heterophylla	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Tarchonanthus camphorantus	(-)	(-)	(-)	(-)	(-)	2	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)
Euphorbia canderubrum	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Lawsonia inermis	(-)	(-)	(-)	(-)	12	(-)	13	(-)	31	(-)	(-)	(-)	(-)	12	(-)	13	(-)	31	(-)	(-)	(-)	(-)	12	(-)	13
Opuntia ficus-indica	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	2	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Dodonaea angustifolia	(-)	5	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	5	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	5	(-)	(-)	(-)	(-)	(-)
Tephrosia candida	(-)	21	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	21	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	21	(-)	(-)	(-)	(-)	(-)
Combretum molle	(-)	(-)	(-)	1	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	3	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	3	(-)	(-)
Sansevieria ehrenbergii	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Fuerstia africana	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	6	(-)	(-)	(-)	(-)	(-)	(-)
Vernonia amygdalina	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Thespesia garckeana	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Hibiscus acicularis	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Acacia xanthophloea	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Acacia mearnsii	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	1	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Ficus sycomorus	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Panicum repens	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Themeda triandra	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Hyperhenia filipendula	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Cynodon dactylon	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Vangueria infausta	(-)	(-)	(-)	(-)	(-)	(-)	87	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	65	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Solanum incunum	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Dracaena aletriformis	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)