LAND USE LAND COVER CHANGES AND THEIR IMPLICATIONS ON LAND DEGRADATION IN ELGEYO ESCARPMENT, KENYA

BY

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DECLARATION

Declaration by the Candidate

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DEDICATION

I dedicate this thesis to my dear parents; Peter Kipkech and Salome Talaa for their blessings and instilling in me the virtues of determination and hard work. I also dedicate this thesis to my lovely children; Laura, Michelle, Angela, Mercy and Shanell for their unwavering support, prayers and goodwill throughout this study.

ABSTRACT

Land use land cover (LULC) changes have become common experience globally with detrimental impacts on the environment. In Elgeyo Marakwet County, agriculture and settlements have extended to the Elgeyo escarpment. However, information on their extent and implications on soil properties and erosion in the escarpment is scanty. This was despite of its fragility, importance as rivers source and tourism. The study mainly determined the implications of LULC changes on land degradation in Elgeyo escarpment. Specifically it; determined LULC dynamics and their drivers, assessed the impact of LULC conversions on soil erosion occurrence and soil properties in Elgeyo escarpment. Landsat 5 (1995) and Landsat 8 satellite images for 2014 and 2020 were downloaded from United States Geological survey website. A structured questionnaire was administered to 180 respondents sampled via snowball method, eight focus group discussions and seven key informant interviews were performed. Sixty soil samples from four purposively selected sites were analyzed using standard laboratory procedures. Remote sensing and geographic information system were used to examine LULC dynamics while Revised Universal Soil Loss Equation was used to compute soil erosion. Differences in soil parameters among LULC classes were tested using one-way ANOVA. The results indicate that in 1995-2014 period, forest, built-up and cropland gained by 411.8%, 201% and 13.6%, respectively while grassland and shrubland decreased by 78.2% and 24.4% respectively. In 2014-2020, grassland, built-up, shrubland and cropland decreased by 79.7%, 39.1%, 21.7% and 11.8% respectively while forest cover increased by 63%. LULC changes were driven by population growth (97.8%), food demand (88.9%) and conflict (44.4%). Average soil erosion in 1995 and 2020 were 14.02 $tha^{-1}y^{-1}$ and 18.76 $tha^{-1}y^{-1}$ respectively. Soil erosion occurrence was 67.1% in Shrubland in 1995 but declined to 39.8% by 2020, comparable to that in forest (39.4%). Soil erosion increased with slope and sections with slope $>30^0$ encountering the highest (1225 t/ha/y) owing to high rainfall erosivity. Soil properties differed among LULC classes. Soil pH was slightly acid (6.20) in forest and moderately acid (5.38) in cropland. Organic carbon was high (4.83 %) in forest and moderate (2.57%) in cropland. Nitrogen levels were moderate (0.12-0.23%) across all LULC classes. Phosphorous was high in forest (81.85 ppm) whereas potassium was high in forest (872.67 ppm). Moisture contents were 19.70% and 14.34% respectively in forest and cropland. Forest had the most (1.00 g/cm^3) and cropland the least (1.40 g/cm^3) favorable soil bulk density. There were profound LULC changes. The conversion of natural ecosystems to farmlands accelerated soil erosion and decline in soil physicochemical properties. Accordingly, enhanced implementation of farm forestry rules, land management laws, Land adjudication and adoption of beekeeping are crucial to sustainably conserve this escarpment.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
AOI	Area of interest
CIDP	County Integrated Development Plan
CO_2	Carbon dioxide
DEM	Digital Elevation Model
EMC	Elgeyo Marakwet County
ETM+	Enhanced Thematic mapper plus
GHG	Green House Gas
GIS	Geographic Information System
Ha	Hectares
KALRO	Kenya Agricultural and Livestock Research Organization
KCSAP	Kenya Climate Smart Agriculture Project
KENSOTER	Kenya Soil Terrain
KM	Kilometer
KM^2	Kilometer Square
LSD	Least Significant Difference
LULC	Land Use Land Cover
LULCC	Land Use Land Cover change
MC	Moisture Content
Ml	milliliter
NDVI	Normalized Differential Vegetation Index
NEMA	National Environment Management Authority
OLI	Operational Land imager
Ppm	Parts per million
REDD	Reducing Emissions from Deforestation and Forest Degradation

ROI	Regions of Interest
ROK	Republic of Kenya
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SDG	Sustainable Development Goals
SE	Standard Error
STRM	Shutter Radar Tomography Mission
STRMG1	Shutter Radar Tomography Mission Global 1
$Tha^{-1}y^{-1}$	Tons per hectare per year
TM	Thematic Mapper
Ty^{-1}	Tons per year
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
UV	Ultra Violet
WB	World Bank
WRS	Worldwide Reference System

OPERATIONAL DEFINITION OF TERMS

Catchment	It is an area of land, including the hills and mountains, woodlands, and buildings which water drains from, before flowing through a common outlet into the streams, rivers, lakes
Drainage basin	It is an area of land from which rain flows into a particular body of water
Escarpment	It is an area of the Earth where elevation changes suddenly and usually refer to the bottom of a cliff or a steep slope.
Land degradation	It is the reduction or loss of the biological or economic productivity of biophysical environment owing to the interaction of both innate and anthropogenic induced processes acting upon land.
Landsat	It is a United States scientific program that acquires satellite imageries on earth's surface using remote-sensing and GIS techniques.
LULC Change	Change in the use or management of land by humans, which may result in changes in land cover
LULCC Driver	Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem. In this study, it refers to causes of LULC changes
Pixel	A tiny area of illumination on a display screen, constituting one of many from which images are composed. The pixel area for both Landsat 5 and Landsat 8 images is (30 x 30) m^2.

Raster	It is a matrix of cells (pixels) organized into rows and columns with each cell containing a value representing information typically in form of imageries from satellite and digital pictures.
Remote sensing	Is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft).
Soil erosion	It is a geological process in which the upper layer of soil (earthen materials) are denudated or worn away and transported by natural agents such as wind or water.
Soil loss	It is depletion of soil nutrients and minerals due to overuse or poor farming practices.
Watershed	An area or ridge of land that separates waters flowing to different rivers, basins, or seas.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Over 75% of the Earth's land surface has been modified via anthropogenic undertakings since 17th century (Luyssaert *et al.*, 2014). Agricultural land increased substantially from 17th century through 1990, as forest and grasslands declined over the same spell (Ramankutty *et al.*, 2018). These Land Use Land Cover (LULC) conversions are imputed to the increase in world human population that has surged to over seven billion and predicted to hit nine billion by the year 2050 (FAO, 2015). Europe was naturally largely under forest cover but today it is a patchwork of landscapes with enormous croplands being situated in Eastern Europe, including Slovakia where 50% of its land area is cropland (Ramankutty *et al.*, 2018). Similarly, a remarkable surge in cropland, built-up and urban land was reported in Libya as natural forests lost (Ahwaidi, 2017). The same trend was observed in sub-Saharan Africa, where agricultural and barren land increased between 1975 and 2000 while forest land diminished in the same period (Brink & Eva, 2009). In eastern Africa, a notable decrease in pasture land was observed between 1992 and 1999 and was attributed to overstocking (Lambin *et al.*, 2003).

Past LULC change inquiries have found that their drivers are varied both temporally and spatially. For example during the postglacial period (10,000 years) ago, global warming permitted favorable conditions for relocation of some organisms from their havens to other environments (Findell *et al.*, 2017). After the Neolithic (agrarian) revolution, human societies begun to modify natural ecosystems, resulting in drastic reduction in the earth's forest cover (Kanianska, 2016). The conversion was most profound between 2000 and 2010 (Kissinger *et al.*, 2012) when large portions of forests worldwide were converted to agriculture (Ramankutty *et al.*, 2018). Rapid population and economic growth birthed the industrial revolution shifting land meant for agricultural production to industrial use (Ramankutty *et al.*, 2018). This was coupled with rural-urban migration experienced during the past fifty years of the 21st century (Miao *et al.*, 2015). The phenomenon was more visible in East Asia, North America, and Europe where cropland was converted to industrial parks throughout their economic transformation (Ramankutty *et al.*, 2018). Notably, China lost her croplands massively, throughout its dramatic economic and market growth following her economic reforms in 1978 (Jie, 2007). In Libya, the conversion of forests and shrublands (Saad *et al.*, 2011) to cropland and built-up were driven by increased population and urbanization (Alsoul, 2016).

Kenya has continued to experience notable and varied LULC changes from 1970s (Campbell *et al.*, 2005) although the predominant LULC types have been the savannah grasslands, agriculture and forests (Njoka *et al.*, 2016). In Kiambu County, a notable rise in urban area was experienced occasioning a corresponding decline in agricultural land between 1984 to 2013 (K. & P., 2015). In Western Kenya, the built-up and agricultural areas increased while forestland, grassland and water reduced significantly between 1995 and 2017 (Kogo *et al.*, 2021). Notable changes in LULC in Kenya have been rampant in the high potential arable zones where land fragmentation and rigorous farming are exercised (Campbell *et al.*, 2005), indicating a clear case of overutilization of land resources (Cheruto *et al.*, 2016). This has been accelerated by rapid population growth (Mutuku, 2019), land inheritance, land markets and historical or cultural perspectives (Demetriou *et al.*, 2013).

The extensive LULC conversions in Kenya have directly impacted adversely on about 75% of farmers (Njoka *et al.*, 2016). For instance, agricultural production in most erodible soils in Kenya has lately been impeded by soil erosion (M'Kaibi *et al.*, 2015) whose rate increases with slope angle and length due to elevated speed and runoff erosivity (Kogo *et al.*, 2021). In addition, deforestation on mountainous ranges, unrestricted land use undertakings together with rigorous tropical rainfall (Boitt *et al.*, 2020) have led to an enduring decrease in soil production capacity in significant land area (Mulinge *et al.*, 2016). Thus leading to decline in agricultural land, altered social interaction, and rise in land and housing costs (Njiru, 2016).

Past studies in Elgeyo Marakwet County (EMC) on LULC changes have reported almost similar trends. For example, bush land and forested land covers of Rimoi wildlife protected area declined resulting in a corresponding increase in agriculture, shrubs and acacia tree cover between 1986 and 2006 (Togoch, 2018). Likewise, (Kipkemoi, 2018), in his Embobut Forest spatio-temporal degradation study found that a huge junk of the forest had been converted to farmlands. Further, (Chebet *et al.*, 2017) modeled the repercussions of land use changes on Arror watershed and established that they considerably influenced the water flows in the watershed. This was corroborated by (Wanjohi, 2019) who reported low tree diversity following LULC conversions in the Embobut River Basin contravening goal 15 of the Sustainable Development Goals (SDGs) that promotes eco-friendly governance of forests and prevention of biodiversity loss (Morton *et al.*, 2017).

The Kenyan government in the realization that the Embobut Forest ecosystem was being threatened by human encroachment instituted an eviction with majority of this population migrating into the escarpment (Kilimo, 2014). Meanwhile, cattle rustling problem that escalated since 1992 in Kerio Valley pitting the inhabitants of Baringo and Elgeyo Marakwet Counties (NCCK, 2009) drove a big number of people (Pkalya *et al.*, 2003) to inhabit the escarpment and thus degenerating the delicate landscape (Kiprono, 2018). These degradations included soil erosion indicated by reports of elevated levels of nutrient elements in water and soil sediments in water bodies Wiborgh (2015) and increased occurrence of land landslides (Kibiiy *et al.*, 2015). Consequently, Kibiiy *et al.* (2015) developed a landslides risk map and a Kerio valley region landslide prediction model.

However, these studies were limited to particular forests such as Embobut and Kibonge and basins for rivers such as Arror and Embobut that flow across the escarpment and not the entire escarpment. Further, the landslide prediction model remained inaccurate due to lack of soil types and properties information. Furthermore, despite indicators of soil erosion, information on erosion was scanty in the escarpment. Therefore, understanding the spatio-temporal LULC dynamics, extent and magnitude of soil loss, soil types and properties are critical in formulating sustainable land use options and conservation measures for the escarpment. This is considering that natural resources change in quantity and quality over time (Kiprono, 2018).

Accordingly, this study classifies and quantifies LULC dynamics enabling sufficient planning, management and monitoring of land in the escarpment. This will ensure the achievement of goal 15 of the SDGs that seeks to guard, restore and advocate sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land decadence and halt biodiversity loss (Scaini *et al.*, 2021). Additionally, the study assessed soil erosion occurrence in the escarpment. Control of soil erosion ensures fertile soils that promote the attainment of goal 2 of the SDGs that advocates for ending of hunger, and achievement of food security and enhanced nourishment and sustainable agriculture. Moreover, this study establishes soil types and their physical and chemical properties, the hitherto missing key components for precise prediction of landslides occurrence in Elgeyo escarpment. This will help in ensuring better preparedness and management of the escarpment and the achievement of SDG 12, 13 and 15 and the Sendai risk reduction priorities (Morton *et al.*, 2017).

1.2 Problem Statement

There has been a marked increase in LULC changes across Elgeyo Marakwet County. Forests have been encroached, farming and settlements have extended further into the steep Elgeyo Escarpment, a fragile ecosystem resulting in a significant loss of natural vegetation cover (Kiprono, 2018). This has happened in spite of the existence of indigenous technical knowledge, policies, regulations, legal and institutional frameworks governing land use and management. Elevated nutrient levels and sediment loads; indicators of soil erosion have been reported in rivers Arror and Embobut flowing downstream into Kerio River Wiborgh (2015). However, there was little information available on LULC, drivers and their impacts in the escarpment, coupled with lack of soil loss quantification despite being detected. Further, landslides cases have been observed in the escarpment with diverse intensity of frequency and ferocity (Kilimo, 2014). Consequently, Kerio Valley region landslide prediction model was developed by Kibiiy *et al.* (2015) but information on soil types and properties crucial for accurate landslides prediction was lacking (Kipkiror *et al.*, 2021). Therefore, this study establishes LULC change trends, drivers and impacts on soil erosion, soil physicochemical properties and recommends sustainable management and protection strategies for the escarpment. If protection measures are not implemented, the escarpment would continue to degrade beyond its recovery capacity, exacerbating low land productivity, occurrence of erosion and landslides disasters resulting in deaths, destruction of properties and displacement of communities.

1.3 Objectives of the Study

The main objective of this study was to determine land use and land cover changes and their implication on land degradation in the Elgeyo Escarpment, Kenya.

1.4 Specific objectives

The study's specific objectives were to:

1. Determine land use land cover changes in Elgeyo Escarpment from 1995 to 2020.
2. Establish land use land cover change drivers in Elgeyo Escarpment from 1995 to 2020.
3. Assess the impact of land use land cover changes on soil erosion in Elgeyo Escarpment from 1995 to 2020.
4. Examine the impact of land use land cover on soil physical and chemical properties in Elgeyo Escarpment from 1995 to 2020.

1.5 Research Questions

1. How have LULC changed in Elgeyo Escarpment in 1995-2020 period?
2. What have been the LULC change drivers in Elgeyo Escarpment in 1995-2020 period
3. How have changes in LULC influenced soil erosion in Elgeyo Escarpment?
4. How have LULC systems impacted soil properties in Elgeyo Escarpment?

1.6 Significance and Justification of the Study

The Elgeyo escarpment is the source of several rivers that form the bulk of Lake Turkana Water Basin. It hosts several water springs, waterfalls and viewpoints that serve as recreation areas and paragliding launching sites. These physical features make sections of the escarpment key tourist attraction sites raking in considerable revenue to the County Government of Elgeyo Marakwet (CGoEM, 2018). However, for the last thirty years, the Elgeyo Escarpment has continued to come under pressure from encroachments by communities evicted from forests such as Embobut Forest (Kilimo, 2014) and displacement by cattle rustling conflict in the Kerio Valley, forcing a large number of people to settle and farm in the escarpment (Pkalya *et al.*, 2003). Although land management laws such as basic land use, farm forestry rules and the Chief's act are in place, their enforcement have been hampered by low land adjudication in the escarpment (CGoEM, 2020). However, despite its fragility owing to its rugged terrain and steep slopes, the extent of LULC changes, impacts and their relative contributions remained scarcely studied and documented. Therefore, to sustainably manage this escarpment, accurate empirical information was required to inform planning and monitoring strategies; which this study generated. This information will help the policy makers develop policies and laws that will synergize land conservation and protection efforts among various stakeholders including the community members, County Environment Officers, KFS, KWTA, Lands and NEMA.

1.7 Scope and Limitations of the Study

This study was conducted in the Elgeyo Escarpment in the County of Elgeyo Marakwet. It centered on LULC conversions and their drivers in the period between 1995 and 2020. Further, the occurrence and severity of soil loss were established over

1995 and 2020 period. Additionally, the study assessed the impacts of LULC on soil chemical and physical attributes in the escarpment. Moreover, the existence, awareness and implementation of legal, policies and regulatory frameworks governing LULC were assessed. However during part of the study period (2003-2014), the Landsat seven sensors failed. Thus satellite images of that period couldn't be clear enough to enable meaningful image classification and change detection. This was mitigated by the acquisition and analysis of Landsat 8 satellite images.

1.8 Study Area

1.8.1 Location and Extent

Elgeyo escarpment is located in Elgeyo Marakwet County, Kenya and is bounded by Latitudes $0^{o}10'0''$ N and $01^{o}17'\ 0''$N and Longitudes $35^{o}30'0''$E and $35^{o}\ 43'0''$E (Figure 1.1). It covers an area of approximately 815.71 km^2. The Escarpment runs 140 km in breadth and approximately five kilometers wide on average extending from a height of 1200 masl to 3000 masl and cuts across all the four sub-counties of the Elgeyo Marakwet County; Keiyo South, Keiyo North, Marakwet East and Marakwet West (KNBS, 2019).

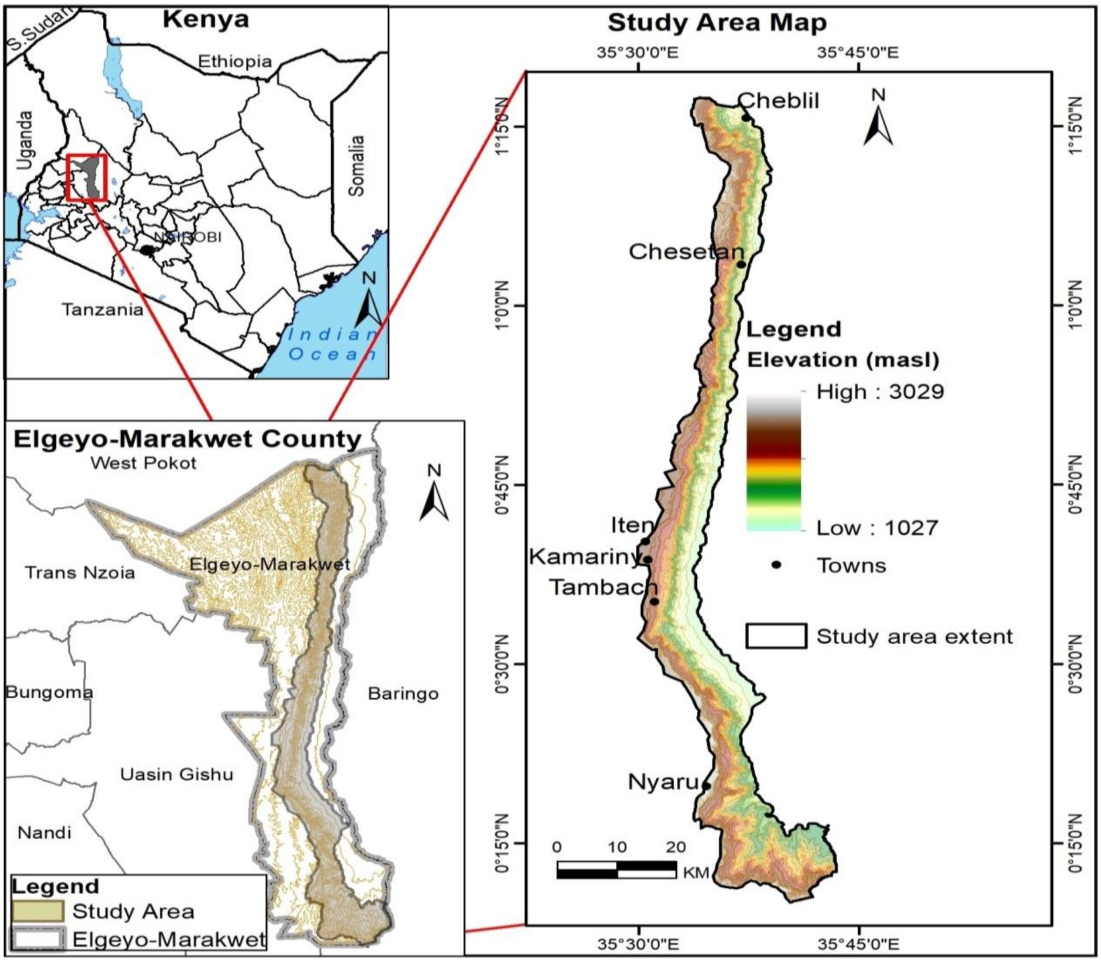

Figure 1.1: Location and Extent of Elgeyo Escarpment (Author, 2022)

1.8.2 Population

The Elgeyo Escarpment is inhabited by approximately 126,000 people comprising of 62,920 males and 63,080 females. Of this population, 44 % are minors (below 18 years), 35% and 16% are youth and middle aged groups respectively while 5% are over 55 years of age (KNBS, 2019).

1.8.3 Topography and Climate

The Elgeyo Escarpment is conspicuous in nature as characterized by its rugged terrain (CGoEM, 2018). It is endowed with fertile soils and reliable rainfall (Sombroek *et al.*, 1982). Mean annual temperature in the Escarpment ranges between 12°C and 22°C during the rainy (April – August) and dry (January - March) seasons respectively. It receives a bimodal rainfall ranging between 735mm and 1476mm per annum (KMS, 2020). The long rainy season falls within March to July while the short rainy season falls within August to November (CGoEM, 2018) as indicated in Figure 1.2.

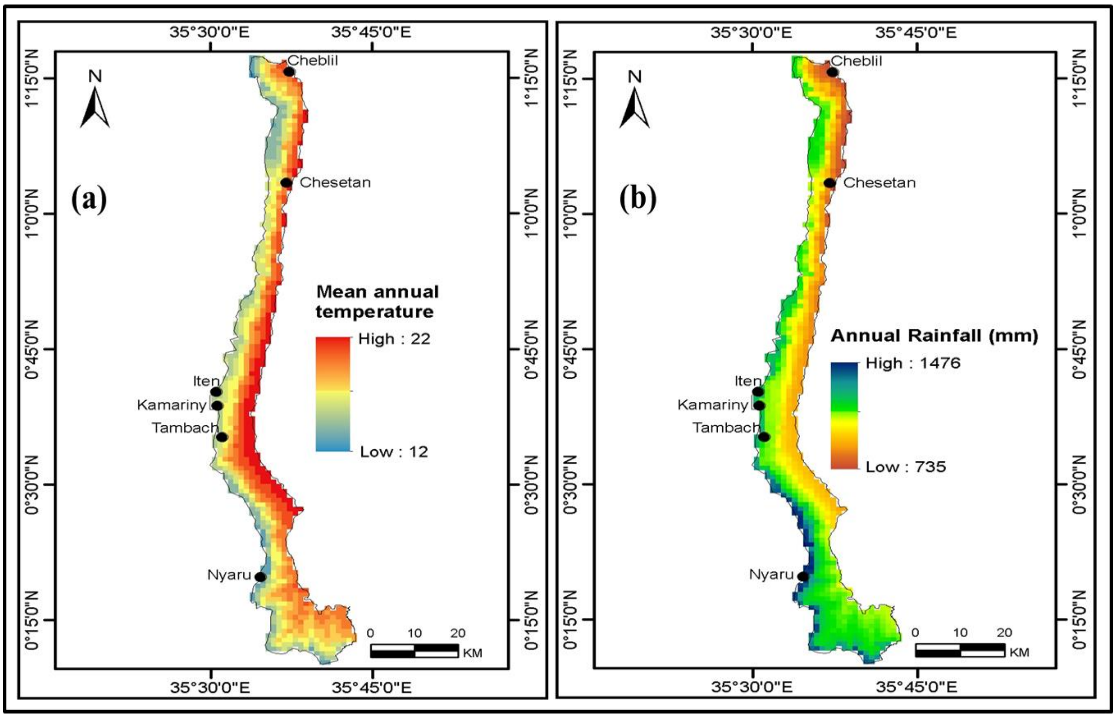

Figure 1.2: Mean Annual Temperature (a) and Rainfall (b) in Elgeyo Escarpment (KMS, 2020)

1.8.4 Drainage System

The Elgeyo Marakwet County hosts Kaptagat and Cherangany forest ecosystems and water towers. These biomes are sources of several rivers forming the main watershed situated beside the Escarpment (Figure 1.3). The Kerio catchment area lies to the eastern side of the watershed and channels its water into Lake Turkana. The rivers in this catchment include; Kerio, Moruny, Embobut, Arror, Torok, Kimwarer, Mong and Endo (KWTA, 2020). The Lake Victoria Basin that constitutes Nzoia, and Moiben drains into Lake Victoria lies to the west of the watershed (Sombroek *et al.*, 1982).

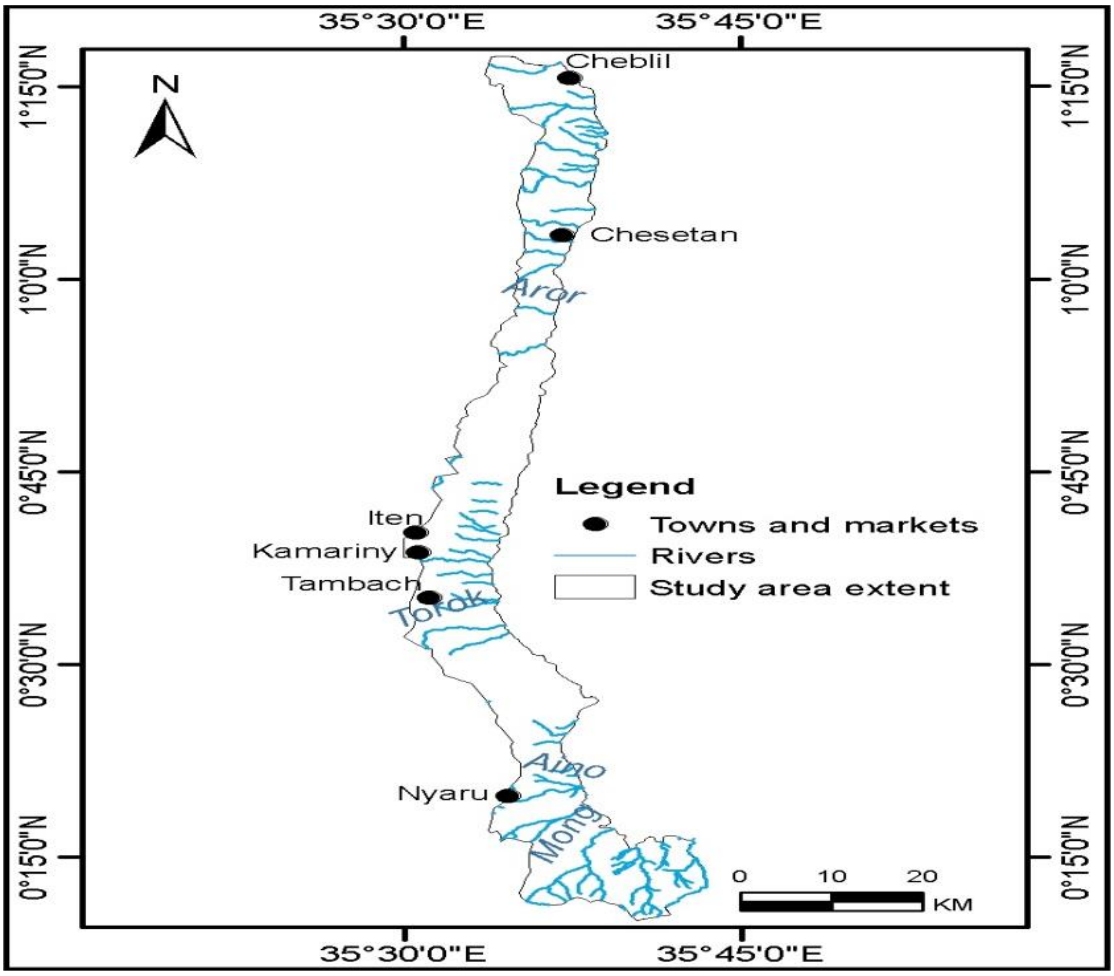

Figure 1.3: Drainage System in Elgeyo Escarpment

1.8.5 Geology and Soils

The major rocks in the escarpment are; undifferentiated basement gneisses rocks, Gneisses rich in ferromagnetic mineral home blend gneisses, basic and ultra-basic igneous rocks, undifferentiated basement gneisses rocks and biolite gneisses rock (Sombroek *et al.*, 1982). Chromic Cambisols, humic nitisols and lithic Leptosols constitute the major soil types in the escarpment, mainly developed on gneisses (Sombroek *et al.*, 1982). Other soil types include; humic cambisols, eutric cambisols and haplic lixisol and eutric gleysols soils developed on basic igneous rocks in Iten and Kamwosor and surrounding areas (Sombroek *et al.*, 1982). The spatial coverage and disposition of the soil types and rocks are indicated in Figure 1.4.

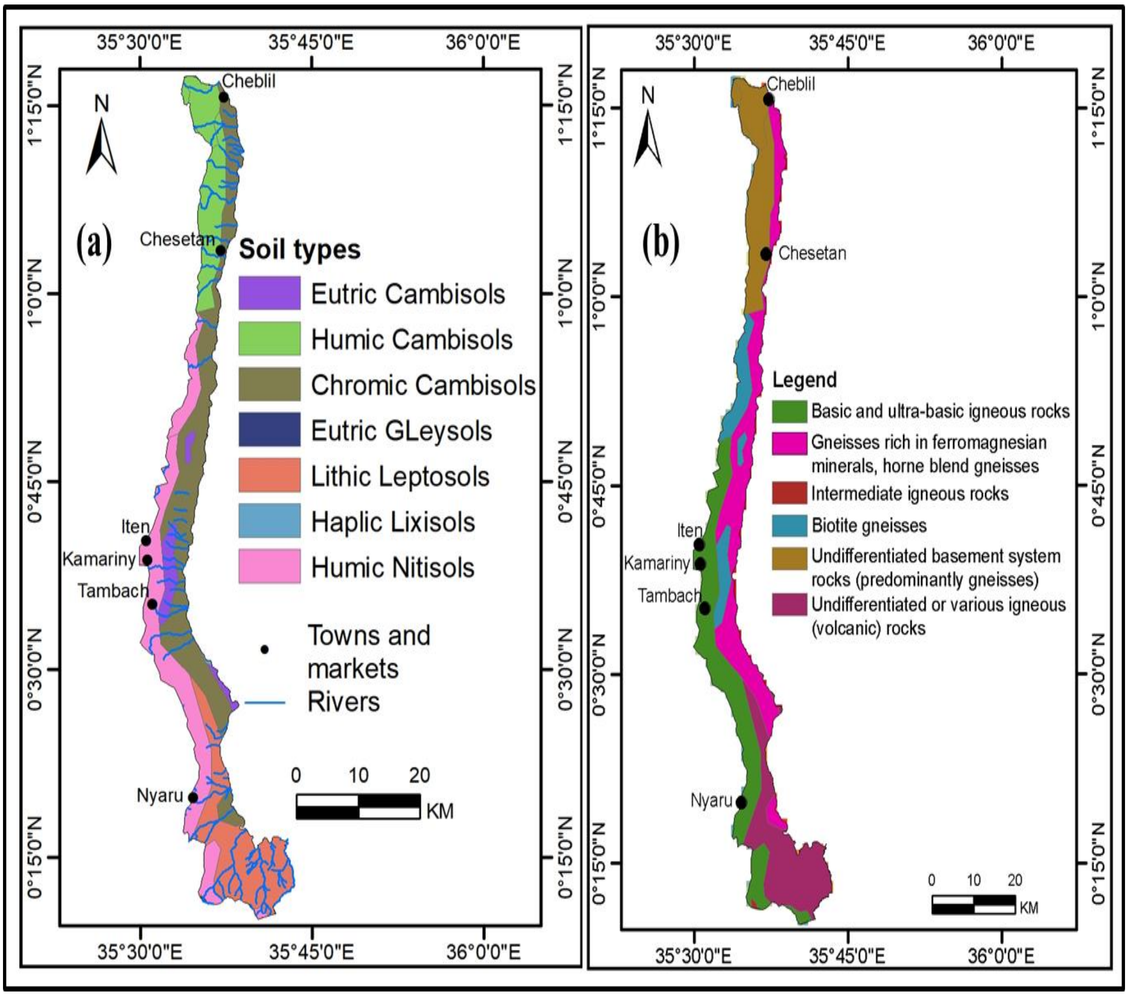

Figure 1.4: Soil Types (a) and Geology (b) in Elgeyo Escarpment (Sombroek *et al.*, 1982)

1.8.6 Socioeconomic Activities

Crop farming and livestock keeping are the main economic activities in the escarpment. Maize, Irish potatoes, and beans, sorghum, millet, cowpeas, and fruits (mangoes, pawpaw, watermelon, oranges, and bananas) are grown in the lower areas of the escarpment. Dairy and beef cattle, goats, sheep and poultry are kept in the area (Muchemi *et al.*, 2002; RoK, 2013). Moreover, sporting activities are very popular in the county and they include athletics and paragliding in the Elgeyo escarpment hence the county is officially referred to as the home of champions (CGoEM, 2018).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter highlights the diverse land use land cover and changes, trends, extend and their drivers. It further details the impacts of LULC changes on soil physical and chemical properties and soil erosion. Additionally, it highlights the land management practices, legal, policies and institutional structures directing land use and management and status of their implementation. Moreover, the theoretical and conceptual frameworks underpinning the study are highlighted.

2.2 Land Use Land Cover Dynamics

The estimated earth's land area is 13.2 billion ha. Of this area, 12 % (1.6 billion ha), 28 % (3.7 billion ha) and 35% (4.6 billion ha) comprise cropland, forest and shrubland biomes respectively (Kanianska, 2016). It is also estimated that about 75% of this earth surface has been amended via anthropogenic undertakings over the last 1000 years (Luyssaert *et al.*, 2014). For example, in the past five decades, the world's cropland surged by 12 % (Ingram, 2011). However, the per capita cropland size has been declining. In 1970 the mean size of agricultural and pasture land per capita were 0.4 ha and 0.8 ha respectively. By 2010 they had declined to 0.2ha and 0.5 ha, respectively (Martens, 2010). This was attributed to the dynamic LULC conversions over centuries but the rates have lately peaked, indicating the increased anthropogenic role in LULC conversions (Hansen *et al.*, 2010). Although anthropogenic modifications of the Earth's landscapes have been occuring since time immemorial, the extent and pace has accelerated over the last three centuries following the advent of industrial revolution and the attendant meteoric economic growth (Foley *et al.*, 2011).

Changes in land use as demonstrated in land cover conversion remain a major element of the global environmental conversion (Foley *et al.*, 2011). This is because they influence average weather conditions, affecting plants and animals' wellbeing and consequently influencing land use options. For example, forests covered about half of the global land area eight millennia ago, today its area has declined to a third (Kanianska, 2016; Ramankutty *et al.*, 2018). This has been as a consequence of the augmentation of agricultural activities in previously natural vegetated areas all over the world in the pursued for food and fiber (Kanianska, 2016). The unparalleled agricultural land expansion since 1700 has increased its cover to over 30% of the global ice-free terrestrial area, constituting the largest biome on the planet (Ramankutty *et al.*, 2018). Through the twentieth century alone, cropland registered a net growth of 50 %, pastureland surged from 0.5 billion ha during the 17th century to around 3.1 billion ha in 1990 (Kanianska, 2016; Ramankutty *et al.*, 2018). These increases were brought forth by deforestation and the modification of innate vegetation leading to forest areas shrinking from 6 billion ha to 5.3 billion ha between 17th century and 1990. Likewise shrubland diminished from 3.2 billion ha to 2.7 billion ha during the same spell (Lambin *et al.*, 2003). The demand for food in most third and second world countries has been spiraling causing a surge in agricultural land (Kanianska, 2016).

Over a 20 year period (2000 and 2020), LULC and conversion across the globe varied geographically. Notably, forest cover decreased marginally by 2.4%, cropland increased by 11.5% while built-up areas increased substantially by 50% (Potapov *et al.*, 2022). Comparing the continents' land use, forest cover was largest in South America and Europe covering 48% and 40% respectively. Australia's forest cover was the least at 17% (Potapov *et al.*, 2022). In North America and Europe, cropland expansion through pastures and long fallow conversions are balanced by reductions through long term abandonment resulting in a small net change (Rosan *et al.*, 2021). The per capita agricultural land in Slovakia, was initially 0.44 ha. This has changed with built- up areas spiraling, often at the expense of cropland since 1990 (Potapov *et al.*, 2022) . Further, the gradual grassland conversion to forestland resulted in increased forest land by 67.7% to 83.7% between 1782 and 2006 in Slovakia (Rosan *et al.*, 2021). In China, there was expansion of cropland and decline in forest cover between 1700 and 1950. In India agricultural land soared almost twofold (from 92 million ha to 140.1 million ha) over the same spell while between 1880 and 2010, forest land declined by 26 million ha from 89 million ha to 63 million ha (Tian *et al.*, 2014).

The blend of agricultural extensification and augmentation appear to vary spatially. For instance, increased fertilizer application and irrigation was adopted by Tropical Asia to increase its food production while Africa and Latin American communities adopted both agricultural augmentation and expansion. The West African communities expanded their croplands eventually decreasing fertilizer application and escalated irrigation (Ramankutty *et al.*, 2018). There was a decrease in natural forest by 9018 ha over 32 years in Al-jabal Al-akhdar area, Libya (Ahwaidi, 2017). Accordingly, the agricultural lands soared by 4095 ha, constituting 55% of its initial area. Likewise, urban and built-up land area doubled between 1985 and 2017 (Ahwaidi, 2017).

In sub-Saharan Africa, agricultural land increased almost two fold (200 million ha to 340 million ha), representing a 57 % increase between 1975 and 2000. Similarly, bare lands increased by 15% amounting to 6.5 million ha (Brink & Eva, 2009). These increases resulted in the decline in forests and shrublands by 71 million ha and 60 million ha respectively. The LULC change assessment results indicate that on average the region gained almost 5 million ha of cropland annually (Brink & Eva, 2009). The deforestation rate has been 0.7%, translating to an annual regional loss of nearly 3 million hectares of forestland (Brink & Eva, 2009). In Eastern Africa, a decrease in pasture land was also observed owing to a dramatic increase in number of livestock to the tune of 0.872 million annually between 1992 and 1999 (Lambin *et al.*, 2003).

Kenya, like most developing global economies, has encountered extensive LULC conversions particularly during the last 30 years owing to varied socioeconomic and demographic dynamics (Campbell *et al.*, 2005). The surging agricultural intensification has exerted pressure across sectors of the environment (CGoEM, 2020). This has been the case because any increase in population results in a corresponding growth in demand for basic needs to satisfy the population, hence agricultural expansion which if not treated cautiously might occasion unsustainable land use and consequently land degradation (Ingram, 2011).

Land is a key factor of production upon which other economic factors stand on. Unfortunately it is a limited natural resource whose size remains constant. For example, Kenya's total land area is 58,264,600 ha that is utilized for various purposes (KNBS, 2019) with savannah grasslands and shrub lands constituting about 70% of the country's land mass. Agriculture accounts for 14,418,600 ha while pasture, forests and irrigated areas cover 39,445,000 ha, 4,010,000 ha, and 141,900 ha respectively (RoK, 2016b). Cropland and bare land cover about 18% and 2% of country's land mass respectively (RoK, 2016b). This was against its ever steadily growing population that was estimated to be 47 million people in 2019, therefore, LULC changes are not surprising (KNBS, 2019).

In Kiambu County, cropland declined from 39.7% to 15.8% from 1984 to 2013 while urban areas soared to 33.5% from 1.9% over the same period indicating an increased demand for housing (Kioo & Odera, 2015). In Western Kenya, built-up and forest cover increased by 71%, and 43% respectively, from 1995 to 2001 (Kogo *et al.*, 2021). The built-up areas and farms surged by over 200% and 17% respectively from 2001 and 2017. The recorded conversions were denoted by spiraling settlements and intrusions into fragile ecosystems (Kogo *et al.*, 2021). A study on LULC conversion of Kakamega Forest revealed that the indigenous forest had been decimated by conversion to other land uses between 1963 and 1991, resulting in considerable decrease in the natural forest cover (Chebet, 2013). Almost same findings were recorded by Kilimo (2014). He observed that the Embobut forest boundary as it existed in the 1960s has been cleared of vegetation and settled on for a distance of up to 9 km in the westward direction. Similarly, human settlements extended eastwards beyond the 1960s forest boundary of 3 km (Kilimo, 2014). A 2011 satellite image indicated that the distance had grown to 9 km, representing an expansion of up to 6km eastwards to the steepest parts of the escarpment, resulting in the loss of over 16,000 hectares of Embobut forest since 1979 (Kilimo, 2014). (Kipkemoi, 2018) found that 7,172.31 hectares of Embobut forest representing 28% of its cover had been encroached from 1986 to 2011.

Togoch (2018) found that bush land and forested land areas of Rimoi wildlife protected area declined by 29.0% and 61.4% respectively between 1986 and 2006, while agriculture, shrubs and acacia trees cover increased by 245.4% and 24.2%

respectively over the 20 year period. From these studies, it is apparent that profound LULC conversions have occurred globally. The studies further reveal a general trend in the reduction of natural forests to farmland, pasture land and build environment particularly in developing countries. However, in the developed economies, agricultural lands were converted to transportation routes, settlements and increased forest cover Particularly in China, Western Europe and North America.

Whereas studies have been conducted to resolve land degradation problem in sections of Elgeyo escarpment, the studies focused on LULC changes on forests, national parks and reserves. Others focused on river basins such as Arror and Embobut that flow across the Elgeyo Escarpment. However, information on LULC conversions and their repercussions on the entire escarpment remained largely scanty. This was despite being a fragile ecosystem and considering that it is increasingly becoming a human settlement. Therefore, this study classified and mapped LULC and changes in the escarpment yielding information that will aid in formulation of policies that promote monitoring, proper land utilization, planning and governance of the escarpment. Consequently, enabling the realization of global 2030 agenda for sustainability including; environmental protection and conservation, climate variability adaptation and mitigation and significant reduction in disaster risks (Morton *et al.*, 2017).

2.3 Land Use Land Cover Change Drivers

The magnitude of LULC conversions has been as a aftermath of both innate and anthropogenic activities. Some of these activities include urbanization, wood harvesting and agriculture including shifting cultivation. These processes have been proven to remarkably effect global and regional climatic variability via surface water balance and energy partitioning (Findell *et al.*, 2017). Agriculture in particular has been attested as a main cause of global environmental degradation (Ramankutty *et al.*, 2018). Evolution of current ecological communities in the postglacial period (Holocene) hinged on remarkable climate conversions. In particular, global warming, about 100 centuries ago (ice age), presented circumstances for retreat of individual species from their havens. However, during agrarian cycle, human societies started directing more profoundly the evolution of innate environment. Consequently, about 50% of the pre-glacial land surface changed via anthropogenic activities (Kanianska, 2016). For instance, about 80 centuries ago, natural vegetation covered over half of the global surface, which has since dwindled to 30% today. This was as a consequence of agriculture expanding into natural ecosystems globally so as to satisfy the increased population demand for basic needs (Kanianska, 2016).

Agriculture has been vouched to have contributed to the conversion of about a third of forests globally (Ramankutty *et al.*, 2018; Rosan *et al.*, 2021). The conversion was dramatic from 2000 and 2010, when transformation of forests to agricultural and grazing lands accounted for over 80% of world's deforestation (Kissinger *et al.*, 2012). The deforestation was more profound in Indonesia and Brazil with the two economies accounting for the deprivation of over 50% of the tropical forest (Baccini *et al.*, 2012).

Notably, the massive fragmentation of huge sprawl of inherent habitats, like the Brazilian Atlantic Forest, today subsisting in deteriorated splinters of less than 1,000 ha in size can be blamed on agricultural activities (Haddad *et al.*, 2015). Developments such as surging population, expeditious economic improvement and industrialization approach have all accelerated urbanization processes thereby becoming critical components that activate and stir landscape transformations

(Ramankutty *et al.*, 2018). For instance, the meteoric global urbanization witnessed in the last 50 years (Miao *et al.*, 2015). Likewise, migration remains a key demographic element driving LULC changes over a couple of decades (Lambin *et al.,* 2003).

Brisk economic growth has converted agricultural land to manufacturing, road and rail networks and built-ups (Ramankutty *et al.*, 2018). Notably, economies in East Asia, North America and Europe lost their croplands following economic transformation (Ramankutty *et al.*, 2018). For example, the marked expansion and global integration of China's economy and market since its economic transformation in 1978 urbanized large junks of arable lands (Jie, 2007). In Libya, majority of the conversions in LULC were as the outcome of changing natural ecosystems into croplands mainly to produce food among other benefits. This anthropogenic LULC conversions have spatially and temporally soared (Saad *et al.*, 2011), driven by population growth and urbanization (Ahwaidi, 2017; Alsoul, 2016).

In Kenya, land and other available innate resources have become over utilized (Cheruto *et al.*, 2016). A scenario hastened by a sustained growth in population over the years (Kiplimo & Ngeno, 2016). This is compounded by poor farming operations presenting inadequate food supplies and community susceptibilities resulting in environmental degradation (Musambayi, 2013). Intensive cultivation is pervasive in the Kenya’s high potential agricultural areas owing to rainfall reliability and fertile soils (Campbell *et al.*, 2005). Further, land fragmentation has been driven by; demographic dynamics, inheritance, land costs and cultural standpoints (Demetriou *et al.*, 2013). The increasing demand for food in many developing and the middle-income countries including Kenya to satisfy their growing population in the past three centuries has persisted. This has triggered substantial expansion of cropland, resulting in a corresponding decline in the natural vegetation (Liu & Tian, 2010).

Market-based incentives have ushered the increased demand for agricultural products encouraging farmers to use unsustainable agricultural practices. These practices include agricultural augmentation, farming on to marginal areas, agricultural mechanization and poor agronomic practices (Chamay *et al.*, 2007) and massive infrastructural development that stirred urbanization including along the Kenya's standard gauge railway corridor (Sang *et al.*, 2022).

Decrease in pasture land has been attributed to overstocking, wild fires and deforestation (Brink & Eva, 2009), clearing of bushes, shrubland and grasslands for agricultural food production, shifting cultivation and prolonged drought (Churchill *et al.*, 2022; Mayer *et al.*, 2022). The shifting cultivation arises mostly due to low land adjudication in the Elgeyo Escarpment which stands at less than 50% (CGoEM, 2020). This was because; land adjudication in the escarpment was differed to discourage settlement and farming in the escarpment owing to its fragile nature (CGoEM, 2020). However, this decision has proved counterproductive as it impeded the proper implementation of among others Agriculture (Farm Forestry) Rules (RoK, 2009), basic land usage rules (RoK, 2012a) and the Chief's act (RoK, 2012b).

A study by Kilimo (2014) found that ballooning human population and the consequent needs to settle and feed many people caused the encroachment of Embobut forest and the Elgeyo escarpment in Tirap Division, Elgeyo Marakwet County. However, the forest dwellers were later evicted by the government from the forest with a section of this population migrating into the Elgeyo escarpment (Kilimo, 2014). Further, urbanization and the necessity for infrastructural expansion has continuously opened up Elgeyo escarpment with newly constructed access roads, a process that has occurred rapidly over the last thirty years since 1979, greatly contributing to accelerated land use and cover changes (Kilimo, 2014).

During this study period there was a protracted conflict between the communities living in the Elgeyo Marakwet and Baringo Counties (NCCK, 2009). This resulted in deaths, loss of properties and spontaneous relocation of a huge number of the Elgeyo Marakwet residents from Kerio valley floor to the Elgeyo Escarpment, zones considered secure (Pkalya *et al.*, 2003). This carried a potential risk of degradation since populations abandoned their land and settled on any available parcels of land irrespective of their suitability (Kiprono, 2018).

Most studies carried out in the area focused on particular river basins and forest ecosystems with least emphasis on the entire Escarpment. Consequently the LULC change drivers were identified based on these ecosystems. Further, although some of the drivers may account for LULC changes even in the escarpment, their contributions were not discerned. Therefore, this study established the LULC change drivers and their relative shares to LULC, information that is crucial in the formulation and enforcement of appropriate conservation policies and measures for sustainable management of the escarpment. In particular, cattle rustling, a retrogressive primitive cultural practice was highlighted and could be mitigated through concerted and sustained literacy and peace building campaigns.

2.4 Impacts of Land Use Land Cover and Changes on the Environment

Land use land cover (LULC) change is a measure of the conversion of a LULC class to the other, whereas LULC conversions refer to the incidental changes that in part influence the attributes of specific land cover (Lambin *et al.*, 2003). Changes in

LULC attributes immensely jolt an areas' productivity therefore sustainability measures must be incorporated to ensure that the area remains conserved (Zewdu *et al.*, 2016). Land degradation has been recognized globally as a threat to ecosystem functions and agricultural productivity with one of its major forms being soil erosion (Bai *et al.*, 2008). The occurrence, rate and severity of soil loss are affected by various key components including; rainfall, topographic features, soil properties and land governance operations (Eswaran *et al.*, 2019; Kogo *et al.*, 2020; Panagopoulos *et al.*, 2019). Further, demographic factors; population dynamics and migration patterns largely influence land use. This is because standards of living change impacting on both rural and urban environments. Thus, shaping the direction of land use change, impacting on the environmental integrity and eventually the societies' socioeconomic wellbeing (Kanianska, 2016).

Land use land cover change impacts arise owing to various stressing factors. For example, agricultural activities deploy pressure on the biophysical environment impacting on it both positively and negatively. This is because on the one hand, mechanized agriculture utilizes fossil fuels that emit CO_2, likewise nitrogenous fertilizers and farmyard manure emit GHGs (nitrous oxide and methane respectively). On the other hand, conservation agriculture, agroforestry and fallowing serve as carbon sinks (Ramankutty *et al.*, 2018). Further, the wide variability among farming systems and practices globally coupled with the contrasting environmental attributes suggest that the impacts arising from agricultural activities on the environment happen at specific sites, locally, regionally and globally (Kanianska, 2016). LULC changes have been verified to modify surface and vegetation characteristics as manifested in surface and atmosphere energy exchanges, hence impacting on regional climate (Weihs *et al.*, 2021). For example, LULC change affects local evapotranspiration which is a major element of water cycle alongside precipitation, thus demonstrating its brunt on both local to regional climate (Lambin *et al.*, 2003).

Agriculture is one of the economic activities that produces and consumes GHGs (sink). Notably, agricultural sector contributes about 13.5% of the global GHGs emissions (Solomon *et al.*, 2007). Conversely, fallows store carbon thus reducing the atmospheric GHGs concentration. Further, agricultural residues are used in bio refineries instead of fossil fuels in the generation of energy carriers and chemicals, hence helping in mitigating climate change and promoting clean power production (Cherubini & Ulgiati, 2010). A study in South Central Ethiopia regarding the impact of LULC on soil properties found significant differences in soil characteristics among four LULC classes. Remarkably, forest land had the most favorable soil properties while intensively cultivated outfields had the least (Bufebo & Elias, 2020). Therefore, it is important to practice conservation agriculture, protect forest cover to ensure desirable soil physical and chemical attributes (Bufebo & Elias, 2020).

Extensive LULC changes have directly negatively impacted on over three quarter of Kenyans, who practice agriculture as their economic mainstay (RoK, 2009a) especially the maize farming, which remains a staple food crop for majority of Kenyans (Nyoro *et al.*, 2004). Despite its importance in food security, maize production, continues to decline particularly in Western Kenya (Njoka *et al.*, 2016). Various forms of land deterioration have been experienced in Kenya, with one of them being soil erosion (Kogo *et al.*, 2020). Evidently, soil loss has accelerated, particularly in areas with high slope angles in excess of 30 degrees. This is due runoff velocity that increases with slope angle and length. Areas having such slope features include hilly and mountainous areas, and escarpments (Kogo *et al.*, 2020).

Agricultural production in Kenya has lately been constrained by soil erosion, population growth and climate change (RoK, 2016a). Deforestation particularly on rugged landscapes combined with unsustainable land governance practices along with continuous rainfall have increased soil erosion in Kenyan highlands (Boitt *et al.*, 2020). Soil erosion due to water in the country's arable land stood at 26 $tha^{-1}yr^{-1}$ (Fenta *et al.*, 2020). This has caused a substantial decrease in agricultural production across 20% of Kenya's total land area (Mulinge *et al.*, 2016). However, despite the profound LULC changes, rugged feature of the escarpment and indicators of soil loss occurrence being reported, information on the extent and intensity remained largely scanty. Accordingly, this study determined the impact of LULC changes on soil erosion occurrence.

LULC changes have caused a decline in cropland and increased urban built-up areas in Kiambu County (Njiru, 2016). Besides, human encroachment of basins such as those of Embobut and Arror rivers and their subsequent conversion into farmland has caused biodiversity loss, as reflected by low distribution in tree abundance and diversity (Wanjohi, 2019). The relocation of residents from the forest and Kerio Valley to the escarpment (NCCK, 2009) threatens several livelihoods downstream (Kiprono, 2018). Among the impacts on the landscape are occurrence of soil loss (Watene *et al.*, 2021) and increased landslides susceptibility (Kibiiy *et al.*, 2015).

The decline in farm productivity, incidences of soil erosion and landslides have prompted scholars into action. A study of Sibou village agricultural landscape by Wiborgh (2015) reported elevated nutrients levels and sediments in river water downstream across the escarpment. Landslides studies have shown increased occurrences in sections of the escarpment (Kilimo, 2014; Kipkiror *et al.*, 2021), prompting Kibiiy *et al.* (2015) to develop a landslide prediction model but it lacked information on soil type and properties rendering it discrepant. Accordingly, this study carried out soil mapping and analysis and established soil types, their physical and chemical properties, information crucial in the accurate landslide prediction in the area, promoting proper land management, preparedness and prevention of disasters.

2.5 Land Management Institutional Frameworks

2.5.1 Land Management Strategies

In recent times, increased consciousness for environmental sustainability has jolted several jurisdictions into action to regularly review and modify their land management systems so as to strike an equilibrium among multiple competing land uses (Ramankutty *et al.*, 2018). One of the adjustments made has been the embrace of organic farming. By 2013, 43.1 million hectares of cropland was under organic farming, inclusive of conversion zones. Oceania and Europe dominated the organic agricultural production (Arbenz *et al.*, 2015).

The recently increased land productivity witnessed has been enabled by some technological breakthroughs. Notably, the advanced knowledge in plant biology has enhanced people's comprehension of genetics, physiology and development (Evenson & Gollin, 2003). With the knowledge of genetics, plant breeders have been enabled to produce new cultivars of plants with worthwhile attributes including high yielding hybrids having enhanced endurance to diseases and pests (Foley *et al.*, 2011). Further, land sparing which is the intensification of agricultural production, hence producing the same or more food quantities on less cropland, thereby sparing portions of land for natural purposes (Kremen, 2015). Once the land is spared, it is important to actually utilize the it for nature conservation (Phalan *et al.*, 2016). Ordinarily, land sparing initiatives are followed with suitable policies to ensure that the intended conservation purpose is actually achieved (Ramankutty *et al.*, 2018). This policy is very desirable in areas adjacent to fragile ecosystems such as escarpments.

It follows that agricultural intensification should be implemented in the high potential areas so that the escarpment can be spared. Therefore, the County Governments in regions predisposed to landslides are obligated to ensure that comprehensive mechanisms including adequate finances and implementing agencies down to the bottom level of authority (Kilimo, 2014). Some of these policies include; non-cultivation on steep slopes, construction of soil conservation structures, planting of deep-rooted trees such as eucalyptus and detailed mapping of degraded areas and sensitization of communities residing around steep slopes (Gichaba *et al.*, 2013). This policy will ensure sustainable protection of the escarpment for the future generation while also avoiding disaster risks.

2.5.2 Policy Framework

Several governments including Kenya appreciate that land degradation presents significant environmental challenges and therefore urgent actions must be taken to alleviate it. To this end, steps have been taken to grapple with land degradation. They include legislations, policies, strategies and regulations. Various legislations have been enacted and operationalized to safeguard Kenya's rich biodiversity and manage the utilization of its innate assets (RoK, 2016a). Among the key instruments include; the Constitution of Kenya, 2010, Kenya Vision 2030, legislations and adoption and implementation of international conventions and treaties. They include; The Environment and Development Declaration of 1972, Agenda 21 of 1992, the Paris

Framework Convention on Climate Change of 2015 and the Ramser Convention of 1992 on the Protection of Wetlands.

Kenya vision 2030 is intended to revolutionize the country into a middle income country providing a high quality of life to all citizens in a clean and secure environment (RoK, 2007). It is anchored on three pillars; economic, social and political governance and supported by a number of foundations such as land reforms. The conceptualization of a national land use policy facilitates the founding of a national spatial data infrastructure for tracking land use patterns thus formulation of a baseline on the state of the environment for future environmental planning.

There are numerous national policies that are tailored towards environmental protection, they include; the National Environment Policy, 2013, a key sector blueprint that strengthens tenable land utilization and preservation of innate resources (RoK, 2013). The Forest Policy, 2014 recognizes that forestry sector plays a crucial task in anchoring the Country's economy with its key aim being to expand and sustain forest coverage to at least ten percent of the Country's land mass. The National Land Policy (NLP) No. 3 of 2009 envisioned to steer the nation to orderly, tenable and fair utilization of land resources for the wellbeing of the future generation (RoK, 2009b). The National Land Reclamation Policy of 2013 highlights major concerns regarding enormity of environmental deterioration as a weighty occurrence that must be addressed through concerted actions (RoK, 2009b).

These policies have been cascaded down to the County Governments. Notably, the Elgeyo Marakwet County Government developed a sustainable forest and tree growing policy. One of the key policy statements is that the County Government will establish and institutionalize the execution of sustainable land management practices covering all land uses on public, private and community land in the County (CGoEM, 2020). This encompasses sustainable agriculture, mainstreaming of human rights, integration of continuous forestry and tree growing into physical and land planning and development control exercises (CGoEM, 2020). This policy is anchored in the Elgeyo Marakwet County Sustainable Forest and Tree Growing Act of 2020 (CGoEM, 2020). Additionally, The Elgeyo Marakwet Water Services Act, 2012 Part IV: Water and Soil Conservation, Section 41(1) confers Water Services Board power to declare an area a water area for purposes of conserving water. Further, Section 41(2) mandates the board to prohibit certain activities such as tillage, clearing of indigenous trees and building structures in relation to the water conservation area.

The Integrated National Land Use Guidelines (INLUG), 2011 recognizes that land is a crucial element of production, thus its suitable control is mandatory for sustainable progress (Kamau, 2013). The Agriculture Sector Development Strategy (ASDS) 2010-2020 enumerates agricultural policy goals and guides the efforts of public and private sectors in addressing the bottlenecks facing the sector (Kamau, 2013). National Climate Change Response Strategy (NCCRS), 2010 is meant to generate mechanisms for alleviating climate change impacts, being among the main drivers of environmental deterioration in Kenya (Solomon *et al.*, 2007).

2.5.3 Legal and Institutional Framework

In Kenya, agricultural, livestock and environmental sectors are guided by a range of legal frameworks. They include the Constitution of Kenya, 2010 and various pieces of legislation. Chapter Two of the Constitution of Kenya 2010, Article 10 (1) provides that national values and principles of governance bind all state officers, public officers and all persons when applying or interpreting the constitution and laws or making or implementing public policy decisions. One of these values is sustainable development enumerated under Article 10 (2) (d). Chapter Four of the Constitution on the Bill of Rights, Article 42 provides that every person is entitled to a clean and healthy environment. Further, Chapter Five, Part 1, on land; Article 60 (1) (c) provides that land resource in Kenya shall be held, used and managed in a sustainable and productive manner. Furthermore, Chapter Five, Part 2, on Environment and Natural Resources; Article 69 (1) and (2) obligate the state and every citizen to ensure sustainable management of the environment. Moreover, Article 70 provides for enforcement of environmental rights contemplated under Article 42. Additionally, Article 72 obligates parliament to enact legislations to operationalize the provisions of this part. Consequently, legislations on the Agriculture, Livestock and Environmental sectors have been enacted so as to harmonize old laws and align them with the new constitution for its operationalization.

The Environmental Management and Coordination Act (EMCA, 1999) as amended in 2015 is a fundamental legislation for the preservation of Country's environment including its biological diversity (RoK, 2015). Of particular interest is the Second Schedule concerning projects requiring submission of an environmental impact assessment study report. These include; major amendments in land utilization and construction of roads in environmentally sensitive areas like the escarpment (RoK, 2015). The Land Registration Act, No. 3 of 2012 aspires to amend, merge and validate registration of land titles, to discharge the essentials and focus of county governments in land certification. The National Land Commission (NLC) Act, No. 5 of 2012, established and directs NLC by laying principles for its composition and operations at the National stage in implementing the National Land Policy. The Lands

Act, No. 6 of 2012, mandates the NLC to pinpoint fragile ecological zones of public lands and act fairly to avert environmental deterioration (Njoka *et al.*, 2016).

The Chiefs' Act; section 10 confers the Chief power to give direction to be heeded by the residents or being within his jurisdiction for regulating the cutting of timber and prohibiting the wasteful destruction of trees (RoK, 2012b). Additionally, Section 13 of the act confers the Chief authority to require task or services for protection of innate resources. Section 18 provides that anybody who, without legal justification, fails to abide by any lawful instructions issued by the chief or his assistant under this act shall be faulty of a felony and subject to a penalty of at most five hundred shillings and in failure to pay, to an extra mural penal service for a period not more than fourteen days (RoK, 2012b).

Section 48 of the Agriculture Act chapter 318 No 9 of 1967, revised in 2012 confers the Minister for Agriculture, power upon the Central Agricultural Board's advice to issue directions; proscribing or controlling the disturbance or opening of land for the purposes of agriculture; Revised Edition 2012 (1986) (RoK, 2012a) **.**

Agriculture (Basic Land Usage) Rules, 1965 (L.N 26/1965) on the preservation of land with slope exceeding 12%, 20% and 35 % provides that; anybody cultivating, cutting down or ruins any plant foliage, or departures animals over any land whose slope is more than 35 % shall be guilt of a felony (RoK, 2012a). Also, a permitted official may in writing; proscribe agricultural activities or annihilation of vegetation on any land whose slope is more than 20 %. Moreover, anybody cultivating any land whose slope exceeds 12 % and less than 35 %, and does not conserve the soil against erosion by preservation works to the contentment of an authorized officer, shall be guilty of a felony. Furthermore, where in the judgment of an authorized officer finds that soil on a slope exceeding 12 % is not, sufficiently conserved from erosion, he may direct the owner in writing to establish such structures or restorative tasks as he sees appropriate within such considerable period of time as may be indicated in the directive (RoK, 2012a). It is against these basic land usage rules that the Spencer line was drawn to demarcate arable land, settlement areas from the steeper sloppy parts of the escarpment. This was meant to conserve the soil desirable properties, control soil loss and prevent landslides which were recipes for disasters (CGoEM, 2018).

Agriculture (Farm Forestry) Rules, 2009 require that a person owning or occupying agricultural land shall set up and sustain at least 10 % of the land on farm forestry. District Agricultural Committees shall pinpoint land under their area that is under threat of land deterioration and initiate actions requisite for guaranteeing its protection such as trees planting. The Agriculture (Basic land usages) Rules shall be enforceable to sloping lands (Agriculture (Basic land usage) Rules, 1965. All land holder or occupiers shall make sure that trees exploitation shall be carried out in a way that maintains a 10% tree cover always, with expansive harvesting necessitating harvesting plan according to stipulations of the Forest Act; No 7 of 2005 (RoK, 2005). Infringement of any of the requirements of Basic Land Usage Act, 1965; Farm Forestry Act, 2009 and Forest Act, 2005 laws amount to commission of an offence.

Accordingly, any person who flouts the stipulations of which no express retribution has been issued shall be at faulty upon sentence to a fine of six thousand shillings or incarceration for six months or both. A person who is culpable of a crime under these Rules shall be subjected to a fine of at most five thousand shillings or incarceration for a period less than six months, or to both Agriculture (Farm Forestry) Rules, 2009 (RoK, 2009). Other legislations establishing and governing institutions concerned with environmental conservation include; the Physical and Land Use Planning Act of 2019, the Water Act of 2002, the Crops Act of 2013, the AFFA Act of 2013 established Agriculture, Food and Fisheries Authority (AFFA) and KALR Act of 2013 established the Kenya Agricultural and Livestock Research Organization. Moreover, land conservation measures enforced in the escarpment include cultural taboos and zoning areas according to slope angles referred to as spencer lines (CGoEM, 2018).

Following the review of the legal environmental protection instruments; policies, strategies, legal and institutional frameworks, it can be deduced that they are sufficient to safeguard every sector of the environment within the study area. However, environmental degradation continues, notwithstanding the existence of the legal safeguards. This scenario was attributed to; non-adherence to good agricultural practices, low capacity to enforce the existing laws and policies, market incentives and low levels of land adjudication in the escarpment (RoK, 2016a).

2.6 Theoretical and Conceptual Framework

2.6.1 Theoretical Framework

This study is hinged on the Malthusian Theory premised on respective rates of resources production (food) and population growth (Malthus, 1798). Malthus observed that in humans there is a passionate push between the sexes to reproduce; be prolific and increase, resulting in birth of more kids hence exponentially population growth and if unchecked, it doubles itself every twenty five (25) years. On the other hand, food production increased arithmetically thus sooner or later human population would surpass resources. Gains in quality of life would be short-lived, and populations would subside to sustenance levels. It is certain that food is indispensable for humans' life (we must eat in order to live). Malthus (1798) envisioned that inhibition in population growth would come in two fashions: positive checks that escalate mortality rate such as extensive famine, diseases epidemics and wars that collapse populations to subsistence levels (Malthusian catastrophe). The preventive checks that diminish birth rates include: birth control, postponing marriages and celibacy (Burger, 2021). However infinite population growth is not possible owing to bounded limits of the earth. Excess workforce in the labor market will emanate from meteoric population growth, resulting in decreased wages (Pham *et al.*, 2020). It further, ends in increased demand for commodities which in turn leads to increased prices of basic commodities resulting in poverty and misery in the society (Burger, 2021) as shown in Figure 2.1.

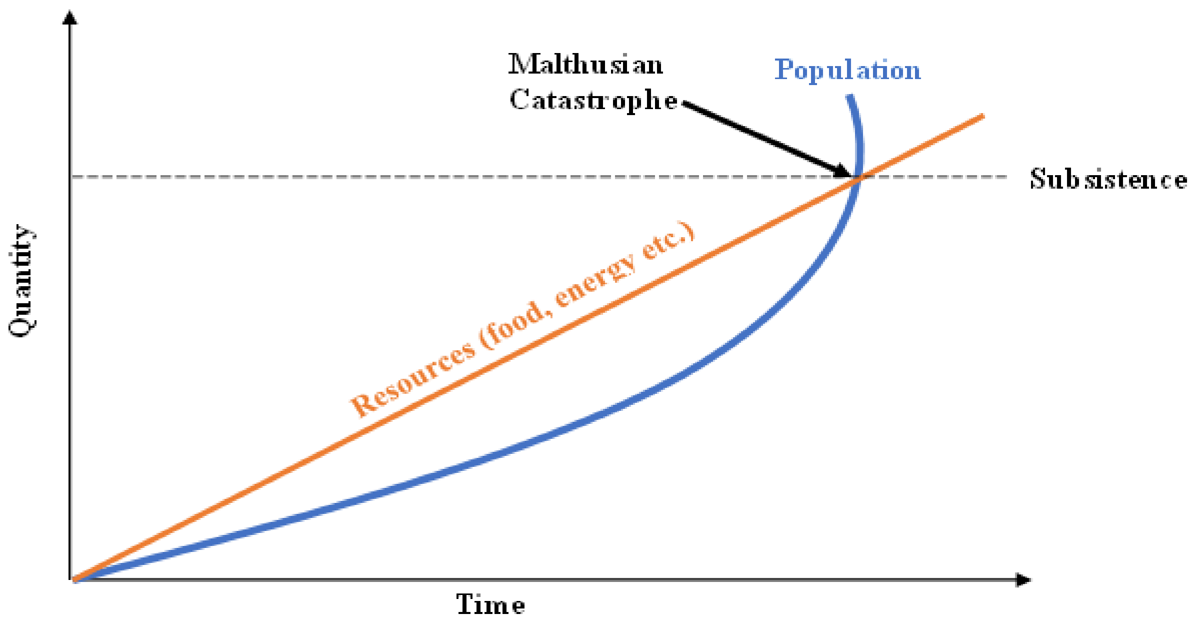

Figure 2.1: Illustration of the Malthusian Theory (Burger, 2021)

This study assessed the correlation among, land resources, LULC changes and their implications on land degradation. Growth in population results in a corresponding demand for basic needs. In the event that the population growth surpasses resource availability, it culminates in the insufficiency of that resource; land meant for cultivation to produce food and settlement. In the process, the population in pursued of their needs is forced to find additional land including a sustained encroachment on fragile areas compromising their natural recovery capacities eventually precipitating land degradation.

Despite the shortcomings of the Malthusian theory, it is still relevant in most parts of the world to date. Although it least applies in Western Europe today, the Malthusian principal tools formed an integral part of this region (Pham *et al.,* 2020). They avoided overpopulation and misery thanks to the bogey and pessimism of Malthusianism. In fact the declining population in France has been blamed on the fear of Malthusianism. The formulation of most policies across the developing countries was informed by this theory. Notably, the family planning policy implemented through the extensive use of birth control methods such as contraceptives across several counties like India, South America, China and Kenya among others represents Neo-Malthusianism (Pham *et al.*, 2020). Additionally, the health insurance policies that restrict the number of dependents to a principal member are largely informed by the Malthusian doctrine (Adama & Audu, 2019). Moreover, the decadal population and housing census, annual population projections and other forms of census are done with the essence being to plan for the needs of people.

2.6.2 Conceptual Framework

The ever-increasing population has continued to exert immense force on the finite innate resources especially land. This is because; land is a key factor of production for basic commodities such as food and fiber (Pham *et al.*, 2020). Increase in population results in a corresponding increase in demand for basic and other needs. Different societies adopt different means of satisfying their increased demand for needs depending on their adaptive capacity (Adama & Audu, 2019). Resource endowed societies would ordinarily adopt environmentally sound measures such as agricultural intensification and other alternative livelihood options while the less endowed societies resort to agricultural extensification. This is a deliberate expansion of the area of arable land frontiers through the conversion of primary land uses and cover such as fallow lands, forests, wood and grasslands or other protected areas to agricultural land (Ramankutty *et al.*, 2018).

Owing to its rugged terrain with steep and long slope lengths and high rainfall, this escarpment is deemed fragile. Societies living within or near fragile ecosystems such as Elgeyo escarpment are often tempted to convert its natural vegetated areas to arable and settlement land to be able to satisfy their nutritional and housing needs. This scenario, coupled with insecurity or ethnic conflicts, force communities to settle and practice agriculture in fragile areas such as Elgeyo Escarpment. Besides, the emerging infrastructural development such as roads construction both by the national and county governments across the escarpment has led to the establishment of schools and other social amenities that constitute life support services.

This has encouraged community members to settle in the escarpment (CGoEM, 2018; Kilimo, 2014). This is compounded by poor land management practices, resulting in deteriorating soil quality and soil erosion occurrence, that are forms of land degradation. Therefore, to reverse this trend and sustainably manage the escarpment, there is need to adopt environmentally sound measures such as; reafforestation, agroforestry, conservation farming, adoption of alternative livelihood sources (beekeeping and fruit trees) zoning, enclosures establishment, and embracing family planning and peace building and increasing literacy levels among locals (Figure 2.2).

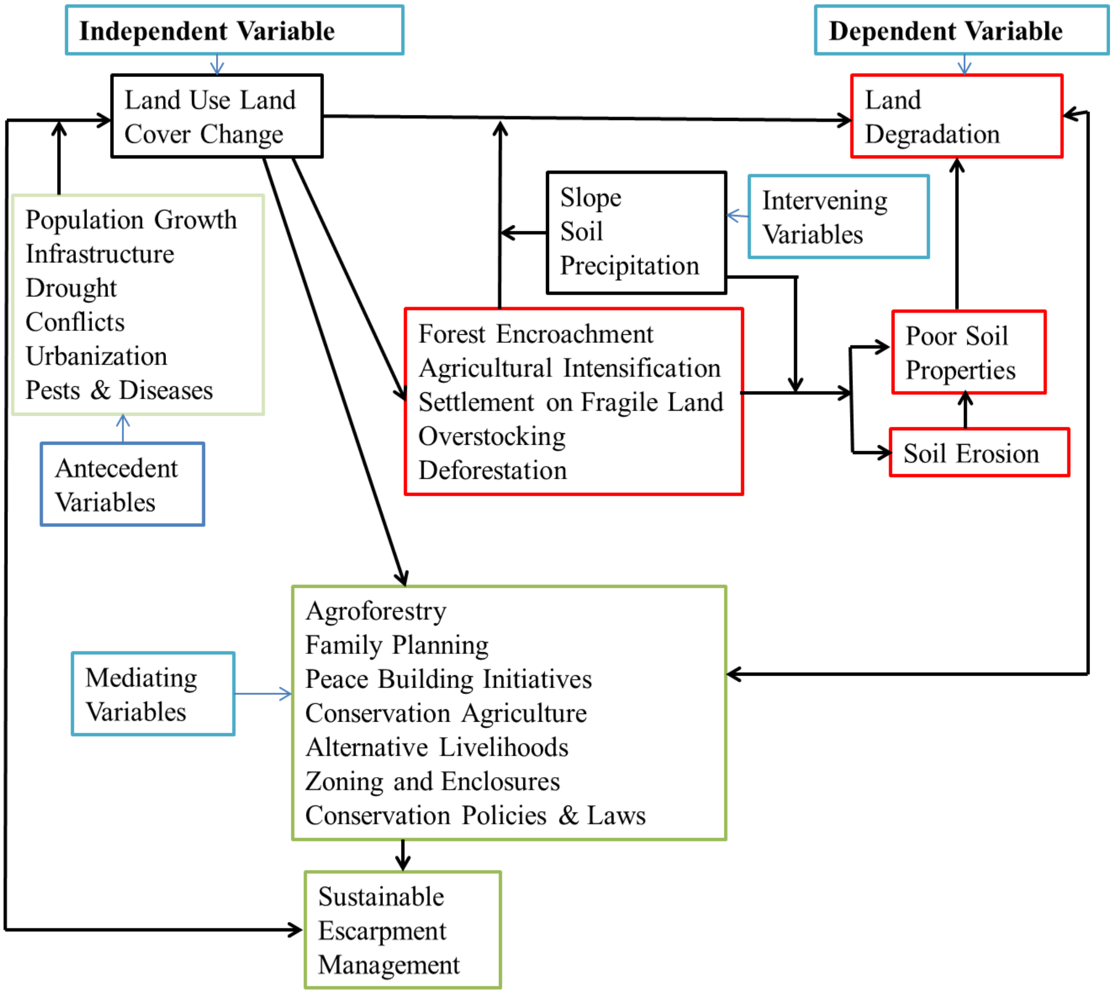

Figure 2.2: Conceptualizing the Drivers and Impacts of LULC and Changes on Land Degradation in Elgeyo Escarpment (Author; 2022).

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The chapter details the study design, materials and methods deployed to conduct the study. It also recounts the target population and sample size, sampling strategies and the tools and devices used in data gathering. It further narrates soil sampling strategies, processing and examination procedures that were employed and data processing and presentation of results.

3.2 The Study Design

Descriptive survey research design was used in this study. The survey entailed collection of data from a sample of individuals via their replies to questions asked (Check & Schutt, 2012). This was done through a diversity of methods to enlist participants, collect data and utilize a variety of instruments. Other than survey tools, spatio-temporal LULC dynamics were determined by Geographic Information Systems and Remote Sensing techniques to discern land use patterns and their impacts on soil loss in the study area. This design was employed to determine LULC and conversion, their drivers and implications on degradation in the escarpment as described in 3.4. The impacts of these LULC on soil physicochemical properties in the study area were assessed and established using a modified land degradation surveillance framework (LDSF). In this model, the Elgeyo escarpment constituted a block with selected wards in the four sub-counties being sub-blocks. The model was used in identification and demarcation of sub-blocks and sampling plots as described in section 3.4.

3.3 Data collection

3.3.1 Secondary Data Collection

A desktop study involving a review of literature materials including reports, maps, and scientific papers pertaining LULC dynamics and degradation was conducted. Relevant study reports on human and LULC issues in the study area were evaluated. Government policy papers, strategies and acts of parliament that concern land and environmental management were reviewed. In particular, the study reviewed reports from the departments of Environment, Agriculture, Water, Devolution and Planning, Lands, Housing, Tourism, and their respective affiliated semi-autonomous government agencies. The data gathered was processed and the historical trends in LULC dynamics discerned. This information was used to determine LULC changes, drivers, scope and their ramifications on land deterioration in the escarpment.

3.3.2 Survey

Prior to the data collection exercise, four sites were selected and, in each site, two enumerators were identified by the Ward Agricultural Extension Officers. The enumerators were trained to understand the tool and how to pose the questions and record the responses. The tool was pre-tested before the actual data collection. During the pre-testing exercise, five respondents comprising three males and two females were interviewed in each study site. The survey targeted area residents who had lived in the area for at least fifty-five years and with deep understanding and memory of the LULC and change patterns over time.

This entailed identification of a respondent who after being interviewed would direct the enumerator to the successive interviewee until no more appropriate interviewees were identified, a non-probability; snowball sampling approach (Naderifar *et al.*, 2017). This technique was suitable since it was difficult to identify and meet respondents with desired attributes. Consequently, the first interviewee recruited the ensuing respondents among their contacts and sampling continued until saturation (Grove *et al.*, 2012).

Following the snowball sampling approach, a total of 180 respondents comprising of 128 men and 52 women aged over 55 years (Grove *et al.*, 2012) were interviewed using a pre-tested structured questionnaire (Appendix 1). They comprised; 40, 50, 40 and 50 respondents from Tambach, Soi South, parts of Embobut/ Endo and Kapsowar/Arror wards in Keiyo North, Keiyo South, Marakwet East and Marakwet West Sub-counties respectively that the escarpment runs through. Eight six-member focus group discussions were carried out using a checklist (Appendix 2).

The groups comprised of 30 men and 18 women aged over 55 years old to ensure a true representation of LULC dynamics of the area over the study period. Further, data from Ministries of Agriculture and Lands and agencies including National Environment Management Authority, Kenya Meteorological Services, Kenya forest service, Geology and Kerio Valley development Authority was collected using a key informant interview schedule (Appendix 3).

3.4 Land Degradation Surveillance Framework

A modified form of Land degradation surveillance framework (LDSF) was employed in this study. The entire Elgeyo escarpment constituted a block with Soy south, Tambach, Kapsowar, Arror, Endo and Embobut wards representing the sampling sites. The sites were purposively selected to constitute the main land uses across the escarpment. Six sites of similar biophysical characteristics (LULC, elevation, slope, climatic conditions and land management practices) were identified in each ward. A site measuring five kilometers square was demarcated and divided into five plots to represent each land use class namely; shrubland, forest, cropland, grassland and built-up identified according to the classification described in Table 3.2. Each land use class (plot) constituted a basic sampling unit. Soil sampling was as described in section 3.7.1. The randomization applied in the LDSF minimized bias in the sampling of LULC classes for soil physical and chemical properties analysis (Vâgen *et al.*, 2010).

3.5 Spatiotemporal Land Use Land Cover and Change Assessment

3.5.1 Datasets and Acquisition

Prior to LULC and change assessment, reconnaissance surveys were conducted to familiarize the researcher with the study area. During these visits cameras and geographic positioning system gadgets were carried for photographic and coordinates recording purposes respectively. Three time period multispectral Landsat images were acquired from the United States Geological Survey (USGS) Earth explorer Website (https://earthexplorer.usgs.gov/). The specifications of the Landsat satellite images located in worldwide reference system (WRS) - path 169 and WRS-rows 60 and 59 utilized in this study are stipulated in Table 3.1. The study area shapefile was acquired from contour interpolation and tracing contour value from 1200m to 2800m. The acquisition period was meant to enable a sustained phenology in all the images.

Table 3.1: Specifications of the Satellite Imageries

Year	Date of acquisition	Satellite platform	Level 1 Sensor	RGB Bands	Spatial resolution (m)
2020	11th February 2020	Landsat 8	OLI	4,3,2; 5,4,3; 7,6,4; 6, 5,4 & 7,5,4	30
2014	25th January 2014	Landsat 8	OLI	4,3,2; 5,4,3; 7,6,4; 6,5,5 & 7,5,4	30
1995	6th February 1995	Landsat 5	TM	3,2,1; 4,3,2; 7,5,3; 5,4,3 & 7,4,3	30

Source: USGS (1995, 2014 and 2020)

Further, digital maps of the County and contour maps (scale of 1:50,000) were obtained from Survey of Kenya. This study took 1995 and 2020 as the base and final reference years respectively. This sufficiently represent the period when remarkable LULC conversions happened in the study area (Alliance, 2015). The images were processed and analyzed by digital image handling software ArcMap version 10.8.

3.5.2 Pre-processing of Satellite Images

The first action done purposely to augment the grade of the image data and reduce geometric and radiometric flaws that arise while obtaining images (Bruce & Hilbert, 2006) and to rectify the atmospheric interference (Duggin & Robinove, 1990; Song *et al.*, 2001). Additionally, dark object diminution was performed to eliminate the upshot of atmospheric dispersion from the distantly sensed data to enhance reparability of the spectral classes (Song *et al.*, 2001). The Landsat images from diverse locations were mosaicked into a sole flawless blended image and clipped using the escarpment's boundary map digital shapefile representing the study's (AOI).

3.5.3 Visual Image Interpretation

The Landsat 5 image of 1995 was interpreted by combining, bands 4, 3 and 2 corresponding to near infra-red, Blue and green false colours respectively. Landsat 8 image for 2014 and 2020 years, bands 5, 4 and 3 were combined corresponding to near infra-red, red and green (NIR, R and G) false colours respectively.

3.5.4 Ground Truthing

Respective Google earth images for the three years were downloaded and a training sample shapefile created. Fifty training samples for each LULC class were randomly digitized on their respective Google earth images totaling to 250 samples for use in ground trothing. The 250 samples were overlaid on the respective classified LULC maps to determine how the classification corresponded to reality on the ground.

3.5.5 Data Analysis

Identification of numbers of training sites for distinct LULC classes was determined by their distinct spectral reflectance. The objects in the various images were visualized through the distinction of the color bands (Red-Green-Blue bands). The spectral properties of the generated regions of interest (ROI) were analyzed for satisfactory separability to guarantee minimum confusion amongst the land cover classes (Gao & Liu, 2010). All the pixels in the satellite images were blended together into LULC information classes (Kadavi & Lee, 2018). Training sites from the pre-processed images were constructed by drawing training samples about the regions of interest to constitute the main LULC classes; explicitly discriminable and devoid of effects arising from period interim differences of the images deployed.

3.5.6 Digital Image Classification

Once the ROIs were satisfactory, supervised classification was conducted in ArcMap 10.8 software utilizing the maximum likelihood algorithm (Hassan *et al.*, 2016). The LULC classification was performed by a classification scheme outlined in Table 3.2. After selecting training samples for each of the five classes, the training sites were saved in ArcMap software for use during supervised classification. The training sites were picked and the entire image scanned through by the software to group samples of similar spectral reflectance into single classes.

Table 3.2: Land Use Land Cover Classification Scheme

No	LULC class	Description
1	Forest	Lands covered by woody plants with a cover of more than15% and height more than five meters.
2	Shrubland	Woody perennial plants with persistent and woody stems and with no defined main stem being less than 5 meters tall.
3	Grassland	Plants without persistent stem or shoots above ground and of devoid definite firm structure. Tree and shrub cover is < 10%
4	Cropland	Cultivated and governed vegetation/agriculture. Lands covered with temporary crops followed by harvest and a bare soil period
5	Built-up	Land covered by buildings and other manmade structures

Source: (FAO, 2000)

3.5.7 Accuracy Assessment

An accuracy evaluation was performed prior to the utilization of image classification outputs in change detection. Thirty samples were digitized into the corresponding reference image and overlaid into the classified images. This was meant to validate the potency of the categorization by establishing how acceptable the resultant LULC correlate with the actual land cover on the ground (Muriithi, 2016). The classification precision was examined using ground truth ROIs sample from Google Earth images.

Collation of classification outputs and the study area's ground reference test pixels were statistically analyzed using assessment tables. The overall, producer and user's accuracies were derived for each of the classified images using the formulae indicated in appendix VII. Further, from each image, the Kappa coefficient was extracted to scrutinize the concurrence of the remotely-sensed categorization and the ground trothed pixels (RoK, 2012b). The overall accuracies and Kappa coefficients realized exceeded 0.7 threshold, consequently enabling detailed image analysis and detection of LULC changes (Lea & Curtis, 2010).

3.5.8 Change Detection

Detection of changes on the images was carried out by ArcMap 10.8 to ascertain any conversions that happened over the study period (Lu *et al.*, 2004). This was done by calculating the changes in land cover between two consecutive images that is 1995-2014 and 2014-2020 to ascertain the magnitude of change among land cover classes. Each of the three classified images; 1995, 2014 and 2020 was converted from raster to polygon and in the attribute table, the classes were labeled and their areas auto generated using calculate geometry tool. Using geoprocessing intersect tool, two successive images i.e., 1995-2014 and 2014-2020 were intersected to establish LULC conversions.

3.6 Soil Erosion Assessment

Soil loss in the study area was assessed using the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1991). The model is an improvement of the Universal Soil Loss Equation (USLE) in terms of accuracy in estimation of soil loss (Renard, 1997). The key components factored to determine soil erosion included; soil, precipitation, topographic data from a DEM, land use management and soil conservation practices (Wischmeier & Smith, 1978). A summary of the methodological framework for soil erosion computation in this study is indicated in Figure 3.1.

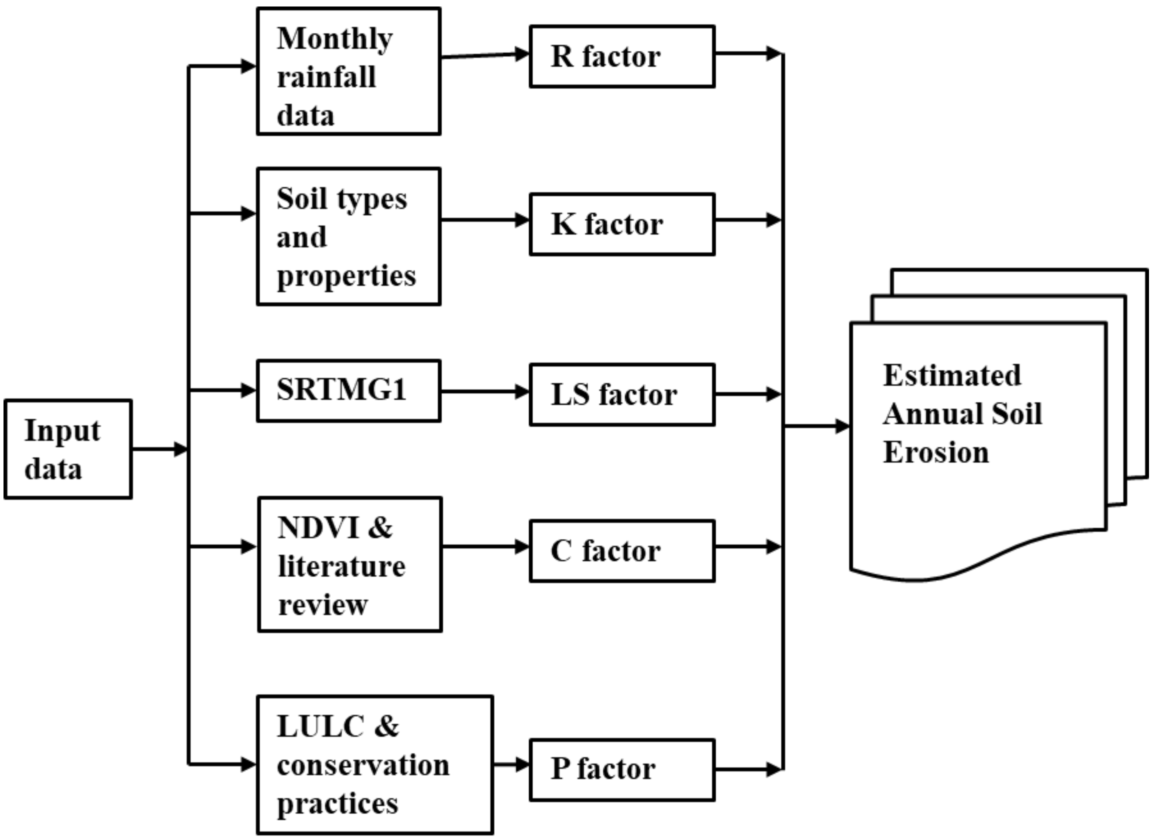

Figure 3.1: Methodological Framework used to Estimate Soil Erosion in Elgeyo Escarpment (Author, 2022)

Annual soil erosion for the study years in the escarpment were estimated following equation 1 of Renard (1997) as indicated below:

$$A = R * K * (LS) * C * P \quad (1)$$

Where: A = Annual average soil loss per unit area ($tha^{-1}y^{-1}$), R = Rainfall erosivity factor (MJ $mmha^{-1}h^{-1}y^{-1}$), K = Soil erodibility factor (ton h $MJ^{-1}mm^{-1}$), LS = slope length and slope steepness factor (dimensionless), C = Cover management factor (dimensionless), P = soil conservation support practice factor (dimensionless).

The study computed soil erosion for the years 1995 and 2020 using the RULSE model and each of these factors in the RUSLE model was determined as described.

3.6.1 Rainfall Erosivity (R) Factor Determination

Since there is strong direct relationship between precipitation magnitude and soil loss, the rainfall erosivity factor remains the major contributor to soil erosion (Kogo *et al.*, 2020). Rainfall data, a key input for determining the rainfall erosivity was acquired from the Kenya Meteorological Service (KMS). In areas without rainfall intensity data, the storm erosivity index values were used instead to estimate erosivity following equation 2; the Wischmeier and Smith equation (Wischmeier & Smith, 1978). The rainfall data over a time span of 1995–2020 was utilized to determine erosivity for the study period. In this study, 1995 was the base period while 2020 constituted the current period.

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5 \log 10\left(\frac{Pi^2}{P}\right) - 0.08188\right)} \quad (2)$$

Where R is the rainfall erosivity in MJ $mmha^{-1}h^{-1}y^{-1}$, Pi is monthly rainfall in millimeters and P is the yearly rainfall in millimeters. R-factor values for the sampled points were processed using Kriging technique to derive their geographical disposition in the escarpment (Lu *et al.*, 2004).

3.6.2 Soil Erodibility (K) Factor

Soil erodibility factor designates the soil particles' power to endure detachment by raindrops and be transported by rainfall runoff (Renard, 1997). The K factor relies on the soil's intrinsic properties like organic matter, texture, structure and permeability (Sujatha & Sridhar, 2018). The soil data for this study was sourced from the Kenya Soil and Terrain Database (KENSOTER, 2004) and K factor estimated following the Sharpley and Williams (1990) erosion productivity impact calculator model.

$$K_{Rusle} = f_{csand} \times f_{cl-si} \times f_{orgC} \times f_{hisand} \qquad (3)$$

$$f_{csand} = 0.2 + 0.3 \times exp\left[-0.256 \times Ms \times \left(1 - \frac{Msilt}{100}\right)\right] \qquad (4)$$

$$f_{cl-si} = \left[\frac{Msilt}{Mc+Msilt}\right]^{0.3} \qquad (5)$$

$$f_{orgC} = \frac{0.0256 \times Mo}{Mo + exp[3.72 - (2.95 \times Mo)]} \qquad (6)$$

$$f_{hisand} = 1 - 0.7 \times \frac{1 - \frac{Ms}{100}}{\left(1 - \frac{Ms}{100}\right) + exp\left[-5.51 + 22.9 \times \left(1 - \frac{Ms}{100}\right)\right]} \qquad (7)$$

Where; Ms, $M_{silt,,}$ Mc and Mo are the % sand, % silt, % clay and % organic matter respectively. The values for K-factor range from 0 to 1, with values inclined towards 1 denoting increased susceptibility to water erosion (Sharpley & Williams, 1990).

3.6.3 Land Topographic (LS) Factor

The LS factor is the merged influence of the topographic length and angle on soil loss (Morgan *et al.*, 1984). Increasing slope length and steepness values accelerates erosion rates because they yield higher overload flow speed (Morgan *et al.*, 1984). This study utilized Shuttle Radar Topography Mission (SRTM) dataset with 30 m resolution downloaded from USGS Earth Explorer website. Additionally, the LS factor was calculated from the ArcGIS hydrology tool and the facet slope steepness (angle) estimated from digital elevation model (DEM). Eventually, the LS factor was estimated by the Matlock model (Matlock & Morgan, 2011).

$$\text{LS} = \left(\frac{\lambda}{22.13}\right)^{m} \times (0.065 + 0.45s + 0.0065s^2) \quad (8)$$

In this equation, λ = slope length; a product of flow buildup and cell resolution (30 m x 30 m) for this study, s = percentage slope angle; m = index hinged on land slope angle. The m values are allocated as: 0.5, 0.4, 0.3 and 0.2 for slopes of >5%, 3–5%, 1–3% and <1%, in that order (Singh *et al*., 1981). The study used the same derived LS factor in both study years since the slope features hardly change.

3.6.4 Conservation Support Practice (P) Factor

The P factor is the description of land management control actions that are geared to minimize runoff water gradient and by extension soil loss. Conventionally, there are three conservation measures practiced in the area including terracing, contouring and strip cropping. In the conservation practice factor, 1 denotes poor conservation practices while 0 denotes proper utilization of conservation measures. This study utilized 1995 and 2020 LULC evaluation images. The images were combined with land slope attributes computed by DEM utilizing ‘union function in ArcGIS to derive P-factor values (Wischmeier & Smith, 1978).

3.6.5 Cover Management (C) Factor

The C factor is an essential element of the RUSLE since it is the value of the contribution of land cover to soil loss (Yang, 2014). The value of C factor was computed using the Normalized Difference Vegetation Index (NDVI), estimated using Van der Knijff equation expressed as equation 9 (Van der Knijff *et al.*, 2000).

$$C = EXP \left[-a \frac{NDVI}{\beta - NDVI} \right] \quad (9)$$

In this model a = 2, β = 1. Conventionally, C factor values range from 0 to 1, with 0 denoting dense vegetation cover while 1 denotes bare lands (Gitas *et al.*, 2009).

3.6.6 Spatial and Temporal Distribution of Soil Loss

Spatiotemporal soil losses were computed by projecting the extracted layers for every RUSLE factor to WGS 1984 UTM Zone 37 N spatial reference and resampled to a 30 × 30 m pixel size. These layers were overlaid in ArcGIS 10.8 to obtain soil loss threat maps for the years under study. The produced maps were grouped into various soil loss categories. Once the erosion risk maps were generated, mean amounts of soil loss were calculated over various altitude and slope zones. Further, the input of LULC and conversions to soil erosion susceptibility in the escarpment across slope zones was estimated using a conversion computation technique.

3.7 Soil Chemical and Physical Properties Assessment

3.7.1 Soil Sampling

Six sites were selected in the study area. Each site was divided into five sampling plots according to LULC classes. Soil sampling was carried out in all the five LULC classes in the six study sites. Soil samples were taken randomly from each of the five LULC classes using a soil auger, mixed thoroughly and a composite sample weighing 0.5 Kg put in plastic bag and clearly labeled with a marker pen. The clearly labeled samples with the tags containing; the site, cluster, depth and date of sampling were taken for analysis in the University of Eldoret Soil Science Laboratories.

Soil Bulk Density (BD) samples were collected from the field using a cylindrical metal sampling ring measuring 5.2 cm high and 5.1 cm in diameter. The ground surface was cleared of organic matter and the ring pushed into the soil until at par with the ground surface level. The ring was then pulled out by tilling about it using a trowel underneath it to avert any soil loss. Excess soil from the ring was removed using a knife and the bottom of the sample flattened and evened with the edges of the ring. The samples were packaged in polythene bags and sealed with rubber band. Each of the polythene bags was recognized by a sample site code. The top soil BD was used to denote differences in soil compaction amongst various land use classes in the escarpment. Sixty soil samples in total were processed for soil chemical and physical properties determination.

3.7.2 Soil Chemical Properties Analysis

The soil samples were dried, crushed gently using wooden mortar and pestle and forced via two millimeter sieve (Salisbury *et al.*, 1970). The sieved samples were subjected to various extraction procedures and chemical properties estimated in the laboratory. Soil analysis for pH, nitrogen, phosphorus, potassium, carbon and zinc was carried out using standard soil laboratory analytical methods as described below. Carbon (C) was estimated using modified Walkley Black method (Okalebo *et al.*, 2002) and Nitrogen (N) established using the Kjeldahl method (McGill & Figueiredo, 1993) while Phosphorus (P) was estimated via the modified Olsen method (Okalebo *et al.*, 2002).

Soil pH

Twenty (20 ± 0.1) g soil samples were weighed using an analytical balance, put into a 100ml plastic bottle and 50 ml of deionized water added and the blend agitated for 10 minutes, let to settle for 30 minutes and agitated again for two minutes and the pH of the soil suspensions estimated using a pH meter. The Soil pH rating ranges from a value of <4.5 denoting extreme acid through a value >8.9 denoting extreme alkaline as indicated in table 3.3.

Table 3.3: Soil pH Value Rating

pH Value	Rating
< 4.5	Extremely acid
4.5 – 4.9	Strongly acid
5.0 – 5.9	Moderately acid
6.0 – 6.4	Slightly acid
6.5 – 6.9	Near neutral
7.0 – 7.4	Slightly alkaline
7.5 – 8.4	Moderately alkaline
8.5 – 8.9	Strongly alkaline
>8.9	Extremely alkaline

Source: (USDA, 2017)

Determination of Soil Nitrogen and Phosphorous

Soil extraction

Soil samples were extracted and analyzed following Okalebo *et al.* (2002) method. Soil samples weighing 0.3 ± 0.001 g, air dried, crushed and passed via a < 0.25 mm, 60 mesh sieve were put in clean, dry labelled digestion tubes. 2.5 ml digestion mixture (3.2-g salicylic acid in 100-ml of sulphuric acid-selenium mixture) added to each tube and the reagent blanks and digested at 110^0C for an hour. The digests were withdrawn, cooled and three successive one milliliter portions of hydrogen peroxide added. Then the temperature was raised to 330^0C with continued heating until the solutions became colorless. The contents were cooled and 25 ml distilled water added and agitated well to ensure maximum sediment dissolution. The mixtures were further cooled and topped to 50 ml with distilled water and let to settle to enable a clear aliquot be drawn from the top of the solution for nitrogen and phosphorous estimation.

Determination of total nitrogen (N)

Reagent 1: 34 grams of sodium salicylate, 25 g ram of sodium citrate and 25gram of sodium tart rate were weighed and solvated into about 750-ml distilled water in a one liter beaker. Then 0.12 g of sodium nitroprusside added and transferred into a one liter volumetric flask and made to the 1-liter mark with distilled water.

Reagent 2: 30 gram sodium hydroxide was dissolved in 750 ml distilled water in a one litre beaker, cooled and 10 ml sodium hypochlorite added, stirred rigorously, transferred into a one litre volumetric flask and made to the liter mark with distilled water.

Stock solution 2500 mgN/litre: 11.793 g of ammonium sulphate $(NH_4)_2SO_4$ was dissolved in1000 ml beaker, transferred into one litre volumetric flask and filled to the mark using distilled water.

Standards reagents

Precisely 2.5 ml of digestion mixture were added in a pristine set of six 100 ml volumetric flasks holding 20ml distilled water. Into the same set, 0-1.0-2.0-4.0-5.0-6.0 mls of the stock solution (9) was added. The concentrations of the standard series eventually were: 0, 25, 50, 75, 100, 125 and 150 mg N/liter. Thereafter, the standard series were diluted to 1+9 (v/`v) using distilled water, resulting in: 0, 2.5, 5.0, 7.5, 10.0 and 15.0 mg N/liter concentrations. The digests and the blanks were diluted to 1+9 (v/v) using distilled water to measure up to the standards. Precisely 0.2 ml of standard series, sample digests and the blanks were pipetted into well marked test tubes using a micropipette. Then, 5.0 ml of reagent N1 was added, shaken, and then 5.0 ml of reagent N2 added and shaken, let to settle for two hours and absorbance estimated at 650 nm wavelength. A calibration curve of absorbance against standards series concentration was plotted and concentration of nitrogen in the solution read off. The concentration of nitrogen in the soil sample (N %) was computed using formula 10 (Anderson & Ingram, 1994).

$$N\ \% = \frac{(a-b)\times v\times 100}{1000\times w\times al\times 1000} \qquad (10)$$

Where: a = N concentration in the solution, b = N concentration in the blank, v = total volume at the end of analysis procedure, w = weight of the dried sample and al = aliquot of solution taken.

Total phosphorous (P)

Reagents

Five normal (5N) Sulphuric acid (H_2SO_4): A one-liter pristine beaker containing 500 ml distilled water was placed on an asbestos mat and 148 ml concentrated H_2SO_4 added slowly with stirring. Once cool, distilled water was added to the one-liter mark, let to cool and stored in a one liter reagent bottle.

Ammonium molybdate $(NH_4)_6Mo_7O_{24}.4H_2O)$/antimony potassium tartrate ($KSb.C_4H_4O_6$) solution: Twelve (12) grams of $(NH_4)_6Mo_7O_{24}.4H_2O$ was dissolved in 250 ml of warm (50^0C) distilled water. Further, 0.291 g of $KSb.C_4H_4O_6$ was dissolved in 100 ml of distilled water. Both solutions were transferred into the 1000 ml of 5N H_2SO_4, mixed thoroughly and diluted with distilled water to 2 liters, transferred to a reagent bottle and stored in a dark, cool place. Ascorbic acid reducing agent: 2.108 g ascorbic acid ($C_6H_8O_6$) was solvated in 400 ml of ammonium molybdate/antimony potassium tartrate solution and mixed well.

Phosphorus stock solution (1000 ppm P): A 1.0967 g of oven-dried KH_2PO_4 was weighed, dissolved in a 200 ml beaker with distilled water, moved into a 250 ml volumetric flask, topped to the mark with distilled water (1 ml = 1 mg P). 10 ppm P working solution: 10 ml of the standard stock solution was moved into a 1-liter volumetric flask and diluted to the mark using distilled water.

Procedure: 0, 1, 2, 3, 4, 5 and 6 ml of the 10 ppm P working standard series and 5 ml of the blanks and the clear wet ashed digest solutions were transferred to 50 ml volumetric flasks and 20ml distilled water and 10ml of the ascorbic acid reducing solution put into each flask. The standards contained 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 ppm P in that order. Each flask was tightly stoppered, shaken well and left undisturbed for one hour to enable proper color formation. The standards, blanks and sample absorbance's (blue color) were quantified at 880 nm wavelength with UV/ visible spectrophotometer. A calibration curve was plotted pitting absorbance versus standard solution concentrations. Concentrations for the samples were estimated by subtracting the average blank value from the samples values; giving values for corrected concentration (Anderson & Ingram, 1994).

$$\text{P } (mgkg^{-1}) \text{ in Soil} = \frac{(a-b)\times v\times f\times 1000}{1000\times w} \quad (11)$$

Where a = concentration of P in the sample extract; b = concentration of analyte in the blank extract; v = volume of the extract solution; w = weight of the soil sample; f = dilution factor.

Exchangeable cations in soils

Reagents

Ammonium acetate, 1 M NH_4OAc: 77.08 g of NH_4OAc was solvated with distilled water in a one-liter volumetric flask and made to the mark. The solution was adjusted to pH 7 with acetic acid and mixed thoroughly.

26.8% Lanthanum chloride solution. 134 g of lanthanum chloride ($LaCl_3.7H_2O$) was solvated in distilled water and made to 500 ml. 1 ml $LaCl_3.7H_2O_{(aq)}$ = 0.1 g La.

Potassium standard stock solution, 250 ppm K: A 0.4678 g of KCl dried at $105^{O}C$ was weighed, dissolved in a 500 ml beaker with distilled water, transferred to a 1-liter volumetric flask and topped to the mark with distilled water resulting in 250 mg K/1000 ml.

Standard solution, 100ppm K: 200-ml of the 250 ppm K stock solution was moved into a 500-ml volumetric flask and topped to the liter mark using distilled water.

Standard Solutions

Potassium standard solutions: 0, 1.25, 2.5, 5.0, 7.5 and 10.0 ml of potassium standard stock solutions was Pipetted into pristine 100 ml volumetric flasks. To each flask, one ml of 26.8% lanthanum chloride solution and 10 ml of the 1 M NH_4OAc extraction solution were added. These solutions contained; 0, 1.25, 2.5, 5.0, 7.5 and 10 ppm K.

Extraction of Soil

Five grams of air-dried soil samples (< 2 mm) were weighed into a clean plastic bottle and 100 ml of one molar ammonium acetate solution (pH 7) added, stoppered and solution agitated for half an hour and passed via No. 42 Whatman filter paper for K determination.

Determination of Potassium (K)

Five milliliters of the soil extract solutions were pipetted into 50 ml volumetric flasks and one milliliter of 26.8% $LaCl_3.7H_2O$ solution added and made to the mark with 1M NH_4OAc extraction solution. The standards, blanks and soil extract solutions were aspirated into the flame of the flame photometer and Potassium concentration estimated at a wavelength of 766nm. The concentrations of potassium (K), in the soil samples expressed in $mgkg^{-1}$ were computed by Anderson and Ingram (1994) model.

$$K\ (mgkg^{-1})\ \text{in Soil} = \frac{(a-b)\times v\times f\times 1000}{1000\times w} \quad (12)$$

Where a = concentration of K in the sample extract; b = concentration of analyte in the blank extract; v = volume of the extract solution; w = weight of the soil sample; f = dilution factor.

Soil organic Carbon (C)

Soil samples weighing 0.3 g sieved through a 60 mm mesh were placed into a block digestion tube, and then 5 ml potassium dichromate solution and 7.5 ml conc. H_2SO_4 added. The tubes were placed in a pre-heated block at 145-155^{0}C precisely for 30 minutes, withdrawn and let to cool. The digests were moved into 100 ml conical flasks, and 0.3 ml of the indicator solution added and stirred by magnetic stirrer, to secure sufficient mixing. The digests were titrated with ferrous ammonium sulphate solution with the endpoint color changing from greenish to brown. The titer volumes were noted and rectified for the average of two reagent blanks (T) and computed by the following Walkley and Black (1934) equation.

$$\text{Organic Carbon (\%)} = \frac{T\times 0.2\times 0.3}{Sample\ weight\ (w)} \quad (13)$$

Where (Vb - Vs) = T (the titration volume). Thus, concentration of C in a 0.3 g soil sample (w) becomes: Organic C (%) = (0.003 × 0.2 (Vb - Vs) × 100)/w

where Vb = volume in ml of 0.2 M ferrous ammonium sulphate used to titrate reagent blank solution, Vs = volume in ml of 0.2 M ferrous ammonium sulphate used to titrate sample solution and 12/4000 is the milliequivalent weight of C in grams.

Soil Zinc (Zn) content

Five grams of air-dried soil passed through a two mm meshed sieve were weighed into pristine 250 ml plastic bottles fixed with tight screw caps and 50 ml of 1% EDTA added and the suspensions mixed in a reciprocating shaker for one hour. The suspensions were filtered via No. 542 Whatman filter paper to secure a supernatant solution for zinc estimation by atomic absorption spectrometer (AAS).

Reagents

The stock solution of 1000 ppm Zn was made by dissolving 4.398 g of zinc sulphate heptahydrate ($ZnSO_4 \cdot 7(H_2O)$ in a beaker, transferred to one liter volumetric flask and made to one liter mark with distilled water. The standard solution of 50 ppm Zn was made by pipetting 25.0 ml of the stock solution into a 500 ml volumetric flask and diluted to 500 ml mark with distilled water.

Standards series: 0, 1.0, 2.0, 4.0, 6.0 and 10.0 ml of the standard stock solution were pipetted into a pristine set of 100 ml volumetric flasks and topped up with 1% solution of EDTA. The standards series contained 0, 0.5, 1.0, 2.0, 3.0 and 5.0 ppm Zn, in that order. The standard series, blank extracts and samples were aspirated in the air-acetylene flame AAS and the absorbance measured at 213.9 nm wavelength. A calibration curve of absorbance versus standards concentration was plotted and zinc concentration in the samples recorded. The zinc concentrations (Zn $mgkg^{-1}$) in the air-dried soil sample, soil were calculated using Okalebo *et al.* (2002) equation.

$$\text{Zn } (mgkg^{-1}) = \frac{(a-b)\times v\times f\times 1000}{1000\times w} \quad (14)$$

Where a = concentration of Zn in the solution, b = concentration of Zn in the mean values of the blanks, v = final volume of the digestion process, w = weight of the sample taken and f = the dilution factor. The Soil analytical results are interpreted based on the ratings outlined in Table 3.4.

Table 3.4: Interpretations of Soil Nutrients Analytical Results

Parameter	Measured value	Rating
Organic Carbon (%)	>3	High
	1.5-3.0	Moderate
	0.5-1.5	Low
	<0.5	Very low
Total Nitrogen (%)	>0.25	High
	0.12-0.25	Moderate
	0.05-0.12	Low
	<0.05	Very low
Phosphorous (Ppm)	>20	High
	11-20	Moderate
	<10	Low
Potassium (Ppm)	300	Very high
	175-300	High
	100-175	Medium
	50-100	Low
	<50	Very low
Zinc (Ppm)	>5	Moderate
	<5	Low

Source: (USDA, 2017); Note: 1Ppm = 1 $MgKg^{-1}$

3.7.3 Soil Physical Properties Determination

Soil moisture Content

Soil moisture content was estimated by the gravimetric method (Rowell, 2014). Soil samples were put into ceramic crucibles and measured to obtain fresh weight. The samples were then oven dried at 105^0C for 24 hours to attain constant weight and the dry weight recorded. The recorded values were then used to compute the soils' moisture contents (Klute, 1986).

Determination of Soil Particle Size by Hydrometer Method

The soil particle sizes were established following the Bouyoucos (1962) method. Fifty grams of air-dried, 2 mm size soil samples were weighed out into a 400 ml beaker and saturated with distilled water and 10 ml of 10 % Calgon solution added and allowed to stand for 10 minutes. The suspensions were transferred into the dispersing cup and made to the mark with distilled water, mixed for two minutes by a high-speed electric stirrer. The suspensions were then moved into a graduated cylinder and the remaining soil rinsed into the cylinder with distilled water. A hydrometer was immersed into the suspension and water added to 1130 ml. The hydrometer was removed and the cylinder covered with a tight-fitting rubber bung and the suspension mixed by inverting the cylinder carefully ten times while noting the time. Three drops of amyl alcohol were quickly added to the soil suspension in order to remove froth and the hydrometer placed gently into the column after 20 seconds. At 40 seconds, the hydrometer reading was taken and the temperature of the suspension measured.

The soil suspensions were mixed ten times again and the cylinders allowed to stand undisturbed for two hours, then both hydrometer and temperature readings taken. Since sand will have settled after 40 seconds, the reading of hydrometer reflects the grams of silt and clay in one liter of the suspension. Therefore, the quantity of sand contained in one liter of the suspension was calculated by subtracting this value from the initial sample mass.

Soil texture

Soil textural class was assigned following the ascertained of its particle sizes distributions deduced from the soil textural triangle. There are several soil textures within the textural triangle stemming from the corresponding segments of soil particles. The right textural classes were obtained by considering the particle size distribution (Klute, 1986).

Soil bulk density determination

Once the fresh weight had been taken as weight (W1) and volume (V) established. The soil samples were dried in an oven at 105^{o}C for two days and weighed (W2) measured and noted. The bulk density was then computed following Anderson and Ingram (1994) equation:

$$\text{Bulk Density } (gcm^{-3}) = \frac{(W_2 - W_1)g}{V(cm^3)} \qquad (15)$$

3.8 Validity and Reliability of the Research Instruments and Methods

Validity is the quality of a measurement to be logically or factually sound (Mugenda & Mugenda, 2003). The validity of the study tools was validated through discussions on the instruments with the supervisors. This made sure that all items were scrutinized to confirm that they measured accurately the issues being investigated, are clear, and understandable among target groups. Additionally, satellite images and remotely sensed data were validated using accuracy assessment and ground truthing. Furthermore, collection and analysis of soil samples were done by subjecting the samples to standard procedures using calibrated modern equipment with adequate controls, standard series and solution blanks.

The reliability of the research instrument was measured through piloting. The exercise involved pretesting of the tool by administering it to selected respondents. The same tool was administered to the piloted respondents to determine its reliability. A questionnaire was administered to a select group of respondents and the exercise repeated after a while maintaining their identities to compute a reliability index. A reliability index alpha equal to or greater than 0.7, for an instrument was reliable enough for use in a study (Mugenda & Mugenda, 2003).

3.9 Data Management and Ethical considerations

Before data was collected from the field, a research license (Appendix IV) was secured from the National Commission for Science, Technology and Innovation (NACOSTI) to satisfy the Science, Technology and innovation Act, 2013. Using the research license, an authority (Appendix V) and permission (Appendix VI) to conduct research in the Elgeyo escarpment were obtained from the County government of Elgeyo Marakwet. Further, informed consent was always sought before a questionnaire could be administered to a respondent with assurance of their responses confidentiality.

3.10 Data Analysis and Presentation

The field data was processed in Microsoft office Excel spreadsheet. Statistical Package for Social Sciences (SPSS) software version 20 was used to carry out statistical data analysis (Einstein & Abernethy, 2000). Soil properties among various LULC classes were tested by One-Way Analysis of Variance (ANOVA). Means were separated using Tukey's-B test and mean comparison performed at $p < 0.05$

significance level. The relationship between population parameters and LULC changes was computed using bivariate regression and correlation analysis.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter details the study results in the form of tables, bar graphs, pie-chart and text. Moreover, the chapter presents the interpretation of the study findings.

4.1.1 Socioeconomic Characteristics of Respondents

The survey results revealed that majority of the respondents engage in crop farming (94.4%), livestock keeping (90%) and formal employment (4.4%) for a living. The education level in the study area was fairly low; 33.3% and 30.6% being illiterate and primary levels respectively. Only 14% attained post-secondary education. All respondents were married (100%) currently or at some point in their lives (Table 4.1).

Table 4.1: Respondents' Attributes in the Elgeyo Escarpment

Attribute	Description	Frequency	Percentage (%)
Gender	Female	52	28.9
	male	128	71.1
Marital Status	Married	180	100
Education level	Illiterate	60	33.3
	Primary	55	30.6
	Secondary	40	22.2
	Tertiary	25	13.9
Occupation	Crop farming	170	94.4
	Livestock keeping	162	90
	Formal employment	8	4.4

Over half (55.6%) of the residents keep chicken while goats, cattle, sheep and donkeys are kept by 33.3 %, 27.8% 19.4 % and 2.8 % respectively in the area (Table 4.2). Majority of the residents (98 %) are crop farmers. The most grown crops are maize (92%) and beans (80.6%). Other crops grown are vegetables and sorghum (Table 4.2).

Table 4.2: Livestock Kept and Crops Grown in the Elgeyo Escarpment

Livestock Kept	**Frequency**	**Percentage**
Cattle	50	27.80
Goats	60	33.30
Sheep	35	19.40
Chicken	100	55.60
Donkey	5	2.80
Crops Grown		
Maize	166	92.2
Beans	145	80.6
Potatoes	42	23.3
Sorghum	48	26.7
Millet	50	27.8
Vegetables	49	27.2

The main livestock grazing mode in the escarpment is herding (73%). Other grazing methods practiced by the residents in the area include free grazing, paddocking and tethering corresponding to 15%, 11% and 11% respectively (Table 4.3). Interestingly, a small section of the residents (16.7%) grazes their livestock in their own farms. However, majority of them graze their livestock in the commons. For example, 57.5%, and 27.8% of the population graze their livestock in the communal land, and the public forest in that order within the escarpment (Table 4.3).

Table 4.3: Livestock Grazing in the Elgeyo Escarpment

Grazing mode	Frequency	Percentage
Free grazing	27	15
Herding	131	73
paddocking	20	11
Tethering	20	11
Grazing land		
Own farm	30	16.7
Communal land	104	57.5
Public forest	50	27.8

4.2 Spatiotemporal Land Use Land Cover and Conversions

4.2.1 Classification Accuracy and LULC Classes

The accuracy assessment carried out indicate that the overall accuracies and Kappa coefficients for the three study years 1995, 2014 and 2020 were 78.4% and 0.70; 76.91% and 0.70; 84.58% and 0.79 respectively (Tables 4.4 - 4.6). The different LULC classes depicted producer and user accuracies of over 70 % as presented in Tables 4.4, 4.5 and 4.6.

Table 4.4: Confusion Matrix of LULC Maps of 1995 for Elgeyo Escarpment

Class	Cropland	Grassland	Shrubland	Forest	Built-up	Total	UA (%)
Cropland	92	6	18	0	0	116	78.6
Grassland	3	17	3	0	2	25	68.0
Shrubland	22	0	114	8	0	144	69.9
Forest	0	0	28	94	0	122	92.2
Built-up	0	2	0	0	17	19	89.5
Total	117	25	163	102	19	426	
PA (%)	79.3	68.0	79.2	77.1	89.5		

Overall accuracy = 78.40 %, Kappa coefficient = 0.70, PA = producer accuracy, UA = user accuracy

Table 4.5: Confusion Matrix of LULC Maps of 2014 for Elgeyo Escarpment

Classified	Cropland	Grassland	Shrubland	Forest	Built-up	Total	UA (%)
Cropland	102	5	22	0	0	129	78.63
Grassland	8	31	4	0	3	46	68.00
Shrubland	17	0	117	13	0	147	69.94
Forest	0	0	33	89	0	122	92.16
Built-up	0	4	0	0	24	28	89.47
Total	127	40	176	102	27	472	
PA (%)	80.31	77.50	66.48	87.25	88.89		

Overall accuracy = 76.91 %, Kappa coefficient = 0.70, PA = producer accuracy, UA = user accuracy

Table 4.6: Confusion Matrix of LULC Maps of 2020 for Elgeyo Escarpment

Classified	**Cropland**	**Grassland**	**Shrubland**	**Forest**	**Built-up**	**Total**	**UA (%)**
Cropland	74	2	16	0	0	92	78.6
Grassland	0	38	5	0	2	45	68.0
Shrubland	12	0	122	16	0	150	69.9
Forest	0	0	9	112	0	121	92.2
Built-up	0	6	0	0	27	33	89.5
Total	86	46	152	128	29	441	
PA (%)	86.05	82.61	80.26	87.50	93.10		

Overall accuracy = 84.58 %, Kappa coefficient = 0.79, PA = producer accuracy, UA = user accuracy

Within the study period, the five main LULC classes in 1995 were; shrubland, cropland, grassland, forest and built-up in that order (Figure 4.1). In 2014; the LULC classes remained five although there were changes in coverage as indicated; shrubland, forest cropland, grassland, and built-up in that order (Figure 4.2). In 2020, the LULC classes in the study area were five with area coverage being; shrubland, forest cropland, grassland, and built-up in that order (Figures 4.3).

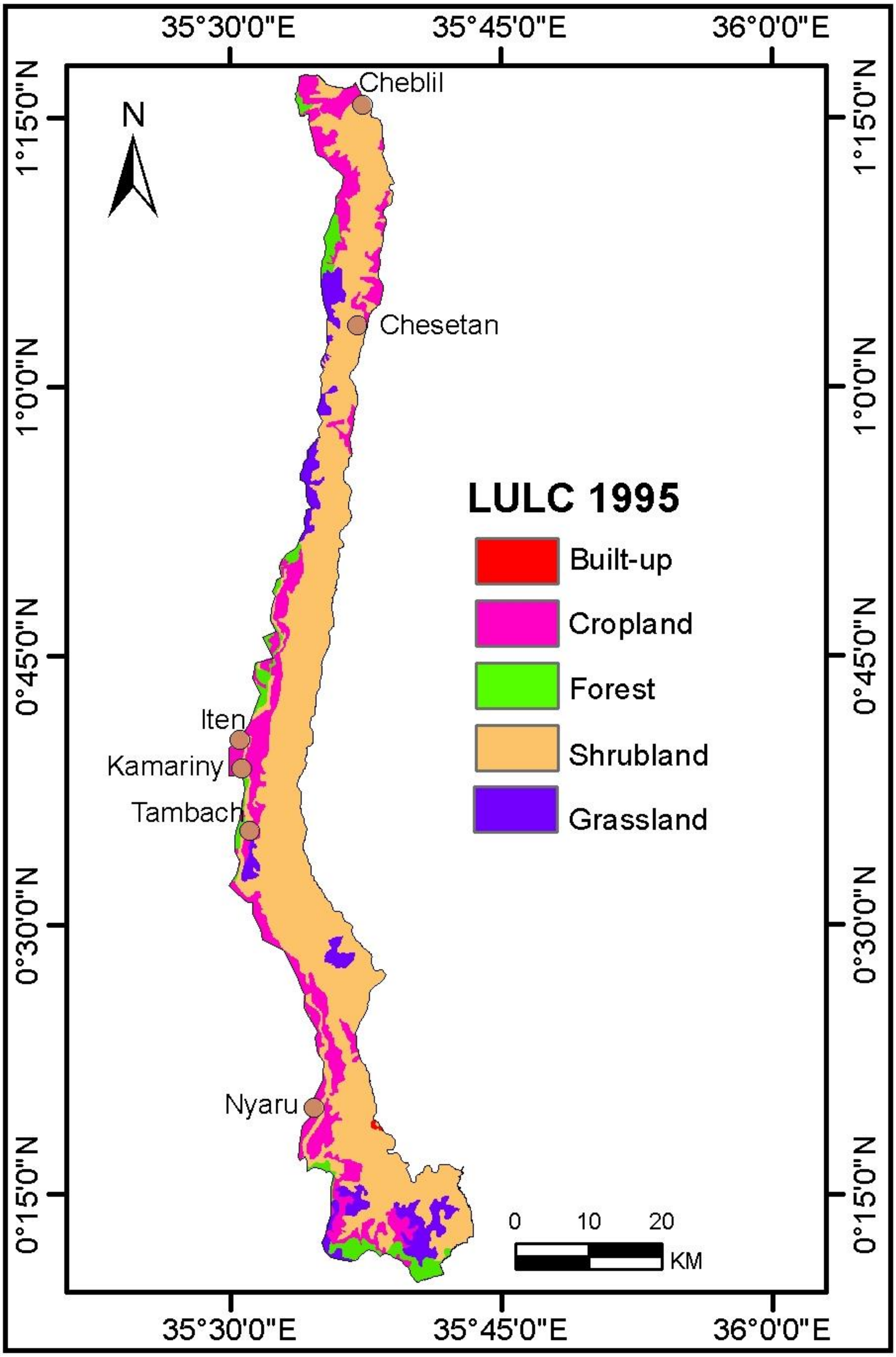

Figure 4.1: Land Use Land Cover of Elgeyo Escarpment for 1995

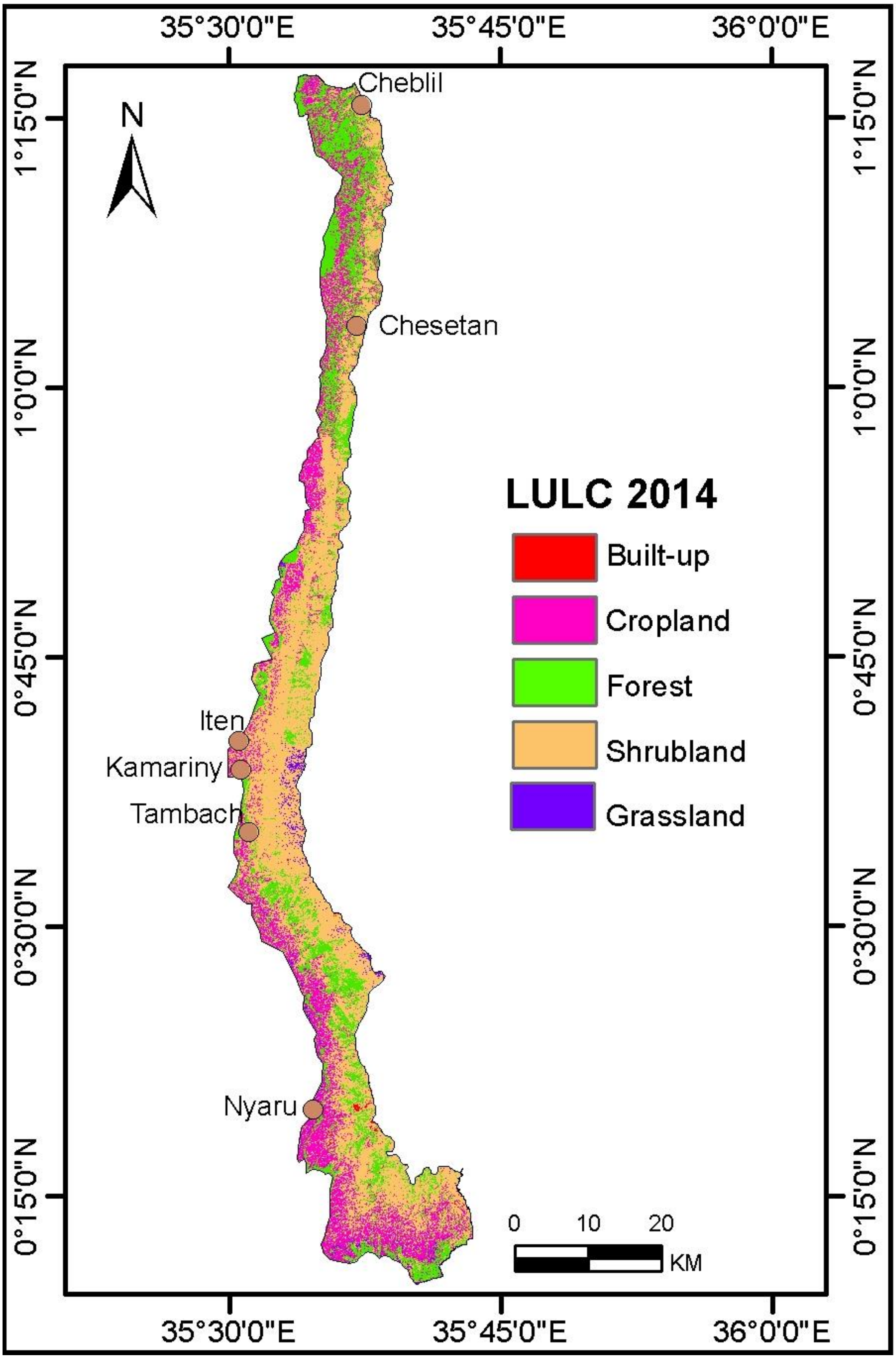

Figure 4.2: Land Use Land Cover of Elgeyo Escarpment for 2014

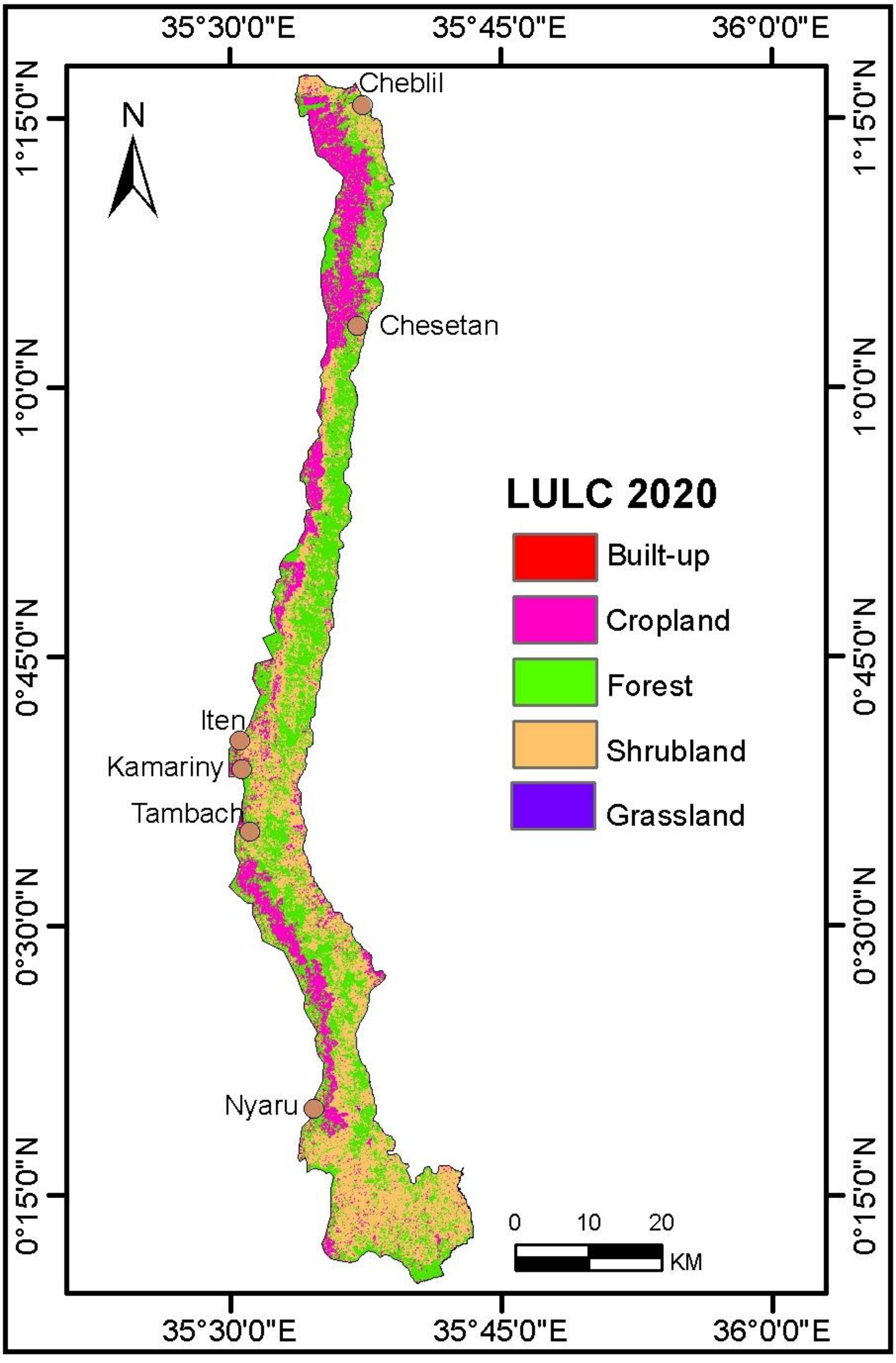

Figure 4.3: Land Use Land Cover of Elgeyo Escarpment for 2020

4.2.2 Land Use Land Cover, Change Trends and Magnitude in Elgeyo Escarpment

The results from LULC assessment showed that the main LULC classes were shrubland, cropland and forest with the three constituting a combined coverage of over 90%. Initially, forest cover was low but depicted a continuous growth while built-up slightly increased over the study period. In 1995, shrubland, cropland, and grassland were the major land uses covering 67.23%, 20.18%, 7.73% respectively. Forests and built-up areas covered 4.72% and 0.14% respectively. By 2014, substantial LULC changes had transpired resulting in a fivefold (from 4.72% to 24.14%) growth in forest cover while cropland increased slightly to 22.93%. Shrubland and grassland declined significantly to 50.82% and 1.96% respectively (Table 4.7). In 2020, forest cover had grown to 39.36% while shrubland had decreased drastically to 39.82%. Cropland and built-up areas decreased marginally to 20.23% and 0.26% respectively. Grassland decreased significantly to 0.34% (Table 4.7).

Table 4.7: Land Use Land Coverage in Elgeyo Escarpment

LULC	1995		2014		2020	
	km^2	%	km^2	%	km^2	%
Cropland	161.77	20.18	183.80	22.93	162.12	20.23
Grassland	61.99	7.73	13.54	1.96	2.75	0.34
Shrubland	538.86	67.23	407.32	50.82	319.45	39.82
Forest	37.80	4.72	193.46	24.14	315.45	39.36
Built-up	1.14	0.14	3.43	0.43	2.09	0.26
Total	801.56	100.00	801.56	100.00	801.56	100.00

In the period 1995-2014, major changes occurred across all the LULC classes. Grassland and shrubland declined significantly by 78.15% and 24.41% respectively. In contrast, forest and built-up increased tremendously by 411.82% and 200.95% respectively. Further, cropland increased by 13.62% during this study period (Table 4.8). In the period 2014-2020, forest cover continued to increase by more than 63% while grassland and built-up declined drastically by 79.7% and 39.14% respectively. Additionally, shrublands and croplands decreased by 21.65% and 11.79% respectively (Table 4.8). Overall, forest cover surged markedly while cropland recorded a marginal gain while shrubland and grasslands decreased over the study period. Forest area gained at a rate of 4.48 km^2 per year, representing an annual increase rate of 12.91 %. Built-up, grassland, Shrubland and cropland all decreased at a rate of 0.05 km^2, 0.45 km^2, 3.53 km^2 and 0.87 km^2 per year constituting an annual change rate of 4.71%, 0.70%, 0.65% and 0.54% respectively (Table 4.8).

Table 4.8: Trend and Rate of Change in LULC Classes over Time in Elgeyo Escarpment

LULC	1995-2014		2014-2020		Average rate of change (1995-2020)	
LULC	km^2	%	km^2	%	km^2 $Year^{-1}$	%
Cropland	22.03	13.62	-21.68	-11.79	-0.87	-0.54
Grassland	-48.45	-78.15	-10.79	-79.69	-0.43	-0.70
Shrubland	-131.54	-24.41	-88.18	-21.65	-3.53	-0.65
Forest	156.66	411.82	121.99	63.06	4.88	12.91
Built-up	2.29	200.95	-1.34	-39.14	-0.05	-4.71

4.2.3 Change Detection and Transition Statistics

The transition statistics for LULC for the study period are presented in Tables 4.9, 4.10 and 4.11. The statistics are comprised of the unchanged LULC class and the changes from one class to another. Between 1995 and 2014, cropland gained 110.02 km^2 through the conversion of grassland (29.3 km^2), shrubland (74.36 km^2), forest (6.27 km^2) and built-up (0.09 km^2). Conversely, cropland lost 3.47 km^2, 54.22 km^2, 29.53 km^2 and 0.77 km^2 to grassland, shrubland and forest respectively recording a net gain of 22.03 km^2. Grassland lost heavily by 48.45 km^2 to cropland, forest and shrubland. Forest gained 167.28 km^2 with most of it (128.78 km^2) being converted from shrubland (Table 4.9).

Table 4.9: LULC Transition Statistics (1995-2014) for Elgeyo Escarpment

LULC	LULCC (km^2)					
	Cropland	Grassland	Shrubland	Forest	Built-up	Total 1995
Cropland	73.78	3.47	54.22	29.53	0.77	161.77
Grassland	29.30	0.90	22.71	8.92	0.17	61.99
Shrubland	74.36	8.02	325.58	128.8	2.12	538.86
Forest	6.27	1.16	4.19	26.10	7.02	37.80
Built-up	0.09	0.0	0.38	0.05	0.29	0.81
Total 2014	183.80	13.54	407.08	193.4	3.43	801.23
Change (2014-1995)	22.03	-48.45	-131.78	155.6	2.62	-

In the period 2014-2020, 64.63 km^2, 45.63 km^2, 0.67 km^2 and 0.61 km^2 of cropland was converted to shrubland, forest, built-up and grassland in that order. Further, 3.62 km^2 and 6.64 km^2 of grassland was converted to cropland and shrubland respectively. Moreover, 157.43 km^2, 50.52 km^2, 1.42 km^2 and 1.04 km^2 of shrubland was converted to forest, cropland, grassland and built-up in that order. Additionally, there was conversion of built-up to shrubland, cropland and grassland by 1.68 km^2 0.87 km^2 and 0.24 km^2 in that order (Table 4.10). Overall, there was a net gain in forest cover (121.99 km^2) as cropland, grassland, shrubland and built-up lost by 20.88 km^2, 10.79 km^2, 88.19 Km^2 and 1.34 km^2 respectively (Table 4.10).

Table 4.10: LULC Transition Statistics (2014-2020) for Elgeyo Escarpment

LULC	Coverage (km^2)					
	Cropland	Grassland	Shrubland	Forest	Built-up	Total 2014
Cropland	72.87	0.61	64.63	45.63	0.67	183.80
Grassland	3.62	0.09	6.64	3.16	0.03	13.54
Shrubland	50.52	1.42	201.00	157.4	1.04	407.33
Forest	37.87	0.39	46.63	108.8	0.20	193.46
Built-up	0.87	0.24	1.68	0.48	0.17	3.43
Total 2020	162.12	2.75	319.14	315.5	2.09	801.56
Change (2020- 2014)	-20.88	-10.79	-88.19	121.9	-1.34	

In the period 1995-2020, 59.76 km^2, 49.92 km^2 and 1.22 km^2 of cropland was converted to shrubland, forest and built-up in that order. Also, 22.44 km^2, 25.54 km^2 and 14.84 km^2 of grassland were converted to cropland, shrubland and forest in that order. Moreover, 227.7 km^2 and 84.21 km^2 of shrubland were converted to forest and cropland respectively. Additionally, built-up lost to cropland, grassland, shrubland, and forest by 0.05 km^2, 0.08 km^2 and 0.29 km^2 and 0.035 km^2 respectively. During the entire study period, forest gained immensely by 281.3 km^2. Built-up and cropland gained albeit marginally by1.28 km^2 and 0.68 km^2 respectively. Conversely, shrubland and grassland lost drastically by 219.67 km^2 and 60.26 km^2 respectively (Table 4.11).

Table 4.11: LULC Transition Statistics (1995-2020) for Elgeyo Escarpment

	LULCC (Km^2)					
LULC	Cropland	Grassland	Shrubland	Forest	Built-up	Total 1995
Cropland	53.44	1.01	59.76	49.92	1.22	165.35
Grassland	22.44	0.18	25.54	14.84	0.11	63.09
Shrubland	84.21	1.55	230.95	227.7	0.71	545.07
Forest	4.54	0.04	6.86	29.09	0.01	40.52
Built-up	0.05	0.08	0.29	0.035	0.09	0.85
Total 2020	164.7	2.83	323.40	321.9	2.13	814.90
Change (2020-1995)	0.68	-60.26	-219.67	281.3	1.28	-

4.3 Land Use and Cover Change Drivers in the Elgeyo Escarpment

Changes in land use and cover across the globe have been driven by various factors. Survey results show that in the 1995-2014 period, LULC changes across the Elgeyo escarpment were mainly driven by population growth (97.2%) setting off increased demand for food (87%), settlement areas (45%) and pursuance of income (5%). The increased food demand encompasses both human and animal feeds. Additionally, 40% of the Kerio Valley residents were driven to the escarpment by disease (malaria) outbreaks. Further, infrastructural development (5%) has emerged as a motivation that resulted in people moving to areas with improved road network, schools, churches and health facilities. Cattle rustling caused 50% of the movements from the valley to the escarpment. This is prevalent particularly in the Tot, Tunyo and Arror divisions of the County. Forest evictions and disasters occurrence contributed to the occupation and LULC changes in the escarpment by 13.9% and 10% respectively.

During the 2014-2020 study period, LULC changes were driven by increased demand for; food, settlement, income, improved infrastructure and landslides occurrence contributed to LULC changes by 90.6%, 59.4%, 34.4%, 28.3% and 25.6% respectively. Conversely, cattle rustling and malaria outbreaks as LULC change drivers declined to 39% and 6% respectively (Table 4.12). The findings moreover indicate that drivers were period dependent (Chi-SQ = 130, DF = 8, P = 0.001).

Table 4.12: Land Use Land Cover Change Drivers in Elgeyo Escarpment

LULC change driver	1995 - 2014		2014 - 2020		1995 - 2020	
	Frequency	%	Frequency	%	Frequency	%
Population growth	175	97.2	177	98.3	176	97.8
Increased food demand	157	87	163	90.6	160	88.9
Settlement	81	45	107	59.4	94	52.2
Income	9	5	62	34.4	36	20.0
Cattle rustling	90	50	70	39.0	80	44.4
Infrastructural expansion	9	5	51	28.3	30	16.7
Disasters	18	10	46	25.6	32	17.8
Disease outbreak	72	40	10	6.0	41	22.8
Forest eviction	25	13.9	32	17.8	29	16.1

Note: Percentages do not add up to 100 since respondents stated multiple responses

A review of Kenya's population growth as a key LULC change driver (Figure 4.4a and b) and Table 11 corroborates the survey results. Kenya and housing census reports indicate that the area's human population increased two-fold between 1989 and 2019. The 1989 report indicates that the population was 68,558 people. This figure grew to 76,190 people by 1999. During the following two census cycles (2009 and 2019), human population had grown to 99,889 and 126,504 people, respectively (Figure 4.4a). This growth in human population brought forth a proportional surge in the number of households. In 1989, there were 12,684 households. In 1999 and 2009 there were 16,581 and 20,940 households respectively. By 2019, the household figures had doubled to 26,762 (Figure 4.4a). Population density exhibited a similar trend with 1989 population density being 85 Persons/km^2. This figure grew to almost double (155 persons/km^2) by 2019 (Figure 4.4b).

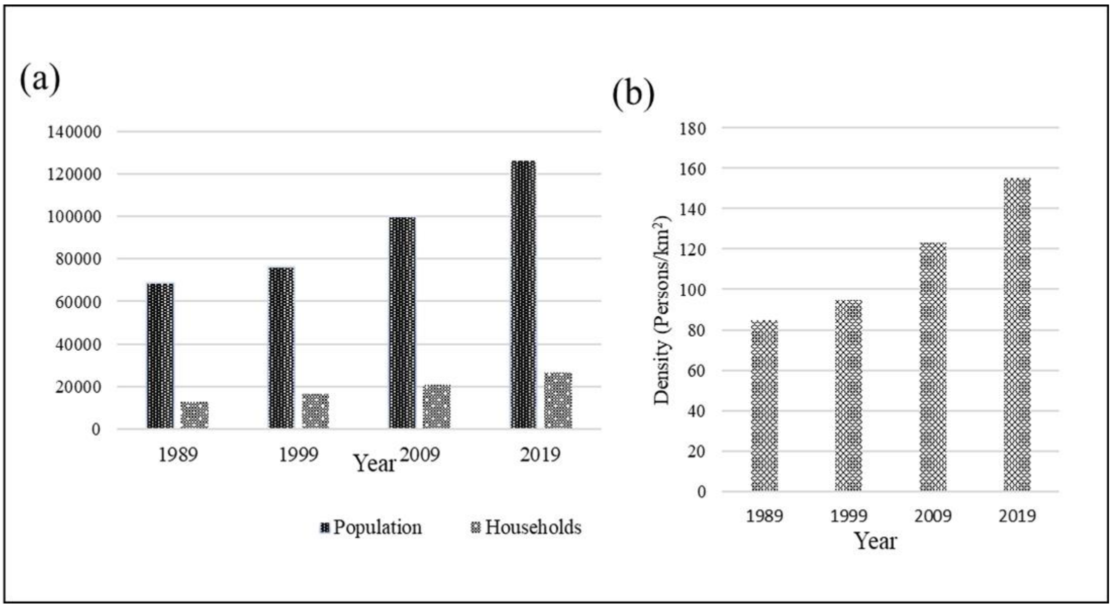

Figure 4.4: Population and Households (a) and Density (b) in Elgeyo Escarpment

The correlation results reveal that forest cover has a remarkable positive correlation with population, households and density. Built-up has a non-significant positive correlation. On the converse, grassland and shrubland have a significant negative correlation with population, household and density. Cropland has a non-significant negative correlation with population, households and density. The results further show that; the total population, number of households and density played a substantial role to the diminished grassland, shrubland and rise in forest cover. They however, had insignificant impact on built-up and cropland (Table 4.13). This scenario can be imputed to eviction of squatters from forests, implementation of farm forestry rules, success of PELIS concept and the conversion of shrubland to forestland.

Table 4.13: Relationship between LULC and Population in Elgeyo Escarpment

LULC Class	Population		Households		Density	
	R-Squared (R^2)	Corr. Coeff (r)	R-Squared (R^2)	Corr. Coeff (r)	R-Squared (R^2)	Corr. Coeff (r)
Cropland	0.003	-0.058	0.005	-0.069	0.001	-0.025
Grassland	0.831	-0.912	0.823	-0.907	0.855	-0.925
Shrubland	0.966	-0.983	0.962	-0.981	0.977	-0.988
Forest	0.980	0.99	0.977	0.988	0.988	0.994
Built-up	0.120	0.346	0.113	0.336	0.143	0.378

In terms of growth, the population to a large extend doubled in most of the geographical areas studied save for the European and global population. The Elgeyo escarpment almost doubled whereas Elgeyo Marakwet County (EMC), Kenyan and African population growth doubled (Table 4.14) thus obeying Malthusian premise of population doubling after 25 years (Adama & Audu, 2019).

Table 4.14: Temporal Population and Growth Factor across various Geographical Areas

Geographical Area	year				Growth Factor
	1989	1999	2009	2019	(2019/1989)
Elgeyo Escarpment	68,558	76,190	99,889	126,504	1.85
Elgeyo Marakwet	216,487	284,594	369,998	454,480	2.09
Kenya (Million)	21.45	28.68	38.61	47.56	2.22
Africa (Billion)	0.62	0.79	1.028	1.327	2.14
Europe (Billion)	0.72	0.73	0.74	0.75	1.04
Global (Billion)	5.2	6.0	6.8	7.7	1.48

In Elgeyo escarpment, population has continued to grow steadily whereas agricultural production particularly maize production fluctuated over the last 30 years (Figure 4.5). Notably, the 1999, 2009 and 2019 human populations were 76,190, 99,889 and 126,000 respectively (KNBS, 2019). This was against a cultivated land of 16,100 ha, 18,300 ha and 16,200 ha in 1999, 2009 and 2019 respectively that produced 161,000, 183,000 and 162,000 90-kilogram bags of maize grains corresponding to 14.49, 16.47 and 14.58 million kilograms respectively (Figure 4.5). This translates to a per capita maize production of 190.2 kg, 164.9 kg and 115.7 kg in 1999, 2009 and 2019 respectively.

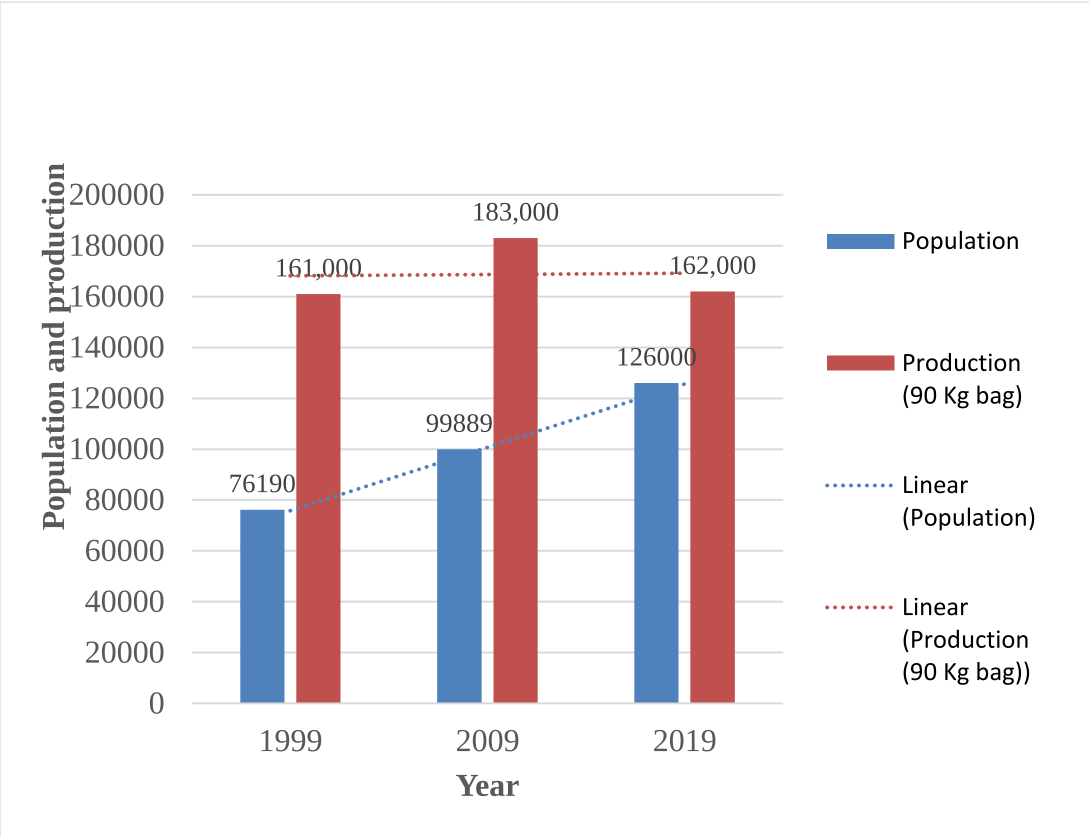

Figure 4.5: Population Growth and Maize Production Trends in Elgeyo Escarpment

4.4 Impacts of Land Use and Cover Change on the Environment in Elgeyo escarpment

Any changes in land use and cover have corresponding impacts on the environment that are both negative and positive. The positive impacts included improved food security (78.9%), improved housing (42.2%) with 28.9% reporting reduced drought (Table 4.15). Conversely, the negative impacts experienced by the population included increased landslides occurrences, increased soil erosion and reduced soil quality by 40%, 26.1% and 52.8% respectively (Table 4.15). A large proportion of the population in the study area attribute the negative impacts of LULC changes to overstocking (58.3%), this is followed by cultivation on steep slopes (52.8%). Further, another 33.9% and 31.1% of the population attributed the negative environmental impacts to monocropping and continuous cropping respectively (Table 4.15).

Table 4.15: LULC Change Impacts in the Elgeyo Escarpment

Impacts	Frequency	Percentage
a) Positive Impacts		
Improved food security	142	78.9
Improved housing access	76	42.2
Reduced drought	52	28.9
b) Negative Impacts		
Increased landslides occurrence	47	26.1
Increased soil erosion	72	40
Poor soil quality	95	52.8
c) Causes of Negative impacts		
Continuous cropping	56	31.1
Mono cropping	61	33.9
Overstocking	105	58.3
Cultivation on steep slopes	95	52.8

Note: Percentages do not add up to 100 because respondents mentioned multiple responses

4.4 Impact of Land Use Land Cover Change on Soil Erosion in Elgeyo Escarpment

4.4.1 RUSLE Factors

The various RUSLE factors determined (Eqn. 2) in this study are presented in Figures (4.6, 4.7, 4.8 and 4.9). The rainfall erosivity (R-factor) values ranged from 394.07 to 910.30 MJ mmha^{-1}h^{-1}year^{-1} (mean of 652.19 MJ mmha^{-1}h^{-1}year^{-1}) in the year 1995. The 2020 rainfall erosivity ranged between 1071.03 and 2649 MJ mm/ha/hr/y with a mean of 1378.02 MJ mmha^{-1}h^{-1}year^{-1} as presented in Figure 4.6.

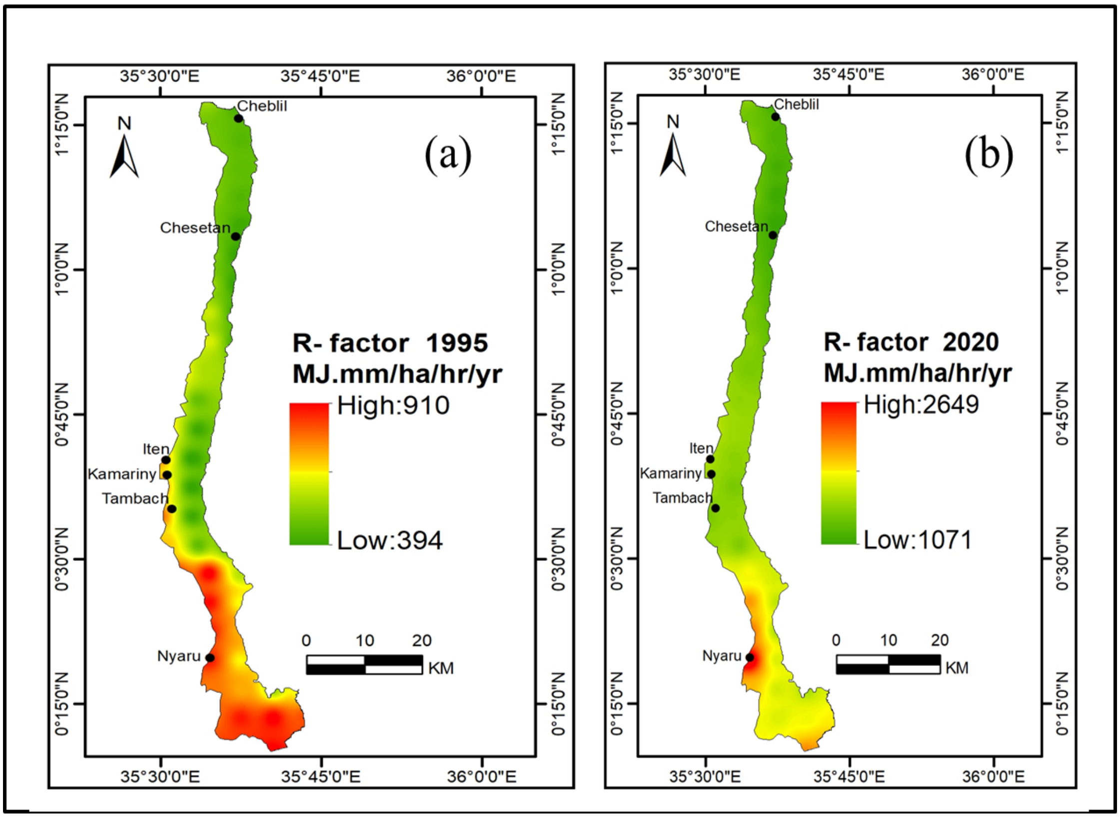

Figure 4.6: Spatial Distribution of Rainfall Erosivity (R-factor) for (a) 1995 and (b) 2020 in Elgeyo Escarpment

The soil erodibility (K-factor) values ranged between 0.11 tons $hMJ^{-1}mm^{-1}$ and 0.28 tons $hMJ^{-1}mm^{-1}$. Parts of the escarpment with K-factor of 0.11 tons $hMJ^{-1}mm^{-1}$ are less susceptible to soil erosion and soil texture tends to be clay or sandy loam whereas the areas with 0.28 tons $hMJ^{-1}mm^{-1}$ are more prone to erosion (silt). The slope length and steepness (LS) factor values ranged between 0^0 and 30^0 (Figure 4.7). Areas with gentle slope experienced the least erosion (0) whereas steep slopes experienced higher erosion.

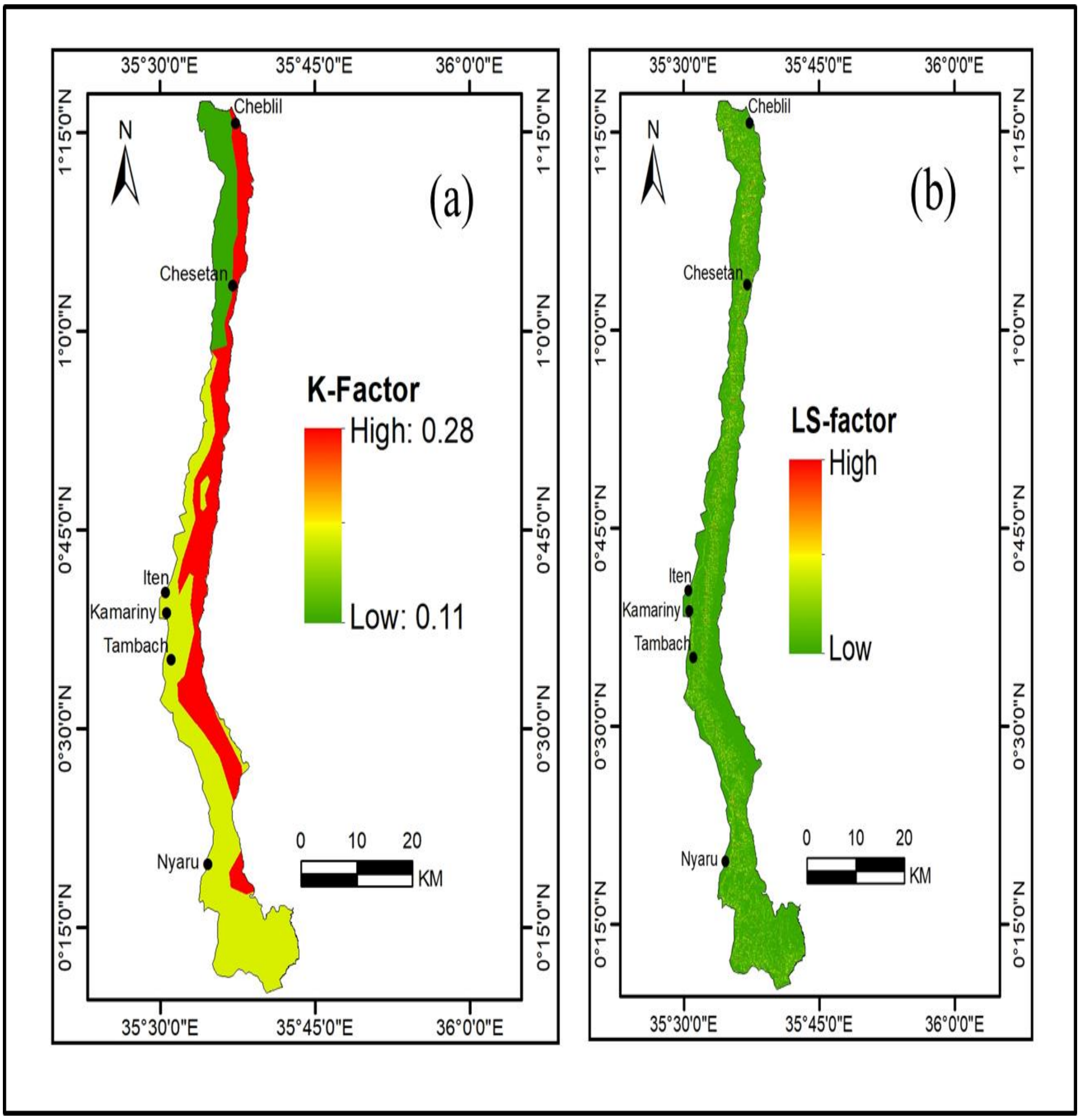

Figure 4.7: Spatial Distribution of (a) Soil Erodibility (K-Factor) and (b) Slope (LS- Factor) in Elgeyo Escarpment

The cover management (c) factor values conventionally range from 0 to 1. The value zero was recorded in areas with least soil erosion with thick vegetation while one was recorded in intensively tilled and smoothly exposed surfaces areas (Figure 4.8). Therefore, bare lands (1) experienced highest while highly vegetated areas (0) experienced the least soil erosion.

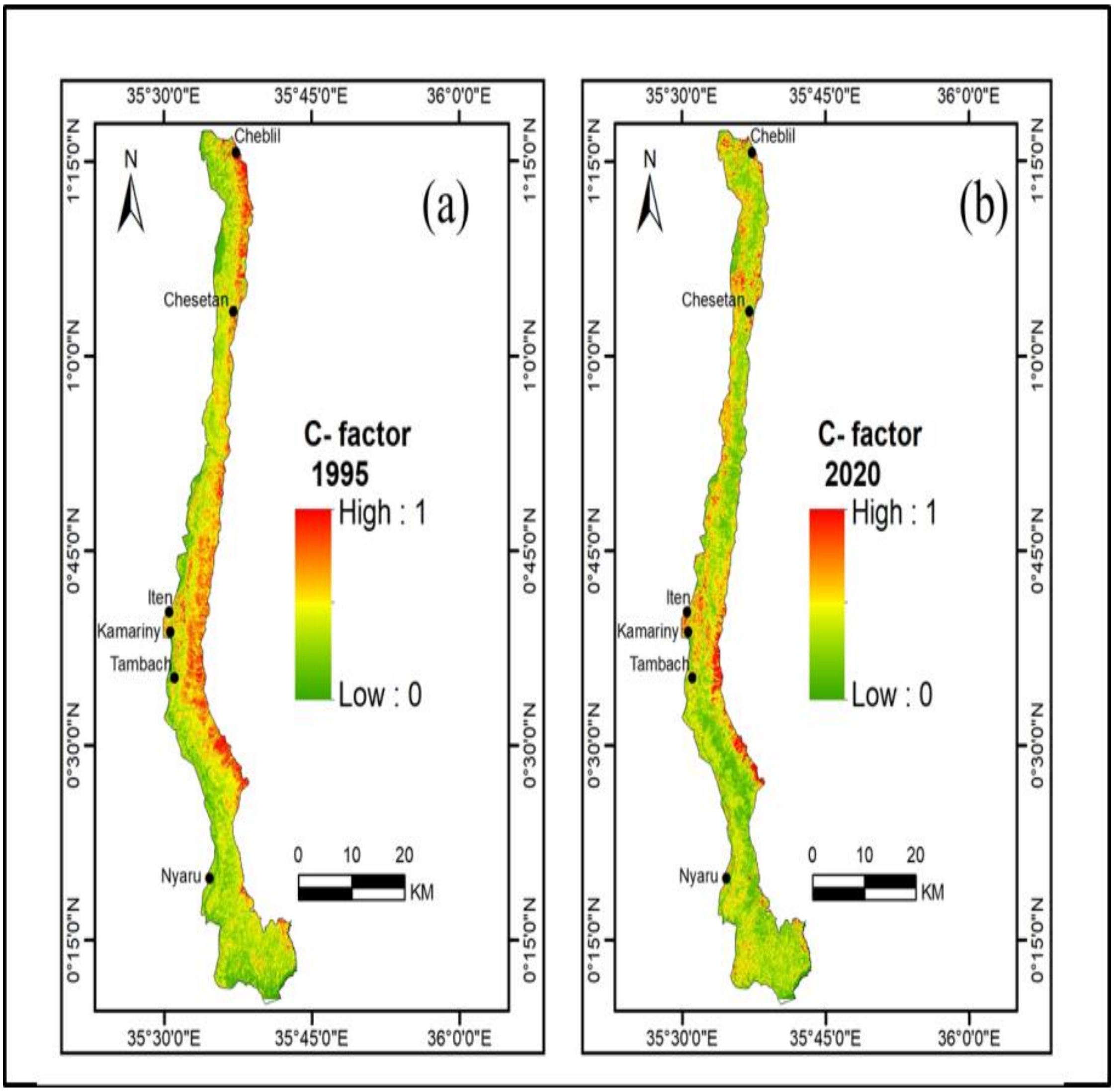

Figure 4.8: Spatial Distribution of Cover Management (C-Factor) for 1995 and 2020 in Elgeyo Escarpment

The conservation practice factor (P-factor) values ranged from 0 to 1 with 1 denoting poor conservation practices while 0 denotes proper utilization of conservation measures (Figure 4.9). These results show that the area was less conserved and therefore the soil was exposed to soil erosion in the year 1995. However, this greatly changed over the years and by 2020, conservation practices had been intensified particularly on the lower sections of the escarpment and as a consequence, soil erosion in the lower sections of the escarpment declined.

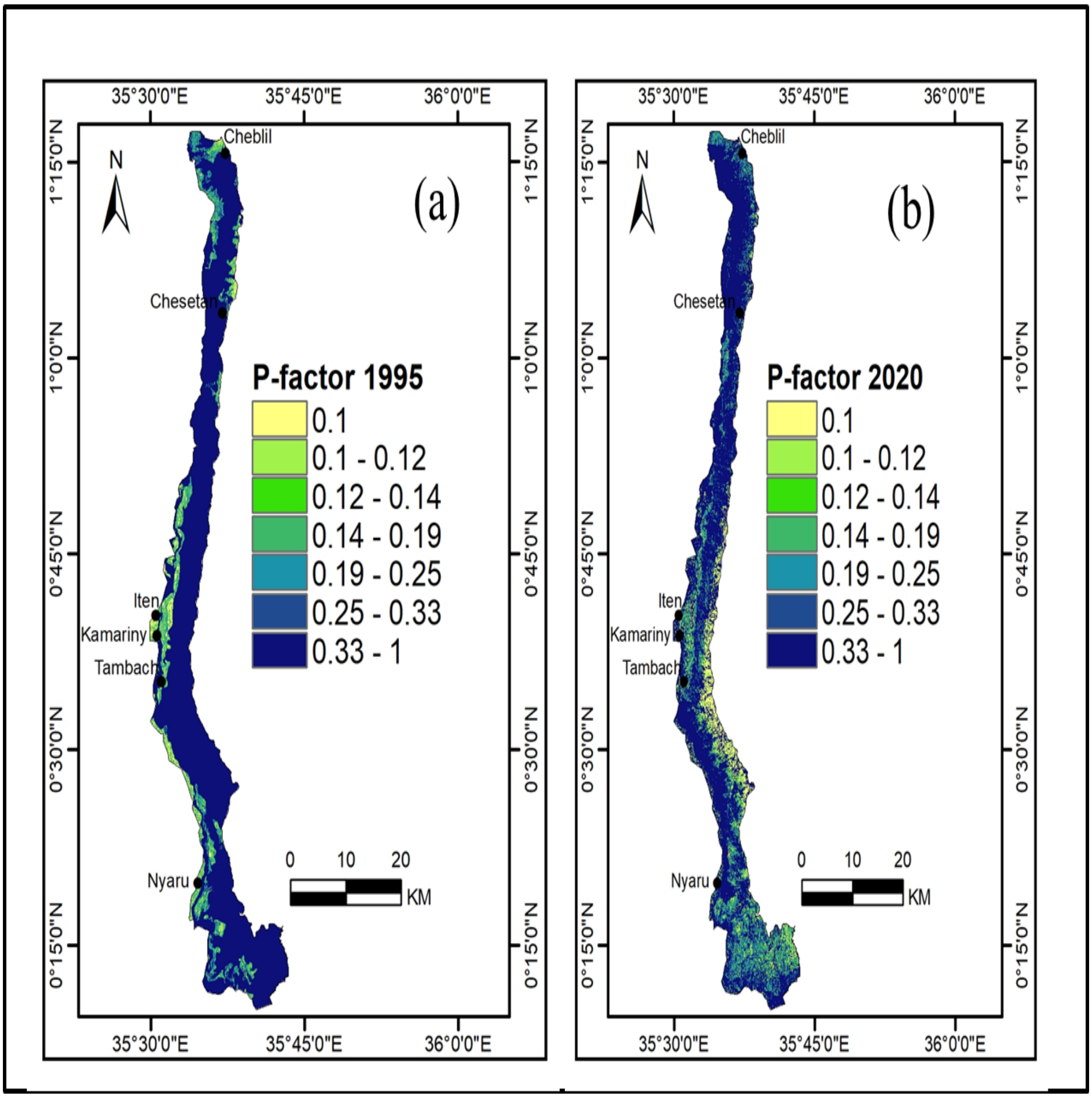

Figure 4.9: Spatial Distribution of Conservation Practice (P-Factor) for (a) 1995 and (b) 2020 in Elgeyo Escarpment

4.4.2 Spatial and Temporal Soil Losses in the Elgeyo Escarpment

The study showed that soil erosion; sheet and rill combined in the Elgeyo escarpment ranged from 0-49.42 $tha^{-1}y^{-1}$ in 1995 and 0-68.85 $tha^{-1}y^{-1}$ in 2020 (Figure 4.10). The mean erosion were 14.02 $tha^{-1}y^{-1}$ and 18.76 $tha^{-1}y^{-1}$ for the years 1995 and 2020 respectively resulting in total soil losses of 407, 456.60 tons/year and 460,139.93 tons/year in 1995 and 2020 respectively (Table 4.16).

Table 4.16: Soil erosion parameters in Elgeyo escarpment

Year	Soil erosion range ($tha^{-1}y^{-1}$)	Mean Soil erosion ($tha^{-1}y^{-1}$)	Total soil loss (ty^{-1})
1995	0 – 49.42 t/ha/y	14.02 ± 1.90	407,456.60
2020	0 – 68.85 t/ha/y	18.76 ± 2.05	460,139.93

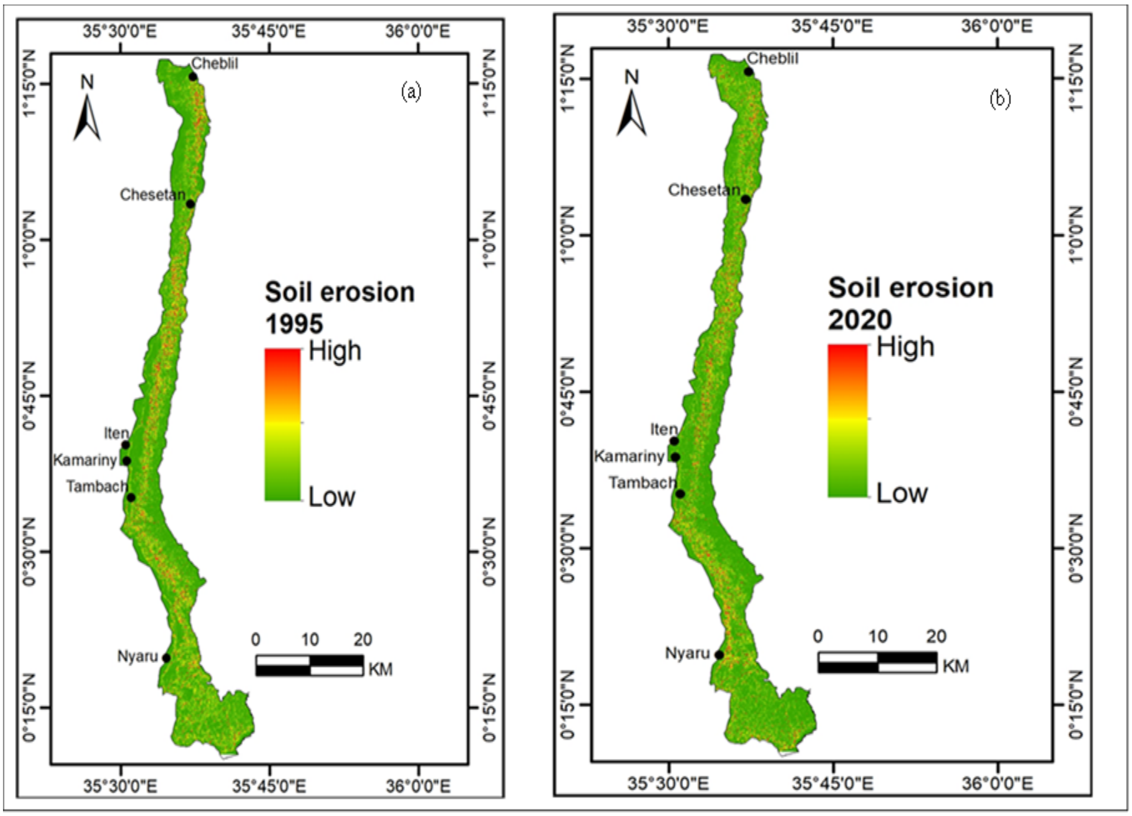

Figure 4.10: Spatiotemporal Distribution of Soil Erosion in 1995 and 2020 in Elgeyo Escarpment

4.4.3 Classification of Soil Erosion on Severity Class in Elgeyo Escarpment

Soil erosion was further categorized into various soil erosion severity classes including: slight (<5 $tha^{-1}y^{-1}$), moderate (5-10 $tha^{-1}y^{-1}$), high (10-20 $tha^{-1}y^{-1}$) and very high (> 20 $tha^{-1}y^{-1}$), as indicated in Table 4.17. The areas that experienced slight, moderate, high and very high erosion measured: 26,878.86 ha, 966.51 ha, 1797.84 ha, and 50928.03 ha respectively in 1995 and 2020. The average soil erosion rates in the slight severity class were 0.39 tha^{-1}y^{-1} and 0.42 tha^{-1}y^{-1} in 1995 and 2020 respectively. The moderate soil erosion were 6.61 tha^{-1}y^{-1} and 6.68 tha^{-1}y^{-1} in the years 1995 and 2020 respectively. High erosion values were 13.23 tha^{-1}y^{-1} and 13.16 tha^{-1}y^{-1}) in 1995 and 2020 respectively. Very high erosion was the most dominant severity class with soil erosion rates of 24.78 tha^{-1}y^{-1} and 26.51 tha^{-1}y^{-1} in years 1995 and 2020 respectively (Table 4.17).

Table 4.17: Temporal Distribution of Soil Erosion under Different Severity Classes in Elgeyo Escarpment

Severity class	Soil erosion (tha^{-1}y^{-1})	1995		2020		Net change (tha^{-1}y^{-1})
		Area (ha)	Soil erosion (tha^{-1}y^{-1})	Area (ha)	Soil erosion (tha^{-1}y^{-1})	
Slight	<5	26878.86	0.39	26878.86	0.42	0.03
Moderate	5 to 10	966.51	6.61	966.51	6.68	0.07
High	10 to 20	1797.84	13.23	1797.84	13.16	-0.07
Very High	>20	50928.03	24.78	50928.03	26.51	1.73

4.4.4 Estimated Rate of Soil Erosion by Elevation

The escarpment was categorized into five altitudinal zones and the corresponding soil erosion values determined (Table 4.18). Soil erosion in the area at an elevation below 1400 m (19209.6 ha) were 0.05 and 1.22 tha^{-1}y^{-1} in the years 1995 and 2020 respectively. The rates of soil loss at the elevation of 1400-1800 m (21191.1 ha) were 0.40 tha^{-1}y^{-1} and 0.36 tha^{-1}y^{-1}. Further, the soil erosion at elevation of 1800-2200 m (23355.9 ha) were 0.57 tha^{-1}y^{-1} and 0.59 tha^{-1}y^{-1} in the years 1995 and 2020 respectively. Furthermore, soil erosion in the elevation 2200-2600 m (15,400 ha) were 0.25 $tha^{-1}y^{-1}$ and 0.52 $tha^{-1}y^{-1}$ in 1995 and 2020 respectively (Table 4.18).

Table 4.18: Soil Erosion in Distinct Elevation Zones in Elgeyo Escarpment

Elevation (masl)	Area (Hectares)	Erosion ($tha^{-1}y^{-1}$) 1995	Erosion ($tha^{-1}y^{-1}$) 2020	Net change ($tha^{-1}y^{-1}$)
<1400	19209.6	0.05	1.22	1.17
1400-1800	21191.1	0.40	0.36	-0.04
1800-2200	22355.9	0.57	0.59	0.02
2200-2600	15400	0.25	0.52	0.27
>2600	2848.5	0.10	0.28	0.18

4.4.5 Estimated Rates of Soil Erosion by Slope in Elgeyo Escarpment

Soil erosion was further classified according to slope of occurrence (Table 4.19). The results show an increase in erosion with rise in slope steepness. The area (12195.1 ha) with slope angle of less than five degrees recorded the lowest soil erosion of 0.08 $tha^{-1}y^{-1}$ and 0.07 $tha^{-1}y^{-1}$ in 1995 and 2020 respectively. In slopes of 5-10 degrees (13155.5 ha), soil losses were 0.18 $tha^{-1}y^{-1}$ and 0.20 $tha^{-1}y^{-1}$ for 1995 and 2020 respectively (Table 4.19).

Table 4.19: Soil Erosion in Different Slope Zones in Elgeyo Escarpment

Slope (Degrees)	Area (Hectares)	Soil Erosion ($tha^{-1}y^{-1}$)		Net change ($tha^{-1}y^{-1}$)
		1995	2020	
<5	12195.1	0.08	0.07	-0.01
5-10	13155.5	0.18	0.20	0.02
10-20	22344.9	0.35	0.40	0.05
20-30	17577.9	0.60	0.69	0.09
>30	15731.7	0.97	1.10	0.13

4.4.6 Contribution of Land Use Land Cover Classes and Changes to Soil Erosion

Distribution of soil erosion over various land use/cover classes indicated that shrubland had the highest erosion occurrence of 67.1% and 39.8% in 1995 and 2020 respectively. Soil loss in cropland was significant although it remained largely constant at 20.1% and 20.2% in 1995 and 2020 respectively. In forest, soil loss depicted an increasing pattern over the study period (Figure 4.11). Grassland and built-up areas had a minimal soil loss throughout the study period (Figure 4.11).

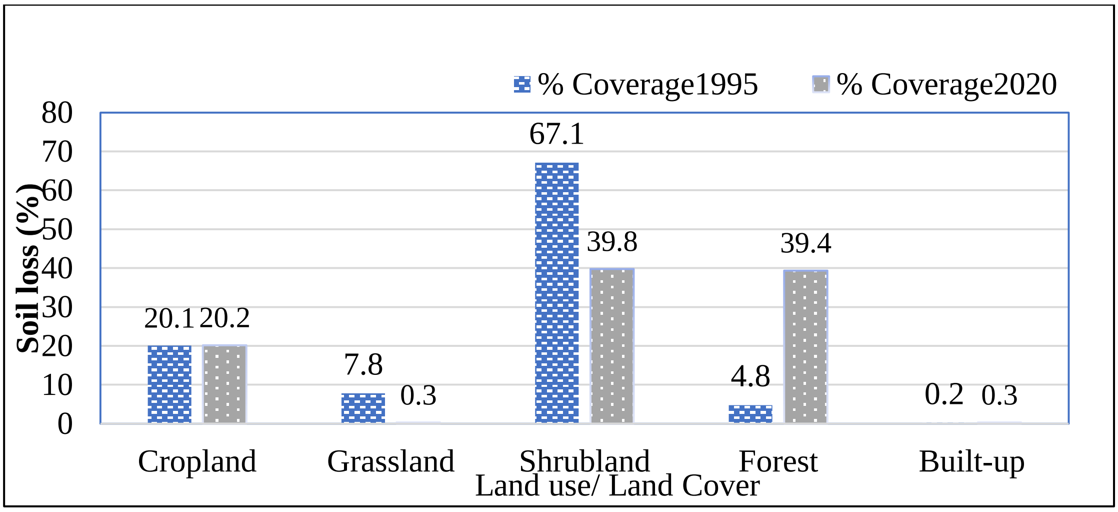

Figure 4.11: Contribution of various Land Uses to Soil Erosion in Elgeyo Escarpment

The spatial distribution of LULC conversions and their contribution to soil erosion is presented in Figure 4.12 and Table 4.20. The major forms of LULC changes were the conversion of 24, 250.77 ha and 10, 664.55 ha of shrub/grassland to forest and cropland resulting in total soil losses of 11,396.50 tons and 7638.08 tons respectively. Further, 6076.98 ha and 4991.85 ha of cropland were converted to shrubland and forest resulting in total loss of 856.85 tons and 969.81 tons of soil respectively. Furthermore, 690.12 ha and 453.51 ha of forest were converted to shrub/grassland and cropland leading to soil loses of 184.74 and 233.38 tons respectively (Table 4.20).

Table 4.20: Soil Erosion under LULC Conversion Classes in Elgeyo Escarpment

LULC conversions	1995-2020		
	Area (ha)	Soil loss (ton)	Soil erosion ($tonha^{-1}$)
Cropland - Shrub/grassland	6,076.98	856.85	0.14
Cropland - forest	4,991.85	969.81	0.19
Cropland - built-up	119.79	41.93	0.35
Shrub/grassland - forest	24,250.77	11,396.50	0.47
Shrub/grassland - cropland	10,664.55	7,638.08	0.72
Shrub/grassland - built-up	81.81	74.18	0.91
Forest - cropland	453.51	233.38	0.51
Forest - shrub/grassland	690.12	184.74	0.27
Forest - built-up	0.27	0.08	0.31
Built-up - cropland	4.77	7.25	1.52
Built-up - forest	34.64	15.94	0.46
Built-up - shrub/grassland	35.01	11.20	0.32

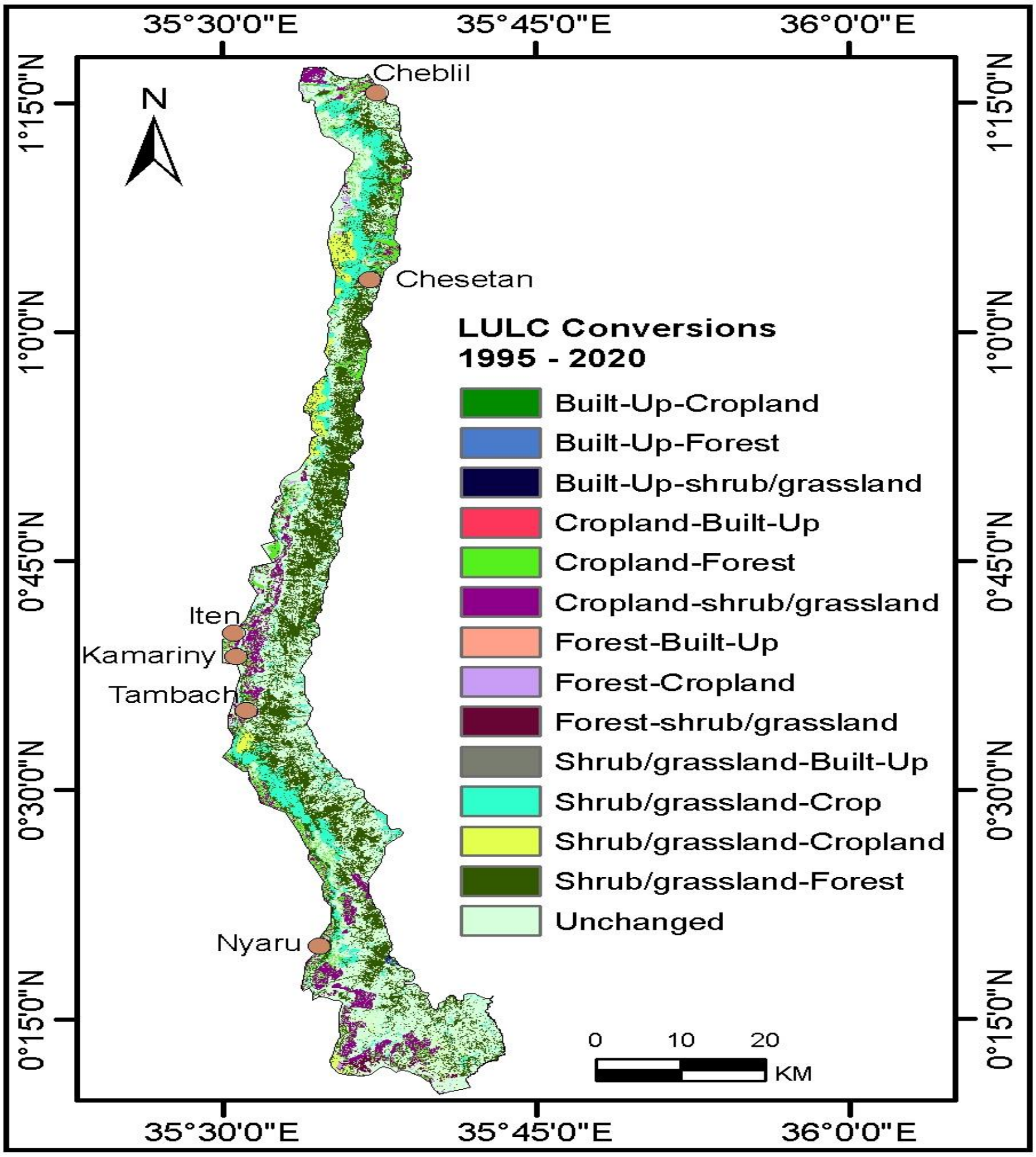

Figure 4.12: LULC Conversions (1995-2020) in Elgeyo Escarpment (Author, 2022)

4.4.7 Land Use Land Cover Conversions under Different Slopes Angles

The extent of LULC conversions in the different slope zones in the 1995-2020 period of study is presented in Table 4.21. The results show that shrub/grassland lost substantial area to forest and cropland across all slope angles. Notably, shrub/grassland recorded the highest conversion to the tune of 4888.44 ha and 4032.22 ha to forest in areas with slope angles of 10-20^0 and 20-30^0 respectively.

Additionally, shrub/grassland continued to record higher conversions to cropland (3375 ha and 2875.23 ha) at slopes of 10-20^0 and 20-30^0 respectively. The conversion of cropland to shrub/grassland was dominant in slopes of <5^0 (1185.57 ha), 5-10^0 (1636.56 ha) and 10-20^0 (1751.01 ha). It however, declined at slope 20-30^0 and >30^0 by 773.01 ha and 423.09 ha respectively. The change of forest to cropland and shrub/grassland was highest at slopes greater than 30^0 (Table 4.21).

Table 4.21: Land Use Land Cover Changes under Different Slopes Angles (1995-2020) in Elgeyo Escarpment

LULCC	Area Changes under Various Slopes					Total Ha
	<5	5-10	11-20	21-30	>30	
Cropland - shrub/grassland	921.4	1538.3	2040.2	1047.2	503.55	6050.6
Cropland - forest	1040.3	1473.4	1461.3	618.66	350.91	4944.60
Cropland - built-up	49.77	45.18	19.71	3.78	3.33	121.77
Shrub/grassland - forest	3071	3506	6491.5	5672	5483.7	24225
Shrub/grassland - cropland	1046	954	2899	2800	2938.86	10639
Shrub/grassland - built-up	28.35	14.94	15.93	13.95	8.64	81.81
Forest - cropland	64.35	81.54	128	85.59	84.69	444.51
Forest - shrub/grassland	47.88	91.53	161.7	143.19	241.74	686.07
Forest - built-up	0.00	0.00	0.18	0.09	0.00	0.27
Built-up - cropland	0.72	0.54	1.26	1.35	1.26	5.13
Built-up - forest	17.46	9.09	5.67	1.53	0.99	34.74
Built-up - shrub/grassland	14.49	9.00	6.21	4.68	1.98	36.36

4.4.8 Soil Erosion in Different Land Use Land Cover Changes and Slopes

During this study period, quantities of soil losses were observed to follow an almost similar trajectory to LULC changes at different slopes although it increased with increase in slope angle (Table 4.16). For example, soil loss was greatest (91403 tons) in the area converted from shrub/grassland to forest at slopes of >30^0 and lowest (5095.88 tons) at a slope of less than 5^0. Similarly, the change of shrub/grassland to cropland occasioned a soil loss of 41,589 tons at slopes greater than 30^0 (Table 4.22).

Table 4.22: Soil Erosion on Different LULC Changes and Slopes (1995-2020) in Elgeyo Escarpment

LULC conversion	Soil Erosion under different slopes					Total	Ton
	<5	5-10	11-20	21-30	>30	(Tons)	/ha
Cropland- shrub/grassland	128.5	717	2756	3207	2643.8	9451	1.6
Cropland - forest	988.6	3929	8844	7327	5941	27029	5.5
Cropland - built-up	46.1	106	128.8	77.0	107.95	465.4	3.8
Shrub/grassland - forest	5096	1547	52739	68078	91403	23278	9.6
Shrub/grassland- cropland	1304	2704	15116	23760	41589	84475	7.9
Shrub/grassland - built-up	51.3	45.4	223.3	308.8	192.6	821.5	10
Forest - cropland	36.1	147	400.6	537.5	1337.4	2458	5.5
Forest - shrub/grassland	3.9	24.6	190.2	439.6	1338.9	1997	2.9
Forest - built-up	0.0	0.0	0.1	0.84	0.0	0.94	3.5
Built-up - cropland	0.7	1.6	11.8	21.9	44.8	80.82	15
Built-up - forest	49.5	45.9	34.3	20.3	26.7	176.6	5.1
Built-up - shrub/grassland	3.8	4.6	8.1	13.6	18.3	47.82	1.3

4.5 Impact of Land Use Land Cover on Soil Properties in Elgeyo Escarpment

4.5.1 Soil Types and Spatial Distribution in Elgeyo Escarpment

Soil mapping showed that, the study area has seven soil types (Figure 3.1). Chromic Cambisols, Humic Nitisols, Lithic Lepthosols and Humic Cambisols are the mos dominant soil types covering 272.19 km^2, 204.76 km^2, 174.51 km^2 and 124.71 km^2 in that order. These comprise percentage coverage of 33.37%, 25.1%, 21.39% and 15.29% in that order. Other soil types include; Eutric Chromic, Haplic Lixisols and Eutric Gleysols (Table 4.23).

Table 4.23: Soil Types and their Coverage in Elgeyo Escarpment

Soil type	Area coverage (km^2)	Percent coverage (%)
Chromic Cambisols	272.19	33.37
Humic Nitisols	204.77	25.10
Lithic Leptosols	174.51	21.39
Humic Cambisols	124.71	15.29
Eutric Chromic	36.03	4.41
Haplic Lixisols	1.23	0.15
Eutric Gleysols	0.52	0.06

4.5.2 Impact of Land Use Land Cover on Soil chemical properties in Elgeyo Escarpment

The study determined and compared pH values, carbon, nitrogen and phosphorous, potassium and zinc contents in soils samples collected from various land use classes. The results indicate that land use classes significantly affected the soils pH (F = 3.36, DF = 4, P = 0.028). The lowest mean (5.38) and the highest mean (6.20) soil pH values were recorded in cropland and forestland respectively (Table 4.24). The results also indicate that LULC had significant difference on soil organic carbon content (F = 2.79, DF = 4, P = 0.048). Forest land had the highest (4.83 %) while croplands had the lowest (2.57%) soil organic carbon contents respectively (Table 4.24), falling between high and moderate ratings (Table 3.4). The mean total nitrogen soil content suggests that it is not significantly affected by LULC (F = 1.58, DF = 4, P = 0.21). Forest and shrubland had the highest total nitrogen concentrations of 0.23% and 0.19% respectively. Conversely, the total nitrogen contents were relatively lower in built-up (0.12%), cropland (0.13%) and grassland (0.14%). These results suggest that nitrogen contents are affected by vegetation cover and increases with increase in vegetation cover. Observably, the nitrogen contents among all the five LULC classes fell within the moderate rating of 0.12% - 0.25% (Table 3.4).

The results, further indicate that, LULC significantly affect soil Phosphorous (F = 4.87, DF = 4, P = 0.005) and potassium contents (F = 2.96, DF = 4, P = 0.039). The mean value of soil phosphorous was highest in forest (81.85 ppm) and lowest in built-up (6.65 ppm). The available mean value of soil potassium was highest in forest (872.67 ppm) and lowest in built-up (392.28 ppm). The soil potassium contents in the other LULC classes were 407.75 ppm, 512.57 ppm and 846.00 ppm for cropland, grassland and shrubland in that order. In addition, zinc contents differed significantly ($p<0.05$) between forest and built-up (Table 4.24).

Table 4.24: Impact of LULC Classes on Soil chemical Properties in Elgeyo escarpment

LULC Class	Parameter					
	pH	C (%)	N (%)	P (ppm)	K (ppm)	Zn (ppm)
Cropland	5.38^{b}	2.57^{c}	0.13^{ba}	8.23^{b}	407.75^{b}	5.40^{b}
Grassland	5.79^{ab}	3.46^{bac}	0.14^{b}	13.78^{b}	512.57^{ba}	6.42^{ba}
Shrubland	5.85^{ab}	4.67^{ba}	0.19^{ba}	20.37^{b}	846.00^{a}	6.64^{ba}
Forest	6.20^{a}	4.83^{a}	0.23^{a}	81.85^{a}	872.67^{a}	15.53^{a}
Built-up	5.78^{ab}	3.07^{bc}	0.12^{ba}	6.65^{b}	392.38^{b}	3.30^{b}
Mean	5.75	3.76	0.16	27.06	597.13	8.02
SE (±)	0.11	0.27	0.02	7.80	69.23	1.53
LSD	0.74	1.60	0.10	42.24	412.09	9.49
Significance	**	**	**	**	**	**

Means in the same column with different superscripts are significantly different at $p<0.05$., SE = standard error of the mean. ** denote significant difference ($p<0.05$)

4.5.3 Impact of Land Use Land Cover on Soil Physical Properties in Elgeyo Escarpment

The mean values of soil properties among the five LULC classes were compared. The results show that there was no significant difference (F = 2.49, DF = 4, P = 0.069) in soil moisture content among the various LULC classes (Table 4.25). The soil moisture contents were 19.70 %, 19.42%, 18.38% and 16.22% in shrubland, grassland, forest and cropland in that order. However, the bulk density (BD) was significantly different among LULC classes (F = 3.15, DF = 4, P = 0.032). The most favorable BDs recorded were; 1.00 g/cm^3, 1.07 g/cm^3 and 1.15 g/cm^3 for the forest, shrubland and grassland in that order. Conversely, croplands and built-up had the highest BD values of 1.20 g/cm^3 and 1.40 g/cm^3 respectively (Table 4.25). The mean values of particle size of soils among various LULC classes were evaluated. The results also suggest that there was significant difference (F = 3.32, DF = 4, P = 0.026) in the percentage sand among LULC classes. The percentage sand was highest in shrubland (88.00%) and forest (85.75%). Additionally, there was significant difference in soil silt content among LULC classes (F = 3.45, DF = 4, P = 0.022). However, there was insignificant difference in the clay content among the LULC classes (F = 0.98, DF = 4, P = 0.43)

Table 4.25: Impact of LULC Class on Soil Physical Properties in Elgeyo escarpment

LULC class	Parameter					
	MC (%)	BD (g/cm^3)	Sand (%)	Clay (%)	Silt (%)	Textural Class
Cropland	14.34^{b}	1.40^{a}	75.14^{bc}	4.00^{a}	20.86^{ba}	Sandy loam
Grassland	19.42^{a}	1.15	76.00^{bc}	5.50^{a}	17.50^{bac}	Loamy sand
Shrubland	19.70^{a}	1.07^{b}	88.00^{a}	6.50^{a}	9.80^{c}	Loamy sand
Forest	18.38^{ba}	1.00	85.75^{ba}	2.63^{a}	11.63^{bc}	Sandy loam
Built-up	16.22^{ba}	1.20^{ba}	71.67^{c}	2.20^{a}	22.83^{a}	Sandy loam
Mean	17.36	1.16	79.53	3.97	16.50	
SE (±)	0.71	0.05	2.01	0.77	1.60	
LSD	4.33	0.28	11.76	5.16	9.28	
Significance	**	**	**	ns	**	

Means with different superscripts in the same column are significantly different (**) at p<0.05, MC = moisture content, BD = bulk density, SE = standard error of the mean.

4.6 Mitigation Measures for Negative LULC Changes Impacts in Elgeyo Escarpment

The most popular intervention measure for soil fertility improvement in the escarpment is the application of organic fertilizers (80%). Other measures are; inorganic fertilizers application (35%) and mixed cropping (30.6%) (Table 4.26).

In solving the soil erosion problem in the escarpment, a greater proportion of the population (76.7%) construct terraces across their farms. This is not surprising considering that the area has between gentle to very steep slope. Other measures include establishment of grass strips (51.1%), agroforestry including fruit trees growing (42.2%) and proper farm planning (25.6%). Overall, there is need to promote a number of interventions in addition to the traditional terracing and contouring technologies. These interventions include; environmental education, adoption of alternative livelihoods such as beekeeping and fruit trees (mangoes, guavas, avocadoes, lemons and oranges) growing and cultural interventions (Table 4.26). The cultural interventions are things to do with taboos, designating areas as cultural sites. This will prohibit certain activities that are detrimental to the environmental wellbeing (Table 4.26)

Table 4.26: Mitigation Measures for Land Degradation in Elgeyo Escarpment

Mitigation measure	Frequency (N=180)	Percentage
a) Soil fertility problem		
Organic fertilizer	144	80
Inorganic fertilizer	63	35
Mixed rotational cropping	55	30.6
b) Soil erosion		
Terracing/contouring	138	76.7
Grass strips	92	51.1
Agroforestry	76	42.2
Proper planning	46	25.6
c) Environmental degradation		
Environmental education	110	61.1
Alternative livelihoods	90	50
Cultural interventions	69	38.3

Note: Percentages do not add to 100 because respondents mentioned multiple responses

CHAPTER FIVE

DISCUSSION

5.1 Spatiotemporal Land Use Land Cover Changes and their Drivers

The study results indicate that the escarpment underwent land use land cover conversion over the last 25-year period. The changes are varied in trends and magnitude both spatially and temporally. Also, they varied with regard to land use and cover classes. The notable change during the study period (1995 – 2020) was the eightfold rise in forest cover and a significant increase in cropland. Built-up areas also almost doubled. The surge in forest, cropland and built-up areas saw an almost corresponding decrease in shrubland and grasslands during the same period. This was attributed to clearing of shrubland and grassland for food production and timber for constructing houses and thus consistent with other past studies. In particular, Kanianska (2016) noted that human societies begun to modify natural ecosystems, resulting in drastic reduction in the earth's vegetation cover (KWTA, 2020).

The observed drastic decline in shrubland and grassland cover between 1995 and 2014 in the study area is also in tune with Kissinger *et al.* (2012) who observed that global vegetation cover conversion was most profound between 2000 and 2010. This is the period when large portions of vegetation, including shrublands and grasslands worldwide were converted to agricultural and settlements areas (Ramankutty *et al.*, 2018). This finding is also in agreement with Sang *et al.* (2022) who found a decrease in shrubland and grassland cover along the Kenya's standard gauge railway corridor owing to mushrooming of settlements. Further, bush fires have been blamed for decimating shrubs and grasses (Rotich *et al.*, 2020). This, clearing of vegetated areas for agricultural purposes would immensely degenerate the soils since the ecologically delicate parameters for the habitat cannot tolerate the attendant effects (Zewdu *et al.*, 2016). Besides, it affects the size of the forest by diminishing its size or changing the structure, presenting threats to animals relying on it for their food (Chirchir *et al.*, 2018).

During the 1995 and 2014 study period, forests cover increased substantially in the Elgeyo escarpment and thus inconsistent with most past studies. For instance, (Ayuyo & Sweta, 2014) reported a reduction in forest cover and attributed it to the trees logging and charcoal burning for various purposes such as crop production, wood fuel and construction materials. Kiptanui (2015) observed a decline in forest cover by 3.6 km^2 in Kimwarer area over a 26-year period which was lost to mining fields and settlement for mining workers. Additionally, Kipkemoi (2018) found that 71.72 km^2 of Embobut forest representing 28% loss of the forest cover in 1986 – 2011 period. He attributed the loss to deforestation owing to the increased population that needed food and shelter.

Forest cover continued to gain during the 2014 - 2020 while shrubland and grasslands declined profoundly. This was due to the lack of brush moving, thus allowing the seeds of invading tree species to germinate and establish themselves converting the area into a forest (RoK, 2009). Cropland and built-up declined minimally over the same time span. This can be linked to routine eviction activities that were conducted by the Republic of Kenya that climaxed in the year 2013 (Amnesty, 2018). Some of the forests involved were; Embobot, Kapchemutwa, Kessup, Sabor, Tingwo and Metkei (KFS, 2021; KWTA, 2020). This is also attributed to forest conservation efforts through legal, policy and community sensitization on forest protection benefits. For example, the compulsory establishment of farm forestry that is legally provided by the Agriculture (Farm Forestry) Rules; section 5(1) (RoK, 2009). This rule prescribes that every person owning or occupying cropland shall institute and sustain at least ten percent (10%) of land under farm forestry (RoK, 2009). Trees growing culture campaigns such as instilling tree growing culture in young generations like school going children to plant trees in their farms and in school compounds have proffered to expanded forest cover in the escarpment (KWTA, 2020). Moreover, the improved concept of Plantation Establishment and Livelihood Improvement Scheme (PELIS); a non-resident cultivation within a state forest or the already harvested areas with the desire to establish a plantation improved forest coverage substantially (KWTA, 2020). Further, fruit trees growing; mangoes, lemons, and avocadoes bolstered forest cover in the escarpment (CGoEM, 2020).

During the entire study period, there was a net minimal rise in built-up areas. This was imputed to population increase. The 1989 census established that the Kenyan population stood at 21.4 million people. This figure increased to 28.7 million people in 1999, 38.6 million people in 2009 and 47 million people in 2019 (KNBS, 2019). In the Elgeyo escarpment, human population grew from 68,558 to 126,504 people between 1989 and 2019. This translates to a growth rate in population of approximately three percent per annum (KNBS, 2019). The population growth follows that the families' land is inherited; shared among the male children who will have come of age to start their own families. This is demonstrated by the continuous surge in the number of households rising from 12, 684 to 26,762 between 1989 and 2019 (KNBS, 2019). These results are in tune with Demetriou *et al.* (2013) who concluded that land bequeathals, land markets and historical or societal beliefs are the main driving forces of land use and cover conversions. Besides, insecurity caused by the conflict pitting the inhabitants of Baringo County against Elgeyo Marakwet county residing in Kerio valley (NCCK, 2009) that forced over 32,000 people to move to higher areas considered safer in Endo, Arror and Kewani wards located in Marakwet East, West and Keiyo North sub-counties respectively (Pkalya *et al.*, 2003) probably degrading the fragile escarpment (Kiprono, 2018).

The overall marginal increase in built-up areas during the study period can be imputed to increased infrastructural development. In the olden days, the area residents used to travel from the highlands, across the escarpment to the Kerio Valley using several foot baths commonly referred to as tracks. Some of the tracks have since been converted into road networks (CGoEM, 2018). These are particularly those murram roads done by the County Government of Elgeyo Marakwet across the Escarpment (Kilimo, 2014). For instance, the earth-surfaced roads cover a total of 564.4 km, of which 258.4 km were roads newly build by the County Government (CGoEM, 2018). This finding is in tune with Sang *et al.* (2022) who found increase in bare land, cropland and built-up and drastic reduction in shrub land and grassland. They attributed the changes to the construction of the standard gauge railway and the advent of devolution which dispersed development to grassroots leading to mushrooming of urban areas and settlements.

Disease (Malaria) outbreaks declined during the 2014-2020 period and thus LULC change due to malaria outbreak declined (Table 4.13). This can be ascribed to deliberate and robust campaigns by the Republic of Kenya’s Ministry of Health and the International Community such as the World Health Organization (WHO) and the United States of America (MoH, 2016; Noor *et al.*, 2012). Although the programme had begun way back in the year 2004, they only targeted children below the age of five years, pregnant mothers and other vulnerable members of the community (Noor *et al.*, 2007). They were later expanded to all members of the society. These programme entailed sensitization, extensive issuance of insecticides treated mosquito nets, spraying mosquitoes breeding areas and encouraging people to sleep under the insecticides treated mosquito nets (Ng’ang’a *et al.*, 2021).

Maize has continued to be a stable food crop for majority of households in Kenya (Nyoro *et al.*, 2004), accounting for 65% of caloric intake from staple foods and 36% of total caloric intake in Kenya (D’Alessandro *et al.*, 2015) and consumed by over 90% of households (Onono *et al.*, 2013; Otieno, 2020). Additionally, maize constitutes more than 50% of smallholder household production in Kenya. However, the yields have not kept the tempo to its increased demand over the years resulting in net deficits. Notably, the annual maize production in Kenya stands at 40 million bags against a demand for 55 million bags. Considering that Kenya’s population stands at 47 million people (KNBS, 2019) translating to a per capita productivity of 0.85 bag (76.5 kg) of maize. This is against, annual average per capita maize demand is about 90 Kg (RoK, 2020). This means there is a national maize deficit of 15 million bags (1.35 billion kg) and a per capita deficit of 28.72 kg that is ordinarily plugged by imports and maize substitutes including rice and wheat (RoK, 2020).

In Elgeyo Marakwet County particularly in the Elgeyo escarpment, maize production has continued to decline over the years while human population continued to surge (Figure 4.5). From the production and population growth trends, it is evident that although, maize production still exceeds the per capita demand of 90 kg (RoK, 2020), sooner or later the demand will surpass the production occasioning deficits. Notably in 1999, the per capita maize production was 190.2 kg, this figure dropped to 164.9 kg in 2009 and 115.7 kg in 2019, representing a per capita decline of 74.5 kg in just two decades. Therefore the slow pace of agricultural production and unchecked fast growing population will shortly surpass resource supply forcing the population to subsistence levels a situation known as Malthusian catastrophe as illustrated in Figure 2.1 (Burger, 2021). Further, during the study period the European and global population grew at a low pace but doubled in most geographical areas in the developing world (Table 4.14) and thus confirming Malthusian postulate of exponential population growth; doubling itself after every 25 years (Adama & Audu, 2019; Pham *et al.*, 2020). This can be imputed to the Malthusian pessimism in the Europe and most developed world (Pham *et al.*, 2020), ignorance and indifference in the developing world (Goldstone, 2016; Pham *et al.*, 2020). Therefore, it is crucial for the populace to understand the associations between household sizes versus resources requirements as this would enable them plan for a family size that can sustainably be supported by the available resources. Likewise, appreciation of acceptable utilization of resources will create realization about environmental sustainability. Deliberate efforts have been brought forward particularly through policies such as Sessional paper No.3 0f 2012 (NCPD, 2013).

5.2 Impacts of Land Use Land Cover Changes on Soil Erosion in Elgeyo Escarpment

Soil erosion in the Elgeyo escarpment was assessed using the RUSLE model in Geographic Information System (GIS) realm. The findings show that spatial distribution of rainfall erosivity in the escarpment is directly proportional to the quantity of rainfall obtained. Notably, Erosivity; erosion due to rainfall differed spatially. For example, the highest erosivity determined are higher towards the southern sections of the study area particularly in Keiyo South part of the escarpment compared to the central and northern sections of the escarpment during the study period. In general, high erosivity in the area occurred mostly during long rainy season; March - May (Mugalavai *et al.*, 2008).

The occurrence and magnitude of soil loss rely on the action of precipitation on the soil thus the amount of erosion will depend on the combination of the potency of the rain and the soil's capacity to resist erosion (Nanko *et al.*, 2008). As rain droplets fall, they gain kinetic energy and as they hit the ground surface, the kinetic energy is expended in the detachment of soil particles (Jiaqing *et al.*, 2018). Once the rain lands on the soil surface, they may infiltrate, evaporate or form runoff. As the runoff flows down the slope and aided by gravitational force, they gain kinetic energy which accounts for scrubbing act on land surface (Lim *et al.*, 2015; Salles *et al.*, 2000). Additionally, continued precipitation wets the soils to saturated conditions, rendering the soil attractive forces less than repulsive forces thus facilitating soil particles to detach and move into suspension (Umesh *et al.*, 2011). Accordingly, this finding is thus consistent with (Yang, 2014) conclusion that soil erosion is directly proportional to erosivity holding other factors constant.

Higher erosion occurred in the middle to lower altitudes of the escarpment. This is attributable to soil characteristics, slope angle and length and LULC dynamics. Soil structure stability relies on its biological, chemical and physical attributes. The percentage of organic matter constituent due to decaying leaves and grass falling off from the vegetation remains an essential integrant. However, there is low vegetation cover in these parts of the escarpment and thus low soil organic matter consequently lowering soil stability resulting in increased soil erosion (Thomas *et al.*, 2018; Umesh *et al.*, 2011). Moreover, the segments of the escarpment with high soil erosion (low erodibility) represent a steep and longer slope length. This occasions low infiltration and high runoff velocity during precipitation events (Kathwas & Patel, 2021).

The lowest soil erosion in the escarpment of 0.39 $tha^{-1}y^{-1}$ (slightly severe) occurred in areas with gentle slope, well conserved vegetated areas hence low erosion severity. This was so since these conditions are less prone to soil erosion (Morgan *et al.*, 1984; Muchemi *et al.*, 2002). On the other hand, very high erosion severity class of 26.51 $tha^{-1}y^{-1}$occurred in very steep, low vegetated and poorly conserved areas of the escarpment, since these conditions are ideal to soil erosion occurrence owing to raindrops and runoff kinetic energy actions (Li *et al.*, 2019). These findings are comparable and agree with those of other past studies including soil erosion in Western Kenya by Kogo *et al.* (2020) and protected areas of Coastal Kenya by Hategekimana *et al.* (2020). Also, Mati *et al.* (2000) found comparable soil erosion in Ewaso Ngiro North basin. The similarities are due to resemblances mainly in topographic characteristics, erosivity, erodibility and vegetation cover (Lim *et al.*, 2015).

The estimated mean erosion for the years 1995 and 2020 at 14.02 $tha^{-1}y^{-1}$and 18.76 $tha^{-1}y^{-1}$respectively are higher than the tolerable mean soil erosion range of 5 $tha^{-1}y^{-1}$ to 11 $tha^{-1}y^{-1}$(Angima *et al.*, 2003; Weldu Woldemariam & Edo Harka, 2020). The mean soil losses are also higher than the estimated mean soil losses of 6.26 $tha^{-1}y^{-1}$and 7.14 $tha^{-1}y^{-1}$in 1990 and 2015 respectively in Kenya Great Rift Valley Region (KGRV) as found by Watene *et al.* (2021). This can be imputed to differences in slope characteristics of the areas. Although Elgeyo escarpment, forms part of the Great Rift Valley, its slope is steeper compared to the KGRV whose terrain comprises of highlands, escarpments and plateaus. However, the mean soil erosion rates fall within the tolerable limits of less than 25 $tha^{-1}y^{-1}$for mountainous landscapes (Koirala *et al.*, 2019) and the African erosion range of 10.8-146 $tha^{-1}y^{-1}$(Stocking, 1984) owing to the similarities in topographic characteristics.

The results indicate that over 63% of the escarpment falls within the very high erosion severity class since it experiences very high erosion; greater than 20 $tha^{-1}y^{-1}$. About 33.4 % of the escarpment experience soil erosion of low severity because it is located in low slope angle and fairly vegetated parts of the escarpment. Therefore, the contribution of the two soil erosion severity classes combined is extremely huge because of the extensive stretch of their occurrence. Accordingly, it is crucial to review LULC, conduct land use suitability study in the escarpment with a view to producing a land use suitability map (zoning) to ensure that this landscape is sustainably managed.

Spatial disposition of soil erosion prospects indicate that the mid and lower altitudes within the escarpment experience higher soil loss rates. This is because, at this elevation range, the slopes are often very steep making the velocity of rainfall runoff very high (Dulo *et al.*, 2010). These results are in tune with Mati *et al.* (2000) and Ziadat and Taimeh (2013) who found a direct relationship between the increase in slope angle and length to increased soil erosion intensity owing to the increased runoff acceleration. High runoff velocity causes rise in shear stress on the soil surface, resulting in increase in silt delivery (Ali & Hagos, 2016). These results suggest that terrain characteristics, mainly slope length and steepness, greatly influence rates of soil loss. This is consistent with Koirala *et al.* (2019) who observed that soil loss increased proportionally with steep slopes. The longer the slope length and higher slope angle, the higher the soil loss. The Elgeyo escarpment is marked by long slope length and steep slopes with almost 50% of its area being within a slope angle that is above 20^0. In addition, there is low vegetation cover with low soil conservation structures and practices and high rainfall (1200mm/year) in the escarpment. These factors, exacerbate soil erosion leading to large flow accumulation downstream (Dulo *et al.*, 2010). The low vegetation cover in the highly erodible sections of the escarpment was attributed to encroachment for settlement, deforestation and agriculture (Kogo *et al.*, 2021; Watene *et al.*, 2021).

Comparing LULC classes and soil erosion, the results suggest that soil loss was at its peak in croplands unlike areas under forest, shrub/grasslands, and built-up. This can be credited to the increased population pushing people from the traditional farming areas to the escarpment. The expansion of agricultural activities results in a corresponding decline in shrub-land and grassland. As farming is continuously intensified to produce food for the growing population, the soil physical properties deteriorate. This makes the soil susceptible to erosion, leading to loss of organic matter, a key component for soil aggregate stability (Deng *et al.*, 2016). Although forests, shrub-land and grasslands in steep slopes are equally prone to soil erosion, quantities of soil lost in these areas are often minimal unlike croplands. This is attributed to vegetation cover that greatly lowers raindrops kinetic energy (Lim *et al.*, 2015).

In terms of nature and magnitude of changes among LULC classes, the results indicate that, shrub/grassland declined significantly while forest gained dramatically. Built-up and croplands gained marginally. The gain in forest, built-up and croplands happened at the expense of shrub/grasslands. This kind of LULC conversion led to the extensive and most amounts of soil loss. The high soil erosion (1.52 $tha^{-1}y^{-1}$) was recorded in built-up areas converted from shrub/grassland. The conversion of shrub/grassland to cropland resulted in marked increase in soil erosion. This can be blamed on increased exposure of soil making it prone to erosion. Further, the change of cropland to forest still resulted in soil erosion. This is in agreement with (Schürz *et al.*, 2020) and (Kogo *et al.*, 2020) who found increased soil erosion in forested areas in West Pokot, Elgeyo Marakwet highlands and Western Kenya respectively. This could be imputed to the trees planted in the forest land having not established enough to prevent soil erosion occurrence. Moreover, soil conservation technologies like land terracing and contouring, effective soil erosion control structures (Ruto *et al.*, 2017) that were hitherto available in cropland may have been abandoned or filled up when the land converted to forest (Taye *et al.*, 2015).

The soil erosion occurrence is observed in all slope angles and lengths although the intensity of soil loss increased with increased slope angle. It is therefore necessary to emphasize zoning in the escarpment so that natural vegetation in the form of forests, and shrub/grasslands are conserved. This is because; they help to replenish soil organic matter ameliorating soil aggregate stability in this fragile ecosystem. Consequently, once vegetation cover improves, the raindrops will fall on trees, shrubs and grass drastically lowering the kinetic energy (Jiaqing *et al.*, 2018), thus reducing the impact of rain on soil hence slowing soil disintegration (Lim *et al.*, 2015). Further, the resultant runoff will flow on vegetated surface with improved stability due to higher organic matter enhancing percolation thus reducing soil erosion significantly (Mulinge *et al.*, 2016).

5.3 Land Use Land Cover Class and Soil Chemical and Physical Properties

The study found that soil pH was highest; slight acid (6.20) in forest land and lowest; moderately acidic (5.38) in croplands (Landon (2014). Understandably, soil pH is determined by inherent factors such as parent material (Fabian *et al.*, 2014; Gruba & Socha, 2016; Reuter *et al.*, 2008), cropping practices and LULC (Tellen & Yerima, 2018). For example granitic soils are acidic in nature (Tellen & Yerima, 2018). Besides, it can be affected by terrain parameters for example slope and topographic wetness index (Moore *et al.*, 1993) and topographic aspect and slope (Chen *et al.*, 1997).

Ordinarily, soil pH tends to be higher (basic) in arid and semi-arid areas often under low elevations, rainfall and high temperatures but lower (acidic) in warm and humid areas (Hazelton & Murphy, 2016). Further, soil in areas with higher vegetation cover tend to be acidic than bare grounds due to decomposition of organic matter (Hazelton & Murphy, 2016). The soil pH is moderately acidic in cultivated outfields but slight acid under forestlands according to Landon rating Landon (2014), suggesting that intensive land use including the application of the mineral fertilizer in cultivated croplands result in low pH (acidification). This finding is inconsistent with those of Hazelton and Murphy (2016), Xiaopeng *et al.* (2017) and KFS (2021) who found low soil pH values in highland forest and slightly higher soil pH in lowland forests such as mangrove forest in coastal areas.

The carbon contents of the soils are moderate under croplands and high under the grassland, shrubland and forestland as presented in Table 4.24. These results are consistent with the findings of Solomon *et al.* (2002) and Iwata *et al.* (2021) who found a lower carbon content in cultivated soils than in those soils under natural vegetation. This can be attributed to intensive agricultural activities speeding up oxidation of the organic matter combined with excessive transportation of crop residues, as animal feed and source of household energy (KFS, 2021). The higher soil carbon contents in the innate ecosystem; forest, shrubland and grassland can be imputed to a higher leaves, grass and twigs fall from the vegetation (RoK, 2020). Soil with low carbon contents like those in cropland possess low moisture holding capacity and poor structure predisposing them to soil erosion (Mganga *et al.*, 2011).

The nitrogen content in cropland is lower than those in the natural ecosystems. This is because intensive and continuous cultivation in cropland accelerates the oxidation of organic matter resulting in low nitrogen contents in cropland soils. Conversely, abundance of the natural vegetation cover in forest, shrubland and grassland, ensures a return of a high biomass. This will in turn increase the soil organic matter, consequently nitrogen content in the soils increases (Sebhatleab, 2014).

The phosphorous contents of the soils were rated high in forest and shrubland, moderate in grassland and low in cropland and built-up. This finding is in agreement with those past studies. For example, Mganga *et al.* (2011) and Bufebo and Elias (2020) found higher phosphorous contents in open grazing land and low phosphorous content in croplands. This scenario was attributed to the routine supply of organic fertilizers in the form of livestock dung (Mganga *et al.*, 2011). Further, the low phosphorous content in the intensively cultivated cropland was attributed to high fixation in the clay colloids (Bufebo & Elias, 2020).

Overall, the soil potassium (K) contents were higher across all LULC classes (Mganga *et al.*, 2011) although lower in built-up and cropland (Table 4.24). These results are in tune with those of Bufebo and Elias (2020) who concluded that most favorable soil properties were recorded in forest land than in intensively farmed outfields. This was attributed to topographic characteristics, land and soil conservation practices. However they disagree with findings of other studies. For example, Lemercier *et al.* (2017) found that soil potassium concentration in cropland were higher than in grassland which in turn were higher than in forest land. Most soil conservation structures are found in farms and rare in naturally vegetated landscapes (Ruto *et al.*, 2017) since they are abandoned as soon as the land converts to forest (Taye *et al.*, 2015). It is therefore expected that levels of nutrients including potassium will be retained in cropland and therefore higher than in forestland, shrub and grasslands thus these results are contrary to this expectation (Chen *et al.*, 1997).

Furthermore, soil zinc contents of between 5.40 ppm and 15.53 ppm with a mean of 8.02 ppm are rated as low to medium. This is consistent with zinc contents of acidic soils (Elias, 2019). The contents of zinc in forest soils were higher than in other land use classes except cropland and thus out of tune with the findings of Alemayehu and Sheleme (2013) who concluded that Agroforestry systems improve soil biophysical and chemical attributes but cereal farming degenerate the soil properties.

Soil moisture content is affected by precipitation, temperature and soil attributes (Du *et al.*, 2021). The analysis of soil for moisture contents among the five LULC classes showed that a higher soil moisture content in natural ecosystems. This was attributed to high proportion of organic matter from the grass and tree leaf litter falling from the innate vegetation (Bufebo & Elias, 2020). Besides, it can be imputed to slope angle and length (Chen *et al.*, 1997). Steep and long slope facilitates movement of runoff instead of percolation and infiltration due to enhanced gravitational force (Moore *et al.*, 1993).

The higher bulk density in cropland and built-up areas than in forests can be attributed to soil compaction and wettability problems under cultivated and built-up and grazing areas (Kinyua *et al.*, 2010). This arise due to trampling by livestock kept in the area (CGoEM, 2018; Muchemi *et al.*, 2002). Intense compaction owing to livestock trampling cause disruption of both percolation and redistribution of moisture in the soils (KFS, 2021). Higher bulk density suggests low soil porosity thus poor air and water movement through the soil (KFS, 2021).

The mean soil sand content (75%) was much higher than those found in most studies. For example Mureithi *et al.* (2014) found mean sand content of between 9% and 13%. The relatively lower sand contents in cropland and built-up than in shrubland, forest and grassland can be attributed to tillage and trampling by livestock which break down sand particles to silt (Deng *et al.*, 2016). There was no significant difference in clay contents among the various LULC classes. This finding is thus inconsistent with most past studies. For instance, Mureithi *et al.* (2014) recorded a soil clay content of between 28% and 42% in communal and private enclosures respectively. additionally, a mean soil clay content of 19.9% was reported in Era-Hayelom Tabias, Northern Ethiopia by Bufebo and Elias (2020). Further, Deng *et al.* (2016) found soil clay distribution ranging between 13.50% and 27.20%.

The mean soil silt contents reported in this study (16.5%) is lower than 29.3%, 42.37%, and >50% found by Bufebo and Elias (2020) and Mureithi *et al.* (2014) respectively but relatively comparable with Deng *et al.* (2016) findings of between 16.76% and 28.01%. This can be explained by the topographic attributes of the landscape. A steep and long slope length favors erosion of clay and silt downstream and as a consequence, the soil silt content diminish (Moore *et al.*, 1993).

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Geospatial techniques, particularly remote sensing and geographical information systems employed in this assessment demonstrated the significance of multispectral satellite images in mapping and carrying out change detection of LULC. Accuracy assessment carried out on the classified images verified that image processing was successful and that the thematic and statistical data produced were sufficient in narrowing the current LULC change information gaps for the escarpment. The results suggest that the area of study experienced profound conversions varying spatially and temporally across the five LULC classes over the period of study. Forest, cropland and built-up increased during the study period. Conversely, shrubland and grassland decreased substantially over the same period. Overall, there was a net increase in forest cover, cropland and built-up areas and a net decline in shrubland and grassland over the period of study.

The LULC changes were driven mainly by increased population, cattle rustling insecurity, and forest evictions. These made the population to seek for land to settle and farm in the escarpment. The recovery of forest cover highlights the significance of timely government actions in the protection of innate resources through evictions and tree planting programs.

The study found that RUSLE model is an applicable method in pinpointing probable soil erosion prone areas and subsequent computation of soil loss. The findings suggest that mean soil erosion rates are intolerable in the escarpment since over 63% of the escarpment falls within the very high erosion severity class with erosion rate being

>20 $tha^{-1}y^{-1}$. Topographic characteristics, particularly slope angle and length greatly influence rates of soil loss with areas having higher slope steepness ($>10^0$) experiencing highest soil erosion. Land use land cover changes influences soil erosion occurrences and intensities. Higher soil erosion was prevalent in areas of the escarpment converted from shrub/grasslands to built-up and croplands. Meaningful conservation of the Elgeyo escarpment calls for protection of natural vegetation including grasslands, shrublands and forests to reduce soil erosion. This can be achieved through the full implementation of agriculture (farm forestry) rules and basic land usage rules on soil conservation practices particularly land terracing and contouring.

The Elgeyo Escarpment is covered by seven soil types, namely chromic cambisols, humic nitisols, lithic leptosols and humic cambisols being dominant. The mean soil pH was moderately acid with high and low mean pH values recorded in forest and cropland respectively. Mean soil organic carbon is high (>3%) with forest, shrubland and grassland recording high carbon contents but low in cropland. Mean soil nitrogen was moderate with high values being found in shrubland. Phosphorous levels in the soil were moderate in cropland and forest but low in grassland and shrubland. Potassium levels were high in the soils across all LULC classes but zinc levels were adequate although they are low in grassland. Therefore, conversion of natural vegetation to croplands and built-ups impacts negatively on soil properties.

There are adequate policies, laws, regulations and rules that govern land use in the study area. However, enforcement of these policies, laws, rules and regulations is weak. Additionally, land use classification suitability in relation to slope angle is not observed and applied. This was despite the existence of spencer line during the colonial era and has been forgotten by the residents.

6.2 Recommendations

Since the escarpment has a rugged topography often with steep slopes, making it very fragile hence susceptible to degradation that comes with anthropogenic activities such as deforestation, settlements and farming. Therefore, to curb further environmental degradation, the study recommends:

a) The escalation of land conservation measures including agroforestry, conservation agriculture and reforestation in the escarpment.

b) The adoption of alternative livelihood sources such as beekeeping and fruit trees farming. Some of the fruit trees recommended include: mangoes, lemons, oranges, guavas and avocadoes.

c) That National Environment Management Authority (NEMA) makes concerted efforts together with the respective lead agencies in coordination of proper implementation of land management policies and legal provisions such as; farm forestry rules, 2009, Agriculture (Basic land usage) Rules, 1965 revised in 2012 and Agriculture (Land Preservation) Rules, 1956 revised in 2012 touching on slope angles and percentages and zoning of hill tops.

d) Land adjudication in the area to minimize shifting cultivation land management practice that is fueled by the communal land ownership. This will help hence enforcement of most provisions of the Agriculture Act particularly those stated in (c) above. In particular, land exceeding 12% may be cultivated but should be protected adequately against soil erosion. However, any land whose slope angle exceeds 20% should be gazetted as conservation area such as forest or community land with conservation uses.

6.3 Recommendation for Further Research

Based on the findings of this study, it is clearly evident that zoning will help in curbing land degradation in the escarpment. Therefore, LULC suitability study is highly recommended in the Elgeyo escarpment. One of the expected outputs of such a study is a LULC suitability map (Zoning). This will help in guiding the residents on which LULC activities to undertake in particular areas of the escarpment so as to ensure a balance between productivity and environmental conservation. Additionally, it will help in better enforcement of the basic land use legal provisions.

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APPENDICES

Appendix I: Household Survey Questionnaire

Hallo, I am Mr. Richard K. Kanda, a PhD Student in the Department of Environmental Planning, Sustainability and Geoinformatics, School of Environment and Natural Resources, University of Eldoret. I am conducting this survey with a sole purpose of enabling me satisfy one of the requirements for the degree.

Date of interview....………………Time…………………Questionnaire No………….

Section A: **Description of Site**

1. County………..……Sub County………………Ward……………………
2. GPS coordinates: Latitude………….… Longitude…………….Altitude………
3. How did you find yourself in the Escarpment? Ancestral land [1] conflict [2] Harsh weather [3] Eviction [4] fear of disease & pests [5] Purchased land [6]
4. For how long (years) have you lived in this area?

   1-5 [1] 6 -10 [2] 11-20 [3] 21-30 [4] 30-50 [5] > 50 [6]

Section B: Respondent Details

5. Respondent Name………………………………Mobile No…………………
6. Sex: Male [1] Female [2]
7. Age: 55-59 years [1] 60- 64 [2] 65-69 [3] 70-74 [4] 75-80 [5]
8. Occupation: Crop farming [1] Livestock Keeping [2] Business [3] Formal employment [4]

Section C: Occupation

9. How many of the following livestock do you keep?

   Goats [2] = [ ] Sheep [3] = [ ] Cattle [1] = [ ]

   Chicken [4] = [ ] Donkeys [5]

10. Livestock mobility Nomadic [1] Sedentary [2]
11. Livestock grazing Herding [1] Paddocking [2] Tethering [3] Free grazing [4]

12. If herding, where do you graze them?

    Own farm [1] Communal land [2] Public Forest [3] Escarpment [4]

13. Which crops do you grow?

    Maize [1] Beans [2] Potatoes [3] Sorghum [4] Millet [5] vegetables [6]

14. How is the slope of your land? Plateau [1] Gentle [2] Steep [3] Very steep [4]

15. Do you practice conservation agriculture? Yes [1] No [2]

16. If yes, which practices?

    Terracing [1] grass strips [2] mulching [3] cut off drains [4] retention ditches [5] woodlots establishment [6] organic farming [7]

17. What informed your decision to practice conservation agriculture?

    Soil erosion control [1] Soil fertility improvement [2] Farm productivity [3]

18. From whom did you learn about the conservation agricultural technologies you practice? Parents [1] School [2] Extension Officers [3] Church Leaders [4] Peers [5] Media [6]

19. Have the agricultural conservation technologies practiced in your farm borne any benefits? Yes [1] No [2]

20. If yes, what are the benefits?

Improved soil fertility [1] increased farm productivity [2] reduced soil erosion [3]

Section E: Land use and land cover dynamics

21. What is the size of your land in acres?
22. What types of land uses do you practice in your farm? Indicate in the table below

Table 1: Land use and land cover

Current land use	Acreage
Homestead	
Agriculture	
Grazing	
Forest	
Fallow	

23. Have you had significant changes in LULC in your farm? Yes [1] No [2]

24. What drove or motivated you to implement the LULC changes?

    Increased food demand [1] increased settlement demand [2]

25. In your opinion do you think these changes have had any impacts? [1] yes [2] No

26. If yes, have the impacts been positive [1] negative [2] Both [3]

27. If both, what have been the positive impacts

    Improved food security [1] improved housing [2] Reduced drought [3]

28. What have been the negative impacts?

    Poor soil quality [1] increased soil erosion [2] increased landslides occurrence [3]

29. How do you mitigate the problem of low soil fertility?

Apply organic fertilizers [1] inorganic fertilizers [2] Mixed/rotational cropping [3]

30. How do you mitigate soil erosion problem?

    Terracing [1] grass strips [2] agroforestry [3] proper planning [4]

31. What are the mitigation measures to environmental degradation?

Alternative livelihoods [1] Environmental education [2] Cultural interventions [3]

32. If alternative livelihoods? Beekeeping [1] fruit trees [2] Others [3] specify

Thank you very much for taking your time to answer my questions

Appendix II: Focus Group Discussion Checklist

Hallo, I am Mr. Richard K. Kanda, a PhD student in the Department of Environmental Planning, Sustainability and Geoinformatics, School of Environment and Natural Resources, University of Eldoret. I am conducting this survey with a sole purpose of enabling me satisfy one of the requirements for the degree.

Participants No ………… Venue ………………………. Time……………….

1. Let us agree on the ground rules to guide our discussions.
2. What is the land use land cover (LULC) history in this area?
3. How has land been used to derive livelihood and how this has changed over time?
4. What were the major land uses in this area thirty years ago?
5. Has LULC changed in the last thirty years?
6. If they have changed, what are LULC changes?
7. What has the trend in LULC changes in your area been?
8. What could be the drivers/causes of the LULC changes?
9. Have LULC changes had any impacts?
10. If yes, what have been the impacts?
11. Have you experienced a drop in crop production in this area? What do you attribute the drop to?
12. Have you experienced soil erosion in this area, what did you attribute these problems to?
13. How have these disasters been occurring? Frequencies, distribution, season?
14. What are the main effects of these disasters?
15. What strategies are employed by this community to reduce the effects of disasters?
16. Which alternative livelihoods have emerged in the past 10 years?

Appendix III: Key Informant Interview Schedule

Hallo, I am Mr. Richard K. Kanda, a PhD student in the Department of Environmental Planning, Sustainability and Geoinformatics, School of Environmental Studies, University of Eldoret. I am conducting this survey with a sole purpose of enabling me satisfy one of the requirements for the degree.

Agriculture

What is the size of arable land in the area?

Types of crops that are grown and acreages

Types of livestock kept

What challenges do farmers face in crop and livestock production?

How are these challenges addressed?

Any significant changes on land use and land cover?

What are the drivers of land use and land cover changes?

Are crop farming and livestock keeping practiced in the escarpment

Are there any restrictions on land use and cover in the escarpment?

Are you aware of the spencer lines, where are they situated in the escarpment?

What are the sectoral legal, policy and strategic frameworks governing the land management?

In your opinion, are they adequate in the protection of the environment from degradation?

What challenges do you face in their full implementation?

Suggest possible remedies to the challenges that you face

Environment (NEMA)

What is the general state of the environment in this area?

Any fragile ecosystems (environmental sensitive areas)

Scenic places

What are the environmental problems existing in the area?

Are there environmental hotspots in this area?

Is the area prone to any disasters, examples?

What are the legal, policy and strategic frameworks governing the escarpments?

In your opinion, are they adequate in the protection of the environment from degradation?

What challenges do you face in their full implementation and enforcement?

What are the consequences of the inability to implement the legal and policy frameworks?

In your view, what are the suitable remedial measures to the challenges?

Geology

What are the major rocks in the area?

The formation of the landscape

Susceptibility to erosion, landslides and earthquakes

Frequency of occurrence of landslides and earthquakes (last one, frequency, distribution magnitude, impacts and mitigation)

Do they occur naturally or they have triggers?

Are their occurrences affected by slope, land use or land cover?

General observation and comment

What are the sectoral legal and policy frameworks in which your department is anchored?

Are there specific provisions in these legal and policy frameworks that concern escarpment protection?

What challenges do you face in their full implementation?

What are the consequences of the inability to implement the legal and policy frameworks?

What are the possible remedies to the challenges that you face?

Department of Meteorological Services

What is the core mandate of this department?

How many weather stations exist in the county?

Does prediction of weather events include disasters?

Do you keep records of disasters occurrence such as landslides?

How often do they occur?

Are there landslides hotspots in the county?

How is the pattern of occurrence?

Do they follow rain seasons? Or geographic

Which topographic zone do landslides occur most?

Lands

What portion of land in this county is adjudicated?

How is land holding? Freehold, Leasehold or communal?

Are there restrictions attached to land holding documents in the area

If they are, what are the restrictions attached to the lands in escarpment zone?

What informed the setting of the land holding restrictions?

What does the department do in the event of violations of land holding restrictions?

What are the sectoral legal, policy and strategic frameworks governing the land management?

What challenges do you face in their full implementation?

What are the consequences of the inability to implement the legal and policy frameworks?

What is the department doing to ensure improved implementation?

Forestry

Which forests are found in county?

What is the size of forest cover in this county?

What are the ecological and economic importance of forests?

Is it only public forests or they are inclusive of private forests?

What percentage constitutes; public forest and private forest?

Has the forest cover changed?

If so, how has change been; negative or positive?

What area of the natural forest has been lost to other uses?

What has caused or triggered the change in land use

Has the loss of forest cover been legal or illegal?

If legal is there a formal gazettement process

If illegal, what is the department doing to repossess the lost forest land

Kerio Valley Development Authority (KVDA)

What is the core mandate of the authority?

How many weather stations does the authority run in the county (EMC)?

How often do they occur?

Are there landslides hotspots in the county?

How is the pattern of occurrence?

Do they follow rain seasons? Or geographic

Which topographic zone do landslides occur most?

What has been attributed to the occurrence in this topographic zone?

What are the sectoral legal, policy and strategic frameworks governing the land management?

What challenges do you face in their full implementation?

Appendix IV: Research License by NACOSTI

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 290755

Date of Issue: 27/September/2022

RESEARCH LICENSE

This is to Certify that Mr.. Richard Kipkemoi Kanda of University of Eldoret, has been licensed to conduct research in Elgeyo-Marakwet on the topic: LAND USE LAND COVER CHANGES AND THEIR IMPLICATIONS ON LAND DEGRADATION IN ELGEYO ESCARPMENT, KENYA. for the period ending : 27/September/2023.

License No: NACOSTI/P/22/20659

290755

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

Appendix V: Research Authorization from the Elgeyo Marakwet County Commissioner

THE PRESIDENCY
MINISTRY OF INTERIOR & COORDINATION OF NATIONAL GOVERNMENT

COUNTY COMMISSIONER'S OFFICE,
ELGEYO-MARAKWET COUNTY,
P.O. BOX 200-30700
ITEN

Telephone: (053) 42007
Fax : (053) 42289
E-mail: ccelgeyomarakwet@yahoo.com
ccelgeyomarakwet@gmail.com
When replying please quote

Ref: **PUB.CC.24/2 VOL.III/137**

Date: **12th October, 2022**

TO WHOM IT MAY CONCERN

RE: RESEARCH AUTHORIZATION

MR. RICHARD KIPKEMOI KANDA

This is to confirm that the above named has been authorized to carry out a research on "**LAND USE LAND COVER CHANGES AND THEIR IMPLICATIONS ON LAND DEGRADATION IN ELGEYO ESCARPMENT, KENYA**" for a period ending 27th September 2023.

Please accord him the necessary assistance.

Julius K. Maiyo, HSC
For: COUNTY COMMISSIONER
ELGEYO MARAKWET COUNTY

c.c. All Deputy County Commissioners
Elgeyo Marakwet.

JKM/bjc

Appendix VI: Permission to conduct Research from Elgeyo Marakwet County Secretary

COUNTY GOVERNMENT OF ELGEYO MARAKWET
OFFICE OF THE COUNTY SECRETARY

All correspondence to be
Addressed to; County Secretary

P.O BOX 220 – 30700, ITEN
TEL: 05342277
Email: emcounty2013@gmail.com

Your Ref...
Our Ref: EMC/ADM 69/III/252.

DATE: 14th October, 2022

RICHARD KIPKEMOI KANDA

RE: PERMISSION TO CONDUCT RESEARCH IN ELGEYO MARAKWET COUNTY.

Richard Kipkemoi Kanda a student of University of Eldoret wishes to conduct a research project on the topic **"Land Use Land Cover Changes and their Implication on land degradation in the Elgeyo escarpment, Kenya.**

He has been granted permission to go ahead with research project within Elgeyo Marakwet County. This is therefore, to request all institutions and individuals within our County to accord him the necessary assistance.

Thank you.

THE COUNTY SECRETARY
ELGEYO MARAKWET COUNTY
P. O. Box 220-30700, ITEN
Email: info@elgeyomarakwet.go.ke

PAUL CHEMMUTTUT
COUNTY SECRETARY/HEAD
OF COUNTY PUBLIC SERVICE

C.C

H.E. GOVERNOR
H.E. D/GOVERNOR
COUNTY COMMISSIONER

Appendix VII: Formulae for computing Accuracies and Kappa Coefficient

1) Overall accuracy = $\left\{\frac{Total\ No.of\ correctly\ classified\ pixels(Diagonal)}{Total\ No.of\ Reference\ Pixels}\right\} \times 100$

2) User Accuracy = $\left\{\frac{No.of\ classified\ pixels\ in\ each\ category}{Total\ No.of\ classified\ pixel\ in\ that\ category(Row)}\right\} \times 100$

3) Producer Accuracy = $\left\{\frac{No.of\ correctly\ classified\ pixels\ per\ category}{Total\ No.of\ Reference\ pixels\ in\ category(Column)}\right\} \times 100$

4) Kappa Coefficient (T) = $\left\{\frac{TS \times TSC - \sum(Column\ Total \times Row\ Total)}{TS^2 - \sum(Column\ Total)(Row\ Total)}\right\} \times 100$

TS= $Total\ Samples$
TSC= $Total\ Correctly\ Classified\ Samples$

Appendix VIII: Similarity Report

University of Eldoret

University of Eldoret

Certificate of Plagiarism Check for Synopsis

Author Name	RICHARD KIPKEMOI KANDA
Course of Study	Type here...
Name of Guide	Type here...
Department	Type here...
Acceptable Maximum Limit	Type here...
Submitted By	slelei@uoeld.ac.ke
Paper Title	LAND USE LAND COVER CHANGES AND THEIR IMPLICATIONS ON LAND DEGRADATION IN ELGEYO ESCARPMENT, KENYA
Similarity	6%
Paper ID	2027840
Submission Date	2024-06-21 12:25:55

Signature of Student

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Head of the Department

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