Addis Ababa University

School of Graduate Studies

LAND USE/COVER DYNAMICS AND ITS IMPACTS ON EROSION RATE, SOIL QUALITY, AND SOIL ORGANIC CARBON AND TOTAL NITROGEN STOCK AT BURURI CATCHMENT, WESTERN ETHIOPIA

By

Wondimu Mamo W/Giorgis

A Dissertation submitted to

The Department of Geography and Environmental Studies

Presented for the Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geography and Environmental Studies (Specialization in Environment and Natural Resources Management)

Addis Ababa University

Addis Ababa, Ethiopia

August, 2021

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Declaration

I, the undersigned, declare that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation, have been fully acknowledged.

Name: ____________________

Signature: ____________

Date: _________

This dissertation has been submitted for examination with my approval as University supervisor.

Supervisor's Name: _______________

Signature: ___________

Date: _____________

Dissertation Approval

Addis Ababa University

Graduate Programme

This is to certify that the dissertation prepared by Wondimu Mamo entitled: “Land Use/Cover Dynamics and Its Impacts on Erosion Rate, Soil Quality, and Soil Organic Carbon and Total Nitrogen Stock At Bururi Catchment, Western Ethiopia” and submitted for the fulfillment of the requirement for the Degree of Doctor of Philosophy (Environment and Natural Resources Management) complies with regulation of the university and meets the accepted standards with originality and quality.

Chairman, Examining Committee

	Name	Signature	Date
Advisor:	---------------------------	----------------	----------------
External Examiner:	---------------------------	----------------	----------------
Internal Examiner:	---------------------------	----------------	----------------

Acknowledgement

First of all, I would like to thank the almighty God for giving me health and endurance to complete this study. Next, I am extremely grateful to my supervisor Professor Mohammed Assen, who tirelessly rendered me guidance, thorough supervision, encouragement, and kindness throughout the time of my study. I am also grateful to Dr. Asmamaw Legass, for his useful suggestions and comments during various phases of this work. I would like to express my sincere gratitude to Addis Ababa University for sponsoring my study.

I humbly acknowledge the cooperation of the sampled farmers, development agents, and different officials working at regional, woreda, and kebele levels of the study catchment. My heartfelt appreciation also goes to my wife, Yadate Kumera not only for her unreserved encouragement and motivation but also for her determination to manage and care for the family in my absence. I also express my deepest gratitude to my children Amarti Wondimu and Natan Wondimu, for their moral support and patience while carrying out this academic career.

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Abbreviations and Acronyms

CEC: Cation Exchange Capacity
CSA: Central Statics Agency
DEM: Digital Elevation Model
EC: Electrical Conductivity
EMA: Ethiopian Mapping Agency
EPA: Environmental Protection Agency
ETM^+: Enhanced Thematic Mapper Plus
FAO: Food and Agriculture Organization of the United Nations
FGD: Focus Group Discussions
GPS: Global Position System
LULC: Land-use and Land-cover
MoFED: Ministry of Finance and Economic Development
MoWIE: Ministry of Water, Irrigation and Electricity
MSS: Multispectral Scanner
NMA: National Meteorological Agency
OLI: Operational Land Imager
PCA: Principal Component Analysis
RUSLE: Revised Universal Soil Loss Equation
SOC: Soil Organic Carbon
STN: Soil Total Nitrogen
TM: Thematic Mapper
UNDP: United Nations Development Program
USGS: United States Geological Survey
UTM: Universal Transverse Mercator
WGS: World Geodetic System
WB: World Bank

Abstract

In order to identify and sustainably utilize the services rendered by the ecosystem, it is important to understand the process of land cover and land use change and its implications for environmental conditions and ecosystem functioning. Together with GIS, remotely sensed data enhance the capacity to assess the human effects on the environment in quantitative, qualitative and spatial terms. Thus, this study assessed the pattern of LULC dynamics and its impact on soil erosion, soil quality, and organic carbon stocks in Bururi catchment, western highlands of Ethiopia. In this study aerial photographs, Landsat imageries, digital elevation model (DEM), rainfall data, soil data, and socio-economic survey data were analyzed. These data were obtained from Ethiopian Mapping Agency (EMA), online archives USGS, and National meteorological service agency. The soil data were generated by Laboratory analysis using a standard procedure while the socio-economic data were gathered from 170 sample farm households, key informants, and natural resources management experts of the study area. The Long-term (1957-2018) LULC change analysis was conducted using ERDAS Imagine (2015) software. To verify the accuracy of image classification, Kappa coefficient, producer's accuracy, and user's accuracy were generated. The soil loss of the study catchment was computed by employing a GIS-based Revised Universal Soil Loss Equation (RUSLE) model. To examine the effect of LULC and topographic elevation on soil quality indicators and organic carbon stocks, principal component analysis (PCA) and multi-variate analysis of variance (MANOVA) in the general linear model (GLM) procedure of SPSS (v.24) were used. The socio-economic data collected through questionnaire survey were analyzed in SPSS (v. 24) by employing both descriptive statistics and binomial logistic regression. The qualitative data gathered through interview, FGD, and field observations were used to substantiate the quantitative analysis of the questionnaire data. The result of LULC change analysis revealed that there have been remarkable changes in the LULC between 1957 and 2018. Forest cover and grassland decreased by 6.7% and 2.8%, respectively. Agricultural, Shrub, and bare/degraded lands had shown increment by 1.3%, 1.9%, and 6.3%, respectively. Due to the effect of the observed LULC change, the mean annual soil loss recorded in 1957 was 41.04 t ha^{-1} *yr*$^{-1}$ *whereas in 2018 increased to 48.91 t ha*$^{-1}$ *yr*$^{-1}$*. On the other hand, LULC and topographic elevation were found to significantly influence the spatial distribution of soil quality indicators and organic carbon stocks. Higher SOC stocks were found under forest cover, shrub land, and grassland compared to agricultural and degraded lands. The result of binomial logistic regression revealed that out of sixteen hypothesized independent variables, twelve were found to have significant influence on farmers' decision to implement land management practices. In general, the LULC dynamics observed in the area remarkably impacted soil erosion, soil quality indicators, and organic carbon stocks. Given the severity and magnitude of the problem following LULC dynamics, the study recommends a design of proper land use policy and sustainable management of land resources to reverse the prevailing land degradation in the study area. The designed land management options need to consider the socio-demographic, biophysical, and institutional factors in the study catchment.*

Key words: LULC, RUSLE, MANOVA, SOC

Chapter One: Introduction

1.1 Background of the Study

Land is a key and finite resource for most human activities (Turner *et al.,* 1993). It is a fundamental factor of production and its basic function is supporting human and other terrestrial ecosystems through most human activities including agriculture, industry, forestry, energy production, settlement, recreation, and water catchment and storage (Richards, 1990; FAO, 2011). The agricultural land uses provide a wide range of goods and services, including the provision of food and fiber. However, land use/cover (LULC) has been changed or modified at global scale and in the meantime their ecosystem functions and services have been altered (Geist *et al.* 2006; Kreuter *et al.,* 2001; Polasky *et al.,* 2010). According to Turner *et al.* (2007), changes in LULC and their implications for global environmental change are research challenges for human-environmental sciences.

At a global scale, LULC change is one of the major drivers of ecosystem destruction (Kubiszewski *et al.,* 2017). The drastic changes in LULC observed in different parts of the world adversely affect the environment and hamper their capability to provide ecosystem functions and services (MEA, 2005). The human-induced LULC change emerged as global environmental issue since it is a driver of climate change (Lambin and Geist, 2001; Woldeamlak, 2002), which is manifested in the form of accelerated emissions of greenhouse gases including carbon dioxide, destruction of biodiversity, fragmentation of natural habitat (Steffen and Tyson, 2001)

Since human kind came to existence, both naturally caused and anthropogenic land use/cover (LULC) changes have exhibited on the surface of the earth (Molders, 2012). This is because human use of the environment and its resources cause alterations to natural processes (Maro, 2011). Humans have modified the earth for resources, which contribute to their livelihoods and provide essential materials for thousands of years (Hassan *et al.,* 2016). LULC dynamics are important manifestations of human-environment interactions (Sharma *et al.,* 2018). Currently, understanding LULC change, its drivers and implications have got a considerable significance in policy making in relation to monitoring of environmental changes and management of natural resources.

A change in LULC is caused by a complex interaction of several biophysical, socio-economic, and institutional factors (Turner *et al.*, 1994; Reid, 2000; Lambin *et al.*, 2001; Lambin and Geist, 2006) and these drivers of LULC change can be grouped into proximate (direct), and underlying (root) drivers (Lambin *et al.*, 2003). The proximate drivers comprise the expansion of diversified agricultural activities, extraction of wood, and infrastructure expansion. On the other hand, the underlying causes encompass a complex of social, political, economic, demographic, technological, and cultural that constitute initial conditions in the human-environment relations (Lambin *et al.*, 2003; Geist *et al.*, 2006).

The conversion of LULC has several implications for the functioning of socio-economic and environmental system (Lesschen *et al.*, 2005). By altering ecosystem services, LULC change affects the ability of biological systems to support human needs (Vitousek *et al.*, 1997); and alters the fluxes of mass and energy in the ecological system, which has consequences for ecological structure, functioning, and the flow of ecological goods and services (Bockstael and Irwin, 1999). It affects key aspects of Earth System functioning (Lambin *et al.*, 2001); and might stress living conditions and threaten the livelihood of society (Bimal *et al.*, 2017). It is also the primary source of soil degradation (Tolba *et al.*, 1992). The most proximate implication and negative consequences of land use/cover changes are related to the issues of land degradation (Shan *et al.*, 2007). It causes soil quality deterioration through loss of vegetation cover, soil moisture, soil organic matter, and by affecting natural regeneration capacity (Khormali et al., 2009). LULC dynamics also plays an important role in affecting spatial patterns of soil erosion (Fu et al., 2000). Human-induced land-use change causes a particularly substantial loss of SOC (Fan *et al*., 2016; Gelaw *et al*., 2014). The LUCC may also reshape the original structure and balance of the ecosystem, causing severe losses of soil organic carbon and total nitrogen (Lal, 2005; Shirvani *et al*., 2010; Gamboa and Galicia, 2011).

Like many other African countries, Ethiopia is also experiencing environmental degradation problem resulting from LULC change especially from removal of natural vegetation to expand built-up and agricultural lands (Kindu *et al.*, 2013), which is known to be very severe in the highlands of the country where the land is cultivated for millennia and population density is very high (Wondie *et al.*, 2012). The expansion of agricultural land at the expense of vegetation cover, too much reliance on wood for fuel and construction materials has contributed to extensive LULC change in the country (Alemu and Damte, 2011). The change in LULC in Ethiopia have implications for land degradation (Lakew *et al.,* 2000, Bezuayehu *et al.,* 2002; MoARD and WB 2007), which leads to the reduction in ecosystem services (Feoli *et al.,* 2002; Kindu *et al.,* 2016).

Deforestation coupled with the traditional farming system in the Ethiopian highlands activated the processes of soil erosion (Mekuria 2005), which leads to irreversible damage to the natural resource base (Hurni, 1988; Hurni, 1990). Scientific studies conducted in Ethiopia revealed that 57% and 28% of the area are moderately and severely affected by soil erosion (Lambin and Geist, 2006). The highest soil erosion rates have occurred in the western parts of the country where rainfall is higher compared to other regions of Ethiopia (Hurni, 1988). The conversion of natural forest to other forms of land use land cover was also reported to aggravate soil erosion and cause soil quality decline (Haycho *et al.,* 2015; Abate & Kibret, 2016;; Adugna & Abegaz, 2016; Teferi *et al.,* 2016; Guteta & Abegaz, 2017). All these authors reported that change of LULC can cause significant variation in soil quality indicators. As a result of the human interference on natural or virgin lands, soil organic carbon has declined to low level mainly in cultivated soils of the highlands of the country (Chibsa and Ta, 2009). In the highlands of southeastern Ethiopia, existence of a significant reduction in the original native quantity of SOC in the upper 100 cm soil layer by 30.9% as a result of converting native forests into cultivated lands over a period of 15 years (Yimer *et al*., 2007) has been reported. Although such LULC change related problems are affecting ecosystem services and functions, the adoption of land management practices to mitigate the problem is challenged in Ethiopia (Yesuf and Kohlin, 2009; Merrey and Gebreselassie, 2011). This could have been due to the fact that investments in land management practices are found to be influenced by complex sets of demographics, socioeconomic, institutional, and biophysical factors (Zeleke *et al.,* 2006; Amsalu and De Graaff, 2007; Adimassu *et al*., 2012; Guteta and Abegaz, 2015).

1.2 Statement of the Problem

Land use land cover dynamics is one of the major environmental problems in Ethiopia (MoA and WB, 2007; Berhan, 2010), affecting ecosystem services (Tolessa *et al.,* 2017). The LULC conversions were mainly from vegetation cover to agricultural land (Abate, 2011; Assen, 2011; Tefera, 2011; Meshesha et al., 2012; Assefa and Bork, 2014; Alemu et al., 2015). This implies that the rising demand for agricultural land has contributed to vegetation degradation in the country (Ariti et al., 2015; Wogderes, 2014). Although the estimated figure lacks consistency from literature to literature, FAO (2015) revealed that forest cover of Ethiopia diminished at a rate of 0.8% per annum from 1990 to 2015. Other studies also reported the reduction of natural vegetation due to conversion of land use and expansion of settlements (Alemu et al., 2015; Bessie et al., 2016; Emiru et al., 2014; Gashaw and Dinkayoh, 2015; Sahle et al., 2016). In contrast, some studies conducted in the northern part of Ethiopia (Nyssen *et al.*, 2009; Bewket and Abebe, 2013) reported improvement of vegetation cover due to plantation and enclosure of the previously degraded areas since 1980s. The expansion of farmlands and the widespread conversion of vegetation cover have implications for land degradation in Ethiopia (Bezuayehu et al. ,2002, Dessalegn, 2001, MoARD and WB, 2007). As reported by Desta *et al.* (2000); Tilahun *et al.* (2001); and Belay (2002), LULC changes towards agricultural land aggravates soil erosion problems and reduce soil quality unless proper land management are implemented. Water induced soil erosion is the dominant and a major degradation process and occurs on cultivated land, with average annual soil loss rates of 42 tones ha^{-1} (Hurni, 1993). The conversion of natural forest to other forms of land use can also lead to a deterioration in soil quality (Abate and Kibret, 2016; Teferi *et al.*, 2016; Guteta and Abegaz, 2017).

Most studies conducted in Ethiopia focused on the drivers of LULC change and impacts of the change on some aspects of land degradation. For instance, some studies (Sisay *et al.*, 2016; Alemayehu *et al.*, 2017; Fikirte *et al.*, 2017; Temesgen *et al.*,2017; Mesfin and Kumelachew, 2018; Emiru *et al.*,2018; Solomon *et al.*,2018; Gebiaw *et al.*, 2018) focused on the pattern and drivers of LULC change. Some others gave more emphasis to impacts of LULC change on soil erosion potential (Beyamo, 2010 Nigatu, 2014; Ebabu et al., 2018; Esa et al., 2018). The impact of LULC change on soil quality was also studied in different regions of Ethiopia (Kidanemariam *et al.*, 2012; Asmamaw and Mohammed, 2012; Moges *et al.*, 2013; Yitbarek *et al.*, 2013; Dessalegn *et al.*, 2014; Haycho *et al.*, 2015; Teferi *et al.*, 2016; Adugna and Abegaz, 2016; Guteta and Abegaz, 2017). Shiferaw et al., (2015); Gelaw *et al.*, (2015); Teferi *et al.*, (2016); Kassa *et al.*, (2017); Berihu *et al.*, (2017); Amanuel *et al.*, (2018); Seyoum *et al.*, (2019); Tsunekawa *et al.*, (2020) studied the impact of LULCC on SOC stocks. These all are focused studies carried out in Ethiopia to assess the impact of LULCC on one of the degradation aspects.

Moreover, several studies in Ethiopia (for instance, Amsalu and De Graaff, 2007; Adimassu *et al.*, 2012; Guteta and Abegaz, 2015) documented the biophysical, socio-demographic, and institutional factors that influence investments in land management practices. However, these factors are largely area specific and their importance is varied between and within agroecological zones and across countries. These all imply that a comprehensive study regarding the driving forces, impacts of LULC, and determinants of land management decisions have been inadequate indicating the need for further studies. Furthermore, the author observed that the study area suffers from LULC change, severe soil erosion, soil fertility decline, and low agricultural productivity. However, it is less researched and no literature is available with respect to the pattern, drivers, and implications of LULC change. This study, therefore, seeks to contribute to the available empirical literature on patterns of LULC dynamics and its impacts on the quality of natural resources. The study also fills the available literature gap by investigating the determinants of farmers' decision in land management investments.

1.3 Objectives of the Study

The overall objective of the study was to assess the pattern of LULC dynamics and its effects on the quality of natural resources in Bururi catchment, western highlands of Ethiopia. More specifically, the study is intended to achieve the following objectives:

1) analyze the spatio-temporal LULC dynamics from 1957 to 2018 and identify the associated drivers and socio-environmental implications of the change
2) Estimate the average annual soil loss from the study watershed using the Revised Universal Soil Loss Equation (RUSLE) and identify socio-economic factors which significantly determine local soil erosion rates so as to recommend options for better soil and water conservation.
3) Examine effects of LULC dynamics and topographic elevation on selected soil quality indicators.
4) Investigate the variations in the SOC and STN stocks in relation to LULC and topographic elevation and suggest plausible solutions to enhance carbon sequestration in soils.

5) Identify the socio-demographic, biophysical, and institutional factors that influence their decision to implement sustainable land management practices.

1.4 Research Questions

The following research questions were formulated based on the specific objectives outlined above.

1. What are the major changes in LULC that have occurred between 1957 to 2018 and what are the perceived drivers and socio-environmental implications of the change?
2. How do LULC dynamics affect soil erosion risk and which areas of the study catchment require immediate intervention?
3) What are the effects of LULC changes and topographic elevation on soil quality indicators?
4) How does soil organic carbon and soil total nitrogen respond to changing land uses and what are the land management options to enhance carbon sequestration in soils?
5) Which socio-demographic, biophysical and institutional factors influence smallholder farmer's decision to implement sustainable land management practices?

1.5 Rationale of the Study

The focus of most LULC studies conducted in Ethiopia and elsewhere was the drivers of LULC dynamics and impacts on some aspect of resource degradation. However, a comprehensive study which reveals the full picture of the problem is lacking. Therefore, this research was highly necessary to make the problems visible to policy makers and practitioners, so as to attract adequate attention from government bodies and non-governmental organizations. A deeper understanding of the drivers of the LULC change, its environmental and socio-economic implications is crucial to inform policy makers and thus promote sustainable land use and management so as to combat land degradation and improve environmental resource management. The result of the study is supposed to have paramount importance for the agricultural sector, environmental planning, and management of natural resources.

In order to design and implement measures that mitigate LULC changes, it is crucial to conduct an integrated study which reveals the full picture of the problem. Understanding how local farmers perceive the problem and make decisions to implement land management practices is also very important. As far as my knowledge is concerned, there is no LULC studies conducted in and around the study area of Bururi catchment. Hence, this study attempts to contribute to the limited literature with respect to the major drivers of LULC change, and effects of these changes on soil erosion risk, soil quality indicators, and soil organic carbon stocks in Bururi catchment, Western Ethiopia.

The academic background of the researcher was another convincing reason for selecting LULC change as a topic. The fact that the researcher carried out his MA thesis on resettlement and land degradation encouraged him to investigate the land degradation problem in the form of LULC dynamics. Moreover, the study catchment and the birth place of the researcher are both found in the same district, which implies better exposure and familiarity of the researcher to the study area.

1.6 Scope and Limitation of the Study

The study was conducted on four rural kebeles of Bururi catchment, western Ethiopia. Although LULC dynamics has several implications, the present study focused on the drivers and effects of LULC change on soil erosion risk, selected soil quality indicators, and soil organic carbon stocks. Farmers' perception of LULC change and determinants of land management decisions were also examined. The study focused on the LULC change occurred in the old area of residence though the farm households are seasonally migrating into the nearby marginal areas and adjacent national park, this study did not consider the LULC change happening in the new area of destination. The LULC change analysis was conducted by using aerial photographs and Landsat images of medium (30 m) spatial resolution. This was due to the limited access to very high-quality images in Ethiopia.

Although LULC change has multiple impacts on ecosystem services and rural livelihoods, due to financial constraint the study limited its scope to effects on soil erosion rate, soil quality indicators, and SOC stocks. Other impacts including water quality change, the social crisis and psychological disturbances facing the seasonal migrants were not considered in this study. For the purpose of soil erosion risk analysis, a GIS based RUSLE model was applied as it relies on easily available data and presents the spatial distribution of soil erosion with better accuracy in larger areas. However, this empirical model has its own limitations in that it was primarily designed for agricultural regions and hence soil loss values identified in non-agricultural regions may be inconsistent. Moreover, as RUSLE requires five input data layers (such as R.K.LS.C.P) to be superimposed and multiplied together, the errors occurred in each layer are similarly multiplied, contributing to a distorted soil loss values. The study has also limitations in terms of the soil analysis, because number of samples collected from the study site are only from the upper 0-20 cm depth and the number of samples collected were limited due to financial constraint.

1.7 Organization of the Dissertation

The dissertation consists of seven chapters. The introductory chapter provides background of the study, statement of the problem, objectives, research questions, rational of the study, scope and limitations of the study, and organization of the dissertation. The second chapter deals with literature review. This chapter is organized to have five sections: definition of key concepts, techniques of LULC change analysis, drivers of LULC change, impacts of LULC dynamics, and determinants of sustainable land management practices. Chapter three describes the study area and research methods. The methodology part is organized into five sections. LULC change assessment, analysis of soil quality indicators, modelling soil erosion, determination of soil organic carbon (SOC) and total nitrogen (TN) stocks, and analysis of socio-economic surveys. Chapters four, five, and six are devoted to present results and discussions. Chapter four presented patterns and drivers of LULC change. The fifth chapter is concerned with effects of LULC change on soil erosion, soil quality, and soil organic carbon and nitrogen stock. Chapter six dealt with farmers' perception of LULC change and determinants of land management decisions. Chapter seven consists of summary, conclusion, and recommendations based on the major findings of the study.

Chapter Two: Review Literature

2.1 An Overview of Land use Land cover Dynamics

Land use/cover (LULC) dynamics is the most prominent form of the global environmental change, which represent impact of human activity (Zhao *et al.,* 2017). The conversion of natural land to anthropogenic landscapes represents the form of human impact on the environment (McGranham *et al*., 2005; Zhao *et al*., 2017). LULC dynamics has been considered a local environmental issue, but it is becoming a subject of global importance (Foley *et al.,* 2005). Though land use and land cover changes are usually local and site specific, their impacts collectively add up to global environmental change, including biodiversity loss, global warming, desertification, and eutrophication, (De Sherbinin, 2002; Rudel *et al.,* 2005). In the present study, land use and land cover are conceptualized as two different but interrelated concepts in which land use refers to the proxy of complex human activities that alter land surface processes whereas land cover denotes the physical and biological cover of the surface of the land (Foley *et al.,* 2005).

Worldwide, LULC change is as old as human activity (Turner et al., 1993). However, the recent rate of change is different from earlier changes (Gebreslassie, 2014) because of major changes in societal development and population growth. The extent of arable land at global scale has grown by more than 45% increasing from 3 million square kilometers to 15 million square kilometers between 1700 and 2000 (Klein *et al.,* 2011). On the other hand, forest cover has been shrinking due to expansion of agricultural land and urbanization (Santa, 2011). According to Geist and Lambin (2001), about 37% of the world’s forest degradation was attributed to agricultural expansion and infrastructural development.

At the regional level, forest cover has been transformed primarily to cultivated land between 1970 and 2000, while some farmland has been converted to built-up areas (Fuchs *et al.,* 2013; Tian *et al.,* 2014). In North American countries, the expansion of agricultural land was observed between 1850 and 1992 (Ramankutty and Foley, 1999), and across Europe the area of cultivated land has shown a decreasing trend by around 18% between 1950 and 2010 (Fuchs *et al.,* 2013). Historical LULC studies quantifying agricultural land use have demonstrated a rising trend in agricultural land use in Asia generally, and in the Himalayas in particular, (Li *et al.*, 2016; Tian *et al.*, 2014).

Africa had lost 16% of its forests and 5% of its woodlands and grasslands over the period of 1975–2000 and at the same time the agricultural areas increased by 57% in sub-Saharan Africa (Brink and Eva, 2009). The forest loss is especially hard on areas with high biodiversity and in the Afromontane areas, where the decrease is estimated to be 3.8% annually according to Eva *et al.*, (2006). In sub-Saharan Africa, the increase of food production is still highly dependent on clearing more land for agriculture. In the future, land grabbing is expected to cause even more intensified increase of croplands as African land is also demanded by non-African nations. Also, natural land-cover change may exist due to changes in precipitation pattern or fires (McMichael and Hope, 2007), which may foster human populations to seek arable land elsewhere or to change their farming practices or crops (Maro, 1988; Sunderlin *et al.*, 2000).

Besides the continental scale studies of land use land cover dynamics (Brink and Eva, 2009), many forest or land-cover-change studies in East Africa indicate intensified land use pressure, evidenced by the loss of forests or bushlands after the 1950s (Lung and Schaab, 2006; Baldyga *et al.*, 2007; Pellikka *et al.*, 2009). A study conducted by Brink and Eva (2009) reported that between 1975 and 2000 significant land use land cover changes have occurred in sub-Saharan Africa. As revealed in their result, agriculture land increased by 57% at the expense of natural vegetation whereas vegetation cover decreased by 21% over the study periods. In Uganda, forest degradation has been on the rise, the tropical high forest dwindled from 12.5% in 1900 to 3% of the total land area in 1987 (NEMA, 2005), which could be attributed to agricultural investments. In Kenya, where significant part of Afromontane is found, and in areas with rich biodiversity, the forest loss is especially hard in which a decrease of 3.8% per annum was recorded (Eva *et al.*, 2006).

As in the other parts of the world and Africa, there have been considerable LULC dynamics in different part of Ethiopia. Previous studies conducted in the country reported that a remarkable increase in agricultural land at the expense of forest cover was found to have occurred at local and regional levels (Gete and Hurni, 2001; Aklilu *et al.*, 2007; Bewket, 2012; Tsehaye and Mohammed, 2013; Hussen *et al.*, 2013; Gebrekidan *et al.*, 2014; Sisay *et al.*, 2016; Alemayehu *et al.*, 2017; Fikirte *et al.*, 2017; Mesfin and Kumelachew, 2018; Solomon *et al.*, 2018; Gebiaw *et al.,* 2018). Most of these researches reported that forestland, grassland, shrub land and wetland have shown a decreasing trend while agricultural lands and built-up areas were increasing at the expense of other land use/cover types. The conversions of forest cover into agricultural land is due to the fact that agricultural activity is backbone of the country's economy which involves about 85% of the total population of the country (Berihun *et al.,* 2019).

According to EFAP (1994), about 40% of the total area of Ethiopia was covered by forest, out of which 90% was found in the highlands. Another report by FAO (2015) revealed that forest cover in the country accounts for only 11-15.5% of the total area. According to this report, Ethiopia lost 28,180 km^2 (18.6% of its forested area) from 1990 to 2015 (FAO, 2015). This huge loss of forest cover was attributed to the expansion of agricultural and grazing land, urbanization, as well as the increasing demand for fuelwood and construction materials (Zeleke and Hurni, 2001; Kindu *et al.,* 2013; FAO, 2015). Such dramatic changes in LULC along with ecological disturbance and unsustainable land management practices seriously affects Ethiopia's rich biodiversity, crop and livestock productivity (Hamza & Iyela, 2012), and have implications for land degradation problem (Lakew *et al.,* 2000, Bezuayehu *et al.,* 2002; MoARD and WB 2007).

Therefore, it is possible to conclude that Land use and land cover (LULC) change is a major issue of concern intimidating the local, regional, and global environment (Qian *et al.,* 2007; Prakasam, 2010), and it is also one of the major environmental challenges in Ethiopia (Berhan, 2010). In such cases, the land cover and land use information gain a significant added value through the analysis, identification and description of ongoing processes. Based on land cover and land use change information, certain processes can be retrieved, which can be used to monitor and maintain the available natural resources (European Communities, 2001).

2.2 Drivers of LULC Dynamics

The analysis of land use dynamics revolves around two central and interrelated issues: the drivers and the environmental and socioeconomic impacts of land use change (Briassoulis, 2008). One of the fundamental theories in the study of land change is the force that cause land change or called driving force (Burgi *et al.,* 2004). There are two main driving forces of land change namely biophysical forces (Lambin *et al.,* 2003) and socioeconomic or anthropogenic drivers (Su *et al.,* 2011). Land use land cover changes are the result of a complex interaction between several biophysical and socio-economic conditions, which may occur on various temporal and spatial scales (Reid, 2000). Driving forces of LULC change can also be grouped into proximate and underlying factors (Lambin *et al*., 2001). The proximate causes of land use changes constitute human activities that originate from intended land use and directly affect land cover (Turner *et al*., 1994). The underlying causes explain the broader context and fundamental forces underpinning the proximate causes (Lambin and Geist, 2007). As a result, underlying causes tend to be complex and tend to operate more diffusely (Lambin and Geist, 2007). They are formed by the interaction of social, political, economic, demographic, technological, culture, and biophysical variables that constitute initial conditions in the human-environment relation (Ledec, 1985; Geist and Lambin, 2002).

Some studies disclosed that the relationship between land change and its causative factors is complex and dynamic (Minale, 2013), strongly related to socioeconomic factors (Long *et al*., 2007) and may occur at various temporal and spatial scales (Reid *et al*., 2000). As a result of complex interaction between several biophysical and socioeconomic conditions (Reid *et al*., 2000), it constantly changes in response to the dynamic interaction between underlying drivers (indirect or root) and proximate causes (direct) (Lambin *et al*., 2003). Generally, physical driving factors are limited, static and easily quantified while anthropogenic factors are diverse and reflect landscape change accurately, however, it is hard to analyze them quantitatively (Su *et al*., 2011).

Several theories of land use change intend to describe the structure of the change in the use of land from one type to another and explain why these changes occur, what causes these changes, what are the mechanisms of changes. The “what” and the “why” of land use change are closely related although existing theories rarely address both (Briassoulis, 2000). The majority of theories of land use change lay in the more general theoretical framework of discipline studying economic, environmental and spatial change (transformation). Theories of land use change can be classified into three main categories (Briassoulis, 2008): the urban and regional economic theories, the sociological (political economy) theories, and the nature-society (human-nature) theories, which address mainly the human role in causing global environmental change. Some theories and models have been conceived simultaneously in which case the terms "theory" and "model" are used interchangeably to denote a set of theoretical and operational statements about reality (Briassoulis, 2008).

2.3 Impacts of LULC Dynamics

Many of the land use land cover change impacts are associated to ‘positive’ influences such as the continues increase in food and fiber production, resource use efficiency, livelihood security and the wellbeing of humans in general (Lambin *et al.,* 2003). However, the effects on ecosystem functions can be clearly associated with undesirable ‘negative’ influences reducing the ability of environmental systems to support human needs (Odum, 1994). Regardless of the socio-economic advantage, land use land cover change possesses unintended consequences on natural environment (Leh, 2013). It has considerable impacts on the functioning of socio-economic and environmental systems with tradeoffs for sustainability, food security, biodiversity and the vulnerability of people and global ecosystem impacts (Lesschen *et al.*, 2005).

At regional scale, the effects of land use land cover change can induce biodiversity loss, decreasing of land fertility, land and water contamination, and the lowering of the ground water tables (Schosser *et al.,* 2010). It also plays an important role in affecting spatial patterns of soil erosion (Francis *et al*., 1986; Fu *et al*., 2000) and soil properties. Land use changes, especially cultivation of deforested land may rapidly diminish soil quality. It causes soil quality deterioration through loss of vegetative cover, top soil moisture, infiltration capacity, water storage, soil organic matter, natural regeneration capacity, and a lower water table (Khormali *et al.,* 2009). The degradation of soil quality, in turn, may severely impact the environment and agricultural viability and this in turn affects natural ecosystems functions and the population’s health, food security, and livelihoods (Achemo, 2011). The following sections discuss some of the most prominent impacts of LULC dynamics.

2.3.1 Impacts on Soil Erosion

Soil is a very important natural component of ecosystems that provide primary ecosystem services (Keesstra *et al*., 2016; Robinson *et al.,* 2017), which is under serious threat due to accelerated soil erosion (FAO, 2015). From the various erosion agents, water-induced soil erosion is a principal land degradation triggering factor (Brady and Weil, 2012; Rodrigo *et al.*, 2015) which leads to decline in ecosystem services and functions *(*Adimassu *et al.,* 2014;

Haregeweyn *et al.,* 2015). The FAO-led Global Soil Partnership (2017) reported that, throughout the world erosion removes about 75 billion tons of soil every year from arable lands. This amount of soil loss was estimated to cost 400 billion US dollar per year.

Soil erosion is a natural process that contributes to the evolution of the Earth's surface and is governed by the underlying geology and soil characteristics, rainfall, topography, vegetation, land use and management practices (Nouri *et al.,* 2018). Although soil erosion results from the interplay of climate, soil type, topography, vegetation cover, and human activities, in areas where climate, soil type and topography are similar, the variations in soil erosion rate is commonly attributed to land use/land cover (Lopez *et al., 1998).* According to Borrelli *et al.* (2017) who investigated the global soil erosion dynamics, land use/land cover changes are the primary causes of accelerated soil erosion, which has substantial implications for the environment and socio-economic conditions. As reported by Zhu and Ren (2000) and Zhang *et al.* (2008) the natural geomorphic process of soil erosion becomes a severe problem primarily as a result of improper land use/land cover management.

The change in land use and land cover (LULC) from natural vegetation to agricultural in in mountain areas usually dramatically accelerates soil erosion rates if the land is used for crop production (Nearing *et al.,* 2017). Shrinkage of grassland and the resultant loss of available fodder for livestock have caused overgrazing and consequent conversion of grasslands into degraded lands (Gete and Hurni, 2001). Expansions of farmlands at the expense of other land cover classes and traditional farming practices are encouraging erosion and loss of available nutrients. In general, soil erosion is strongly related to the land cover and land use (Garcia-Ruiz, 2010; Ranzi *et al.,* 2012; Pacheco *et al*., 2014) and land use land cover changes or the percent of vegetation has many effects on soil loss (Asselman *et al*., 2003; Alkharabsheh *et al*., 2013; Zare *et al.,* 2017). Therefore, identification of trends of soil erosion changes, together with studying the effect of land cover changes in the study catchment plays an important role in management of the watershed and erosion control and water and soil resources.

Soil erosion in Ethiopia is affecting the productive capacity of agricultural land, which in turn aggravates poverty and food insecurity (Lal, 2001; Erkossa *et al.,* 2015; Gessesse *et al.,* 2015). The study conducted by FAO (1984) confirmed that about 27 million hectares of land were seriously affected by soil erosion. Though a number of efforts have been made by the past and present governments of Ethiopia to reduce the accelerated soil erosion, the problem is still becoming persistent challenge. Therefore, though difficult to fully alleviate the problem, it is crucial to estimate the annual erosion rate, identify causes, and prioritize hotspot areas of soil loss to minimize the risk and its adverse onsite and off-site consequences.

Several soil erosion studies have been conducted in Ethiopia (Hurni 1996; Sonneveld and Keyzer, 2003; Amsalu *et al*., 2007; Amare, 2007; Bewket & Teferi, 2009; Nyssen *et al.*, 2009; Haregeweyn *et al.,* 2013; Erkossa *et al.*, 2015; Gelagay, 2016; Haregeweyn *et al*., 2017; Gezahegn *et al.,* 2018; Mengesha *et al.,* 2018; Asmamaw & Mohammed, 2019; Yesuph & Dagnew, 2019). All these researches emphasized the severity of soil erosion and attempted to foreword the way out in alleviating the constraint. However, the magnitude, the spatial distribution and drivers of the problem are not the same in different geographical areas. The vulnerability and magnitude of soil erosion varies among different regions of the country due to differences in geomorphological, geological, and vegetation attributes. This reveals that site-specific soil erosion studies are important in order to plan and implement site-specific soil management interventions.

Several conceptual and empirical models had been proposed to estimate soil erosion by water (Lal, 2001; Morgan, 2005). Each model has its own characteristics and application scopes (Boggs *et al.*, 2001; Lu *et al.*, 2004; Dabral *et al.*, 2008; Tian *et al.*, 2009). The choice to apply these models depends on the availability of input data and type of required information (Yesuph and Dagnew, 2019). However, the Revised Universal Soil Loss Equation (RUSLE) is widely used empirical model in different countries to estimate erosion by water, because of its convenience in application and compatibility with GIS and RS software (Lu *et al.,* 2004; Jasrotia and Singh, 2006; Dabral *et al.*, 2008; Kouli *et al*., 2009; Pandey *et al.*, 2009; Bonilla *et al.,* 2010). Hence, the RUSLE Model have been chosen for this research with the consideration of limited availability of data, compatibility with GIS, and its simplicity to apply in estimating the annual soil loss of an area.

2.3.2 Impacts on Soil Quality (SQ)

Soil is a foundation of life as it has many functions such as providing a medium for plant growth, water supply, providing habitat for organisms and nutrient recycling to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994; Karlen *et al.,* 1997; Bonuma, 2002; Winder, 2003). The ability of a soil to carry those ecological functions is known as soil quality (Doran and Parkin, 1994). It was reported in several literature that the quality of soil is deteriorating in many regions of the world and posed a challenge to increasing agricultural productivity, economic growth, and healthy environment (Eswaran *et al.,* 2001; Girmay *et al.,* 2008). SQ degradation is largely associated to conversions of forest into agricultural land or other forms of land use (Oguike and Mbagwu, 2009), intensive land use (Jamala and Oke, 2013), inappropriate land use and management, erratic and erosive rainfall, steep terrain, deforestation, and overgrazing (Girmay *et al*., 2008; Lal, 1981; Lal *et al.*, 2003). Immediate actions of reducing degradation and restoring degraded lands are therefore needed to maintain ecosystem function and productivity, preserve biodiversity, mitigate climate change, and secure food production and resource provision (Keesstra *et al.*, 2016; Bouma, 2016).

Land use land cover (LULC) changes such as forest clearing and crop production have remarkable effects on the dynamics of soil quality parameters (Biro *et al.*, 2013; Houghton *et al.*, 1999), yet the sign and magnitude of changes in soil quality vary with land cover and land management (Baskin, 1998; Celik, 2005). The conversion of forestland into other uses may reduce organic residues and results in a decline in soil quality (Munoz-Rojas *et al.,* 2015), increased rate of erosion (Biro *et al.,* 2013), and the loss of soil organic matter and nutrients (Saha and Kakul, 2015). As in the other parts of the world, several interrelated factors in Ethiopia have led to the conversion of natural forest and grassland into farmland (Tesfahunegn, 2014). In the absence of intensification, smallholders always seek more land for cultivation to meet the increasing demand for food and fiber. Consequently, deforestation and conversion of grassland to cropland take place even in marginal lands (Teferi *et al.,* 2016). Such land use changes have contributed to soil degradation and soil loss by deteriorating the soil physical and chemical properties. As reported by Misra *et al.* (2003), Ethiopia is among the sub-Saharan African countries with very high nutrient depletion rates. This very high nutrient depletion is an indication of the prevailing unsustainable land use and management systems (Teferi *et al.,* 2016).

Soil quality and functions cannot be measured directly but must can be inferred from measurements soil properties that serve as soil quality indicators (Brejda and Moorman, 2001; USDA, 2015). The variations in these indicators are used to determine whether soil quality is improving or declining with changes in land use and management (Brejda and Moorman, 2001). There are two aspects of soil properties that can be used to evaluate soil quality variations: inherent and dynamic soil properties (USDA, 2015). The inherent soil properties change very little or not at all with management whereas dynamic, or management dependent, soil properties are affected by human management and natural disturbances over the human time scale (Larson and Pierce 1994; USDA, 2015). Soil quality indicators are site-specific (Shukla *et al*., 2006) and not the same for all places. However, Doran and Parkin (1994) proposed a minimum datasets that should be measured to assess soil quality including physical indicators (texture, topsoil and rooting depth, infiltration, bulk density, and water holding capacity), chemical indicators (soil organic matter, pH, electrical conductivity, Extractable N, P,K) and biological indicators (microbial biomass C and N, Potentially mineralizable N, and soil respiration). Several techniques have been proposed to identify minimum datasets of soil quality indicators, including scoring functions method (Karlen *et al*., 1994; Hussain *et al*., 1999), factor analysis (Bachmann and Kinzel, 1992; Wander and Bollero, 1999; Brejda *et al*., 2000, Shukla *et al*., 2004), and principal component analysis (Teferi *et al*., 2016; Tesfahunegn and Gebru, 2020). However, the most widely reported techniques of SQ indicators are expert opinion and statistical tools (e.g., regression, principal component analysis (Andrews *et al.,* 2004; Masto *et al.,* 2008).

With respect to the effects of LULC on soil quality, several studies have been conducted in Ethiopia (Kidanemariam *et al.,* 2012; Asmamaw and Mohammed, 2012; Chimdi *et al.,* 2012; Kiflu and Beyene, 2013; Moges *et al.,* 2013; Yitbarek *et al.*, 2013; Dessalegn *et al.,* 2014; Haycho *et al.,* 2015; Abate and Kibret, 2016; Teferi *et al.,* 2016; Adugna and Abegaz, 2016; Guteta and Abegaz, 2017). These all authors reported that change of LULC can cause significant variation in soil quality parameters. These researchers have found that the conversion of natural forest to other forms of land use can aggravate soil erosion and lead to a reduction in soil quality. However, effects of land use changes on soil properties is inherently regional and highly dependent on the soil type (Abu Hashim *et al.,* 2016), climate (Teferi *et al.,* 2016), and topography (Baskan et *al.,* 2016). Hence, more researches that focus on different ecological regions and land use types are required.

2.3.3 Impact on Soil Organic Carbon and Total Nitrogen Stocks

Carbon and nitrogen are the two chemical elements in organic matter which are the most important, especially in their relation and proportion to each other. Carbon and nitrogen are both important for energy generation and growth regulation (Miller 2000) and both play important roles in global warming and climate change (IPCC, 2007). Soil organic carbon (SOC) is extremely important in the global carbon cycle. Carbon sequestration in non-disturbed ecosystems are the best sinks of carbon and mitigate global climate change (Parras-Alcantara *et al.,* 2015). The world's soils store more carbon than the planet's biomass and atmosphere combined (FAO-UN, 1999; IUCN, 2020). Soil organic carbon (SOC) occupies approximately more than 75 percent of the total carbon pool in the terrestrial ecosystem (Amundson, 2001; Lal 2004). As a consequence, small changes in SOC levels can have significant impact on atmospheric carbon concentration (Stockmann *et al.*, 2013). SOC is widely used as a proxy measure for soil fertility and soil health (Gregorich *et al.*, 1994; Moncada *et al.,* 2014) and serves as the most useful indicator of soil quality (Soil Carbon Initiative, 2011; Bünemann *et al.,* 2018). Therefore, a loss of soil organic carbon is one of the principal signs of land degradation, which forms one of the leading challenges for sustainable agricultural development, biodiversity conservation, and mitigating and adapting to climate change (IUCN, 2020).

The amount of SOC in a terrestrial ecosystem is influenced by both natural and anthropogenic factors (Sun *et al.*, 2015), such as land use, topography, parent material, and soil depth (Fu *et al.*, 2004; Johnson *et al.,* 2000; Ollinger *et al.,* 2002). Human-induced land-use change causes a particularly substantial loss of SOC (Fan *et al*., 2016; Gelaw *et al*., 2014). The LUCC may reshape the original structure and balance of the ecosystem, causing severe losses of soil organic carbon and total nitrogen (Lal, 2005; Shirvani *et al*., 2010; Covaleda *et al*., 2011; Gamboa and Galicia, 2011). Land use land cover change is associated with ecosystem carbon change (Fu *et al*., 2010) and drives negative impacts on climate and the environment. Previous studies have demonstrated that land use land cover changes will directly change soil carbon pool, thus causing environmental degradation and global climate change (Harris *et al*., 2012; Wiesmeier *et al*., 2016). According to Yang *et al*. (2017), changes in land use patterns will change soil carbon and nitrogen storage in local areas.

Land use land cover changes from natural forest and grasslands into agriculture contributes to GHG emissions through the mineralization of soil carbon and decomposition of vegetation (Lal, 2004). The greatest losses of SOC result from conversion of forests to agriculture, and this is true when the biomass of the trees is included. As reported by Guo and Gifford (2002) grassland soils converted to crop land lost 59% of their carbon, while forest soils lost 42%. In parallel, land degradation caused by SOC loss may damage ecosystem structure and function (Costantini *et al.*, 2016) and directly influence the hydrological and biogeochemical cycles in the earth system (Garcia-Diaz *et al*., 2016; Sonneveld *et al*., 2016).

Topography also influences SOC through its modification impact on precipitation and temperature (Tsui *et al.,* 2004), solar radiation, and relative humidity (Finney *et al.,* 1962; Franzmeier *et al.,* 1969) and by altering the input and output of carbon via hydrological processes, processes of soil erosion and sediment deposition (Dialynas *et al.,* 2016). Topographic elevation is one of the local terrain attributes, which appears to influence SOC storage at local scales, where the soil properties do not vary a lot (Wiesmeier *et al.,* 2019). Aspect determines length of exposure to sun light and can influence weathering and vegetation (Rech *et al.,* 2001; Sidari *et al.,* 2008; Yimer *et al.,* 2006).

In Ethiopia, as a result of the human interference on natural or virgin lands, soil organic Carbon has declined to low level mainly in cultivated soils of the highlands of the country (Chibsa and Ta, 2009). This SOC change showed regional patterns of variations associated with land use management, topography, local agro-ecology, and climate. In the highlands of southeastern Ethiopia, a study indicated an existence of a significant reduction in the original native quantity of SOC in the upper 100 cm soil layer by 30.9% as a result of converting native forests into cultivated lands over a period of 15 years (Yimer *et al*., 2007). The topsoil (0 to 20 cm) of natural forest lands has higher levels of SOC concentration than in the modified and/or transformed agroforestry and agricultural lands (Singh *et al.,* 2010). As a result, the 0-10 cm surface soil, the highest SOC (12.9%) concentration was recorded in natural forest with the least concentration of 2.6% in cultivated land (Abera and Belachew, 2011). Another study made in Wondo Genet, Southern Ethiopia by Kim *et al.* (2015) reported about 18 to 30% SOC losses as a result of the conversion of home garden agroforestry to annual crop fields.

Therefore, there is still considerable disagreement on the direction and magnitude of changes in soil carbon stock with land-use change (Van der Werf *et al.,* 2009; Deng *et al.,* 2016). Besides, microlevel researches on effects of topographic attributes such as altitude and slope characteristics and local land use and management on SOC stock are not consistent (Tsunekawa *et al.,* 2020), This showed that combined several factors operate at local scale in affecting SOC stock and would be difficult explaining its variation both in space and time with limited studies.

In summary, the changes in SOC and TN stocks due to the LUCC are critical for maintaining ecosystem sustainability, which should be evaluated scientifically. Hence, in-depth Information is required regarding the effects of land use changes on carbon and nitrogen stocks on different soil types to mitigate climate change.

2.4 Factors influencing the implementation of Sustainable Land Management Practices

Sustainable land management (SLM) is "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions" (United Nations, 1992). It enables land users to maximize the economic and social benefits from the land while maintaining the ecological support functions of the land resources (TerrAfrica, 2006; FAO, 2009). The adoption of SLM practices is one of the major solutions to combating the problem of land degradation (WMO, 2005) and very important for achieving sustainability by conserving, protecting, and enhancing natural resources management (FAO, 2017).

Empirical evidences suggest that the ugly trend of land degradation cannot be reversed in a sustained manner unless farmers adopt sustainable land management practices or pursue livelihood strategies that are less demanding of the land resource (Jones *et al.,* 2003; Bai *et al.* 2008; Lal and Stewart, 2013; Zucca *et al.,* 2014). However, studies reveal that farmers adoption of SLM practices is at lower rate (Thompson *et al.,* 2009; Chasek*et al.,* 2011; Akhtar-Schuster *et al.,* 2011; Reed *et al.,* 2011; ELD Initiative, 2013) and their response to recommended SLM varies from place to place and from household to household. This is due to the fact that adoption of SLM Practices is determined by interactive effects of household's socio-economic characteristics, biophysical conditions of the land, resource availability, and institutional support provided by the Government or NGO sector (Garcia 2001; Paudel and Thapa, 2004; Pilbeam et al., 2005; Nederlof and Dan-gbegnon 2007).

Scientific evidences in Ethiopia also demonstrate that there is variation among smallholder farmers in the adoption of SLM practices with respect to a range of demographic, socio-economic, biophysical, and institutional, factors (Amsalu and De Graaff, 2007; Adimassu et al., 2012; Guteta and Abegaz, 2015; Haregeweyn et al., 2015; Teklewold et al.,2013; Teshome et al., 2016; Zeleke et al. 2006). In addition, Tadesse (2011) also reported that government policies and programs, socioeconomic and institutional factors, farmer's local knowledge and practices, household's endowments of physical and human capital as well as topography, soil type and climate are the most important factors that could influence land management practices. However, these factors are largely area specific and their importance is varied between and within agroecological zones and across countries. Thus, it seems difficult to generalize such individual constraints across regions and countries (Kirui and Mirzabaev, 2019).

More specifically, Adugna and Bekele (2007) found that socio-economic variables such as family size, plot ownership, land to labor ratio, and livestock holding have an influence on adoption of land conservation practices. On the other hand, de Graaff et al. (2008) and Miheretu and Yimer (2017) reported biophysical characteristics of plots, topography, and agro-ecological variations to influence the implementation of land management practices. Institutional factors such as land insecurity, access to credit, proximity to all weather road, and market access were also reported as determinants of land management practices (World Bank, 2007; Yirga, 2007). Furthermore, perceived erosion risk (Teshome *et al.,* 2016); access to off-farm activities (Shiferaw and Holden, 1998); tenure insecurity (Gebremedhin and Swinton, 2003); access to credit (Abebe and Sewnet, 2014); and agricultural extension services (Yesuf *et al.*, 2008), and were also identified to affect the adoption of SLM practices. However, the results obtained from most of the studies are often contradictory regarding any given variable, which implies that further site-specific studies are required.

2.5 An overview of Land use Policy in Ethiopia

Scientific studies conducted in different parts of Ethiopia indicate that except in urban centers with master plans and zoning in effect, the land has been used for a very long period in unplanned and uncontrolled manner without due regard to its potential use and without due consideration for conservation of natural resources and safeguarding the environment (Emiru and Taye, 2012; Hailemariam *et al.,* 2016; Gashaw *et al.,* 2017; Miheretu and Yimer, 2017). As a consequence, land degradation has been one of the severe environmental problems of the country which requires great effort and resources to ameliorate (Hurni *et al.,* 2005; Adgo *et al.,* 2013; Nyssen *et al.,* 2015). The problem is more severe in the highlands (above 1500 m above sea level and covering 45% of total area) where roughly 90% of the population lives and 95% of the regularly cultivated lands are found (Bewket, 2007; Hurni *et al.,* 2005; Nyssen *et al.,* 2015; Adgo *et al.,* 2013).

There is a great need to help the Ethiopian government think about how it can modify land policy and administration in ways that will encourage farmers to improve their land management and produce more without reducing their livelihood security. This can be addressed through a multi-step process involving a national land policy conference and the establishment of a land policy task force that will be able to continue the refinement of the land policy (USAID, 2004). Informed by the recommendations of studies, the Ethiopian government gave attention for formulating a national land use policy and for preparing a national integrated land use plans (Zemen *et al.,* 2017). However, the process is not expected to go smoothly and without challenges.

Chapter Three: The Study Area and Research Methods

3.1 The Study Area

The study site roughly lies between 8^{o}54’59’’ to 9^{o}02’48’’North latitude and 34^{o}58’38’’-35^{o}04’14’’East longitude and covers 6400 hectares (Figure 3.1). It is part of the upper course of Baro-Akobo River basin of western Ethiopia making the upper tributary of the Blue Nile River. The area is characterized by rugged topographic features with altitudinal ranges of 1406 to 2238 meters above mean sea level. Most of the study area falls within slopping to strongly slopping (8-30% slope). The study area has a sub-humid tropical climate with a mean annual rainfall of 1762 mm and mean annual temperature of 20.8 degree Celsius. The mean annual rainfall varies from 877 to 2332 mm. This showed a presence of high inter-annual rainfall variability, making the pattern of rainfall distribution to be less dependable for local traditional rainfed agriculture. The main rainy season (covering about 90% of the annual rainfall amount) runs from May to October and the dry season is between December and February (NMSA, 2018).

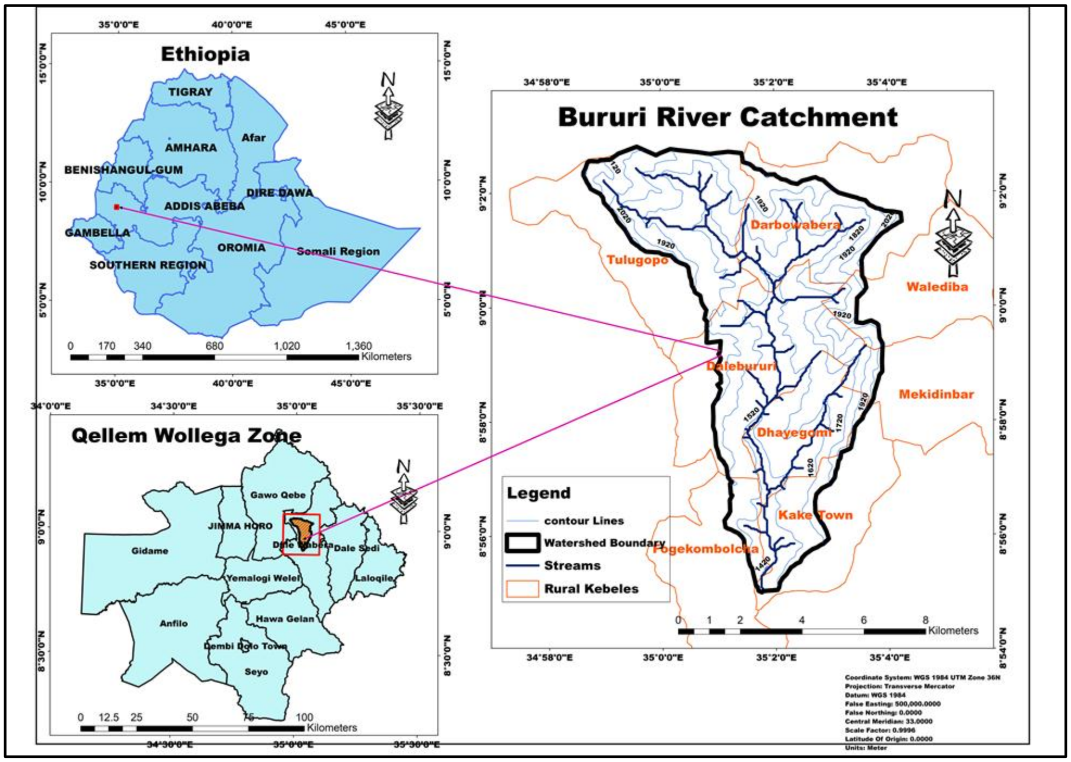


Figure 3.1. Location Map of Bururi River Catchment in Western Ethiopia

The major natural vegetation types in the watershed are mountain forest and bush formation with low woods mainly evergreens of widely changing composition. The native tree and shrub species common in the study catchment are *Abbayyii (Maesa lanceolata), Bakkanniisa (Croton macrostachyus), Baddeessaa (syzygium guineense), Qararoo (Aningeria), Qilxuu (FicusVasta), Laaftoo (Acacia abyssinica), Reejjii (Vernonia myriantha), and Waddeessa* (*Cordia Africana).* In addition, exotic tree species like *Baargamoo diimaa (Eucalyptus camaldulensis)* are dominant and planted for fuelwood and construction purposes. The dominant soil types in the watershed are Acrisols, Alisols, Luvisols, Leptosols, and Cambisols. *Various types of soil and water conservation measures are implemented in the study area including traditional measures such as the addition of animal* manure to farm plots, fallowing, crop rotation, planting leguminous plants, coffee-based agroforestry, and tree planting, as well as modern conservation practices consisting of stone and soil bunds, check dams, compost use, and application of chemical fertilizers.

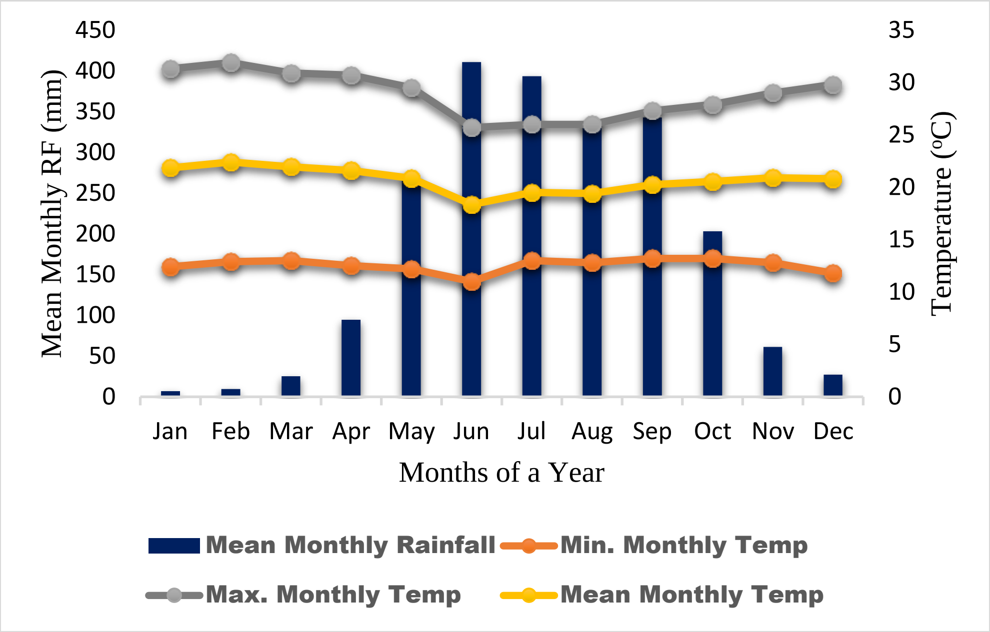


Figure 3.2. Mean Monthly Rainfall and Mean Monthly Temperature of Bururi Catchment (1986-2010) based on the Records from nearby meteorological Station (1630 m.a.s.l), Western Ethiopia (NMSA, 2018)

The study area consisted of 2,172 households (HHs) located in two upstream rural villages and two downstream rural villages. There is also one urban center in the watershed having 1716 households (CSA, 2007). The major economic activity was subsistence rain-fed mixed crop and livestock production. Locally, small-scale supplementary irrigation was also practiced and crops like maize, haricot bean, and potato were grown by irrigation. The major crops produced in the watershed were maize (*Zeamays L.),* sorghum, *(Sorghum bicolour),* finger millet *(Eleusine coracana*), potato *(Solanum tuberosum*), and coffee *(Coffee arabica*). Honey production was also a major income contributor to some of the catchment households. The study area is characterized by high annual rainfall, steep terrain, and rugged topography, which contribute to accelerated soil erosion and the human activity also played an important role in changing the ecosystem into degraded environment. It is an old occupied area where soil is highly eroded and exhausted. The information obtained from respective *woreda* revealed that severe soil erosion and a remarkable decline in agricultural productivity was observed in the catchment over the past two decades (DWWAO, 2017). The smallholder farmers in the study catchment were responding to the problem mainly by changing the land use from cropland to other uses like grazing land and also abandoning their previous farmland to extend cultivation into nearby marginal lands and protected areas, which have a negative implication on the marginal ecosystem and their livelihoods. The local agricultural development offices considered the problem as a high priority environmental issue and recognized that there is lack of clear understanding of the causes and implications of the problem. As a response to the problem, they distributed new farmlands to the local farmers, which may not be a sustainable solution and affect the marginal fragile ecosystem.

3.2 Materials and Methods

3.2.1 LULC Change Assessment

The basic data used in this research were topographic maps (1:50,000), Aerial Photos (1: 50,000), Landsat imageries, and ground measurements (using GPS Receiver). The Landsat imageries used for this study were Thematic Mapper (30m resolution for 1987); and Landsat 8 OLI TIRS (Operational Land Imager Thermal Infrared Sensor) with 30m resolution for 2018. As illustrated in Table 3.1, all analyzed satellite images were obtained from the online archives of US Geological Survey (USGS Earth explorer). The Landsat images were preferred due to the fact that they are freely available compared to other satellite imageries. Digital Elevation model (DEM) data of 30m spatial resolution, obtained from USGS online archive was also used in this study for delineating the boundary of the study watershed. For the ease of analysis, dry season and cloud-free images were used and all the images (1987 and 2018) were obtained for the months of January and February. The remote sensing data acquired from different sources were analyzed using ERDAS IMAGINE 2015 and ArcGIS 10.6 software.

Table 3.1. Remote sensing Data sources

Data Type	Path/Row	Spatial Resolution/Scale	Acquisition Date	Source
Satellite Images				
Landsat Thematic Mapper 5	171/054	30 meter	13-Jan-87	US Geological Survey
Landsat OLI TIRS 8			6-Feb-18	
Aster DEM				
Aerial Photo				
Black and White		1:50,000	Dec, 1957	EMA

*OLI TIRS stands for Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS); EMA represents Ethiopian Mapping Agency

The aerial photos of 1957 were scanned and georeferenced using ground control points (GCPs) obtained from topographic maps, with a root mean square (RMS) error of half a pixel. The georeferenced aerial photo (15m resolution) was then mosaicked and resampled to 30m by using band one of Landsat 8 imagery so as to make comparison with other satellite imageries. Later, the resampled aerial photos were clipped using a shape file of the study area. Thereafter, a visual stereoscopic interpretation of the various features on the aerial photos was done. Before the LULC Classification, the satellite images were clipped by using the boundary map of the study area. The boundary of the study catchment was defined from digital elevation model (DEM) using watersheds delineation procedure in ArcGIS.

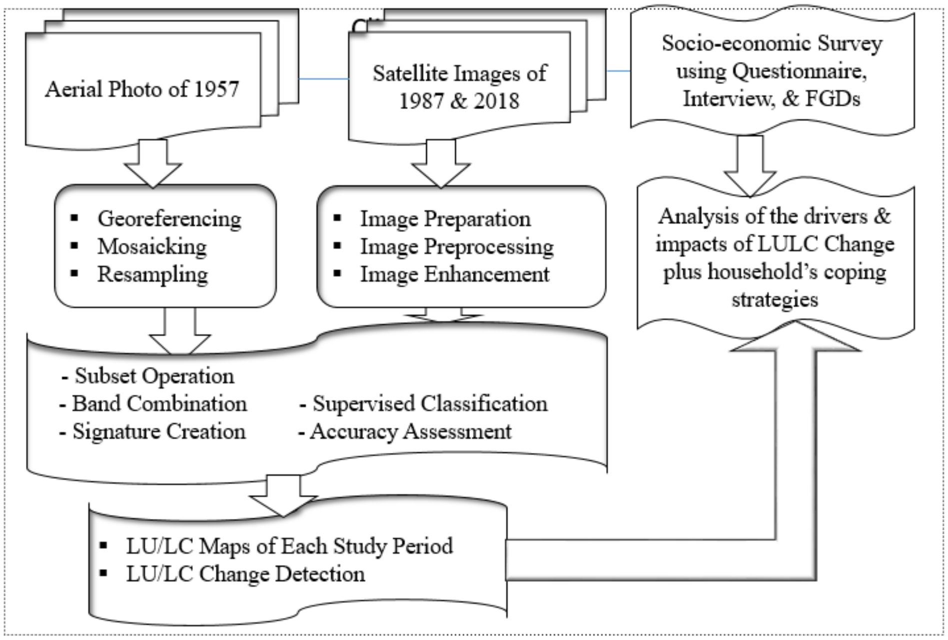


Figure 3.3. Flowchart of the Research Methodology

Later, the automated unsupervised classification of LULC has been carried out within ERDAS IMAGINE 2015 software. This helped to understand the nature of LULC classes in the study catchment. Based on the result obtained, a supervised classification was performed with the help of Google Earth's high-resolution image and a Maximum Likelihood method was employed to assign each pixel within the image to a discrete class. Finally, five dominant LULC classes (Table 3.2) were identified for the subsequent spatio-temporal LULC analysis. To compose the classified LULC maps, ArcMap 10.6 was employed because it is relatively simple and convenient to produce maps. During the classification process, natural forest and plantations were considered as forestland since it was difficult to differentiate natural vegetation from plantation in medium resolution images. Similarly, scattered rural dwelling units were grouped with agricultural land while fallow plots were taken as grassland. Since they had the same spectral nature on such medium resolution images, it was difficult to differentiate those features. The LULC Change detection was conducted by using ERDAS IMAGINE 2015 software. From the various change detection algorithms, post-classification comparison was applied which required rectification and classification of each remotely sensed image.

Table 3.2. Description of Land Use Land Cover Categories

LULC Class	Description
Forestland	Areas dominated by natural forests including plantations.
Shrub land	Areas covered with short trees, bushes, and shrubs, including coffee Shrubs. Scattered large trees can be found and livestock grazing is usual.
Grassland	Areas with grass cover and small shrubs dominated by grass, including revegetated fallow plots. Open or uncontrolled grazing is common practice.
Agricultural land	This unit includes areas used for rain-fed and irrigated crop cultivation, homesteads, and rural dwelling units.
Degraded Land	Land that already gets bad due to erosion or misuses, including overgrazed abandoned plots.

Accuracy assessment

According to Congalton (1991), for the information derived from remote sensing data, its quality should be assessed. The most common elements of accuracy assessment that should be incorporated in verifying image classification (Lu and Weng, 2007) are kappa coefficient, producer's accuracy, and user's accuracy. These all were generated for the three periods of study by using ERDAS IMAGINE Software. Kappa coefficients were computed to measure the agreement between classification and truth-values (Congalton *et al.*, 1983). A Kappa value of one represents perfect agreement, while a value of 0 represents no agreement. The Kappa coefficient attempts to control for chance agreement by incorporating all marginal distributions of the error matrix (Congalton, 1991). Furthermore, Rosenfield and Fitzpatrick-Lins (1986) also recommended Kappa as a standard coefficient. As indicated in Fleiss *et al.* (2003), Kappa coefficient over 0.75 is excellent, 0.40 to 0.75 is fair to good, and below 0.40 is poor.

In order to analyze the LULC dynamics, area of LULC categories and percentage changes of three periods (1957-1987, 1987-2018, and overall change of 1957-2018) were calculated. The net change of LULC types (in hectares) was obtained by subtracting the area of the first-time image analysis from the second time image analysis within the same category while the percentage change was calculated by using the following equation (Dinka and Chaka, 2019):

$$Percentage\ of\ LULCC = \left[\frac{(A_2 - A_1)}{T_A} * 100\right]$$

Where; A_1 represents the area of the first imagery, A_2 stands for area of the second imagery; and T_A is total area.

Finally, the annual rate of change in LULC was computed using the following equation (Puyravaud, 2003; Dinka, 2012).

$$r = (\frac{1}{t_2 - t_1}) * \ln\left(\frac{A_2}{A_1}\right)$$

Where: r= rate of Change, t_1=is the initial Year; t_2=is the final Year; A=Area in Hectare

3.2.2 Soil Lab Analysis

Both disturbed and undisturbed soil samples were collected from five dominant LULC classes and two elevation categories – representing local agroclimatic types of *kola* and *woyna dega.* As a result, the study catchment was further classified into elevation ranges based on traditional classification as lower elevation (below 1600 meter) is representing *kola* (warm sub-humid) and upper elevation (above 1600) representing woina *dega* (cool sub-humid) agro-ecologies (MoA, 2000). Accordingly, for the purpose of soil sampling, map of the two elevation categories were superimposed over the recognized LULC categories.

Considering the five LULC types and two elevation categories, a total of 30 sample sites (five LULC classes * two elevation categories * three replicates) were identified. Locating the sampling sites was undertaken by overlying LULC map and elevation map of the study area. The samples were taken from the upper 0-20 cm depth. This depth was chosen because it contains the highest concentrations of required soil nutrients for plant growth and it is the heavily affected layer by human activities (Assefa *et al.,* 2016). As a result, it is the depth where most changes are expected to occur as a result of long-term land use changes and soil management practices (Tsehaye and Mohammed, 2013).

The disturbed soil samples were collected using soil auger from four corners and at the center within the 10m x10m plots giving five sub-samples that were composited to make one sample. Approximately one kilogram of composite sample was taken from each sample site. The collected samples were then put into plastic bags, air-dried at room temperature, crushed, homogenized, and passed through a 2 mm sieve before laboratory analysis. Soil samples were analyzed using standard procedures for selected soil parameters considered as soil quality indicators including particle size analysis, pH, organic carbon (OC), total nitrogen (TN), cation exchange capacity (CEC), exchangeable bases (sodium, potassium, calcium, and magnesium) and available phosphorus. On the other hand, the undisturbed soil samples were collected using a core sampler for the determination of soil bulk density (*Db*).

The analysis of particle size distribution was done using the Bouyoucos Hydrometer method (Black *et al.,* 1965). Soil bulk density (Db) was measured from undisturbed soil samples collected using a core sampler (5 cm long and 5 cm diameter). The soil pH was measured in suspension of a 1:2.5 (w/v) soil-water ratio (Landon, 1954; Carter, 1993). Determination of exchangeable cations (Ca, Na, K, and Mg) and cation exchange capacity (CEC) were made with 1M ammonium acetate (NH_4OAC) at pH 7 of the soil as suggested by McLean (1965). Available phosphorus was measured by using Olsen's method of bicarbonate extraction (Olsen et al., 1954). Total nitrogen was determined by Kjeldahl process. Organic carbon measurements were made using the Walkley-Black dichromate method as described by Hesse (1971) and the result was given as the percentage by weight of organic carbon in the soil. The values of organic carbon percentages were multiplied by a conversion factor of 1.724 to obtain soil organic matter, assuming the organic carbon is 58% of the total organic matter (Landon, 1984).

3.2.3 Measurement of Soil Erosion Potential

Several conceptual and empirical models had been proposed to describe and predict soil erosion by water and associated sediment yield (Lal, 2001; Morgan, 2005). Each model has its own characteristics and application scopes (Boggs *et al.,* 2001; Lu *et al.,* 2004; Dabral *et al.,* 2008; Tian *et al.,* 2009). The choice to apply these models depends on the availability of input data and type of required information (Yesuph and Dagnew, 2019). However, the Revised Universal Soil Loss Equation (RUSLE) is widely used empirical model in different countries to estimate erosion by water, because of its convenience in application and compatibility with GIS and RS software (Lu *et al.,* 2004; Jasrotia and Singh, 2006; Dabral *et al.,* 2008; Kouli *et al.,* 2009; Pandey *et al.,* 2009; Bonilla *et al.,* 2010). Hence, the RUSLE Model has been chosen for this research with the consideration of limited availability of data, compatibility with GIS, and its simplicity to apply in estimating the annual soil loss of an area. The RUSLE model estimates the annual average rate of soil erosion based on the integrated effect of rainfall, soil, topographic factor, land use/ cover, and management practice data.

The formula used to compute annual soil loss rate by RUSLE model is expressed as:

$$A = R * K * LS * C * P \tag{1}$$

Where, A is the annual soil loss (metric tons $ha^{-1}yr^{-1}$); R is the rainfall erosivity factor (MJ mm h^{-1} ha^{-1} yr^{-1}); K is soil erodibility factor (metric tons ha^{-1} MJ^{-1} mm^{-1}); LS = slope length factor (dimensionless); C is land cover and management factor (dimensionless); and P is conservation practice factor (dimensionless). Data sources and measurements of each factor are as discussed hereunder.

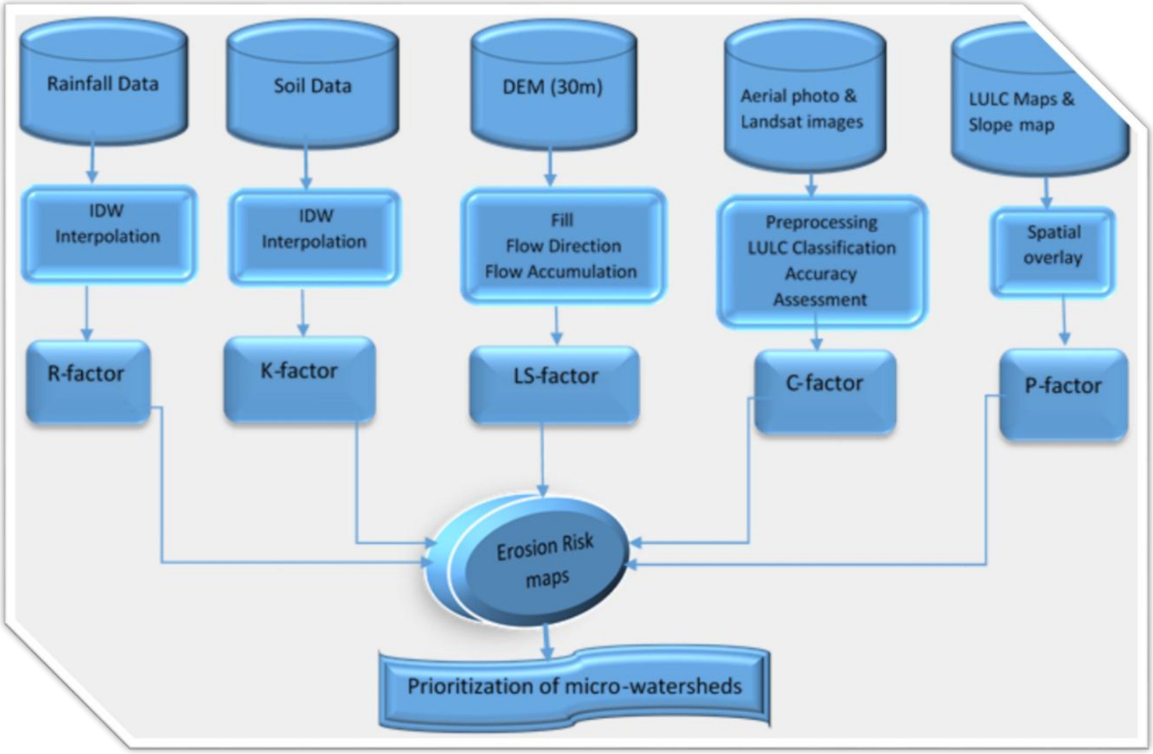


Figure 3.4 Flowchart indicating the data input of RUSLE model and GIS processes to be conducted in estimating annual soil loss rate of Bururi River Catchment in Western Ethiopia.

Rainfall Erosivity (R) Factor

The R factor is an expression of the erosivity of rainfall and runoff at a particular location. The value of R increases following the rise in the amount and intensity of rainfall. Among the many RUSLE parameters, computation of R factor appeared to be the most complicated due to the rainfall data requirement. Farhan and Nawaiseh (2015) also found that the amount, energy and size of raindrops as well as the pattern of rainfall and the subsequent run-off potentially affected the computation of R factor. For this study, the R factor was derived from a time-series rainfall data, which was obtained from Ethiopian Meteorological Service Agency (EMSA). Unfortunately, there was no meteorological station in Bururi catchment and the authors attempted to characterize the study area by using long-term rainfall records of 10 nearby metrological stations, namely Begi, Nejo, Ayira, Kebe, Gidami, Yubdo, Alem Teferi, Chanka, Seko Humbi and Dembi Dollo. As the R-factor is computed by averaging annual sum of the obtained rainfall data, the data collected from the National Meteorological Service Agency (NMSA) was screened to fill the incomplete datasets (missing values). Later, the average annual rainfall was computed for each station (Table 3.3).

Table 3.3 The attribute of the nearby Meteorological stations and the value of R factor (1986-2010)

S.N	**Station**	**Altitude** (m)	**Lat** (°N)	**Long** (°E)	**Av. Annual RF** (mm)	**R_Factor** (MJ mm/ha/h/y)
1	Alem Teferi	1630	8.90	35.23	1828	1019.2
2	Ayira	1555	9.10	35.55	1642	914.7
3	Begi	1650	9.33	34.53	1337	743.3
4	Chanka	1517	8.85	35.07	1249	694.0
5	Dembi Dollo	1850	8.52	34.80	1307	726.4
6	Gidami	1776	9.00	35.15	1411	784.9
7	Kebe	1725	8.98	34.97	2085	1163.7
8	Nedjo	1800	9.50	35.45	1654	921.4
9	Seko Humbi	1860	8.72	34.98	1355	753.3
10	Yubdo	1550	8.93	35.12	1669	929.9

To convert the station-based rainfall point data into raster grid, a GIS-based inverse distance weight (IDW) interpolation technique was applied and rainfall erosivity map was generated. The IDW interpolation method was chosen as it enables quick interpolation of the required data from grid based irregularly spaced samples (Li and Heap, 2008). The R factor value was then calculated from the average annual rainfall using a raster calculator tool in GIS environment. Based on the available mean annual rainfall, Hurni (1985) formula has been used to compute the R factor.

$$R = -8.12 + (0.562 * P) \qquad (2)$$

Where, *R is the rainfall erosivity factor (in MJ mm* ha^{-1} h^{-1} y^{-1}*), P is the mean annual rainfall in mm.*

Soil Erodibility (K) factor

The K factor represents the influence of different soil properties to erosion susceptibility of (Renard et al., 1997). It is the inherent erodibility of the soil at a particular site. The higher K-factor values indicate the soil's higher susceptibility to soil erosion (Adornado *et al.*, 2009). The value of K is a function of soil texture, organic matter content, soil structure, and profile permeability (Wischmeier and Smith, 1978; Renard *et al.,* 1997). However, some alternative equations have been developed that exclude the soil structure and profile permeability in estimating the K factor values (Benavidez et al., 2018). Similarly, in the present study, the K factor was calculated by employing indirect method of soil erodibility computation (Sharpley and Williams, 1990; Williams, 1995; Neitsch *et al.*, 2000; Khassaf and Rammahi, 2018) based on only soil texture and organic carbon content data. The RUSLE K factor was then derived based on USLE K formula (Williams, 1995) represented in equation 3.

$$K_{USLE} = f_{csand} \times f_{cl-si} \times f_{orgC} \times f_{hisand} \tag{3}$$

Where, K_{USLE} is USLE model soil erodibility factor; f_{csand} is a factor that gives low soil erodibility factor for soils with high coarse-sand contents and high values for soils with little sand; f_{cl-si} is a factor that gives low soil erodibilty factors for soils with high clay to silt ratios; f_{orgC} is a factor that reduces soil erodibility for soils with high organic carbon content*; and* f_{hisand} is a factor that reduces soil erodibility for soils with extremely high sand contents. The variables required for computing the RUSLE K factors have been calculated using the following equations (Appendix 1).

$$f_{csand} = \left[0.2 + 0.3 \times exp\left(-0.256 \times m_s \times \left(1 - \frac{m_{silt}}{100}\right)\right)\right] \tag{4}$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \tag{5}$$

$$f_{orgC} = \left(1 - \frac{0.256 \times orgC}{orgC + exp[3.75 - 2.95 \times orgC]}\right) \tag{6}$$

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

Finally, the RUSLE K-factor was computed using equation eight (Khassaf and Rammahi, 2018)

$$K_{RUSLE} = K_{USLE} \times 0.1317 \qquad (8)$$

Where, K_{RUSLE} is the RUSLE model soil erodibility factor, m_s is the percent sand fraction content (0.05-2.00mm diameter particles), m_{silt} is the percent silt content (0.002-0.05 mm diameter particles), m_c is the percent of clay fraction (<0.002mm), and $orgC$ is the percentage organic carbon content.

Slope length and Slope steepness (LS) Factor

The LS factor illustrates the effect of topography on sheet, inter-rill and rill erosion by water (Wischmeier and Smith, 1978). It describes the combined effects of slope length (L) and slope gradient (S), which strongly controls the transport of soil particles (Yesuph and Dagnew, 2019). In this study, 30m by 30m DEM was employed to generate flow accumulation and slope in degrees, which have been in turn used in the LS equation (Eq. 9) in order to produce RUSLE LS-factor.

$$LS = \left[FA \times \frac{cell\ size}{22.13}\right]^{0.5} \times \left[\frac{\sin(slope\ in\ degrees)}{0.0896}\right]^{1.3} \qquad (9)$$

Where, FA is flow accumulation; cell size is the resolution of the grid (in our case 30 m by 30m); 22.13 is the RUSLE standard plot length; 0.5 is the exponent of slope length; and 1.3 is empirical constant (Moore and Wilson, 1992) of slope angle coefficients.

Cover Management (C) Factor

Different land use/cover patterns have varying degrees of soil protection capacity from erosion. Therefore, the C factor reveals how land use/land cover types influence rates of soil erosion (Renard *et al.*, 1997). Land use/cover with better vegetation cover have lower C values and low degree of soil erosion hazard and vice versa (Asmamaw and Mohammed, 2019). In this particular study, to achieve the intended objective of assessing the effects of LULC change on soil erosion risk, three LULC Maps were prepared for the years 1957, 1987, and 2018.

Table 3.4 C-factor values of cover management adopted in this study

LULC Class	C-Value	Reference
Forest	0.001	Hurni (1985)
Shrub land	0.01	Asmamaw & Mohammed (2019); Hurni (1985)
Grass/grazing land	0.05	Hurni (1985), Bewket and Teferi (2009)
Cultivated land	0.15	Hurni (1985), Bewket and Teferi (2009)
Bare/Degraded land	1	Eweg et al. (1998), Hurni (1985)

In order to assign the C-values for each LULC class of three periods (1957, 1987, and 2018), the classified raster images were first converted into vector format in ArcGIS and then the corresponding/assigned C values were given for each LULC classes (Table 3.4). The same procedure was adopted to assign the C value of each LU/LC category the three periods. Finally, the C factor maps of the three periods were produced.

Support Practice (P) factor

The P factor indicates the various land use and management practices that reduce soil erosion and speed of runoff exerted on soil surface (Panagos *et al.*, 2015). Since there is no available data on the soil conservation activities implemented in the present study area, the P-values were determined based on the suggestion of Wischmeier and Smith (1978). This method was widely adopted in Ethiopia (Bewket and Teferi, 2009; Abate, 2011; Ebrahim *et al*.,2018; Asmamaw and Mohammed, 2019) as it is difficult to obtain data on soil conservation strategies. Accordingly, the LULC map of the three study years (1957, 1987, and 2018) and slope gradient maps of the study area were overlaid to produce the agricultural land of six different slope classes and the non-agricultural land (Table 3.5).

Table 3.5 The adopted Conservation Practice (P) values (Wischmeier and Smith, 1978)

LULC Category	Slope (%)	P-Factor Value
Agricultural Land	0 to 5	0.1
	5 to 10	0.12
	10 to 20	0.14
	20 to 30	0.19
	30 to 50	0.25
	50 to 100	0.33
Non-Agricultural	All	1

Since slope gradient determines the type of land management practices, agricultural fields were classified into six slope categories with their assigned P-factor values. By converting the intersection map into vector format, the P-factor values were assigned based on Wischmeier and Smith (1978) recommendation as indicated in Table 3.5.

3.2.4 Determination of SOC and STN Stock

To determine the SOC and STN stock, the soil lab results of SOC and STN concentrations were used (Table 3.6).

Table 3.6 SOC and STN Concentrations, and C:N ratio under five LULC and Two Elevation Categories

		Topographic Elevation					
		Lower			Upper		
LULC	Area (ha.)	SOC (%)	STN (%)	C:N	SOC (%)	STN (%)	C:N
Agricultural land	1549	2.2	0.35	6.15	1.4	0.21	6.66
Degraded land	638	1.6	0.17	8.94	1.2	0.15	8.25
Forest	625	3.2	0.64	4.95	2.7	0.42	6.36
Grassland	2413	2.1	0.33	6.26	2.0	0.22	9.16
Shrub land	1652	2.9	0.63	4.65	2.4	0.30	7.93

Where LULC=Land use/cover; SOC=Soil organic carbon STN =Soil Total Nitrogen

The SOC and STN concentrations were converted to a mass basis per unit area using the formulae suggested by Wairiu and Lal (2003) and Sainepo Bernice *et al.* (2018).

$$\text{SOC stock (Mg } ha^{-1}) = \left[\frac{\%SOC}{100} \times \text{ BD (g } cm^{-3}) \times \text{layer thickness (cm)} \times 100\right]$$

$$\text{STN stock (Mg } ha^{-1}) = \left[\frac{\%STN}{100} \times \text{ BD (g } cm^{-3}) \times \text{layer thickness (cm)} \times 100\right]$$

Where %SOC and %STN are the concentrations of soil organic carbon and total nitrogen, 100 is the conversion factor for the unit of carbon stock from g cm^2 to Mg ha^{-1}.

3.2.5 Socio-economic Data and Sampling of Respondents

Socioeconomic data were gathered through focus group discussion (FGD), questionnaire survey, and key informant interviews (KII). The first step in the sampling procedure was to estimate the number of farm households residing in the study catchment. Thus, with the help of local village administrators and agricultural extension workers, the total number of farm households incorporated in the delineated catchment (micro-watershed) were found to be 1035 households (of which 452 were in the lower and 583 in the upper catchment. The next step was to determine the number of sample households required for the study, which was carried out using the formula provided by Yamane (1967).

$$n = \frac{N}{(1+N(e)^2} \qquad (1)$$

Where, *n* is the required sample size, *N* is the population size, *e* is significance level (0.07). The total sample size required for the study was found to be 170 households and then representative samples were drawn proportionally from each rural kebele as the household sizes are different in each kebele (Table 3.7). This is in line with the sample size guideline for logistic regression, which recommends a minimum of 10 cases per predictor (Schwab, 2002) since 16 cases (independent variables) were included in the study. The list of the householders was obtained from their respective kebeles and samples were drawn using systematic random sampling technique, in which the researcher fixed the sampling interval and then selects a random starting point between the first person in the list and the sampling interval. The remaining samples are supposed to be selected by using the fixed interval, until the required sample size is obtained.

Table 3.7 Distribution of Sampled Households in Bururi Catchment

Catchment	Kebele	Households in Bururi Catchment	Sample Households
Lower	Dalle Bururi	218	37
	Dhaye Gomi	234	39
Upper	Darbo Wabera	276	45
	Tullu Gopo	307	49
	Total	1035	170

The household survey was conducted using a questionnaire, which was first prepared in English and later translated to the local language (Afan Oromo). Information pertaining to socio-economic and demographic background, farmer’s perception of land degradation, land management practices implemented by farm households, and perceived challenges were covered by the questionnaire. A pilot test was conducted by administering the questionnaire to ten selected respondents and necessary modifications were made based on the feedback obtained from the pre-test. Then, the questionnaire was administered by well-trained interviewers, who could understand the local language.

Moreover, in-depth interviews were held using semi-structured questions to gather data from the key informants that included Five natural resource management experts, four development agents, and four kebele administrators, who are well informed and can better describe about the land management practices in their localities. Other primary data were gathered through FGDs held in each sample kebele comprising six to ten people from both sexes and different age groups. The FGDs were conducted to acquire detailed information pertaining to farmer's perception of land degradation and factors influencing their land management decisions. Six FGDs were held in Dalle Bururi and Dhaye Gommi, and Darbo Wabera kebeles, which were analyzed qualitatively. Furthermore, field observation was made using a checklist to assess the nature of land degradation and the types land management practices implemented in the study area.

3.2.5.1 Statistical Analysis

The data collected through questionnaire survey was analyzed using SPSS (v. 24) by employing both descriptive (like frequency, percentage, mean, standard deviation) and inferential statistics (binomial logistic regression). The qualitative information gathered through interview, FGD, and field observations were used to substantiate the quantitative analysis of the questionnaire data. To identify appropriate soil quality indicators from all measured soil parameters, Principal component analysis (PCA) was computed in SPSS (V.24). PCA was used by several authors to select minimum data sets of soil quality assessment (Bachmann and Kinzel, 1992; Wander and Bollero, 1999; Brejda *et al.*, 2000; Andews *et al.*, 2002; Shukla *et al.*, 2004; Teferi *et al.*, 2016; Tesfahunegn and Gebru, 2020).

Furthermore, in order to confirm if the data had patterned relationships, the *Bartlett's Test of Sphericity* was checked. We determined if our data is suitable for PCA by looking at the *Kaiser-Meyer-Olkin Measure (KMO)* of Sampling Adequacy (cutoff above 0.5). Principal component analysis (PCA) was performed on the soil parameters meeting the preliminary assumptions to examine the relationship among the variables by statistically grouping them into principal components through the varimax rotation procedure. The principal components (PCs) which have eigenvalue more than 1 (Kaiser, 1960; Brejda *et al.,* 2000; Rezaei *et al.,* 2006) were retained and selected for further analysis. Analysis of variance (ANOVA) was conducted on the selected soil parameters to determine their significant variation in relation to LULC and topographic elevation. The significant components were then subjected to a two-way multivariate ANOVA (at $P<0.05$). The two-way multivariate ANOVA was preferred because it enables to test the main effect for each independent variable and explore the possibility of an interaction effect (Pallant, 2011). *Tukey's* HSD (Honestly Significant Difference) post hoc comparisons were employed to test for differences among specific interaction levels. These all tasks were performed using the GLM procedure in SPSS (v. 24). The magnitude of the effects of LULC, topographic elevation, and their interaction on soil quality parameters were evaluated using *partial eta squared*, which is the effect size index in ANOVA (Cohen, 1988; Muijs, 2004; Pallant, 2011).

The SOC and STN stock data were statistically analyzed by using two-way between-subjects multi-variate analysis of variance (MANOVA) in SPSS (v.24) to determine the effect of LULC and topographic elevation on SOC and STN Stock. This technique allows us to look at the individual and joint effect of two independent variables on more than one dependent variable. MANOVA is appropriate when you have more than one dependent variable (Pallant, 2011). Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multi-collinearity, with no serious violations noted. Differences in means between groups were analyzed using Tukey's HSD (honestly significant difference) test. The post hoc tests tells us where the differences lie. The Statistical analyses were conducted using SPSS software (version 24). The significance level was set at alpha=0.05. Finally, percent change was computed based on the assumptions that SOC and STN stock under the other LULC types (shrubland, grassland, agricultural, and degraded land) were once similar to that of forest soil. Therefore, differences between mean values of SOC and STN stock under the different LULC types were compared with mean values of SOC and STN stock under forestland and expressed as a percentage of the mean value of individual SOC and STN stock.

In the present study, binary logistic regression model was applied to examine factors that influence farmers' decision on the adoption of sustainable land management practices (such as structural erosion control measures, agronomic practices, vegetative/biological measures, and management measures). These four categories of SLM or dependent variables were presented as dummy variables (1 if implemented, 0 otherwise). The logistic model used in this study was chosen as it is useful in describing the relationships between dichotomous categorical response variables (adoption) and one or more predictor variables that is categorical or continuous (Tarling, 2009). Moreover, it was computationally easier and has interpretable results than the other models (Long, 1997; Southavilay *et al.*, 2012). In cases where adoption is measured as a dummy variable that take a value of 1 for adoption and 0 otherwise, researchers usually suggest the use of limited dependent variable models such as the probit or logit model. The two models give the same outcomes (i.e. same parameter estimates) and the choice between them is usually a matter of preference (Aldrich and Nelson, 1984). However, authors often prefer the logit model because it has faintly flatter tails than the probit model (Gujarati, 2009). It was with this background that we preferred the logit (logistic) regression model in this study. According to Retherford and Choe (1993), and Hosmer and Lemeshow (2000) the binary logistic regression function can be stated as:

$$Logit(Y)\ or\ ln\left[\frac{p}{1-p}\right] = B_0 + B_1x_1 + B_2x_2 + B_3x_3 + \ldots . B_ix_i \quad (2)$$

Where, y is the binary dependent variable (adoption of a particular land management option); P is the predicted probability to adopt (coded as 1); 1−P represents the probability of no adoption (coded as 0)**;** B_0 is the intercept or the constant; and B_1, B_2 . . . B_i are regression coefficients of the predictor variables of x_1, x_2 . . . and x_i. The value [P/(1−P)] is the odds ratio (likelihoods) of adoption of a particular land management option. In this research, we reported the Odds ratios, which estimate probability change in adoption, associated with a change in the predictors (independent variables). If the value of the odds ratio is greater than 1, the likelihood of the effect of the independent variable on the dependent variable is increased (positive relationship). Odds ratio value with one indicates that there is no relationship and a value less than one indicate negative relationship (Field, 2009). To evaluate the goodness of fit of the logistic regression model, *Omnibus Tests of Model Coefficients* and the *Nagelkerke's* coefficient of determination (R^2) were computed. Furthermore, the overall percentage of classification was used as it indicates how well the model is able to predict the correct category (adopter/non-adopter) for each case.

Dependent Variable

The dependent variable in this study was the adoption of a particular land management option. The land management types specifically implemented in the study area were grouped into four categories (physical structures, agronomic, vegetative/biological, and management measures) and a respondent is considered as an adopter for one category if he/she implemented one of land management types mentioned in that particular category (Table 3.8). Therefore, a householder classified as an adopter in one land management category might be a non-adopter in another category, and vice versa. The description of the dependent variables is given in Table 3.8.

Table 3.8 Description of Dependent Variables (WOCAT, 2007; Babalola and Olayemi, 2013)

Type of Land Management	Description
Structural Measure	SWC measures such as waterways/cut-off drains, diversion ditches, soil/stone bund, check dam, and terraces (1 if implemented, 0 otherwise)
Agronomic Practices	Includes compost and manure application, multiple cropping, contour ploughing, fallowing, crop rotation, and leaving crop residue (1 if implemented, 0 otherwise)
Vegetative Measure	The growth of multi-purpose trees and grass strips for their fruit, coffee shade, and animal fodder (1 if implemented, 0 otherwise).
Management Measure	Changing land use type (for e.g. into area closure); change of land management/intensity level (for e.g. from free grazing to controlled grazing); Change of plant species (for e.g. to termite resistant species)

Variables specification

Independent variables

In this research, a range of predictors (or independent variables) were used and based on their effects they were grouped into socio-economic and demographic factors, biophysical attributes, and institutional variables (Nkoya *et al.*, 2004; Jansen *et al.*, 2006; Saguye, 2017; Kirui and Mirzabaev, 2019). To test for multicollinearity, we used a linear regression procedure in SPSS, as there is no way in the logistic regression (Pallant, 2011). The requested collinearity diagnostics in this way produced two important values in the coefficient table: Tolerance values and Variance Inflation Factor (VIF). As a rule of thumb, the tolerance values that are very low (less than 0.1) or the value of VIF above 10 indicate that there is multicolinearity problem and the non-significant variables should be excluded from the analysis (O'brien, 2007; Pallant, 2011***).*** In this study, the tolerance values ranged from 0.41 to 0.94 and showed no problem of multicollinearity.

1) Socio-economic and demographic attributes: The socio-economic and demographic factors included in this study were age of the household head, sex, educational status, household size, farmland size, livestock size, and access to off-farm activity.

Age: The effect of farmer's age on land management decision may be either negative or positive (Lapar and Pandey, 1999; Bekele and Drake, 2003). Some studies in Ethiopia have shown that older age is associated with long years of farming experience and positively influence conservation decisions (Yesuf *et al.,* 2008; Temesgen *et al.*, 2009). Other authors (for e.g. Barungi and Maonga, 2011) asserted that the age of the household head reduces the adoption of land management technologies and negatively influence land management investments. This means, younger farmers with longer planning horizons are supposed to invest more in conservation measures.

Sex: It was also hypothesized that having a female-headed household may negatively affect the adoption of conservation measures, as women may have limited access to information, land, and other resources due to socio-cultural barriers (Temesgen *et al.*, 2009; Barungi and Maonga, 2011).

Education: some land management structures (like terraces and bunds) require human labor and high level of know-how for the establishment and maintenance. In this study, it was hypothesized that education of the HH head has positive and significant influence on the adoption of LMP. This implies that longer schooling of the HH head increases their ability to access information, and strengthen their analytical capabilities with new technology. Many authors report that education has a positive impact in the adoption of improved conservation measures (Lapar and Ehui 2004; Mbaga-Semgalawe and Folmer 2000).

Household size: This might have dual effects on householders' conservation decisions. Large family size may relax labor constraints needed to carry out land management practices. It may also encourage investment in conservation practices due to the higher demand for more produce. The effect is therefore expected to be positive (Amsalu and de Graaff, 2007). In contrast, households with large families may be forced to divert part of the labor force to off-farm activities in order to earn income to safeguard the consumption pressure imposed by a large family (Temesgen *et al.*, 2009). In this study, it was hypothesized that family size has positive relationships with labor-intensive land management practices, such as structural measures and biological conservation practices.

Farmland size: Previous studies indicated that farmland size has both positive and negative impacts on adoption of land management practices (Temesgen *et al.*, 2009). Large farms could reflect greater capacity that encourages conservation (Cramb *et al.*, 1999), as conservation structures occupy part of the scarce land. This potential loss of land for conservation may discourage investments on small farms (Bekele and Holden, 1998; Amsalu and de Graaff, 2007). Contrary to this, some studies have shown that more land may reduce the need to conserve land (Gebremedhin and Swinton, 2003). Therefore, in this study farmland size was expected to positively or negatively influence land management practices.

Livestock size: In this study, livestock ownership was hypothesized to positively or negatively affect the decision to adopt land management practices. The fact that livestock is considered as an asset that could be used in the production process or exchanged for cash suggests a positive influence on conservation decision (Bekele and Drake, 2003). Conversely, more specialization into livestock away from cropping may reduce the economic impact of soil erosion, and increase the availability of manure needed for soil fertility management (Bekele and Holden, 1998; Amsalu and de Graaff, 2007).

Access to off-farm activity: Households with off-farm income can invest higher sums of money in the adoption of conservation techniques as they have a constant source of income as was found in previous studies (Bekele and Holden, 1998; Adeogun *et al.*, 2008).

2) Biophysical factors: Biophysical attributes included in the logistic regression model were awareness of land degradation problem, farmland slope Steepness, home to plot distance, termite infestation, and number of plots per household (land fragmentation).

Awareness of land degradation: Farmers' perception of land degradation problem was hypothesized to positively influence the decision to invest in land management practices. Because, farmers having better awareness are expected to invest more in conservation activities (Amsalu and de Graaff, 2007).

Perceived slope steepness: The effect of slope steepness on the decision to adopt land management practices was hypothesized to be positive. Because, farmers are more likely to adopt conservation measures in plots that are steep as erosion severity is likely to increase with steepness in slope (Shiferaw and Holden, 1998; Berhanu and Swinton, 2003).

Plot distance: Home to plot distance was hypothesized to negatively influence the decision to implement land management practices due to increased travel and operational costs (Gebremedhin and Swinton, 2003; Abera, 2003). Farm households give more attention to nearby plots compared to the distant farmlands (Bekele and Drake, 2003; Berhanu and Swinton, 2003).

Termite infestation: Perceived termite infestation was hypothesized to influence farmers' land management decision positively. Termites cause severe devastations on the forest, and thus soil remains bare and exposed to elements of soil erosion (Gebreslasie and Meressa, 2018). Therefore, farmers are expected to invest more in conservation activities to reduce the impact of soil erosion.

Number of plots per household (land fragmentation): In this study, the impact of agricultural land fragmentation was hypothesized to negatively influence the decision to implement land management practices, as it costs time and money to transport labor, materials, agricultural inputs, and products. Therefore, farmers having several fragmented plots might lack sufficient time and capital to spend in land management investments.

3) Institutional variables: In this study the institutional support variables hypothesized to influence the adoption of sustainable land management practices were home to market distance, the distance of agricultural Extension office from home, access to Credit service, and land tenure security.

Market distance: As home to market distance increases, the production costs increases as well and this hinders the adoption of land management practices. Therefore, the effect is negative.

Areas of relatively high agricultural potential but remote from major markets face several challenges in marketing their outputs (Gidoi *et al.*, 2013)

Distance of agricultural extension office: Currently, the agricultural extension service is everywhere but the problem is expected to be the distance between farmers' home and the extension office. The hypothesis in the present study was that as the distance between home and agricultural extension office increases; farmers lack access to information and hence reduces the adoption of land management practices. Lack of better access to extension was reported to negatively influence the adoption of sustainable land management practices (Yesuf *et al.*, 2008; Luk, 2011).

Credit access: Access to credit was hypothesized to positively influence the decision to invest in land management practices. Availability of credit can significantly contribute to households in meeting their financial needs which can be used for the purchase of improved agricultural inputs (Tenaw and Islam, 2009; Anyiro and Oriaku, 2011; Abebe and Sewnet, 2014).

Tenure security: Farmers' feeling about land security was hypothesized to have a positive effect on their decision to adopt land management practices. Some authors (for e.g. Holden *et al.*, 2009**;** Amare, 2013) found an overall improvement in land management investments with improved tenure security**.**

Table 3.9 Description of explanatory variables included in the binary logistic model

Independent Variables	Label	Description	Effect
a) Socio-economic & Demographic attributes			
Age	Age of the Household Head in years	Continuous	+/–
Sex	Sex of the household head	Dummy: (1 for Male, 0 otherwise)	–
Education	Schooling Period in Number of years Studied	Continuous	+
Household size	Number of HH members who are currently living within the family	Continuous	+
Farmland size	The total size of Farmland in hectare	Continuous	+/–
Livestock	Livestock holding in tropical livestock unit (TLU)	Continuous	+
Off-farm activity	Access to off farm activity	Dummy: (1 if yes, 0 otherwise)	+/–
b) Biophysical factors			
Land Degradation Problem	Household's awareness about the severity of land degradation problem on his/her farm plot	Dummy: (1 if aware, 0 otherwise)	+
Slope steepness	Slope steepness of his/her farm plot as perceived by a householder	Dummy: (1 if steep, 0 otherwise)	+
Termite Infestation	Severity of termite infestation problem on his/her plot	Dummy: (1 if severe, 0 otherwise)	+
Plot distance	Mean distance from home to farm plots in walking minutes	Continuous	–
Plot number	Number of plots owned by a household (land fragmentation)	Continuous	–
c) Institutional variables			–
Extension Service	Distance between their home and agricultural extension office (in walking minutes)	Continuous	–
Credit service	Access to agricultural credit service	Dummy: (1 if yes, 0 otherwise)	+
Market distance	Distance between their home and the Nearest market (in walking minutes)	Continuous	–
Tenure Security	Land tenure security	Dummy: (1 if secured, 0 otherwise)	+

Chapter Four: Patterns and Drivers of LULC Change

4.1 LULC Classification

Following the results of LULC analysis, the study catchment was classified into five dominant LULC classes (Figure 4.1) and post-classification change detection was made for three study periods 1957-1987, 1987-2018, and 1957-2018. In the early study period (1957) about 38% (2606 ha) of Bururi micro-catchment was covered by grass and only 3% (203 ha) of the total area had been degraded (Table 4.). During the initial year of the study, degraded land was confined to few parts of the catchment and later expanded and dominated the middle and lower parts of the catchment (Figure 4.1). The proportions of the LULC types of forest, shrub, and agricultural land were 15.8%, 22.2%, and 21.2% respectively (Table 4.2). After about 60 years (in 2018), the forest cover declined to 9.1% whereas degraded land increased to 9.3% including the overgrazed fallow plots. According to this study, proportion of degraded land has steadily increased over the study period.

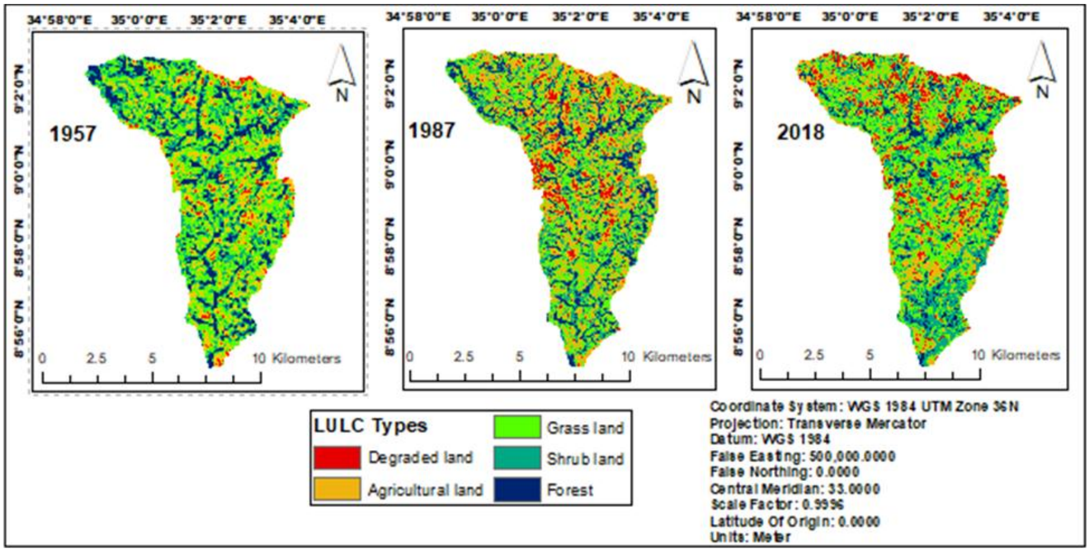


Figure 4.1 LULC Classification Maps for Study Periods

The result of accuracy assessment revealed that the overall accuracy for the year 2018 was 96.98% while the Kappa coefficient was 0.96, which showed a high level of agreement (Fleiss et al., 2003). Producer and user accuracies of the 2018 classified image ranged from 92.05% to 99.68% and 96.01% to 99.29%, respectively (Table 4.1). This indicates that both commission and omission errors are very low inferring acceptable classification accuracy. Producer's accuracy indicates how well the situation on the ground is mapped, whereas user's accuracy implies how reliable is the map. The latter one tells how often the class on the map will actually be present on the ground.

Table 4.1 Results of Accuracy Assessment

LULC Category	1957		1987		2018	
	Producer Accuracy (%)	User Accuracy (%)	Producer Accuracy (%)	User Accuracy (%)	Producer Accuracy (%)	User Accuracy (%)
Forest	91.06	91.62	100	99.85	96.01	99.68
Shrub land	80.69	85.24	100	100	99.29	92.05
Grassland	76.55	59.88	99.8	99.8	97.83	92.78
Agriculture	86.82	91.09	99.85	99.85	96.05	97.33
Degraded land	94.81	96.54	99.68	100	97.48	99.15
Overal Accuracy (%)	87.11		99.90		96.98	
Kappa Coefficient	0.84		0.99		0.96	

4.2 The Analysis of LULC Dynamics

The analysis of LULC dynamics was conducted for three study periods (1957-1987, 1987-2018, and 1957-2018) and the result is presented as percent change and annual rate of change. The net change area in hectares and percent change of LULC for the study periods are portrayed in Table 4.2.

Table 4.2 Net Change and Percent change of LULC in Different Study Periods

LULC Category	Area						Net & Percent Change of LULC						Annual rate of Change (% per yr)		
	1957		1987		2018		1957-1987		1987-2018		1957-2018				
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	1957-1987	1987-2018	1957-2018
Forest	1084	15.8	1033	15.0	625	9.1	-51	-0.7	-408	-5.9	-459	-6.7	-0.35	-3.14	-0.90
Shrub land	1524	22.2	1315	19.1	1652	24.0	-209	-3.0	337	4.9	127.4	1.9	-1.06	1.42	0.13
Grass land	2606	37.9	1898	27.6	2413	35.1	-710	-10.3	515	7.5	-192.5	-2.8	-2.27	1.50	-0.13
Agricultural	1459	21.2	2212	32.2	1549	22.5	753	10.9	-663	-9.6	90	1.3	2.97	-2.23	0.10
Degraded	203	3.0	420	6.1	638	9.3	217	3.2	219	3.2	434	6.3	5.18	2.61	1.87
Total Area	6878		6878		6878										

The 1957-1987 period: The analysis (Table 4.2) revealed that during the first study period more changes were observed for grassland (-10.3%) and agricultural land (+10.9) than for other LULC classes. During this period, the proportion of shrub land and forestland has decreased respectively by 3%, 0.7% whereas degraded land increased by 3.2%. This is an indication of expansion of cultivated and settlement land and a decrease in area of non-cultivated lands, such as grassland and forestland. The annual rate of change for forest cover, shrub land, and grassland was -0.35%, -1.06% and -2.27% per year. Contrary to this, degraded land increased at rate of 0.052% per year. As indicated in Table 4.2, degraded land has expanded suggesting that land was becoming out of use for cultivation, forest or grasslands purposes.

The 1987-2018 period: During the second period, forest cover and agricultural land showed reduction by -5.9% (-408 ha) and -9.6% (-663 ha), respectively. The reduction in forest cover in Bururi catchment implies that the pace of deforestation in the study area exceeds the afforestation rate. During this period the Ethiopian Evangelical Church Mekane Yesus Western Wollega Bethel Synod (EECMY-WWBS) project initiated a reafforestation program in the study catchment. On the other hand, shrubland, grassland, and degraded area increased by 4.9%, 7.5%, and 3.2%, respectively (Table 4.2). During this period (1987-2018), the growth in the area of grassland was due to increased area of abandoned fallow plots, which had been considered as grassland cover in the LULC classification. Moreover, the government of Ethiopia recently (in 2011) initiated a nationwide 30 days public work campaign for watershed management activities and this work have contributed to the rehabilitation of some fallow plots and degraded areas of Bururi micro-catchment.

The 1957-2018 periods: Generally, from 1957 to 2018, forest cover declined by 6.7%. The area of forest cover declined from 1084 ha (15.8%) in 1957 to 625 ha (9.1%) in 2018 (Table 4.2). Forest cover and grassland declined annually with rates of 0.9% and 0.1% respectively. In contrast, shrub land, agricultural land, and degraded land increased annually with rates 0.1%, 0.1%, and 1.9% respectively. The net change in forest cover between 1957 and 2018 was -459 hectares, with gains of 255 hectares and losses of 714 hectares (Figure 4.2). The proportion of grassland also showed a reduction by 2.8% (Table 4.2). As depicted in Figure 4.2, grassland lost 1478 hectares and gained 1286 hectares with a net change of-2.8% (-192 ha). The losses in grass cover were related to its conversion to cultivated and rural settlement land (9.8%), shrub land (7.2%), and degraded land (3.4%) (Table 4.2). In some areas of the study catchment, grasslands were converted to coffee shrubs and in some other areas overgrazed by livestock or highly eroded. The revegetated abandoned plots in the study area, have contributed to the gains (1286 hectares).

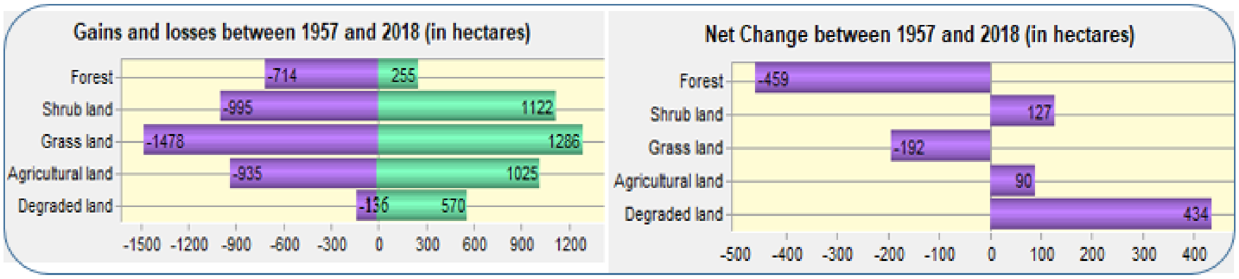


Figure 4.2 Gains, Losses, and Net Change observed between 1957 and 2018

In contrast, shrub land and agricultural land showed a slight increase by about 1.9% and 1.3% respectively. Shrub land lost 995 hectares (14.5%) and gained 1122 hectares (16.3%) between 1957 and 2018, with net change of 127 hectares (1.8%) (Figure 4.2). The increment of shrub land in the catchment is associated to the expansion of coffee shrubs, which is the dominant cash crop in the area. From 1957 to 2018, it was observed that agricultural land increased slightly. It gained 1025 hectares (14.9%) and lost 935 hectares (18.8%) with a net change of 90 hectares (Figure 4.2), which is linked to the expansion of bare/degraded land at the expense of other LULC types, mainly agricultural land and grassland.

In the period between 1957 and 2018, a remarkable change was observed in degraded land which showed an increment by 434 ha (6.3%). It rose from 203 ha (3%) in 1957 to 638 ha (9.3%) in 2018 (Table 4.2). Daniel (2008) also reported similar findings in the upper Dijo catchment of southern Ethiopia who documented the expansion of bare land. This result is also consistent with the findings of Hassen and Assen (2017) who reported increment of bare land area in *Gelda* catchment of Lake Tana watershed, Northern Ethiopia. Degraded land gained 570 hectares (8.3%) but lost 136 hectares (2.7%) with a net change of 434 hectares (Figure 4.2). This LULC type markedly increased because of continuous cultivation of land without fallow periods and appropriate land management. The information obtained from DWWAO (2017), revealed that because of improper agricultural practices, termite infestation, and topographic effects most areas of the watershed were eroded and converted to bare grounds. Similar findings were also reported in different parts of Ethiopia (Kindu *et al.,* 2013; Demissie *et al.*, 2017).

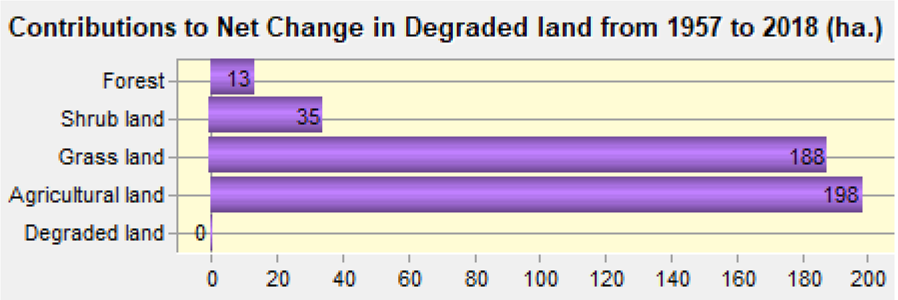


Figure 4.3. Contributions to Net change in Degraded land

Between 1957 and 2018, all LULC types have contributed to the net change in degraded land. The major contributions were made by agricultural land and grassland with inputs of 198 hectares and 188 hectares, respectively. The contribution of forest cover and shrubland to the degraded land was relatively low when compared to other LULC types (Figure 4.3). This implied that forest cover and shrubland resisted soil erosion and bareland exapnsion more strongly than the remaining LULC classes.

4.3 Patterns of Land use Land cover Dynamics

The pattern of LULC change was assessed using a LULC conversion matrix (Table 4.3). Accordingly, during the period between 1957 and 2018 forest cover gained 2.39%, 1.07%, 0.23%, and 0.03% from shrub land, grassland, agricultural, and degraded land, respectively. On the other hand, 6.5%, 2.69%, 0.97%, and 0.22% of the forest cover were converted into shrub, grass, agriculture, and degraded land, respectively. The reduction in forest cover in turn led to several socio-economic and environmental consequences such as a reduction in biodiversity (such as loss of plant species), soil erosion, and a change in micro-climate.

Table 4.3 LULC Change Detection Matrix for 1957 to 2018

		LULC Change To: (%)				
		Forest	Shrub land	Grassland	Agricultural land	Degraded land
LULC Change From: (%)	Forest	5.38	6.50	2.69	0.97	0.22
	Shrubland	2.39	7.69	8.34	3.00	0.73
	Grassland	1.07	7.22	16.39	9.85	3.37
	Agricultural land	0.23	2.38	7.02	7.62	3.97
	Degraded land	0.03	0.23	0.63	1.09	0.98

In 1957 the area covered by shrub was 1524 ha (22.2%) and in 2018 this number increased to 1652 ha (24%) with a net change of 127 ha (Table 4.2). Between 1957 and 2018, only 7.69% persisted as a shrub and the remaining 2.39%, 8.34%, 3%, and 0.73% were converted into forest, grassland, agricultural land, and degraded land respectively. On the other hand, this LULC type gained 6.5%, 7.2%, 2.38%, and 0.23% from forest, grassland, agricultural land, and degraded land, respectively (Table 4.3).

From 1957 to 2018 grassland was mainly converted into shrub land (7.22%), agricultural land (9.85%), and degraded land (3.37%). In contrast, grassland gained 8.34% from shrub land, 7.02% from agricultural land, and 2.69% from forest cover (Table 4.3). This implied that while some areas of grassland were converted into agriculture and bare ground, some other areas were reclaimed by grassland because of watershed management efforts.

The area of agricultural land increased from 21.2% in 1957 to 32.2% in 1987. However, this figure dropped to 22.5% in 2018 due to of its conversion to bare/degraded land (Table 4.2). The highest (3.97%) contribution to the expansion of bare/degraded land was made by agricultural land, followed by grassland (3.37%). Forest and shrub land contributed very small proportion (0.95%) to degraded land (Table 4.3). However, due to the soil and water conservation efforts, 1.09%, 0.63%, and 0.23% of the degraded land were reclaimed by agriculture, grassland, and shrub land respectively.

4.4 Farmers’ Perceptions of the Drivers of LULC Dynamics

The surveyed data presented in Table 4.4 revealed that both proximate and underlying factors played a role in causing the conversion LULC in Bururi catchment. The proximate or direct causes of LULC change perceived by the local farmers were agricultural activities (84.7%), termite infestation (82.4%), overgrazing (74.7%), land abandonment (68.8%), demand for specific crops (61.8%), and extraction of wood (47.6%). These are immediate actions and activities which directly affected the LULC of the study area. On the other hand, the perceived underlying/root causes of LULC dynamics that push proximate causes into immediate action (Geist and Lambin, 2002) were population pressure (51.8%), and land tenure system (53.8%).

Table 4.4. Drivers of LULC Dynamics as Perceived by Local Farmers in Bururi Catchment

Drivers of LULC Change	No	% of Cases
Demand for specific crops	105	61.8
Population growth	88	51.8
Agricultural Activities	144	84.7
Land abandonment	117	68.8
Over grazing	127	74.7
Wood extraction	81	47.6
Lack of effective land use Policy	91	53.5
Termite Infestation	140	82.4

**Total number of Valid Cases was 170 and multiple counts were possible*

4.4.1 Proximate Drivers of LULC Dynamics

Agricultural practices: Bururi catchment is an agricultural watershed dominated by mixed farming practices particularly subsistence rain-fed farming. During the first study period (1957-1987), the catchment was known by cereal crops production but starting from early 1990s with the rise of Ethiopian coffee price in the global market, the farmers inclined to the production of Arabica coffee and other cash crops. As depicted in Table 4.4, 84.7% of the surveyed farm households recognized that agricultural activities and associated problems were one of the major proximate drivers of LULC dynamics. The analysis of remote sensing data also revealed that 753 hectares (11%) of land area was added to agricultural land between 1957 and 1987 at the expense of other LULC categories. This and This shows that expansion of agricultural land forms a driver of LULC dynamics in the study are as in the other parts of Ethiopia (Berhan and Woldeamlak , 2014). In fact, this LULC type had shown reduction by 663 hectares during the second study period (1987-2018), due to the prevalence of land degradation particularly observed on agricultural land. The key informants and the focus group discussants also confirmed the expansion of agriculture into forested mountainous areas, river valleys, and steeper slopes.

The area of forest cover in the catchment also diminished and only few patches remained in the valleys of the watershed. The inappropriate use of chemical fertilizers also contributed to the expansion of bare land by increasing the area of abandoned plots due to crop failure. During the FGD, it was raised that the local farmers were applying chemical fertilizers without sufficient knowledge of the amount required and without soil test information.

Termite infestation: the key informants and focus group discussants have shown that termite infestation was a major threat to crop production in the study area and many farm plots were abandoned associated with termite infestation. Termites damaged crops, grazing land, and forest cover (exotic forest like *Grevillea, Tid*), which enhanced land degradation problem through the expansion of bare grounds. About 82% of the sampled respondents also confirmed that termite infestation was one of the major drivers of LULC change in Bururi catchment (Table 4.4). As studied (Abdulahi *et al.* 2010; Taye *et al.,* 2013) the problem of termites is more serous in the western part of Ethiopia, which is a symptom of land degradation and poor soil quality. As reported by Bezuayehu *et al.* (2002), vegetation loss leads to termite infestation, which in turn contributes to further vegetation loss and enhances soil erosion

Overgrazing: In addition to cereal and cash crop production, farmers in Bururi catchment were also engaged in livestock rearing. Although livestock density was not a problem in the catchment, the abandoned farm plots due to the prevailing land degradation had been exposed to free grazing which facilitates soil erosion and bare land expansion. Most of the interviewed farmers and FGD participants recognized that they partially abandoned their original farmland and migrated seasonally into marginal areas by withdrawing conservation practices from the degraded plots. Overgrazing as a driver of LULC change was also reported by 74.7% of the sample respondents.

Figure 4.4. Evidence of overgrazing in Bururi Catchment (field photo, 2017)

Land abandonment: As understood from the survey, nearly 68.8% of the respondents replied that farmland abandonment was one of the principal drivers of LULC dynamics in Bururi catchment (Table 4.4). Key informants and FGD participants also confirmed that most local farmers in the catchment abandoned their degraded farm plots and expand croplands into the surrounding marginal areas. In such cases, local farmers completely or partially destroy applied conservation structures from the abandoned plots and this cause the land to be degraded.

Demand for specific crops (Economic motive): About 61.8% of the sampled households responded that demand for specific crops (particularly Arabica Coffee) have caused LULC change in the study catchment. This was due to expansion of growing of Ethiopian coffee as cash crop, which locally served as major cash crop. In the study area, it was observed that coffee production is expanding mainly at the expense of forest and shrub land.

4.4.2 Underlying Drivers of LULC Dynamics

Lack of National Integrated Land Use Policy: About 54% of the surveyed farm households in Bururi catchment responded that the absence of land use policy in Ethiopia had a contribution to the LULC dynamics, particularly to the expansion of degraded areas. Key informants and focus group discussants confirmed that the farm households have been using land in uncontrolled and unplanned manner without identifying the best potential use and without safeguarding the natural environment. Except in urban areas having master plans, there was no land use plan which incorporate the rural areas. The country could not prepare an integrated land use plan, which helps to identify and allocate land for different purposes based on suitability, productivity, and sustainability. Therefore, a comprehensive national land use policy has to be formulated to prevent further of degradation natural resources.

Population pressure: According to FGDs and key informants, population pressure increased over time and this puts great pressure on the fragile and degraded resources of the watershed. The increase both in human and animal population number has led to a demand for more food crop, timber, settlement land and feed resources. For this reason, as discussed above, forest, bush, steeper and other marginal lands were turned to cultivation, settlement and grazing lands. Some traditional soil management methods, as in fallowing, which were considered as important methods of soil fertility maintenance in the older times were no more practiced in the study micro catchment. This situation exacerbated the problem of land degradation in the micro catchment. As indicated by other studies (Lesterlin and Giordano, 2007; Agidew and Singh, 2017), induced population pressure tended to alter the existing local land use patterns.

Based on a census conducted in 2007 by Central Statistical Agency (CSA) of Ethiopia, Kellem Wollega zone has a total population of 721, 389 (CSA, 2007). This number was projected to be 965, 099 in 2014; 990, 047 in 2015; 1,015,267 in 2016 and 1,040,585 in 2017 (CSA, 2013). The information gathered from FGDs and key informant interviews revealed that the rise in population growth is attributed to the natural population growth, resettlement, and immigration. There were resettlement schemes during the Derg regime and the EPRDF rule, which relocated huge number of people to this area from Wollo and Hararghe respectively. The information obtained from key informant interviews revealed that the spontaneous unplanned migration to this area from Hararghe is still continued and this might cause further increase in population and exert extra pressure on the ecosystem of destination area.

4.5 Socio-environmental Implications of LULC Dynamics

The conversion of LULC usually has an unintended consequence on the social and natural environment. The surveyed household heads identified seven major social and environmental implications of LULC dynamics in Bururi catchment. Increased soil erosion and soil fertility decline were the top ranked environmental implications perceived by 92.9% and 90% of the sampled respondents respectively. The information obtained from FGDs also reflect the severity of soil erosion and a decline of soil fertility, which seriously affected agricultural production. Other socio-environmental implications such as the expansion of degraded land, shortage of grazing land, and deforestation were also indicated by 80%, 76%, and 76% of the respondents respectively (Table 4.5).

Table 4.5. Perceived Effects of LULC Dynamics in Bururi Catchment, Western Ethiopia

Implications of LULC Dynamics	No	% of Cases
Increased soil Erosion	158	92.9
Expansion of Bare/degraded land	136	80.0
Deforestation	114	67.1
Shortage of grazing land	129	75.9
Soil fertility decline	153	90.0
Food insecurity	147	86.5
Seasonal out-migration	141	82.9

**Total number of Valid Cases was 170 and multiple counts were possible*

Soil Erosion: The focus group discussants indicated that soil erosion by water is becoming a major threat in the catchment and the problem is worsening due to termite-induced vegetation removal and the expansion of agricultural fields into mountainous areas. The change in land use land cover, particularly from natural vegetation to agricultural land, caused severe soil erosion and loss of top soil. Forest cover, shrub, and grassland can modify surface hydrology and reduce soil erosion. However, the loss of these land cover types and the expansion of farmland and bare soil aggravate soil erosion and consequently affect soil quality. The LULC change analysis revealed that forest cover and grassland showed a declining trend from 1957 to 2018 (Figure 4.2) which is evidenced by a negative net change. During field survey the researcher observed rills and gullies in areas of steep slope and low vegetation cover.

Figure 4.5. Evidences of soil Erosion in Bururi River Catchment (photo captured at Dhaye gomi village, 2017)

Decline of soil fertility: Land use changes especially cultivation in deforested and in unsuitable lands may rapidly diminish the quality of the soil. Discussants in the focus group discussions indicated that when the symptoms of land degradation and crop failure occurred, the local farmers attempt to increase productivity by utilizing chemical fertilizers. As perceived by the focus group discussants, the major reasons for the decline of soil fertility were continuous cultivation associated with shortening of fallow period and cultivation of steeper slopes. Continuous cultivation in the absence of soil fertility management has led to soil degradation that forced farmers to abandon their exhausted fields.

Shortage of grazing land: The information gathered from focus group discussions depicted that with the conversion of grass, shrub lands into other LULC types, the farmers in the study area faced shortage of animal feed, and they were forced to move their cattle seasonally with them into their new area of destination. During the discussion, the participants were complaining that their cattle were suffering from lack of feed in the old site and susceptible to diseases (like *Trypanosomiasis*) in the new area of settlement.

Deforestation: The information obtained from key informants and FGDs has revealed that the catchment was previously covered by dense forest and was used as sources of livelihood such as fruit gathering. Now with the changing pattern of forest cover, only few patches remained in the river valleys. Because of the scarcity of tree cover, honey production seriously declined in the past two decades. On the other hand, the LULC change induced seasonal migrants were clearing natural vegetation in their area of destination (around the national park) to acquire additional farmlands. This, in turn, disrupted the park ecosystem and transplanting the environmental degradation problem observed in their area of origin.

Social implications: About 86% and 83% of the surveyed households indicated that food insecurity and seasonal outmigration, respectively, were the principal social impacts of the LULC dynamics in Bururi watershed (Table 4.5). According to the report by UNCCD (2017), the expansion of degraded land will have direct and indirect effects on rural livelihoods by causing increased risk of crop losses and food insecurity.

Although the study catchment was supposed to be one of the areas having relatively better agricultural lands in the region, the information obtained from the district agricultural office revealed that the severity of soil erosion increased in the last 20 years and the watershed was suffering from loss of topsoil and extensive gullies. A complete decline in agricultural productivity was observed during the early 2000s and as a response to the prevailing food insecurity, the local administration was forced to allocate new farmlands to the vulnerable farmers. As estimated by the district agricultural and Natural Resources Management office (2017), more than 90% of the households from Bururi catchment have abandoned their degraded farmland and seasonally moved to adjacent woredas and kebeles to acquire better farmlands.

However, the out-migration adversely affected their livelihood in one way or the other. Only a very few proportion (about 10%) of the migrants have settled permanently in their area of new destination. The remaining 90% shuttles between the old and the new sites. As pointed out by the focus group discussions, since the new farm site is very far from their area of origin, they were compelled to walk a long distance (seven hours at an average for single trip). The old and the new plots are very far from each other, which caused farm fragmentation. This in turn associated affected labor utilization and adoption of soil conservation practices.

The seasonal migrants have also reported that they were suffering from lack of infrastructure (such as road, electricity) and social services (like clean water, health services, school, etc.) in their area of destination. As a result, children drop out schooling during the harvesting season and assist their parents. In addition, there is agro-climatic difference between the new and the old sites. They were living in *woina-dega* but now moved to kola agro-climate, which exposed the households to different lowland diseases. Those who migrated from *Dalle Bururi* and *Tullu-gopo* villages settled in *Gawa-echo* (near the *Dhati-welel* National Park) and the wild animals in the park area attacked their crops frequently.

Chapter Five: Effects of Land use/Cover Dynamics

This chapter deals with effects of Land use/cover dynamics on soil erosion risk, soil quality indicators, and soil organic carbon stock in Bururi catchment, western Ethiopia.

5.1 Effects of Land use/Cover Dynamics on Soil Erosion Risk

5.1.1 Result of the RUSLE Parameters

The spatial distribution maps of the five RUSLE parameters, which were used in the computation of soil loss rate and erosion risk are presented in this section. The result of the analysis demonstrated that the R-factor values range from 882 to 1087 MJ mm ha^{-1} h^{-1} yr^{-1}, with an average value of 984.5 MJ mm ha^{-1} h^{-1} yr^{-1} for the entire study catchment. The R-factor reflects the effect of rainfall to cause soil erosion in a given area and describes the sensitivity to erosion based on the amount and intensity of rainfall. The rainfall erosivity values showed a decreasing trend from western part of the catchment towards the eastern part, vertically displaying a uniform erosivity values.

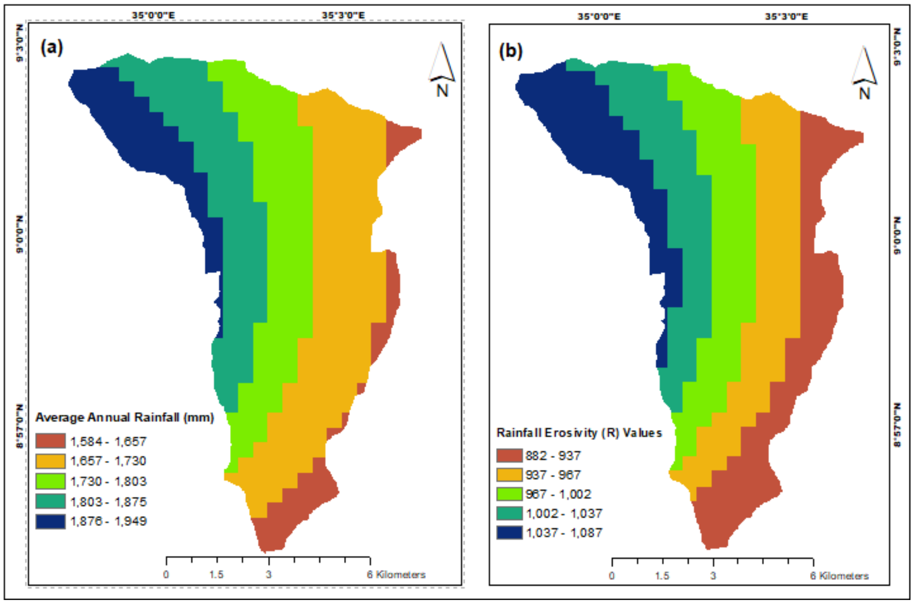


Figure 5.1 Average annual rainfall (a) and rainfall erosivity values (b) of Bururi Catchment

Soil erodibility (K-factor) is a numerical description of the intrinsic soil erodibility and a measure of the susceptibility of soil particles to detachment and movement by runoff. In this study, the K-factor map of Bururi catchment was generated by using soil texture and organic matter content data based on the RUSLE K-factor formula suggested by Khassaf and Rammahi (2018). As a result, the K-factor values of the study catchment varied between 0.012 to 0.019, and is relatively less erodible when compared to K-values of most Ethiopian soils, which ranges from 0.05 to 0.6 (FAO/UNDP, 1984). The highest K-factor value (0.019) was found along the south west coast and north eastern part of the study catchment.

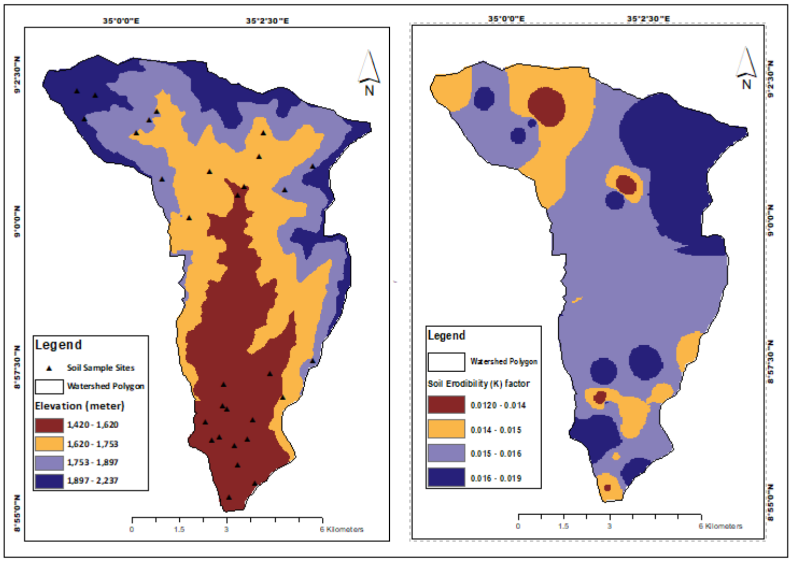


Figure 5.2 Soil Sample Sites and K Factor Map of Bururi Catchment in Western Ethiopia

The topographic factor (LS) of Bururi catchment was derived from 30-meter digital elevation model (DEM) using equation 9 and varied between 0.69 and 250.6 with an average value of 125.6. The lower LS-values were observed along the river valleys and the higher values occurred along the drainage divide, where the slope is relatively steep. The higher LS-factor values are associated to higher amount of erosion as slope length and steepness increase the speed of surface runoff (Morgan, 1995).

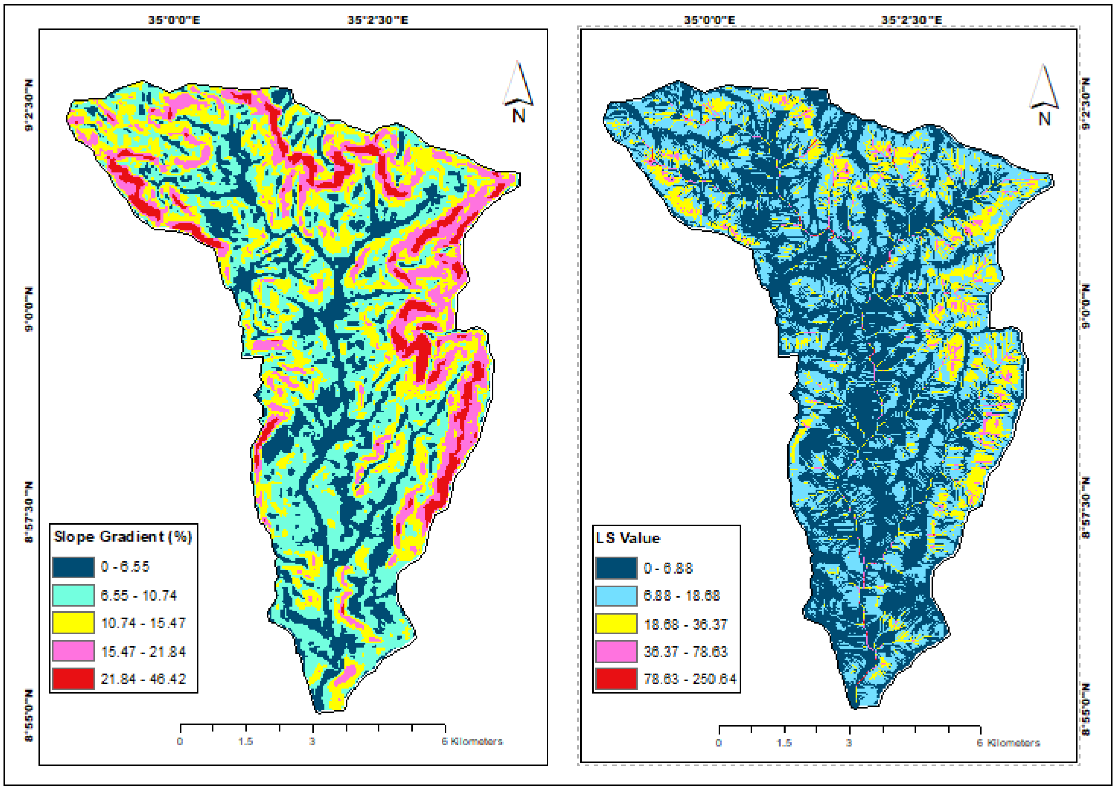


Figure 5.3 Slope in degree and LS factor of Bururi Catchment in Western Ethiopia

In RUSLE model, the cover management (C-factor) accounts for how land use and its management cause soil erosion (Kinnell, 2010). The various land use and land cover types have different role in controlling soil erosion. For instance, land covered by better vegetation protects the soil against erosion (Morgan, 1977) (and in contrary vegetation removal for different purposes leads to the depletion of soil organic matter (SOM) and increase soil erosion risk. To determine the C-factors in the present study, the LULC maps of 1957, 1987, and 2018 were used and this was done to examine effects of LULC dynamics on soil erosion rate.

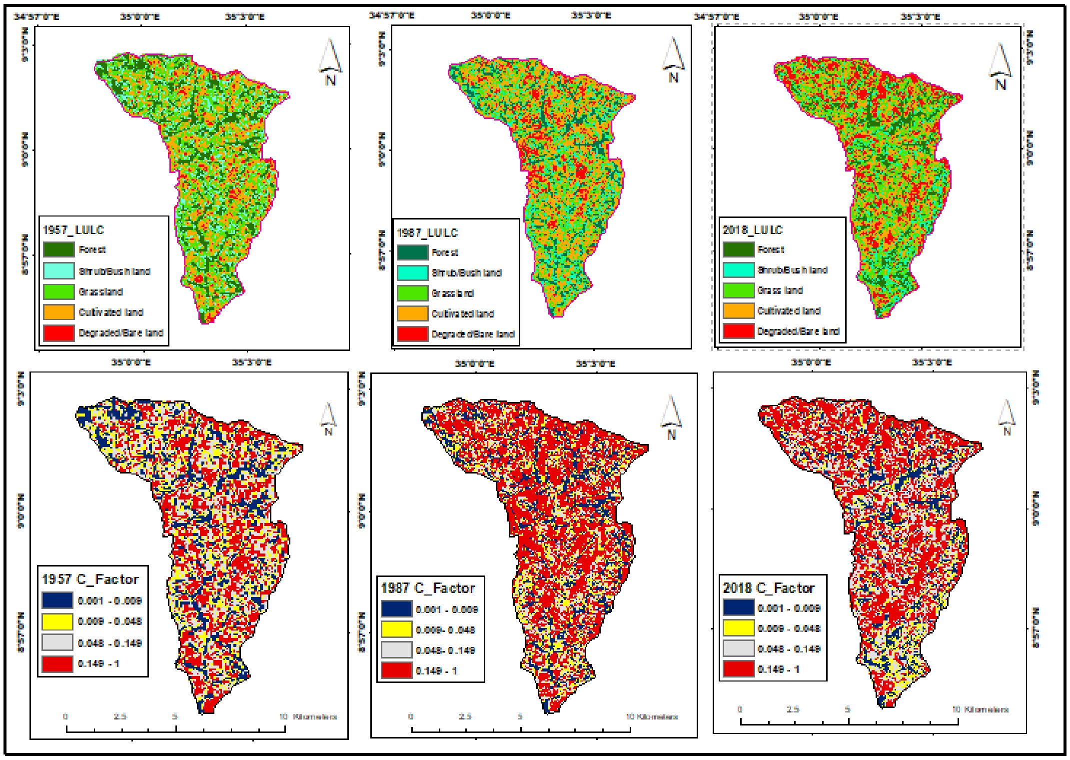


Figure 5.4 The LULC and C factor Maps of three periods (1957, 1987, & 2018) in Bururi Catchment in Western Ethiopia

The support practice (P-factor) is an expression of the total effects of conservation practices such as contour ploughing, terracing, and strip cropping. These practices mainly affect water erosion by modifying the flow pattern, direction of sub-surface runoff and by reducing the volume of runoff. The P-factor value decreases by implementing these conservation practices as they reduce soil loss. However, in the present study, due to lack of data on conservation practices, study area was classified into two (i.e. cultivated and non-cultivated) and progressively increasing numbers were assigned to the cultivated fields based on ascending topographic slope. Therefore, the P-factor values gradually increase with the rising of topographic slope. On the other hand, the P value of 1 is used for all the nonarable lands with no conservation measures (Morgan, 1980).

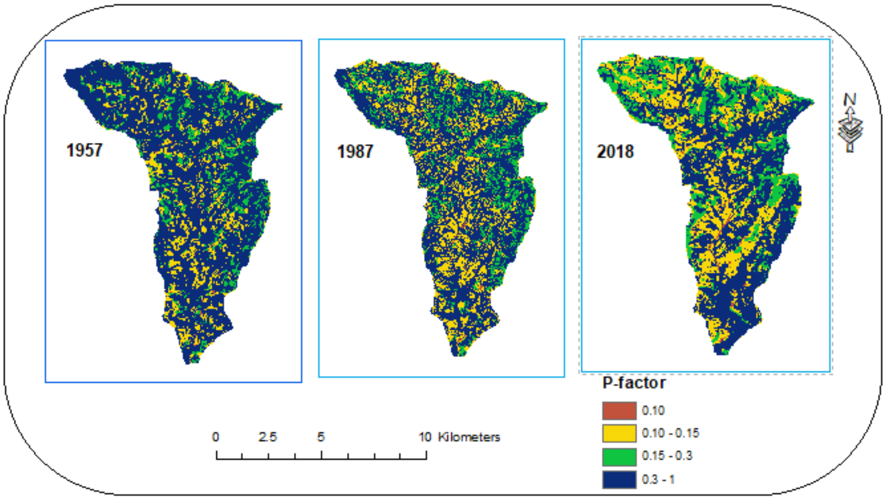


Figure 5.5 Spatial Distribution of P-factor Values in Bururi Catchment (1957-2018)

5.1.2 Effects of LULC Dynamics on Soil Erosion Rate in Bururi Catchment

From 1957 to 2018, considerable changes in LULC have occurred in different parts of Bururi catchment. The most notable changes were the reduction of important land cover to protect land from erosion such as shrub land, forest and grassland and a remarkable increase of bare land area. This process is supposed to induce soil erosion and further land degradation. The analysis of soil erosion risk in Bururi catchment revealed that the rate of soil erosion in 1957 ranged from 0 in many parts of the catchment to 116 t ha^{-1} y^{-1} in very few parts, with a mean annual soil loss of 41.04 t ha^{-1} y^{-1}. In 1987 soil erosion rate of 0 to 233 t ha^{-1} y^{-1} was recorded, with an average annual soil loss of 52.13 t ha^{-1} y^{-1}. However, in 2018 the rate of soil erosion was estimated to be between 0 in areas of riverine forest and 249 in the upstream and southwestern parts of the catchment, with a mean annual soil loss of 48.91 t ha^{-1} y^{-1} for the entire catchment (Figure 5.6). This mean value is still greater than the normal soil loss tolerance value (5 to 11 t ha^{-1} y^{-1}) suggested by Renard *et al.* (1996) and the national maximum tolerable soil loss estimate (18 t ha^{-1} y^{-1}) recommended by Hurni (1985).

The trend analysis of the temporal soil erosion dynamics revealed that mean annual soil loss in Bururi catchment increased by 27% from 1957 to 1987. During the second study period (1987-2018), erosion rate was reduced by 6.18%, which might be attributed to the implementation of some conservation works in the study area including the recent watershed management activities through public campaign. In general, from 1957 to 2018 the mean annual soil loss increased by

19.18%, which could be due to the decline of forest cover and associated organic matter content. The focus group discussion with local farmers also revealed some 3 or 4 decades ago the study area was covered by dense forest and soil erosion was also very slight. With the conversion of the land covered by natural vegetation (such as forest, shrubland, and grassland) into agricultural land and degraded land, the topsoil erosion increased as there are no roots to hold the soil.

The occurrence of higher mean annual soil loss above the soil loss tolerance rate (18 t ha^{-1} y^{-1}) recommended for the Ethiopia by Hurni (1985), imply the severity of soil erosion at Bururi catchment. The soil loss tolerance, the maximum soil loss that can occur from a given land without further degradation (Morgan, 2005), is the threshold of soil erosion for Ethiopia. A research conducted in Greece by Kouli *et al.* (2008) indicated, erosion rate above 1 t ha^{-1} y^{-1} will not be reversed within short period of time and it is estimated to take from 5 to 10 decades. In 2018, about 38% of the total area of Bururi catchment has experienced higher soil loss rate which exceed the soil loss tolerance value suggested by Hurni (1983). Thus, sustainable land management has to be carried out to reverse degradation and improve status of natural resources in the study area. Based on the country’s tolerable soil loss rate and available literature (Haregeweyn *et al*, 2017; Yesuph and Dagnew, 2019) the spatial and temporal variation in the magnitude of soil erosion of the study catchment was classified as very slight, slight, moderate, severe; and very severe erosion risk (Table 5.1).

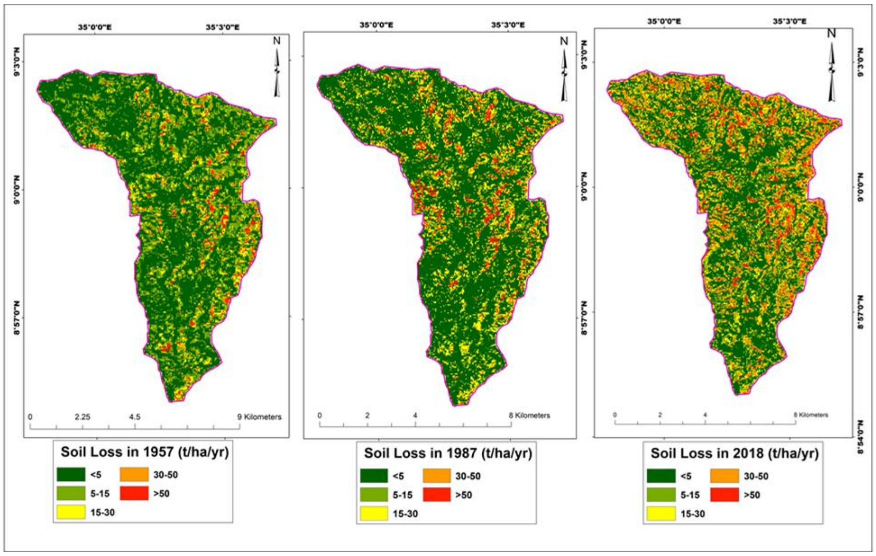


Figure 5.6 Spatial and Temporal variations of mean annual soil Loss in Bururi Catchment

As illustrated in Figure 5.6, in 1957, 5918 ha (86.04%) of the study catchment had experienced very slight to slight erosion with annual soil loss rate ranging from < 5 to15 t ha^{-1} y^{-1}. A small portion that covers 380 ha (5.52%) of the area in the upper and middle part of the catchment exhibited severe to very severe soil erosion. However, severe and very severe erosion had affected 1843 hectare of the total catchment which cover almost 5 times of the area affected during 1957 (Table 5.1). This dramatic change in soil erosion rate was mainly due to the change in land use/ land cover, since the other four factors (R-factor, K-factor, LS factor, and P factor) were controlled and remain unchanged during the analysis.

Table 5.1 Erosion Severity Classes with their corresponding areas and percentages

Soil Loss Rate (t/ha/yr)	**Severity Class**	**1957**		**1987**		**2018**	
		Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
<5	Very slight	4066	59.12	3644.19	52.98	3295	47.91
5 to 15	Slight	1852	26.93	975.95	14.19	986	14.34
15 to 30	Moderate	579	8.43	791.01	11.50	753	10.95
30 to 50	Severe	169	2.45	872.31	12.68	1255	18.25
>50	Very Severe	211	3.07	594.53	8.64	588	8.55
Total		6878	100	6878	100	6878	100

The computed mean annual soil loss for each land use/cover type revealed that in 2018, the highest erosion rates were recorded over the degraded and grass lands (4.60 and 4.27 t ha^{-1} y^{-1} respectively). Uncontrolled grazing on communal lands and fallow plots as well as extensive termite infestation were responsible factors for higher soil erosion rate on those LULC types in the catchment. In contrast, lowest erosion rates were observed in forest (1.19 t ha^{-1} y^{-1}) and shrub land (2.93 t ha^{-1} y^{-1}), which could be attributed to the role of vegetation cover in lowering water movement and reducing soil erosion.

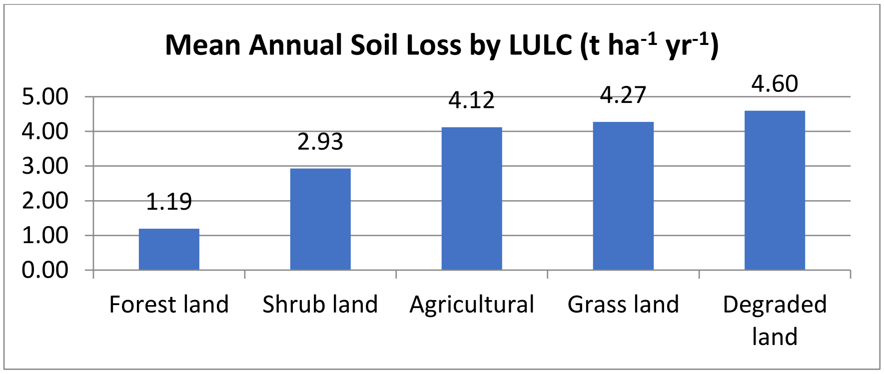


Figure 5.7 Mean Annual Soil Loss of each LULC type in 2018

Figure 5.7 Evidences of Overgrazing and degradation on the severity of Soil Erosion in Bururi Catchment (2018)

This study also attempted to examine the impact of LU/LC change on soil erosion rate from 1957 to 2018. Forest cover and cultivated lands experienced low rate, while shrubs, grass, and bare lands have increased rate of erosion (Table 5.2). Lower erosion rate in forest and cultivated land is probably linked to resistance of vegetation cover and better conservation practices on forest and cultivated lands respectively. On the other hand, the higher rate of erosion on shrubs, grass, and bare lands is likely caused by overgrazing and removal of vegetation cover from those land cover types. With increasing proportion of bare land (434 ha), overgrazed land, and decline of forest cover, the mean annual soil loss rate of the study catchment has as well increased from 41.04 t ha^{-1} y^{-1} in 1957 to 48.91 t ha^{-1} y^{-1} in 2018. By controlling all other factors of erosion and only manipulating the (C) factor, it was possible to conclude that the observed variation in the rate of soil erosion was highly attributed to LULC dynamics in the study area. Similar finding was reported by Lopez et al. (1998), which stated that when climate, soil type and topography are similar, differences in soil erosion rates are commonly related to variation in land use/land cover.

Table 5.2 LULC Change and Average Rate of Soil Erosion by years of study

LULC Category	Area of LULC				Net & Percent Change	
	1957		2018		1957-2018	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	1084	15.8	625	9.1	-459	-6.7
Shrub land	1524	22.2	1652	24.0	127.4	1.9
Grass land	2606	37.9	2413	35.1	-192.5	-2.8
Agricultural	1459	21.2	1549	22.5	90	1.3
Degraded	203	3.0	638	9.3	434	6.3
Mean Soil Loss Rate	41.04 t ha^{-1} y^{-1}		48.91 t ha^{-1} y^{-1}			

5.1.3 Prioritization of Micro-watersheds for Conservation Measures

The design and implementation of soil and water conservation measures require proper identification of severely affected areas by soil erosion. Therefore, the prioritization of micro-catchments for conservation was conducted based on the magnitude of mean annual soil loss. Thus, the study catchment was first classified into ten sub-catchments (SC-01 to SC-10) (Figure 5.8). Then, computation of the geometric intersection of soil loss (2018) and the classified sub-catchment maps were overlapped. Finally, the mean annual soil loss and areal coverage of each sub-catchment was computed (Table 5.3).

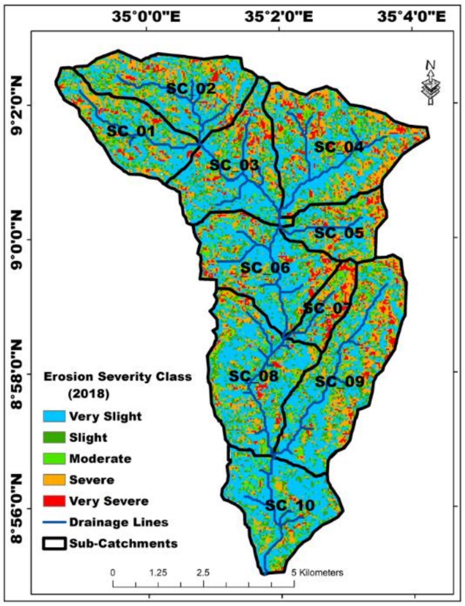


Figure 5.8 Micro-catchments of Bururi Catchment, Western Ethiopia

As depicted in Figure 5.8, SC-10 had very low severe erosion and most of its parts fell with in very slight erosion class. Therefore, the sub-catchment had the lowest mean annual soil loss (2.2 t ha^{-1} y^{-1}) and this might be mainly due to its low slope gradient and high forest cover in the area. However, red spots that have extensive areal coverage of severe and very severe erosion were observed in the middle and upper sub-catchments, and this largely attributed to the prevalence of steep slope, low forest cover, and limited land management practices. The prioritization of sub-catchments for conservation measures was conducted on the magnitude of mean annual soil loss of each sub-catchment (Table 5.3). As a result, the sub-catchments with the highest mean annual soil loss were given the first priority; the second and third priority had been given to sub-catchments the modest and lowest mean annual soil loss (Table 5.3).

Table 5.3 Prioritization of soil conservation measures in the sub-catchments of Bururi area, western Ethiopia.

Sub-Catchment	Total Area (Ha)	Erosion Severity Class										Mean Annual Soil Loss (t ha^{-1} yr^{-1})	Priority Class	Range of Mean Values
		Very Slight		Slight		Moderate		Severe		Very Severe				
		Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%			
SC_03	718.0	375.0	52.2	98.0	13.7	68.8	9.6	115.9	16.1	60.2	8.4	4.7	1st	4.19-6.50
SC_05	375.1	158.8	42.3	52.3	13.9	39.4	10.5	80.4	21.4	44.2	11.8	5.4		
SC_06	770.0	416.7	54.1	95.8	12.4	75.2	9.8	114.8	14.9	67.4	8.8	4.2		
SC_07	235.5	78.0	33.1	28.4	12.1	24.7	10.5	51.8	22.0	52.5	22.3	6.5		
SC_02	710.2	305.7	43.0	107.5	15.1	82.8	11.7	153.7	21.6	60.5	8.5	3.1	2nd	3.13-4.18
SC_04	985.7	417.4	42.3	134.5	13.7	105.4	10.7	231.9	23.5	96.5	9.8	4.0		
SC_09	1025.5	464.7	45.3	154.6	15.1	124.3	12.1	202.3	19.7	79.6	7.8	3.9		
SC_01	548.8	243.0	44.3	85.5	15.6	61.5	11.2	113.4	20.7	45.4	8.3	2.7	3rd	2.24-3.12
SC_08	858.3	439.4	51.2	133.6	15.6	98.8	11.5	132.9	15.5	53.7	6.3	2.3		
SC_10	651.4	396.4	60.9	95.6	14.7	72.7	11.2	57.9	8.9	28.7	4.4	2.2		
Total	**6878**	**3295**		**986**		**754**		**1255**		**589**				

Among the ten micro-watersheds, the mean annual soil loss was relatively high (4.19-6.5 t ha^{-1} y^{-1}) in SC-03, SC-05, SC-06, and SC-07 (Table 5.3). Thus, the first priority of soil and water conservation intervention has to be conducted in these micro-watersheds. To the contrary, the 3rd/last priority of conservation measures have to be carried in SC-1, SC-08 and SC-10 due to the prevalence of the lowest mean annual soil loss of less than 3.13 t ha^{-1} y^{-1}. As it has been confirmed during the field survey, the sub-catchments with the first priority of soil conservation measures are geographically located in Tullugopo, Darbowabera, Dallebururi, and Dhayegommi rural villages. The majority of the farm households living in these sub-catchments are seasonally migrating to other new areas. However, farming households who could not move to other areas due to old age and other reasons were cultivating degraded soils. The seasonal migrant farm households did not totally leave their previous farmlands. However, they have withdrawn conservation practices in their former farmlands and aggravated the degradation of soils. Therefore, the abandonment of soil conservation practices on some arable lands contributes to the further expansion of severe soil erosion in the area.

5.2 Effects of LULC Dynamics and Topographic Elevation on Selected Soil Quality Indicators

5.2.1 Selection of Soil Quality Indicators

The result of Principal component analysis (PCA) revealed that fourteen measured soil attributes (0-20 cm depth) were grouped into three main components with Eigen value greater than the Kaiser’s criterion of 1 and cumulatively explained about 68% of the total variance. The three retained principal components were associated to one or more soil functions such as aeration, moisture retention, storing and cycling nutrients, physical **s**tability and support, sustaining biological diversity and productivity (USDA, 2015). Table 5.4 presented the factor loadings after Varimax rotation with Kaiser Normalization and only the variables with factor loadings > 0.7 were selected from each principal component (Tesfahunegn, 2014; Teferi *et al.,* 2016; Tesfahunegn and Gebru, 2020). Principal Component-1 explained 26.85% of the variance with Eigenvalue of 3.76 which included high positive factor loadings from OM (0.753) and negative factor loading from sand (-0.772) and BD (-0.779). This emanates from strong significant correlation of OM with sand (r=-0.654); and BD (r= -0.715). This first PC is named as “moisture & nutrient holding capacity” factor based on the critical indicators in this group.

Organic matter enhances soil quality by improving nutrient and water retention capacity, and microbial activity (Arshad and Coen, 1992). It improves soil fertility and reduces erosion by influencing aggregation (Doran *et al.,* 1996; Sikora and Stott, 1996). Bulk density is also an important measurement used to assess the amount of soil compaction. According to Arshad *et al.* (1996), higher bulk density values negatively influence moisture retention capacity, water and nutrient cycling, and root development.

Table 5.4 The Rotated Component Matrix and communality estimates (factor loadings above 0.7 were retained)

Soil Attribute	Principal Component 1	2	3	Communalities Extraction
Sand (%)	**-0.772**	-0.211	-0.123	0.65
Clay (%)	0.524	0.529	0.206	0.60
Bulk Density (g/cm^3)	**-0.779**	-0.266	-0.255	0.74
EC (mS/cm)	-0.112	0.557	0.567	0.64
Soil pH	0.232	**0.855**	0.131	0.80
Organic Matter (%)	**0.753**	0.501	0.121	0.83
Total Nitrogen (%)	0.139	0.258	**0.817**	0.75
Available P (ppm)	0.364	0.060	**0.836**	0.83
CEC (meq/100 g)	0.279	**0.838**	0.143	0.80
Na^+ (meq/100 g)	0.596	-0.071	-0.092	0.37
K^+ (meq/100 g)	0.582	0.350	-0.005	0.46
Ca^{2+} (meq/100 g)	0.568	0.500	-0.108	0.58
Mg^{2+} (meq/100 g)	0.584	0.546	-0.244	0.70
Carbon to Nitrogen Ratio	0.248	0.115	**-0.796**	0.71
Eigenvalues	3.758	3.151	2.576	
% of Variance	26.85	22.50	18.40	
Cumulative Variance (%)	26.85	49.35	67.75	

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

The second principal component (PC2) included positive factor loadings of pH (0.855) and CEC (0.838) which explained 22.5% of the variance in the soil quality parameters (Table 5.4). This is the result of strong correlation (*r*=0.765) between CEC and pH parameter. The retention of nutrients and the buffering capacity of the soil depend on the soil's cation exchange capacity. Similarly, soil pH reflects the hydrogen ion (H^+) activity in the soil solution and defines most chemical and biological activity thresholds. Nutrient availability depends highly on soil pH (Arshad and Coen, 1992). It also influences biomass production and its return to the soil (Shukla *et al.,* 2006). Therefore, based on all these characteristics the second PC was labeled as “Nutrient supply and storage” factor.

With regard to PC3, the high loading soil parameters were TN (0.817), Av. P (0.836) and C/N (-0.796), which explained 18.4% of the total variance in soil quality with eigenvalue of 2.58 (Table 3.2). This emanates from high correlation between TN and Av. P (r=0.744) as well as TN and C/N (-0.525). Nitrogen and Phosphorus are essential soil parameters used in soil quality assessment that limits agricultural yields in soils (Cardoso *et al.,* 2013). Since, available P is the high loaded parameter in this group (Table 5.4), it is referred to as “soil macro-nutrient availability” factor. Phosphorus is a major essential plant macro-nutrient which is needed for plant growth and development (Koralage *et al.,* 2015). Nitrogen is also a key major nutrient influencing crop production (Gupta, 2016).

Table 5.5 Pearson correlation coefficients of the physical and chemical properties

	Sand	Clay	BD	EC	pH	OM	TN	Av. P	CEC	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	C/N
Sand (%)	1													
Clay (%)	-.649**	1												
Bulk Density (g/cm^{3})	.592**	-.648**	1											
EC (mS/cm)	-0.033	.374*	-0.280	1										
Soil pH	-.393*	.579**	-.477**	.477**	1									
Organic Matter (%)	-.654**	.609**	-.715**	0.287	.549**	1								
Total Nitrogen (%)	-0.193	0.191	-0.307	.498**	0.315	0.360	1							
Available P (ppm)	-.383*	.404*	-.492**	.381*	0.270	.421*	.744**	1						
CEC (Cmolc kg^{-1} soil)	-.413*	.560**	-.437*	.424*	.765**	.641**	.406*	0.303	1					
Na^{+} (Cmolc kg^{-1} soil)	-0.235	0.122	-.426*	0.080	0.166	0.326	-0.002	0.035	0.153	1				
K^{+} (Cmolc kg^{-1} soil)	-.396*	.408*	-.451*	0.155	.387*	.649**	0.189	0.198	.477**	0.340	1			
Ca^{2+} (Cmolc kg^{-1} soil)	-.553**	.382*	-.421*	0.042	.500**	.758**	0.265	0.090	.511**	0.221	.416*	1		
Mg^{2+} (Cmolc kg^{-1} soil)	-.507**	.536**	-.579**	0.061	.535**	.590**	0.080	0.049	.532**	0.281	.424*	.647**	1	
Carbon to Nitrogen	-0.059	0.010	-0.050	-0.350	0.026	0.208	-.525**	-.438*	0.071	0.191	0.168	0.163	0.330	1

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).

The estimated communalities of SQ parameters presented in table 5.4 revealed that the contribution of individual parameters ranged from 37% to 83% of the total variance. More specifically, the SQ indicators explained >80% in OM, Available P, pH, and CEC. Organic matter (OM) is important dynamic factor and affects soil CEC, available P and pH. It was reported to influence available P in soil solution by complexing P from adsorption site and increase the movement of inorganic P, by decreasing chemical activity of iron and aluminum (Materechera and Mkhabela, 2001). Secondly, >70% was explained in TN, BD, C/N, and Mg^{2+}. In addition, >60% was explained by sand, EC and clay, which is an important soil physical quality indicator. Lastly, >45% was explained in Ca^{2+} and K^{+}. Compared to other soil parameters, exchangeable Na^{+} was the least important soil quality attribute due to the lowest (37%) communality estimates (Table 5.4). Estimated communalities depict how much a variable has in common with the remaining variables in the analysis (Meyers *et al.*, 2006; Johnson and Wichern, 1998; Yong and Pearce, 2013).

The loading plot in Figure 5.9 shows the relationship between the PCs and the Soil quality parameters, which helped to identify which soil quality parameters, have the largest effect on each component. The loadings ranged from -1 to 1, and loadings close -1 or 1 indicate that the soil parameters strongly influence the principal component. Loadings close to 0 implies the variable has a weak influence on the component.

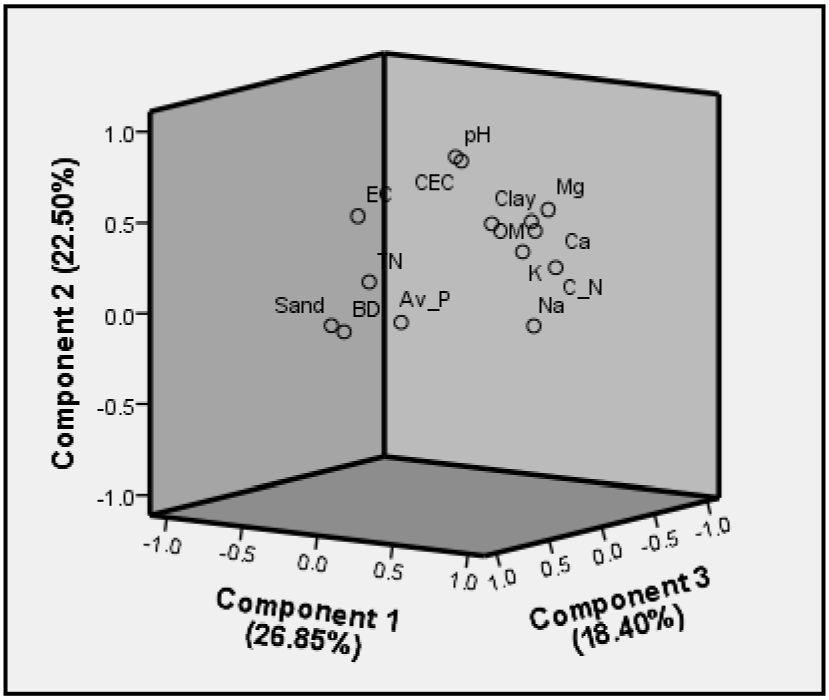


Figure 5.9 Component Plot in Rotated Space, showing the Relationships among Soil Quality Parameters in PC1, PC2, and PC3

Results of ANOVA

The results of ANOVA revealed statistically significant effects of LULC, topographic elevation, and interaction effects on the three principal components. Therefore, all the retained variables in the three significant components (soil quality indicators), were considered for further analysis in multivariate ANOVA. Finally, the principal components selected to better explain about 68% of the variability in soil quality were moisture holding and infiltration capacity (sand content, BD, OM), Nutrient retention and availability factor (pH, CEC), and soil macro-nutrient availability factor (TN, Available P, C/N ratio). Other similar studies in Ethiopia (Tesfahunegn, 2014; Teferi *et al.*, 2016; Tesfahunegn and Gebru, 2020) also reported OM, pH, BD, and CEC as important parameters for soil quality assessment.

5.2.2 The Analysis of Main Effects and Interaction Effects LULC and Elevation

As depicted in Table 5.6, the four multivariate tests produced significant results with slight differences in level of significance, and we preferred the most commonly reported statistic, the Wilks' Lambda and associated values in corresponding columns. The result showed significant main effect of LULC [*F* (12, 61.144) = 4.317, *P* = 0.000; Wilks' Lambda = 0.197; *partial eta squared* = 0.418]; topographic elevation [*F* (3, 26) = 5.742, *P* = 0.004; Wilks' Lambda = 0.601; *partial eta squared* = 0.399]; as well as interaction effect [*F* (27, 53) =3.714, *P* = 0.000; Wilks' Lambda =0.045; *partial eta squared* = 0.643].

Table 5.6 Result of Multivariate Tests

Effect	Multivariate Tests	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
LULC	Pillai's Trace	0.871	2.557	12.000	75.000	0.007	0.290
	Wilks' Lambda	0.197	4.317	12.000	61.144	0.000	0.418
	Hotelling's Trace	3.727	6.730	12.000	65.000	0.000	0.554
	Roy's Largest Root	3.632	22.703	4.000	25.000	0.000	0.784
Topographic Elevation	Pillai's Trace	0.399	5.742	3.000	26.000	0.004	0.399
	Wilks' Lambda	0.601	5.742	3.000	26.000	0.004	0.399
	Hotelling's Trace	0.663	5.742	3.000	26.000	0.004	0.399
	Roy's Largest Root	0.663	5.742	3.000	26.000	0.004	0.399
LULC * Elevation	Pillai's Trace	1.556	2.396	27.000	60.000	0.003	0.519
	Wilks' Lambda	0.045	3.714	27.000	53.212	0.000	0.643
	Hotelling's Trace	9.783	6.039	27.000	50.000	0.000	0.765
	Roy's Largest Root	8.748	19.44	9.000	20.000	0.000	0.897

The effect size statistic revealed that the interaction effect of LULC and topographic elevation (partial eta squared=0.643) was very large whereas the main effects of LULC (partial eta squared=0.418) and topographic elevation (partial eta squared=0.399) were medium as per the rating table provided by Cohen (1988). According to the generally accepted criteria of Cohen (1988), values of partial eta squared ranges from 0 to 1, and a value of 0-0.2 is small effect; 0.5 is medium; and greater than 0.5 is a large effect (Cohen, 1988). Since the multivariate tests showed a significant result for all independent variables, we proceed to investigate the soil quality indicators, which were specifically influenced by LULC, topographic elevation, and/or the combined effects.

Table 5.7 Mean Values of Soil Quality Indicators (0-20 cm depth) as Identified by PCA (N=30)

LULC	Elevation	Sand (%)	Clay (%)	BD (g/cm^3)	EC (mS/cm)	pH	OM (%)	TN (%)	Av. P (ppm)	CEC (Cmolc kg^{-1} soil)	Na^+ (Cmolc kg^{-1} soil)	K^+ (Cmolc kg^{-1} soil)	Ca^{2+} (Cmolc kg^{-1} soil)	Mg^{2+} (Cmolc kg^{-1} soil)	C/N
Agricultural	Lower	30.00	38.67	0.92	0.04	4.97	3.70	0.22	6.80	33.17	0.45	0.34	4.93	4.37	16.80
	Upper	29.67	36.00	1.39	0.03	5.02	2.37	0.23	3.60	26.59	0.32	0.17	6.22	3.60	11.06
Degraded	Lower	34.67	29.00	1.39	0.07	4.50	2.67	0.20	4.67	21.03	0.20	0.12	2.83	1.90	13.33
	Upper	44.67	28.33	1.53	0.04	4.42	2.08	0.17	2.80	16.13	0.21	0.13	2.98	1.79	13.82
Forest	Lower	19.33	54.00	0.86	0.08	5.97	5.44	0.94	8.67	54.93	0.44	0.90	9.23	5.00	14.26
	Upper	29.33	44.67	0.98	0.03	5.27	4.63	0.26	3.87	33.98	0.39	1.17	9.23	4.70	21.48
Grassland	Lower	25.00	51.00	1.23	0.03	5.12	3.59	0.32	7.13	31.76	0.19	0.12	6.60	2.98	11.09
	Upper	37.00	28.00	1.45	0.05	5.07	3.52	0.20	3.47	43.47	0.24	0.27	7.80	3.20	17.36
Shrub land	Lower	23.33	57.33	0.91	0.17	6.10	5.01	0.53	7.67	47.83	0.38	0.93	8.23	4.17	10.71
	Upper	26.67	33.33	1.24	0.04	5.53	4.14	0.19	3.20	35.47	0.60	0.38	8.53	4.50	23.05
Overall LULC	Lower	26.47	46.00	1.06	0.08	5.33	4.08	0.44	6.99	37.75	0.33	0.48	6.37	3.68	13.24
	Upper	33.47	34.07	1.32	0.04	5.06	3.35	0.21	3.39	31.13	0.35	0.43	6.95	3.56	17.35
	Average	29.97	40.03	1.19	0.06	5.20	3.72	0.33	5.19	34.44	0.34	0.45	6.66	3.62	15.30

5.2.3 Effects of Land use/cover and Topographic Elevation on Soil Quality Indicators

In this study, the dynamics of LULC showed a remarkable effect on selected soil quality indicators. The multivariate ANOVA revealed that LULC had statistically significant effect ($p<0.05$) on sand content, BD, OM, pH, CEC. Whereas the effect of LULC on soil macro-nutrient availability (TN, Available P, C:N) was found insignificant ($p>0.05$). On the other hand, topographic elevation showed a remarkable impact on sand content, BD, OM, and available P. The result presented in Table 5.8 revealed that the effect of elevation on nutrient retention and availability component (PC_2) was statistically insignificant ($p>0.05$).

5.2.3.1 Effects on Soil Particle Size Classes

Contents of sand fraction in Bururi catchment revealed a statistically significant ($P<0.01$) variation across the five LULC types (Table 5.8). Tukey's HSD multiple comparison test revealed that significant mean differences of sand fraction were mainly observed between degraded land and forest soils with a mean difference of 15.3% as well as between degraded land and shrub land (mean difference=14.7%). A high and low mean sand content were respectively found in degraded (39.7%) and under forest cover soils (Table 5.7). This is because fine particles (clay and silt) are washed out on degraded soils, whereas these are protected on forest lands.

Therefore, this indicates erosion resistance capacity of the forest land. The lower vegetation cover in degraded lands could contribute to the washing out of the finer soil materials by water erosion. As degraded lands have very low or no vegetation cover, their soils are more susceptible to erosion and lost the finer soil particles as compared to soils of other LULC types. According to Lobe *et al.* (2001), the conversion of natural ecosystem into managed land use system is known to deteriorate soil properties making the land more susceptible to erosion, which can modify soil properties such as changing soil texture.

On the other hand, the effect of topographic elevation on the sand content was statistically significant ($P<0.01$) in the present study, demonstrating a remarkable difference of sand fraction between the upper and lower altitude sites. As displayed in Table 3.4, a relatively higher sand content was recorded in the upper elevation (33.47%) compared to that of the lower elevation, which confirmed the findings of Haycho *et al.* (2015), who reported spatial variations of sand content across elevation ranges of the Bale mountains. They found higher mean percentage of sand in the upper elevation compared to that of the lower elevation. In addition to this, Najar *et al.* (2006) also reported increasing proportion of sand content with an increase in elevation gradient. Furthermore, in their research conducted in Pulwama district of India Wani *et al.* (2017) also reported the same finding in that sand content increased significantly with the altitude.

The higher level of sand content in the upper elevation could be associated to the geomorphic process, which selectively remove and transport the finer soil particles from the higher altitude area and allow the accumulation of coarser (sand) particles in the lower elevation site. As the area under study receives high amount of annual rainfall, the resultant soil erosion on steep slopes cause the translocation of huge finer particles from the upper elevation area especially during the rainy summer season. Although the spatial variation of particle size is the result of effects of natural factors, it is also evident that land management practices and farming activities also contribute to these variations.

5.2.3.2 Effects on Soil Bulk Density Values

Soil bulk density values revealed statistically significant ($P<0.01$) variation with respect to LULC but did not show significant difference in relation to the interaction effect. Regardless of topographic elevation, the soil under natural forest had the lowest mean value of bulk density (0.92 g/cm3) compared to that of the other land use/cover types. Whereas soils under degraded land had a higher level of bulk density values (mean=1.46 g/cm3). Lower bulk densities values are common in soils of less anthropogenic interferences such as native forests where the greater levels of soil organic matter permit a better aggregation of soil particles, improving the soil structure.

The highest bulk density observed in degraded land was due to the fact that most degraded lands in Bururi catchment were previously agricultural lands which had been abandoned for some years and were exposed to free grazing, followed by soil compaction resulting in higher values of bulk densities. The post hoc multiple-comparison test revealed that the significant mean differences of bulk density were observed with the conversion of forest and shrub land into degraded land (Table 3.6). The change from forest to grassland also exhibited a mean difference in bulk density values. The mean values of bulk density increased by 0.54 g/cm3, 0.38 g/cm3, and 0.42 g/cm3 with the conversion of forest to degraded, shrub land to degraded, and forest to grassland respectively (Table 5.9). The relatively lower bulk density in forest soils is associated to the presence of high organic matter, which makes the soil loose and porous, thereby reducing its compactness (Celik, 2005). Other studies (Fantaw and Abdu, 2011; Teferi *et al.* 2016) also found an increase in bulk density after the conversion of native woodlands into farmland and grazing land. According to Kakaire *et al.* (2015), a higher soil bulk density value indicates less infiltration and less amount of water would be retained in the soil at field capacity. In contrast, a lower soil bulk density value implies soils are less compacted and are able to retain much water. The effect of topographic elevation was also observed on soil bulk density of Bururi catchment. Bulk density values significantly ($P<0.01$) varied between the two elevation categories. In line with this, Kidanemariam *et al.* (2012); Teferi *et al.* (2016); Wani *et al.* (2017) also reported a statistically significant variation of soil bulk density with respect to topographic elevation.

Table 5.8 Tests of Between-Subjects Effects

Soil Quality Indicator	Source of Variation					
	LULC		Elevation		LULC * Elevation	
	F	Sig.	*F*	Sig.	*F*	Sig.
Moisture and Nutrient Holding (PC_1)						
Sand (%)	5.514	0.004**	8.913	0.007**	1.002	0.429
Bulk Density (g/cm3)	6.124	0.002**	11.035	0.003**	0.714	0.592
Organic matter (%)	76.938	0.000***	43.319	0.000***	3.424	0.027*
Nutrient Supply and Storage (PC_2)						
Soil pH	3.750	0.020*	1.171	0.292	0.375	0.824
CEC (Cmolc kg^{-1} soil)	4.671	0.008**	2.354	0.141	1.550	0.226
Macro-nutrient availability (PC_3)						
Total Nitrogen (%)	1.306	0.302	3.142	0.092	0.927	0.468
Available P (ppm)	1.124	0.373	21.735	0.000***	0.449	0.772
Carbon to Nitrogen (C/N)	0.584	0.678	3.276	0.085	1.860	0.157

* Significant at the 0.05 level ; ** Significant at the 0.01 level; *** Significant at the 0.001 level

5.2.3.3 Effects on Soil Organic Matter Content

In this study, LULC and topographic elevation separately and jointly exerted significant effect on soil organic matter content. As depicted by the MANOVA result, the interactive effect was statistically significant ($P<0.05$) suggesting that the effect of LULC on organic matter content depends on topographic elevation. Overall, the LULC in the lower altitude had higher organic matter (4.08%) compared to the LULC in the upper elevation (3.35%) (Table 5.7). This could be due to the influence of environmental factors on soil organic carbon concentration along altitudinal belts. With respect to the interactive effects, the highest organic matter content (5.44%) was observed in forest soils of lower elevation, whereas the lowest value (2.08%) was recorded in degraded land. Regardless of topographic elevation, the main effect of LULC on SOM was highly significant (P<0.001) and therefore the mean values of SOM were higher (5.04%) in forest soils but lower (2.37%) in soils of degraded land (Table 5.7). This is consistent with other previous findings (Abbasi *et al.* 2007; Asmamaw and Mohammed, 2013; Kalu *et al.*, 2015; Teferi *et al.,* 2016; Guteta and Abegaz, 2017); Molla and Yalew, 2018) who reported a significant variation of organic matter content with respect to LULC types. The mean value of soil organic matter in this study displayed a pattern of forest>shrub land>grassland>agricultural land>degraded land.

The relatively lower organic matter in degraded land could be associated to a reduction in total organic inputs or less litter fall as well as the its loss by soil erosion induced by little vegetation cover. As evidenced by the post hoc multiple comparison test, forest, shrub land, and grassland had higher organic matter compared to agricultural and degraded soils (Table 5.9). There was a mean difference of 0.66% and 1.18% organic matter with a conversion of agricultural land and shrub land to degraded land respectively. Following the conversion of forest into agricultural land, degraded land, and grassland land, soil organic matter showed significant variation by 2%, 2.7%, 1.5%, respectively. The conversion of shrub land into agricultural land, degraded, and grassland also showed a mean difference of 1.5%, 2.20%, and 1%, respectively.

Topography is one of the major factors affecting the distribution of SOM content. The present study demonstrated that the effect of topographic elevation on soil organic matter was statistically significant ($P<0.001$), implying the variation of organic matter content along the two elevation categories. This result is congruent with the findings of Lemenih and Itanna (2004) Kidanemariam *et al*. (2012); Yüksek *et al. (*2013); (Teferi *et al.* (2016); and Wani *et al.* (2017) who reported the existence of considerable differences in the amount of soil organic matter along elevation gradients. As depicted in Table 5.7, the mean organic matter content of the overall LULC types was relatively higher (4.08%) in the lower elevation compared to that of the upper elevation (3.35%)which agrees with the findings of Teferi *et al.* (2016) who reported higher soil organic matter content in the headwater area of the Blue Nile basin of Ethiopia. In Contrast to this, Kidanemariam *et al.* (2012) and Wani *et al.* (2017) reported higher OM in higher altitude compared to that of the lower elevation. These contradictory results suggest the presence of variations in the characteristics of studied ecosystems, which also control the relationship between soil organic matter and altitude.

The difference in soil organic matter content between the upper and lower elevation could be attributed to variations in local climate, which affects the decomposition and mineralization of plant litter. Accordingly, the available amount of soil organic matter could be associated to quantity and type of plant residues that are returned to the soil in that particular environment (Nanganoa et al., 2019). With respect to local climate, the relatively higher temperature in the lower elevation areas may facilitate the decomposition of organic matter and thereby reduces its accumulation. In general, the change in topographic elevation can influence soil organic matter by controlling local climate, soil erosion, soil water balance, and depositional process.

5.2.3.4 Effects on value of Soil pH

In the present study, soil pH value showed significant *($P<0.05$)* spatial variation across the five LULC types (Table 5.8), but the interaction effect was non-significant ($P>0.05$). This is in agreement with several authors including Abbasi *et al.* (2007); Molla *et al.* (2009); Asmamaw and Mohammed (2013); Negasa *et al.* (2017)**;** Tellen and Yerima (2018) who found a significant variation of soil pH with a change in land use/cover types. In contrast to this, Bewket and Stroosnijder (2003); Moges *et al.* (2013); Teferi *et al.* (2016) reported a non-significant difference in soil pH across different land use/cover types, which is attributed to spatial heterogeneity in land use and management practices. With respect to the main effect of LULC, higher pH values were recorded in shrub land (5.82), followed by forest soils (5.62) whereas degraded land (4.46) and agricultural land (4.99) showed pH values of below 5. The significantly higher pH values in forest land could be attributed to the effect of the high accumulation of organic matter at surface which was evidenced in the study area by strongly positive correlation ($r=0.549$) between pH and organic matter (Table 5.5). Although SOM lowers pH value by increasing hydrogen ion (H^+), the present result could be due to more return of bases to soils from decay of plant leaves, roots, barks, grasses/ undergrowth. On the other hand, the lower pH values of degraded land and agricultural soils might be due to the removal of basic cations because of crop residue harvest, intensive farming over a number of years with addition of inorganic fertilizers on cultivated land, overgrazing and severe soil erosion (Molla and Yalew, 2018). Although acidity is naturally occurring, the removal of plant residues carrying organic anions and excess cations from farmland is likely to accelerate soil acidification. In general, the acidic nature of soils in the study area is attributed to the high mean annual rainfall (1411 mm) which leads to intense leaching of base forming minerals (Adugna and Abegaz, 2016)

5.2.3.5 Effect on Cation Exchange Capacity (CEC)

In general, based on the ratings of CEC results for top soils forwarded by Landon (1991) the CEC values of the Bururi catchment was found to be in the range of medium to very high (16-54 $\mathrm{Cmol_c\ kg^{-1}}$ soil) across the different land use/cover classes and topographic elevation.

Irrespective of altitudinal variation, LULC significantly (P<0.01) influenced CEC values (Table 5.8), as a result of which mean CEC values varied across the recognized five LULC categories. The relatively high mean CEC values (44.46 $\text{Cmol}_c\ \text{kg}^{-1}$ soil) was observed in forest cover followed by shrub land and grassland while the low mean value (18.58 $\text{Cmol}_c\ \text{kg}^{-1}$ soil) was recorded in degraded soils. As depicted by *Tukey's post-hoc* test result, a significant mean difference of CEC (25.88 $\text{Cmol}_c\ \text{kg}^{-1}$ soil) was observed with the transformation of forest cover into degraded land. The conversion of shrub land into degraded soil also reduced mean CEC values by 23.07 $\text{Cmol}_c\ \text{kg}^{-1}$ soil (Table 5.9).

The higher CEC values in forest soils might be associated to the presence of better organic matter and clay contents. As a consequence, lower values of CEC in degraded land could be associated to low contents of soil organic matter and clay. In fact, CEC is a function of available levels of SOM and contents of clay particle (Hazelton and Murphy, 2007).

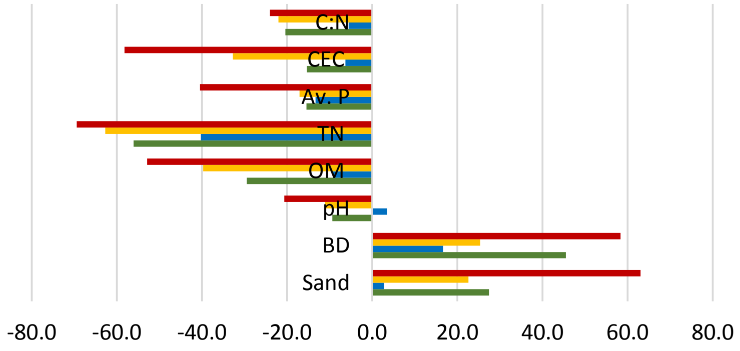
Table 5.9 Multiple comparisons of Tukey's HSD post hoc Test for the Effect of LULC on Soil Quality Parameters

Soil Properties	LULC (I)	LULC (J)	Mean Difference (I-J)	Sig.
Sand (%)	Degraded land	Forest	15.3333*	0.004
		Shrub land	14.6667*	0.006
Bulk Density (g/cm^3)	Degraded land	Forest	.5383*	0.002
		Shrub land	.3833*	0.036
	Grassland	Forest	.4200*	0.019
Soil pH	Shrub land	Degraded land	1.3567*	0.019
Organic Matter (%)	Agricultural	Degraded land	.6633*	0.010
	Forest	Agricultural	2.0000*	0.000
		Degraded land	2.6633*	0.000
		Grassland	1.4833*	0.000
	Grassland	Degraded land	1.1800*	0.000
	Shrub land	Agricultural	1.5400*	0.000
		Degraded land	2.2033*	0.000
		Grassland	1.0233*	0.000
CEC (meq/100 gm)	Forest	Degraded land	25.8767*	0.009
	Shrub land	Degraded land	23.0700*	0.022

5.2.3.6 Effects on Available Phosphorus

As depicted in Table 5.8 the main effect of topographic elevation on available phosphorus (Av. P) was statistically significant (*P*<0.001) suggesting a remarkable spatial variation between the upper and lower elevation categories. In line with this study, Saeed *et al*. (2014); Tasung and Ahmed (2017); and Singh *et al.* (2018) found significant difference of available P with topographic altitude. However, Haycho *et al.*, (2015) reported a non-significant difference in available P content across the elevations of Kasso catchment in Bale Mountains.

The mean value of Av. P was relatively higher (6.99 ppm) in the lower altitude of Bururi catchment as compared to that of the upper elevation area (Table 5.7). The low availability of P in the upper elevation could be associated to lower accumulation of organic matter, effects of soil erosion, and soil compaction, which may cause loss of available P from the upper elevation**.** As described by Dawit *et al.* (2002), since most of the phosphorus available in plants is acquired from the soil organic matter, the distribution of available P in the soil is regulated by biochemical processes. This result confirms the findings of Tasung and Ahmed (2017) who reported the decrease of available P with increasing altitude. However, Saeed et al. (2014) found a contradictory result and reported that the percentage of available P in the soil increased with increasing altitude. Additionally, Singh *et al.* (2018) also found the same result in soils of the Indian Himalayas and associated higher phosphorus content with higher altitude. Such contrasting results could be ascribed to the history and intensity of land use in addition to the soil properties, which determine the dynamics and availability of phosphorus in soils (Schjonning *et al.*, 2004). As stated in Magid *et al.* (1996), the distribution of phosphorus in a variety of forms reflects the history, structure and function of an ecosystem. Variations in available P content in soils are also related to the intensity of soil weathering or soil disturbance (Achalu *et al.*, 2012) and continuous application of mineral P fertilizer sources (Paulos, 1996).



	Sand	BD	pH	OM	TN	Av. P	CEC	C:N
🟥 Degraded land	63.0	58.33	-20.64	-52.91	-69.44	-40.46	-58.21	-24.03
🟨 Agricultural	22.6	25.36	-11.15	-39.75	-62.78	-17.07	-32.80	-22.03
🟦 Shrub land	2.8	16.67	3.50	-9.19	-40.28	-13.34	-6.32	-5.53
🟩 Grassland	27.4	45.47	-9.40	-29.50	-56.11	-15.47	-15.40	-20.40

Figure 5.10 Percentage Changes of Soil Quality indicators under different LULC types as compared to forestland

5.3. Effects of Land use Dynamics and Topographic Elevation on Soil Organic Carbon and Total Nitrogen Stock

The result of two-way ANOVA (Table 5.10) depicts the existence of statistically significant mean differences between soil organic carbon (SOC) and soil total nitrogen (STN) stock, considered as dependent variables, and the independent variables of LULC and topographic elevation , as well as their interaction (LULC*Elevation). The interactive effect of LULC and topographic elevation was found to be significant ($p<0.05$) for soil total nitrogen (STN) stock but non-significant ($p>0.05$) for soil organic carbon (SOC) stock. Furthermore, the main effect of LULC was statistically significant for SOC stock ($p<0.01$) and STN stock ($p<0.01$).

Table 5.10 Summary of Two-way ANOVA results for SOC & STN Stock in relation to LULC & Topographic Elevation

	Source of Variation					
	LULC		Elevation		LULC * Elevation	
Dependent Variable	*F*	Sig.	*F*	Sig.	*F*	Sig.
SOC Stock (Mg ha^{-1})	4.998	0.006**	0.117	0.736	0.478	0.752
TN Stock (Mg ha^{-1})	24.585	0.000***	18.267	0.000***	3.523	0.025*

* Significant at the 0.05 level ; ** Significant at the 0.01 level; *** Significant at the 0.001 level

5.3.1 Effects of LULC and Topographic Elevation on SOC Stock

In this study, the mean SOC stock showed significant variation under different LULC types and decreased following in the order of forest>shrubland>grassland>agricultural>degraded land. The overall mean SOC stock of the entire study catchment was 48.64 Mg ha^{-1}, which is relatively higher than the mean SOC stock reported by Biazin *et al.*, (2018) in Wondo Genet area and Amanuel *et al.* (2018) in Birr watershed of the upper Blue Nile basin. The higher SOC stock observed in this study might be attributed to the variation in agroecology and vegetation type. The spatial distribution of SOC depends on the relative contributions of different factors, such as climate, vegetation, parent material, soil, and their interaction (Oueslati *et al.,* 2013). Therefore, SOC buildup and decomposition rates vary remarkably under different temperature and moisture conditions (Sigua and Coleman, 2010).

In the present study, forest soil showed the highest mean SOC stock (56.47 Mg ha^{-1}) followed by shrubland (55.38 Mg ha^{-1}) compared to other LULC types. This is due to the high litter production in forests and shrubs which is important for increasing SOC storage. Forest and shrubs generate more plant litter than other LULC types, and a larger proportion of it is returned to the soil. Mineralization of organic matter and the problem of erosion problems are also minimal under forests (Hillel *et al.,* 2004). Vegetation cover may introduce a large variability of SOC at local scales (Zhou *et al.,* 2006; Luyssaert *et al.* , 2008). The ITPS (2015) report also revealed that the conversion forests, shrub, and grassland to cultivated land in tropical regions cause a decline of SOC by 25 to 35% whereas the change from cultivated land to those natural vegetations leads to a comparable increase in SOC.

Table 5.11 Statistical summary of SOC and STN Stockin relation to LULC and Topographic Elevation (mean ± SE)

		SOC Stock (Mg ha^{-1})		STN Stock (Mg ha^{-1})	
Source of Variation	Category	Mean	SD	Mean	SD
LULC	Agricultural land	39.93	3.97	5.62	0.74
	Degraded land	38.00	10.66	4.60	1.01
	Forest	56.47	13.44	9.53	2.00
	Grassland	53.43	6.57	7.33	1.15
	Shrubland	55.38	8.27	9.12	2.20
	Overall LULC	48.64	11.77	7.24	2.41
Elevation	Lower elevation	48.03	12.72	8.07	2.88
	Upper elavation	49.25	11.16	6.41	1.52
	Total	48.64	11.77	7.24	2.41
LULC *Elevation	Agricultural_Lower	42.97	3.00	5.50	0.87
	Agricultural_Upper	36.90	1.65	5.73	0.75
	Degraded_Lower	37.77	16.78	4.77	1.01
	Degraded_Upper	38.23	1.54	4.43	1.21
	Forest_Lower	53.83	20.44	10.93	1.96
	Forest_Upper	59.10	3.58	8.13	0.55
	Grassland_Lower	54.17	6.47	8.20	1.00
	Grassland_Upper	52.70	8.02	6.47	0.25
	Shrubland_Lower	51.43	7.81	10.93	0.81
	Shrubland_Upper	59.33	7.94	7.30	1.25

On the other hand, agricultural soils and degraded land use categories have less SOC stock than other LULC categories, with a mean value of 39.9 Mg ha^{-1} and 38 Mg ha^{-1} respectively (Table 5.11). This might be due to the removal of crop residue from crop fields which reduces the accumulation of organic matter in soils. Moreover, degraded soils in the study area were mostly barren and exposed to soil erosion. Therefore, by rehabilitating degraded land, it is possible to improve the sequestration of organic carbon in soils and hence, mitigate climate change. According to the FAO (2021), as a healthy amount of soil organic carbon can help plants cope with climate change, carbon sequestration and monitoring in soils can also improve food security and enhance climate resilience.

In general, a noticeable difference in SOC stock between the LULC types was a result of differences in how the different ecosystems function. In forests for example, huge amounts of organic matter created by decomposition of litter and animal remains are incorporated into the cycle every year. In contrast, agricultural and degraded lands are often characterized by severe soil erosion and soil degradation. The post hoc multiple comparison results (Table 5.12) revealed statistically significant differences in SOC stock between grassland and agriculture ($p<0.05$) as well as shrubland and agricultural land ($p<0.05$). Taking forest soil as a reference SOC stock showed a reduction of 69.2% and 67.3% following the conversion of grassland and shrubland in to agriculture, respectively. The observed orderly land use land cover transformation (forest>shrubland>grassland>agricultural land>degraded land) in the study area resulted in loss in natural vegetation and led to a decrease in soil carbon stock. This in turn, affect the local climate as well as the global carbon dynamics by influencing the distribution of SOC and STN in the ecosystem.

Although statistically non-significant, higher value of mean SOC stock (49.25 Mg ha^{-1}) was recorded in the lower elevation compared to the upper elevation (Table 5.11). Other similar studies (Garten *et al.,* 1999; Krishnan *et al.,* 2007; Sah and Brumme, 2003; Sheikh *et al.,* 2009; Kidanemariam*et al.,* 2012) also reported SOC variations along altitudinal gradients. The increasing tendency of carbon concentration with decreasing altitude may be because of better stabilization of SOC at lower altitudes (Sheikh *et al.,* 2009; Bangroo*et al.,* 2017) and increased likelihood of accumulation of eroded material at lower elevation areas, leading to high SOC stock (Sorensen *et al.,* 2006). As depicted by Tukey's *post hoc* multiple comparisons in Table 5.12, the mean difference in SOC stock between grassland and agricultural land, as well as shrub land and agricultural land was statistically significant. The conversion of shrub land to agricultural land reduces SOC stock by 18.47 Mg ha^{-1} (Table 5.12), which might be due to the lower organic carbon inputs to cropland, soil erosion, and the removal of the crop residues from cultivated fields during crop harvesting and continuous tillage practices that contributes to the decline and loss of SOC storage. As stated by Haileselassie *et al.* (2005), the removal of the crop residues for cooking and animal feed almost leaves no biomass to be returned to the soil.

The percentage change of SOC stock in degraded land was the highest (-32.71%) followed by agricultural land (-29.28%), as compared to the SOC stock in forestland (Table 5.13). This implies that land degradation is one of the biggest contributors to climate change by reducing the capacity of the soil to stock organic carbon. According to IUCN (2020) when land is degraded, soil carbon is released into the atmosphere, along with nitrous oxide. During the process of land degradation the decline of soil organic carbon content and the decrease of vegetation cover may exacerbate the greenhouse effect (Schlesinger *et al.,* 1990). Soil erosion can lead to soil organic carbon consumption, which has a negative impact on terrestrial ecosystem carbon pool.

According to Fang *et al.* (2004), accelerated erosion under disturbance of human activities is a destructive process, which not only destroys soil structure reduces soil fertility, but also affects soil carbon cycle.

5.3.2 Effects of LULC and Topographic Elevation on STN Stock

Topographic elevation is one of the major factors affecting the distribution of SOC and STN stock (Hanawalt and Whittaker, 1976). The result in Table 5.10 revealed that the mean STN stock is significantly influenced by LULC (p<0.001), topographic elevation (p<0.001), and the interaction effect of the two (p<0.05). The statistically significant interactive effects imply that the mean differences in STN stock across LULC types depend on elevation Accordingly, the highest STN stock was observed in forestland of the lower elevation (10.93 Mg ha^{-1}) and shrub land of the lower elevation (10.93 Mg ha^{-1}) as compared to the remaining LULC types (Table 5.11).

On the other hand, the information presented in Figure 5.11 revealed that the lowest STN stock was recorded in degraded soils of the upper elevation (4.43 Mg ha^{-1}) which is attributed to the relatively higher soil erosion in the upper catchment which removes the available organic matter.

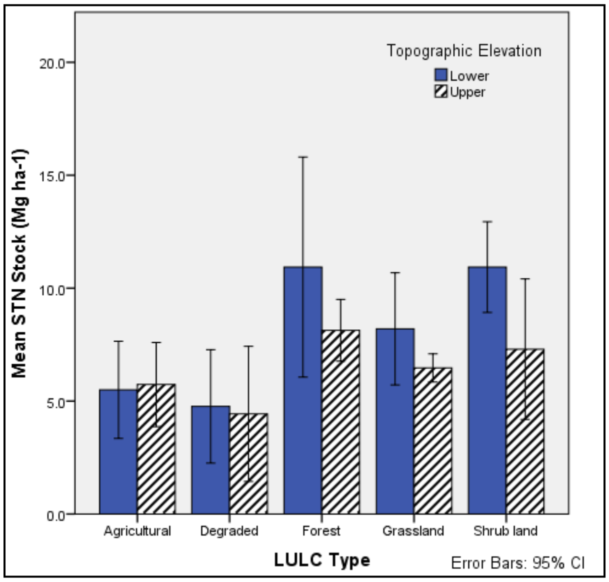


Figure 5.11 Interactive effects of LULC and Topographic Elevation on STN Stock

The mean value of STN stock was in the order of forest > shrub land > grassland > agricultural land > degraded land. On the other hand, the SOC stock in the lower elevation is significantly higher than that of the upper elevation (Table 5.10). The relatively lower STN stock in the upper catchment is attributed to prolonged crop cultivation and mismanagement of the landscape. The upper catchment of the study area was more vulnerable to soil erosion, which is a common problem in Ethiopia and serves as a source of run-off for the lower positions. Soil erosion often causes translocation of soil material from the upper slope to lower area and contributes to the loss of soil organic matter (Yimer *et al.*, 2007).

Table 5.12 Multiple comparisons of SOC Stock and percentage change for the statistically significant

Soil Properties	LULC (I)	LULC (J)	Mean Difference (I-J)	Sig.
SOC Stock (Mg ha^{-1}	Grassland	Agricultural	17.38	0.042*
	Shrub land	Agricultural	18.47	0.028*
STN Stock (Mg ha^{-1}	Forest	Agricultural	3.92	0.000***
		Degraded	4.93	0.000***
		Grassland	2.20	0.014*
	Grassland	Degraded	2.73	0.002**
	Shrub land	Agricultural	3.50	0.000***
		Degraded	4.52	0.000***

** Significant at the 0.05 level ; ** Significant at the 0.01 level; ***Significant at the 0.001 level*

As portrayed by Tukey's *post hoc* test multiple comparison test (Table 5.12), the STN stock in agricultural soils, degraded land, and grassland was significantly (p<0.001 and p<0.01) lower than that of forest land. The STN stock in degraded land was also significantly (p<0.01) lower than that of grassland (Table 5.11). In addition, the STN stock in shrubland was significantly higher than that of agricultural (p<0.001) and degraded land (p<0.001) as shown by Tukey's *post hoc* multiple comparisons test.

Table 5.13 Percentage Changes of SOC and STN Stock under Four LULC Types Compared to That of Forest land

LULC	Mean SOC Stock (Mg ha^{-1})	% of Change in SOC Stock	Mean STN Stock (Mg ha^{-1})	% of Change in STN Stock
Forest	56.47		9.53	
Grassland	53.43	-5.38	7.33	-23.05
Shrubland	55.38	-1.92	9.12	-4.34
Agricultural land	39.93	-29.28	5.62	-41.06
Degraded land	38.00	-32.71	4.60	-51.73

Furthermore, the information presented in Table 5.13 demonstrated that the percentage change of STN stock was largest in degraded land (-51.73%), followed by agricultural land (-41.06%), grassland (-23.05), and lowest in shrub land (-4.34%). This means the conversion of forest cover into grassland, agricultural land, and degraded land significantly reduces STN stock by 23.05%, 41.06%, and 51.73%, respectively. Changes from vegetation cover to other types of LULC categories reduces the addition of plant litter and thereby lowers accumulated STN stock. The lower STN stock in shrub land and grassland as compared to that of the forestland could be due to differences in management practices between the land use systems (Amanuel *et al.,* 2018), and soils under forest cover are well protected with little disturbance but that of open grassland are mostly overgrazed and hence susceptible to surface erosion (Abera and Belachew, 2011). Overgrazing causes a reduction in plant cover with accepted consequences on soil infiltration and soil erosion, thereby resulting in the loss of soil organic matter (Mchunu & Chaplot, 2012).

In general, SOC and STN stock showed almost similar trend with respect to the effect of LULC dynamics. Higher SOC and STN stock were recorded in the forest and shrubland compared to all other land cover types. This may be attributed to higher litter input and soil moisture found under the canopies within the forest and shrubs. The area covered by forest and shrub land have been relatively better managed by local farmers since the known cash crops in the study area (Arabica coffee) is planted in those areas under the shade of the trees.

Grassland had lower SOC and STN stock compared to forestland and shrub land. This may be linked to the uncontrolled grazing within the catchment. According to Galloway *et al.* (2008), poor grazing management and the subsequent disruption of carbon inputs as well as excessive harvesting of above ground biomass by livestock alters the carbon and nitrogen cycle within the ecosystem. However, recently enclosures and controlled grazing has begun to appear in some parts of the study catchment, which improves the organic matter content of grasslands.

Agricultural land showed relatively lower SOC and STN stock as compared to grassland but it has higher values as compared to degraded land. Reduced inputs of organic matter and frequent tillage of agricultural land encourages oxidation of organic matter and consequently lowers SOC and STN stock. On the other hand, the application of animal manure and leaving crop residues on agricultural fields improve SOC and STN stock by increasing SOM storage. The degraded land in the current study area is characterized by severe soil erosion that led to general degradation of the study area, which was evidenced by lowest SOC and STN stock recorded in this study. Similar results were reported in previous findings that soil erosion reduces SOC stock in degraded land (Lal, 2004) and increases the loss of soil nutrients (Smaling and Dixon, 2006) including SOC and STN. Moreover, the UNCCD (2015) report revealed that depletion of organic carbon in soils is exacerbated by soil degradation.

Chapter Six: Determinants of Land Management Decisions among Farm households

6.1 Socio-economic and Demographic Characteristics of the Households

The result presented in Table 6.1 revealed that majority (87.1%) of the sample households in the study area were male headed and 12.9% were female headed households. The age of the household heads ranged between 22 and 66 years with an average age of 41.5 years across the studied households (Table 6.2). This has implication on available agricultural labor force, the households' farm experience and the choice of land management practices. Farmers' age (their experience in farming) is expected to increase quality and quantity of output by reducing pre-harvest and post-harvest losses, increase use of conservation technologies and increase efficiency of the farmers (Babalola and Olayemi, 2013).

The educational status of the sampled farm households ranged from non-educated to 14 years of education (Table 6.2). The average schooling period in terms of number of years studied was found to be 2.5 years, which means literacy level in the study area is still very low, with a majority of farmers having only early primary school education. In fact, education enhances the capacity of individuals to obtain, process, and utilize information disseminated by different sources and literate farmers are in a better position to get information and use it in such a way that it contributes in their adoption of land management practices.

With respect to agricultural labor force, the minimum and maximum household size in the study area was found to be 2 and 10 respectively, with an average household size of 5 persons per household. Normally, there was no serious shortage of labor force in the study area, but due to the seasonal outmigration into the newly accessed farmland (which is averagely 6 walking hours from their original home), they share the available household labor for the two places (the old and the new site). This may have caused labor constraints among the studied households.

All the surveyed households had their own land but there was disparity in land size owned. The average land holding size of the surveyed households was found to be 2.2 hectares with the maximum of 8 ha. and minimum of 0.8 hectare. The information obtained from interviews of the woreda agricultural experts revealed that those having large farmland size were contributing less to the conservation measures, compared to farmers with small land size ownership.

The size of the livestock owed (in TLU) by the surveyed households ranged from none to 8 with an average value of 3.1 (Table 6.2). The study area was suitable for cattle production but recently shortage of grazing land was observed following the shrinking and degradation of communal grazing lands. According to Barungi and Maonga (2011), livestock are source of income and also provide manure for soil fertility management.

A vast majority of the households involved in the study (65.3%) had no off-farm activities and they largely depended on their farming. Only 34.7% of the respondents had had access to off-farm activities. As pointed out during focus group discussions, the available off-farm activities in the study were found to be daily labor, petty trading, and small-scale handcrafts. When farmers have no access to off-farm activities and as they fully rely on farm income, with limited farm size, farmers tend to invest on other land management practices than biological measures (such as tree planting) which do not compete for the limited available farmland.

Table 6.1 Categorical Variables (N-170)

Categorical Variables	Category	Frequency	Percentage
Sex of the Household Head	Male	148	87.1
	Female	22	12.9
Access to off-farm activity	No	59	34.7
	Yes	111	65.3
Awareness of land degradation problem	No awareness	57	33.5
	Have awareness	113	66.5
Slope steepness of farmland	Not steep	57	33.5
	Steep	113	66.5
Termite Infestation	Not Severe	44	25.9
	Severe	126	74.1
Access to agricultural credit	No	37	21.8
	Yes	133	78.2
Land tenure security	Do not feel secured	69	40.6
	Feel secured	101	59.4

6.2 Farmer’s Perception of Land Degradation

From the total (N=170) surveyed households, 66.5% of the respondents had awareness about the prevailing land degradation in the study area. According to focus group discussions participants, the farmers had better awareness of soil erosion problem and fertility decline, which are the predominant forms of land degradation. In their discussion, they confirmed that soil erosion accompanied by fertility decline was increasing and seriously affecting the agricultural productivity during the last fifteen years. Moreover, agricultural extension workers and FGD participants pointed out some indicators of land degradation including formation of rills and gullies, change in soil color to reddish, expansion of barren land, reduced vegetation cover, increased stoniness, declining crop yield per unit of land, increasing fertilizer consumption, and stunted crop growth.

The surveyed household heads were asked to identify the slope of their farmland as steep or non-steep. The majority of the sampled households (66.5%) recognized the steepness of their farm plot (Table 3.1), which means they were cultivating steep slopes and they are more vulnerable to soil erosion. Therefore, they are more expected to implement land management practices than those cultivating undulating or flat terrains. The sampled farm households were also requested to estimate the average distance of their farm plots from home in walking minutes. The result showed that they averagely travel for about 40 minutes, with a minimum distance of 10 minutes and a maximum distance of 120 minutes (Table 6.2). Number of plots owned was used as a proxy for land fragmentation and the surveyed farmers had about 3 plots in average while the minimum and maximum values were 1 and 6 plots respectively. The problem of land degradation in the study area caused a decline in agricultural productivity and exposed the rural farm households to search for additional plots, which increased the number of plots owned.

Majority of the surveyed households (74.1%) reported that there was severe infestation of termite on their farm plot. The interviewed experts working in the study area also added that termites have caused severe damage on agricultural crops, forests, grazing lands, and houses (Figure 6.1). It severely devastates the available vegetation and thus expose the land to agents of soil erosion. They had been using chemicals and indigenous methods to minimize the effect but still it was a major problem.

From the sampled farm households only 21.8% had access to credit service while the remaining 78.2% could not get access. The information gathered from focus group discussions revealed that previously they were getting credit from the local agricultural office but that was also stopped. Currently, the only available source of credit service in the study area is Oromia Credit and Saving Association (OCSA), which is found in the woreda town. The establishment of some physical conservation structures (like terraces and bunds) requires considerable labor and material inputs. Therefore, it is important that farmers have access to micro-credit service to be motivated and participate in such practices (Liniger, *et al.*, 2011)

Figure 6.1 Termite infestations destroying live shrubs and grasses (*Dalle Bururi* kebele, 2017)

Regarding land tenure security, about 59.4% of the households replied that they feel secured and the remaining 40.6% do not feel secured. The government of Ethiopia introduced a land certification program in the late 1990s to alleviate the problem of land tenure insecurity. The program was reported to have many positive impacts, including reduced conflict and improved investments in land and other natural resources management (Deininger *et al.*, 2009; Holden *et al.*, 2011). However, in the present study the FGD participants raised that in relation to the seasonal outmigration of farm households into the newly accessed remote farmlands, they withdrawn conservation practices from the degraded original farmland, and because of this, the local agricultural extension workers repeatedly warn the owner either to conserve the land or to transfer into another farmer. Hence, some farmers worry that their original farmlands might be re-distributed unless they appropriately conserve it.

Table 6.2 Continuous Variables (N=170)

Continuous Variables	Minimum	Maximum	Mean	Deviation
Age of the Household Head	22.0	66.0	41.5	9.8
Schooling Period (in Number of years Studied)	0.0	14.0	2.5	3.0
Family Size	2.0	10.0	4.5	1.6
Total size of Farmland (in Hectar)	0.8	8.0	2.2	1.0
Livestock ownership (in Tropical Livestock Unit)	0.0	8.0	3.1	1.9
Average distance from home to farm plot (in walking minutes)	10.0	120.0	39.6	21.5
Number of plots owned	1.0	6.0	2.7	1.1
Distance to the agricultural extension office (in walking minutes)	2.0	50.0	13.2	10.9
Distance from the Nearest market (in walking minutes)	30.0	250.0	95.0	54.7

Contact with extension agents help farmers get access to information needed to make decisions on land management practices. The surveyed farm households estimated the mean distance of agricultural extension office from their home to be 13.2 walking minutes, with a minimum of 2 minutes (the nearest) and a maximum of 50 minutes (the farthest home).

The average distance of the nearest market from the farm households was estimated to be 95 walking minutes, with a minimum of 30 minutes and the farthest was 250 walking minutes. During field survey, the researcher observed that market access was constrained by highly rugged topography and lack of road infrastructure. Because vehicles cannot reach the study area, farmers use pack animals (particularly donkeys) to transport their agricultural produce to local markets and even they carry on their shoulder. The qualitative data collected through interview with Dalle Wabera woreda agricultural office experts demonstrated that some farm households in the study area (particularly in the upper catchment) often associate the recommended land management practices with the absence of infrastructure and are reluctant to participate in conservation campaigns.

6.3 Implementation of Land Management Practices

By recognizing the problem of land degradation, farm households in the study area applied various land management techniques in order to reduce soil erosion and maintain soil fertility. The land management practices implemented in Bururi catchment were grouped into four groups as physical structures, agronomic practices, vegetative/biological measures, and management measures.

Structural measures: The structural measures implemented in the study area included drainage furrows, diversion ditches, soil bunds, terracing, stone bunds, and check dams, which had been adopted by 91.8%, 77.6%, 57.6%, 35.9%, 33.5%, and 31.8% of the surveyed households respectively. The adoption of Terraces, bunds and check dams was relatively lower as they are expensive and labor demanding. From these traditional and improved erosion control measures, diversion ditches (cut-off drains) were mostly used in cultivated fields to collect runoff from the land above and to divert it safely to a waterway or river, thus protecting the land below from excessive erosion (Hurni *et al.*, 2016).

Figure 6.2 Farmers participating in Physical land management by mass campaign (*Dhaye Gommi* Kebele, 2017)

Terracing mostly takes place in sloppy and stone available areas, and used to reduce the effect of the slope and runoff on soil erosion. Likewise, traditional wooden check dams were used for rehabilitation of gullies and reduce erosion velocity. The government of Ethiopia introduced a community-based watershed management practices in all districts through public campaign, the participation of farmers in the study area was very low probably due to the seasonal outmigration of farm households into the recently accessed agricultural area. The construction of Gabion check dam was also recently started in the lower catchment of the study area (particularly in *Dhaye Gomi* kebele) by Menschen für Menschen foundation to rehabilitate gullies and control soil erosion.

Table 6.3 Land Management practices implemented by surveyed households in Bururi Catchment (N=170)

Structural Measures	No. (%)	Agronomic Practices	No. (%)	Vegetative Measures	No. (%)	Management Measures	No. (%)
Drainage furrows	156 (91.8)	Crop rotation	95 (55.9)	Coffee-based Agroforestry	146 (85.9)	Area closure	15 (8.8)
Diversion ditches	132 (77.6)	Manure application	109 (64.1)			Changing plant species	43 (25.3)
Soil bunds	98 (57.6)	Compost use	79 (46.5)	Grass strips	97 (57.1)		
Stone bund	57 (33.5)	Mixed cropping	76 (44.7)	Tree planting	105 (61.8)	Fallowing	61 (35.9)
Terrace construction	61 (35.9)	Leaving crop residue	66 (38.8)				
Check-dams	54 (31.8)						

Agronomic practices: As part of the agronomic land management practices, the sampled respondents adopted crop rotation with legumes (55.9%), manure application (64.1%), compost use (46.5%), fallowing (35.9%), mixed cropping (44.7%), and leaving crop residues on farm plot or mulching (38.8%). Crop rotation (typically cereals followed by legumes) is the successive cultivation of different crops in a specified order on the same fields, to allow replenishment of nutrients. In the present study area, cultivation of cereal crops for two to three years, followed by peas and beans is a common practice. It is one of the most important means of improving soil fertility as well as conserving the soils. Animal manure and compost were also used to enhance productivity by improving the structure and fertility of the soil, as well as its capacity for infiltration and water retention. Recently the use of animal manure and crop residue is declining from time to time probably due to the increasing demand for manure as a source of fuel and shortage of animal fodder, which is in turn associated to the degradation and shortage of grazing land.

Figure 6.3 Example of Manure Applications in Tullu goppo and Dhaye Gommi kebeles

Mixed cropping is an agronomic practice that consists the growing of two or more crops on the same land simultaneously in a given growing season. The commonly applied intercropping technique in the study area was the combination of maize and haricot bean. The information obtained from local agricultural extension workers revealed that after the widespread land degradation in the study area the traditional method of regenerating soil fertility through fallowing become a common practice. However, due to uncontrolled grazing, the fallow plots could not regenerate and even degradation worsened in such areas.

Vegetative/biological Measures: Among the biological conservation measures coffee-based agroforestry was implemented by 85.9% of the sampled households, which was followed by grass strips (57.1%), and tree planting (61.8%). The information gathered through FGDs revealed that coffee-based agroforestry was an old and common practice among farmers of the study area, as coffee plantation (the major cash crop in the area) highly needs shade. Furthermore, they commonly grow vetiver and elephant grasses to rehabilitate the severely eroded steep slopes. Vetiver grass (*Vetiveria zizanioides*) is a tough grass, which is very suitable for erosion control and conserving soil moisture (Wolde, 2015; Hurni *et al.,* 2016).

The information obtained from interviews and FGDs also indicated that different multi-purpose trees and shrubs were grown in the study area including *Gravilia robusta*, *Cordia Africana*, *Vernonia amygdalina*, *Podocarpus falcatus*, *Juniperous procera*, *Croton macrostachyus*, *Albizia gummifera*, *Eucalyptus Camuludinus*, *Sesbania sesban*, *Leucaena leeucocephala*, *Persea americana*, and *Mangifera indica* etc. The FGD participants raised that around 2004 the Ethiopian Evangelical Church Mekane Yesus Western Wollega Bethel Synod (EECMY-WWBS) project was disseminating seedlings of different plant species (like *Gravilia robusta*, *Podocarpus falcatus*, *Persea Americana)* and supporting the agroforestry practices in the upper catchment (particularly in *Tullu Goppo* kebele). In addition to the soil and water conservation, trees in the study area were planted for different purposes including construction of houses and fences, fuel wood, coffee shade, animal fodder, for hanging beehives, as well as income generation by cutting and selling the matured trees. A study conducted in West Wollega by Tazebew and Asfaw (2018) reported that cultivation of coffee under varieties of shade trees is common practice and the most widely used shade trees in smallholder coffee farms *were found to be Cordia Africana, Vernonia amygdalina, Croton macrostachyus,* and *Albizia gummifera*.

Management measures: According to WOCAT (2007), management measures included changing land use type (for e.g. into area closure); change of land management/intensity level (for e.g. from free grazing to controlled grazing); Change of plant species (for e.g. to termite resistant species). The questionnaire survey conducted in Bururi catchment revealed that very small proportion of the surveyed households (8.8%) used area closure as a strategy of land management. The development agents (DAs) working in the catchment also added that area closure on private farmland was not a common practice but few farmers started to implement recently and they were benefited by selling the grown grass on the closed area to be used as animal fodder. Area closure was also observed on degraded communal lands of the study catchment, and some of the closed areas could successfully revegetate, where human and animal interferences were seriously restricted. On the other hand, the FGD participants raised that about 25% of the respondents replied that they changed grass and tree species into termite resistant varieties such as Neem tree and *Croton macrostachyus* (Table 6.3). The selection of termite tolerant crop and plant varieties was found to reduce termite attack by about 90% (Agunbiade *et al.*, 2009).

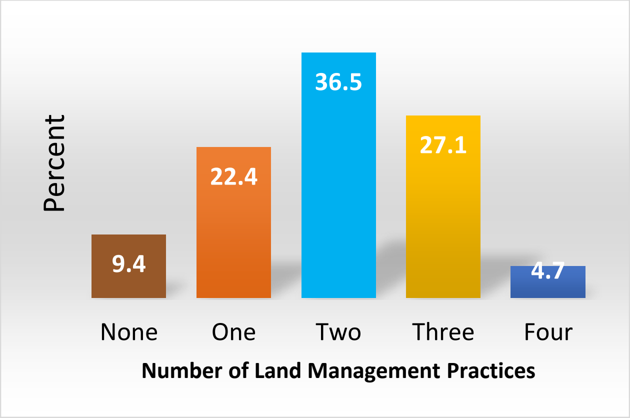


Figure 6.4 Number of Land Management practice implemented in Bururi Catchment (Source: Survey results, 2018)

Regarding the overall land management adoption, although all the four groups of land management practices (such as structural, agronomic, vegetative measures, and management measures) were implemented in the study area, the overall adoption rate is found to be low. The survey result presented in Figure 6.4 revealed that only 4.7% of the households have participated in all types of land management practices. The remaining 27.1%, 36.5% and 22.4% implemented three, two and one type of land management practices. The decision to adopt land management practices might be influenced by several factors and the determinants were examined in the next section.

6.4 Determinants of farmers' Adoption decision on Land Management Practices

Binary logistic regression was computed to assess the impact of several socio-demographic, biophysical and institutional variables on farmers' adoption of land management practices. The binary logistic regression used in the present study contained sixteen independent variables. The Omnibus Tests of Model Coefficients (the goodness of fit test) was found to be statistically significant which gives us an overall indication of how well the model performs. As presented in Table 3.4, the full model containing all predictors was highly significant ($chi^2 = 0.000$) uniformly for all dependent variables, indicating that the model was able to distinguish between adopters and non-adopters. The model as a whole (Nagelkerke R squared) explained 75.9%, 69.3%, 83.2%. And 75.1% of the variance in the adoption of structural, agronomic, vegetative, and management measures respectively. The model also correctly classified 88.8% (for structural), 84.1% (for agronomic), 88.8% (for vegetative), and 92.9% (for management measures) of overall percentage (Table 6.4). This figure provides us with an indication of how well the model is able to predict the correct category (adopters/non-adopters) for each case. The Exp(B) column in Table 3.4 presents the extent to which raising the corresponding measure by one unit influences the odds ratio. If the value exceeds 1 then the odds ratio of an outcome occurring increases; if the figure is less than 1, any increase in the predictor leads to a drop in the odds of the outcome occurring.

Table 6.4 Binary logit Results on determinants of Land Management Practices

Explanatory Variables	Dependent Variables (Land Management Practices)							
	Structural Measures		Agronomic Measures		Vegetative Measures		Management Measures	
	Sig.	Exp(B)	Sig.	Exp(B)	Sig.	Exp(B)	Sig.	Exp(B)
Age of the Household Head	0.101	0.945	0.357	1.026	0.06	0.929	0.385	0.961
Sex of the Household Head	0.057	9.343	0.004*	0.07	0.335	4.671	0.724	0.594
Schooling Period	0.259	1.135	0.358	1.102	0.725	1.035	0.000*	3.437*
Household Size	0.004*	1.929	0.4	0.854	0.037*	1.706	0.972	1.011
Farmland Size	0.668	1.236	0.043*	0.448	0.001*	8.734	0.290	0.541
Livestock Size (TLU)	0.713	0.936	0.000*	5.176	0.063	1.741	0.924	0.974
Access to off-farm activity	0.257	0.423	0.145	2.799	0.953	1.053	0.432	2.198
Awareness of Land Degradation	0.032*	6.184	0.587	1.433	0.045*	7.275	0.473	2.145
Perceived slope steepness	0.037*	4.693	0.17	2.48	0.38	0.478	0.247	3.642
Termite Infestation	0.065	3.818	0.817	0.85	0.002*	0.008	0.938	1.076
Home to plot distance	0.047*	0.963	0.001*	0.943	0.645	0.99	0.408	1.018
Number of plots owned	0.001*	0.271	0.959	1.017	0.001*	5.497	0.130	2.294
Distance from extension office	0.478	0.975	0.096	0.952	0.054	0.907	0.594	1.022
Distance from the Nearest market	0.001*	0.968	0.040*	1.012	0.129	1.013	0.427	0.994
Credit access	0.012*	5.913	0.738	0.789	0.264	2.467	0.338	2.672
Land tenure security	0.231	2.277	0.094	2.843	0.247	2.712	0.884	1.167
Constant	0.737	2.706	0.934	1.231	0.023	0.000	0.041	0.000
Omnibus Tests of Model	*P* <0.0005		*P* <0.0005		*P* <0.0005		*P* <0.0005	
Chi-square	142.26 (*df*= 16)		118.62 (*df*=16)		165.43 (*df*=16)		108.11 (*df*=16)	
Nagelkerke R Square	0.759		0.693		0.832		0.751	
Overall Percentage	88.8		84.1		88.8		92.9	

Exp(B) represents odds ratio, which is the change in the odds of the event of interest to a one-unit change in the predictor. Values without asterisks are non-significant at 0.05 level.

The output of logistic regression analysis presented in Table 6.4 revealed that out of sixteen hypothesized independent variables twelve were found to have significant influence on farmers' adoption of land management practices. Among socio-economic and demographic attributes sex, education, household size, farmland size, livestock size were found to have significant influence on the adoption of land management practices. In addition, biophysical factors including awareness of land degradation, perceived slope steepness, termite infestation, home to plot distance, and number of plots owned (land fragmentation) were also statistically significant. The result of the study also revealed that among institutional variables market distance and access to credit service were the important predictors of the adoption of land management practices. Out of the 12 significant explanatory variables, some have positively influenced while some others showed negative effect.

More specifically, as can be seen from Table 6.4 sex of the household head significantly but negatively influenced the adoption of agronomic measures by farm households in Bururi catchment. The negative effect is indicated by the Exp(*B*) value, which is less than 1. Being a male-headed household decreased the probability of adopting agronomic practices by 0.07 times, implying that female-headed households were more likely to adopt agronomic practices than the male-headed households holding other factors constant. In another similar study, Desta (2012) reported a negative but non-significant relationship between sex of household head and agronomic measures (particularly manure application), which implies that women are more likely to practice manure application than men. In contrast, it was reported that male-headed households are more likely to adopt land management techniques in Ethiopia compared to female-headed households (Kirui and Mirzabaev, 2019), which was attributed to the existing cultural and social setup that tend to discriminate against women and dictate access to and control over farm resources and other external inputs. On the other hand, the remaining three groups of land management (such as the structural, vegetative, and management measures) were not significantly correlated with sex of the household heads.

As hypothesized, the effect of education was found to be positive and significant with respect to management measures, suggesting that educated farmers are more likely to invest in this category. As portrayed in Table 6.4, a one-year increase in the schooling period increases the adoption of management measures by 3.4 times, which underlines the importance of education in the adoption of sustainable land management practices. This result confirms the idea that education positively influence the adoption of SLM technologies, in which more education is associated with greater ability to search and apply new information and knowledge pertaining to SLM (Kirui and Mirzabaev, 2019). Other empirical studies (for .e.g. Babalola and Olayemi, 2013; Miheretu and Yimer, 2017; Meseret and Amsalu, 2017; Saguye, 2017; Moges and Taye, 2017) also reported a positively significant effect of education on farmers decision to invest in land management measures.

The household size positively and significantly influenced the adoption of structural erosion control measures and vegetative/biological conservation measures. As can be seen from Table 6.4, the Exp(B) value or the odds ratio associated to household size under structural measures column is 1.93, hence with an increase in one household member the householders are 1.93 more times likely to adopt the physical structures of land management. Again, the Exp(B) value associated to household size under vegetative measures column is 1.71, and therefore, when the household size is increased by one person (one household member) the householders are 1.71

times more likely to adopt vegetative/biological conservation measures. This is in line with previous findings (for e.g. Gebremedhin and Swinton, 2003; Miheretu and Yimer, 2017; Kirui and Mirzabaev, 2019), who found a positively significant relationship between household size and land management adoption. Gebremedhin and Swinton (2003) reported that the presence of more working-age household members favored adoption of labor-demanding stone terraces. Similarly, Miheretu and Yimer (2017) and Kirui and Mirzabaev (2019) reported that larger household sizes may be associated with higher labor endowment, and are tend to use labor-intensive land management practices. In contrast, Aklilu and De Graaff (2007) found out the significant negative effect of family size on farmers' conservation decision, which implies that households with large family size are not likely to continue using the structural measures (stone terraces). However, the effect of household size on agronomic practices and management measures was found statistically non-significant.

In this study, the size of farmland owned by individual farmer significantly influenced the agronomic land management practices and vegetative/biological conservation measures. With respect to agronomic practices, the logistic regression analysis revealed that for every unit increase in farm size the likelihood of farmers' decision to adopt agronomic measures was reduced by 0.45 times. This agrees with earlier studies (such has Babalola and Olayemi, 2013; Gebre and Weldemariam, 2013) who found negatively significant effect of farmland size on land management practices. A study conducted by Babalola and Olayemi (2013) in Nigeria reported that farm size negatively influenced the use of Agronomic practices and this implies that users of agronomic practices were those with small farm sizes. Similarly, Gebre and Weldemariam (2013) showed that farmers having larger farm size are not interested to invest on soil conservation measures.

With respect to vegetative/biological conservation measures, out of the five significant variables influencing the adoption of vegetative measures, farmland size was found to be the strongest predictor, with an odds ratio of 8.73. This means when farmland size increases by one unit (one hectare), the householders are 8.73 times more likely to adopt biological conservation measures than the non-adopters. This result is consistent with the findings of several authors (including Amsalu and de Graaff, 2007; Babalola and Olayemi, 2013; Meseret and Amsalu, 2017; Moges and Taye, 2017; Song *et al.,* 2020) who reported a positive and siginficant association between farmland size and biological conservation measures. They indicated that farmers having larger farm size were more likely to adopt land management practices than those who have smaller farm size. This positive relationship could be due to the subsistence nature of the smallholders' agricultural practices, in which they strive to meet the households demand for food.

In the present study, only agronomic practices were found to be significantly influenced by the size of livestock owned. As can be seen from Table 6.4, from the five significant variables under agronomic column, the size of livestock (in TLU) was found to be the strongest predictor, recording an odds ratio of 5.18. Therefore, with every unit increase in livestock size (TLU) the householders are 5.18 more times likely to adopt agronomic measures than the non-adopters, controlling for all other factors in the model. This could be explained by the fact that farmers with more livestock have better availability of manure which could be more than what they need for cooking (Desta, 2012). This result agrees with the findings of Saguye (2017), who reported a significantly positive effect of livestock size on agronomic measures (particularly manure application).

Awareness of land degradation problem was found to significantly influence structural erosion control measures and vegetative conservation measures. The output of logistic regression presented in Table 6.4 indicate that awareness of land degradation problem positively and significantly influenced the adoption of structural measures, with an odds ratio of 6.184, which implied that the households who had awareness of land degradation problem were over 6 times more likely to adopt structural measures on their farmlands than farmers without awareness. Having a clear perception on the forms of land degradation by farmers is a key step for sustainable and successful intervention introduction, targeting the nature of the problem (Oldeman, 1994; Tesfahunegn *et al.,* 2012). The effect of land degradation awareness was also significant and positive on vegetative conservation measures, recording an odds ratio of 7.28, which revealed that farmers having awareness were 7.28 times more likely to adopt biological conservation measures than those lacking awareness, controlling for all other factors in the model. This is consistent with the findings of Saguye (2017) who reported a positively significant influence of land degradation awareness on SLM practices. Householders' awareness of land degradation is associated to their perception of the negative consequences of soil erosion and the benefits of conservation measures.

As hypothesized, steepness of farm slope significantly influenced land management practices (particularly structural measures). The result of the binary logistic regression portrayed in Table 6.4 revealed that householders who were cultivating steep slope were 4.69 times more likely to adopt physical structures than those having non-steep farm plots. This implies that farmers having plots on steeper slopes tend to invest more in land management practices than those having on gentle slope. This is because such areas are more susceptible to soil erosion and those plots can only be productive if protected by conservation structures. This is consistent with the findings of earlier studies (Amsalu and De Graaff, 2007; Miheretu and Yimer, 2017; Babalola and Olayemi, 2013; Saguye, 2017; Moges and Taye, 2017) who reported that slope of the plot positively and significantly affected adoption decision on land management practices. In a study conducted by Amsalu and de Graaff (2007) slope steepness positively and significantly influenced the adoption of stone bund. Similarly, Babalola and Olayemi (2013) and Saguye (2017) reported a positive effect of slope steepness on the adoption of land management practices.

In the present study, termite infestation was also hypothesized to influence land management practices and it was found that this negatively affected the biological measures. Those households who perceived severe termite infestation on their farm plot were 0.008 times less likely to adopt biological conservation measures (Table 6.4). This implies that the destructive effects of termites on crops and growing plants discouraged farmers' investments in vegetative/biological conservation measures. Termites have both positive and negative impacts on agricultural land depending on the species of termite present, population level and type of crop grown (Otieno, 2018). However, despite their benefits, some species of termites have detrimental effects on crop production specifically attributed to their feeding habits on both food crops and trees.

Home to plot distance significantly and negatively influenced the structural measures and agronomic practices (Table 6.4). The odds ratio of 0.96 for home to plot distance was less than one, signifying that for every additional walking minutes farmers were 0.96 times less likely to adopt structural measures, controlling for other factors in the model. Similarly, for every unit increase in home to plot distance the likelihood of farmers' decision to adopt agronomic measures was found to be reduced by 0.94 times. This implies that as distance between home and farm plot increases, farmers will be discouraged to participate in land management practices, as it demands more time and energy compared to plots in the homestead. This result agrees with the findings of Moges and Taye (2017) and Meseret and Amsalu (2017) who found a negatively significant influence of plot distance on farmers decision to adopt land management practices.

In this study, land fragmentation, which is explained by the number of land owned by individual household was found to significantly influence the adoption of physical structures and vegetative/biological measures. The output of regression analysis in Table 3.4 revealed that as the number of plots owned per household increased, the likelihood of farmers' decision to adopt structural measures decreased by 0.271 times. This means that the time and energy lost to travel between the distant parcels discourages farmers not to invest in land management practices. On the other hand, an additional piece of land owned by the household increased the likelihood of the adoption of vegetative/biological conservation practices 5.497 times. This is consistent with the findings of Tadesse and Belay (2004), who associated ownership of more pieces of land with better conservation measures.

The result of logistic regression presented in Table 6.4 also revealed that market access, which was measured in terms of distance from nearest market, significantly influenced the structural measures and agronomic practices. It showed a negatively significant influence on structural measures, and every additional unit in the distance of the nearest market was found to reduce the probability of implementing structural measures by 0.968 times. This suggest that distance from the nearest market represents the travel costs related to marketing of inputs and outputs. This agrees with the findings of Kirui and Mirzabaev (2019) who reported a negatively significant influence of market distance on the probability of land management adoption in Malawi and Tanzania. On the other hand, the effect of market distance was found to be positive and significant with respect to agronomic practices. Therefore, as distance from the nearest market increases by 1 unit (one minute) the odds ratio is 1.01 times as large and therefore, the householders are 1.01 more times likely to adopt agronomic measures.

In the present study, access to credit service was found to increase the likelihood of adoption of structural erosion control measures by 5.91 times than those who have no access, by controlling for all other factors in the model. This implies that the availability of credit service encourages farmers to invest more in land management practices and those farmers having the access were participating in structural land management practices. This confirms the findings of previous studies, who reported a positive and significant relationship between farm credit and chemical fertilizer adoption (Miheretu and Yimer, 2017). A study conducted by Kirui and Mirzabaev (2019) in East Africa also found that credit access increased probability SLM adoption, by relieving cash constraints and facilitating the acquisition of farm implements, irrigation infrastructure, and purchase of farm inputs. However, the result of this study contrast with the findings of Desta (2012) and Karidjo *et al.* (2018) who found that farmers' access to credit services is negatively associated to the adoption of soil erosion controlling measures. This might be explained by the fear of high risk to invest in conservation measures and the borrowed money has to be repaid by any means (Karidjo *et al.*, 2018).

Chapter Seven: Summary, Conclusion, and Recommendations

7.1 Summary

This study examined the pattern, drivers, and impacts of LULC change on soil erosion risk, soil quality, and soil organic carbon stock in Bururi catchment, western highlands of Ethiopia. Farmers perception of land degradation and the determinants of land management decisions were also explored.

The study employed a mixed method approach and thus collected both qualitative and quantitative data from primary and secondary sources to achieve the intended objectives. To assess the long-term LULC change (1957-2018), aerial photos and satellite imageries have been acquired from Ethiopian Mapping Agency (EMA) and USGS online archives respectively. Ground truth data collected by using a hand-held GPS receiver was also used to assist the LULC classification. The collected remote sensing data were analyzed using geo-spatial techniques and SPSS software.

The soil loss of the study catchment was computed by employing a GIS-based Revised Universal Soil Loss Equation (RUSLE) model. To generate the required inputs for the model, station-based rainfall data; soil texture and organic carbon content; 30m by 30m digital elevation model (DEM); and LU/LC Maps of three periods (1957, 1987, and 2018) have been employed.

To examine the effects of LULC and topographic elevation on selected soil quality parameters, thirty soil samples (0-20cm depth) collected from five dominant LULC types and two elevation categories were measured in soil laboratory following a standard procedure. From the measured soil attributes, only eight parameters (such as sand content, bulk density, soil pH, organic matter, total nitrogen, available phosphorus, CEC, and carbon to nitrogen ratio) were identified as appropriate soil quality parameters by using principal component analysis (PCA).

To analyze effects of LULC and topographic elevation on SOC and STN stock, the measured percent organic carbon and total nitrogen data were used to derive SOC and STN stock. Then two-way between-subjects multi-variate analysis of variance (MANOVA) in the general linear model (GLM) procedure of SPSS (v.24) was used to analyze the data.

To investigates the socio-economic, biophysical, and institutional factors that influenced the implementation of sustainable land management practices, the primary data were collected from 170 sample households using semi-structured questionnaire. The data collected through questionnaire survey was analyzed using SPSS (v. 24) by employing both descriptive statistics (like frequency, percentage, mean, Standard deviation) and inferential statistics (binomial logistic regression). We also explored local perceptions through field observations, focus group discussions, and key informant interviews to substantiate the quantitative data analysis.

The result of the study revealed that there have been remarkable changes in the LULC during the last 60 years (1957-2018). Forest cover and grassland decreased by 6.7% and 2.8% respectively. Agricultural, Shrub, and bare/degraded land had shown increment by 1.3%, 1.9%, and 6.3% respectively. It was also found that degraded land gained 570 hectares and lost 136 hectares with a net change of 434 hectares. The observed LULC dynamics were instigated by a combination of proximate and underlying factors such as agricultural activities, termite infestation, overgrazing, land abandonment, demand for specific crops, wood extraction, population pressure and lack of effective land use policy. Increased soil erosion, soil fertility decline, bare/degraded land expansion, shortage of grazing land, deforestation, food insecurity and seasonal outmigration were the major socio-environmental impacts of LULC dynamics observed in the study area.

The annual erosion rate was calculated using raster calculator of ArcGIS 10.6. As a result, erosion risk and watershed prioritization map were produced as important output of the analysis. The result revealed that soil erosion rate in 1957 ranged from 0 to 116 t ha^{-1} yr^{-1} with mean annual soil loss of 41.04 t ha^{-1} yr^{-1}. Whereas, in 2018 it was estimated to be between 0 in areas covered by riverine vegetation and 249 t ha^{-1} yr^{-1} in the upstream and southwest parts of the catchment, with a mean annual soil loss of 48.91 ha^{-1} yr^{-1} for the entire catchment. This difference in soil erosion loss between the two study years (1957 and 2018) indicated that changes in land use/ land cover have substantial impact on the ramification of soil loss.

The result of two-way multivariate ANOVA revealed that both LULC and topographic elevation significantly influenced the spatial variation of the studied soil quality parameters. The interaction effect was significant only for organic matter and consequently forest soils in the lower elevation revealed the highest organic matter content compared to other LULC types whereas degraded land in the upper altitude displayed the lowest mean value. With respect to

LULC, five parameters (such as sand content, bulk density, soil pH, organic matter, and CEC) showed significant variation. The conversions of forest cover and shrub land into agricultural and degraded land caused a depletion of soil pH, organic matter, CEC and increase bulk density or soil compaction.

The present study demonstrated that the spatial distribution of SOC stock across the study area was found to be influenced by LULC and topographic elevation. However, the effect of LULC was more pronounced than the topographic elevation. Lower SOC concentrations were observed in the upper elevation compared to the lower catchments. On the other hand, higher SOC stock were found under forest cover, shrub land, and grassland compared to agricultural and degraded land. Forest and shrub land were found to be more effective in sequestering SOC compared to the remaining LULC types under study. The study also revealed a significant effect of LULC conversions on SOC stock. Land use conversions from forest cover into agricultural, grazing, and degraded land significantly reduced SOC content by 51%, 45%, 72% respectively. Similarly, SOC stock have shown a decreasing trend after land use change from forest, grass, and shrub into degraded land, implying the remarkable loss of SOC following the change from natural ecosystem to managed ecosystem.

The result of binomial logistic regression revealed that out of sixteen hypothesized independent variables, twelve were found to have significant influence on farmers' decision to implement land management practices. The variables found significant are: sex, education, household size, farmland size, livestock size, awareness of land degradation, perceived slope steepness, termite infestation, home to plot distance, and number of plots owned (land fragmentation), market distance, and access to credit service. In general, farmers' decision to invest in sustainable land management was significantly influenced by socio-demographic, biophysical, and institutional factors.

7.2 Conclusion and Recommendations

The result of the study revealed that forest cover and grassland showed reduction while the remaining three LULC types (Degraded, agriculture, and shrub land) increased at the expense of other LULC types. As displayed by the obtained net change, bare/degraded land gained more land area than it lost during the study period. This remarkable increase of bare/degraded land was at the expense of agricultural, grass, shrub land, and forest cover. However, the significant contribution to degraded land was from agricultural and grassland.

Agricultural practices, termite infestation, overgrazing, land abandonment, demand for specific crops, and wood extraction were the identified proximate drivers of LULC dynamics while population pressure and lack of effective land use policy were the major underlying driving factors identified in Bururi catchment. The LULC dynamics had various social and environmental implications. Increased soil erosion, soil fertility decline, bare/degraded land expansion, shortage of grazing land, deforestation, food insecurity and seasonal outmigration were the major socio-environmental impacts of LULC dynamics. The seasonal migrants from the upper and middle parts of the study catchment were moved to adjacent areas of *Dhati-welel* National Park and those from lower catchment were relocated to *Qeto* resettlement site. They were cultivating the newly acquired farmlands near the park and come back to their original home after harvesting season, which negatively affected both the living condition of the households and the surrounding ecosystem. In general, if these problems persist, the sustainability of natural resources could be at risk and can seriously affect agricultural production. Therefore, as part of the solution we recommend that the government, NGOs, and other concerned bodies should introduce off-farm income generating activities in order to release the high pressure on the available land resource; the LULC policy need to be devised to prevent further degradation and save the fragile marginal ecosystem; participatory watershed management programs to rehabilitate the degraded areas. Further, the seasonal migration into the national park area have negative environmental implication on the National park. In the absence of effective land use plan and improved land management practices, it degrades the newly acquired land resources and affects the park ecosystem. Hence, a land use plan should be prepared to protect such marginal areas from further degradation.

This study also assessed the effects of LULC dynamics on soil erosion risk. The study demonstrated that the GIS-based RUSLE model is very useful and applicable compared to other erosion models, which require huge input data, given the inherent limitations of the RUSLE model. The result of the study provided good estimation of mean annual soil loss and erosion risk maps, which could be used for planning and implementing sustainable land management practices and land rehabilitation activities. The analysis of soil erosion risk revealed that the mean annual soil loss increased from 41.04 t ha^{-1} y^{-1} in 1957 to 48.91 t ha^{-1} y^{-1} in 2018. The variation in soil loss between the two years implied to be the result of changes in land use/land cover, which was reflected by expansion of bare land, shrub land, grazing land, and decline of forest cover that significantly affect the magnitude of soil erosion. Given the severity of the problem, the study finally recommends that due attention be given to hotspot areas where appropriate soil conservation measures should be prioritized in the catchment to reverse the prevailing of soil degradation. Conservation planners have to design proper soil and water conservation activities and implement based on the severity levels of soil erosion in the catchment.

Furthermore, the present study demonstrated that PCA could be used to identify potential soil quality parameters that can be used to assess the effect of LULC and topographic elevation on those parameters. It could be used to reduce the redundancy of data sets while retaining as much as possible of the variation present in the dataset. From several measured soil attributes only eight parameters were found to be appropriate including sand content, bulk density, soil pH, organic matter, total nitrogen, available phosphorus, CEC, and carbon to nitrogen ratio. These parameters cumulatively explained 68 percent of the total variation under three principal components. Both LULC and topographic elevation remarkably influenced the spatial variation of the studied soil quality parameters in Bururi catchment. The interaction effect was significant only for organic matter and consequently forest soils in the lower elevation revealed the highest organic matter content compared to other LULC types whereas degraded land in the upper altitude displayed the lowest mean value. With respect to LULC, five parameters (such as sand content, bulk density, soil pH, organic matter, and CEC) showed significant variation. On the other hand, topographic elevation showed a remarkable influence on sand content, bulk density, organic matter, and available phosphorus. The conversions of native ecosystem into managed land use system substantially reduced the studied soil quality parameters. Particularly, the change of forest cover and shrub land into agricultural and degraded land caused a depletion of sand content, soil pH, organic matter, and CEC and increase bulk density, which is associated to soil compaction. Such LULC conversions in the study area together with overgrazing, crop residue harvest, inappropriate application of organic fertilizers, and severe soil erosion could lead to further degradation and hamper sustainable crop production.

The present study also demonstrated that the spatial distribution of SOC and STN stock across the study area (Bururi catchment) was found to be influenced by LULC, topographic elevation, and the interactive effects. However, the effect of LULC was more pronounced than the topographic elevation, as both SOC and STN were significantly influenced by LULC, and the effect of topographic elevation was statistically significant only on STN stock. With respect to LULC, SOC and STN stock were remarkably higher under forest, shrub land, and grassland relative to agricultural and degraded land, indicating that conserving the natural ecosystem is very important for improving soil quality and increasing SOC and STN stock. Higher SOC and STN stock in forest, shrub land, and grassland might be attributed to higher residues decomposition from surface litter input which increased SOC concentrations. On the other hand, the lower values of SOC and STN stock in agricultural soils and degraded land call for urgent need to initiate sustainable land management which would reduce soil degradation. Lower SOC and STN stock observed in agricultural land and degraded soils might be explained by severe soil erosion which is exacerbated by unsustainable land management practices and the use of plant residues as livestock fodder and fuel. Moreover, higher STN stock were recorded in the lower elevation compared to the upper elevation area. This variation could be attributed to the high vulnerability of the upper catchment to soil erosion and increased likelihood of accumulation of eroded material in the lower elevation areas. SOC stock have shown a decreasing trend after LULC change from forest, grass, and shrub into agricultural and degraded land, implying the remarkable loss of SOC and STN following the change from natural ecosystem to managed ecosystem. Therefore, reversing these land use changes can lead over time to reversal in these trends and help to return carbon from the atmosphere to the soil.

Soil organic carbon stock can be increased through appropriate land management practices. As part of the solution, we suggest an urgent implementation of land rehabilitation practices (such as agroforestry, enclosures, revegetation of the degraded area) to reduce SOC and STN losses. This requires a concerted effort of all stakeholders including the local farmers, the Ministry of Agriculture and Natural Resource, the Ministry of Climate Change, and other concerned governmental and non-governmental agencies. Other agricultural practices, such as balanced use of fertilizers, crop rotation, intercropping, hedgerows and tree planting, managed grazing, animal manure application, and crop residue management can be employed to reverse the loss of SOC and improve soil quality. Although, many studies have been conducted on SOC stock in Ethiopia, more studies are still needed to understand soil carbon sequestration for different sites, land uses, management systems.

Finally, the study attempted to characterize the smallholder farmers in Bururi catchment in their adoption of sustainable land management practices and examined the socio-demographic, biophysical, and institutional factors that influence their decision on implementing the recommended conservation measures. Based on the result of the study it can be concluded that different land management practices have been implemented in the study area, but the overall adoption rate was minimal and land degradation continued to be a major challenge to agricultural land productivity. This could be attributed to the socio-demographic, biophysical, and institutional factors that influence farmers' decision to invest in conservation measures. Empirical results of the logistic regression revealed that twelve out of sixteen hypothesized predictors were found to significantly influence the adoption of sustainable land management practices. Among socio-economic and demographic attributes sex, education, household size, farmland size, and livestock size were found to have significant influence on the adoption of land management practices. In addition, biophysical factors including awareness of land degradation, slope steepness, termite infestation, home to plot distance, and number of plots owned (land fragmentation) were also statistically significant. The result of the study also showed that among institutional variables market distance and access to credit service were the important predictors of the adoption of sustainable land management practices. Therefore, the designed land and natural resource management strategies should consider the socio-demographic characteristics of farm households, biophysical attributes, and institutional factors to promote better adoption of the recommended conservation measures. Moreover, there is urgent need to empower farm households through education, training, and other agricultural extension services. Since the effect of termites discourage farmers' investments in the biological conservation measures by destructing growing plants and shrubs, the government and other stakeholders should jointly act to control the prevalence of termites in the study area by integrating both traditional and modern methods. For the recovery of fallow plots in the study area, controlled grazing should be promoted in such a way that no degradation of vegetation and soils occurs. The findings also suggested that improved access to infrastructure and credit services could motivate farmers and enhance the adoption of sustainable land management practices.

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Appendices

APPENDIX 1. SURVEY QUESTIONNAIRE FOR HOUSEHOLDS

Addis Ababa University
School of Graduate Studies
Dept. of Geography and Environmental Studies

SURVEY QUESTIONNAIRE FOR HOUSEHOLDS

The purpose of this questionnaire is to gather data on the long-term dynamics of land use/ land cover and its impact on erosion rate, soil quality, and soil organic carbon stocks from farm households in Bururi watershed of Oromia region, Western Ethiopia.

Dear respondent,

The result of this study will provide helpful information for policy makers, land users and development practitioners about magnitude and trends of land use and land cover change and its implication on the ecosystem services. Your responses will stay confidential and your name will be anonymous unless you are willing to be disclosed. Therefore, you are kindly requested to provide genuine responses. Your right to involve or not is also highly respected.

Identification of the Respondents (Household head)

- Code No._______________
- Kebele Name: _________________________________Village: ________________
- Date of interview: ____________________________
- Name and Signature of the Enumerator: ________________________________

Part I. GENERAL CHARACTERISTICS OF THE FARM HOUSEHOLDS

(Please, encircle your choice for the questions with alternatives)

1.1 Demographic Characteristics

1) Sex of the household head 1) Male 2) Female

2) Age of the Household Head: __________________

3) Marital status of the household head 1) married 2) single 3) divorced 4) widow 5) separate

4) Family size: ____________

5) Years of schooling: _________________

6) Years of experience as a farmer: ______________________

7) Distance to the nearest market (in walking minutes/hours): _____________________

8) Distance to the nearest main road (in walking minutes/ hours): ___________________

9) Distance from agricultural office (in walking minutes/ hours): ___________________

10) What type of transport do you use to sell your produce? 1) Public/vehicle transport 2) donkey back 3) donkey cart 4) other, specify_____________________________

11) Number of household members involved in agriculture: ______________

12) Do you have off-farm income? 1) Yes 2) no

13) If your response to Q. No. 12 is "yes":

13.1please specify the types of the off-farm-income: ____

13.2For what purposes do you use this income? ____

2.1 Economic Background of the Household

2.1.1 Farmland Ownership

14) Do you have a farmland? 1) Yes 2) no

15) If yes, please would you tell me the total size of your farmland? ______________timad.

16) How many plots do you have? ___________

17) Means of farmland acquisition (*more than one response is allowed*):

1) 1st distribution 2) Redistribution 3) Inheritance
4) Inheritance and Redistribution 5) Gift 6) Share cropping
7) Renting 8) others, specify _________________________

18) The total size of your farmland land, including the rented or sharecropped?

16.1Private: _________________________*timad*
16.2Rented: _________________________*timad*
16.3Sharecropped: ____________________*timad.*

19) Please, indicate the size of land you had in *timad* at different period of time.

Time Interval	**Size of Each Parcel of Land**			
	Homestead	**Cropland**	**Private grazing land**	**Plantation**
Current				
10 years ago				
20 years ago				
30 years ago				
40 years ago				

20) Do you think that your farmland is getting smaller or bigger? 1) Smaller 2) bigger 3) no change

21) If getting smaller, what could be the reasons? 1) land redistribution 2) sharing to new household in the family 3) land become unproductive/degraded 4) any other____________

22) Do you think larger households own more land than smaller households? 1) Yes 2) no

23) Please, indicate type of land do you own. 1) Crop land 2) forest land 3) grazing land 4) grassland 5) others, specify: __________________________________

24) What is the fertility status of your land? 1) Fertile 2) medium fertile 3) less fertile 4) degraded

25) Presently the farmland your household owned is: 1) Adequate 2) not adequate

26) If "not adequate", what coping mechanism do you use to solve the problem?

1) Intensification of the existing farm plot 2) expansion toward forest area
3) cultivation of steep slope and valley areas 4) cultivation of wetlands
5) Engage in to non-farming activities 6) Others: ________________________

27) What is the distance of farmland from your home? 1) Very close 2) close 3) far 4) very far

28) How many plots of farmland do your households have? 1) One 2) two 3) three 4) four 5) five or more

29) How do you describe your farm plots in terms of climate and topography?

Plots No.	**Climate**	**Topography/Relief** (e.g. Flat, undulating, Hilly, mountainous, steep)
Plot 1		
Plot 2		
Plot 3		
Plot 4		
Plot 5		
…		

30) How do you describe your farm plots in terms of slope? 1) steep 2) not steep

31) How do you rate termite infestation on your farmland? 1) severe 2) not severe

32) Have you access to agricultural credit? 1) yes 2) no

33) what do you feel about Land tenure security? 1) feel secured 2) do not feel secured

2.1.2 Livestock Ownership

34) Do you own livestock? 1) Yes 2) No

35) If "yes", how many livestock do you own? Fill in the table below.

No.	**Livestock Type**	**Quantity in Number**
1	Cow	
2	Oxen	
3	Calf	
4	Heifers	
5	Goats	
6	Sheep	
7	Horses	
8	Mule	
9	Donkeys	
10	Poultry	
	Others…	

36) What are the significances of livestock to your households? 1) ______________ 2) ____________ 3) _____________________ 4) ________________ 5) ___________

37) Where is the location of your grazing land? 1) Plain 2) hillside 3) valley side 4) in the forest 5) around home stead

38) What are the major sources of animals feed? 1) Crop Straw 2) Grazing private pasture 3) communal grazing land 4) Grazing around homestead 5) Private fallow 6) others, specify: ___________________________

39) Has your number of livestock been increasing or decreasing over the past years?

Type of livestock	Increasing	Decreasing	No change
Cow			
Oxen			
Calf			
Heifers			
Goats			
Sheep			
Horses			
Mule			
Donkeys			
Poultry			

40) Would you tell us the reasons, in the order of importance for the above trend? 1) Lack of fodder 2) Shortage of grazing land 3) Disease prevalence 4) Lack of veterinary services 5) Shortage of water 6) other, specify____

41) If the numbers of livestock is decreasing, do you think that it has implications on your livelihoods? 1) Yes 2) no

42) If **yes**, what are these implications 1) income decline 2) mal-nutrition problem 3) shortage of animal labour for farm activity and transportation 4) any other______________

43) Do you have a problem of grazing land? 1) Yes 2) no

44) What land management methods do you use to sustain your grazing land? 1) post-harvest feed 2) rotational grazing 3) short fallow (one year) 4) seasonal mobility (encroach into forest and enclosed areas) 5) others, specify______________________

2.1.3) Crop Production

45) List the major crops that frequently grown in the order of their importance: 1) ____________ 2)__________________ 3)___________________ 4)_________________ 5)_____________

46) Why these crops are being the most important? ____ ____.

47) On which type of soil these crops are grown? _____________________________

48) Where is the location of your farmland? 1) Hillside 2) plain 3) along valley 4) others_______

49) How do you state the trend of yield on your farmland over the past years? 1) Increasing 2) no change 3) decreasing 4) I don't know

50) Crop productivity per hectare of cropland by crop types:

		Crop Productivity per hectare (*4 timad*) in Quintals				
No.	**Crop type**	In 1970s	1980s	1990s	2000s	Current
1						
2						
3						

51) What are in your opinion the major causes of crop yield reduction and **rank** according to importance 1) erratic rainfall__ 2) scarcity and high price of improved seed ___ 3) unaffordable price of fertilizer____ 4) shortage of plowing oxen___ 5) soil degradation (erosion, low fertility, etc.)____ 6) pest prevalence (parasite, diseases, weed, etc.)____ 7) lack of money lenders_____ 8) food aid_____ 9) other, specify____

Part II. Land use land cover change: its pattern, drivers and impacts

52) Have you noticed any change in the land use/land cover in your locality over the past 50 years or so? 1. Yes 2. No

53) If "yes" what major changes occurred in your locality in the past 50 years? Give your opinion as (*increasing, decreasing, and no change*).

Land use type	**1970s to 1985**	**1986-2000s**	**Since 2000**
Cropland			
Grazing land private			
Grazing land communal			
Natural vegetation			
Plantation forest			
Fallow			
Abandoned land			
Closed area			
Volume of streams			
Number of wildlife			

54) What are the factors that prompted the alterations in land use/land cover? 1) Market prices and availability 2) Household size (Population) 3) Sustenance 4) infrastructure 5) climate 6) others, specify________

55) In general, what are your observations of the land use land cover dynamics that have occurred in the area since the time you began residing in the area?

____

____

56) Following the land use/land cover change, which environmental problems become very common in your area? 1) Soil erosion 2) degradation of watersheds 3) change in local climate 4) lack of grazing land 5) lack of trees to hang beehives 6) others, specify______________________

Part III. Soil Erosion Risk: Causes and implications

57) Have you experienced the incidence of soil erosion on your farm plot? 1)Yes 2) No

58) If **yes**, what are the symptoms/indicators for the occurrence of soil erosion? (put in order from most to least important)

No.	Indicators	Ranks (1, 2…)
1	Rills and Gully development	
2	Observing the color of run-off water	
3	Accumulation of dump near to valleys	
4	Stoniness of soil	
5	Slope Steepness	
6	Absence of fertile topsoil	
7	Root exposure	
8	Poor crop and grass growth	

59) How do you describe the level of soil erosion on your farmland? 1) Severe 2) Moderate 3) Minor

60) Which type of erosion is severe on your land? (More than one is allowed). 1) Sheet erosion 2) Rill erosion 3) Gully erosion

61) The percentage of your farmland seriously affected by soil erosion? ________ %.

62) Which lands are more affected by soil erosion (put in order from more to less affected)? 1) Cultivated____ 2) Grazing land____ 3) Forested land______ 4) grassland_____

63) Observed change in erosion intensity over the last 50 years. 1) Has become more severe 2) Has become less severe 3) No change

64) What do you think of the main causes of soil erosion on your plots? (put in order from most to least important).

No	**Causes of soil erosion**	**Rank** (1, 2, 3…)
1	Steepness of the terrain	
2	Continual cultivation and absence of fallowing	
3	Soil erodibility	
4	Intensity of rainfall	
5	Absence and delay of soil conservation measures	
6	Deforestation	
7	Overgrazing	
8	Run-off from upslope areas	

65) What are the negative impacts of soil erosion observed in your locality?

No.	Effects of Soil Erosion	Rank (1, 2, 3…)
1	Loss of topsoil	
2	Reduction in yield over time	
3	Gullies reduced farm and grazing lands	
4	Floods	
5	Affected water quality	
6	Others…	

66) How do you describe the extent of impact of erosion on crop yields? 1) Severe 2) Moderate 3) less effect 4) has no effect

Part IV. Soil Quality Decline

67) How do you perceive the fertility of your land? 1) Improving 2) Constant 3) Declining 4) do not know

68) If the fertility of your land is declining, what are the symptoms? *(More than one response is allowed).* 1) Annual yield per specific unit 2) Appearance of weeds on the farm 3) Change in soil colour 4) More fertilizer consumption 5) Others, specify______________________________________

69) What could be the causes of soil fertility decline? (More than one answer is allowed)

1) Erosion 2) over cultivation 3) inadequate soil fertility management practices 4) others, specify__________________

Part V) Land Degradation and Management

70) Have you noticed the problem of environmental degradation in your locality? 1) yes 2) no

71) which symptoms of land degradation did you observe in your locality?

____

72) Which land management practices do you prefer to implement?

- Drainage furrows   Crop rotation   Coffee-based Agroforestry

- Diversion ditches
- Soil bunds
- Stone bund
- Terrace construction
- Manure application
- Compost use
- Fallowing
- Area closure
- Changing plant species
- Grass strips
- Tree planting
- Area closure
- -others (specify)______

Part VI) Environmental Degradation and Management

73) Have you noticed the problem of environmental degradation in your locality? 1) yes 2) no

74) If your answer is “yes”, how do you explain the process of degradation? (in relation to vegetation, soil, local climate, water bodies, wild life etc.)

____

____

75) What crises did your household face due to the problem? *You can underline more than one answer.* (health crises, food shortage, crop failures, loss of cattle, death, lack of capital, soil fertility decline, insects and pests, land scarcity, high price of crop at purchase and vice versa, deteriorating social network, lack of animal feed, oxen shortage, lack of wood, labor shortage, and others, specify)

____

76) What were your coping strategies during the occurrence of the problems? 1) Reducing consumption in each meal 2) Eating famine period food or less preferred food 3) Borrow grain or money to buy food 4) Selling firewood 5) Selling charcoal 6) Rely on food aid 7) Selling small animals (goat, sheep, chicken) 8) Selling cattle 9) Migrate to nearby urban areas for casual wage labor 10) Migrate to other areas for farmland acquisition 11) others, specify ____

____

Forest Resources

77) What is your perception of trees? 1) Source of forest products (e.g. fodder, fuel wood, and shelter for local people)__2) Source of supplementary income__ 3) Source of government revenue __ 4) Obstacles to agricultural expansion ___ 5) Climatic importance__

78) Do you have trees on your farmland? 1) yes 2) no

79) What do you think are the importance of trees on the farmland? 1) Improve soil fertility 2) fuel wood 3) fodder 4) shade 5) soil erosion protection

80) What is the principal construction material of your house and fence? 1) Bamboo/cane 2) wood with mud and/or dung 3) Cement 4) others, specify ______________________

____

81) What is the type of fuel used by the household?

Energy Type/Fuel	Cooking	Lighting	Heating
1) Charcoal		▨	
2) Fuel wood			
3) Candles	▨		▨
4) Kerosene			
5) Animal dung			
6) Electricity			
7) Others, specify__________________________			

82) If firewood is commonly used, please indicate the source. 1) Own forest /plantation 2) community forest 3) Government forest 4) Market 5) others_________________________

83) From your household members, who is responsible to collect the firewood? 1) Father 2) Mother 3) sons 4) daughters 5) others, specify

____

84) Time spent to collect and bring the firewood (the average) to home: ________ minutes or _____hrs.

85)Who will carry and transport the collected firewood to home? _________________________

86) Currently, is there adequate forest cover in your village? 1) Yes 2) No

87) While you compare the present natural forest with the past years: 1) Highly decreased 2) decreased 3) no change 4) increased 5) Highly increased

88) In your opinion, what are the major causes of damage to forests in your village?

1) Over-cultivation_______ 2) need of cropland______ 3) Cyclic events (e.g. erratic rainfall, drought) __ 4) Illegal cutting of wood_______ 5) Over-grazing_______ 6) Government weak forest law enforcement

89) Has the change (much decrease) negatively affected your livelihoods? 1) Yes 2) No

90) If **yes,** what are some of the negative changes? 1) Scarcity of fuel wood and construction materials 2) stream flow decreased or dried up 3) runoff increased 4) yield has declined 5) Gullies and rills occurred

91) How do you gain access to the woodland forest reserves? 1) Permission from local Kebele administration __ 2) Permission from DAs 3) Permission from woreda adminstration___4) No permission_

92) Are you aware of the forest law? 1) Conscious________ 2) Unconscious______

93) Who should manage the forest reserves? 1) PA_______ 2) Federal government________ 3) local government________ 4) Immediate users at local level_______

94) Give reasons why you think the forest reserves need to be managed?

1) Mismanaged by the farmers______ 2) Excessive deforestation for crop, grazing and sale of fuel wood ________ 3) Increase in prices of forest products_______ 4) others______________

95) Are you willing to contribute to the management of forest reserves? 1) Yes__ 2) No__

96) If the answer to question 50 is “Yes”, mention the form of contribution. 1) Effort only_ 2) Ideas and organization efforts_ 3) others____

97) Are you willing to plant trees? 1) Yes_______ 2) No________

98) If you answered “No” to Question 56, what is the main reason? 1) Low level of motivation_______ 2) Lack of technical support_______ 3) Reduction of crop yields by trees________ 4) Land/tree tenure dilemma__ 5) others____

99) If you answered “Yes” to Question 45, what is the main purpose? 1) Fuelwood and charcoal_ 2) Shade 3) Fodder 4) Timber 5) Fruits 6) others______________________________

100) If you answered “Yes” to Question 56, which major tree species would you prefer to planting and why?

Preferred Tree species	**Reasons for preference**

101) What land units are allocating for tree growing in your land-use system? 1) Land set aside 2) Farm boundary 3) Home stead 4) On crop land 5) Degraded, like shallow soils and gully cuts etc. 6) others______________________________

102) Which strategies you suggest to increase forest coverage in your village? 1) Reforestation of degraded common properties of forests 2) afforestation of unused or marginal lands 3) Focus on existing forests to improve them 4) others, specify

____

____

Water Resources

103) What are the purposes or importance of water in your locality? 1) for drinking 2) for washing clothes, dishes, etc. 3) Bathing 4) cooking 5) Watering animals 6) watering plants or trees near the home

104) Please indicate are the sources of water:

a) For home consumption? ____

b) For livestock? ____

105) From your household member, who is responsible to fetch (collect) water? 1) Father 2) mother 3) sons 4) daughters 5) others, specify___________________________

106) Time spent to walk from your home to the water sources (in walking minutes or hours)

Water Sources	**Time spent**
Source 1	_________min. or _______Hrs
Source 2	_________min. or _______Hrs
Source 3	_________min. or _______Hrs
….	

107) Time spent for collecting water (including the time spent walking from the house to the water source, the time spent waiting to fill the container, and the time spent walking home)

Water Source	**Time spent waiting to fill the container**	**Time spent in walking (Both trips)**
Source 1	_________min. or _______Hrs	_________min. or _______Hrs
Source 2	_________min. or _______Hrs	_________min. or _______Hrs
Source 3	_________min. or _______Hrs	_________min. or _______Hrs
….		

108) What is the color of water during the rainy season? 1) clear 2) white or cloudy 3) Brown 4) others ____

109) What is the color of water during dry season? 1) clear 2) white or cloudy 3) Brown 4) others

____

110) How would you rank the quality of the water from this sources during the rainy season? 1) very clean 2) somewhat clean 3) Average 4) Not clean 5) very unclean

111) How would you rank the quality of the water from this sources during dry season? 1) very clean 2) somewhat clean 3) Average 4) Not clean 5) very unclean

112) How do you explain the trend of a stream or a river volume and flow over the past 50 years?

1) Increasing 2) decreasing 3) no change

113) If it is decreasing, what do you think is the reason? 1) ________________________

2)______________________________ 3) _____________________________

114) What are the problems associated with water volume /flow decrease? 1) _______________

2)_______________________________ 3) ___________________________

115) How do you overcome water scarcity during dry season? 1) Use harvested rain water during wet season 2) travelling long distance to get water 3) others _______________________

Soil Resources

116) Do you believe that erosion can be controlled? 1) yes 2) no

117) If "yes" did you take any conservation measures to minimize problem of soil erosion? 1) yes 2) no

118) If your answer is "no", Please list some of the reasons. 1)

____________________________ 2)______________________

3)______________________4)_______________________

119) If your answer is **yes**, please specify some of the conservation methods you have applied. (Indicate the type of land use and topographic condition on which you have applied.)

Conservation Methods	**Land use type** (e.g. cultivated, forested, grazing land, etc.)	**Topography** (e.g. steep slope, hilly, undulating, flat land)
Contour plough		
Soil bunds		
Stone bunds		
Cut-off drains		
Artificial waterways		
Traditional ditches		
Terracing		
Check dams		
Grass strips		
Afforestation		
Agro-forestry		
Others…		

120) Are you facing labor shortage to apply the SWC measures? 1) yes 2) no

121) Can periodic land redistribution in any way affect your decisions on adopting SWC measures? 1) It discourages me 2) It does not have any effect

122) Do you feel that you have sufficient knowledge on conservation measures? 1) Yes 2) No

123) Have you ever been trained on erosion controlling measures? 1) Yes 2) No

124) If your response is "yes", who organized the training? 1) Woreda experts 2) Local DAs 3) NGOs 4) others, specify________________________________

125) Do you think that the training was sufficient or not? Why? ______________________

____

126) Soil fertility status of your land a) poor___b) moderate_____c) relatively fertile ____

127) From traditional land rehabilitation measures for mitigating soil fertility problems, which one do you apply? 1) Addition of soil organic matter__ 2) Crop rotation__ 3) fallowing___ 4) Ploughing once__ 5) Double ploughing___ 6) Ploughing thrice 7) kan biro

____

128) Do you remove crop residuals from farmland after crop harvesting? 1) Yes 2) no

129) If **yes**, for what purposes? 1) Animals feed 2) sale 3) as biofuel for cooking/baking 4) for house roofing (covering) 5) any other, specify __________________________________

130) Do you have a practice of burning crop residuals on your plot assuming that weeds will be destroyed? 1) Yes 2) no

131) How you manage soil fertility on your farm land: 1) crop rotation 2) chemical fertilizer 3) Animal manure 4) Fallowing 5) inter-cropping (rotation with legumes) 6) compost 7) others, specify ____

132) Do you use animal manure frequently to improve soil fertility? 1) yes 2) no

133) If **no**, why? 1) Low perception of its use in improving soil fertility 2) used as source of fuel 3) shortages of animal manure 4) labor intense 5) fear of weed intensification 6) any other____

134) In general, are there any environmental management/conservation schemes like afforestation, reforestation, closure, terracing etc. in your area? 1) Yes 2) no

135) If “yes” please specify the conservation schemes applied in order of importance.

____

____.

136) Who is responsible for environmental management/protection? 1) Local Farmers themselves 2) the community 3) government 4) NGOs 5) all

137) What do you think are the factors influencing farmers' decision making on resource management options? 1) Educational status of households 2) level of extension service provision 3) wealth of households possessed 4) fragmentations of the farmland 5) lack of awareness of the problem 6) any other ____________________________

____

138) What are the most priority environmental issues in your locality that needs intervention? Please forward your suggestion.

____

____

____ .

Any comments and observations not covered?

APPENDIX 2. GUIDING QUESTIONS FOR KEY INFORMANTS AND FGDS

1. Is natural vegetation available in your locality?
2. What are the significances of natural forest to the local community?
3. What major changes in land use/cover type occurred in your locality in the past 40 years?
4. What do you think are the causes for these changes (increasing and decreasing) of land use/cover (specifically natural forests) that occurred in your locality in the last 40 years?
5. What effects do these land use/cover changes have brought upon local environment (forest, soil, wildlife, grazing land, water resources or hydrology, climate) and local livelihoods (resource availability, incomes and living conditions)?
6. How do you or the local community cope with these changes and the impacts?
7. Are there any environmental management/conservation schemes in your locality? If **yes**, please explain them.
8. If no, what do you think is the reason? ____
9. What natural and human factors affect land resource management?
10. Have you attended any workshop, training and discussion on land management and conservation program organized by government, NGOs and others?
11. Who is responsible for environmental management/protection? (Farmers themselves, the community, government, NGOs)
12. What are the traditional or indigenous methods of resource conservation and management the local community practice in your area? (Soil, forest, grazing land, water, wildlife)
13. What do you think are the major production constraints of the study area? (Crop, livestock, forest)
14. Is there an effort made (government or NGOs) that encourage farmers to largely rely on natural fertilizer than chemical fertilizer to improve soil fertility?
15. Who practice soil conservation and soil management more, the poor or the rich, and why?
16. How can you improve your resource management practices for the sustainability of your livelihoods and the environment?

Any comments and observations not covered?

Thank you for participating!

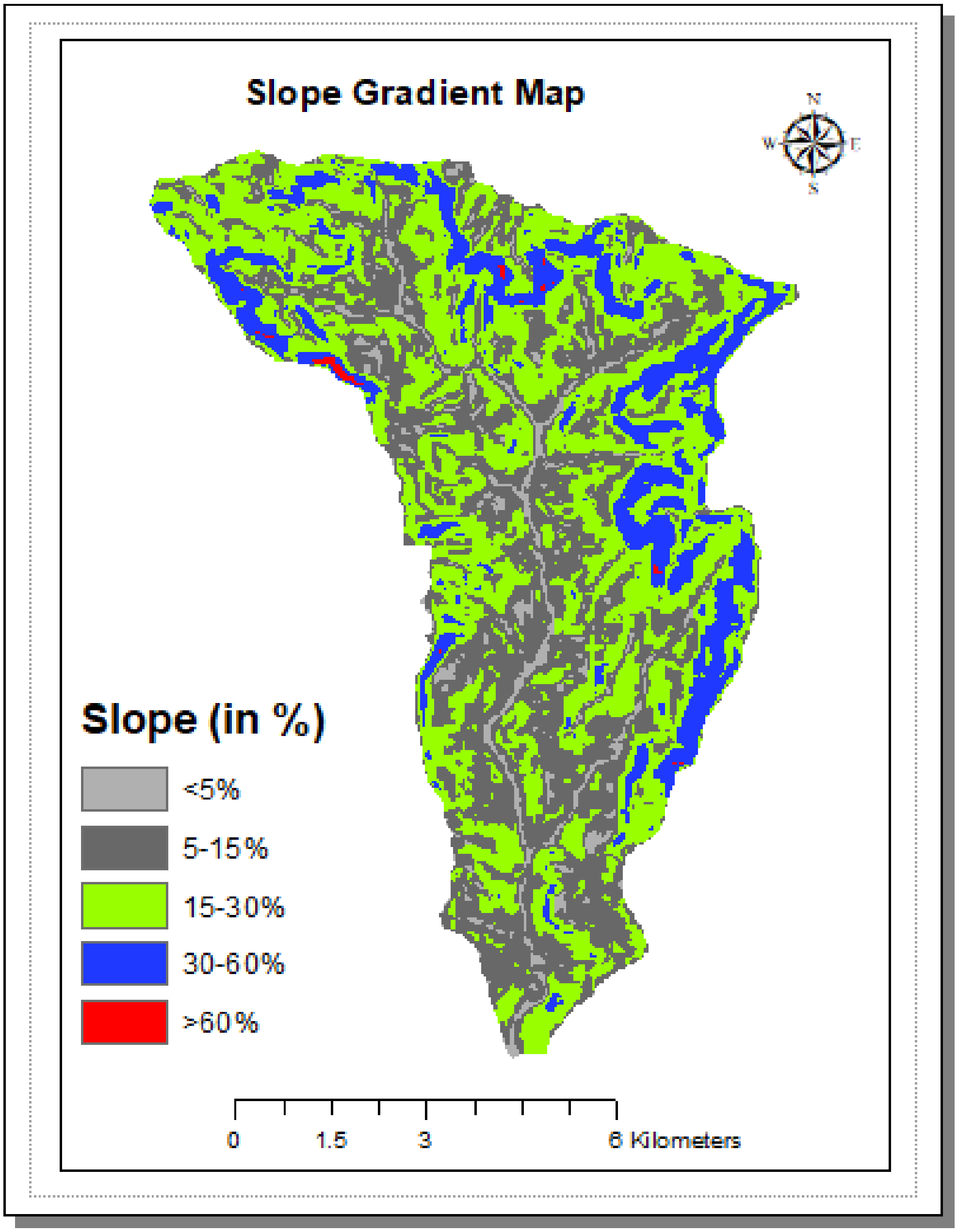
Appendix 3 Soil Physical and Chemical Properties

Lab_ID	Elevation	LULC	Elev*LULC	Sand	Silt	Clay	BD	EC	pH	OC	OM	TN	Av_P	CEC	Na	K	Ca	Mg	C:N
2245/17	LC	FL	LE Forest	17.00	16.00	67.00	.75	.03	5.70	3.20	5.50	.21	7.60	42.80	.40	.80	8.60	5.70	26.19
2246/17	UC	FL	UE Forest	26.00	28.00	46.00	.81	.02	4.90	2.70	4.64	.42	5.20	35.60	.60	1.50	9.30	4.10	11.05
2247/17	UC	FL	UE Forest	28.00	24.00	48.00	1.01	.03	5.60	2.74	4.71	.14	3.20	48.80	.20	1.90	7.60	5.80	33.64
2248/17	LC	FL	LE Forest	26.00	32.00	42.00	.93	.15	5.80	2.88	4.95	2.20	14.00	59.20	.20	.50	8.90	3.90	2.25
2249/17	UC	FL	UE Forest	34.00	26.00	40.00	1.12	.04	5.30	2.64	4.54	.23	3.20	17.54	.38	.12	10.80	4.20	19.74
2250/17	LC	FL	LE Forest	15.00	32.00	53.00	.89	.05	6.40	3.42	5.88	.41	4.40	62.80	.73	1.40	10.20	5.40	14.34
2251/17	LC	ShL	LE Shrubland	31.00	13.00	56.00	.73	.21	7.40	2.81	4.83	.78	10.00	51.40	.90	1.50	7.30	3.80	6.19
2252/17	UC	ShL	UE Shrubland	20.00	38.00	42.00	1.05	.07	5.70	2.62	4.51	.21	2.80	48.90	.90	.65	9.80	4.90	21.48
2253/17	LC	ShL	LE Shrubland	19.00	15.00	66.00	.79	.20	6.10	2.73	4.70	.33	4.40	50.90	.15	.10	8.50	5.50	14.24
2254/17	LC	ShL	LE Shrubland	20.00	30.00	50.00	1.21	.09	4.80	3.20	5.50	.47	8.60	41.20	.10	1.20	8.90	3.20	11.70
2255/17	UC	ShL	UE Shrubland	29.00	49.00	22.00	1.32	.02	5.10	2.30	3.96	.23	2.80	15.30	.20	.40	8.30	4.70	17.22
2256/17	UC	ShL	UE Shrubland	31.00	33.00	36.00	1.34	.03	5.80	2.30	3.96	.13	4.00	42.20	.70	.10	7.50	3.90	30.46
2257/17	UC	GL	UE Grassland	41.00	31.00	28.00	1.59	.09	5.50	2.15	3.70	.21	2.80	52.90	.10	.20	7.40	2.30	17.62
2258/17	LC	GL	LE Grassland	31.00	15.00	54.00	1.16	.03	5.60	2.15	3.70	.31	4.60	48.10	.27	.10	6.90	3.20	11.94
2259/17	UC	GL	UE Grassland	32.00	36.00	32.00	1.34	.02	4.20	2.09	3.59	.19	2.40	34.10	.50	.50	9.30	4.70	18.89
2260/17	UC	GL	UE Grassland	38.00	38.00	24.00	1.41	.03	5.50	1.90	3.27	.21	5.20	43.40	.11	.10	6.70	2.60	15.57
2261/17	LC	GL	LE Grassland	26.00	29.00	45.00	1.32	.04	4.25	2.27	3.90	.35	7.60	11.58	.20	.16	7.50	1.83	11.14
2262/17	LC	GL	LE Grassland	18.00	28.00	54.00	1.21	.01	5.50	1.84	3.16	.31	9.20	35.60	.10	.10	5.40	3.90	10.19
2263/17	LC	AgL	LE Agricultural	28.00	37.00	35.00	.72	.04	4.20	2.27	3.90	.22	7.20	24.60	1.15	.32	4.59	4.90	17.73
2264/17	UC	AgL	UE Agricultural	35.00	35.00	30.00	1.36	.03	4.70	1.47	2.53	.17	3.20	29.60	.40	.08	6.50	3.20	14.88
2265/17	LC	AgL	LE Agricultural	28.00	27.00	45.00	.52	.03	5.50	2.32	3.99	.23	7.60	33.70	.10	.10	5.70	4.10	17.35
2266/17	LC	AgL	LE Agricultural	34.00	30.00	36.00	1.51	.04	5.20	1.87	3.22	.21	5.60	41.20	.10	.60	4.50	4.10	15.33
2267/17	UC	AgL	UE Agricultural	25.00	31.00	44.00	1.40	.05	4.56	1.33	2.29	.22	4.80	20.76	.46	.34	3.25	2.01	10.41
2268/17	UC	AgL	UE Agricultural	29.00	37.00	34.00	1.41	.02	5.80	1.33	2.29	.29	2.80	29.40	.10	.10	8.90	5.60	7.90
2269/17	LC	DegL	LE Degraded	45.00	40.00	15.00	1.49	.07	3.90	1.53	2.63	.20	5.20	11.40	.30	.06	2.50	1.79	13.15
2270/17	LC	DegL	LE Degraded	20.00	56.00	24.00	1.33	.02	4.50	1.64	2.82	.20	4.80	17.20	.20	.20	4.30	.70	14.10
2271/17	UC	DegL	UE Degraded	46.00	19.00	35.00	1.53	.04	4.40	1.17	2.01	.20	3.20	20.40	.10	.10	3.90	2.90	10.05
2272/17	LC	DegL	LE Degraded	39.00	13.00	48.00	1.34	.13	5.10	1.48	2.55	.20	4.00	34.50	.10	.10	1.70	3.20	12.75
2273/17	UC	DegL	UE Degraded	41.00	29.00	30.00	1.63	.05	4.76	1.19	2.05	.10	2.40	15.20	.33	.20	3.25	1.87	20.50
2274/17	UC	DegL	UE Degraded	47.00	33.00	20.00	1.42	.04	4.10	1.27	2.18	.20	2.80	12.78	.21	.10	1.80	.60	10.90

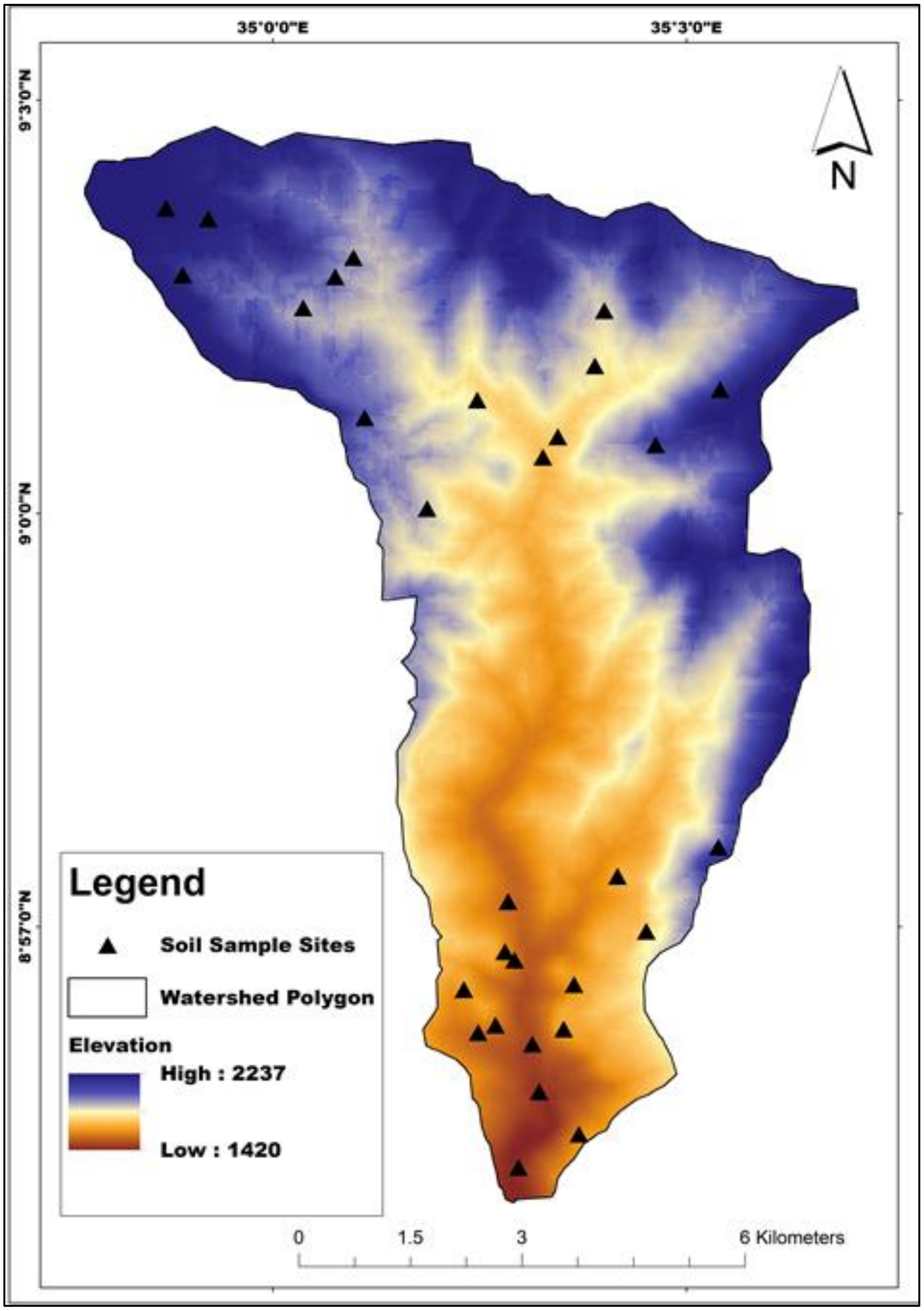
Note: LC=lower elevation; UC=upper elevation; FL=forest land; ShL= shrubland; GL=grassland; AgL=agricultural land; DegL=Degraded land.

Appendix 4. Soil Parameters used in PCA and their mean values

	LULC_Class									
	Agricultural		Degraded land		Forest		Grassland		Shrub land	
Soil Parameter	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Sand (%)	30.00	29.67	34.67	44.67	19.33	29.33	25.00	37.00	23.33	26.67
Silt (%)	31.33	34.33	36.33	27.00	26.67	26.00	24.00	35.00	19.33	40.00
Clay (%)	38.67	36.00	29.00	28.33	54.00	44.67	51.00	28.00	57.33	33.33
Bulk Density (g cm^{-3})	0.92	1.39	1.39	1.53	0.86	0.98	1.23	1.45	0.91	1.24
Total Porosity (%)	65.41	47.55	47.67	42.39	67.68	63.02	53.59	45.41	65.66	53.33
EC (mS/cm)	0.04	0.03	0.07	0.04	0.08	0.03	0.03	0.05	0.17	0.04
PH (H2O)	4.97	5.02	4.50	4.42	5.97	5.27	5.12	5.07	6.10	5.53
Soil Organic Carbon (%)	2.15	1.38	1.55	1.21	3.17	2.69	2.09	2.05	2.91	2.41
Organic matter (%)	3.70	2.37	2.67	2.08	5.44	4.63	3.59	3.52	5.01	4.14
Total Nitrogen (%)	0.22	0.23	0.20	0.17	0.94	0.26	0.32	0.20	0.53	0.19
Available P (ppm)	6.80	3.60	4.67	2.80	8.67	3.87	7.13	3.47	7.67	3.20
CEC (Cmolc kg^{-1} soil)	33.17	26.59	21.03	16.13	54.93	33.98	31.76	43.47	47.83	35.47
Na+ (Cmolc kg^{-1} soil)	0.45	0.32	0.20	0.21	0.44	0.39	0.19	0.24	0.38	0.60
K+ (Cmolc kg^{-1} soil)	0.34	0.17	0.12	0.13	0.90	1.17	0.12	0.27	0.93	0.38
Ca2+ (Cmolc kg^{-1} soil)	4.93	6.22	2.83	2.98	9.23	9.23	6.60	7.80	8.23	8.53
Mg2+ (Cmolc kg^{-1} soil)	4.37	3.60	1.90	1.79	5.00	4.70	2.98	3.20	4.17	4.50



Appendix 5 Slope Map of Bururi Catchment



Appendix 6. Sites of Soil Samples

Appendix 7: Soil data used to compute the RUSLE K-factor

ID	**(%) Sand**	**(%) Silt**	**(%) Clay**	**% OC**	***ƒ csand***	***ƒ cl-si***	***ƒ orgc***	***ƒ hisand***	**USLE_K**	**RUSLE_K**
1	26	28	46	4.89	0.202488	0.747099	0.750001	0.999994	0.113458	0.014942
2	26	32	42	3.75	0.203247	0.777634	0.750044	0.999994	0.118545	0.015612
3	67	17	16	2.81	0.200000	0.819560	0.750946	0.971392	0.119568	0.015747
4	28	24	48	5.17	0.201292	0.719223	0.750000	0.999991	0.108579	0.014300
5	15	32	53	2.53	0.222034	0.745966	0.752387	0.999999	0.124618	0.016412
6	40	34	26	2.89	0.200348	0.843331	0.750727	0.999888	0.126829	0.016703
7	42	38	20	4.23	0.200382	0.880860	0.750010	0.999829	0.132360	0.017432
8	20	30	50	2.49	0.208329	0.745091	0.752726	0.999998	0.116841	0.015388
9	49	29	22	4.88	0.200041	0.844206	0.750001	0.999253	0.126562	0.016668
10	31	33	36	2.59	0.201472	0.801492	0.751957	0.999984	0.121423	0.015991
11	31	13	56	3.61	0.200301	0.606078	0.750070	0.999984	0.091055	0.011992
12	19	15	66	2.77	0.204804	0.602951	0.751080	0.999999	0.092748	0.012215
13	41	31	28	2.99	0.200215	0.824428	0.750524	0.999862	0.123866	0.016313
14	31	15	54	2.52	0.200353	0.632663	0.752468	0.999984	0.095378	0.012561
15	32	36	32	2.51	0.201586	0.826301	0.752551	0.999980	0.125350	0.016509
16	38	38	24	2.40	0.200721	0.863411	0.753674	0.999927	0.130605	0.017201
17	26	29	45	2.74	0.202659	0.755005	0.751192	0.999994	0.114938	0.015137
18	18	28	54	3.71	0.210870	0.724441	0.750051	0.999999	0.114580	0.015090
19	35	35	30	2.43	0.200887	0.830513	0.753326	0.999961	0.125679	0.016552
20	28	37	35	2.72	0.203280	0.818956	0.751273	0.999991	0.125069	0.016472
21	25	31	44	2.63	0.203625	0.767167	0.751714	0.999995	0.117428	0.015465
22	29	37	34	4.63	0.202792	0.822400	0.750003	0.999989	0.125081	0.016473
23	28	27	45	2.58	0.201602	0.745091	0.752023	0.999991	0.112962	0.014877
24	34	30	36	1.51	0.200678	0.789357	0.811660	0.999969	0.128568	0.016932
25	41	9	50	0.64	0.200021	0.568875	0.977390	0.999862	0.111199	0.014645
26	47	20	33	0.86	0.200020	0.746494	0.949095	0.999509	0.141643	0.018654
27	40	15	45	1.41	0.200050	0.659754	0.830037	0.999888	0.109539	0.014426
28	46	19	35	2.15	0.200022	0.730984	0.758409	0.999602	0.110845	0.014598
29	56	20	24	1.78	0.200003	0.789357	0.777823	0.996812	0.122406	0.016121
30	39	13	48	0.70	0.200051	0.628904	0.971276	0.999909	0.122188	0.016092