Land Degradation and Sustainable Land Management in the Upper Blue Nile: The Case of North Gojjam Sub-Basin

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Declaration

I declare that this dissertation is comprised my original work and it ha
any other qualification in this university or anywhere else and all ot
used in this dissertation have been fully acknowledged.

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This is to certify that the dissertation prepared by Alelgn Ewunetu Temesgen, entitled "**Land Degradation and Sustainable Land Management in the Upper Blue Nile: The Case of North Gojjam Sub-Basin**" and submitted in the fulfillment of the requirements for the degree of Doctor of Philosophy (Ph.D.) in Development Studies (Environment and Development Studies) complies with the regulation of the University and meets the accepted standard for originality and quality.

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General Abstract

Ethiopia is facing an acute land degradation problem attributable to complex natural and manmade drivers, and this challenged the ability of rural farmers to meet the growing of food demand. The main objective of this study was to assess land degradation and sustainable land management to improve household food security in the north Gojjam sub-basin of the Upper Blue Nile. The study was depended on the holistic data gathered through multistage sampling via different instruments including from Landsat images, 414 randomly selected households' survey, key informant interviews, series of focus group discussions, and field observation. Landsat images were analyzed using ArcGIS10.5, QGIS3.1, and ERDAS IMAGINE14 software. Whereas socioeconomic data were analyzed using advanced econometric models and simple descriptive statistics using STATA14 and Microsoft excel. The analysis of the LULC results informs that agricultural land use was the most dominant cover, followed by grazing land and bush and shrublands. From the period 1986 to 2017 there were significant LULC changes in the sub-basin. Agriculture and plantation forest covers have been increased, but other land covers (waterbodies, bar land, forest, grazing land, and bush and shrublands) have been decreased due to human and natural driving and pressure. The RUSLE showed that on average 46t $ha^{-1}yr^{-1}$ or a total of 65.21 million tons of topsoil have been lost annually from the sub-basin. The finding of combined spatial multicriteria analysis (MCA) of biological, chemical, and physical land degradation indicators show, one-third of the sub-basin was highly degraded. Similarly, land users also confirmed as land degradation is a severe problem and has been increasing in the last 10 years. There was a consensus with land owners as the productivity of crops, livestock, and the quantity and quality of water and firewood have been declined and in turn, adversely affect the income and food security of the community. The most widely used SLM measures in the sub-basin were inorganic fertilizer, soil bund, and animal manure. The result from MVP model analysis shows that most adopted SLM technologies are complementary. The model result also depicts farm size, family size, male-headed household, participating in local institution, perception on soil erosion severity, livestock size, total income, and extension service increased the adoption probability of most SLM technologies. The result of the endogenous switching regression (ESR) model shown that the adoption of integrated SLM technologies significantly increased rural farm household food security. Hence, the study suggested that drivers of land degradation should be ceased and sustainable resource use is required, otherwise the limited land resources will be soon lost and no longer be able to play their role in socio-economic development. The adoption of integrated SLM technologies contributes to improving households' welfare and the pathway for reducing rural poverty. Thus, ISLM practice should be promoted in the study area and elsewhere through the motivating of land users via education and training as well as increasing the supply of external agriculture inputs.

Keywords: *Land Degradation, Land Use Land Cover, Impact, Livelihood, Sustainable Land management, food security, Universal soil loss Equation, Multifactorial Analysis*

List of Original Papers

This dissertation is produced based on the following articles and manuscripts:

1. Ewunetu, A., Simane, B., Teferi, E., & Zaitchik, B. F. (2021a). Land Cover Change in the Blue Nile River Headwaters: Farmers' Perceptions, Pressures, and Satellite-Based Mapping. *Land*, *10* (1), 68. https://doi.org/10.3390/land10010068
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Abbreviation and Acronyms

AFSIS	Africa Soil Information Service
AHP	Analytic Hierarchy Process
amsl	above mean sea level
ASTER	Advanced Space born Thermal Emission and Reflection Radiometer Radar for Topography Mission
CHIRPS	Climate Hazards Center InfraRed Precipitation with Station data
CIA	Central Intelligence Agency
CSA	Central Statistical Agency
DA	Development Agent
DN	Digital Numbers
DPSIR	Driver-Pressure-State-Impact-Response
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resource Data Analysis System
ESR	Endogenous Switching Regression
ETB	Ethiopian Birr
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
FDRE	Federal Democratic Republic of Ethiopia
FGD	Focus Group Discussion
GCP	Ground Control Point
GDEM	Global Digital Elevation Model
GDP	Gross Domestic Product
GIS	Geographic Information System
GLASOD	Global Assessment of Human-induced Soil Degradation
GPS	Global Positioning System
GTP	Growth and Transformation Plan
ha	hectare

HDDS	Household Dietary Diversity Score
HFCE	Household Food Consumption Expenditure
HFIAS	Household Food Insecurity Access Scale
HH	Households
ISLM	Integrated Sustainable Land Management
LADA	Land Degradation Assessment in Drylands
LULC	Land Use Land Cover
MA	Millennium Ecosystem Assessment
MCA	Multi-Criteria Analysis
mm	Millimeter
MVP	Multivariate Probit
NGO	Non-Governmental Organization
OLI	Operational Land Imager
PR	Poison Regression
RUSLE	Revised Universal Soil Loss Equation
SAVI	Soil Adjusted Vegetation Index
SLM	Sustainable Land Management
SSA	Sub-Saharan Africa
SWC	Soil and Water Conservation
TIRS	Thermal Infrared Sensor
TLU	Tropical Livestock Unit
TM	Thematic Mapper
TOA	Top of Atmosphere
UNCCD	United Nation Convention to Combat Desertification
UNDP	United Nation Development Program
USAID	United States Agency for International Development
USGS	United States Geological Survey

1. General Introduction

1.1. Background of the Study

Land is the most fundamental natural capital, which provides habitat and livelihood for all living things. Nonetheless, land degradation accelerated the deterioration of the ecosystem services of land, mainly in the 20th and 21st centuries (UNCCD, 2013a). According to Nkonya and Mirzabaev (2016), land degradation affected about 30% of the total global terrestrial land and from 5 to 8 million ha of productive agriculture land have been out of use per year (FAO, 2003). Similarly, the latest reports of UNDP show that about 40% of agricultural land degraded over the past 50 years at different levels (UNDP, 2015). The problem is severe in low-income countries, where agriculture is the largest sector of the economy and the basis for population's livelihood (Bulletin, 2009; Stavi and Lal, 2014).

Africa is the most vulnerable to land degradation (UNEP, 2015). In this continent, land quality deterioration is the main challenge in striving for achieving agricultural productivity and food security (Liniger et al., 2011). In the Sub-Saharan African (SSA) countries agriculture sector contributes on average about 30% of GDP, 40% of export items, 40% of the foreign revenue, and created about 70-80% of job opportunities (Commission for Africa, 2016). However, the sector has been affected by abject land degradation in the region (Liniger et al., 2011). Therefore, in the region most of the population is vulnerable to extreme poverty (Nkonya et al., 2016).

Ethiopia is rich in blend of natural resources attributable to its tropical location joined with remarkable latitudinal variation in a short range of distance which permits the country to have diverse fauna and flora resources (Bewket, 2003; Amsalu, 2006). Agriculture is the backbone of the national economy, generates about 43% of GDP; bases for over 80% of total employment and 90% of export earnings (Chanyalew et al., 2015). However, the sector continues to be hampered by abject land degradation in the form of soil erosion, soil nutrient depletion, lack of soil moisture, and drought (Pender and Gebremedhin, 2006). It estimated that the country has been lost from 5-9% of its agricultural yield caused by land degradation coupled with climate extremes (FAO, 2011). As a result, the country has persisted as one of the poorest countries of the world and people are remained chronically food insecure (Amsalu, 2006) and, has become a major food aid recipient country in Africa. The problem is very pervasive in many parts of the country, but it is the worst in the highland regions, where in most densely populated areas (Zeleke, 2007).

Ethiopia is experienced to various land degradation extending from physical, biological, and recently chemical degradation (Abate et al., 2017; Gebreselassie et al., 2016). The country can be defined as mountainous because more than 45% of its part is above 1500 masl altitude and are the center of the country's main economic activity (Amsalu and Graaff, 2006; Hurni et al., 2010). The region produces the country's 95% of the crop production and about 60% of livestock number and 90% of the population settled here (Hurni et al., 2010). This region, including the upper Blue Nile basin of Ethiopia, once endowed with rich natural resources has been exploited for millennia and, at present highly degraded and the decline of natural resources productivity is acute (Cassells, 1995; Nyssen et al., 2009; Tadesse and Belay, 2004; Gebreselassie et al., 2016).

Land degradation in Ethiopia is the result of various complex webs of human and natural driving and pressure forces (Gebreselassie et al., 2016; Taddese, 2001). Key driving forces such as rapid population growth, land tenure insecurity, poverty, low and poor implementation of SLM technologies, institutional dynamics, erosive rainfall, and cultivation of steep slope areas are major factors for the occurrence of direct land degradation drivers (Berry et al., 2003; FAO, 1986; Gebreselassie et al, 2016; Kirui, 2017). Similarly, major pressures such as destruction of woodland and forest, poor farming technique, and over and free grazing, deforestation, and overexploitation natural resources (soil, water, forest, and rangeland), the use of dung and crop residue for domestic energy, and house construction have been accelerated land degradation in the country (Berry et al, 2003; Kirui, 2016). Cultivated land which has a slope greater than 30% should not normally be used for crop production, but it is recommended to use for forestry. However, in Ethiopia, there is no well-known land-use policy implementation that excludes farmers from allocating such land types of cereal crops (Gebreselassie et al., 2016).

In Ethiopia, though land degradation is an old problem, public and government intervention is the latest phenomenon. Before the 1970s, land management was negligible, and very little effort was made to combat land degradation (Bekele, 2003; Shiferaw and Holden, 1998). Since the 1970s modern SWC technology was introduced by land users, the government, and international NGOs

(Bekele, 2003; Shiferaw and Holden, 1998). Mainly, an effort towards land management strategy was started after the Ethiopia government initiated massive SWC program following the 1975 land reform and the most programs were implemented through Food for Work strategic approach (Shiferaw and Holden, 1998). During the 1980s different research centers, institutions and organizations were established to introduce and promote land management technologies on different public and private land-use types (Shiferaw and Holden, 1998; Berry et al., 2003). Nevertheless, the impact of those efforts did not curb the impact of land degradation and the adopted SLM technologies show so far seem to have limited success, and failed in many areas (Amsalu et al., 2007). Different explanations are often given for unsuccessful efforts. Reputedly cited factors of the failure of adopted technologies are ignoring indigenous land management measures, high initial costs, and also trying to apply uniform SLM technologies in the heterogeneous agro-ecological and livelihood zones, followed a top-down approach in the planning and lack of farmers awareness (Amsalu and Graaff, 2006; Bekele, 2003). The main contribution of farmers in soil and water conservation (SWC) practices was labor, which was compulsory or based on food-for-work payments (Bewket, 2003).

Considering the past limitations, the country re-established new SLM strategies, approaches, and technologies designed for farmers by technical experts (Abi et al., 2018; Bewket, 2007;Teshome et al., 2016). Mainly, since 1995 the government has integrated several SLM technologies into agricultural extension packages through community mass mobilization at the watershed level (Abi et al., 2018;Teshome et al., 2016). For example, Growth and Transformation Program-GTP I and II (FDRE, 2016); Sustainable Land Management Project-SLMP (SLMP-I (2008 – 2013) and SLMP-II (2013 – 2018)); Making Environmental Resource to Enable Transition to More Sustainable Livelihood (MERET) project; Climate Resilient Green Economy Strategy (CRGE) (Awraris et al., 2014); Public Works Program of the Productive Safety net program (PSNP) and many others (World Bank, 2020). Similarly, the country has followed an agricultural production intensification approach to boost crop productivity through the application of modern agricultural inputs, mainly improved seed, agronomic practices, and fertilizer technologies to feed the rapidly growing population (Dorosh and Rashid, 2013; Sime, 2018; Sisay et al., 2017).

Thus, there is considerable interest in understanding the major drivers of land resources change (soil, water, and vegetation), and current comprehensive land degradation status, the effect of its degradation on the livelihood, and constraints to the wider adoption technologies against the resources degradation as well as response effect on households' food security. These processes need to show the complexity and chain synergies of land degradation process systematically using a clear framework (*driver-pressure-state-impact-response*) DPSIR framework that can show a chain of causal linkage, starting from 'driving forces' through 'pressures' to 'states' and 'impacts' on land resource bases (ecosystem services) and eventually leads to policy 'responses' (Agyemang et al., 2007). Thus, the present study primarily focused on major land use/land cover change and the drivers of change; the status of comprehensive land degradation; and its impacts on rural livelihoods; the determinants of farmers' decision on adoption of multiple SLM technologies against land degradation, and finally evaluate the effect of integrated SLM technology adoption on household food security in the north Gojjam sub-basin, upper Blue Nile of Ethiopia.

The rationale for selecting the north Gojjam sub-basin for this research is derived from the following three key reasons. First, although the north Gojjam sub-basin is a high potential region for agricultural production, the ecosystem service is highly fragile and susceptible to high soil erosion and land degradation. Second, in the sub-basin there have been various SLM interventions, therefore, it is important to document landscape change and the impact of an intervention on households' welfare (food security). Third, it is very important to insight the erosion risk on the Ethiopian Grand Renaissance Dam (EGRD) because the area is the main source of water for the dam. Fourth, little or no up-to-date comprehensive empirical research was carried out on the process of land degradation and the response measures via holistic data and robust methodology for further intervention in this particular sub-basin because this study include various and relevant land degradation indicators (soil erosion, soil compaction, soil derange, soil depth , vegetation cover, soil organic matter and soil acidity), the effect of land degradation on rural livelihood and responses against land degradation including its effectiveness.

1.2. General Problem Statement

Land degradation and deterioration of landscape health, affects upstream productivity and downstream investments of irrigation and hydropower, have been a primordial challenge in Ethiopia. Although encouraging results have been achieved with the implementation of different public strategies to rehabilitate degraded land and improve the productivity of ecosystem services, land degradation continues to constitute a fundamental challenge to sustain the realization of the full potential of the Ethiopian landscape productivity (World Bank, 2020).

In Ethiopia, land degradation is a major immediate cause of declining natural resource base productivity and low agricultural productivity, persistent food insecurity, and rural poverty (Awraris et al., 2014; Ayele et al., 2020; Motbainor et al., 2016; Zeleke, 2007). These are the result of a vicious cycle of natural resource degradation and poverty (Zeleke, 2007) and makes the country's food production far behind the growing population and one of the African countries that witness the power of land degradation deriving people out of their residence (Belay, 2015).

Upper Blue Nile/ Abbay basin, including the north Gojjam sub-basin, is naturally endowed with ample natural resources and good potential for the production of ecosystem services. The basin is suitable for the growth of a wide range of tropical, subtropical, and temperate crops. But, the area has been continuously exploited with the historical development of agriculture and human settlement, and the present condition is very alarming (Simane et al., 2016; Zeleke and Hurni, 2001). The natural resource bases (soil, water, forest, and rangeland) are under intense pressure from population growth and unsustainable natural resource use, and hence natural vegetation clearance and soil erosion are very serious and its adverse effect on agricultural production has been continuous. As a result, the livelihood of the farming community faces severe constraints related to the fragile ecosystem, shortage of cultivated land, natural vegetation degradation, soil erosion, soil acidity, the decline of soil fertility, water scarcity, and shortage of livestock fodder.

In recent years, some studies assessed landscape dynamics in the upper Blue Nile (Bewket, 2003; Teferi et al., 2013). However, the landscape in Ethiopia in general and in the Abbay basin, in particular, has been characterized by significant differences in terms of population distribution, socio-economic condition, agroecosystem, soil characteristics, climate condition, farming system, and biodiversity distribution (Simane et al., 2016). Prevailing these heterogeneities, local-based landscape assessment is very important to capture the complexity of land degradation dynamics and to avoid blanket conclusions and incorrect policy implications. Likewise, evidence shows that the biophysical environment is subjected to ongoing research because human activity has rapidly changed ecosystem services beyond its carrying capacity (Agyemang, 2012). This is true in the Abbay basin (Merrey and Gebreselassie, 2011) including our study area. Although there is a spiral of historical land degradation, there are best practices that can be taken as exemplary works on land management in SSA countries (FAO, 2011). Though land degradation is a problem, efforts have been made by the government, NGOs, and the local community to reverse ecosystem degradation and improve rural livelihood in the Abbay basin through applying diverse SLM technologies (Merrey and Gebreselassie, 2011; Simane et al., 2016). As a result, this study investigated the recent land use/cover (LULC) change in the north Gojjam sub-basin using remote sensing data integrated with local land users' knowledge.

Studies in the past have identified the physical and human factors for the occurrence of land degradation and landscape change in Ethiopia in general (Berry, 2003; Gebreselassie et al., 2016) and in the Abbay basin in particular (Bewket, 2003; Teferi et al., 2013). However, most of the studies were focused on the type of drivers for LULC change instead of more concerned about the priority of the key driving forces and pressures of change using local land users' knowledge for effective responses against the drivers and pressures of land degradation. Besides, as we indicated above, since 1995 there are efforts taken by the government and local community against land degradation, such as giving land certification for land users, the establishment of a protected area, introducing new energy-saving technologies, preventing charcoal production, and firewood collection from natural forest, promoting cut and carry system, improving rural infrastructure and accessing training for rural farmers through extension agents (Gebru, 2016). Nonetheless, the effect of these and other activities yet well documented in the Abbay basin in general and in the north Gojjam sub-basin in particular.

Mapping and quantifying land degradation status plays an important role in the cost-effective design of land management policies and strategies. This enables stakeholders to identify the most vulnerable areas and to give priority for the locational intervention (Bewket and Teferi, 2009; Moore and Wilson, 1992). But, these types of studies are scant in the Ethiopian highlands. Most of the GIS-based land degradation assessments in the past were based on a single indicator, for instance, soil erosion (Bewket and Teferi, 2009; Haregeweyn et al., 2017; Molla and Sisheber, 2016; Gelagay and Minale, 2016). Thus, to fill this gap we used a new approach for the development of a comprehensive land degradation status map using remote sensing, GIS, analytical hierarchy process (AHP), and multicriteria analysis (MCA) techniques to account for many factors responsible for land degradation in the north Gojjam sub-basin.

Concerning the impacts of land degradation, researches have been undertaken in Ethiopia (Amsalu and Graaff, 2006; Bewket, 2012; Saguye, 2018) that focuses mainly on specific locational factors that drive perception and response of land degradation. As a result, there is a substantial deficit of location-specific information about the process of autonomous impacts of land degradation and farmers' perception of the processes of degradation at their locality. Likewise, up-to-date information on the impact of land degradation on livelihood strategies is very important for quick intervention (Zeleke, 2007), but such types of studies are scant in the Abbay basin and no in the north Gojjam sub-basin as we reviewed. As a result, understanding local perceptions on their livelihood strategies provides better insights and information relevant to a policy that helps to address the challenge of sustainable livelihood development.

Taking into consideration the past limitations, the current government established new SLM strategies, approaches and designed for smallholder farmers through technical experts. Nevertheless, the effort has not been successful as it is expected in the Abbay basin (Merrey and Gebreselassie, 2011). Several studies have identified recent constraints on SLM adoption decisions in the Abbay sub-basins, such as household characteristics, capital asset, level of education, institutional support, and biophysical factors that affect landholders to adopt and use continuously (Belay and Bewket, 2013; Teshome et al., 2016). Though most of the findings on the variables are concerned with erosion control, far from soil fertility management technology adoption determinants (Teshome et al., 2016). Besides, most researchers used a binary regression model to estimate farmers' adoption behavior on SLM technology adoption but, ignoring supplementary and complementary characteristics of technology using a robust model like a multivariate model. Because the decision on different SLM technologies are assumed to be interdependent; the use of one SLM strategy may hinder or foster the use of other SLM strategies. Past studies missing important variables such as the adoption of compost and improved seed (Nigussie et al., 2017). Therefore, there is a research gap that identifies the causality and determinants of simultaneous use as well as the intensity of adoption of SLM technologies by smallholders.

In the past, most of the researchers evaluated the effect of a single SLM technology at different locations, but not combination of ISLM practices implemented on a single plot in the Abbay basin (Merrey and Gebreselassie, 2011). The reports are often mixed, some researchers reported a high positive impact of the SLM intervention (Pender and Gebremedhin, 2004), while others reported minimal or even negative outcome of the intervention measures (Kassie et al., 2008; Khonje et al., 2015; Teklewold et al., 2019). Moreover, no studies have systematically addressed the linkage between rural welfare and ISLM adoption benefits measured by food security using the robust model. Therefore, generally based on the literature, researchers' knowledge of the study area, and the real existing problem mentioned above, we initiated to assess comprehensive land degradation problems in the north Gojjam sub-basin of the upper Blue Nile basin.

1.3. Objectives of the Study

The main objective of this study is to assess the status of land degradation and sustainable land management in the north Gojjam sub-basin of the upper Blue Nile.

1.3.1. Specific objectives

To achieve the general objective, the following specific objectives are formulated:

1. To analyze land use/land cover change (1986-2017) and the drivers of changes
2. To map and quantify comprehensive land degradation status
3. To assess perceived impacts of land degradation on rural livelihood
4. To identify the determinants of household's decision to adopt SLM technologies
5. To look at the effect of integrated SLM technology adoption on household food security

1.3.2. Basic Research Questions

To achieve the stated objectives, the following basic research questions are formulated.

1. To what extent and the pattern of LULC have been changed for the last 31 years? How do farmers perceive LULC change? Is there any difference between Landsat image analysis result and local knowledge on LULC change?
2. What are the major driving forces and pressures of LULC change?
3. What are the perceived impacts of land degradation on the livelihood?
4. What level of physical, biological, chemical land degradation status found?
5. What factors determine farmers' decision to use SLM technologies?
6. To what extent the integrated SLM technologies improve food security status?

1.4. Significance of the Study

Detail significances of this research are presented in each respective chapters. However, in this section, some of the significances are described briefly hereafter. The novelty of this study is using an improved, holistic, and robust methodological approaches to evaluate the problem of land degradation and SLM technology adoption using the *driver-pressure-state-impact-response* (DPSIR) to capture a wide range of heterogeneous indicators in the north Gojjam sub-basin. It is the first which provides a comprehensive assessment that identified various driver forces that aggravate comprehensive land degradation pressures; determine the current state of land resource bases (soil, water, and forest) and types of land degradation due to drivers and pressures; adverse impacts of degradation on rural livelihoods; factors affecting land management technology adoption choice and the effect of adoption of ISLM technologies on households' food security. Therefore, the conceptual framework used in this study links spiral land resource management to rural households' welfare effect, mainly food security in the Ethiopian context as it exclusively employs beyond single equation regression. Further, the study invested landscape change and land degradation status at basin level and its impacts at community level, and the responses at community and household level. Thus, this study has the methodological contribution for future research on agriculture and land management scientific researches in Ethiopia and elsewhere for sustainable development.

Besides, this study provides important empirical evidence to policymakers, researchers, academicians, and other stakeholders about the recent change and the current state of natural capital (i.e. cultivated land, surface water, forest, and soil), and the main driving forces and pressures of landscape change in particular and land degradation in general in the north Gojjam sub-basin. As well, it enables to know the current problem of land degradation on the main rural household livelihood strategies (crop and livestock production, water resources, firewood, and food security), particularly in the north Gojjam sub-basin. It also updated constraints that affect farmers' decision to adopt SLM technologies and its effect on rural households' food security in the north Gojjam sub-basin. The study insight sedimentation risk on the Ethiopian Great Renascence Dam (EGRD) because the study area is the main source of water for the great dam. As well, the study identified some gaps for future research that need further investigation.

1.5. Scope and Limitation of the Study

This study has some limitations due to time and financial resource constraints. The scope of this study delimited on the aspect of land degradation assessment. Particularly the study addressed LULC change and drivers and pressures for change, estimated average soil loss using the RUSLE model, and mapping and quantifying of comprehensive land degradation status through the combination of biological, physical, and chemical land degradation indicators using multicriteria evaluation technique. Moreover, the study includes the perceived impacts of land degradation on the key rural livelihood strategies, identified land management strategies, and determinants of farmers' decision to adopt different SLM technologies to control or reclaimed degraded ecosystem services. Besides, this study focuses on the effect of ISLM technology adoption on rural household food security in the north Gojjam sub-basin. However, the study was limited to cross-sectional data collected from 414 randomly distributed farm households instead of using time-series data to evaluate the overtime impact of land degradation on rural livelihood, and the long-term effect of land management efforts on household food security attributable to the scarcity of full panel data.

Despite these limitations, this study added significant values to the existing knowledge pool on broader concept and current issue of land degradation process which include drivers, pressures, current statute and types of land degradation, perceived livelihood impacts of degradation, and determinants of farmers' response against land degradation and the response effect on food security in north Gojjam sub-basin of upper Blue Nile, Ethiopia.

2.2. Organization of the Dissertation

This Ph.D. dissertation contains nine separate chapters. The first chapter presents a general introduction and problem statement as well as the objectives of the study, scope, and limitation, the second chapter contains literature review and theoretical literature and the general conceptual framework of the study. The third chapter involves a brief description of the study area and general methodology. The fourth chapter constitutes land cover change in the Blue Nile River Headwaters: farmers' perceptions, pressures, and Satellite-based mapping. Chapter five, on the other hand, mapping and quantifying the status of comprehensive land degradation using multicriteria analysis (MCA). Furthermore, chapter six also assessed the impact of land degradation on rural livelihoods. Chapter seven further identified the determinants of household's decision of multiple sustainable land management (SLM) technologies adoption. Likewise, chapter eight contains the effect of adopted integrated sustainable land (ISLM) technology on rural households' food security. Finally, chapter nine is a synthesis that brings with collected main issues and key findings cutting from across all the prior units and highlights the important recommendations and policy implications for sustainable environmental management and economic development.

2. Literature Review

2.1 . Concepts and Definition of Compressive Land Degradation

There are wide range of concepts and definitions about land degradation in the literature which causes of confusion, misunderstanding, and misinterpretation (Eswaran et al., 2001). Some common terms used are soil degradation, desertification, and land degradation. However, there is a clear difference between soil and land. The word land refers to the terrestrial ecosystem consists of not only soil, but also vegetation, water, landscape setting, lower climate, and ecological processes which operate within the ecosystem (MA, 2005). This implies that soil degradation is one of the single parts of land degradation. On the other hand, there is a clear distinction between land degradation and desertification. Desertification is a very narrow concept relative to land degradation because severe land degradation occurs in all climatic zones, such as in the temperate humid and the humid tropic regions (Eswaran et al., 2001; Utuk and Daniel, 2015). This definition implies that land degradation is a composite term, that describes how one or more land resource bases include; soil, water, vegetation, and biodiversity have changed to the worst (Utuk and Daniel, 2015). Therefore, land degradation is a biophysical process that determined by socioeconomic and political reasons. In this study the state of comprehensive land degradation refers to a combination of biological, physical and chemical land degradation on a particular geographic region.

2.2. Theoretical Framework

2.2.1. Extent and rate of land degradation

The types and processes of land degradation are complex due to different human induce and natural drivers of land resources changed to the worst. Lal (1994) has classified the initiate land degradation mechanisms into physical, chemical, and biological processes. Physical land degradation results from many interrelated processes, including sealing, compaction, erosion, desertification, reduction in permeability and aeration, waterlogging, and subsidence of organic soils. Many of these processes result in reduced soil porosity, surface sealing, and crusting of the soil surface. On the other hand, chemical degradation consists of soil acidification, salinization, and soil fertility depletion. Conversely, biological degradation states the reduction in total carbon and biomass, and decline in land biodiversity of the soil. It mostly occurs in areas where the natural vegetation covers ecologically cleared and degraded. These include the reduction in biomass carbon, loss of vegetation cover, loss of vegetation species, loss of habitat, and decline of soil biodiversity (Eswaran et al., 2001; Oldeman, 1994; Lal, 1994).

Global Assessment of Human-induced Soil Degradation (GLASOD) is the initial global study to be mentioned (Eswaran et al., 2001). The study was mainly focused on the assessment of human-induced soil degradation (Oldeman 1994). According to this study, the global extent of land degradation was about 1.9 billion ha, and only in dry areas, the degradation of the world extent covers about 3.6 billion ha or 70% of the total area (Oldeman, 1994). Specifically, GLASOD revealed that soil erosion by water is the most significant land degradation type accounted for about 56% of the total area attributable to human factors. The study also confirmed about 28% of the degraded area was resulting from wind erosion while 12% of the area was caused by chemical land degradation (Oldeman, 1994).

Although there are potential and economic achievements, SSA countries faced the challenge of achieving livelihood security due to land degradation. About 28% of the population in SSA live in areas that have experienced degradation since the 1980s (Le et al., 2016). In the region, land degradation occurs in different land LULC types i.e. about 40% of grasslands, 26% of forestland, and 12% of croplands degraded (Le et al., 2016). The high and severe land degradation rate coupled with economic development reflects the tradeoffs involved in clearing forests in the region (Nkonya et al., 2016). Specifically, the evidence from NDVI measures shows that land degradation affects east African countries, for example, about 51%, 41%, 23%, and 22% portion of the terrestrial ecosystem in Tanzania, Malawi, Ethiopia, and Kenya, respectively affected from 1982-2006 years (Kirui, 2016).

2.2.2. Land-use/land-cover (LULC) change and its implications

The concern of LULC change has been gaining as the critical cause of ecosystem service change in the recent decades (Munthali, et al., 2019). It is one of the key issues in the current environmental research and the decision-making agenda (Cheruto et al., 2016; Lambin et al., 2003; Shi et al., 2010). The issue of LULC change has become a center for current strategies of natural resource management and ecosystem service change evaluation (MA, 2005; Rawat et al., 2013). LULC change plays an important role in Spatio-temporal environmental pattern stability, however, it is shaped under the influence of human needs (Reis 2008; Teixeira, et al., 2014). It has a linkage with local, regional, and global climate conditions, carbon cycle, biodiversity stability, clean water, agriculture, and food security (Shi et al., 2010). For this reason, there is a need for updated knowledge about LULC change patterns, trends, and rates on the local, regional and global levels (Rawat et al., 2013). Because, it is essential for the understanding of the environmental change process and problem that must be solved if living conditions and standards are to be improved (Anderson et al. 1976). This enables public agencies and private organizations to know what is happening and to make sound plans for their future intervention and design effective land management policies and decisions (Lambin et al., 2003). So, timely information on LULC change of the landscape is extremely important for understanding the relationships and interactions between human and natural phenomena for better management of natural resource bases which are the main sources of livelihood for the rural poor.

The terms “land use” and “land cover” are different, but often used interchangeably. Land use is described as human uses of land, or the immediate action altering of land cover features for the economic purpose, such as forest land cover may be used for agriculture and/or settlement (Ellis, 2011). On the other hand, the term land cover refers to the biophysical features of the earth’s surface and immediate subsurface, which used to sink most of the materials and energy movement. It may include water bodies, plantations, bare soils, and/or other physical features of the land formed merely by human actions like settlement, plantation, and mine exposure (Lambin et al. 2003; Ellis 2011; Abbas 2012; Abbas et al. 2018).

Landscape change in Ethiopia is as old as the use of fire, and the emergence of agricultural activities and human settlement (Hurni 1987). The extent and depth of the LULC change increased with the agricultural expansion, particularly after the 1900s (Hurni 1993). For example, >80% of the country’s forest cover was destroyed within only a little more than half a century between 1900 and 1960 (EFAP, 1994). The major LULC changes in Ethiopia occurred in densely populated areas, mainly in the highlands. The changes were mainly the conversion of forest and grasslands into agriculture and settlement due to population growth, large forest areas were changed into cropland in response to the ever-increasing demand for food and firewood (Bewket, 2003; Teferi et al., 2013; Teketay, 2001). Limited technology and livelihood options have aggravated the competition between different uses, and government policy and tenure have also played a considerable role (Teferi et al., 2013).

Even though the magnitude of degradation in Ethiopia was severe for the millennia, public and government intervention for the response is the latest phenomenon. Before the 1970s, land management was negligible, and very little effort was made to control land degradation and land-use change (Shimeles, 2012). The degradation problem was of course recognized before 1970 but was not addressed because of staff limitations and prevailing land tenure (FAO, 1986). Since the 1970s modern SWC technology was introduced by the government and the external conservation supporters (Bekele and Dark, 2003; Shimeles 2012). An effort towards the problem of land management strategy was started after the Ethiopian government initiated a massive SWC program following the 1975 land reform. And the program was implemented through Food for Work (F.F.W) strategic approach (Amsalu and Graaff, 2006; Shimeles 2012). The incidence of famine was the main cause for SWC practice and afforestation on the government agenda. Different research centers, institutions, and organizations were established to introduce and promote land management measures directly on the variety of public and private land-use systems. During the 1980s land management work was widespread by the government and international community for this purpose there were about 2,488 projects (Amsalu and Graaff, 2006). But, the majority of the soil conservation works did not appreciate by farmers and most of the technologies were removed (Amsalu and Graaff, 2006).

2.2.2. Driving and pressure forces of land degradation

The shreds of evidence show that no single theory can sufficiently explain the complex interactions of the population growth, sustainable livelihoods, and land degradation synergy, and thus, researchers depend on different theoretical frameworks for developing a holistic and integrated framework of land degradation assessment (Manikandan & Kurian, 2016). In the literature, there are debates between population growth, resource management, and land degradation interaction. Regarding these, there are two theories about the relationship between population growth and environmental degradation nexus. The Malthusian and Boserupian perspectives represent the two main historical viewpoints in the population and environmental interaction. Malthus argued that the increasing population results in farmland sacristy. This problem is solved by only two methods:

firstly, clearing more of one's land or appropriating neighboring lands; and secondly by migrating to other areas to develop new land for the agricultural purpose by clearing forests which leads to deforestation and vegetation clearance. According to hem if the population growth is increased the effect-impact is double-edged and simultaneously increases the demand on the environmental resources to support the growth of the population (Manikandan & Kurian, 2016). Conversely, Boserup takes into consideration technological change, but not against population growth. She supported population growth because population density might persuade technological changes that allow more food production to keep pace with growing demand (Boserup, 1965). She explained that surplus labor positively contributes to land management through land development practices such as natural resource base conservation and irrigation activities. Population growth is not necessarily linked to land degradation; it is what a population does to the land resources that determine the level of degradation. People can be a major asset in restoring a reversing a trend towards land degradation. Nevertheless, they need to be healthy and politically and economically motivated to care for the land, as subsistence agriculture, poverty, and illiteracy can be central causes of land resource degradation (Eswaran et al, 2001).

On the other hand, scholars also associated land degradation with rural poverty (Nkonya et al., 2016). Though economic growth may damage the environment and natural capital as there are mass resources and energy consumption and production of pollution into the environment, poverty is one key indirect cause of land degradation in low-income countries (MA, 2005). Several studies have hypothesized the linking between rural poverty and the environment as a 'downward spiral', where poverty leads to environmental degradation and in turn worsen poverty (Ravnborg, 2003; Scherr, 2000). They argued that poor people depend on natural resources (water, soil, forest) to produce subsistence agricultural yield/production for a living. Meanwhile, a poor household cannot invest enough external farm inputs for improving land quality (Kangalawe and Lyimo, 2010). On the other hand, poor farmers do not want to be poor for a long and choose actively to damage their environments. On the other hand, poor people live in marginalized areas and their livelihoods are depending on natural capital (ecosystem services) thus, they exploit the natural resources using inappropriate and technology (World Bank, 2006). Nevertheless, there are also still disputes on whether poverty is a primary driver of land degradation (Way 2006) or not (Nkonya et al., 2016). Market and other infrastructure inaccessibility, lack of appropriate policies, and poor implementation rules are the other root causes of land degradation (Kirui and Mirzabaev, 2015). But, there are disagreements whether market access leads to sustainable land management (Pender et al. 2006), or for land degradation (Scherr and Hazell 1994).

Others scholars take into consideration a political ecology concept to explain chains of drivers and impacts of land degradation (Andersson et al., 2011). Political ecology school of land degradation philosophers accepts a comprehensive system to study human and environmental synergy. These systems are related to the choices for livelihood support and environmental management (Reynolds et al., 2007). On the other hand, the socioeconomic approach connects the socioeconomic system to the environment through enunciating land use/land cover conversion as a function of multi-scale root causes and proximate causes for accelerating land degradation. Land use/land cover model emanating on the identification of the natural environment and socioeconomic attributes, and the distribution, quantity, and the rates of change at a different location (Hill et al., 2008).

2.2.3. Impact of Land Degradation on Rural Livelihood

Land degradation adversely affects people's livelihoods and occurs over a quarter of the Earth's ice-free land area (Gessesew, 2017; Walmsley, 2002; Woodhouse et al., 2000). The majority of the 1.3 to 3.2 billion affected people are living in developing countries (Olsson et al., 2019). Particularly, land degradation has a great impact on the livelihood of rural communities that depend on primary economic activities mainly agriculture and it has also impacted the national GDP of Ethiopia (FAO 1986; Berry 2003)**.** For the last five decades worldwide, land degradation is one of the biggest threats to sustainable development and challenges to poverty reduction (MA, 2005). Each year about 10 million ha of cropland lost due to soil erosion, thus reducing the cropland size and production for world food production (Pimentel and Burgess, 2013). The soil being lost from agricultural areas ranged from 10 to 40 times faster than the rate of soil formation. This is jeopardizing humanity's food security and causes population migration and conflict (Pimentel and Burgess, 2013). Soil erosion may have both on-site and off-site effects on ecosystem services. The on-site effect comes from the loss in soil productive capacity, result in the reduction of agricultural outputs (crop and livestock yields) or the need to increase external farm input, such as fertilizer, to realize the same yield level. On the other hand, off-site impact refers to the indirect effects of soil degradation and usually takes the form of externalities. Most off-site costs can be traced to the effect of silt; soil nutrients washed into surface water or leached into subterranean aquifers by runoff. So, off-site effects rise from the negative effect of agricultural activities run-off on downstream land users (Woodhouse et al., 2000). A case study carried out by Tun et al. (2015) in the Dry Zone of Myanmar land degraded reduces crop productivity from 3–12 times compared with the yields of these crops grown in a less degraded area. According to this study, the livelihoods of the farmers in the high-degraded area were affected by crop yield reduction, increased cultivation cost, and increased uncultivable land area.

Many African countries including Ethiopia, land degradation is a major problem due to the agrarian nature of their economy. (70%), Ghana and (85%), Ethiopia, depending on the land for their livelihoods (Peprah, 2014). The economic implication of land degradation is severe in sub-Saharan African countries. This is because 65% of the population lives in rural areas and the main livelihood of 90% of the population is agriculture. The majority of the Ethiopian population relies on land resources for their livelihood, mainly through land cultivation.

Land degradation is one of the major causes of low and declining agricultural productivity and continued food insecurity and rural poverty in Ethiopia. The country losses billions of birrs because of soil erosion, water, and biodiversity losses (Dubale, 2001). The highlands of Ethiopia are affected by deforestation and soil degradation, which erode the resource base and increase the repeated food shortage caused by drought (Tilahun et al., 2001). The decline of grazing land as a result of a high degree of land degradation highly affects the productivity of livestock. This, in turn, affects the livelihood of the population particularly in rural areas because of that in rural area livelihood of the population is highly dependent on livestock productivity (Tilahun et al., 2001). Most of the people of the country depend on firewood as a source of energy. But land degradation causes a lack of firewood (Meles., 2014). On the other hand, the annual cost of land degradation associated with land use and cover change in Ethiopia is estimated to be about $4.3 billion (Gebreselassie et al., 2016).

As a result, land degradation remains the main intimidation to the world's capacity to meet the growing demand for food, energy, and water (Olsson et al., 2019). Land degradation results in food insecurity, poverty, and out-migration for those rural communities whose livelihood depends on land resources. The link between livelihood and land degradation is said to be a symbiotic relationship in a form of a vicious cycle. It is considered an upward spiral in which causality runs both ways. Hence, livelihood improvement should be integrated alongside the control of land degradation activities to achieve sustainable development.

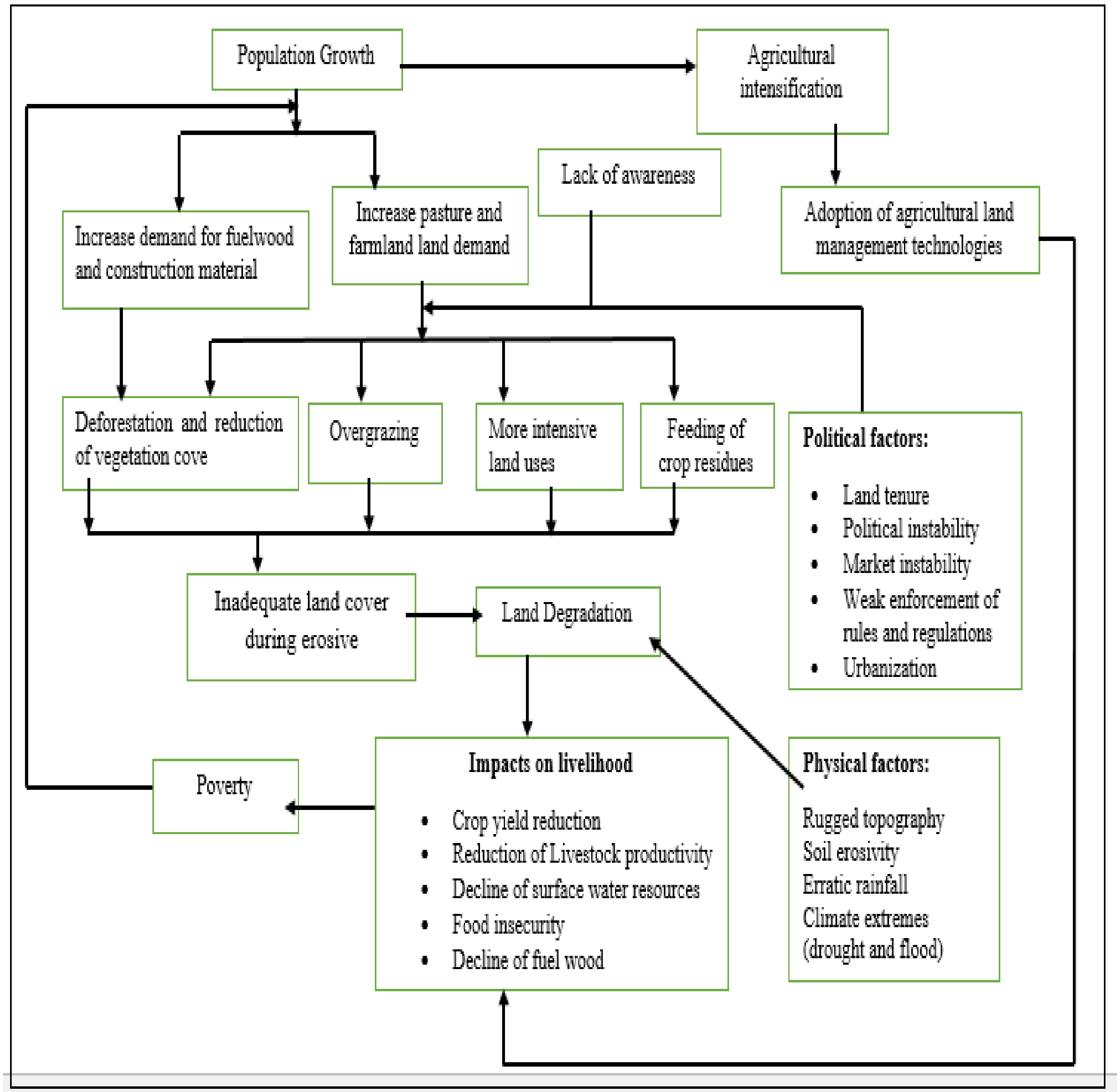

Figure 2.1. Theoretical framework showing the population growth and some causes for land degradation (Researcher‘s own construction based on Kiage (2013) and FAO (2017)).

2.2.3. Sustainable Land Management (SLM)

Action/response for land degradation is expressed as what the society perceives should be done to improve or mitigate to realize a better ecosystem service (Agyemang et al., 2007). A 'response' by society and policymakers is the result of an undesired impact that can affect any part of the chain between driving forces and impacts (World Bank, 2006). In the context of land degradation response adopting and adapting multiple SLM measures is the best option (World Bank, 2006; Thomas, 2008; FAO, 2011). SLM is defined as a knowledge-based process that helps to integrate natural resource bases such as soil, water, biodiversity, and environmental management to meet rising human food demand and sustaining natural ecosystem services (World Bank, 2006, 2008; FAO, 2011). SLM practices are adapted practices for the range of land-use systems- and rain-fed and irrigated cropping, grazing, and forest, as well as protected areas. Sustainable management implies the appropriate and integrated management of crops (including trees and forage species), livestock grazing/browsing, soil, water, nutrients, biodiversity, diseases, and pests to optimize and sustain the delivery of a range of ecosystem services (provisioning, regulating, cultural and supporting) for the present benefit without affecting the future generation (World Bank, 2006). SLM is an essential prerequisite to sustainable development; and requires attention at all levels (from local to national, transboundary, and global) to optimize resource use and minimize conflicts over resources and demonstrate benefits in terms of the interlinked development concerns of food security, poverty alleviation, livelihood improvement, energy supply (biomass), and land and water governance. There are various groups of SLM measures practiced by stokeholds. These are structural, agronomic, vegetative, management, and combination measures (FAO, 2011).

2.3.Empirical Studies

2.3.1. Farmers' Perception on Land Degradation and Land management

There are different literatures in Ethiopia and elsewhere about framers' perception of land degradation and soil conservation practices. Some of these are explained as follow: The study done by Zegeye (2010) at Debere Mewi watershed in the Amhara region reveals that all interviewed farmers perceived soil erosion as the problem of consternating crop production. Most of the respondents recognize that the occurrence of erosion damage gets bigger which the soil is bare (before vegetative growth). According to him, farmers in this area expressed their outlook the loss of soil from cultivated fields reduced production potential. Rill erosion was predominating maintain by farmers. However, sheet erosion was not recognized by most farmers as rill and gully erosion.

Similarly, Akililu and de Graaf (2004) were investigated farmers' view of SWC in Beressa watershed, highlands of Ethiopia, the result shows that 72 % of farmers reported that soil erosion as a problem and they considered erosion to be severed mostly when visible signs, like Debere mewi farmers when rills and gullies appeared on their farm fields. The majority of farmers believed that erosion could be halted and they use arrange of practice for erosion control and fertility improvements such as crop rotation, application of organic matter (animal manure, household trash, and crop residues), and chemical fertilizers. On the other hand, Tschop *et al*., (2001) conduct in the Ethiopia highlands (Wollo and Gurage area). This study has revealed that farmers have lack insight into the impact of land gradation on their livelihood strategies (crop and livestock). These scholars recommended that the study area farmers need increased community-based awareness and participatory training on the conservation of agricultural fields.

The study carried by Saguye (2018) in Jeldu District in west Shewa zone, Ethiopia, shows that 57% of the respondents were perceived the severity and its impact on agricultural land productivity. According to the author, the following indicators of soil erosion and fertility loss were indicators generally perceived and observed by farmers in the study area: gullies formations, soil accumulation around clumps of vegetation, soil deposits on gentle slopes, exposed roots, muddy water, sedimentation in streams and rivers, change in vegetation species, increased runoff, and reduced rooting depth. The direct human activities which were perceived to be causing land degradation in the study area were deforestation and clearing of vegetation, overgrazing, steep slope cultivation, and continuous cropping. Similarly, Bewket (2007) in the northwestern highlands of Ethiopia, revealed that more than 83 % respondents stated that soil erosion was damaging their agricultural lands. Visible soil erosion results like rills and gullies were not only identified by respondent farmers as indicators of erosion, but were also used to assess the severity of the problem. According to him, almost all of the interviewed farmers were aware of the major causes and consequences of soil erosion as well as the link between soil erosion and declines in soil fertility in the Chemoga watershed.

In another case study conducted by Moges and Holden (2007), in the Sidama zone of southern Ethiopia farmers can identify soil erosion and fertility loss indicators, take a holistic view of soil degradation, and have a broad knowledge of the reasons for soil degradation. They perceive soil degradation mainly by reducing yields, soil changing in appearance, and becoming stony or coarse. The most frequently mentioned soil erosion indicators were soil becoming coarse and stony, followed by rill formation, dissection of fields and gullies, and topsoil removal. The most important perceived indicator of soil fertility loss was reduced crop yield, followed by poor crop performance and yellowing of the crop. Farmers also know solutions; however, participation in soil conservation activities is minimal because of the immediate threat of food insecurity.

The study conducted by Akinnagbe (2011) in Ethiope, East local government area of delta state, Nigeria, revealed that the majority of farmers perceived and identified the major causes of land degradation in their locality. According to this author, the main causes as perceived were accelerated erosion, deforestation, non-adoption of adequate soil conservation measures, administrative and institutional problems, and exploration of crude oil. On the other hand, the perceived major impacts of land degradation were decreased farmland available, reduction in farm yields, and loss of nutrients. Likewise, Orchard et al. (2017) in Swaziland, found that observations of land degradation are perceived mainly through changes in land productivity, with chemical degradation occurring predominantly on arable land and physical degradation and erosion mainly in rangeland areas. Changes in rainfall are particularly important in determining responses. While perceptions of the causes and impacts of degradation largely concur with the scientific literature, responses were constrained by poor land availability, shorter and more unpredictable cropping seasons because of changing rains, and low awareness, access to, or knowledge of agricultural inputs.

Kerr and Pender, (2005) in India reveal farmers are quite aware of rill and gully erosion, but less aware of sheet erosion on their fields. They believe that soil erosion contributes to yield losses, but they also see opportunities to reverse the yield losses from erosion by investing in soil conservation measures that retain organic matter and fertilizer, facilitate moisture infiltration, and harvest soil that erodes upstream.

Based on the above illustrated imperial studies, it can be generalized that farmers have a good perception of land degradation; its indicators, causes and consequences, and responses. These empirical results imply that farmers have been living on the land for life and their daily ways of life are dependent upon land resource observation. Therefore, farmers can identify land, whether good or poor based on crop productivity and grazing land caring capacity experience. Their awareness of land degradation is the result of cumulative experiences over a long period. As a result, understanding the farmers' perception of environmental issues is a prerequisite in designing effective resource management policies and land management strategies (Bekele and Drake, 2015; Pender and Gebremedhin, 2004).

2.3.2. Determinants of Farmers' Decision to Adopt SLM technology

Determinants of farmers' decision to adopt SLM technologies continue to receive wide interest in the natural resources management and agriculture sector researchers in the worldwide. Different studies indicate that such factors that farmers SLM technology adoption decision determined by different demographic, socioeconomic, institutional, and physical factors. Among the existing literature, a case study undertaken by Wordofa et al. (2020) in the Haramaya district of eastern Ethiopia is one of the recent shreds of pieces of evidence. The study examines factors that influence the SLM adoption decision of farmers using multinomial model analysis and the result shows that education level, farming experience, plot area, number of economically active household members, and extension contact were found to significantly affect the use of improved structural SWC strategies on a farm plots. Moreover, another recent case study conducted by Yifru and Miheretu (2021) in South Wollo, Ethiopia using a binary Logistic regression model revealed that adoption of structural SWC practices in the study area is significantly and positively influenced by the perception of farmers on erosion problem and SWC practices, labor, education, and membership in local institutions. But, distance from residence to the nearest market and farmland, off-farm activities, and the ratio of cultivable land to family size influenced the adoption of SWC practices negatively.

Mekuriaw et al. (2018) in the central highland Ethiop, have also identified factors that influence the SLM adoption decision of farmers using binary logistic regression model and found that lack of awareness of physical SWC structures' possible long-term benefits, low short-term economic benefits of SWC structures, and political factors and off-farm activities such as petty trade and selling of firewood are the key factors significantly determine farmers' use of SWC structures. But, accessibility to the main road did not have significant impacts on the construction and maintenance of SWC structures in the central highlands of Ethiopia.

Analogously, a study undertaken by Guta and Abegaz (2016) has identified the determinants of integrated soil fertility management technologies using binary logistic regression models in Arsamma watershed, southwestern Ethiopian Highlands. They identified that farmland size, farmer training, participation in agricultural extension programs, years of chemical fertilizer application to farmland, and perception of farmers toward continuous use of mono-chemical fertilizers were found to the statistically significant predictors of ISFM adoption. Improving the productivity of the limited farmland, designing pro-poor approaches, provision of action-based farm training targeting on agricultural extension programs, and raising awareness of farmers about negative impacts of mono-chemical fertilizer technology in the study catchment.

Miheretu and Yimer (2017) in Gelana sub-watershed of Northern highlands of Ethiopia by using multinomial logit model, showed that education, family size, the slope of the plot, tenure security, training, access to farm credit and extension service positively and significantly affect the adoption of land management practices while age has a negative and significant influence on adoption. Similarly, Bekele and Drake (2003) using multinomial logit analysis of the survey data show that plot-level adoption of conservation measures is positively related to access to information, support programs for initial investment, slope, and area of the plot. They have also shown that landholding per economically active person of the family is found to have a negative influence on conservation decisions. Participation of women in fieldwork activities, farmer's age group, use duration of a plot, credit for fertilizer and food, livestock holding, type of crop grown, and plot soil type did not influence plot-level conservation decisions by farmers in the Eastern Highlands of Ethiopia, in Hunde-Lafto area.

Challa and Tilahun, (2014), the result of the logistic regression showed that household heads' education level, farm size, credit accessibility, perception of farmers about the cost of the inputs, and off-farm income positively and significantly affected the farm households' adoption decision; while family size affected their decision negatively and significantly. Demeke (2003) in Farta district, Northern Ethiopia shows that farm size and perception of benefit from conservation positively and significantly affected framers' decision to adopt conservation structures. Whereas distance of a plot from the homestead had sound negative and significantly influence farmers’ soil conservation decisions. Similarly, the study made by Shiferaw and Holden (1998) using a two-stage process and employed an ordinal logit model of estimation in Ethiopia highland also reveals that household size has been identified to have a negative and significant effect on the adoption of soil conservation technologies. The study conducted by Asfaw and Neka (2017) in south Wollo using a binary logistic regression model showed that sex of household heads, education status of household heads, access to extension services, and training were positively correlated at a significant level with the adoption of the introduced SWC practices. On the other hand, the age of household heads, off-farm activity, and distance of farmland from homesteads influenced the adoption of introduced SWC practices negatively. Another study conducted by Aklilu (2006) Using a sequential decision-making model in Ethiopia highlands found that factors influencing adoption and continued use of the stone terraces to be different. The same study indicated that adoption was influenced by farmers age, farm size, perceptions on technology profitability, slope, livestock size, and soil fertility, while the decision to continue practice is influenced by actual technology profitability, slope, soil fertility, family size, farm size and participation in off-farm.

Generally, the above empirical evidences show that different determinants that encourage or discourage farmers to adopt various SLM technologies on their farmland. But, previous studies have focused on a single technology and ignored complementarity and trade-offs between SLM practices and the results are contradicted. Additionally, the majority of these studies modeled the implementation of SLM technologies as a binary variable (adopter and non-adopter) and did not account for the intensity of SLM adoption and the interrelationship of adopted SLM technologies. These types of modeling approaches cannot capture the preference of land users’ behavior for different SLM technologies and simultaneous acceptance or non-acceptance decisions. Since SLM technology adoption choices are multivariate, it is necessary to consider simultaneous and consecutive decision-making processes and potential trade-offs related to the adopted SLM technologies.

2.3.3. Effects of SLM technology adoption on food security

The adoption of SLM technologies and their consequences on food security continue to receive wide interest from land management and food policy researchers. The study undertaken by few researchers highlighted that SLM adoption has played significant roles in improving food security. Among the existing literature on land management and its impact on food security, a case study carried out by Wekesa et al. (2018) in Kenya using principal component analysis, found that the greatest effect of land management technology adopter by 56.83% more food security in terms of HFCS and 25.44% in terms of HDDS. Biru et al. (2019), have also evaluated the impact of the modern SLM technology in Ethiopia using a two-stage multinomial endogenous switching regression model combined with the Mundlak approach, found that the adoption of improved technologies increases consumption expenditure significantly and the greatest impact is attained when farmers combine multiple complementary SLM technologies. Similarly, the likelihood of households remaining poor or vulnerable decreased with the adoption of different complementary SLM technologies.

Analogously, a study undertaken by Teklewold et al. (2019) has identified the impact of small-scale irrigation on household food security in eastern Hararghe of Ethiopia. The study found that adoption of land management increases dietary diversity and improves calorie and protein availability. These benefits increase with the adoption of combinations of innovations, relative to adopting innovation in isolation. A study carried out by Challa and Tilahun, (2014) using propensity score matching estimation showed that the average income and consumption expenditure of adopters is greater than that of non-adopters in West Wollega. Schmidt and Tadesse (2019), assessed the impact of SLMP on farm household food security in the upper Blue Nile, Ethiopia. The finding shows that the SLMP is not associated with significant increases in household-level agricultural value of production after 4 years of program participation, regardless of agro-ecological zone or landscape type in 177 micro-watersheds in six regions of Ethiopia.

On the other hand, Yitayal and Adam (2014) were evaluated the impact of the adoption of SWC technologies on household income and food crop production in Adama District of Ethiopia using PSM analysis estimation but, the result did not show a significant difference between the program participants and non-participant households in terms of total crop yield and household income.

Similarly, Yenealem *et al.* (2013) evaluate the impact of those integrated land management interventions on food crop production value per hectare and annual gross income of smallholder farm households in west Harerghe, Ethiopia uses descriptive statistics and PSM. The result showed the existence of a positive additional significance on crop production value premium of Birr 1,510.42 (US$ 80.55) per hectare and annual gross income of Birr 4,288.29 (US$ 228.7) for program groups compared to non-program groups. Generally, above result shows metrical studies on the impacts of SLM on food security in Ethiopia are mixed and locational specific. Furthermore, there is less emphasis on the impact of the integrated SLM technologies on households' food security. No such type of study conducted in the Blue Nile, particularly in the north Gojjam sub-basin that show SLM efforts whether to improve households' food security status using robust model.

2.4.Conceptual Framework

As discussed in the preceding sections, land degradation process and response measures are complex and in a continuous state of spatio-temporal change, have spiral synergy resulting from the occurrence of several human and natural drivers and pressures on the state of land resource bases (forest, soil, and water) and, the effects on the livelihood strategies in the ecosystem. As a result of this, stockholders adopt various SLM technologies to prevent the drivers and pressures of land degradation; adapt to the state of degradation situation, and mitigate its impact on the livelihood strategies. Such type of interaction is termed as ***'the drivers- pressures- state- impacts and responses (DPSIR)'*** (World Bank, 2008; FAO, 2017). The framework was proposed by the European Environmental Agency (EEA) as an integrated approach to environmental management (FAO 2017). DPSIR framework has been rapidly popular by researchers and policymakers as the best means of structuring information concerning specific environmental problems and to show existing causes, state, imports, effective responses and trends, and the dynamic relationships within the component/ ecosystem (Agyemang et al., 2007; Kristensen, 2004). This systematic framework helps to identify the full range of empirical factors included in this study and describes the linkages between human activity and the environmental components, encourages transdisciplinary research, or acts as an empirical instrument for complex system analysis (Lewison et al., 2016). In other words, the DPSIR framework integrates social, economic, ecological, political issues in one study structure (FAO, 2004).

Thus, for this research, the conceptual framework showed in Figure 2.2 is built following the DPSIR framework based on the above revised conceptual, theoretical, and empirical literature that show the linkages of land degradation drivers, impacts on livelihood, land management technologies, and the determinants of household's decision to adopt various SLM technologies as well as the effect of integrated SLM technologies on rural household food security.

Agriculture in Ethiopia, which is the base of food security for the majority of the population, is vulnerable to extreme land degradation. Therefore, the government has given great attention to SLM technology adoption as a means to ensure food security and alleviate poverty (Bekele, 2003; Biru et al., 2019; Gashu and Muchie, 2018). SLM is imperative to reduce land degradation, rehabilitating degraded ecosystem services, and safeguarding the best use of land resources for the benefit of the present without affecting future generation benefits (Liniger et al., 2011). It is an acknowledged procedure that helps to integrate land resources and environmental management, including input and output externalities to meet rising food and fiber demands while sustaining ecosystem service and livelihoods (Liniger et al., 2011).

The conceptual model for this study, therefore, combines many critical variables to show how different factors affected farmers' diction to adopt different SLM technologies to improve their food security level through improving agricultural land productivity. As a vital resource in the agriculture sector, the researcher hypothesizes that land management contributes to improving agricultural productivity and rural food security through improving land productivity.

On the other hand, the type and level of SLM adoption decision depend on the state of land degradation perception, farmers' personal/demographic (age, sex, education status, marital status, family size, and dependent ratio), economic (land size, livestock size, off-farm income, and total income), institutional (extension service, training, access to media, access to credit, market distance, road distance and participating in local association) and physical factors (soil fertility, slope position, plot distant, plot fragmentation) and the nature of adopted SLM technologies (complementarity and supplementary nature of SLM). So, improving agricultural productivity is a means for enhanced rural income, availability of food, and other livelihood assets (Figure 2.2). The independent variables assumed to be influenced farmers' decisions on the use of modern physical soil conservation measures and food security.

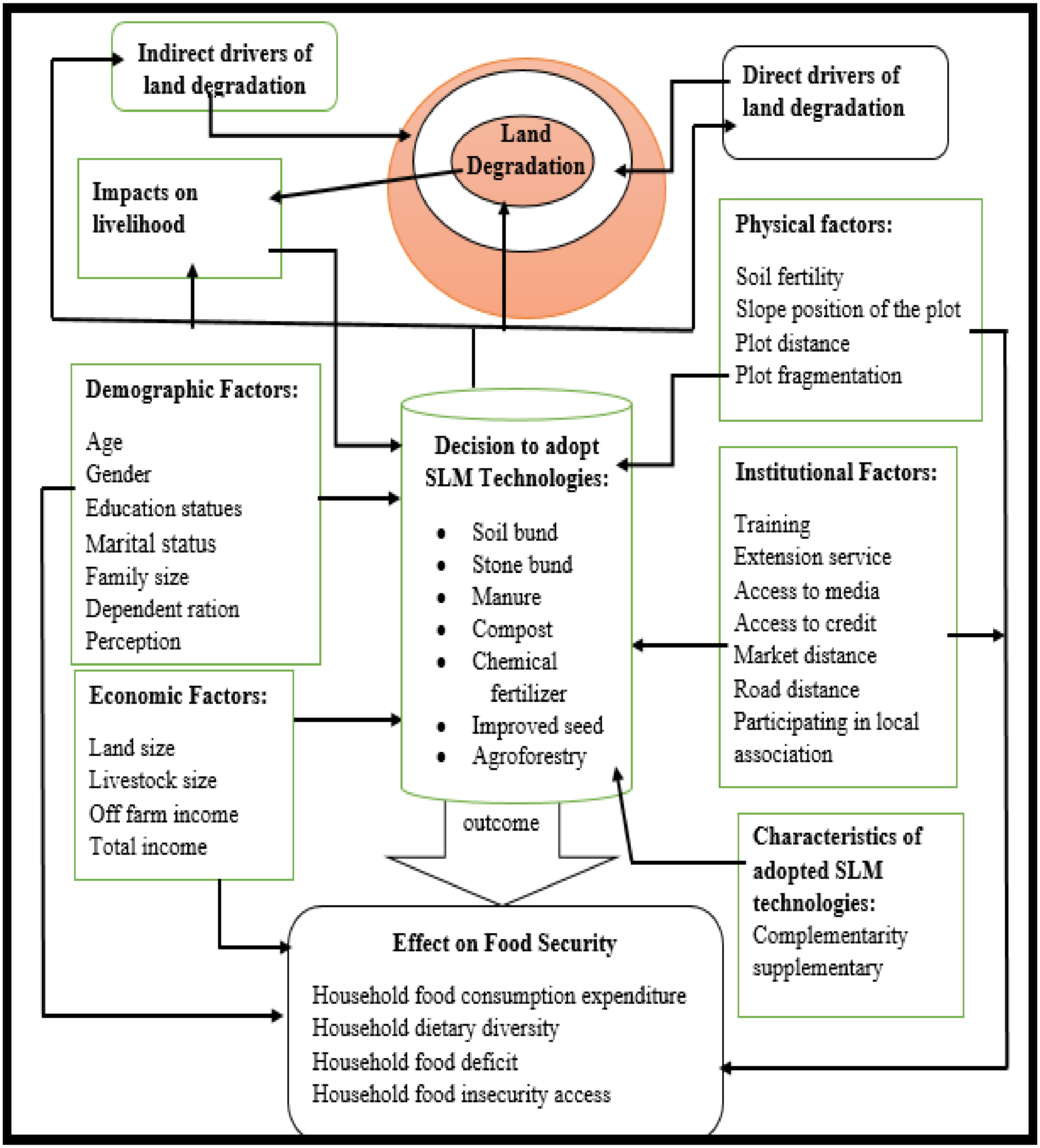

Figure 2.2. Conceptual Framework of the study (Researcher 's own construction based on FAO, (2017).

2.5. Ethiopian Land Policy

Recent land tenure regimes in Ethiopia fall into three broad time periods. Before 1975, land tenure was based on a feudal system where land was concentrated in the hands of absentee landlords and the church, tenure rights were highly insecure, and arbitrary evictions took place. Following the overthrow of the imperial regime in 1974, the Marxist-oriented government (the Derg) transferred ownership of all rural land to the state for the distribution of use rights to cultivators through local peasant associations (EFDR, 2005). The further transfer of land rights was highly restricted, because transfer through sales, lease, exchange, or mortgage was prohibited, and inheritance was severely restricted. Tenure security was further weakened by the peasant associations' and other authorities' ability to redistribute land. The government that took power in 1991 following the fall of the Derg-while committed to a free market philosophy has made little substantive change to farmers' land rights, which are still considered inadequate (EFDR, 2005).

The 1994 Ethiopian Constitution draws a broad framework for land policy in the country and enshrines the concept of public land ownership and the inalienability of landholdings. The Ethiopian Constitution asserts state ownership of land; there are no private property rights in land. Article 40(3) states: The right to own rural and urban land as well as natural resources belongs only to the state and the people. Land is an inalienable common property of the nations, nationalities and peoples of Ethiopia and shall not be subject to sale or to other means of transfer. Ethiopia's national land policy has been further clarified by Proclamation No. 89/1997, "Rural Land Administration." This law defines the scope of individual land use rights and states that such rights can be leased and bequeathed. The land rights themselves cannot be sold or exchanged, but private property improvements to the land can be sold or exchanged (EFDR, 2005).

Federal government proclamations provide some land rights guarantees and some requirements for regional councils, but there is no national land policy and institution that might serve as a coordinating body at the national level of government for policy discussion and coordination of land administration (EFDR, 2005).

1. In any type of rural land where soil and water conservation works have been undertaken a system of free grazing shall be prohibited and a system of cut and carry feeding shall be introduced step by step.

2. The management of rural lands the slope of which is less than 30 percent shall follow the strategy of soil conservation and water harvesting. The details shall be determined by rural fan administration law of a regions.
3. Development of annual crops on rural lands that have slopes between 3 1-60 percent may be allowed only through making bench terraces.
4. Rural lands, the. slope of which is more than 60 percent; shall not be used for farming and free grazing; they shall be used for development of trees, perennial plants and forage production.
5. Rural land of any slope which is highly degraded shall be closed from human and animal interference fora given period of time to let it recover, and shall be' put to use when ascertained that it has recovered. Unless the degradation is caused by the negligence of the peasant farmers, semi pastoralist and pastoralist the users shall be given compensation or other alternatives for the interim period.
6. rural lands that have gullies shall be made to rehabilitate by private and neighboring holders and, as appropriate, by the local community, using biological and physical works.
7. Rural lands that have gullies and are located on hilly areas shall be rehabilitated and developed communally and' as appropriate by" private individuals.
8. The biodiversity il1 rural wetland shall be conserved and utilized as necessary, In accordance with a suitable land use strategy.

Responsibility of Regions

1. Each regional council shall enact rural land administration and Land use law, which consists of detailed provisions necessary to implement this Proclamation (EFDR, 2005).
2. Regions shall establish institutions at all levels that shall implement rural land administration and Land use systems, and shall strengthen the institutions already established (EFDR, 2005).

3. The Study Area and General Methodology

3.1. Description of the Study Area

The study area is described based on published and unpublished written materials, and information from the local communities through focus group discussions, key informant interviews, and intensive field observation.

3.1.1. Location of the Study Area

The study area, north Gojjam sub-Basin, is one of the 16 sub-basins of the Upper Blue Nile basin. The Ethiopian part of the Blue Nile is known as Abbay basin, which covers about 199,812 km^2 and located in the central and northwestern parts of Ethiopia, lies within 7^0 45’ N and 12^0 46’ N latitude, and 34^0 05’ E and 39^0 49’ E longitude (Figure 3.1). The Abbay basin covers much of the Amhara National Regional State and Beneshangul-Gumuz region, and some portion of the Oromia region. The 16 sub-basins of Abbay are “Didessa, Anger, Guder, Tana, north Gojjam, south Gojjam, Dubas, Finch, Beshilo, Jemma, Muger, Welaka, Beles, Wombera, Rahad and Dinder” (Figure 3.1). Particularly, north Gojjam sub-basin is located between 37.30° E to 39.6° E longitude and 10.8° N to 11.9° N latitude and it covers an area of 1,431,360 ha. The relatively the sub-basin is location in Amhara regional state, particularly at the border of East Gojjam, west Gojjam, and south Gonder zones. It stretched between Choke and Guna mountain and lies on 19 districts. The north Gojjam sub-basin is the main water source for the Abbay River.

3.1.2. Topography and Drainage

The origin of Ethiopian highland is predominantly Trapp series of Tertiary rocks, chiefly basaltic and volcanic matter. The north Gojjam sub-basin is a part of the north western Ethiopian highlands and thus belongs to the origin Trapp series of Tertiary volcanic eruption. It is generally well known for its irregular relief features which comprise different types of relief configuration, which including mountains with a steep slope, hills, valleys, and plains (Simane et al., 2016). The altitude of the sub-basin is ranged from 1044 to 4094 amsl (Figure 3.1). The sub-basin stretches from Abbay gorge to Guna and Choke mountain peaks. In the lowland fragmented valleys along the gorge is characterized by relatively unfavorable agro-ecologic conditions: rugged terrain, erratic and more sporadic rainfall than the upper and middle parts, and extensive land degradation is common (Yilma and Awulachew, 2009). The sub-basin is endowed with abundant water resources and, is the water tower of the region, serving as the catchment of the upper Blue Nile basin sources (Figure 3.1). The major rivers are Suha, Chiye, Sedie, Teme, Bina, Azuari, Tsiwa, Gumara, Tigdar, Abia, Wanka, and other small streams. These and other streams are used for both human domestic purposes and livestock drinking. However, water used for irrigation farming activity in the area is very low compared to the available water potential (Simane et al., 2013).

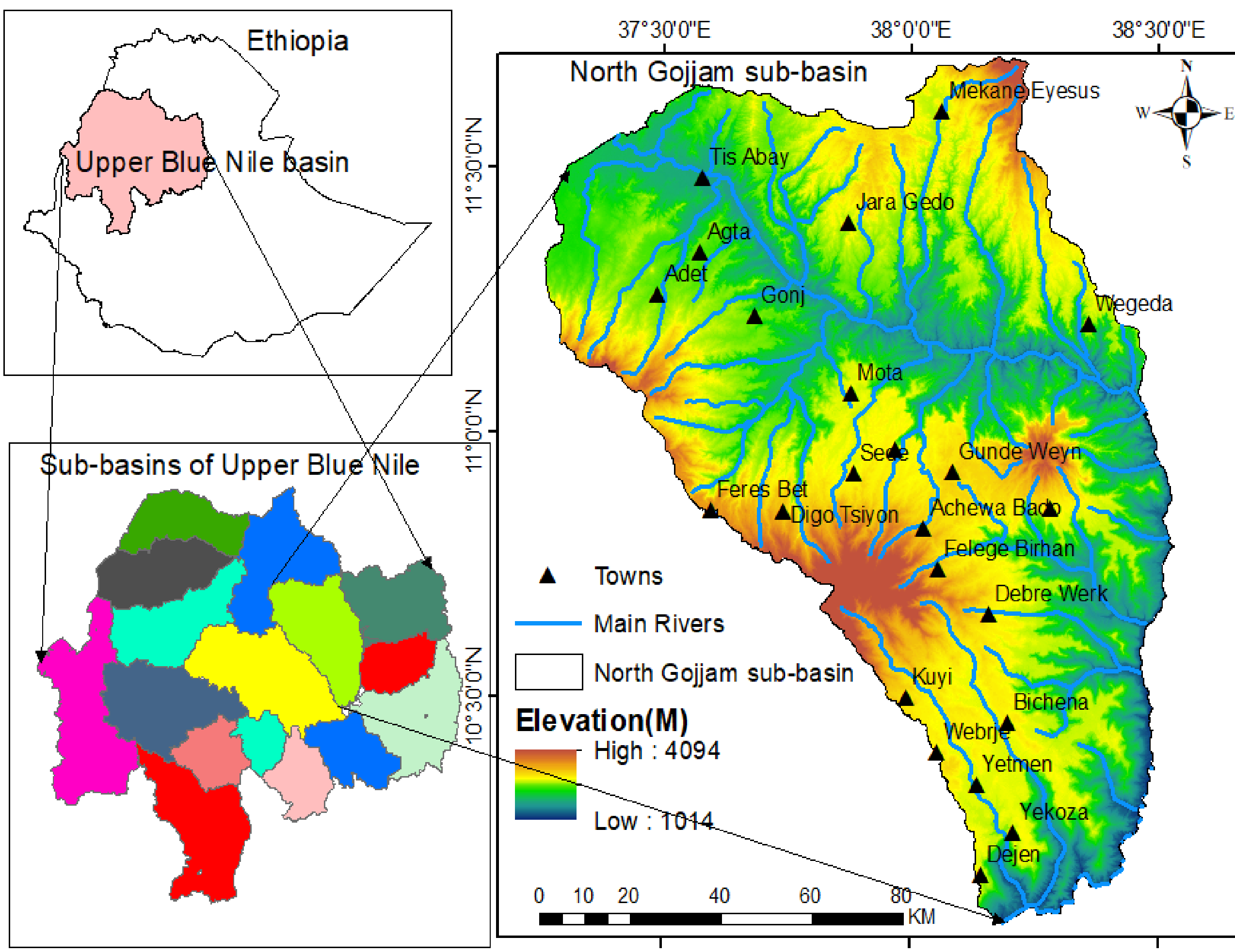

Figure 3.1 Location and topography of north Gojjam sub-basin

3.1.3. Climate Condition

The dominant climate condition of the sub-basin is the tropical highland monsoon (Simane et al., 2013). According to these authors, the climate condition is influenced by altitude and global weather systems. Rainfall is closely correlated with the annual migration of the Inter-Tropical Convergence Zone (ITCZ) (Simane et al., 2013) and mostly occurs in with most rain falling during the May–October *kiremt* rainy season. The sub-basin is characterized by a mono-modal (*i.e.* a single rainfall maximum per year) pattern of rainfall and peaking in July and August. The distribution of rainfall across the sub-basin is uneven; the highland tends to be wetter than the lowlands but it is more eroding in the lowland region. The Inter-annual variability in precipitation has significant impacts on agricultural production and causes for soil erosion. The meteorological records from the stations within and the surrounding study area (1986-2017) indicated that the mean total rainfall was 1334.48 mm with a minimum of 810 mm and a maximum of 1815 mm (Table 3.1). According to Ethiopian National Meteorological Agency (2018), the average maximum and minimum temperature of the sub-basin, various from 24.6^0C-28.1^0C and 11.0^0C-14.51^0C, respectively, and generally the mean annual temperature is 19.41°C. Temperature is highest in March and April while lower in November and December (Table 3.1). The mean annual temperature is declining through an elevation in the sub-basin (Sileshi et al., 2012).

Table 3.1: Average monthly rainfall, maximum and minimum temperature records (1986-2017)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	8.35	12.5	54.5	74.4	180.	290.0	677.6	661.9	358.9	140.3	34.47	14.07
TMPMAX	25.36	27.5	28.1	28.6	27.9	26.95	25.69	25.4	24.6	24.8	24.79	24.7
TMPMIN	11.13	12.4	13.4	14.3	14.5	14.1	13.01	12.6	12.5	12.1	11.0	10.3
MEANTMP	18.3	19.9	20.8	21.5	21.2	20.50	19.4	19.0	18.6	18.4	17.9	17.5

TMPMAX=maximum temperature; TMPMIN= minimum temperature; MEANTMP = mean temperature

3.1.4. Agroecology

The north Gojjam sub-basin is characterized by tepid to cool moist mid highlands, and cold to very cold moist sub-Afroalpine to Afroalpine agroecology. The lowlands in the eastern and southeastern parts of the sub-basin are hot to warm moist temperatures (Yilma and Awulachew, 2009). The dominant agro-ecological zones are "high wurch, moist wurch, moist dega, moist woinadega, dry woinadega, moist kolla, dry kolla, and bereha" (Hurni, 1998).

3.1.5. Geology and Major Soil Types

The geology of the sub-basin is dominated by basalt, but the lowlands is dominated by sandstone. There are Coluvium, and Alluvium deposits in the sub-basin (Figure 3.2). North Gojjam sub-basin is characterized by a wide range of soil types. The dominant soil types are Cambisols, Leptosols, Vertisols, Luvisols, and Regosols (Figure 3.3).

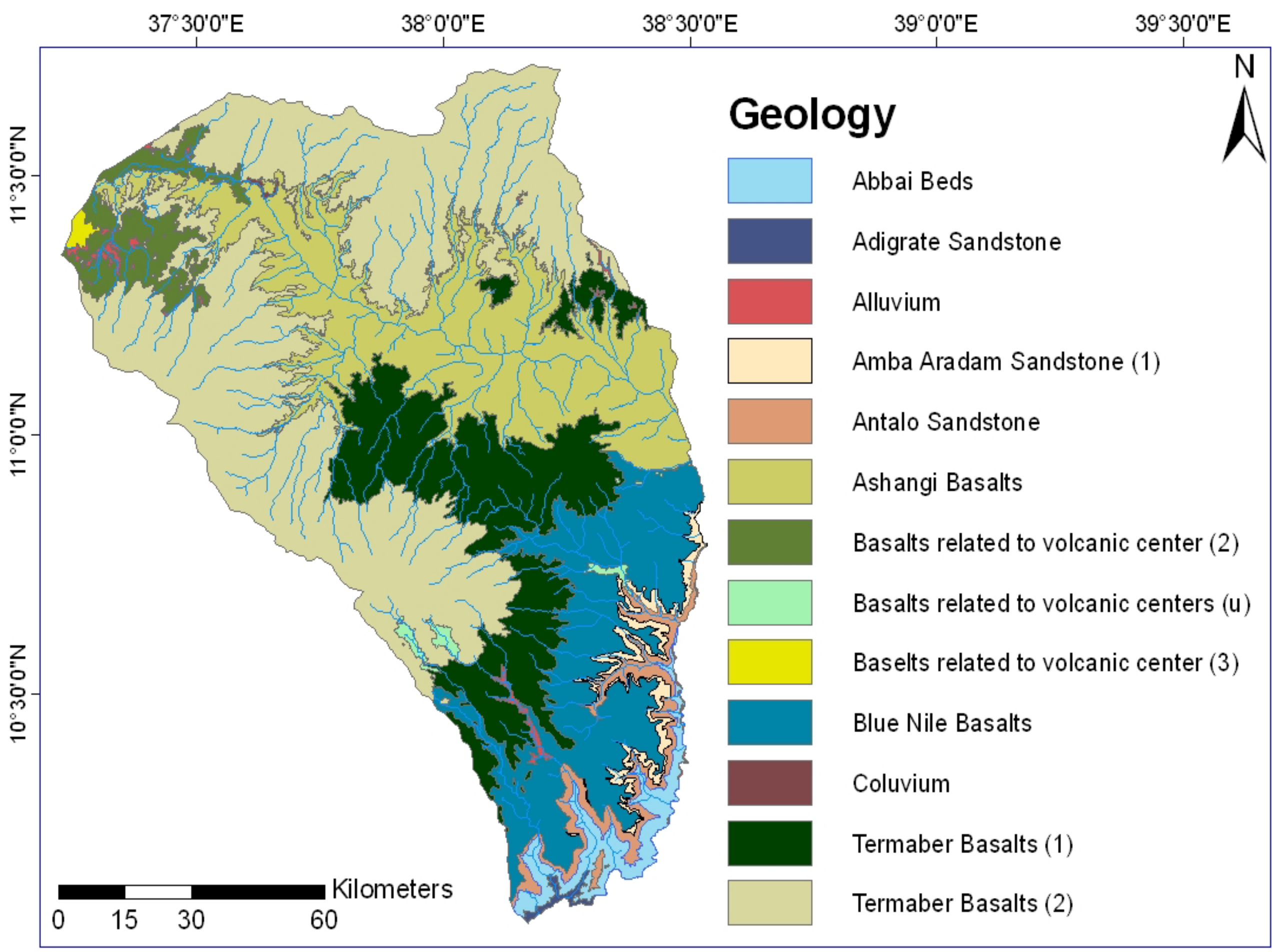

Figure 3.2. Geology of North Gojjam sub basin (Yilma and Awulachew, 2009).

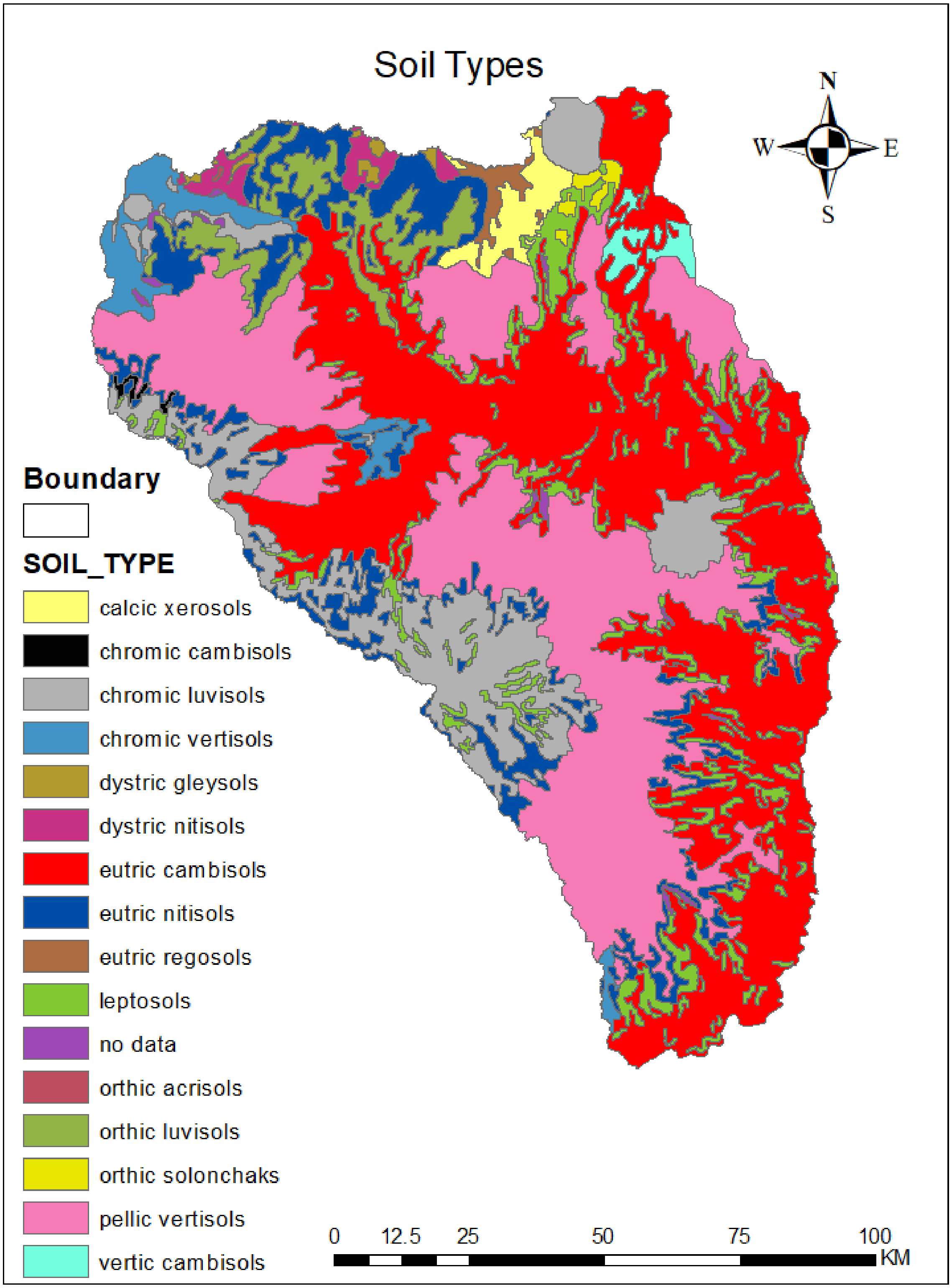

Figure 3.3. The distribution major soil types in North Gojjam sub basin

3.1.6. Natural Vegetation

North Gojjam sub-basin is endowed with various agroecology and topography, and this makes the sub-basin has a variety of vegetation types. However, the extent of natural vegetation has been reduced attributable to the expansion of cropland; overgrazing, and cutting of trees for construction and domestic fuel consumption. As a result, land cover change has been inclined to agricultural land, but natural vegetation has been reduced in type and quantity. The dominant indigenous trees in the sub-basin, like Bamboo (*Kerkeha*), Scheflera (*Getem*), Acacia (*Girar)*, Ficusvasfa (*worka*), Ficus (*Sholla*), Oliva (*woira*), Haginia (*Kosso*), Polystcha (*Anfar*), Bersam (*Azamera*), Fobia (Korich), juniprus (Tid*)*, Albniza (*Sesa*), Rosa Abyssina (*kega*), Asta, Jibara and other shrubs and bush vegetation cover and grass are found through scattering in different parts of the sub-basin. Natural forests are mainly concentrated around churches, riverbanks, hillsides, and some trees also found on farm and grazing lands. Kosso tree is a rare species among the most endangered species trees, which is becoming extinct now at different places. Eucalyptus globules forest is the dominant introduced tree and has been expanded because it can adapt almost all agro-ecological zones in the area and by its fast-growing nature and multiplying easily. It is one of the most sources of the cash crop in the sub-basin, particularly in the upper part.

3.1.7. Population Size and Spatial Distribution

Based on CSA (1994, 2007, and 2016) data, the total population of the sub-basin and surrounding *kebeles*[1] was 2.8 million in 1994 and 3.1 million in 2007 and it increased to 3.6 million in 2016. Of the total population male was about 1, 808, 280 (49.81%) while the female was about 1,791,720 (50.23%) and on average household size was 4.5 member. The above figure shows that sex ratio was almost proportion, meaning the number of male and female was almost equal. This was very close to the national average of 4.8 persons per household. Population settlement was dispersed in the sub-basin and the majority was living in foot hillside areas by forming small villages with relatives. The average population density in the sub-basin was 204.17/km^2 with lower 117 to higher 288/ km^2 (Figure 3.4). There is notable variation in population density from district to district (Figure 3.4). Of the total population of the sub-basin, about 99.95% was Amhara ethnic group and all were Amharic speakers, and 98.95% of inhabitants practiced Ethiopian Orthodox Christianity.

[1] *Kebele* is the smallest administration unit in Ethiopia

The proportion of urban and ruler population has great difference. This indicates that the majority of the population found in the sub-basin were rural dwellers, engaged on sub-substance agriculture.

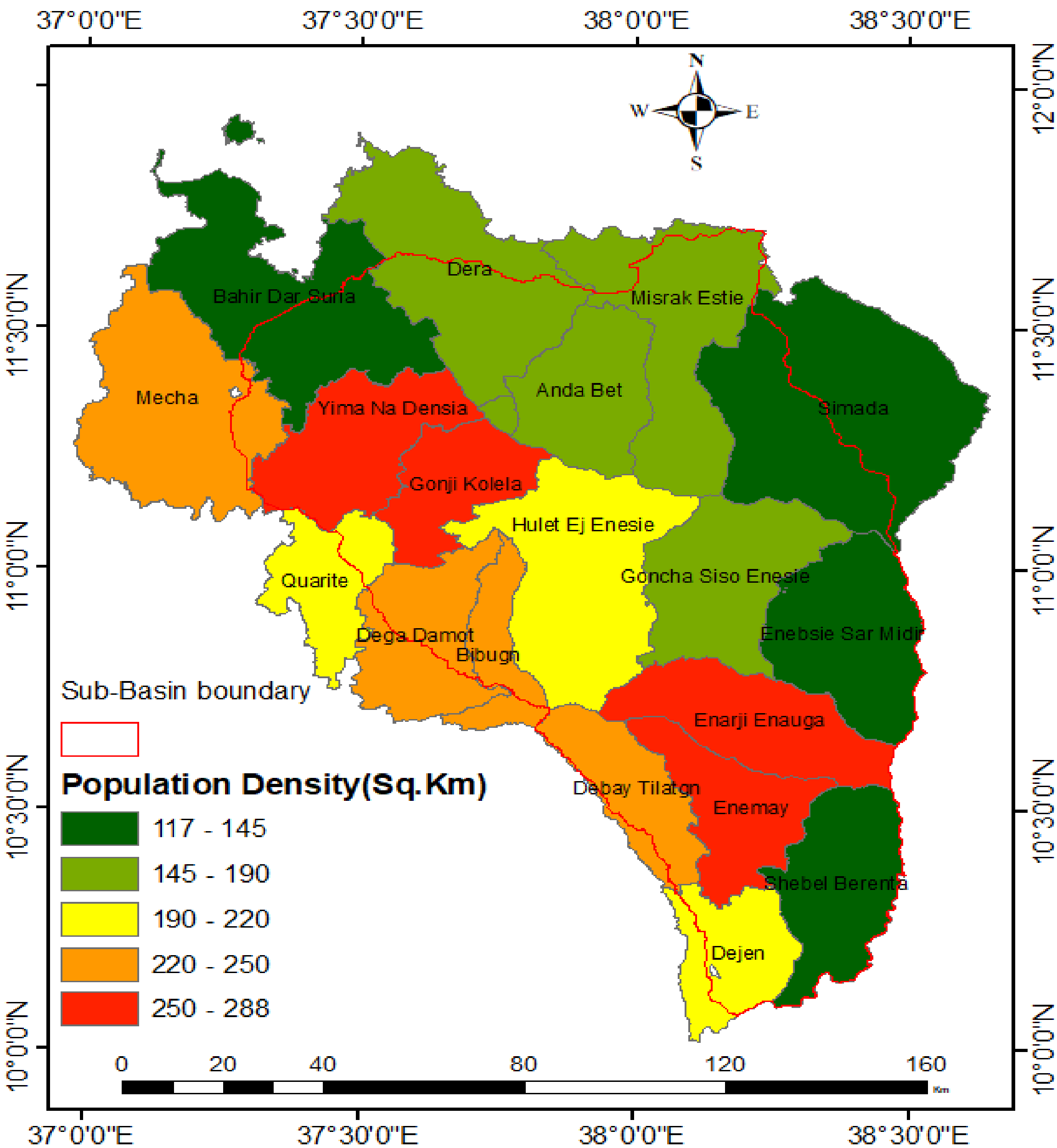

Figure 3.4. The population density in the north Gojjam sub-basin (Statistical Abstract, 2013).

3.1.8. Economic Activity

Agriculture is the backbone of economic activity in the sub-basin. Almost all rural people heavenly depends on volatile subsistent agricultural activity. Because of poor agricultural activity, low technology, low investment, abject soil degradation, deforestation, and population growth, the productivity of agriculture is very low. As the result of these per capita income of the community was very low and the living condition was decreasing continuously. Agriculture was characterized by crop-livestock mixed systems, which were practiced by independent stallholders on small-size plots (Simane et al., 2013). Rain-fed crop and mono-cropping production systems were the primary sources of livelihood for the majority of the population in the sub-basin.

Different types of crops have been produced to a great extent, but vegetation and fruit production are not common in the sub-basin. The farming system is diversified and determined by agroecology. Although several annual crops were grown in the sub-basin, the dominant crop types are cereals (wheat, barley, *teff*, and maize, sorghum), pulses (horse bean, lentil, chickpea, and field bean), and oilseeds (*nug*, *teliba*, cabbage). Cereal crops are the dominant in production, followed by pulses and oilseeds and potato and these were playing a great role in sources of food and cash. In general, crop production in the sub-basin is almost rain feed and the average productivity was 13.qt/ha for cereals (Simane et al., 2013).

As a whole, the farming system in the sub-basin was grouped into three zones: wheat-potato based in *dega* climatic region/upper part of the sub-basin; teff-wheat based farming system in the woinadega/middle and teff-haricot bean-based farming system in *kolla* climate region/lower part of the sub-basin. A farming characteristic of cropping systems in the area is the use of the ancient Ethiopian *ard* (locally called *maresha*) plowing system to prepare crop fields (Simane et al., 2013). The traditional up-down farming across the slope of the cultivated land leads to severe soil erosion and severe land degradation. The system of weeding and harvesting were manual and time and labour consuming activates.

Livestock was another wide agricultural activity in the sub-basin. It is a key source of food, income, used for agricultural activities, and transportation for goods and human due to lower road infrastructure accessibility in the sub-basin. The majority of the population who lived in *dega/*temperate climatic zone was not self-sufficient with crop production alone for feeding their family, but they bought a variety of crops from the market by selling livestock and livestock products (Districts office, 2018). Even though livestock number was higher, the productivity was very low due to lack of fodder, water, animal disease, poor animal genetics, and a backward breeding system. Livestock has created job opportunities for landless farmers in the area. The dominant livestock types are cattle, sheep, goats, horses, donkeys, mules, and poultry. Free grazing is the main livestock feeding system integrated with crop residue. Shortage of grazing land and feed; shortage of experts and materials to improve animal verity and lack of improved verity were the main challenges of full livestock production in the sub-basin. According to FGDs and key informant interviews, no significant off-farm activities support rural livelihoods in the sub-basin.

3.2. General Methodology of the Study

3.2.1. Study Design and Justification

Research design is defined as the procedure or blueprint for economically collection and analysis of data in a manner that aims to combine relevant things for the research purpose. Indeed, it is an outline of what the researcher will do from writing the hypothesis and analysis of data to its final operational implications (Kothari, 2004). This study employed cross-sectional, except Landsat data, research design because socioeconomic data were collected by one round trip. The reason for choosing this research design is its flexibility and low cost, and data can be accessed through the household survey at once. The study employed a mixed (qualitative and quantitative) approach with a concurrent triangulation method and hence the types of data collected are both qualitative and quantitative. The concurrent mixed research approach enables to gather of quantitative and qualitative data at the same time (Creswell, 2009). Likewise, this approach is preferred over others due to its merits to substantiate, cross-validate, or confirm the findings within a single study (Creswell, 2009). Besides, it demands the application of diverse data collection instruments to capture various information as possible. Likewise, this strategy is enabling the researcher to collect data within a short period (Creswell, 2009). Nevertheless, more weight was given to the quantitative approach due to the nature of this study. The qualitative information was primarily used to supplement and triangulate the quantitative results to draw valid conclusions.

3.2.2. Types and Sources of Data

Primary data sources: household heads, elders, community leaders, development agents, and expertise in the north Gojjam sub-basin were the main primary data sources for this study.

Secondary data sources: secondary data related to the study objectives were obtained from published and unpublished materials. These include information on the agro-ecologies of the study area, crop and livestock, demographic, meteorological, topographic maps, and vector overlays such as rivers and towns data were obtained from government offices. Moreover, other data such as soil data were obtained from the AFSIS website. International rainfall data for the period 2009-2017 was obtained from the CHIRPS website. Likewise, Landsat images and ASTER-GDEM were downloaded from the US Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS).

3.2.3. Sampling Technique and Sample Size

To acquire data for this study, we followed multistage sampling techniques and both probability and non-probability sampling techniques. In the first stage, north Gojjam was selected from 16 sub-basin of the Abbay Basin purposively, based on the information obtained from a panel discussion with stakeholders and the authors' prior knowledge about the study area. The study area is vulnerable to ecosystem services change and land degradation problem was less researched. In the second stage, three districts were selected purposively based on the administration, geographical location, and population density criteria (Table 3.2). Because the sub-basin is comprised of different agro-ecologies and administrative zones. In the third stage, from the selected districts, 9 rural villages/ kebeles (3 of each) were selected from upper, middle, and lower parts of the sub-basin based on agro-ecological variation criteria (Table 3.2). To determine the total sample size, we used the mathematical model developed by Miller (2003).

$$n = \frac{N}{1+N(\alpha)^2} \tag{3.1}$$

where, n = total sample of household required for the study, N= total household head in the study *Kebeles* and α = sampling error margin from 95% confidence interval

$$n = \frac{11158}{1+11158(0.05)^2} = 385$$

but, to strengthen the econometric model's robustness in this study, 414 household heads were selected using systematic random sampling techniques from the lists of the households obtained from the respective local agricultural offices in the fourth stage. Finally, the sample size in the respective districts and villages was determined following the proportional stratifying sampling technique (Table 3.2).

Table 3.2: Sample distribution of the served household heads

Zone	District	Kebele/Village	Agroecology	Total HH	Sample HH
East-Gojjam	Enarj Enauga	Koso-zira	Upper	932	34
		Titar Badima Yizar	Middle	1151	43
		Gedeb Georgis	Lower	1649	61
West-Gojjam	Dega Damot	Ziqual-Wogem	Upper	1154	43
		A/Medhanyalem	Middle	1120	42
		G/T/Haymanot	Lower	642	24
South-Gonder	Andabet	Gota	Upper	1644	61
		Yedidi Gimegne	Middle	1250	46
		Genete Mariyam	Lower	1616	60
Total	-	-	-	11158	414

Besides, 127 (78 Male and 47 Female) FGD participants were purposively selected from a different society in each sample village. For in-depth interviews, respondents were selected purposively from farmers, DAs, and district natural resource experts to capture the variety of information and to strengthen the robustness of this study results.

3.2.4. Data Gathering Instruments

To strength the robustness of each data gathering instrument and collect comprehensive data, we used diverse instruments for this study.

Household Survey questionnaire

All relevant primary cross-sectional data about the study objectives were collected from rural households using open and close-ended questionnaires in May and June 2018. The questionnaire has different demographic, socioeconomic, topographic, plot, infrastructure, and institutional characteristics. It was also comprised land users' perception of soil erosion and soil fertility status. Besides, farmers' view on land degradation impact and the trend of crop and livestock production, water, energy, food, and income of the household in the last 10 years. The questionnaire cover data on household and communitys' land management strategies. Besides, household food security indicators such as food gap/deficit, Household Food Insecurity Access Scare scale (HFIAS), Household Dietary Diversity Score (HDDS), and Household Food Consumption Expenditure (HFCE) were collected using a standard questionnaire. Along with the qualitative survey, quantitative data were collated to catch a variety of information and elucidate farmers' views on the state of land degradation and its effect on their living conditions.

To confirm the reliability and validity, the questionnaire was passed several tasks. At the outset, it was drafted based on a review of the previous empirical studies to understand the specific indicators of land degradation drivers, pressure, status, and the effects on livelihood and farmers' land management strategies to improve their living status. Then, the draft was contextualized by extension agents and development practitioners who working in the study area. Once the instrument design was completed, it was pre-tested using 20 farm household heads in a similar, but non-sample district (Bibugn district) in the east Gojjam zone to check for relevance, completeness, and measurability of indicators proposed for the study. Based on the feedback obtained from the inputs some questionnaires were omitted, amended, refined, and rearranged for the actual data collection held. Finally, the questionnaires were translated into the local language (Amharic). The survey was administered by well-trained enumerators under the close supervision of the researcher and the field assistance (Appendix A).

Focus Group Discussion (FGD)

In this study, to triangulating quantitative data, 18 FGDs (2 in each selected village) were conducted with different local communities. To catch various information, FGD participants were selected from different social classes based on their age, gender, and local knowledge of the study area. There is no conclusive design for the number of participants in one FGD meeting. But, the most recommended in one FGD meeting is ranged from 6 to 10 participants. Because, if the participant number is lower than 6 it may be restricting the diversity of the opinions to be offered while if it is more than 10 participants may be difficult for everyone to express their opinions broadly (Marczyk, 2005). Therefore, group members were limited from 6-10 people in this study.

In each study village/ *kebeles,* two FGDs were held. For this intention, the moderator was the researcher and field assistance using unstructured questionnaire (Appendix B).

Key Informant Interview (KII)

Key informant interview was used to gather qualitative information. Using this instrument in-depth information about the processes of LULC change and drivers of change, soil erosion, soil compaction, soil drainage, soil depth reduction, and soil nutrient depletion and impact of land degradation on the rural livelihood, and land management measures, as well as its effectiveness on households' food security collected. The key informants of this study were the elderly people who lived for long years in the study area and expertise of natural resources management, crop, and livestock productivity in each selected site. For these purposes, a total of 45 key informant interviews were conducted. The interview was employed by the researcher using the checklist (Appendix C).

Field Observation

Field observation was applied to document some of the observable evidence of the study. This enables to observe the actual situation and current biophysical status of the land resource bases. Likewise, it enables the identification of various SLM technologies and their effectiveness across different landscape and land use types. The observation data were recorded in the form of photos and text to supplement results from other data sources.

Figure 3.5. Observation at G/T/Haymanot, Koso-Zira, and Yedidi Gimegne, respectively (2018)

GPS Survey: A reconnaissance field survey was held using 1:50,000 topographic maps, local knowledgeable persons, and observing google earth pro map to identify major LULC types. Using the stratified random sampling technique, GCP points were collected for accuracy assessment and classification purposes using a handholding GPS instrument.

3.2.5. Methods of Data Analysis

Qualitative data gathered from key informants, FGDs participants, and observation were used to triangulate, substitute and complement quantitative data. Also, the qualitative data were used to describe the study area composed of information gained from the secondary data sources. Besides, Landsat imagers were analyzed using ERDAS IMGINE14, QGIS3.14, and ArcGIS10.5 software. On the other hand, quantitative data were analyzed with both basic descriptive statistics and econometric model regression techniques via STATA/SE14.0 software. Descriptive statistical methods that used in this study were frequency, mean, standard devotion, and percentage. These methods were used to reveal the farm households' key socioeconomic, demographic, institutional, and plot characteristics that determine household heads' SLM technology adoption. Moreover, descriptive statistical tools were applied to compare variables of interest that include: households' perceptions on land degradation and drivers of landscape change, and its impact on rural living, the response against land degradation, and the rate of SLM adoption in the north Gojjam sub-basin.

The econometrics models employed in this study were customized from agricultural and land management technology adoption and the impact analysis studies. The models we used are advanced as most of them are beyond a single regression equation analysis. In this respect, the multivariate probit regression model was employed to identify the factors that influence the adoption of multiple SLM technologies on their plot of lands and to examine the causal interlinkage between the adopted SLM technologies on their farmland. Similarly, to capture the determinants of households' decisions on several SLM technologies on their plot, Poisson regression model was applied. Finally, to assess the impact of ISLM adoption on rural household food security, the endogenous switched regression model was used.

Chapter Four

4. Land Cover Change in the Blue Nile River Headwaters: Farmers' Perceptions, Pressures, and Satellite-Based Mapping

Abstract

The headwaters of the Blue Nile River in Ethiopia contain fragile mountain ecosystems and are highly susceptible to land degradation that impacts water quality and flow dynamics in a major transboundary river system. This study evaluates the status of land use/cover (LULC) change and key drivers of change over the past 31 years through a combination of satellite remote sensing and surveying of the local understanding of LULC patterns and drivers. Seven major LULC types (forest land, plantation forest, grazing land, agriculture land, bush and shrub land, bare land, and water bodies) from Landsat images of 1986, 1994, 2007, and 2017 were mapped. Agriculture and plantation forest land use/cover types increased by 21.4% and 368.8%, respectively, while other land use/cover types showed a decreasing trend: water body by 50.0%, bare land by 7.9%, grassland by 41.7%, forest by 28.9%, and bush and shrubland by 38.4%. Overall, 34.6% of the landscape experienced at least one LULC transition over the past 31 years, with 15.3% representing the net change and 19.3% representing the swap change. The percentage change in plantation forest land increased with an increasing altitude and slope gradient during the study period. The mapped LULC changes are consistent with the pressures reported by local resident They are also consistent with root causes that include population growth, land tenure and common property rights, persistent poverty, weak enforcement of rules and low levels of extension services, a lack of public awareness, and poor infrastructure. Hence, the drivers for LULC should be controlled, and sustainable resources use is required; otherwise, these resources will soon be lost and will no longer be able to play their role in socioeconomic development and environmental sustainability.

Keywords: *LULC change; drivers; pressures; North Gojjam sub-basin; remote sensing; GIS*

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4.1. Introduction

Land use/cover (LULC) change is a persistent environmental issue encountered on a global scale (Lambin et al., 2003; MA, 2005), and Africa is experiencing significant changes across the continent. In recent decades, African grassland, woodland, and other vegetated areas have been increasingly converted into agricultural and settlement areas (MA, 2005). Africa lost 16% of its forests and 5% of its woodlands and grasslands during the period from 1975 to 2000, and more than 50,000 km^2 per year of natural vegetation has disappeared (Eva et al., 2006). According to the same source, the majority of vegetation cover has been converted into agricultural and settlement land. LULC change in Ethiopia has followed a similar trend, with significant implications for land degradation and loss of ecosystem services. According to a global land degradation assessment, more than 26% of Ethiopian land has been degraded, and 30% of the population’s livelihood has been affected from the period of 1981-2003 attributable to land degradation (Bai et al., 2008). In Ethiopia, deforestation is an ongoing process, and it is a cause of biodiversity loss, changing climatic conditions, desertification, and soil erosion (Bewket, 2003; Gebru, 2016). Forest cover in Ethiopia, which was more than 40% at the beginning of the 20th century, reduced to 2.36% in 2000 as a result of population growth (Gebru, 2016), though the standardized LULC calculation method is required to quantify the recent forest cover. The population size of the country has more than doubled in the last three decades from 40 million in 1984 to over 90 million in 2014, and it is estimated to reach 130 million by the year 2030 (CSA, 2016). More than 85% of the population lives in rural areas and highly depend on natural resources to sustain their way of life, and this results in an increasing resource demand in the country (Berry et al., 2003).

The Blue Nile (Abbay) basin, located in the western highlands of Ethiopia, is located in a critically important agricultural region. As it is also the location of the headwaters of the largest tributary of the Nile River, land and water dynamics in the basin have received particular attention from the research community. Several studies have been conducted on the biophysical state of change in the basin using remote sensing and GIS technologies. For example, (Bewket, 2003) conducted a LULC study on the Chemoga watershed for the period of 1957–1998 and found that forest cover was increased. Teferi et al. (2013) studied the Jedeb catchment from 1957 to 2009 and confirmed that plantation forest and cultivated land cover increased at the expense of other land uses, but the expansion of cultivated land ceased from the period of 1994–2009. Gebrehiwot et al. (2014) found that cultivated land increased alarmingly in place of forest land in Birr and Upper-Didesa from 1957 to 2000. Bewket and Abebe (2016) observed that the area of forest and dense tree cover decreased from the period of 1950–2001 in the Gish Abbay watershed. However, these studies did not have sub-basin focus and did not include land users' knowledge, and the findings were contradictory, perhaps because of the study areas' heterogeneity in natural resource distribution and management systems (Merrey and Gebreselassie, 2011). Most of the previous studies also missed considerable biophysical factors, such as elevation and slope gradient in relation to individual land use type change.

The drivers of LULC change are dynamic, and they differ across regions depending on the dominant socioeconomic and biophysical factors. For example, Gessesse and Bewket (2014) confirmed that the expansion of infrastructure at the expense of other LULC units in the Modjo watershed since the 1970s in the central highlands of Ethiopia was one of the drivers of landscape change. Expansion of farmland was confirmed by Gebrehiwot et al. (2014), but not in the Jedeb watershed as tested by Teferi et al. (2013) in the period of 1994–2009. In the Wollo area, population growth has been reported as a contributing factor for bush and shrubland expansion (Shimeles, 2012), but it has harmed bush and shrubland expansion in the Chemoga (Bewket, 2003) and Jedeb watersheds (Teferi et al., 2013). Thus, it is worth noting that the causes of LULC change are also time and location-specific. A driver identified a decade ago may not be valid in current times if interventions are made regarding the driving factor (Munthali et al., 2019). For example, deforestation was previously a key direct driver of land-use change in the Wollo area of the Ethiopian highlands, but recently, reforestation has been identified as a dominant driver of land degradation (Shimeles, 2012). Therefore, the biophysical environment is subjected to change caused by human activities, which have been continuously modifying ecosystem services (MA,2005; Munthali, 2019). Such continuous human intervention can also be observed in the Upper Blue Nile basin of Ethiopia (Merrey Gebreselassie, 2011; Yalew et al., 2012). Though land degradation is a problem, efforts are being made by the government, NGOs, and the local community to engage in sustainable land management practices in the Abbay basin (Merrey and Gebreselassie, 2012; Simane et al., 2013). But, the recent land management effect on ecosystem rehabilitation is not well-studied, particularly in the North Gojjam sub-basin.

Remote sensing offers a powerful tool for LULC change analysis, but studies of LULC change based solely on remote sensing may not be relevant or trustworthy for locally specific environmental applications. Integrated, place-based research on LULC change requires a combination of agent-based systems and narrative perspectives for an in-depth understanding of biophysical states (Fairhead and Leach, 1995; Muloo et al., 2019). The integration of remote sensing information with local land users' information can yield deeper insights into LULC change and the drivers of change. As a result, there is a growing need for the integration of scientifically proven knowledge with farmers' local knowledge of the state of land resources evaluation (Fairhead and Leach, 1995; Muloo et al., 2019; Ouma and Sterk, 2006). The farmers' knowledge was accumulated from day-to-day observations of changes in the capacity of the ecosystem services to support their livelihoods. On the other hand, Landsat images were selected for years that align with major events that occurred in the study area. Accordingly, the 1986 image is indicative of conditions toward the end of the Dergue regime, following a period of collectivization of land resources in Ethiopia (Teferi et al., 2013; Tsegaye et al., 2010).

The year 1994 represents the period in the aftermath of the fall of the Dergue regime and the early years of rule by the Ethiopian People's Revolutionary Democratic Front (EPRDF). During this time, there was massive deforestation and expansion of agricultural land (Ellis, 2011). The 2007 image was selected to evaluate the introduction of sustainable land management programs in the headwater of Abbay (Belay, 2014). Finally, to include recent changes and the current biophysical status in the study area, the 2017 Landsat image was selected. Therefore, this study evaluates the status of LULC change and key drivers of change over the past 31 years for a sub-basin at the source of the Blue Nile river (North Gojjam sub-basin) through a combination of satellite remote sensing and surveying of local understanding of LULC patterns and drivers. The specific objectives were (1) to quantify the extent, trend, and annual rate of LULC change in the period from 1986 to 2017; (2) to obtain local people's perspectives on LULC change; and (3) to identify key biophysical and socioeconomic drivers of LULC change in the sub-basin.

4.2. Materials and Method

4.2.1. Data Sources and Types

Socioeconomic Data: While there are various methods to conduct socioeconomic data based on the aim of the study, FGDs, in-depth interviews, and field observation were used to gain detailed information from local communities regarding the trends of LULC change and the importance of driving forces for changing landscape in the North Gojjam sub-basin between the years 1986 and 2017. To obtain in-depth and diverse information, FGD participants were selected from different agroecology and social classes based on their age, gender, and local knowledge. Similarly, the interview was held by the first researcher using an open-ended questionnaire at the DAs offices, churches, and farm fields. To gain a better understanding of the major observed problems of the sub-basin, transect walks and informal talks with farmers were conducted.

Spatial Data: Four Landsat images were downloaded from the US Geological Survey (USGS) Earth Explorer (http://earthexplorer.usgs.gov) for land LULC classification analysis. On the other hand, ASTER-GDEM was obtained from the Aster Global Digital Elevation Model Version 3 (http://gdex.cr.usgs.gov/gdex/). All Landsat images were obtained from January, the dry season, to avoid major differences in vegetation phenology and to gain fewer cloud cover images (Hano, 2013; Zewdie & Csaplovics, 2016; Zewdie & Csaplovies, 2017). We used comparable bands for LULC classification: band 1-7 for Landsat thematic mapper (TM) and enhanced thematic mapper (ETM)+ (with the exclusion of band 6) and band 2–7 for Landsat operational land imager/thermal infrared sensor (OLI/TIRS) (Table 4.1). TM and ETM are the two sensors in Landsat, and they have been in use since 1982. The sensors are important for LULC change analyses. Obtaining adequate datasets requires the selection of the type of sensor, relevant wavelength bands, and date(s) of acquisition (Hailemariam et al., 2016). Landsat 8 (OLI/TIRS) was launched in 2013 by improving the past Landsat qualities, and it was applied for the observation of land use and cover since this period.

Ground Truth Data: ground truth data for LULC calcification and accuracy assessment were collected using different information. The reference data for the 1986 and 1994 images were collected based on interviewing local elders about known locations in the locality. These elders were not involved in both FGDs and the in-depth interview in this study. Information collected from elderly people in a participatory approach is a good source of reference data for validation of old LULC maps. Old topo-sheets were used to initiate the discussion among the group members of the elderly people, while the 2007 image reference data were collected from Google Earth using a time slider image. For the recent image (2017), reference data were collected based on field observations using a handheld global positioning system (GPS) instrument for recording reference truth points (latitude and longitude). Using a simple random sampling technique, 2500 sample points were collected from the representatives of LULC classes for each study year. Of these total ground truth points, 547, 587, 724, and 738 were used for accuracy assessment of image classification for the years 1986, 1994, 2007, and 2017, respectively.

Table 4.1: List of time series Landsat data used in this study

Sensor	Path/Row	Acquisition date	Resolution	Source
1986 TM	170/052	01/19/1986	30 x 30	USGS
	169/052 &053	01/28/1986	30 x 30	USGS
1994 TM	170/052	01/25/1994	30 x 30	USGS
	169/052 &053	01/18/1994	30 x 30	USGS
2007 ETM+	170/052	01/21/2007	30 x 30	USGS
	169/052 & 053	01/17/2007	30 x 30	USGS
2017 OLI	170/052	01/24/2017	30 x 30	USGS
	169 /052&053	01/17/2017	30 x 30	USGS

4.2.2. Satellite Image Preprocessing

Satellite image preprocessing operations were carried out to improve the images quality. Because of the technical conditions of the sensors and platforms, and the state of the atmosphere, earth rotation, and terrain effects, the images acquired by the sensors can be subject to errors and distortions (Young et al.,2019; Park et al., 2018). To reduce these effects and to facilitate effective monitoring of biophysical change, image preprocessing is vital (Richards , 2013). Image preprocessing can be achieved through various radiometric and geometric correction techniques (Chander et al., 2009). Such radiometric techniques are a prerequisite for creating good quality sensor data and a higher level of downstream products (Chander et al., 2009). This helps to reduce the variability among scenes and increases the comparability of data obtained from different times and different sensors (Chander et al., 2009). Landsat satellite sensors' digital number (DN) values were converted to radiance and then to top-of-atmosphere (TOA) reflectance (Richards , 2013). The images acquired from the Earth Explorer website are in this format (https://earthexplorer.usgs.gov/). Radiometric calibration of the, TM, ETM+, and OLI sensors involves rescaling of the raw digital numbers (Q) transmitted from the satellite to calibrated digital numbers (Qcal), which have the same radiometric scaling for all scenes processed on the ground for a specific period. Thus, we used the following equation previously used by Chander et al. (2009) to perform the Qcal-to-spectral radiance conversion using QGIS3.1.

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{colmax} - Q_{calmin}}\right)(Q_{col} - Q_{colmin}) + LMIN_\lambda \quad (4.1)$$

where:

L_λ = Spectral radiance at the sensor's aperture $[W/(M^2\ sr\mu m)]$

Q_{col} = Quantized calibrated pixel value [DN]

Q_{calmin} = Minimum quantized calibrated pixel value corresponding to $LMIN_\lambda$

Q_{colmax} = Maximum quantized calibrated pixel value corresponding to $LMIN_\lambda$

$LMIN_\lambda$ = Spectral at-sensor radiance that is scaled to Q_{calmin} $[W/(M^2\ sr\mu m)]$

$LMAX_\lambda$= Spectral at-sensor radiance that is scaled to Q_{colmax} $[W/(M^2\ sr\mu m)]$

The second step of the radiometric calibration operation was the conversion of the at-sensor spectral radiance to top-of-atmosphere (TOA) reflectance. This has three advantages: (1) it removes the cosine effect of different solar zenith angles due to the time difference between data acquisitions; (2) TOA reflectance compensates for different values of exoatmospheric solar irradiance arising from spectral band differences; (3) the TOA reflectance is corrected to the variation in the Earth-Sun distance between different data acquisition dates. TOA reflectance was computed using Equation (4.2) in QGIS3.1.

$$P_\lambda = \left(\frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos\theta_S}\right) \quad (4.\ 2)$$

P_λ = Planetary TOA reflectance [unitless]; π = constant approximately to 3.14159 [unitless]; L_λ = Spectral radiance at the sensor's aperture $[W/(M^2\ sr\mu m)]$; d = Earth–Sun distance [astronomical units]; $ESUN_\lambda$= Mean exoatmospheric solar irradiance $[W/(M^2\ sr\mu m)]$.

Parameters used for Landsat TM and ETM+ images for radiometric calibration are available in the image metadata in text file format. The value of exoatmospheric solar irradiance was summarized for the TM and ETM+ sensors using the Thuillier solar spectrum (Chander & Markham, 2003).

For Landsat 8 (OLI 2017), the digital numbers (DN) of the images were directly converted to the ToA reflectance using the formula given in U.S. Geological Survey (2016) using QGIS software.

$$\mathrm{L}_\lambda = \frac{\mathrm{M_L\ Q_{col} + A_L}}{\sin\theta} \quad (4.3)$$

where: L_λ= Spectral radiance $[W/(M^2\ sr\mu m)]$

M_L =Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata)

A_L =Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata). Q_{col}= L1 pixel value in DN; θ_S = Solar Elevation Angle in the study area.

Focal analysis or Gap filling was completed to build bad lines for Landsat 7 ETM+ before radiometric correction made using ERDAS IMAGINE14. Though, Landsat images acquired from USGS already geo-referenced into WGS_84_UTM_ zone_37 N and datum_D_WGS_1984, all did not correctly fit each other. For instance, Landsat 2017 image does not perfectly fit with other images. As a result, the first 2017 images were geo-referenced using the georeferenced topographic map. Then, other images were registered with the image-to-image geo-referencing technique using 2017 images as a base in ERDAS IMAGINE 14. Satisfactory Ground Control Points (GCPs) were taken from permanent points, such as from rivers and streams intersection. Each georeferenced image root means square error (RMSE) result was less than 0.29 pixels. Then, the images were re-projected to the same projection system (WGS_84_UTM_zone_37N) and resampled to 30-meter resolution via nearest neighbor algorithm. There are various Landsat image enhancement techniques to aid visual interpretation and clear visual appearance of the image. But, histogram equalization was applied in this study, as this method is the best technique for the frequency distribution of the large pixel values through the image. After subsequent preprocessing, all images were in mosaic form prepared image, and the sub-basin study images were masked using digitized shapefile of the sub-basin using ArcGIS10.5 tools.

4.2.3. Landsat Image Classification

In this study, unsupervised classification was initially applied before the field survey, using the visual interpretation method to differentiate various land use/cover types in the studied sub-basin. Then, supervised image classification was applied after the collection of training data from existing LULC classes. Using ERDAS IMAGINE 14 from each of the predetermined LULC classes, signatures of polygon were delineated based on the information obtained from field observations, local people, Google Earth, and the image visual interpretation through false-color composite interpretation (Teferi et al., 2013).

The use of high-resolution Google Earth images to derive the ground truth for land use classification accuracy has been suggested in previous studies (Batar et al., 2017; Scharsich et al., 2017). Spectral signatures of the respective land use/cover class derived from the satellite imageries were recorded using the pixels enclosed by these polygons. A polygon of the homogenous map class was selected as a sample unit instead of a single-pixel to reduce misregistration and to increase the quality of match image segmentation analysis. Landsat pixels that overlap the training areas were then used to perform the classification (Butt et al., 2015). A stratified random sampling method was used to collect an optimum number of sample reference polygons for the classification. A satisfactory spectral signature ensures minimal confusion in the mapped land cover. The number of training sites varied from one LULC to another depending on the ease of identification and level of variability (Cheruto et al., 2016). Then, each pixel of the image dataset was placed in a LULC class via maximum likelihood classifier, and outputs were presented in different tables and figures. The maximum likelihood classifier (MLC) is the most widely adopted parametric classification algorithm, and it uses a per-pixel method to account for the spectral information of LULC classes (Cheruto et al., 2016; Rwanga & Ndambuki, 2017; Teferi et al., 2013; Tsegaye et al., 2010). Generally, the steps of the current LULC change classification procedure are presented in Figure 4.2.

The nomenclature for LULC types was given based on the authors' prior knowledge about the study area, brief field survey, and Google Earth map observation and the review literature (Anderson et al., 2001). All LULC types have a given clear and precise description as they have distinct differences from each other (Table 4.2 and Figure 4.1). The classification of LULC types from a satellite image of the study area depended on the purpose, nature of the study area, and resolution of the satellite imagery. For example, we classified settlements as agricultural land for two reasons. The first reason is that during 1986, most houses' roofs were built from grass and straw, and they look considerably like cropland in the images. On the contrary, in 2017, most of the houses were built from tin and thus do not have similar reflectance as 1986 house types. Second, the study sub-basin is primarily rural; most houses are scattered and small in size, and they are almost surrounded by cropland. This makes it difficult to separate settlements from cropland at a 30m resolution via 30-meter image resolution.

Table 4.2: Description of land use/land cover classes

LULC Classes	Description
Agriculture land	The area is covered with crop cultivation. This land-use type includes rural settlements fenced with trees that are commonly found around homesteads and towns. This class also includes homesteads and the scattered trees on farmlands.
Water bodies	An area of land covered with surface water bodies such as lakes, rivers, and ponds.
Bare land	Areas under degraded lands and with some areas that are of bare ground, including sand, gravel, bedrocks, and riverbed gravels.
Grassing land	The area is covered by permanent grass that is used for communal and private grazing lands. This class also includes rangelands.
Forest land	Areas covered by dense natural trees forming closed or nearly closed canopies, mainly growing naturally in the reserved areas and along the riverbanks and the hillsides.
Plantation forest	Areas composed of transplanted seedlings of plants, mainly Eucalyptus globulus, junipers, and bamboo trees.
Bush and shrub land	Land covered by bush and shrubland vegetation. This class also includes sparse trees on shrub and bushland.

Figure 4.1 Views of partial LULC types in the north Gojjam Sub basin (A-F)

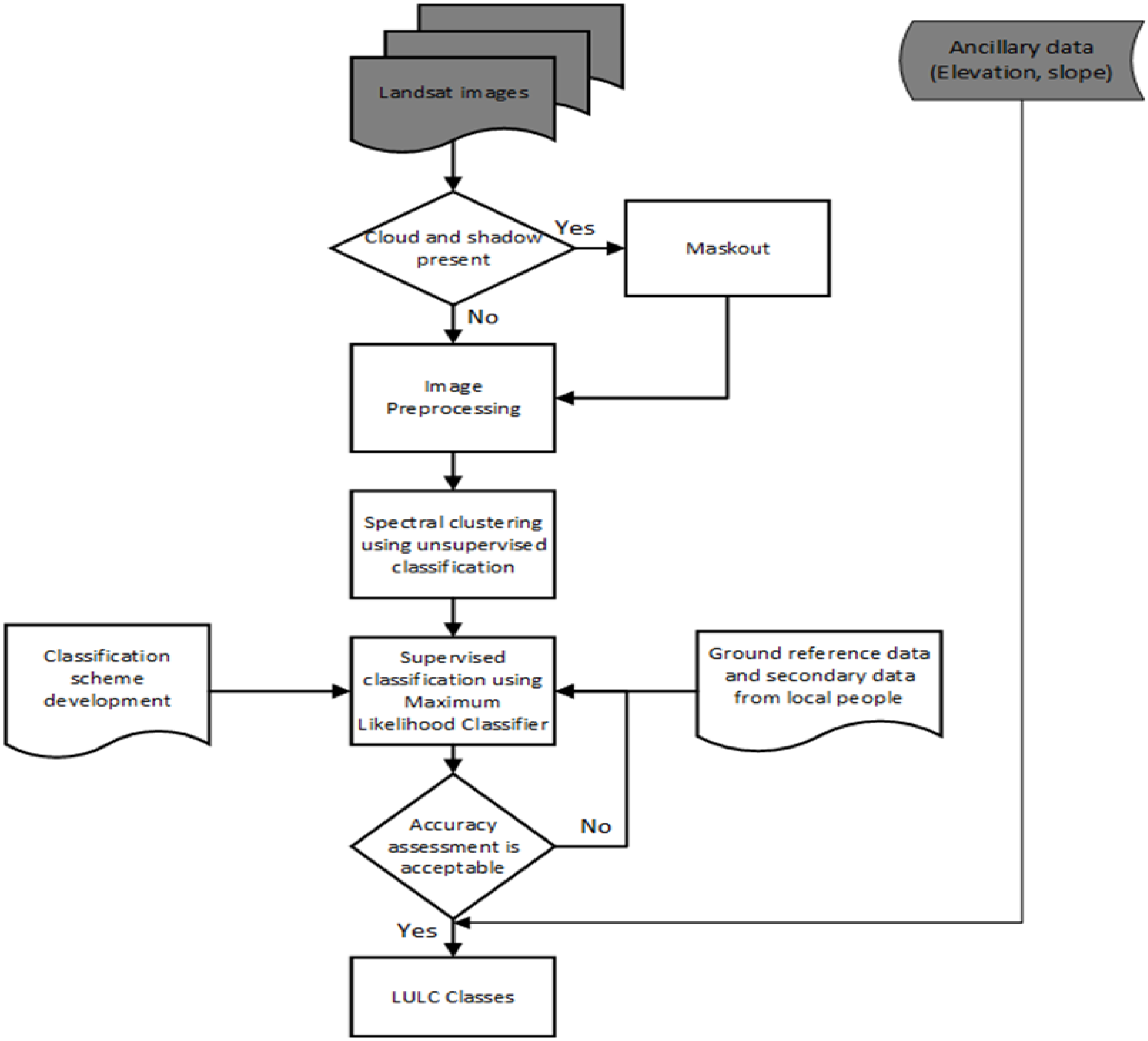

Figure 4.2. Flowchart showing the procedures used to arrive at the final LULC

4.2.4. Derivation of Topographic Attributes

Topographic characteristics of altitude and slopes were generated from ASTER-GDEM using Arc GIS10.5. Applying the classification system developed by Bewket and Teferi (2009), the slope class in the study area was reclassified into six classes: very gentle (0%–5%), gentle (5%–10%), moderate (10%–20%), steep (20%–30%), very steep (30%–50%), and extremely steep (50%–

100%) slopes. Likewise, the elevation range was divided into six classes with an interval of 500 m elevation range. Finally, by overlaying the classified maps of each study year (1986 and 2017) on the elevation and slope maps, thematic information showing the relationship between LULC distribution and changes in each class of topographic variables was extracted using ArcGIS10.5.

4.2.5. Method of Socioeconomic Data Analysis

First, all 18 FGDs participants discussed, identified, and ranked the key drivers of land use/cover change based on their severity at all of the selected villages. Then, the results obtained from each group were added and changed to the percentage total for aggregate results. Moreover, qualitative information gathered from key informant interviews, observation, and FGDs were used to triangulate, substitute, and complement quantitative data/Landsat information results.

4.2.6. Post Classification Processing

4.2.6.1. Classification Accuracy Assessment

To validate the quality of information derived from remotely sensed data, accuracy assessment is a key step in the process of remote sensing data analysis (Amuti and Luo, 2014; Cheruto et al., 2016; Federici et al., 2015). Accuracy assessment in spectral image classification is measured through a set of reference pixels via creating an error matrix (Cheruto et al., 2016; Haque and Basak, 2017). Accordingly, all Landsat image classification accuracy levels of this study were checked using the error matrix rule, which allowed us to evaluate the kappa coefficient, overall accuracy, and the producer's and user's accuracy. Each supervised LULC classification validation was analyzed using more than 540 validation points.

4.2.6.2. Analysis of LULC Change Detection

Gross loss, gross gain, net change, and swap of LULC change for each class were calculated using the transition matrix methodology used by Teferi et al. (2013) and Zewdie and Csaplovies (2016) by applying it to each pair of sequential images: 1986–1994, 1994–2007, 2007–2017, and the entire period,1986–2017. In this approach, the transition matrix contains rows that include land cover classes at time 1 and columns for land cover categories at time 2. The proportion of land that transitions from category i to category j between the two time periods are denoted by P_{ij}. Persistence appears along the diagonal of the matrix and is denoted by P_{jj}. The entries off the diagonal indicate a transition from category i to a different category, namely category j. According to Pontius et al. (2004), the proportion of the landscape in category i in time 1 (P_{i+}) is the sum of (P_{ij}) over all j, and the proportion of the landscape in category j in time 2 (P_{+j}) is the sum of (P_{ij}) over all i. The gains were computed from the difference between column total and persistence, while the losses were computed from the difference between the row totals and persistence. The total change (C_j) of a land use category was computed using the sum of gains and losses. The total change includes swap change (S_j), which denotes simultaneous gain and loss of a category on the landscape. The amount of swaps of land class j was calculated as two time the minimum of the gain and loss to create a pair of grid cells that swap each grid cell that gains with a grid cell that loses (Teferi et al., 2013). Net changes (D_j) are the differences between gain and loss of the successive land cover/use class.

$$S_j = 2 * MIN(P_{j+} - P_{jj}, P_{+j} - P_{jj}) \tag{4.4}$$

$$C_j = D_j + S_j = P_{j+} + P_{+j} - P_{jj} \tag{4.5}$$

$$D_j = |P_{+j} - P_{j+}| \tag{4.6}$$

The annual rate of LULC changes between study periods and was calculated using the standard formula derived from the compound interest law recently applied by Teferi et al. (2013), as it is a standardized method of land use classification with good estimation and biological meaning classification (Puyravaud, 2003).

$$R_\Delta = \left(\frac{1}{T}\right) \times ln\left(\frac{A_2}{A_1}\right) \times 100 \tag{4.7}$$

where R_Δ = average annual rate of change (%); A_1 = amount of land cover in time 1; A_2= amount of land cover in time 2; and T = the time interval between the two study years.

4.3. Results and Discussion

4.3.1. Local Views on Direct Drivers of LULC Change

Deforestation and Vegetation Cover Clearance: in Ethiopia, deforestation is an ongoing problem that causes ecosystem service change and fragmentation (Berry et al., 2003; Bewket, 2003; Kirui and Mirzabaev, 2015; Kirui, 2016b). The impact of deforestation and vegetation clearance for LULC change was ranked by 70.9% of FGDs participants' in the North Gojjam sub-basin (Figure 4.3). According to the local viewpoint, natural vegetation covers have been declining for the last 31 years, mainly associated with agricultural land expansion. According to local inhabitants, wood cutting for domestic energy, charcoal production, building, wood selling, furniture making, and farm tools continue to be factors for the forest, bush, and shrubland degradation. As a result, natural vegetation has significantly diminished and is currently observed only in churches, riverbanks, and hillside areas. But, farmers explained in interviews that plantation forests (Eucalyptus globulus) have been increasing in the sub-basin, particularly in temperate and sub-temperate agroecology zones. Due to the low productivity of agriculture land and land degradation, farmers have been begun to use their land for commercial tree plantation, particularly in the highland regions. This results in replacing other indigenous trees, farmland, bush and shrubs, and wetlands and grassland covers. However, there is a challenge regarding reforestation and afforestation of indigenous plants in the sub-basin due to the shortage of land, free grazing, shortage of water, and lack of follow-up after planting. Hence, vegetation cover clearance was the key driver of land-use change in the study area.

Overgrazing/free grazing: Livestock pressure and poor management of grazing land are direct drivers of LULC change (Berry et al., 2003; Teferi et al., 2013). Similar to this, farmers in the FGDs and in-depth interviews reported that the number of low productive livestock is higher than before and has been increasing with the increasing population growth but decreasing per household. Regarding this, 21.3% and 65.3% of FGDs participants ranked livestock pressure in first and second place, respectively, as it is a direct driver of LULC change in the North Gojjam sub-basin (Figure 4.3). Likewise, according to local experts, livestock is not improved in genetic potential, and, thus, they are poor in productive capacity. The feeding system also remains undeveloped and mainly depends on free grazing and crop residue/straw. Recently, the livestock grazing system has been shifted to bush and shrublands because of the conversion of grazing land to agricultural land. This results in the emergence of key drivers of vegetation cover clearance and soil erosion in the sub-basin. Even if farmers are recommended by experts to reduce livestock numbers and to use cut-and-carry systems for feeding, most farmers are not willing to do so. Farmers reported that the cut-and-carry system is difficult for feeding sheep and goats and that it is also labor-intensive, particularly in the temperate area where most farmers' livelihoods depend on sheep and horses. Thus, it is a challenge to implement a cut-and-carry system, particularly among landless youths, as they depend on communal grazing land. Similarly, farmers perceived that feeding animals using a cut-and-carry system makes animals weaker than those feeding via free grazing. The FGD and in-depth interview participants also indicated that farmers share manpower, livestock, and waterway tracks on land with a steep slope. This aggravates high soil erosion in the rainy season and causes the formation of gullies. This implies that overgrazing and poor grazing practices result in land-use change and interfere with ecosystem rehabilitation efforts through afforestation and reforestation in the sub-basin.

Using Biomass for Fuel Energy: it is one of the key direct causes of land degradation in Ethiopia (Berry et al., 2003; Kirui & Mirzabaev, 2015; Kirui, 2016b). According to FGD participants, almost all people in the sub-basin used firewood followed by cow dung and crop residue for cooking, heating, and lighting. Collecting firewood and charcoal production is recognized by 64.6% of participants as the third direct cause of LULC change in the studied sub-basin (Figure 4.3). According to them, not only rural people but also those living in towns depend on charcoal and firewood energy for cooking and heating due to the scarcity of electric power.

Poor land management: inappropriate land use affects the ecosystem services and leads to a failure to land productivity (Alemu, 2015; Zeleke & Hurni, 2019). Farmers in the informal discussion confirmed that poor agricultural activities such as cultivating very steep land, marginal lands, plowing ups and downs (cress-cross tillage), and poor grazing systems are key causes for LULC change and severe soil erosion in the sub-basin. Besides, as experts pointed out, misused land management technologies and poor irrigation systems are other factors for the conversion of productive land to poor land use in the sub-basin. This implies that the farming system was the proximate cause of land resources conversion in the north Gojjam sub-basin. But, FGD percipients didn't rank poor land management among the top five direct drivers of LULC change.

Biophysical (Natural) Factors: Natural factors are key drivers of land-use change in the North Gojjam sub-basin. FGDs and in-depth interview participants noted erratic rainfall and rugged topography as biophysical factors contributing to LULC change in general, and land degradation, particularly in the study area. According to them, the sub-basin is well known for its irregular relief features, which include mountains with steep slopes, hills, gorges, and plains. These terrain features provide running water with energy to wear away topsoil.

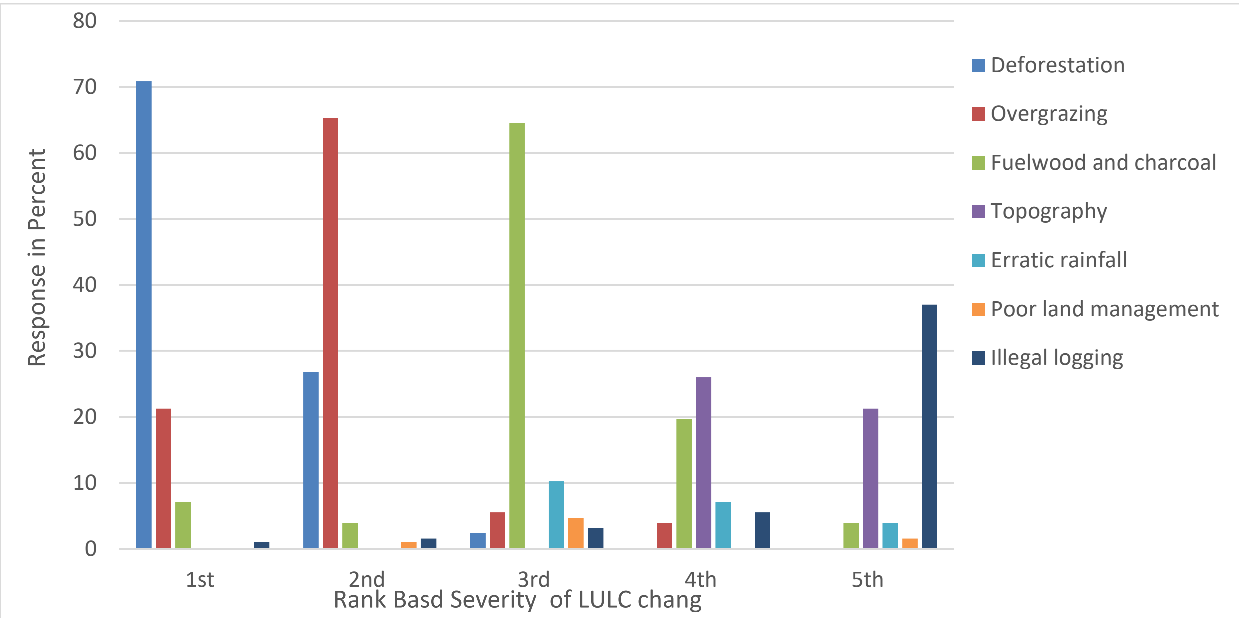

Figure 4.3. Direct drivers of LULC change in the North Gojjam sub-basin.

Approximately 26% and 21% of participants ranked topography as the fourth and fifth most important factor among the drivers of land-use change, respectively (Figure 4.3). The sub-basin has unimodal rainfall that occurs during the summer season, extending from June to September, which results in high soil erosion mainly in the early summer season. Besides, soil erosion generally causes the removal of fertile portions of topsoil; the creation of degraded land cover types; and the formation of gullies, bare lands, and rock levels in the study area.

4.3.2. Landsat LUCL Mapping

Having gathered local land users' perspectives on key LULC trends and the pressures that drive them, we now examine the representation of these changes in the satellite record.

4.3.2.1. Image Classification Accuracy Assessment

The accuracy assessment result of LULC for this study shows that for 1986, overall accuracy was 89.8% with a kappa coefficient of 0.9; for 1994, overall accuracy was 92.6% with kappa coefficients of 0.8. Similarly, in 2007, the overall accuracy was 87.8%, while the kappa coefficient was 0.8. In 2017, the overall accuracy was 91.6%, and the kappa coefficient was equal to 0.9. The user's accuracy of the individual LULC class ranged from 76.7% to 95%, and the producer was found between 75.7% and 95% in all classification years (Table 4.3). Previous authors have set different thresholds for determining whether LULC classification is acceptable. Congalton (1991) states that accuracy is "very good" if the overall classification accuracy result is above 81%, whereas the USGS guidelines call for overall accuracy is greater than 85% (Fonji & Taff, 2014). According to (Ismail & Jusoff, 2008), the agreed criteria for kappa (K) statistics are classified as poor if $K < 0.4$, good if $0.4 < K < 0.7$, and excellent if $k > 0.75$. By all of these measures, the LULC classification maps generated in this study qualify as high-quality. Each LULC class validation was checked by more than 540 reference points.

Table 4.3. Accuracy of LULC classification of the North Gojjam sub-basin (1986–2017).

LULC	1986 (%)		1994 (%)		2007 (%)		2017 (%)	
Classes	Producer's	User's	Producer's	User's	Producer's	User's	Producer's	User's
AL	90.4	92.5	89.6	94.9	88.9	90.7	96.8	92.8
WB	93.3	75.7	96.0	88.9	96.0	88.9	86.7	100.0
BL	90.2	93.9	83.3	95.3	76.7	95.8	90.1	87.6
GL	89.8	87.2	92.0	81.8	90.0	82.4	92.4	94.0
FL	86.0	90.5	90.4	90.4	78.6	90.2	88.4	87.5
PL	79.0	94.4	78.0	80.0	79.0	79.0	89.3	89.3
BSL	93.6	86.5	90.0	85.7	92.3	85.7	79.1	91.3
Overall	89.8		92.6		87.6		91.6	
Kappa	0.9		0.8		0.8		0.9	

Note: AL = agriculture land and settlement, WB = water body, FL = forest land, BSL = bush and shrubland GL = grazing land, PL = plantation, BL = bare land.

4.3.2.2. Analysis of Land Use/Land Cover Change

The distribution of LULC types in the North Gojjam sub-basin for the years 1986, 1994, 2007, and 2017 are presented in Figures 4.4 and 4.5. The area extent, trend, annual rate of change, and matrix of land use and cover results of the sub-basin are provided in Tables 4.5-4.7. As displayed in Tables 4.4 and 4.5, significant LULC change occurred over the last 31 years in the North Gojjam sub-basin. At the beginning of the study period (1986), agricultural land was the most dominant type, covering 58.2% of the total sub-basin area, followed by grazing land (21.4%), bush and shrubland (13.43%), bare land (3.2%), natural forest (2.9%), plantation forest (0.8%) and water bodies (0.08%). During the first study period time interval (1986–1994), agriculture cover increased from 58.2% to 61.7% in areal extent and plantation forest showed an increase of 105.2% from its original size. In this period, some degraded land was rehabilitated. Similarly, local land users confirmed that afforestation and reclamation measures expanded due to mass plantation campaigns during this period on communal grazing land, bare land, and bush and shrubland areas. Conversely, natural forest, bare land, bush and shrubland, and grazing land covers declined by 27.5, 16.1, 14.1, and 5.1% during the period from 1986 to 1994, respectively (Table 4.5).

In the second study period (1994–2007) agricultural land increases from 61.7 to 66.5% in the areal extent as a result of cropland and settlement expansion into grazing land and natural vegetation (Table 4.4). During the same period, land covered by plantation and natural forest increased by 333.8% and 7.1%, respectively (Table 4.5). According to local farmers’ view, during this period, bush and shrubland covers were regenerated into the dense forest. Besides, afforestation and reforestation practices were applied to expand forest cover. These increases in agriculture, plantation, and forest land cover were at the expense of other land covers: bare land, grazing land, bush and shrubland, and water bodies decreased by 48%, 29.6%, 17.6%, and 12.5%, respectively (Table 4.5). The result indicates that, like in the first years, the trends of agriculture and plantation expansion continued.

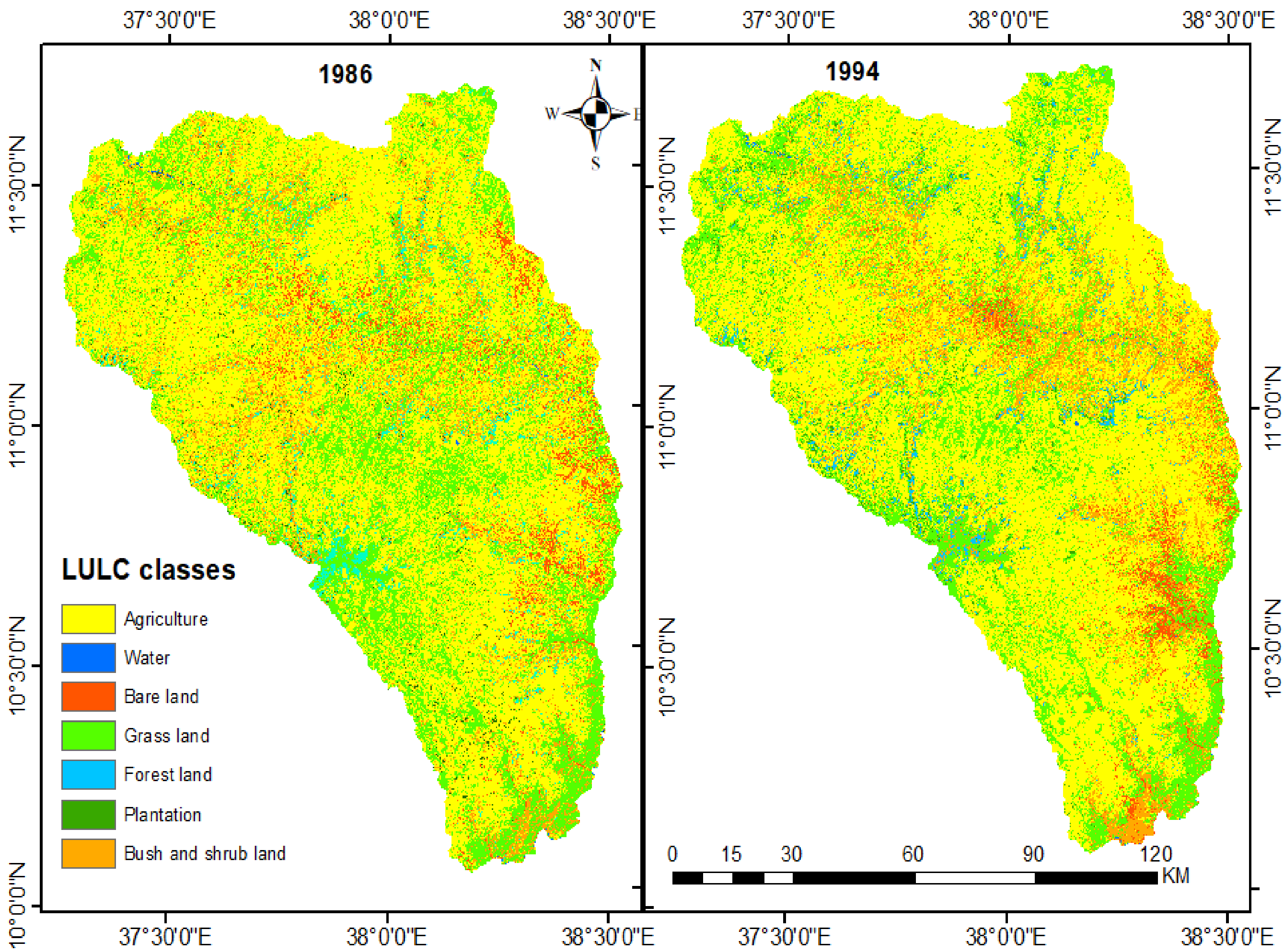

Figure 4.4. 1986 and 1994 LULC maps of the North Gojjam sub-basin.

In the third study period (2007–2017), the expansion of agricultural land and plantation continued, increasing from 66.7 to 70.7% and 3.3 to 3.6%, respectively (Table 4.4). In this period, the degraded land cover also increased, with an area extent of change of 77.2%. However, unlike the previous period, forest cover slightly decreased from 2.3 to 2.1% in the areal extent (Table 4.4). Similarly, waterbodies, bush and shrubland, and grazing land were reduced by 42.9%, 25.8%, and 17.2%, respectively (Table 4.5). Generally, though specific trends varied, the pattern of landscape change showed a continued tendency toward more land being brought under cultivation, settlement, and plantation at the expense of other LULC classes in the sub-basin. In the whole study period (1986–2017), although fluctuating rates and trends were observed, agricultural land showed a noteworthy increase of 58.2-70.7% at the expense of natural vegetation and grazing land (Table 4.4). Similarly, the magnitude of plantation forest cover showed a remarkable areal increase with more than threefold (368.83%) trend, and by 4.98% annual rate of change; mainly, the rapid expansion pattern was observed between 1994 and 2007 (Table 4.5 and Figure 4.6).

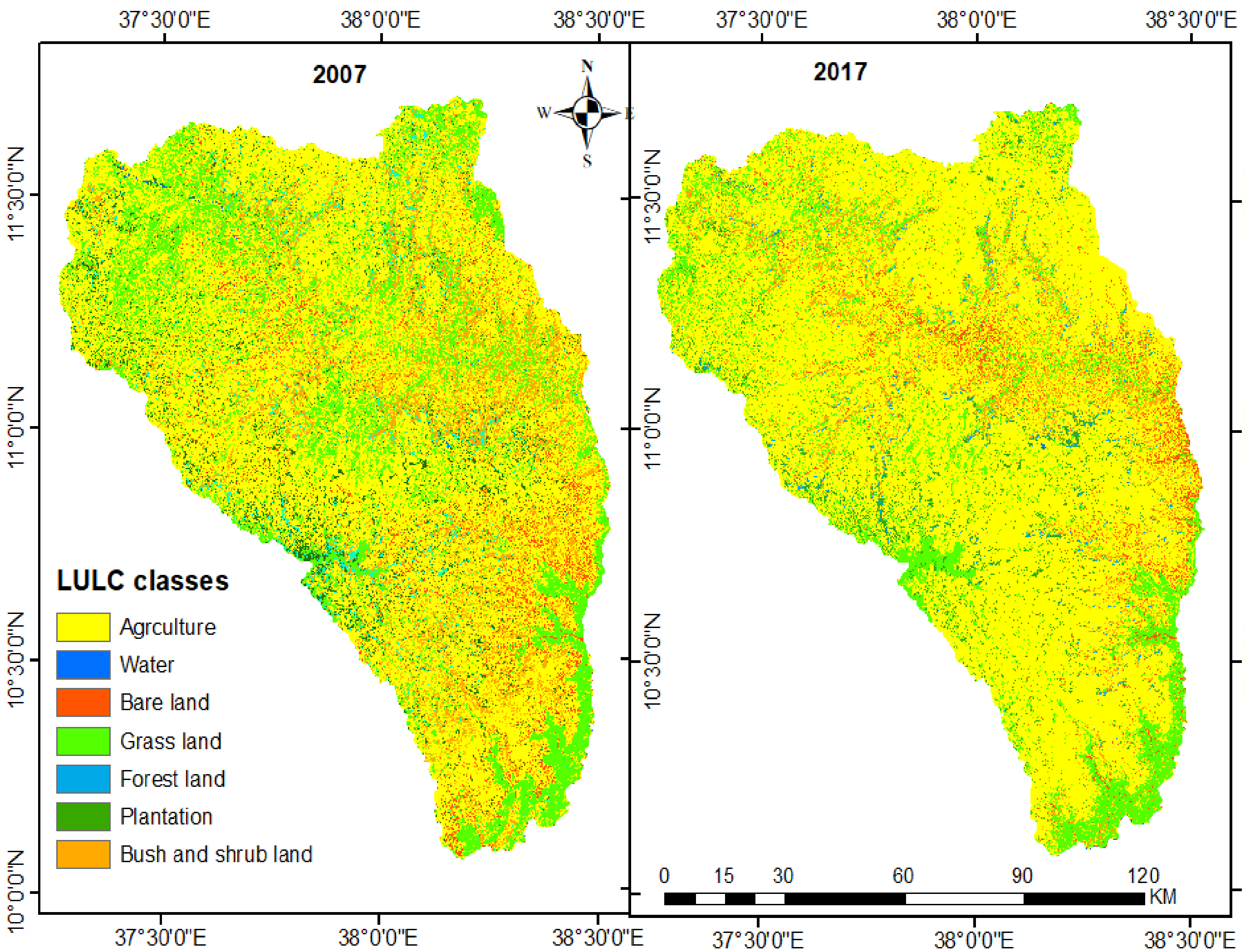

Figure 4.5. 2007 and 2017 LULC maps of the North Gojjam sub-basin.

Table 4.4: LULC distribution of the North Gojjam sub-basin for 1986, 1994, 2007, and 2017**.**

LULC	1986		1994		2007		2017	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area(ha)	Area (%)	Area (ha)	Area(%)
AL	833,337.79	58.22	883,292.26	61.71	952,283.8	66.53	1,011,542.1	70.67
WB	1145.09	0.08	1288.22	0.09	1001.95	0.07	572.54	0.04
BL	45,230.98	3.16	37,931.04	2.65	23,474.30	1.64	41,652.58	2.91
GL	306,740.45	21.43	290,995.4	20.33	215,992.2	15.09	178,776.86	12.49
FL	41,652.58	2.91	30,201.70	2.11	32,348.74	2.26	29,629.15	2.07
PL	11,021.47	0.77	22,615.49	1.58	47,807.42	3.34	51,672.10	3.61
BSL	192,231.65	13.43	165,178.9	11.54	158,451.5	11.07	117,514.66	8.21
Total	1,431,360	100	1,431,360	100	1,431,360	100	1,431,360	100

Note: AL= agriculture land and settlement, WB = waterbody, FL = forest land, BSL = bush and shrub land, GL = grassland, PL = plantation, BL = bare land.

However, other LULC types declined in areal size in the reference period. The areal size of natural vegetation and grazing land substantially declined from their original sizes (forest from 2.9 to 2% with a trend of 28.87% and annually by 1.1% rate and shrubland cover from 13.4 to 8.2% with 38.87% trend and 1.59% in each year; grazing land from 21.4 to 12.5% (Table 4.4). Local respondents also confirmed that grassland cover has consistently declined for the last three decades in favor of agriculture and buildings. According to them, communal grazing land cover has been converted to cropland, institutions (offices, schools, churches, and health centers), and rural towns. The decline in barren land was attributed to rehabilitation measures. Even though ponds in the sub-basin have been built, water bodies have experienced a reduction over the last 31 years. Local people also confirmed that water bodies have been declining in number and noted the disappearance and shrinkage of springs, streams, and swamps in the sub-basin. This could be due to a reduction in hydrological base flow associated with reductions in natural forest cover in favor of agricultural lands and with increases in water-hungry eucalyptus plantations.

Table 4.5. Magnitude and trend of LULC in the North Gojjam sub-basin.

LULC	The magnitude of LULC Change in a Hectare				LULC Change (Trend) in %				Annual rate of LULC change (1986– 2017)
	1986–1994	1994–2007	2007–2017	1986–2017	1986–1994	1994–2007	2007–2017	1986–2017	
AL	49,954.46	68,991.55	59,258.30	178,204.32	5.99	14.27	6.22	21.38	0.63
WB	143.14	−286.27	−429.41	−572.54	12.50	−12.50	−42.86	−50.00	-2.24
BL	−7299.94	−14,456.74	18,178.27	−3578.40	−16.14	−48.10	77.44	−7.91	-0.27
GR	−15,744.96	−75,003.26	−37,215.36	−127,963.58	−5.13	−29.58	−17.23	−41.72	-1.74
FL	−11,450.88	2147.04	−2719.58	−12,023.42	−27.49	7.11	−8.41	−28.87	-1.10
PL	11,594.02	25,191.94	3864.67	40,650.62	105.19	333.77	8.08	368.83	4.98
BSL	−27,052.70	−6727.39	−40,936.90	−74,716.99	−14.07	−17.57	−25.84	−38.87	-1.59

Note: AL = agriculture land and settlement, WB= waterbody, FL = forest land, BSL = bush and shrub land, GL = grazing land, PL=plantation, BL = bare land.

Generally, in the whole period, LULC change analysis of the North Gojjam sub-basin for the last 31 years (1986–2017) shows a dynamic landscape change (Tables 4.4 and 4.5). The results show that removal of natural vegetation, and cropland and settlement expansion due to deforestation, poor grazing, misuse of land management technologies, using biomass for fuel, rugged topography, and erratic rainfall. Deforestation is among the key drivers of natural vegetation degradation in the sub-basin, particularly in the middle parts of the sub-basin because of the expansion of agricultural land to hillside-like areas in Ethiopia (Oo et al., 2017). Agriculture and grazing land constituted the main land cover types, though the former has been by far the most dominant cover from 1986 to 2017. Of the total area of the sub-basin, agriculture shared about 58.2% in 1986 and 70.7% in 2017 and with 21.38% trend and 0.63% annual rate of change. Similarly, plantation forest cover increased more than threefold from its original amount, though eucalyptus plantations were the dominant type. In contrast, other LULC types showed a decreasing trend during this period: water bodies, bare land, grazing land, forest land, and bush and shrubland. Dense forest has diminished and is currently observed in churches, riverbanks, and hillside areas. Studies conducted in different parts of the upper Blue Nile of Ethiopia also showed consistent results with this study-for example, Gebrehiwot et al. (2012) in Birr and the Upper-Didesa watershed, (Gashaw et al., 2017) in the Andassa watershed, and Dibaba et al. (2020) in Fincha catchment. Additionally, Birhanu et al. (2019) found an increase in farmland when compared with other land use types in the Ethiopian highlands. However, in contrast to our findings, Bewket (2003) observed a rapid increase in forest cover in the Chemoga Watershed.

4.3.2.3. Gain, Loss, and Persistence Quantity of LULC Change

In the last 31 years (1986–2017), almost all LULC classes experienced some degree of change in the North Gojjam sub-basin (Table 4.6). In the entire study period, about 50.7% of the area that was covered with agricultural land in 1986 persisted in 2017 followed by grazing land (6.8%), bush and shrubland (5.5%), natural forest (1.2%), bare land (0.8%), plantation forest (0.4%) and water bodies (0.02%) (Table 4.6). The majority of agricultural land that was lost was converted to grazing land and plantations. Conversely, much of the land added to cropland was from grassland, bush and shrubland, and barren land.

The largest gross increase in agricultural land (17.2%) was observed between 1994 and 2007 with the establishment of the Ethiopian People's Democratic Revolutionary Front (EPDRF), followed by grazing land (5.6%) from 1986 to 1994 (Table 4.6). The highest gross loss was observed for grazing land (12.8%) from the period 1994 to 2007, followed by agriculture (12.4%) during the period from 2007 to 2017 (Appendix, Table A). Generally, the results show that the gain in the area of agriculture was nearly three times greater than the loss and much of the expansion came through encroachment on grazing lands. Land that was previously crop agriculture land most frequently changed to grazing land and plantation forests.

In the study period, about 3.6% plantation cover was gained from other LULCs, mainly from cropland and bush and shrubland (Table 4.6). This shows that most plantation expansions took place on cropland over the last three decades, but that some also encroached on lands previously covered with natural vegetation.

Table 4.7: LULC transition matrices of the North Gojjam sub-basin from 1986 to 2017

LULC	CS	WB	BR	GL	FL	PL	BSL	Total	Loss	T_c	N_c	S	G_p	L_p
AL	50.69	0.01	1.12	3.23	0.17	1.64	1.36	58.22	7.53	27.51	12.45	15.06	0.39	0.15
WB	0.02	0.02	0.01	0.00	0.02	0.00	0.01	0.08	0.06	0.08	0.04	0.04	1.00	3.00
BL	2.11	0.01	0.81	0.03	0.01	0.00	0.19	3.16	2.35	4.43	0.27	4.16	2.57	2.90
GL	12.67	0.00	0.83	6.87	0.03	0.60	0.42	21.43	14.56	20.18	8.94	11.24	0.82	2.12
FL	0.41	0.00	0.00	0.38	1.16	0.40	0.56	2.91	1.75	2.67	0.83	1.84	0.79	1.51
PL	0.30	0.00	0.00	0.02	0.05	0.35	0.15	0.77	0.42	3.69	2.85	0.84	9.34	1.20
BSL	4.47	0.00	0.12	1.96	0.64	0.73	5.53	13.43	7.90	10.59	5.21	5.38	0.49	1.43
Total	70.67	0.04	2.89	12.49	2.08	3.62	8.22	100.00	34.57	34.57	15.30	19.27		
Gain	19.98	0.02	2.08	5.62	0.92	3.27	2.69	34.58						

Note: AL = agriculture land and settlement, WB = waterbody, FL = forest cover, BSL = bush and shrub land, GL = grazing land, PL = plantation, BL = bare land, Tc = total change, N_c = net loss, S = swap, $L_p = loss\ to\ persistence, G_p = gain\ to\ persistence$.

Overall, land cover persistence was 65.1%, 63.8%, and 66.9% of the landscape for the periods 1986–1994, 1994–2007, and 2007–2017, respectively (Appendix 4.1 Table A). Over the entire study period (1986–2017), nearly 65.4% of the landscape did not experience LULC change, and 34.6% of the area showed a transition from one LULC class to another. Of this, about 15.3% is attributable to net change, while 19.3% is due to swap change. This implies that the wide range of LULC conversions occurred on agriculture land and grazing land use types. Similarly, Teferi et al. (2013) reported that the highest gain of agriculture land was obtained from grazing and shrubland from 1972 to 2009 in the Jedeb watershed (Table 4.6). These findings suggest that during the study period, agriculture land cover was the most dominant in terms of persistence, followed by grassland land cover. But, this dominance may be attributable to the fact that agricultural land is represented by the highest proportion in the studied landscape. Similarly, the highest gain in the landscape was occupied by agricultural land followed by grassland, but the highest loss was under grazing land cover followed by cultivated land when compared to other LULC classes in the landscape.

4.3.2.4. LULC Vulnerability to Change

The vulnerability of individual land use/cover class to change was calculated via the gain-to-persistence (G_p) and the loss to persistence ratio (L_p) (Ouedraogo et al. 2010; Zewdie and Csaplovies 2017). The vulnerability status of land-cover classes to transition during the study period (1986 -2017) is shown in Table 8. The outcome shows, plantation forest, and bare land covers had greater than one G_p ratio value, but not have other LULC types in the landscape. This implies that plantation forests and bare land cover had the tendency to increase the extent of the size compared to the original area of 1986. On the other hand, all other land use/cover classes had a value of below one, confirmed that the extent of the extra area is less than the area of their persistent extent from its origin. In contrast, all land cover classes exception of agricultural land had a L_p ratio value greater than one (Table 4.7). This indicated that most land use/cover classes had a higher trend to lose than persist in the north Gojjam sub basin during the study period. However, agriculture land revealed a tendency to continue or gain instead of losing. From there, it can conclude that agricultural land cover is the most stable in the landscape while the highest change was observed on plantation forest relative to its original size cover of the categories.

4.3.2.5. Net Change and Swap of LULC

Swap, net change, and total land use/cover change were calculated based on the change matrix result from the period of 1986 to 2017 (Table 4.6). Thus, change as a result of consideration simultaneous gain and loss in different locations (swap) were highest for agricultural land (16%), followed by grazing land (11.3%) in the sub-basin. Likewise, change related to the quantity of net change was highest for agricultural land (12.5%) followed by grassland (9%) and bush and shrubland (5.2%) in the sub-basin. Similarly, the change attributed to swap and net change accounted for about 19.3% and 15.3%, respectively, for the last 31 years (Table 4.6). Moreover, the highest total change was observed on agricultural land (27.5%) followed by grassland (20.2%) and bush and shrubland (11%), and the observed total change was about 34.6%, providing both swap change and net change, which are vital to recognize the total transitions within the landscape (Table 4.6). The results imply that all LULC classes of the landscape experienced both swap and net change in the sub-basin over the last 31 years. The change attributable to quantity (net change) was lower than the change as a result of shifting location (swap change) of the landscape. Most of the changes associated with agricultural land expansion may be from the largest class in the landscape. The findings of this paper are consistent with those of Teferi et al. (2013) and Zewdie and Csaplovics (2016).

4.3.2.6. LULC Change Distribution Across Altitude

In the North Gojjam sub-basin, there was a distinct relationship between LULC distribution and altitude difference. In both study periods (1986 and 2017), agriculture was the most dominant land use/cover type within the 1500-3500m elevation range. This shows that the proportion of agriculture was higher in the middle altitude, likely reflecting the suitability of these lands for crop production and settlement. The size of agricultural land cover increased in all altitude ranges for the period from 1986 to 2017 in the sub-basin; however, the conversion rate was higher above 3500m elevation (Table 4.7). Between 1500 and 3500m elevation. Grazing land cover was the second dominant land cover type after agriculture. During the study period, the proportion of grazing land cover decreased up to 3500 m altitude, but it increased above this elevation (Table 4.7). The highest grassland cover conversion was observed between 2500 and 3000 m elevation in the two study periods (Table 4.7). Generally, the results show that grazing land areas are mostly located in the lower and upper parts of the sub-basin, because the regions are quite rugged and not suitable for crop production and settlements.

The distribution of plantation forest was more concentrated in the upper parts of the sub-basin, above 3000 m altitude. Over the last 31 years, plantation forest cover has shown an increasing trend with different magnitudes across all elevation ranges below 3500 m, with particularly strong trends in the 2500–3500 m range (Table 4.7). Its cover expanded by more than six-fold during the reference years because of a decline in crop productivity in these areas. The proportion of bush and shrubland cover showed decreasing trends in all elevation ranges in the reference study periods, except for the 1500–2000 m elevation range. These decreases are most commonly associated with agriculture expansion in the middle of the sub-basin and overgrazing in the upper parts. The highest chance to other land use was observed in the altitude range of from 3000 to 3500 m (Table 4.7). In part, this could be related to the fact that at lower elevations, the ratio of bush and shrubland cover was higher as compared to natural and plantation forest covers due to climate limitations on forest growth and the distance of some of these lands from settlements. Similarly, the size of bare land is greatest in the low land area (below 1500 m elevation) due to high soil erosion and shallow soil characteristics in this area. The bare land class decreased with increasing elevation in the sub-basin (Table 4.7). Over the last 31 years, waterbodies recorded the lowest areal extent in all elevation ranges and showed a decreasing trend across the elevations during the study period. This result is similar to the finding of (Birhane, Ashfare, Almaw, & Hishe, 2018), who found that the proportion of forest cover is lower than bush and shrubland covers in lower altitudes in Hugumburda national forest, northern Ethiopia. However, our result is similar to other findings of Birhanu et al. (2019), who reported that farmlands were mostly located in the study area with 2000–2500 m of elevation in Ethiopian highlands.

4.3.2.7. LULC Distributions and Changes Along Slopes

The spatial distribution and areal changes of LULC have a strong association with the slope in the North Gojjam sub-basin. More or less all of the LULC types were found across all six slope classes with different proportions in the years 1986 and 2017. Agriculture was the dominant cover type followed by grazing land in all slope classes during the study period. However, the highest cultivated land ratio was observed on very gentle (0–5%) and gentle (5–10%) sloped landscapes. Agriculture increased with a decreasing rate across the slope gradient over the last three decades. Comparably, an increase in agriculture was mainly observed in the 0–5% and 5–10% slope classes (Table 4.7). The results show that the expansion of agriculture covers is relatively higher in gentle and moderate slopes than in very steep slope gradients in the sub-basin. On the other hand, bare land decreased in almost all slope classes, but not above the 50% slope class gradient, where the higher expansion of farmland was observed. This may be due to high soil erosion in very sloped areas. In contrast, grazing land area generally decreased in all slope classes. Conversion of grazing land to others was higher in very gentle (0–5%) and gentle (5–10%) slope classes due to it being occupied by cropland and settlements (Table 4.7). In the course of the study period, grazing land decreased in all slope classes. Comparably, a decrease was mainly observed in 0–5% and 5–10% slope gradients (Table 4.7).

Plantation forests were more commonly located in higher slope classes, particularly above the 20% slope gradient. During the last 31 years, while plantation forests increased in number, mainly above the regions of the 20% slope gradient, the rate of increase was more than four-fold in this elevation range. This implies that plantation forests consistently increased with the increasing rate of the slope gradient over the last 31 years. This shows that communities in the study area generally plant trees on steep slopes due to soil erosion and low productivity of the land. Similarly, natural forest cover was mainly located at quite rugged landscapes and above 50% slope values, which are not suitable for cultivation. However, the highest regeneration of forest was common in the steep slope gradient (0–20% value) areas, while conversion to other land uses was higher in the steep areas (20–100% value) during the study period (Table 4.7).

In general, the result shows that dense forest area was found on steep and very steep slope land, which is an unsuitable area for settlement, agricultural activity, and grazing. On the other hand, higher concentrations of bush and shrublands were located in higher slope gradient areas, mainly in very extreme steep slope areas in both study periods. Moreover, bush and shrubland cover decreased at the 50–100% slope gradients, but a higher conversion was observed at the 20–30% slope gradient (Table 4.7) due to farmland expansion. In general, in the sub-basin, agriculture and grazing land patterns showed fluctuating trends in all slope classes, but all vegetation covers (i.e., planation, forest, bush, and shrubland) showed an increasing pattern with an increasing slope gradient, while agriculture, waterbody and bare land covers declined.

The lowest area in all slope ranges was recorded for the size of water bodies. Similarly, a consistent increase rate of change was observed for plantation forests, while a consistent decrement rate was observed for grazing land cover across all slope gradients between 1986 and 2017. This study asserts that LULC change was significantly determined by slope inclination differences in the study area. The results of this study are in line with the study conducted by Birhane et al. (2018), who reported that slope inclination is a major driving force of LULC changes in Hugumburda national forest, northern Ethiopian highlands. A similar result was also reported by Zeleke and Hurni (2001), in which cultivation land expanded to marginal areas as steep as >30% in the northwestern Ethiopian Highlands. The increase in forests can be observed to occur in steep slopes more than in other land uses, which may be because these areas are inaccessible to human activities, unlike the moderate and gentle slope gradients. In contrast, (Kindu et al., 2013) noted that forests declined by half from about 63% in 1973 to 32% in 2012 on steep slopes in Munessa-Shashemene, Ethiopian highlands.

Table 4.7: Percentage changes in LULC along an altitudinal and slope between 1986 and 2017.

LULC Class	Altitudinal Range (m)						Slope (%)					
	<1500	1500–2000	2000–2500	2500–3000	3000–3500	>3500	0–5	5–10	10–20	20–30	30–50	>50
AL	8.03	15.07	16.20	30.90	32.72	124.9	25.7	24.99	22.73	19.00	14.63	7.89
WB	−85.5	−57.7	−17.0	34.42	−82.35	0.00	−52.8	−46.3	−49.5	−52.0	−69.9	−92.4
BL	63.14	−15.1	−45.1	−9.34	4612.0	22.52	−38.6	−33.8	−17.6	−3.23	−4.00	3.17
GL	−1.83	−32.8	−50.6	−74.1	−55.23	14.40	−57.0	−56.9	−52.9	−41.0	−30.4	−24.4
FL	30.15	−6.99	0.03	11.42	−58.68	−92.2	329	1.03	21.51	−38.1	−20.7	−26.7
PL	56.53	121.4	155.6	552.6	670.28	273.2	49.1	97.38	253.1	465.0	499.3	558.7
BSL	−31.3	5.88	−34.1	−75.1	−89.30	−99.8	−67.7	−66.6	−4.74	−45.7	−22.3	5.14

Note: AL = agriculture and settlement, WB = waterbody, FL = forest land, BSL = bush and shrub land, GL = grazing land, PL = plantation, BL = bare land.

4.3.3. Local Perceptions Compared to Satellite Mapping

Overall, the qualitative land cover change narratives reported by locals and the quantitative remote sensing approach yield generally similar results. This enhances our confidence in both methods. Given the similarity of the results, the advantages of using the remote sensing method are its spatial completeness, quantitative nature, and objectivity. However, this approach includes some sources of error and gives no information on why changes have occurred (Kleemann et al., 2017). In contrast, the reasons behind LULC changes were explained in depth by local land users, and the types of drivers that are more likely to cause change were also identified via interaction with the local land users. For example, local land users provided an in-depth explanation as to why grazing land changed to cultivated land and why dense forests are located at riverbanks and hillsides in the sub-basin. This implies that the limited remote sensing quantitative data can be triangulated by qualitative data from local land users' knowledge. In this study, the advantages of multi-temporal remote sensing data over local perception were the ability to quantify the extent, rate, and spatiotemporal pattern of LULC change numerically. But, the local viewpoint method permitted the in-depth discussion of why these processes happened during the specified study period. Therefore, the advantages of local knowledge allow for the identification of the key drivers of LULC change, mainly indirect drivers which cannot be easily determined by geospatial analysis. Using local viewpoints, the key drivers of LULC were ranked from the most to least observed in the study area. Geospatial methods assist the analysis of LULC dynamics in less time and with low costs in the entire sub-basin. However, local perception is time-consuming and limited to the specific local areas that farmers become aware of over their lifetime. This implies that studies from local interviews are mainly locally specific, which can cause bias in the analysis of a large study area over long time intervals.

4.3.4. Indirect Driving Forces of LULC Change

Indirect driving forces for LULC change in Ethiopia are varied and context-specific. Such driving forces concern both human and natural drivers (Berry et al., 2003). However, rapid population growth is significantly related to the increasing demand for scarce land resources (Berry et al., 2003; Hailu et al., 2015; Kirui, 2016a). The population in the North Gojjam sub-basin has increased. Likewise, the official district population data for the sub-basin and surrounding villages show a population increase of from 2,705,913 in 1994 to 3,565,892 in 2016 (CSA,1994; CSA 2015). Reflecting this trend, FDG participants and key informants in interviews confirmed population increase as the main root cause of natural resource changes in the North Gojjam sub-basin (Figure 4.6). As a result of continuous population growth, farmland owned by the parents is continuously divided by the number of descendants before or after their death, and, thus, land fragmentation increases, but its size decreases. Population growth has resulted in resource scarcity and has furthered natural resource degradation in the sub-basin. Further, it results in agriculture land encroachment at the expense of forest land, rangeland, bush, and shrubland in the sub-basin. Natural forests have also been lost due to increased demands for firewood, building materials, and other household furniture and farm equipment. Government redistribution of communal grazing land for landless youths is the major cause of the reduction of grazing land to agricultural land. Our results are in agreement with those of recent studies focusing on other parts of Ethiopia, which have indicated that population growth is the most influential factor in LULC change (Bewket, 2003; Gebru, 2016; CSA,1994); however, this conclusion is not similar to the findings of Shimeles (2012).

In Ethiopia, the majority of rural communities are poor and depend on mixed subsistence crop-livestock farming systems, biomass fuel energy, and the inability to invest in livelihood diversification strategies (Berry et al., 2003; Dibala et al.,2019). Similarly, poverty is the second root cause of LULC change in the North Gojjam sub-basin (Figure 4. 6). The majority of the population in the sub-basin depends on mixed subsistence crop-livestock farming systems supplement by the sale of forest products. Many of the inhabitants of this area borrow money from Amhara Microfinance (ACSI), and they have no alternative household energy sources to substitute biomass fuel. The livelihoods of many poor people depend on selling firewood, dung cake, and charcoal. The majority of local people were not aware of the impact of natural resource degradation. As a result of this, there is high vegetation cover conversion in the sub-basin, while there is a significant scarcity of natural vegetation cover. These results are similar to those of the study conducted in the Bale Mountain by Hailemariam et al. (2016) and in the Gog district, Gambella region by Oo et al. (2019) in Ethiopia.

Low implementation of environmental rules and extension services are other factors of ecosystem service change in the North Gojjam sub-basin. Evidence from local respondents shows that there was considerable weakness in implementing environmental law and extension services at ground level in the sub-basin. Agricultural activity still depends on rain feed as well as low input and output due to lack of improved seed varieties and fertilizer accessibility and water for irrigation. Improved livestock herds and feeding systems also remain of poor quality. Moreover, there are no well-organized off-farm activities, such as beekeeping or poultry farming, to integrate landless youths and to decrease population pressure on land by extension service staff. Similarly, about 59.8% of FGD respondents ranked this issue in third place as it is an underlying cause of LULC change in their locality (Figure 4. 6). Weak law enforcement, on the other hand, was a significant indirect driver of LULC change in the study area and was ranked by 43.3% of FGD participants in fifth place. From the discussion, it was observed that key indicators, such as illegal logging, charcoal making, free grazing, and firewood collection from the natural forest were not implemented, as there were restrictions, rules, and regulations in place in the sample districts.

Local land users confirmed that infrastructure expansions such as schools, health centers, churches, roads, and offices caused the conversion of communal grazing land into settlements over the last few decades in the study area. Moreover, one interviewee argued that gravel road accessibility and better market opportunities for firewood, charcoal, timber and timber products, and agricultural outputs facilitate land cover change in the study area. Furthermore, as observed during the field survey and confirmed in the interview, eucalyptus forest expansion is highly dependent on road and market accessibility in the study area.

Many changes have been observed in land ownership in Ethiopia, which continues to provide uncertainty to land users. The traditional feudal system was followed by a communal form of government ownership and policies regarding the security of tenure and land resource rights remain to confuse the regional level (Berry et al., 2003). According to these authors, land tenure arrangement influences Ethiopian farmers' decisions concerning land management to whether the land is managed privately or communally; the ability to manage the land; and the ability to transfer land by sale, lease, or bequest. Similarly, key informants highlighted that, historically, land tenure insecurity was one of the drivers of land degradation in the study area. However, in current time, land tenure insecurity is not much of a problem about land management, except communal (grazing and woodlands) lands, as they obtained land certification card.

The findings of this study suggest that unless driving forces and pressures are ceased, LULC change in this sub-basin will continue and further contribute to land degradation. This could be a major threat to agricultural sector development and also a potential threat to environmental sustainability and the balance of ecosystems in general, as well as the biodiversity of the study area in particular. Moreover, the fact that the study area is located in the transboundary upper Blue Nile basin emphasizes the fact that the prevailing LULC change and associated problems observed in the area have environmental implications for other communities and at the regional, national, and international levels. Finally, this study has highlighted integrated use of remote sensing and GIS technologies with land users is important for the triangulation of their relationship, and it has emphasized the importance of increasing the robustness of quantitative information regarding remote sensing with quantitative local viewpoints to improve our understanding of the process of land LULC change.

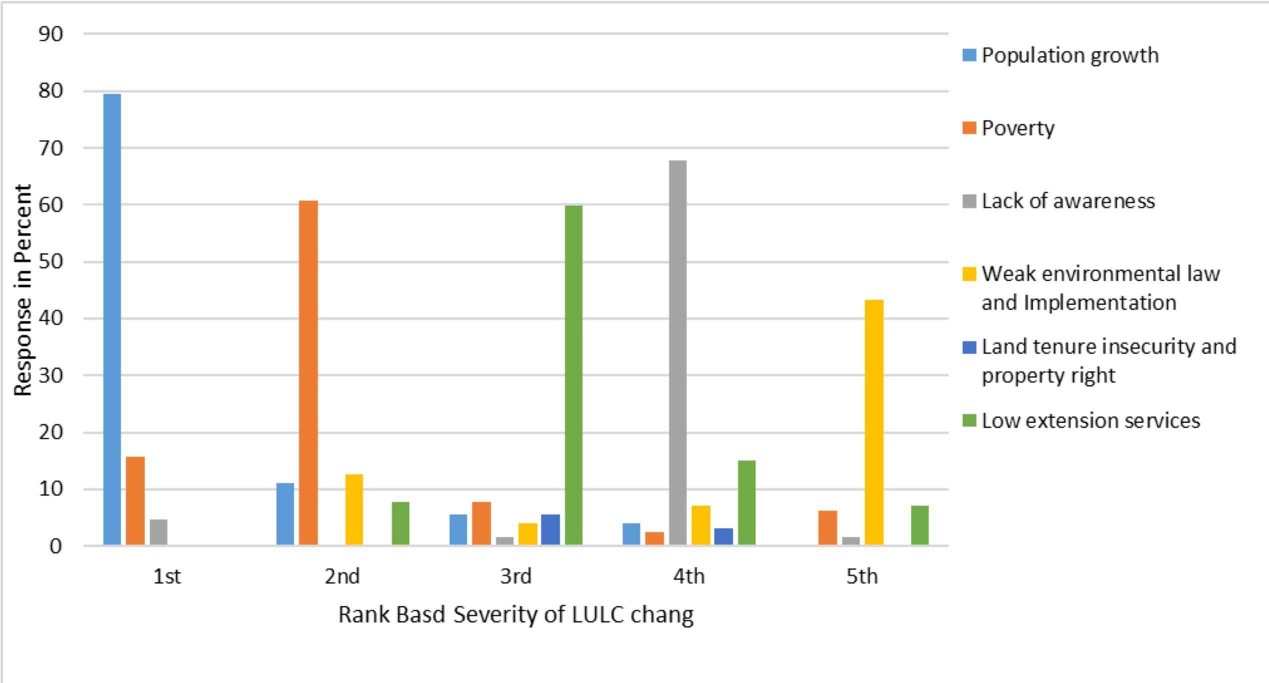

Figure 4.6. Indirect drivers of LULC change in the North Gojjam sub-basin.

4.4. Conclusions and Policy Implications

LULC change is increasingly a matter of concern in the current ecosystem services associated researches and development agenda attributable to its effect on ecosystem integrity and productivity. It is also an essential part of global environmental dynamics and a starting point for biophysical assessment efforts. Up-to-date holistic information about the condition of LULC and the drivers helps minimize the wrong utilization of natural resources and creating policies for resources management. As a result, this paper identified the extent, pattern, and rate of LULC change and their driving forces to change in the north Gojjam sub-basin, at the source region of the upper Blue Nile river using a mixed approach of remote sensing image and local knowledge.

The study confirmed seven main LULC types in the sub-basin included agricultural land, bare land, waterbody, grazing land, natural forest, plantation forest, and bush and shrubland. The study found that the sub-basin has experienced significant LULC changes for the last 31 years. In all study periods, agriculture land cover was the dominant followed by grazing land, but the former has been by far the largest coverage. Of the total area of the basin, agricultural land shared about 58.2% in 1986, and 70.7% in 2017. During the study period, the grazing land cover size was continuously reduced and corresponding to mixed rate was observed in the forest, and bush and shrubland, barren land, and waterbody. Forest land has declined almost by half during the study period. Similarly, one-fourth of bush and shrubland have been converted to other LULC types. Plantation forest has been increased by more than threefold from its original size, though, the eucalyptus tree was dominant, particularly in the upper part of the sub-basin. But, the benefits of eucalyptus plantation may not always positive in the long run to ensure sustainable agriculture and ecological rehabilitation in the study area because eucalyptus has several ecological negative effects (FAO,1988).

In the entire study period, agricultural land experienced the highest gain (20%), while grassland revealed the highest loss (14.6%). Most stability and persistence were observed on the agricultural land cover in the landscape. About 34.6% of the landscape area experienced a transition over the last 31 years, out of this 15.3% attributable to the net change while 19.3% attributable to swap change in the sub-basin.

Topography is determined the special distribution and areal change of LULC change in the study area. Natural forest and plantation covers are significantly increased across all elevation ranges and slope gradients. Agriculture cover, on the other hand, was highly located on gentle and moderate slopes areas in the reference periods (1986-2017). A high proportion of bush and shrubland and bare land were located in lower altitude and steep slope land areas. A high concentration of grazing land was located in the upper and lower altitude range in the study area.

Local land users confirmed LULC changes were driven by several factors in the north Gojjam sub-basin; the most cited pressures were; removal of natural vegetation, cropland and settlement expansion, poor grazing, misuse of land management technologies, using biomass for fuel, topography, and erratic rainfall. According to local viewpoints, the root causes which triggered LULC change pressures were population growth, poverty, weak enforcement of rules and low level of extension service, lack of awareness and infrastructure. The key causes for agricultural and settlement land expansion are the rise of population numbers by natural increase. Population growth causes cultivated land and other natural resources scarcity in the sub-basin and that in turn results in serious land degradation and persistent poverty.

The finding of this study shows that mixed approach-remote sensing and survey methods provide a holistic analysis of qualitative and quantitative data of LULC change and, their direct and indirect driving forces of changes. This approach permits to complement of the remote sensing data and local knowledge to validate and compensate the methodological weaknesses of one method through the strengths of another method in the biophysical assessment for further policy intervention.

The findings of this study suggest that unless driving forces and pressures are ceased, LULC change continuously and resulting to further land degradation in general and ecosystem service in particular in the sub-basin. Otherwise, the available limited natural resources will soon be lost and no longer be able to play their role in the socio-economic development of the area and challenged to rehabilitate to the former condition. This could be a major threat to the agricultural sector development and also be a potential threat to the environmental sustainability and balance of ecosystems in general and biodiversity of the area in particular. Moreover, it is very important to understand, that the prevailing LULC change and associated problems observed in the study area have environmental implications to other local, regional, national and international levels because the consequence of such environmental change has no boundaries.

5. Mapping and Quantifying Comprehensive Land Degradation Status Using Spatial Multicriteria Evaluation Technique in the Headwaters Area of Upper Blue Nile River

Abstract

Mapping and quantifying land degradation status is important for identifying vulnerable areas and to design sustainable landscape management. This study maps and quantifies land degradation status in the north Gojjam sub-basin of the Upper Blue Nile River (Abbay) using GIS and remote sensing integrated with multicriteria analysis (MCA). This is accomplished using a combination of biological, physical, and chemical land degradation indicators to generate a comprehensive land degradation assessment. All indicators were standardized and weighted using analytical hierarchy and pairwise comparison techniques. About 45.3% of the sub-basin was found to experience high to very high soil loss risk, with an average soil loss of 46 t $ha^{-1}yr^{-1}$. More than half of the sub-basin was found to experience moderate to high level of biological degradation (low vegetation status and low soil organic matter level). In total, 80.2% of the area is characterized as having a moderate level of physical land degradation. Similarly, the status of chemical degradation for about 55.8% and 39% of the sub-basin was grouped as low and moderate, respectively. The combined spatial MCA of biological, chemical, and physical land degradation indicators showed that about 1.14%, 32%, 35.4%, and 30.5% of the sub-basin exhibited very low, low, moderate, and high degradation level, respectively. This study has concluded that soil erosion and high level of biological degradation are the most important indicators of land degradation in the north Gojjam sub-basin. Hence, the study suggests the need for integrated land management practices to reduce land degradation, enhance the soil organic matter content, and increase the vegetation cover in the sub-basin.

Keywords: Comprehensive land degradation; soil loss; GIS; MCA; Upper Blue Nile

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5.1. Introduction

Land is a critical natural resource for human survival and the base for all terrestrial ecosystem services. Healthy land quality is vital for sustainable development, including food security and improved livelihoods (Nkonya et al., 2013), serving as a key factor in many production processes and economic growth (Sadik-zada, 2020). Unsustainable use of land resources, however, results in degradation of land quality and quantity (Nkonya et al., 2013). Land degradation here primarily refers to the loss of life-supporting land resources through a mix of processes that include soil erosion, soil compaction, destruction of soil structure, loss of soil organic matter, loss of vegetation cover, desertification, salinization, and acidification (Le et al., 2016; El-gammal et al., 2015). Land degradation reduces the economic value of ecosystem services and goods derived from land resource bases (ELD, 2013). It has become a problem of great concern due to its impacts on food production, water supply, energy supply, and ecosystem services as a whole. According to the United Nations Convention to Combat Desertification (UNCCD), about 25% of the total land area of our planet Earth is severely degraded or undergoing degradation (UNCCD, 2015). Africa is the continent most severely affected by land degradation (Nellemann, 2009). According to the estimates made by the UNCCD (2013b), land degradation affects up to two-thirds of the productive land area in Africa. In Ethiopia specifically, land degradation is a chronic and ongoing problem (Berry et al., 2003; Hurni et al., 2010; Zeleke and Hurni, 2001). More than 85% of country's landmass is degraded to a various degree (Gebreselassie et al., 2016) due to population pressure, persistent poverty, rugged topography, climatic condition, use of biomass for fuel, lack of awareness, and misuse of land management technologies (Berry et al., 2003; FAO, 1986; Hurni et al., 2010; Oo et al., 2017).

Deforestation is a continuing process of land degradation and results in local soil erosion, biodiversity loss, changes to hydrology and climate, and contributes to global climate change (Reusing et al., 2017). Forest covered about 40% of Ethiopia's land area at the beginning of the 20th century and reduced to 2.36% cover in 2000 (Gebru, 2016); however, recent evidence shows that forest cover has rebounded to 12% (Gashaw et al., 2014). Soil erosion is a highly visible form of land degradation in Ethiopia that has depleted topsoil for many years, primarily through water erosion (Esa et al., 2018; Haregeweyn et al., 2017; Meseret and Gangadhara, 2017; Molla and Sisheber, 2017). For example, it is estimated that northern Ethiopia has lost 45t $ha^{-1}yr^{-1}$ topsoil due to water erosion alone (Tamene et al., 2017). Estimates from northwestern Ethiopia indicate topsoil loss rates of 33.7t $ha^{-1}yr^{-1}$ (Belachew and Zuberi, 2015). Similarly, on average, about 27.5 t $ha^{-1}yr^{-1}$ topsoil resource is being eroded from the entire Upper Blue Nile (Abbay) basin (Haregeweyn et al., 2017). Besides, soil acidity has become a serious concern in the Ethiopian highlands in recent decades (Agegnehu and Yirga, 2019). The study area, North Gojjam sub-basin, is in the Ethiopian highlands and was historically well known to be an area of high potential for agricultural production (Zeleke and Hurni, 2001), but land resources of the area have been continuously degraded and the ecosystem productivity has declined at an alarming rate (Simane et al., 2016).

Mapping and quantifying land degradation status plays an important role in the cost-effective design of land management strategies. It enables researchers and land managers to identify the most vulnerable areas and to give priority to the locational intervention (Bewket and Teferi, 2009; Moore and Wilson, 1992). Evidence of land degradation assessment can be collected using myriad methods, such as questionnaires, focus group discussions, direct observation, and expert judgment (Lu et al., 2007). The application of remote sensing technologies has provided great opportunities to provide evidence of degradation over large areas at relatively low cost and time investment (Lu et al., 2007; Rahman et al., 2009).

The indicators of land quality degradation assessment include physical, biological, and chemical factors, as well as socio-economic changes (Chabrillat, 2014; FAO, 2004; Abdelrahman, 2018). Previous studies on mapping and quantifying land degradation have focused on the most visible forms of degradation, such as soil erosion and deforestation (Bewket and Teferi, 2009; Haregeweyn et al., 2017). In reality, a range of indicators of land degradation, including soil fertility status, soil acidity, salinization, and loss of vegetation cover also has to be considered to assess the level of land degradation (Rabia and Rabia, 2012). This multifactorial approach is necessary because the design of appropriate land management for sustainable development requires a holistic inventory and rating of vulnerable areas for degradation (FAO, 2004; Oldeman,1996), according to multiple risks and potential interventions. It is also important to update assessment regularly, as land degradation is a dynamic process that responds to coupled natural-human factors (Agyemang, 2012).

It can be challenging to integrate diverse degradation metrics that are obtained through different measurement techniques and are not always directly comparable to each other. Spatial multicriteria analysis (MCA) can be of considerable use in land degradation analysis. MCA methods are widely used for problems that involve multiple factors and multiple perspectives. In this study, a new approach for the development of a comprehensive land degradation map is proposed, in which remote sensing, GIS, analytical hierarchy process (AHP), and MCA techniques are applied to account for many factors responsible for land degradation. Specifically, the study aims to: (1) estimate average annual soil loss; (2) map and quantify key biological, physical, and chemical land degradation status; and (3) develop comprehensive land degradation indicators.

This study provides empirical evidence to policymakers and land users to identify specific areas vulnerable to land degradation as well as offering a comprehensive assessment of land degradation vulnerability in the north Gojjam sub-basin. This information is valuable for informing environmental rehabilitation activities and sustainable agriculture. The rest of the paper is organized as follows: Section 2 gives a brief overview of the study area and MCA procedures, along with a description of data; results are presented in Section 3; Section 4 concludes with the main findings of the paper.

5.2. Method and Materials

5.2.1. Nature and Data Sources

Landsat images were downloaded from the US Geological Survey (USGS) Earth Explorer (http://glovis.usgs.gov) for January, in the dry season, to obtain low cloud cover images. ASTER Global Digital Elevation Model (ASTER-GDEM) data were obtained from (http://gdex.cr.usgs.gov/gdex/). Currently, precipitation estimations based on satellite products have developed an alternative source of sparse rainfall gauge data for different hydrologic practices, mainly in limited data regions like Africa which suffer from a scarcity of surface monitoring resources. Among others, Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is commonly used in research (Abdelmoneim et al, 2020). For the present study, rainfall data from the years 2009-2017 were obtained from the CHIRPS website (https://www.che.ucsb.edu/data/chirps/). Gridded soil data with 250 m spatial resolution were downloaded from AFSIS) website[2].

[2] The soil data were downloaded from http://www.isric.org/content/african-soilgrids-250m-geotiffs

A total of 2500 ground truth data points for land use and land cover (LULC) classification and accuracy assessment were collected from the field based on in-situ field observation, with geolocation obtained using a handheld Garmin GPS instrument and from Google Earth using a time slider image. Of these total ground truth points, 738 were used for accuracy assessment of image classification using the error matrix, which allowed us to evaluate the kappa coefficient, overall accuracy, and the producer's and user's accuracy. To capture additional information, including qualitative perceptions from 18 focus group discussions (FGDs) and key interviews

5.2.2. Spatial Multi-Criteria Analysis (MCA)

Evaluating comprehensive land degradation is not a trivial task, because it includes a wide range of factors that can be challenging to combine into a single index. To address this challenge, MCA can be applied to a combination of geospatial datasets (Jaiswal et al., 2015). MCA is an evaluation technique that is used to identify vulnerable areas for sustainable natural resource management (Ananda and Herath, 2009; Belal et al., 2015; Jafari and Zaredar, 2010) by ranking or scoring the performance of decision options against multiple criteria (Hajkowicz, 2007). The MCA process includes several steps: describe objectives, select the criteria to measure the objectives, identify alternatives, renovate the criterion scales into commensurable units, assign weights to the criteria that reveal their relative importance, choose and apply a mathematical algorithm for ranking alternatives, choose an alternative, and combine criteria into a single index (Ananda & Herath, 2009; Belal et al., 2015; Hajkowicz, 2007; Jafari and Zaredar, 2010; Sałabun et al., 2016; Zolekar and Bhagat, 2015). Spatial MCA operates as a raster process on multiple digital input maps of relevance to land quality indicators.

Based on the nature of the alternatives to be evaluated, MCA methods can be classified into two major types: continuous and discrete (Orhan et al., 2003). Continuous methods are used to determine an optimal quantity, which can vary continuously in a decision problem (Jafari and Zaredar, 2010). On the other hand, discrete methods can be defined as decision support techniques that have a finite number of alternatives, a set of objectives and criteria by which the alternatives are to be judged, and a method of ranking alternatives depending on how well they satisfy the objectives and criteria (Saaty, 2001). Discrete methods can be further subdivided into weighting and ranking methods. These categories can be additionally subdivided into qualitative, quantitative, and mixed methods. Qualitative methods use only ordinal performance measures, while mixed qualitative and quantitative methods use different decision rules based on value and utility using mathematical functions (Saaty, 2001). The present study applied the discrete method because the indicators are finite and categorized.

There is a wide range of decision-making techniques in the MCA literature that are used to model complex problems (Khoshabi et al., 2020). The most common include analytic hierarchy process (AHP) (Saaty, 2008); technique for order of preference by similarity to ideal solution (TOPSIS) (Ashtiani et al., 2009); preference ranking organization method for enrichment evaluations (PROMETHEE) (Hajkowicz and Higgins, 2008); complex proportional assessment method (COPRAS) (Mihajlo et al.,2019); additive ratio assessment (ARAS); visekriterijumska optimizacija I kompromisno resenje (VIKOR) method (Bhushan and Rai, 2004; Mokhtarian et al., 2014); multi-attribute utility theory (MAUT) (Sarin, 2013); and others. However, these methods have been criticized due to an issue called the rank reversal problem (RRP). RR refers to a change in the ordering among alternatives previously defined, after the addition or removal of an alternative from the group previously ordered (Sałabun et al., 2016). The characteristic object's method (COMET) is completely free of the rank reversal paradox and can be used in exchange for the AHP method (Sałabun et al., 2016), but the most popular in the field of natural resource management is the AHP method. The theoretical foundations of AHP were developed by Saaty (2001). It is a prominent and powerful tool for making decisions in conditions relating to multiple objectives. The present study used the AHP method integrated with GIS. The integration of GIS and AHP is a powerful approach to identify the suitable areas for agriculture and vulnerable areas to land degradation (Ananda and Herath, 2009; Şener, 2010). The indicators of the study are not complex and, thus, are not subjected to the rank reversal problem as we analyzed manually.

Here we implement MCA in combination with an AHP that allows pairwise comparison and applies weights to each factor when merging to a single output index (Jafari & Zaredar, 2010). Three hierarchical levels were applied (Figure 5.1). In the first hierarchy, individual land degradation indicator raster maps were prepared based on international standard values which were developed by organizations and scientists. In the second hierarchical level, primary indicators are grouped into classes. Vegetation cover (Chabrillat, 2014) and soil organic matter (Oldeman, 1994) were grouped as biological land degradation indicator alternatives. Soil erosion (Nachtergaele et al., 2009), soil compaction (ASTM, 2001), soil drainage (USDA, 2008), and soil depth (USDA, 2015) were grouped as physical land degradation indicator alternatives. Soil acidity represented a single chemical land degradation indicator (Nachtergaele et al., 2009). These groupings yielded a biological degradation index, physical degradation index, and chemical degradation index alternatives. In the final hierarchical stage, these three grouped indicators are combined into a single inclusive land degradation index (Figure 5.1).

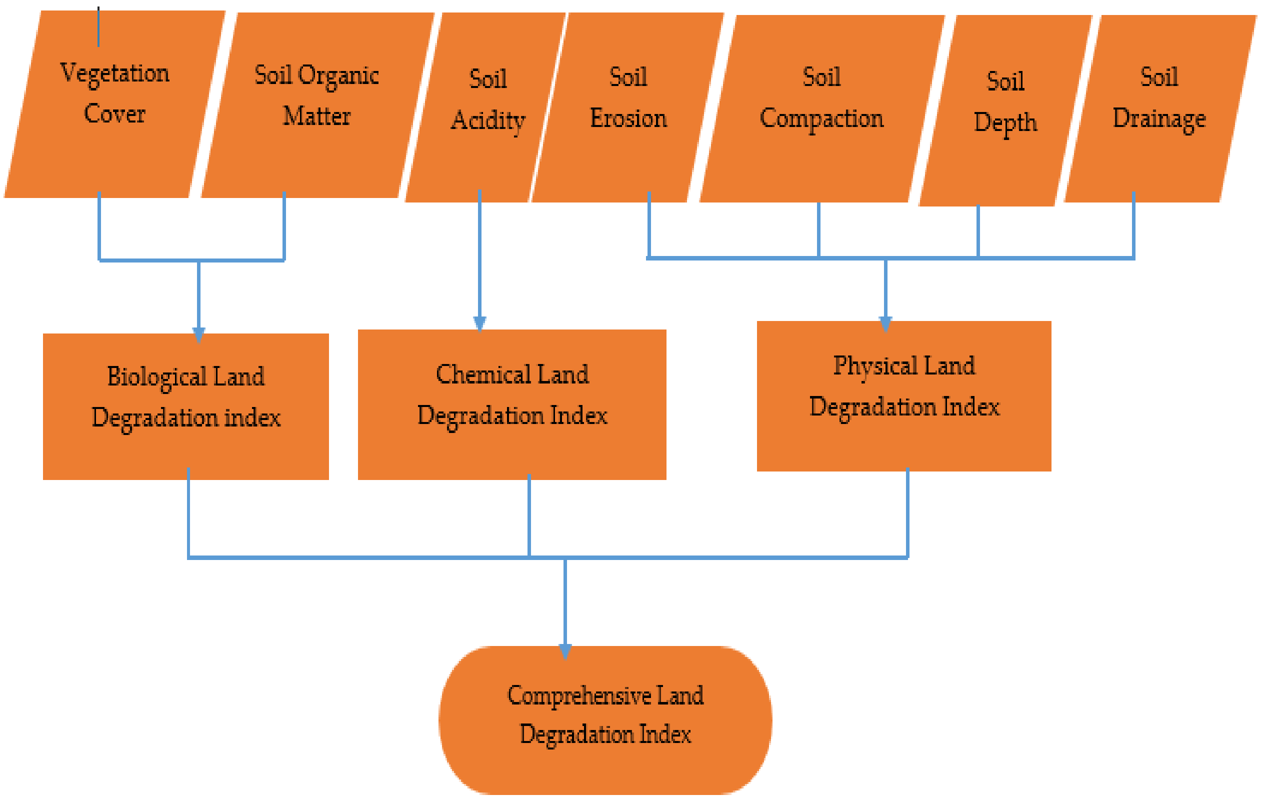

Figure 5.1 Hierarchical structures of land degradation status assessment model in MCA

MCA requires that the indicators be adjusted into similar units and a common value scale to make the comparison meaningful (Jafari and Zaredar, 2010). Value scaling/standardization, is a process of converting different indicators to a common unit and scale. In doing so, it possible to generate comparable alternatives according to their perceived relevance (Carver and Carver, 2007).

Linear scale transformation is the most commonly used method for criteria standardization in spatial MCA (Eastman, 2012), and it is applied here for ease of interpretation. All criteria were standardized and then scaled to a value range from 1 to 5, representing a very low to very high degradation level. There are three common weighting methods in spatial MCA: ranking, rating, and pairwise comparison (Malczewski, 2007; Prasad and Kousalya, 2017). Of these, the pairwise comparison method is most widely used in spatial MCA to estimate the overall weight of individual criteria (Saaty, 1980), and we apply this method here. The criteria were weighted through the pairwise comparison of individual land degradation indicators derived from raster data (maps) following the AHP approach. In this method, when two criteria are compared, the less important criteria will get a reciprocal value of the most important criteria. In this approach, some sorts of inconsistencies may occur during the assignment of preference values. As a result, the consistency of the pairwise comparison needs to be checked. On the other hand, the pairwise comparison matrix attained by the decision-maker should satisfy Saaty's consistency situation which is Consistency Ratio $(C.R) = \frac{C.I}{R.I} < 0.1$, where $(C.I) = \frac{\lambda_{max} - n}{n-1}$. Here λ_{max} is the maximum Eigenvalue of n x n reciprocal pairwise comparison matrix, and n is the number of observations and RI=Random consistency Index (Saaty, 2008; Prasad & Kousalya, 2017). Saaty proposed that the comparison matrix is absolutely consistent if $\lambda_{max} = n$. On the other hand, if consistency ratio is > 0.10 or 10% the decision maker should be reviewing his/her decisions. If the value of consistency ratio is less than 0.10, it is considered as a consistent comparison (Saaty, 2008; Mishra et al., 2015; Prasad & Kousalya, 2017). If the consistency index failed to reach a threshold level, the comparisons were re-examined. Finally, the weighted overlay technique was used to combine/aggregate the criteria maps, and each standardized criterion was multiplied by its weight in the overlay process. All geospatial procedures are implemented using ArcGIS10.5 tool.

5.2.3. Develop Physical Land Degradation Indicators

A wide range of indicators can be applied to characterize physical soil/land degradation and the vulnerability of ecosystem health. Among others, soil compaction, soil drainage, and soil depth are commonly applied as indicators of soil ecosystem service productivity and, in turn, land degradation status (Nachtergaele et al., 2009; ASTM, 2001; USDA, 2008). We considered soil erosion, soil compaction, soil drainage, and soil depth as physical land degradation indicators.

5.2.3.1. Soil Loss Estimation Using RUSLE Model

Soil erosion is the main indicator of land degradation (Berry et al., 2003; Hurni et al., 2010; Oldman, 1994). The agent of soil erosion may be water and/or wind. Given the humid climate condition of large parts of Ethiopian highlands, including the study area, water erosion is the dominant form of soil erosion. Soil loss by water can be estimated using the revised universal soil loss equation (RUSLE) (Wischmeier and Smith, 1978). But, this model only addresses rill and inter-rill erosion induced by raindrop and surface runoff without considering other forms of erosion such as gully erosion and landslides (Renard and Foster, 1985). Despite its limitations, the RUSLE has been the most frequently used erosion estimation model worldwide (Farhan and Nawaiseh, 2015a; Ganasri and Ramesh, 2016a; Haregeweyn et al., 2017). The RUSLE is a very powerful tool when integrated with GIS, especially for developing countries that lack data for more physically based models. Some of the other reasons for the selection of the model for this study include its simplicity to apply and its compatibility with remote sensing data and GIS inputs in a computer interface (Farhan and Nawaiseh, 2015). Most of the input parameters of the model were adjusted for the Ethiopian highland context in a previous study (Hurni, 1985). The model estimates soil loss by taking into consideration rainfall, soil properties, topography, cover management, and conservation practices in a particular area (Renard and Foster, 1985).

$$A = R.K.LS.C.P \tag{5.1}$$

where "A" is the mean annual soil loss (t $ha^{-1}yr^{-1}$); "R" represents a rainfall erosivity factor (MJ mm $ha^{-1}h^{-1}yr^{-1}$); "K" is a soil erodibility factor (t $ha^{-1}MJ^{-1}mm^{-1}$); "LS" is a dimensionless topographic factor that accounts for length of the slope (L) and slope steepness (S). "C" describes the land cover factor and "P" is the erosion control support practice factor.

Rainfall erosivity factor (R-factor): indicates the input, which determines the sheet and rill erosion processes. R-factor depends mainly on the amount, intensity, and distribution of rainfall (Farhan and Nawaiseh, 2015). Soil loss is strongly associated with rainfall amount, intensity, energy, duration, pattern, and size of a raindrop through the detaching power of a raindrop striking the soil surface and for the incidence of runoff on the soil surface (Renard and Foster, 1985).

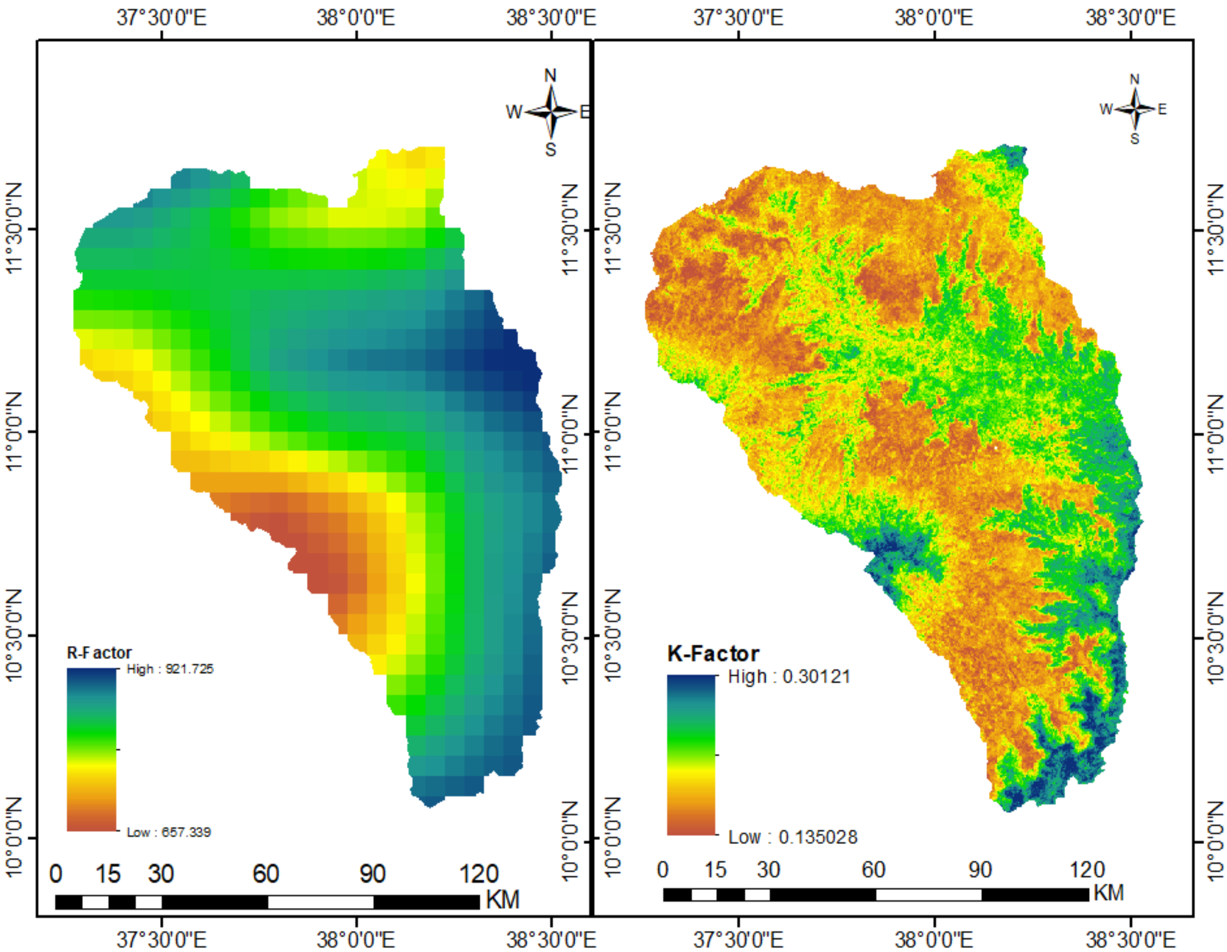

Figure 5.2. Rainfall erosivity (left) and soil erodiabilty (right) in the north Gojjam sub-basin.

But, such data do not exist for the study area, due to the absence of an automatic rain-gauge, so, R-factor was generated using long-term mean annual rainfall following the equation developed by Hurni (1985).

$$R = -8.12 + 562(Pa) \tag{5.2}$$

where "R" is rainfall erosivity value (MJ mm $ha^{-1}h^{-1}yr^{-1}$) and "Pa" is mean annual rainfall (mm). For this purpose, nine years' mean annual rainfall data was obtained from the CHIRPS website. As depicted in Figure 5.2, rainfall is higher in the lowland parts of the sub-basin, because in the highland region the rainfall characteristic is the shower. Thus, the lower part of the sub-basin has higher erosivity values than the middle and upper parts. The spatial distribution of the rainfall erosivity factor of the north Gojjam sub-basin ranged from 657.34 to 921.73 MJ mm $ha^{-1}h^{-1}yr^{-1}$ (Figure 5.2).

Soil erodibility factor (K-factor): represents the sensitivity of soil particles and surface materials to detachment and transport through the power of rainfall and runoff (Laflen and Flanagan, 2013; Renard and Foster, 1985). It is associated with soil characteristics such as organic matter, texture, structure, permeability, and total stability (Yang et al., 2018). The availability of organic matter in the soil decreases soil loss because it makes soil particles attached together (Yang et al., 2018). There are different formulas developed by scholars to determine soil erodibility status (Romkens, 1997). Among others, Equation (5.3), shown below, is a formula widely used to calculate soil erodibility in different environments. Using this method, the K-factor of the study area was calculated using soil properties, or texture class, and organic matter content (Song, 2011).

$$K = \left\{0.2 + 0.3exp\left[0.0256SAN\left(1.0 - \frac{SIT}{100}\right)\right]\right\}\left(\frac{SIT}{CLY + SIT}\right)^{0.3}\left(1.0 - \frac{0.25C}{C + \exp(3.72 - 2.95C)}\right)$$

$$\left(1.0 - \frac{0.7\left(\frac{1-SAN}{100}\right)}{\left(\frac{1-SAN}{100}\right) + exp(-5.51 + 22.9\ \left(\frac{1-SAN}{100}\right))}\right) \quad (5.3)$$

where SAN= sand in %, SIT= silt in %, CLY= clay in % and C = organic carbon in %.

The result indicated that soil erodibility value in the north Gojjam sub-basin was ranged from 0.13t $ha^{-1}MJ^{-1}mm^{-1}$ on upper and lower to 0.30 t$ha^{-1}MJ^{-1}mm^{-1}$on the middle part (Fig. 5.2).

Topographic factor (LS-factor):it refers to the effect of topography on soil erosion. Slope length (L) and slope gradient (S) factors are joined into a single index, LS-factor, to describe the topographic factor for soil loss (Ganasri and Ramesh, 2016b). The slope length refers to the distance from the point of origin of overland flow to the point where either the slope gradient declines enough in which sedimentation starts or the runoff water enters a well-defined channel (Wischmeier and Smith, 2007). The extent and rate of soil erosion are highly associated with slope length and gradient. Soil loss increases with increases in slope gradient (S) and slope length (L) resulting from respective increases in velocity and volume of surface runoff (Bewket and Teferi, 2009).

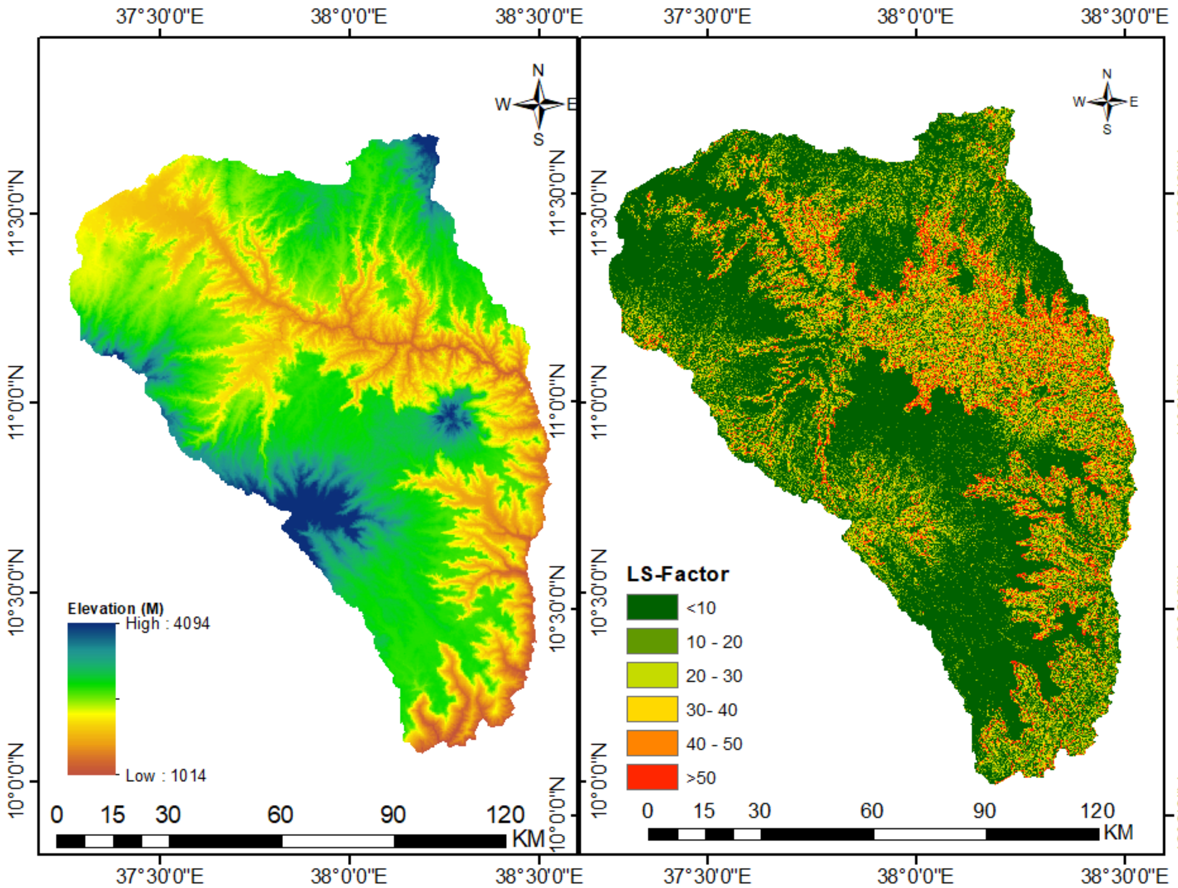

Figure 5.3. Map of digital elevation model(left) and LS-factor (right) of the north Gojjam sub-basin

We used modified equations for computing the topographic factor (LS-factor) suggested by Renard et al. (2011):

$$L = \left(\frac{\lambda}{22.13}\right)^{m} \tag{5.4}$$

$$m = {}^{F}/_{(1+F)} \tag{5.5}$$

$$F = \frac{\sin\beta /_{0.896}}{3.0(\sin\beta)^{0.8} + 0.56} \tag{5.6}$$

where L is a slope length factor, λ is the multiplication of flow accumulation and cell size, m is slope length exponent, F is calculated for conditions when the soil is moderately susceptible to both rill and inter-rill erosion while β is the slope angle in degree (slope in degree * 0.01745).

$$S = 10.8 * \sin\beta + 0.03 \quad \delta < 9\%$$

$$S = 16.8 * \sin\beta - 0.05 \quad \delta \geq 9\% \tag{5.7}$$

where S is a slope steepness factor, β is the slope angle in degree and δ is slope gradient in percent. The LS-factor map was generated from a 30m pixel resolution ASTER global digital elevation model (GDEM). A stepwise technique was followed to generate inputs for LS-factor includes; slope generating, filling sinks, flow direction, and flow accumulation. After calculating L and S-values the LS-value was computed by multiplying the two together. As depicted in Figure 5.3, the LS-factor value in the study sub-basin varied from 2 to 109. However, the majority of the sub-basin has LS value of less than 10.

Cover management factor (C-factor): describes the effect of cropping and management practices in agricultural land and ground cover (i.e., grass and tree canopy) on non-agricultural land on reducing soil loss (Bewket and Teferi, 2009; Haregeweyn et al., 2017). To compute cover factor values in the RUSLE model, data are required associated with the role of the plant canopy, crop residues, soil management practice, surface roughness, and moisture content of soil (Wischmeier, and Smith, 1978). Acquiring each of the parameters is difficult due to the scarcity of data for combination and calibration. Alternatively, the C-factor can be calibrated from the LULC map. Using this simpler approach, the C-factor LULC map of the study area was prepared from a Landsat 8 image acquired in January 2017 using supervised classification techniques in ERDAS IMAGINE14 (Figure 5.4). Ground truth data were used for reference for classification and accuracy assessment validation. The overall classification accuracy was 92% and the kappa coefficient index was 0.9. After classification was performed, the raster map was converted to vector format to assign C-factor values for each LULC type based on suggestions in previous literature (Table 5.1). Finally, the C-factor map changed to the raster layer using the raster conversion tool in ArcGIS10.5 environments. This method was employed by different authors in studies of the Ethiopian highlands (Bewket and Teferi, 2009; Haregeweyn et al., 2017; Zerihun et al., 2018). The cover management factor value in the sub-basin varied from 0 on water bodies to 0.6 on bare land (Figure 5.4). The smallest value indicates lower susceptibility to soil erosion.

Table 5.1: Adopted C-factor values for different land uses/cover types

LULC	C-value	Sources
Natural Forest	0.01	(Bewket & Teferi, 2009; Tiruneh & Ayalew, 2015)
Plantation Forest	0.01	(Bewket & Teferi, 2009; Tiruneh & Ayalew, 2015)
Shrub and bush	0.20	(Bewket & Teferi, 2009; Tiruneh & Ayalew, 2015)
Grassland	0.05	(Hurni, 1986;Tiruneh & Ayalew, 2015)
Agriculture	0.15	(Hurni, 1986;Tiruneh & Ayalew, 2015)
Bare land	0.60	(Tiruneh & Ayalew, 2015)
Waterbody	0.00	(Haregeweyn et al., 2017)

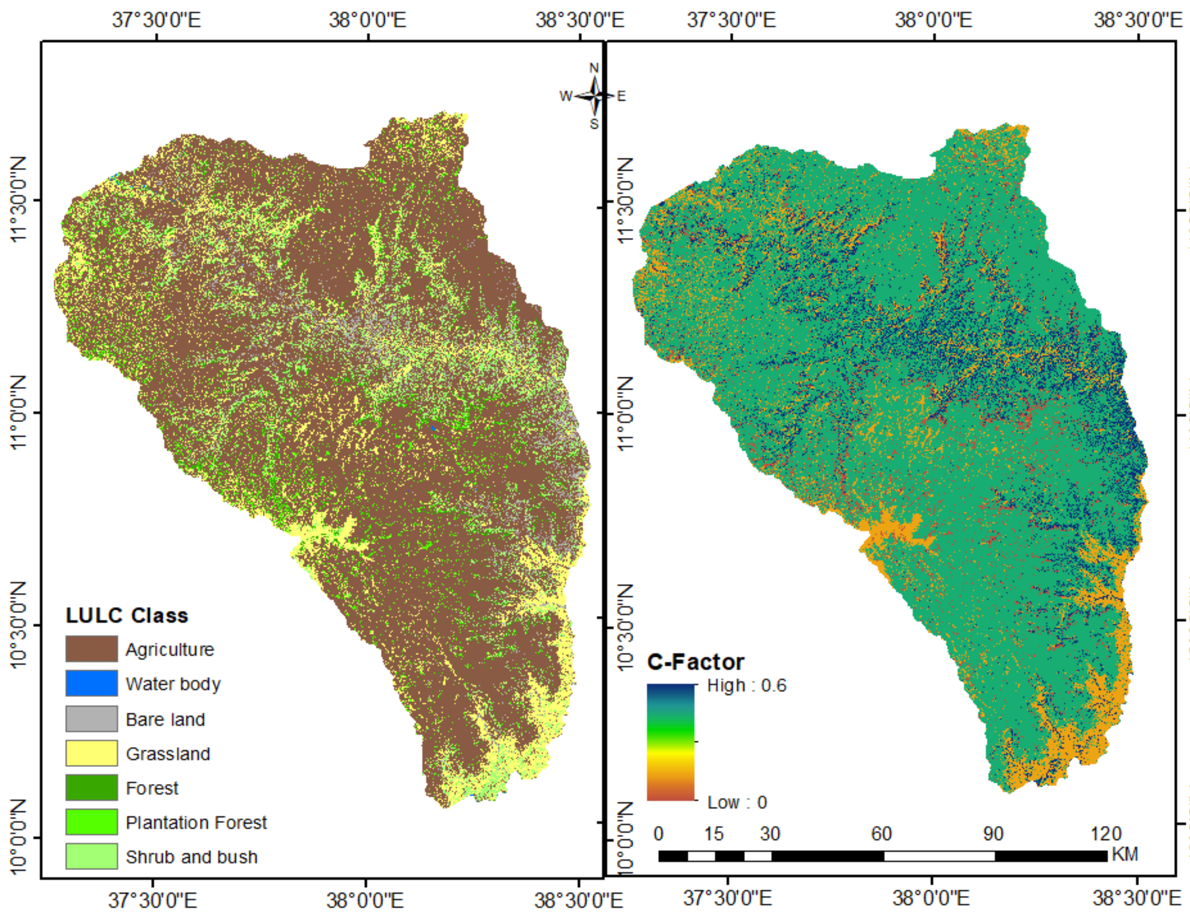

Figure 5.4. LULC types (left) and the cover factor (right) values in the north Gojjam sub-basin

Erosion management practice (P-factor): it is a measure of the effect of soil management to reduce the extent of soil loss (Ganasri and Ramesh, 2016b; Panagos et al., 2015). It involves several types of agricultural land management practices, such as terracing, contour farming, and strip cropping (Farhan and Nawaiseh, 2015). Unlike the previous studies in Ethiopia (Bewket and Teferi, 2009; Haregeweyn et al., 2017; Zerihun et al., 2018), this study generated P-values from conservation technology instead of using land use and topography. To determine agricultural land management practices for this study, intensive field observation, key informant interviews, and Google Earth Pro observations were employed. Soil bund, stone bunds, hillside terraces, traditional ditches, cutoff drains, waterways, check-dams, and plantations on the bund, afforestation, and revegetation have been implemented to various extents. From these technologies, we considered only soil and stone bunds conservation structures because most other land management options observed in the sub-basin were not well-designed and not widely used. As Figure 5.5 and Table 5.2 shows, almost half of the study areas were well terraced (48%), mainly the upslope parts, while about 30% of landscape needs structural measures and 17% of the sub-basin shows no need for conservation practices. The estimated p-values ranged from 0.02 on the terraced area to 1 on non-terraced agricultural land use types. The smaller value shows less vulnerability to soil loss (Table 5.2 and Figure 5.5).

Table 5.2: Erosion control status and management factor (P) values

Erosion control measures	Area in %	P-factor	Sources
Area no need/little conservation structure	17.79	0.02	(Molla & Sisheber, 2017)
The area that needs conservation stricture	33.90	1.00	(Molla & Sisheber, 2017)
Terraced landscape	48.31	0.50	(Haregeweyn et al., 2017)

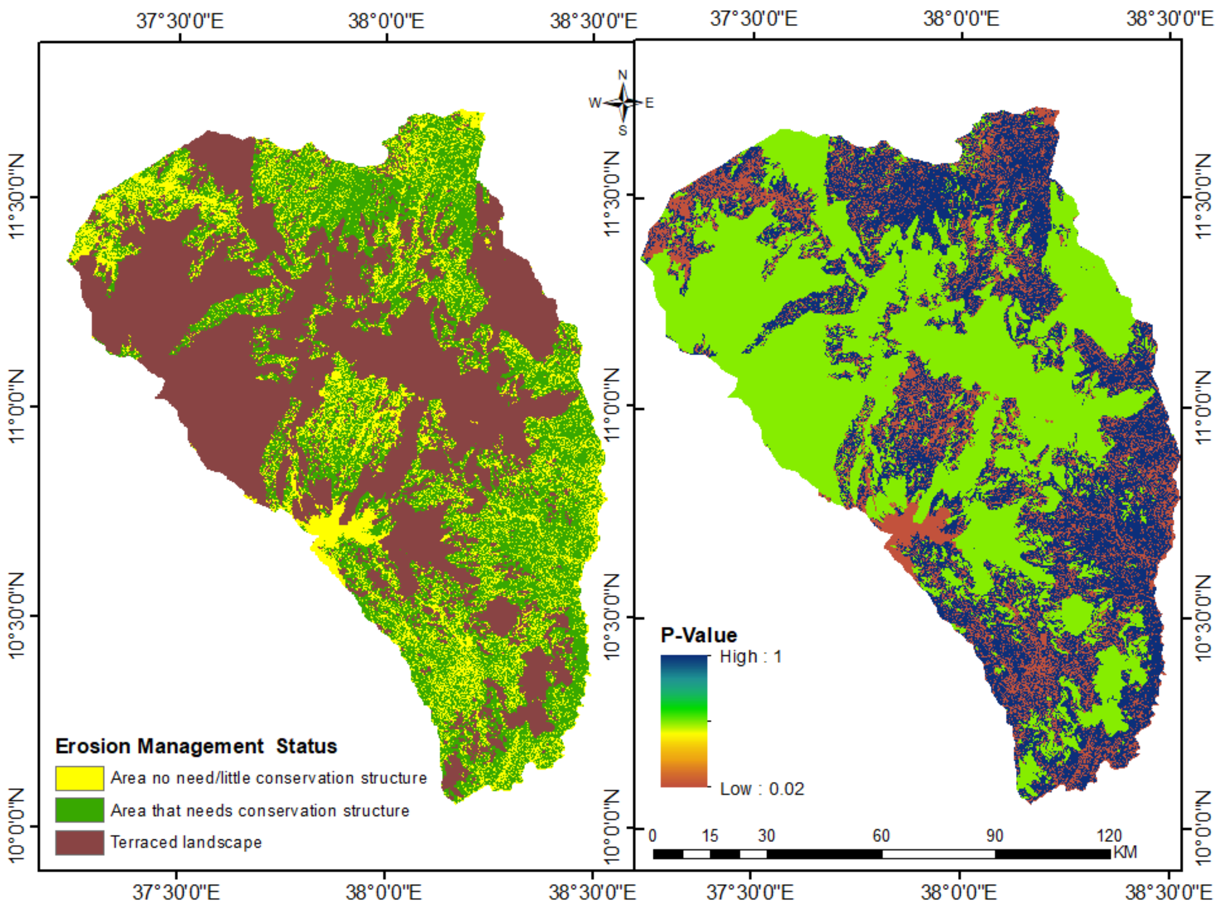

Figure 5.5. Erosion control measures(left) and management (P-factor) values (right)

Finally, the annual soil loss was estimated on a cell-by-cell basis by multiplying the five RUSLE factors using Equation (5.1). As Landsat images and ASTER-GDEM used in this study had 30 m spatial resolution, all the raster maps were resampled to 30 ×30 m cell size and re-projected to UTM Zone 37° N, WGS 1984 datum. The estimated annual soil loss was classified into six severity categories following soil erosion severity classification standards suggested by Haregeweyn et al. (2017) and Yesuph and Dagnew (2019). The validation and consistency of the model output were compared with the quantitative outputs of previous experimental observations and similar empirical studies conducted in Ethiopia, mainly in the northwestern highlands. Besides, selected field observations were carried out. In supporting this process, the color printed model output soil erosion severity map was taken in the field to check the reality on the ground.

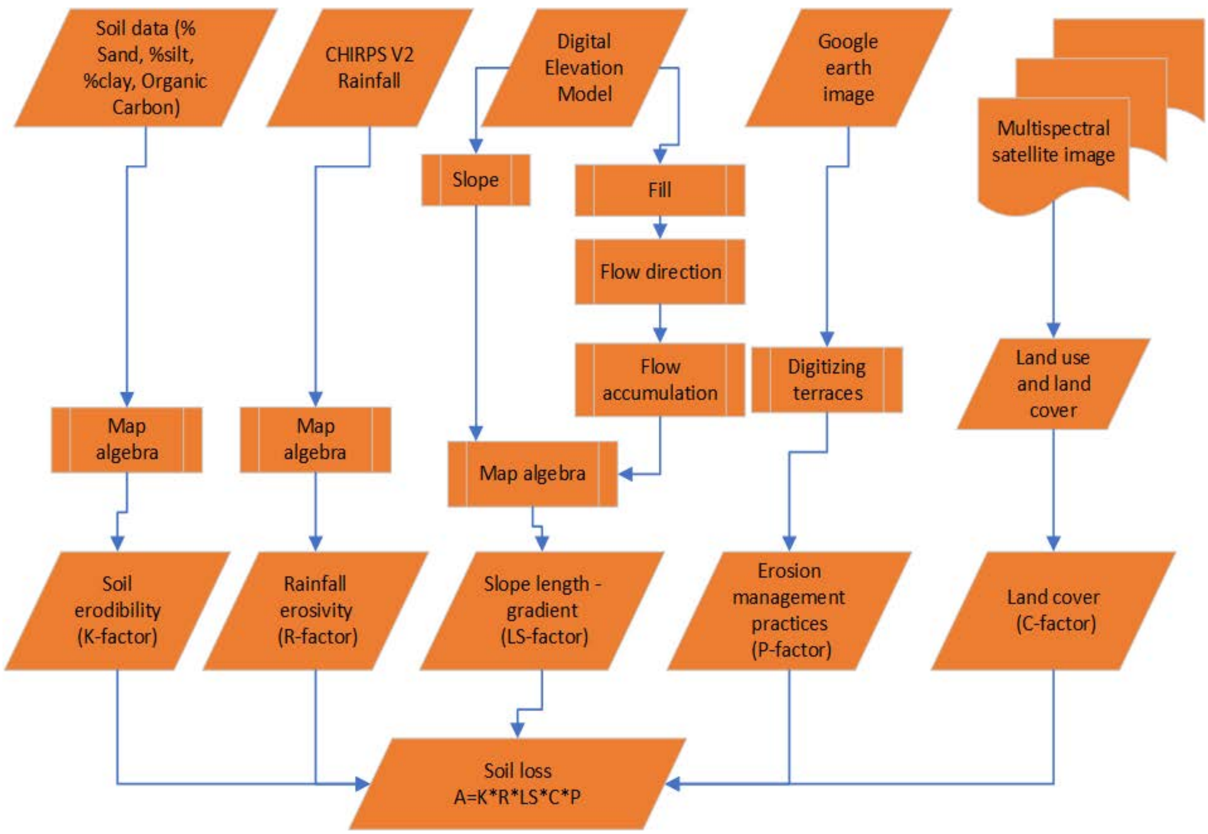

Figure 5.6. Flow chart showing the methodology of soil loss estimation.

Soil Compaction: it is the other key indicator of physical land degradation (Oldman, 1994). It is expressed as an oven-dry soil mass per unit volume of soil particles (Chaudhari et al., 2013). Soil compaction has an inverse relationship with the amount of pore space and soil organic matter content. It depends on soil textural (for example, clay, silt, and clay loam surface soil shows low bulk density as compared to sand and sandy loam soil that depicts high bulk density value (Nawaz and Bourrié, 2013). When pressure is applied to the soil surface, compaction takes place. This changed soil characteristics such as porosity and permeability. Pores become disconnected and, air and water movement through the soil are delayed, resulting in the reduced availability of water and oxygen and plant root growth is restricted(Nawaz and Bourrié, 2013). Soil compaction can encourage other soil degradation processes, such as erosion or landslides due to reducing the infiltration rate and increasing soil layer weight. In the upper part is causing landslides and on the plains area waterlogging, resulting in the destruction of soil aggregation, and causes for crust formation (Zolekar and Bhagat, 2015). Soil compaction is measured using soil bulk density (Nawaz and Bourrié, 2013). Soil bulk density reflects soil compactness and soil health (Zolekar and Bhagat, 2015). We obtained a soil bulk density map from (Hengl et al., 2017) in raster format and then reclassified based on the value range given in Table 5.3 to assign a level of compaction that is used as a physical land degradation indicator.

Table 5.3: soil compaction class (ASTM, 2001)

Soil bulk density class	Compaction status
< 1 g/cm^3	Low soil compaction
1-1.25 g/cm^3	Medium soil compaction
1.25-1.55 g/cm^3	High soil compaction
> 1.55 g/cm^3	Very high soil compaction

Soil Drainage: it refers to the process of removing excess water from the soil surface and soil profile. Poor drainage is causing waterlogged and crusting (Abdelrahman et al., 2016). Drainage can be either natural or artificial. Natural soil drainage refers to the frequency and duration of wet periods under conditions similar to those under which the soil is formed. Alterations of the water regime by human activities, either through drainage or irrigation, are not a consideration unless they have significantly changed the morphology of the soil (Zia-ur-rehman et al., 2016). Drainage classes can be determined from observations of water tables, soil wetness, landscape position, and soil morphology. In many soils, the depth and duration of wetness relate to the quantity, nature, and pattern of redoximorphic features (Zia-ur-rehman et al., 2016). According to USDA, soil drainage class is usually classified into seven based on water removing rate from the soil (USDA, 2016). To evaluate the soil drainage status of the north Gojjam sub-basin, a soil drainage raster map was obtained from (Hengl et al., 2017) and reclassified based on the value given in Table 5.4.

Table 5.4: Soil drainage classes status (2008)

Drainage class	Level drainage	Status Description
1	Very poor	Excessively Drained
2	Poor	Somewhat Excessively Drained
3	Imperfect	Well Drained
4	Moderate	Moderately Well Drained
5	Well	Somewhat Poorly Drained
6	Somewhat excessive	Poorly Drained
7	Excessive	Very Poorly Drained

Soil Depth: it is another important indicator of physical land degradation status. Soil thickness has a relation to soil quality and crop productivity (Eastman, 2012). Soils in which the rooting depth is limited by the presence of a physical constraint are generally less productive, show more degradation. Deep soils are favorable for the growth and development of plant roots with a higher supply of nutrients and minerals (Eastman, 2012) implies less degradation. Soil qualities such as water holding capacity (Bhagat et al., 2014), level of moisture (Zolekar and Bhagat, 2015), amount of soil nutrients (Jobbágy and Jackson, 2001), rate of infiltration (Rabia and Terribile, 2013), and growth of plants as well as agricultural productivity (Yu et al., 2011) varies according to the soil depth (Zolekar & Bhagat, 2015). Soil depth is not only required by plants for root extension but also by several soil biotas like earthworms (Zia-ur-rehman et al., 2016). Therefore, to estimate soil depth and used for the indicator of physical degradation status in our study area, the raster soil depth map was obtained from Hengl et al. (2017) and reclassified into the standard classification system (Table 5.5.).

Table 5.5: The status of soil depth categories (USDA,2017)

Soil depth class	Severity level	Description
< 30 cm	Very low	Shallow soil
30-50 cm	Low	Moderate shallow soil
50-100 cm	Moderate	Deep shallow soil
100- 150 cm	High	Very deep shallow soil
> 150 cm	Very high	Shallow soil

5.2.4. Develop Biological Land Degradation Indicators

There are several indicators for biological land degradation implications. Among others, vegetation cover, soil organic matter, the reduction of soil organisms and soil fauna are common indicators of land degradation (Huete,1988). In this study, vegetation cover and soil organic matter were considered to estimate biological land degradation status.

Vegetation Cover: Land degradation results in the reduction of biomass production and vegetation cover in all forms of land use types (Masoudi et al., 2018). Hence, vegetation cover is widely used to estimate land degradation status (Chabrillat, 2014; Gibbs and Salmon, 2015; Li, Lewis, Rowland, Tappan, and Tieszen, 2004; Olsson & Tengberg, 2018). Normalized Difference Vegetation Index (NDVI) value is ranged between -1 and +1, value below 0 representing water, bare soils are somewhere around 0 and the vegetation cover has more than 0.1 values. An increment in the positive NDVI esteems greener the vegetation or less degraded area (Ganie and Nusrath, 2016). This implies that increasing positive NDVI value confirms less land degradation area. Vegetation cover can be measured using model-based approach indicators and proxy variables. The most widely used model is NDVI, calculated from the red and near-infrared spectral information indexes. However, NDVI has a well-known weakness due to its sensitivity to soil background, especially when vegetation cover is low (Gilabert et al., 2002; Olsson & Tengberg, 2018) in the case of our study area. Advanced vegetation indices overcome this problem, for example, Soil Adjusted Vegetation Index (SAVI) model (Huete, 1988). According to (Gilabert et al. 2002), SAVI has better efficiency to calculate vegetation index via reducing the influence of soil background of vegetation. Therefore, SAVI has been used to calculate the vegetation index in this study. Simple SAVI classification was computed from the calibrated Landsat 8 bands following the work of Qi et al. (1994) and Chabrillat (2015):

$$SAVI = \frac{(NIR-RED)}{(NIR+RED+L)}(1+L) \tag{5.8}$$

where NIR is the reflectance in the near-infrared and RED is the reflectance radiated in the visible red. L is a coefficient of vegetation density (ranging from 0 for very dense vegetation cover to 1 for very sparse). We tested several values for L, following recommendations from Huete (1988) (0.25, 0.5, and 0.75). Visual interpretation of images led us to choose 0.5, which is an intermediate value that has been applied in several previous studies (Huete,1988; Qi et al., 1994). As a result, we used 0.5 as a constant to determine the vegetation index in this study.

Soil Organic Matter (SOM): it is another useful biological land quality indicator (Chabrillat, 2014). SOM describes the organic component of soil, which primarily consists of small plant residues and micro-soil living organisms; decomposing organic materials, and humus materials (FAO, 2005). Organic carbon together with pH is the best and simple indicator of soil health and quality. Moderate to high amounts of organic carbon in the soil is associated with fertile soils with a good soil structure (Nachtergaele et al. 2008; Lorenz, 2019). Soil organic matter is used as a source of nutrients for crop production, preserves soil aggregation, assists nutrient exchange, retains moisture, decreases compaction, reduces surface crusting, and prompts water penetration into soil (Combs and Nathan, 1998; FAO, 2005; Lorenz, 2019). This shows that soil organic matter is one of the key indicators of soil and land quality of the particular area.

The amount of soil organic carbon is usually measured in the laboratory. However, it was difficult for this study to measure soil organic matter at the sub-basin level because of the time and financial constraints. Therefore, for this study, a soil organic carbon raster map was obtained from Hengl et al., (2017) to determine the status of soil organic matter in particular and biological land degradation in general in the sub-basin. It is estimated that soil organic matter contains 58% organic carbon. Thus, the soil organic carbon raster map was converted to soil organic matter using the map algebra raster calculator following the equation used by (Combs and Nathan 1998).

$$Percentage\ of\ organic\ matter\ =\ Percentage\ of\ total\ organic\ carbon\ x\ 1.72 \quad (5.9)$$

Table 5.6: Classes of soil organic matter status in soil (Eastman, 2012)

Category in %	Description
< 0.2	Very poor soil organic matter content in the soil
0.2-0.6	Poor soil organic matter content in the soil
0.6-1.2	Medium soil organic matter content in the soil
1.2-2.0	High soil organic matter content in the soil
>2.0	Very high soil organic matter content in the soil

5.2.5. Chemical Land Degradation Indicator

Soil chemical degradation refers to the undesirable changes in soil chemical characteristics due to the soil quality decline mainly via human intervention (Osman 2013). The most important indicators of chemical land degradation indicators are soil acidity, salinity, and Sodicity (Oldman, 1994, Osman, 2013). But, this study is concerned only with soil acidity since the study area is mostly humid and the application of chemical fertilizer and removable crop residue are common practices. The level of soil acidity is an important indicator of chemical soil degradation (Zia-ur-rehman et al., 2016), may be caused by natural factors like acid rain and weathering process and/or man-made factors such as crop production and removal, and the application of acid-forming fertilizers, (Osman 2013; Zia-ur-rehman et., 2016). Soil acidity can be measured via pH value from solution soil in water (Nachtergaele et al., 2008). To identify the status of soil acidity in the sub-basin, a soil pH raster map developed by (Hengl et al., 2017) was used. The soil acidity digital map was classified using standardized soil pH class ranges (Table 5.7).

Table 5.7: Category of soil acidity level based on pH value (Nachtergaele et al., 2009)

PH value	Description
< 4.5	Extremely acid soils include acid sulfate soils
4.5 -5.5	Very acid soils suffering often from toxicity.
5.5-7.2	Acid to neutral soils: these are the best pH conditions for nutrient availability and suitable for most crops.
7.2-8.5	These pH values are indicative of carbonate-rich soils
> 8.5	Indicates alkaline soils often very alkaline soils

5.3. Results and Discussion

5.3.1. Physical Land Degradation Indicators

5.3.1.1. Estimation of Annual soil loss using RUSLE model

The annual soil loss was estimated based on the five erosion rate factors. These are climate, soil characteristics, topography, land cover, and land management using the RUSLE model. The model result of these factors shows that much of the middle part of the sub-basin has lost topsoil at a rate of 0 to 75 t ha^{-1}yr^{-1}, and that soil loss rates exceed 75 t ha^{-1}yr^{-1} in upstream and downstream zones as well as in some erosion hotspot areas (Figure 5.7). As indicated in Table 5.8, about 31.3% and 19.3% of the sub-basin experienced a very low and low soil loss rate, ranging from 0-5 t ha^{-1}yr^{-1} and 5-15 t ha^{-1}yr^{-1}, respectively. The result shows that about 13.6% of the sub-basin experienced soil loss ranging from 15 to 30 t ha^{-1}yr^{-1}, which is characterized as a moderate erosion rate. Further, about 17.3% of the sub-basin lost topsoil with rates from 30 to 75 t ha^{-1}yr^{-1}, indicating a high to very high soil loss rate. The remaining 18.5% of the sub-basin was under severe erosion rate with soil loss exceeding 75 t ha^{-1}yr^{-1} (Table 5.8). As shown in Table 5.8, the area under high to severe soil loss class covers about 35.9% area of the sub-basin, found in most upper and lower parts in very steep-sloped areas (Figure 5.7).

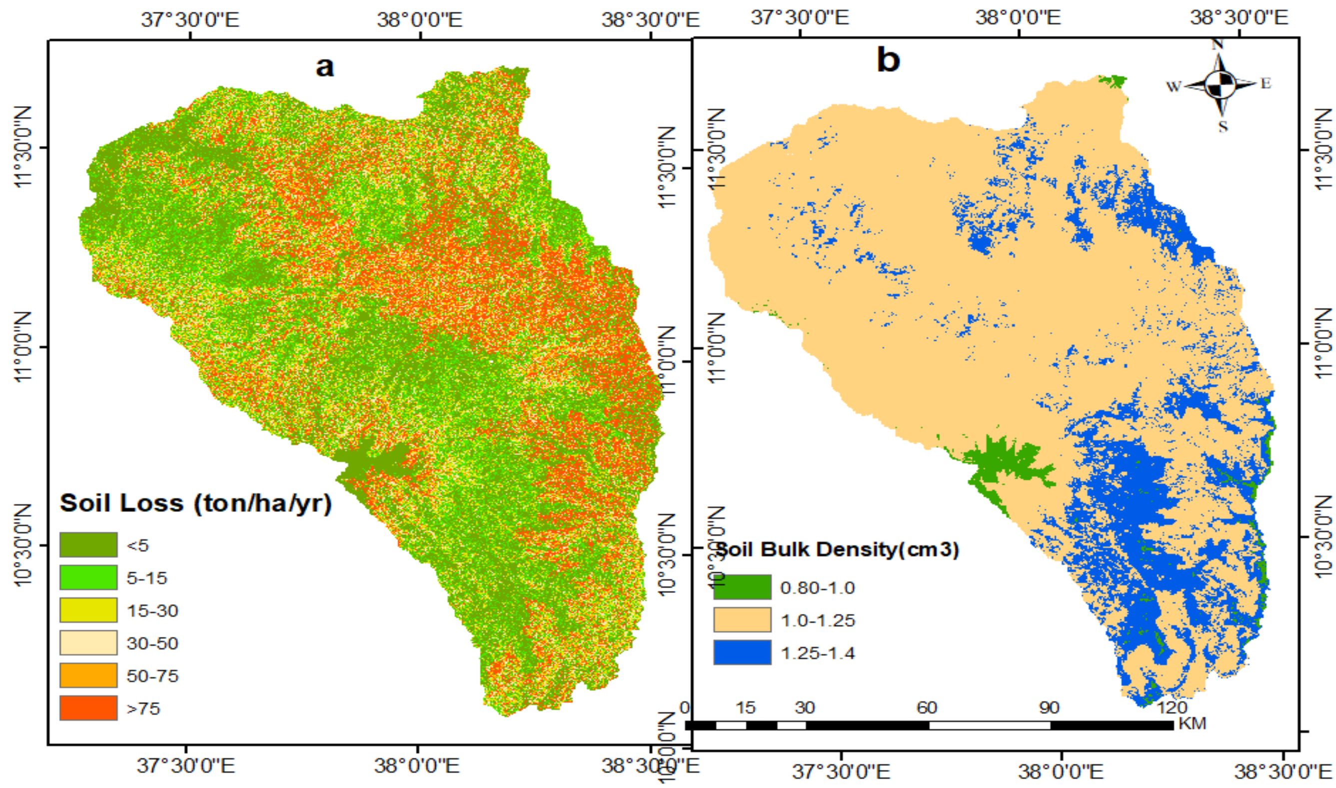

Figure 5.7. The annual soil loss (a) and soil bulk density (b) of the north Gojjam sub-basin

The average annual soil loss of the entire north Gojjam sub-basin was estimated at 46 t ha^{-1}yr^{-1} which is generally greater than the tolerable soil loss of two-times of the maximum (18 t ha^{-1}yr^{-1}) soil loss tolerance value given by Hurni (1985) for the Ethiopian highlands. It implies that a total of 65.2 million tons of soil has been lost annually from the entire sub-basin. Any soil loss rate greater than 10 t $ha^{-1}yr^{-1}$ soil loss rate will not be restored in a period of 5 to 10 decades (Kouli and Soupios, 2009). Accordingly, nearly half of the north Gojjam sub-basin was beyond the threshold of soil loss tolerance level (Table 5.8).

Table 5.8: Annual soil loss class and risk levels in the north Gojjam sub-basin

Soil Loss (t/ha/yr.)	Area (ha)	Percentage	Severity level	Assigned value	Risk level
<5	447872.54	31.29	Very slight	1	Very Low
5-15	276252.48	19.30	Slight	2	Low
15-30	193949.28	13.55	Moderate	3	Medium
30-50	141847.78	9.91	High	4	High
50- 75	106350.05	7.43	Very high	5	Very high
>75	265087.87	18.52	Sever	5	Very high

Consistency and validation of the model estimation: The estimated average soil loss rate and the spatial patterns of this study are, in general, accurate, compared to what can be observed in the field as well as findings from previous experimental studies. Based on field assessment of rill and inter-rill erosion, (Bewket and Sterk, 2003) found the annual soil loss ranged from 18 to 79 t $ha^{-1}yr^{-1}$ in parts of the same and adjacent watershed of this study sub-basin. Similarly, in five years of monitoring in an experimental micro-watershed (the Anjeni) located to the northwest adjacent to this study area, soil loss from cultivated fields under the traditional land-use practices was ranged from 17 to 176 t $ha^{-1}yr^{-1}$ (Herweg and Ludi,1999). Recently, (Belayneh et al., 2020) confirmed that the mean rate of soil loss in the new and old-graded soil bund-treated and non-treated plots was 23.5, 45.6, and 58.1 t $ha^{-1}yr^{-1}$, respectively using an experimental study from cultivated land in Gumara sub-watershed located within the present study sub-basin. Hurni (1993) in Ethiopian highland estimated average soil loss from cultivated fields at 42 t $ha^{-1}yr^{-1}$ accounting from re-deposition of mobilized sedimentation. In addition, to check the validity, selected field observations were carried out. In supporting this process, the color-printed model output soil erosion severity map was taken into the field and checked against the reality on the ground.

The estimated soil loss rate of this study was also consistent with the empirical evidence from previously published studies. For example, 24.3 t $ha^{-1}yr^{-1}$ average soil loss was reported in the

Gelana sub-watershed, north Wollo (Miheretu & Yimer, 2018); about 23.7 t $ha^{-1}yr^{-1}$ attested in the Geleda watershed (Gashaw et al., 2017); nearly 24.9 t $ha^{-1}yr^{-1}$ reported in the Enfraz watershed (Tiruneh and Ayalew, 2015); the study conducted soil loss from the entire upper Blue Nile basin confirmed about 27.5 t $ha^{-1}yr^{-1}$ (Haregeweyn et al., 2017); other results reported a relatively comparable estimation result to the present study from Jabi Tehinan district (30.6 t $ha^{-1}yr^{-1}$), west Gojjam zone (Amsalu and Mengaw, 2014).

On the other hand, the result of this study was most similar to recent empirical studies. For example, average soil loss of about 47.4t $ha^{-1}yr^{-1}$ and 42t $ha^{-1}yr^{-1}$ was reported in the Koga watershed, upper Blue Nile (Molla and Sisheber, 2016; Gelagay and Minale, 2016); about 49 t $ha^{-1}yr^{-1}$ mean soil loss was found in the Dembecha District, west Gojjam zone (Zerihun et al., 2018). In contrast, some other studies undertaken in various regions of Ethiopia reported a relatively higher average soil loss rate than this study. For instance, it was much lower than the mean soil loss rate of 243t $ha^{-1}yr^{-1}$ reported by Zeleke (2000) for north-western Ethiopian highland due to rugged topography, low vegetation cover, and absence of land management technology; about 93t $ha^{-1}yr^{-1}$ average soil loss was reported in the Chemoga watershed (Bewket and Teferi, 2009); 84t $ha^{-1}yr^{-1}$ average soil loss in northwestern Ethiopia found by Selassie and Belay (2013); and 75t $ha^{-1}yr^{-1}$ in the entire upper Blue Nile Basin (Tamene and Le, 2015). Generally, the above empirical evidence indicated that though soil erosion is a common problem in Ethiopian highlands, the quantitative results are still uncertain and inconsistent. The variation may be observed from the heterogeneity of soil erosion determinants such as rainfall, soil property, topography, land management, and land use types, and may also stem from methodological differences between the studies.

Soil compaction: The spatial distribution of soil compaction in the sub-basin ranged from 0.8 to 1.4 g/cm^3 (Figure 5.7). On the other hand, Table 5.9 indicates that 80.9% of the sub-basin soil bulk density was between 1 and 1.25 g/cm^3, indicative of medium compaction. The result shows that the status of soil compaction in a large area of the sub-basin can be considered as a medium, which is attributed to the absence of heavy machine farming activity in the area. Low soil compaction was found in colder climate zones and areas with and more vegetation cover, located in a mountain area where higher precipitation rate and low temperature are found. The result implies that soil compaction was not much of a problem in the north Gojjam sub-basin.

Soil drainage: As seen from Table 5.9, about 74.4% of the sub-basin have good drainage characteristics. The spatial distribution of soil drainage in the sub-basin is shown in Figure 5.8. The result is similar to the soil drainage map prepared by the agricultural transformation agency (ATA, 2017) in the Amhara regional state and local land users' perception.

Soil depth: Spatial distribution of soil depth in the sub-basin ranged from 25-175 cm (Figure 3.8). As presented in Table 3.9, about 40.9% of the sub-basin has very deep soils (>150 cm), which indicates a very low land degradation level to this indicator, while about 50.3% of the sub-basin has shallow soil, ranging from 25–30 cm, which indicates a very high degree of degradation. Most midland parts of the sub-basin are characterized by high soil depth while the lower part has very shallow soil, reflecting higher erosion rates and greater soil degradation.

Table 5.9: Statistics for physical land degradation indicators in the north Gojjam sub-basin

Factor	Classes	Area (Ha)	Percentage	Assigned value	Degradation level
Soil bulk density (g/cm^3)	< 1	19323.36	1.35	2	Low
	1-1.25	1158399.65	80.93	3	Moderate
	1.25-1.55	253636.99	17.72	4	High
Level of drainage	Poor	2,147.04	0.15	1	Very low
	Imperfect	110,787.26	7.74	2	Low
	Moderate	214,990.27	15.02	3	Moderate
	Well	1,064,788.70	74.39	4	High
	Somewhat excessive	38,646.72	2.70	5	Very high
Soil depth class (cm)	25-30	719544.67	50.27	5	Very high
	30-50	3864.67	0.27	4	High
	50- 100	1145.09	0.08	3	Moderate
	100-150	122524.42	8.56	2	Low
	>150	584281.15	40.82	1	Very low

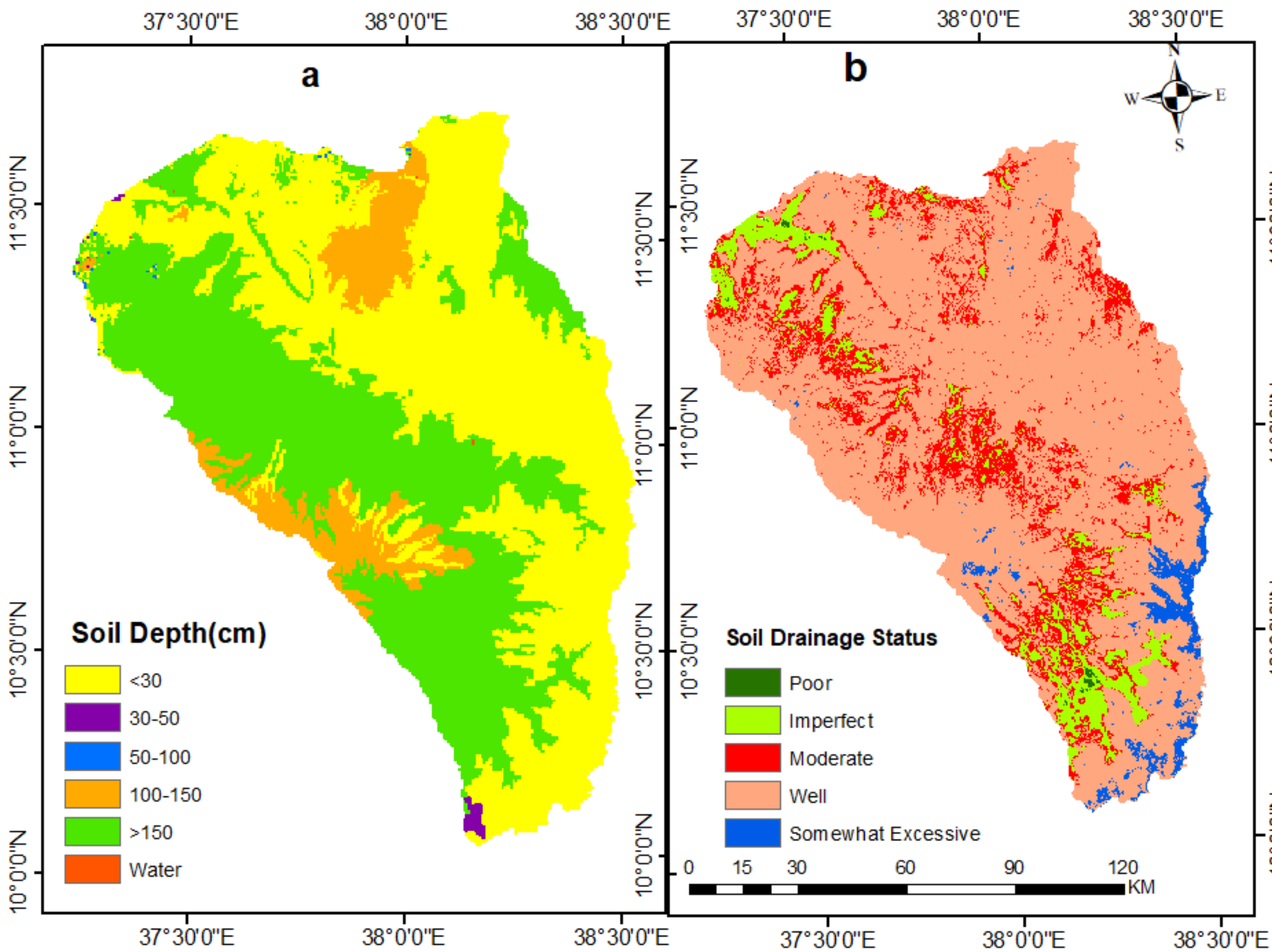

Figure 5.8. Soil bulk depth (a) and soil drainage (b) in the north Gojjam sub-basin.

5.3.2. The State of Physical Land Degradation

The weights of the four indicators which contribute to physical land degradation (soil erosion, soil compaction, soil drainage, and soil depth) have been derived through a pairwise comparison. The weight has been given based on the influence of every subclass on land degradation. The calculated pairwise comparison matrix consistency ratio is 0.01, indicating a consistent comparison. As the overlay analysis result depicted in Figure 5.9 shows, the majority (72.8%) of the sub-basin physical land degradation level was moderate.

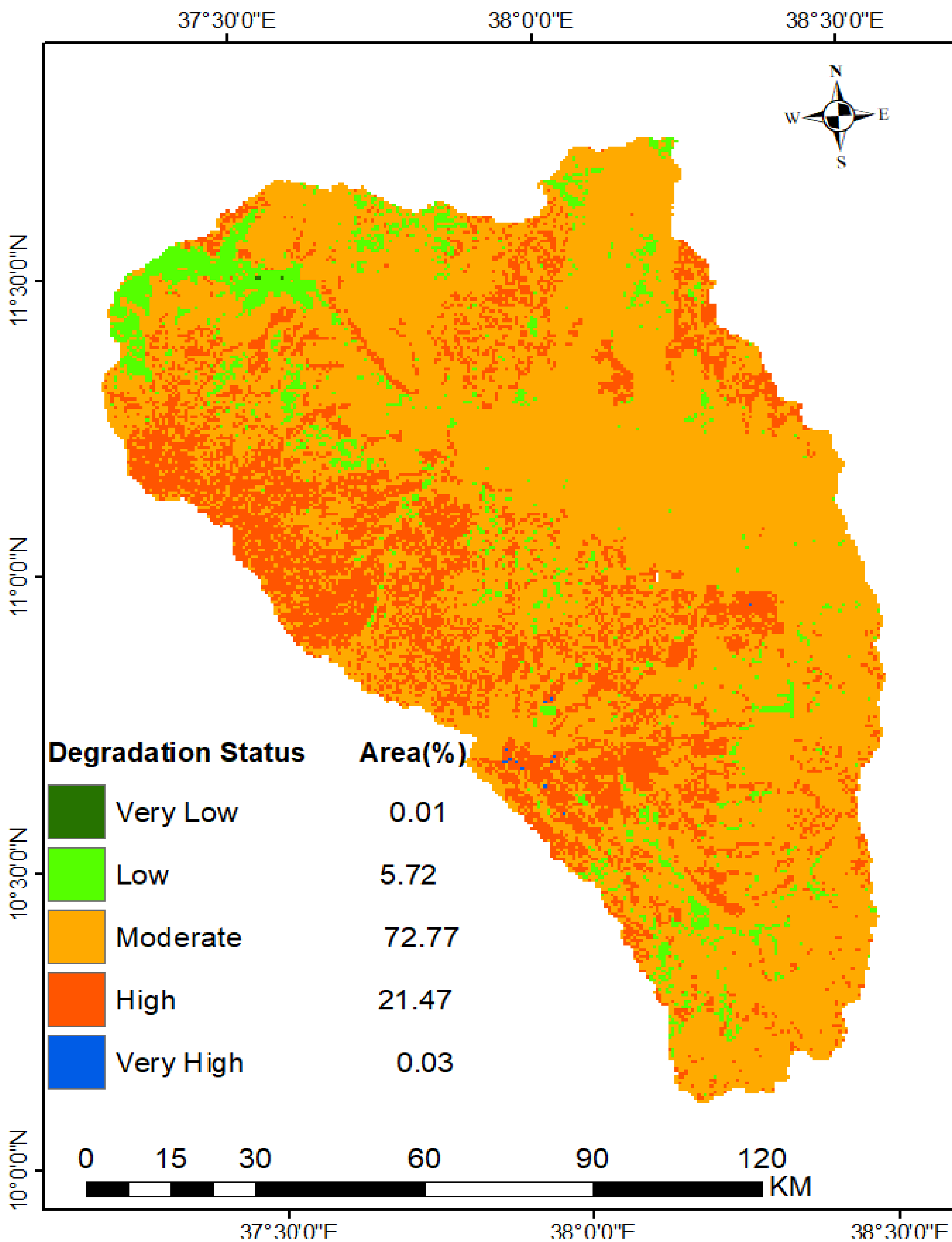

Figure 5.9. State of physical land degradation in the north Gojjam sub-basin.

The weights of pairwise comparison matrix result show that soil drainage, soil depth, soil erosion, and soil compaction were the most to the least important physical land degradation indicators in the north Gojjam sub-basin (Table 5.10). This implies that the wider area of the sub-basin's physical land degradation status was moderate (Figure 5.9). Most low vegetation cover areas fall under the shallow soil depth due to the presence of high soil erosion. Similarly, local farmers in the study area reported physical land degradation problems in the form of low soil infiltration rate, soil depth reduction, and soil erosion. In both formal and informal discussions, farmers explained that there is an increasing problem related to soil compaction on their farm fields. They did report that due to soil compaction, rainwater infiltration into the soil has been decreasing and result in an increasing soil erosion rate. Soil depth has decreased due to erosion from runoff water and continuous cultivation, particularly on steep slopes and croplands. These discussion points suggest that physical land degradation may be an increasing problem in the sub-basin. According to Amede (2003), soil erosion by water is the mainland degradation agent in the Amhara regional state.

Table 5.10: Pairwise comparison matrix for physical land degradation indicators

Criteria	Soil drainage	Soil depth	Soil Erosion	Soil compaction	Criteria Weighting
Soil drainage	0.49	0.52	0.47	0.42	0.48
Soil depth	0.25	0.26	0.32	0.25	0.27
Soil Erosion	0.16	0.13	0.16	0.25	0.18
Soil compaction	0.10	0.09	0.05	0.08	0.08

5.3.3. Biological Land Degradation Indicator

Vegetation cover: As Figure 5.10 shows, the spatial patterns of vegetation indices in the north Gojjam sub-basin ranged from -0.2 to 0.86. As seen in Table 5.11, about 20.9% and 60.3% part of the sub-basin have moderate and poor vegetation cover, respectively. These areas are characterized as moderate and high land degradation status, respectively. As shown in Table 5.11 and Figure 5.10, more than half of the sub-basin was classified as having high to very high land degradation levels according to the vegetation indicator. The severity was higher in the lowland area than the highland in the sub-basin, where the concentrations of plantation and grazing land were low.

Table 5.11: Statistics of mean soil adjusted vegetation index (SAVI)

SAVI classes	Area (ha)	Area (%)	Cover Status	Assigned values	Degradation level
< 0.1	67972.77	4.75	Very poor	5	Very high
0.1-0.2	862529.67	60.26	Poor	4	High
0.2-0.3	298752.48	20.87	Moderate	3	Moderate
0.3.- 0.4	172708.74	12.07	High	2	Low
> 0.4	29396.34	2.05	Very high	1	Very low

The status of soil organic matter (SOM): The spatial distribution of soil organic matter content in the north Gojjam sub-basin ranged from 0.15% to 1.86% (Figure 5.10). As Table 5.12 depicts, for a large area (72.6%) of the sub-basin soil organic matter proportion ranged from 0.2 to 0.6%, a low SOM value that is considered to be highly degraded for this indicator. Low SOM is associated with greater erosion and with low levels of micro-organisms in the soil. Higher SOM indicates the presence of richer flora and fauna residues at various stages of decomposition, and soils that are rich in humus content. The low level of SOM found over most of the north Gojjam sub-basin may be due to continued cultivation and collection of crop residues for domestic energy, livestock feed, and home building materials in favor of use as mulch on the farm fields. Free grazing is also one of the causes of decreasing crop residue in the study sub-basin.

Table 5.12: Levels of soil organic matter of topsoil in the north Gojjam sub-basin

Category(%)	Area (Ha)	Percentage(%)	Level of SOM	Severity level	Assign value
0.15- 0.2	19624.79	1.73	Very low	Very high	5
0.2-0.6	348429.04	72.56	Low	High	4
0.6-1.2	1038570.57	24.34	Medium	Moderate	3
1.2-1.86	24735.61	1.37	High	Low	2

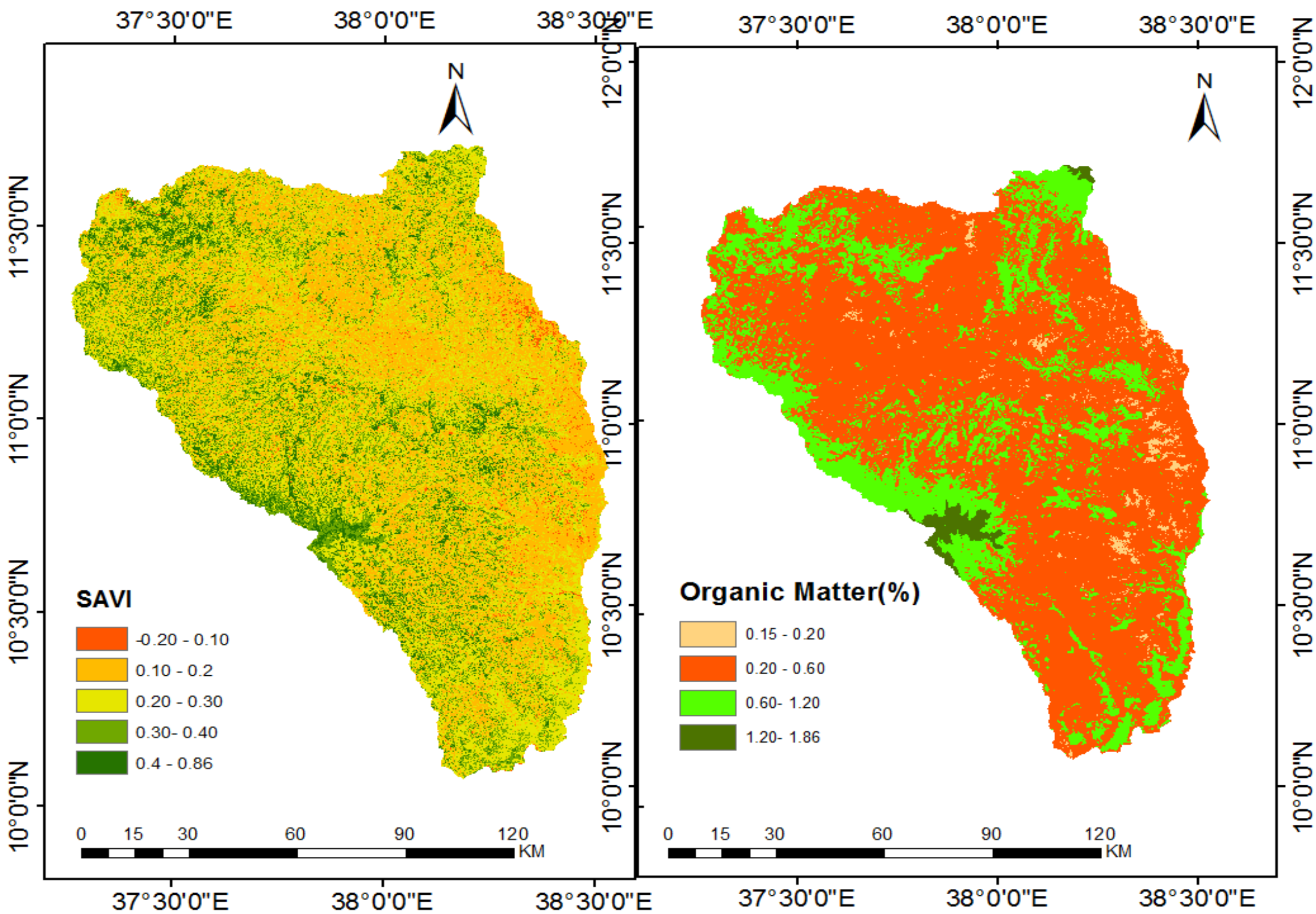

Figure 5.10. Soil Adjusted Vegetation Index (left) and soil organic matter (right) of the sub-basin

5.3.4. The Status of Biological Land Degradation

Similar to physical land degradation indicators, the weights of the two indicators which contribute to biological land degradation (vegetation cover and soil organic matter) have been derived through a pairwise comparison matrix. The weight has been given based on the influence of every sub-class for land degradation. As presented in Table 5.11, soil organic matter was a more influential indicator than vegetation covers for biological land degradation in the sub-basin. The calculated pairwise comparison consistency ratio was zero, which implies that the comparison was perfectly consistent and the comparison is acceptable. As the weight overlay analysis shows in Figure 5.11, 60% and 4.7% of the sub-basin were high to very highly degraded. About 30.8% and 4.4% of the sub-basin has been degraded in moderate and low-level risk. This suggests that more than half of the north Gojjam sub-basin was highly degraded biologically due to vegetation cover degradation and soil organic matter depletion. This result is consistent with local land users' view. In the formal and informal discussions, farmers reported that both fauna and flora have been declining through time on their farmland due to over-exploitation of natural resources. According to the respondents' view, soil nutrient loss by water is an unsolved form of land degradation and is an ongoing problem. They conclude that the loss of nutrients and reduction of organic matter has increased over the recent few decades in the sub-basin.

Table 5.13. Pairwise comparison matrix of biophysical land degradation indicators.

Criteria	Organic matter	Vegetation cover	Criteria weighting
Organic matter	0.67	0.67	0.67
Vegetation Cover	0.33	0.33	0.33

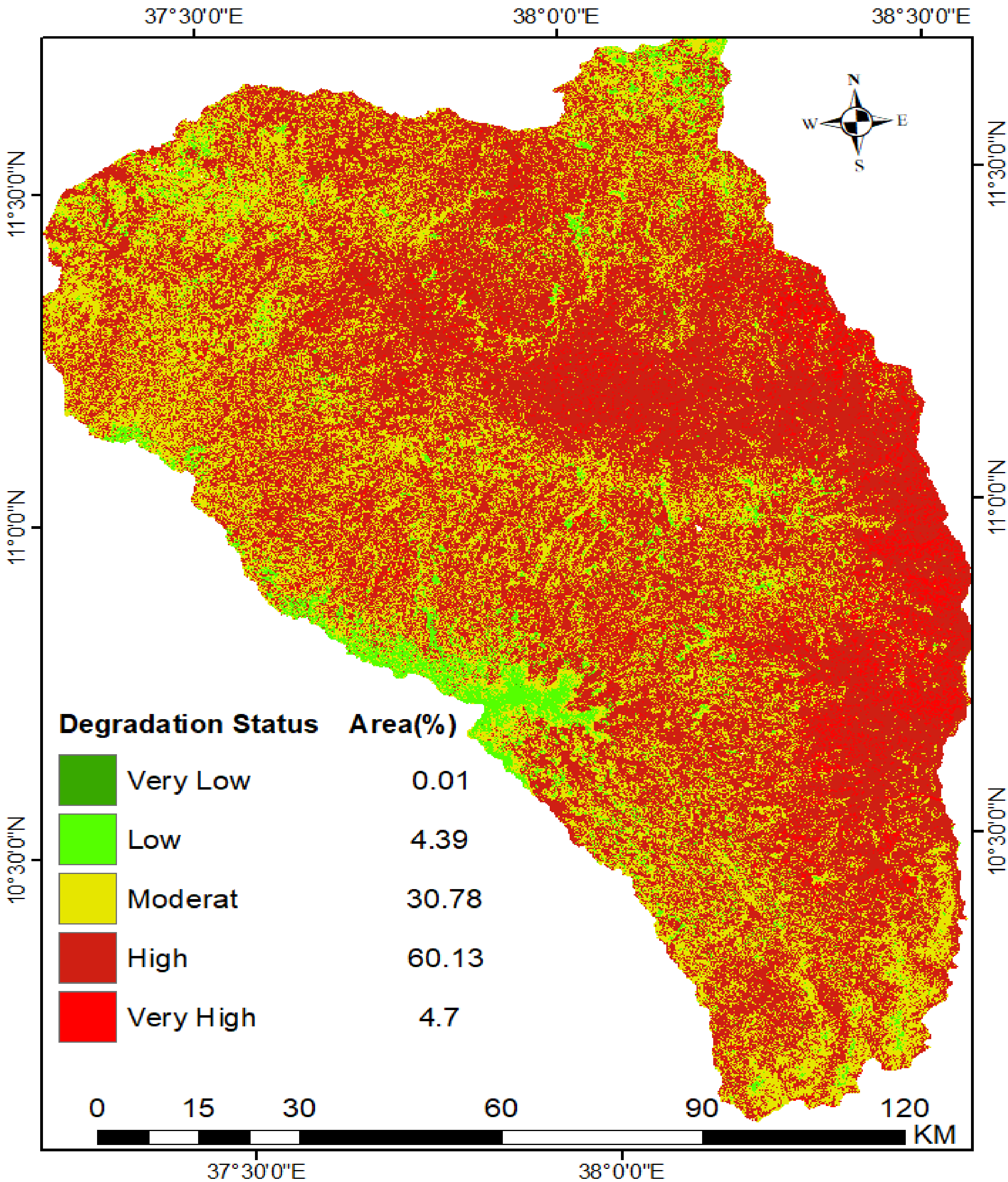

Figure 5.11. Biological land degradation status in the north Gojjam sub-basin

5.3.5. The State of Chemical Land Degradation

The spatial variation of chemical land degradation in the form of soil acidity in the north Gojjam sub-basin varied from 5 to 7.8 pH value (Figure 5.12 and Table 5.14). The result shows that soil acidity level for about an area covered about 4% was less than 5.5 pH value which is considered as high. High soil pH concentration is found in the Choke mountain reserved area, where wet climate condition and water availability is higher as well as the area covered by natural forest and afro-alpine grass. Wet climate and high rainfall leach soluble nutrients from the soil, such as calcium and magnesium which are specifically replaced by aluminum and increased potential for acidic soils (Abate et al., 2017). The decomposition of organic matter produces hydrogen ions, which are responsible for soil acidity formation (Golla, 2019).

About 39% part of the sub-basin experienced soil acidity ranged from 5.5 to 6.7 pH value, which expressed a medium level of degradation (Table 5.14). As Figure 5.13 observed most highland and midland parts of the sub-basin, in which continuous agriculture activity and continuous application of chemical fertilizers takes place, as well as eucalyptus plantation being common, were vulnerable to soil acidity. This might be from the application of acid-forming fertilizers and over-cultivation. According to local experts, due to population growth and persistent demand for food and fuel, the removal of agricultural by-products (crop residues) and continuous crop harvest, and the use of acid-forming inorganic fertilizers are important contributions for increasing soil acidity in the sub-basin. Continuous application of chemical fertilizers with nitrogen and/or phosphorus nutrients only in the form of diammonium phosphate (DAP) and urea has adversely affected soil chemical properties (Golla, 2019). Land used for eucalyptus fields is the most affected by soil acidity (Abate et al., 2017).

However, the majority of the area (55.8%) soil pH value varied from 6.7 to 7.3, a range that is considered neutral, whereas the pH value for the remaining 1.23% of the sub-basin ranged from 7.3 to 7.8, which is characterized as alkaline soil (Table 5.14). The low soil acidity level is located in low land areas, in driest areas. The result implies that almost half of the study area was vulnerable to chemical land degradation. However, no area in the sub-basin was affected by strong soil acidity. FGDs and key informant participants reported that the application of lime on the cropland has been increasing in the last 10 years, due to the increasing problem of soil acidity, mainly in the heavily cultivated middle and upper part of the sub-basin. Nevertheless, most farmers do not use lime to reclaim acid soil due to the scarcity of lime supply.

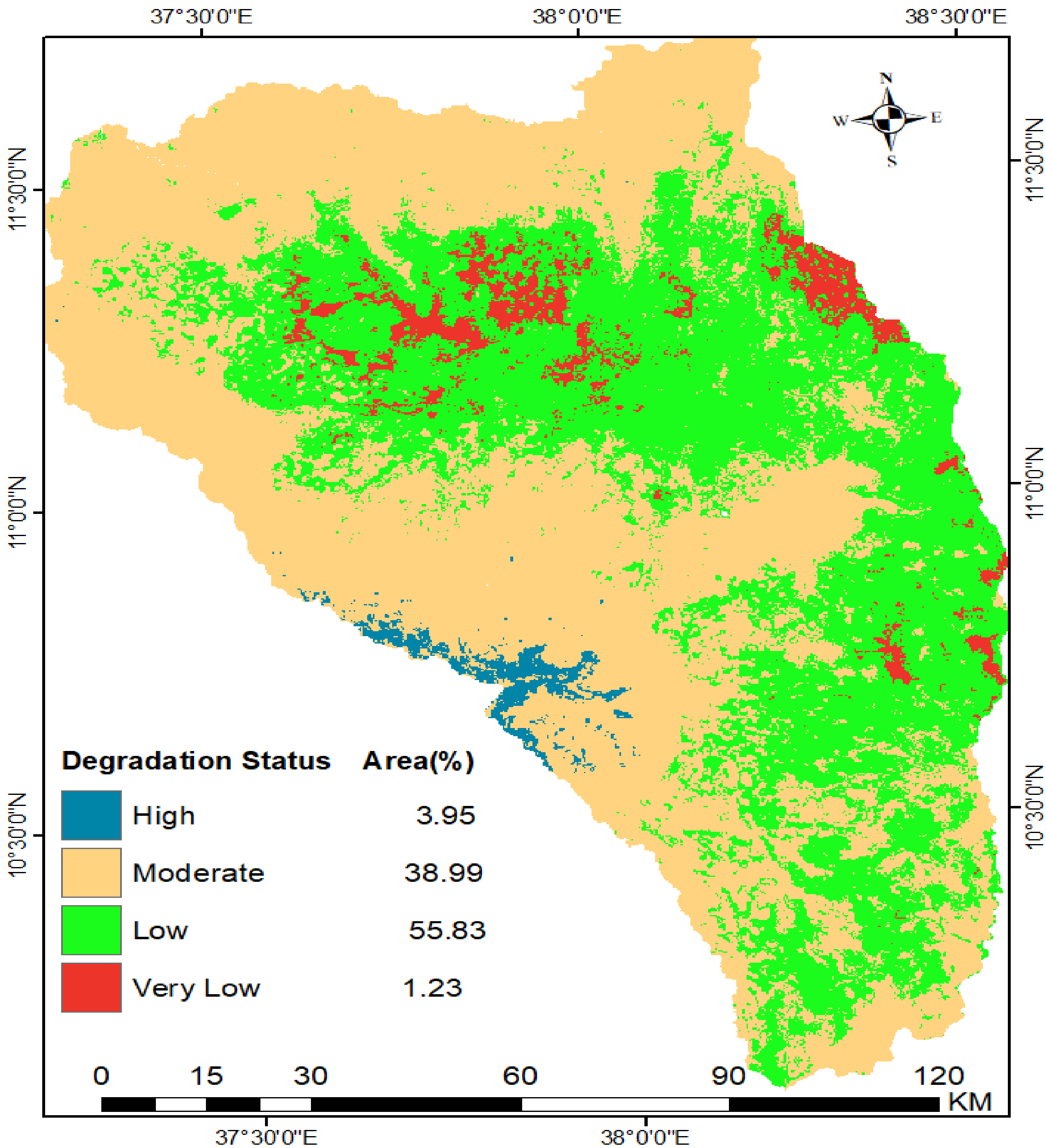

Figure 5.12. Soil acidity status in the north Gojjam sub-basin

Table 5.14: The status of soil acidity in the north Gojjam sub-basin

Soil PH	Area (Ha)	Percentage (%)	Level	Assigned value
5-5.5	56525.14	3.95	High	4
5.5-6.7	558078.76	38.99	Medium	3
6.7-7.3	799124.40	55.83	Low	2
7.3-7.8	17631.70	1.23	Very low	1

5.3.6. The Status of Comprehensive Land Degradation

The comprehensive land degradation map of this study was produced by combining biological, physical, and chemical land degradation indicators. All the parameter raster maps were resampled to 30×30m cell size and re-projected to UTM Zone 37°N, WGS 1984 datum. As seen from the pairwise comparison matrix result in Table 5.15, biological, physical, and chemical degradation indicators were the most to the least important factors for contributing comprehensive land degradation in the north Gojjam sub-basin. The weighted comparison consistency ratio was 0.09, and thus, the comparison was acceptable as the value is less than 0.10.

The result shows that about 32% of the sub-basin area exhibits low-level degradation while about 35.4% is moderately and 30.5% is highly degraded (Figure 5.13). The result shows that the spatial distribution of land degradation in the sub-basin was uneven. As depicted in Figure 5.13, the most highly degraded areas are located in the lower part of the sub-basin. This is a result of several factors: steep slopes, poor land management, and continued cultivation, rugged topography, population pressure, and erratic rainfall.

The moderately degraded areas were located in the middle elevation portion of the sub-basins, where the area is characterized by plain topography and low vulnerability to soil erosion. These factors are confirmed by local land users. Local communities explained that a combination of soil erosion, low vegetation cover, low soil organic matter, and soil acidity contributed to land degradation in the north Gojjam sub-basin. Moreover, they reported that climate conditions, poor agricultural activity, poor grazing, and poor quality of soils had contributed to soil erosion in particular and land degradation in general in the sub-basin. Overall, the combined degradation analysis shows that more than 60% of the sub-basin was moderate to highly degraded. This implies that land degradation is a serious environmental and economic problem in the north Gojjam sub-basin.

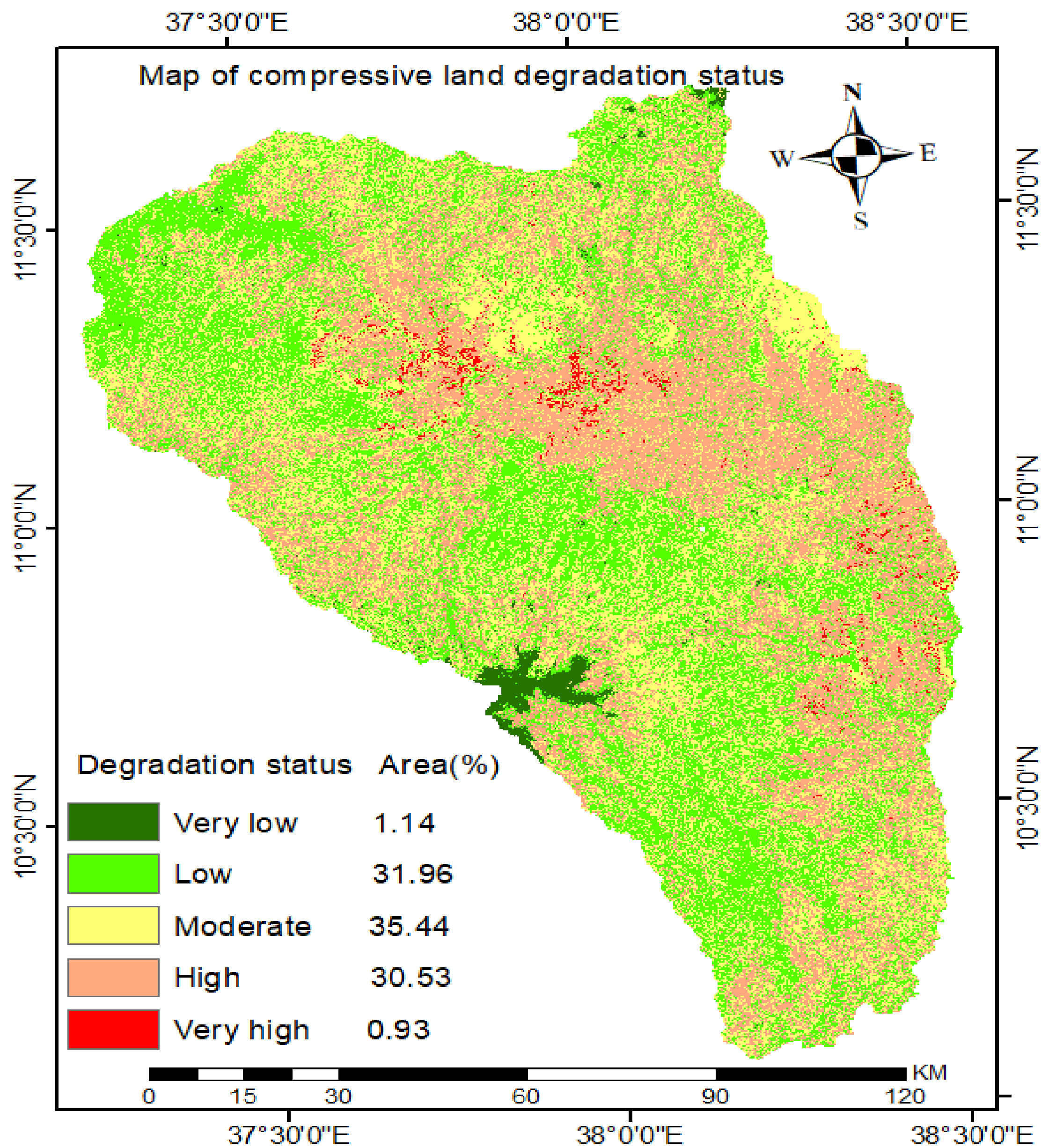

Figure 5.13. Comprehensive land degradation map of the north Gojjam sub-basin.

Table 5.15: Pairwise comparison matrix of land degradation status in the north Gojjam sub-basin

Criteria	Biophysical degradation	Physical degradation	Chemical degradation	Criteria weighting
Biophysical degradation	0.68	0.67	0.70	0.68
Physical degradation	0.23	0.22	0.20	0.22
Chemical degradation	0.10	0.11	0.10	0.10

5.4. Conclusion and Policy Implications

Assessment of land degradation is a prerequisite to developing evidence-based and efficient land management planning. To meet this need, this study mapped and quantified the status of comprehensive land degradation in a typical highland of Ethiopia, the north Gojjam sub-basin of the upper Blue Nile basin. To map and quantify different land degradation indicators into a single indicator, we followed the standardized classification technique in ArcGIS10.5 and the hierarchical spatial MCA approach. The rate of soil loss was estimated using the RUSLE model taking into account the basic factors of soil erosion, including topography, soil characteristics, rainfall, land cover, and local land management measures.

The RUSLE model yields an estimate that on average 46 t $ha^{-1}yr^{-1}$ or a total of 65.2 million tons of topsoil has been lost from the sub-basin annually. About 45.3% of the sub-basin was evaluated to be at high and very high soil loss risk. Most parts of the sub-basin suffered from high to very high biological land degradation. The majority of the sub-basin is moderately affected by soil acidity and physical deterioration of land quality, but biological land degradation was considered to be a more important factor in land degradation than chemical or physical indicators. The result of the combined land degradation indicators confirmed that more than 60% of the sub-basin was moderate to highly degraded.

The diverse aspects of land degradation in the sub-basin point to the need to integrate structural, biological, and agronomic land management measures to maintain sustainable environmental management and economic development. Particularly, lime application and organic fertilizer (compost, manure, and mulching) application are very important to reverse soil acidity and to improve soil fertility status. The adoption of agroforestry and economically viable multi-purpose perennial crops should be promoted to reverse soil degradation and reduce soil erosion in the sub-basin. This requires the collaboration of all the stakeholders to rehabilitate formerly degraded areas and to minimize the current degradation rate as well as to improve ecosystem health and maintain sustainable development in the area. Further, the study confirmed that the use of GIS and remote sensing technologies combined with the spatial MCA technique is a useful tool in mapping and characterizing land degradation using a combination of spatial data indicators. This study considers rill and inter-rill erosion by water. Thus, future researchers should consider gully and riverbank erosion. Soil quality can be measured using different soil essential elements such as hydrogen ion concentration, electrical conductivity, total nitrogen, available phosphorus, potassium, calcium, magnesium, sodium, and others. Future researchers should consider these gaps in the north Gojjam sub-basin. In general, land resource bases are dynamic and diverse across a region depending on the dominant socioeconomic and biophysical factors of that location. This implies that the need for regular engagement with farmers to address emerging opportunities and challenges.

6. Impacts of Land Degradation in the North Gojjam Sub-Basin: Analyzing from Local Land Users' Perspective

Abstract

The objective of this study is to assess the impact of land degradation on rural livelihood in the north Gojjam sub-basin of upper Blue Nile. For the sake of this, questionnaires were administered for 414 household heads and a series of FGD and in-depth interviews with key informants were made. Qualitative data were analyzed using descriptive statistics whereas quantitative data were buildup via description and narration methods. The result indicates that all farmers perceive land degradation as the major environmental problem in the last 10 years in the form of soil erosion; soil nutrient depletion; soil acidity and soil biodiversity reduction in the sub-basin. Most of them perceived its severity as high and increasing from time to time, mainly on crop land during spring season aggravated by unsustainable land management and rugged topography. The majority of farmers perceived as land degradation has been reduced the productivity of crops, livestock, burning materials, and firewood and surface water for the last 10 years. Various water resources such as springs, ponds, and streams were disappearing and rivers have been shrinking. Similarly, the result shows that rural households' food security and net income in the sub-basin have been declined due to land degradation. Further, this paper shows that farmers used various physical land management technologies against land degradation, such as soil bund, stone bund, hillside terrace, check dam, traditional ditches, and waterways. To minimize the impact of land degradation on rural living, agricultural transformation, adoption landscape friendly SLM technology, promoting diverse off-farm livelihoods strategies, improved livestock heredities and the feeding systems, encourage energy-saving technologies and rural electricity are not only very important but also very urgent in the sub-basin to achieve eco-friendly sustainable development.

Keywords*: land degradation, soil erosion, livelihood, impact, north Gojjam sub-basin, Ethiopia*

6.1. Introduction

Land degradation has been threatened the livelihood of billions of people in the world (Crossland et al., 2018; Lal, 2012, 2015; Stavi and Lal, 2014; Utuk and Daniel, 2015). It is the key factor for persistent poverty and food insecurity of the poor living in Asia (Xie et al., 2015), Africa (Khan et al., 2020; Stringer and Dougill, 2013), and Latin America (Torres et al., 2015). According to the evidence from global land degradation assessment, Africa particularly is the most vulnerable to land degradation and the continent has remained a net food importer since the mid-1980s (Obalum et al., 2012; Stringer, 2016). The economic implication particularly severe in Sub-Saharan Africa countries (Nkonya et al., 2008; FAO, 2011; World Bank, 2012) because agricultural production, which is the backbone of the economy, has been extremely affected by abject land degradation (Utuk and Daniel, 2015).

Agriculture is the mainstay of the Ethiopian national economy and about 80% of the population's livelihood (Etsay et al., 2019). But, the productivity of agriculture has been seriously treated by abject land degradation (Berry et al., 2003; Saguye, 2017b). Though in Ethiopia the Estimation effect of land degradation varies considerably, every year the country is losing billions of Birr in the form of soil erosion, soil nutrient depletion, water, and biodiversity losses (Berry et al., 2003; Dubale, 2001; Hurni et al., 2010). For example, soil erosion reduced about 2.2% of agricultural production in the 1986 cropping season (FAO, 1986). Moreover, in 1990 alone reduced soil depth caused by erosion resulted in a grain production loss of 57,000 to 128,000 tons which would have been sufficient to feed more than 4 million people (NCSS, 1991). Similarly, livestock production loss is estimated to be between 35,000 and 78,000 tropical livestock unit (TLU) (NCSS, 1991). Together, these losses represent financial losses of 18 to 40 million *birr*, equivalent to 0.5 to 1.1% of the 1990 agricultural GDP (NCSS, 1991). Besides, nearly 3% of agriculture GDP directly loss attributable to soil loss (Berry et al, 2003).

Gojjam was well known for the abundant cereal production and export of surplus product to Ethiopian cities and other rural regions (Zeleke, 2001). But, the ecosystem productivity has been increasingly challenged by abject soil degradation, climate variability, and poor land management practices (Simane et al., 2016; Zeleke and Hurni, 2001). Thus, the community has been changed from food surplus to food deficit for the last decades (Simane et al., 2012).

The impact of land degradation can be evaluated in many ways from the perspectives of several different scientific methods (Warren, 2002), including satellite remote sensing image, measuring of soil characters, ecological assessment, economic estimation, and expert opinions (Muloo et al., 2019; Reed and Dougill, 2002). But, science has its limitations and may not always provide an accurate diagnosis (Fairhead and Leach, 1995; Muloo et al., 2019). As a result, there is growing calls for integrating scientifically proven knowledge with those of the farmers' local knowledge on the recent land resources degradation problem to develop policies and strategies to promote successful land management strategies (Mairura et al., 2008; Muloo et al., 2019; Ouma and Sterk, 2006). Local people tend to have a concept about the degree of land degradation on their ecosystems, though they may not directly use the term land degradation (Mairura et al., 2008; Ouma and Sterk, 2006). On the other hand, farmers who work closely with agricultural fields have a better perception of the land degradation-related problem. This knowledge has been built from the day-to-day observation of changes in the capacity of the ecosystem services to support their livelihood sources. Such types of ecological land users' knowledge are known as local knowledge (Muloo et al., 2019; Purcell, 1998).

Ethiopian farmers have long been aware of the problems of land degradation (Amsalu and de Graaff, 2007; Nigussie et al., 2017; Saguye, 2018). They have been living on the land for life and their daily ways of life are dependent upon land resources observation. Therefore, farmers can identify land whether good or poor based on crop productivity and grazing land caring capacity experience (Joshi et al. 2019; Muloo et al., 2019). Their awareness of land degradation is the result of cumulative experiences over a long period. As a result, understanding the local people's perception of environmental issues is a prerequisite in making successful and sustainable resource management policy design and promoting land management strategies (Bekele and Drake, 2015; Pender and Gebremedhin, 2004).

Therefore, one can understand farmers' perception of land degradation issue, on the other hand, can identify the level of land degradation problems on livelihood strategies in the locality. Nevertheless, such types of update evidence are scant in Ethiopia in general (Amsalu and Graaff, 2006; Berry, 2003; Bewket, 2012) and no in the north Gojjam sub-basin in particular. As a result, we initiated to assess the recent impact of land degradation on communities' livelihood strategies using local knowledge. Also, this study complements and supplements the previous chapters of biophysical assessments using remote sensing and GIS by seeking to understand how land users in the study area perceived the effect of land degradation related to problems on their livelihoods. Consequently, the rationale of this study emanates from these recognitions.

Therefore, the main objective of the study is to assess the recent impact of land degradation on rural livelihood based on local land users' view in the north Gojjam sub-basin of the upper Blue Nile. The purpose of this study is, therefore: 1) to understand the local people's perceptions on land degradation, which is a prerequisite in making successful resource management strategies. 2) to show land degradation problems associated with farmers' perception of the key livelihood strategies. This information is useful to design projects for sustainable land management and agriculture for increasing farmers' living standards.

6. 2. Methodology

6.2.1. Conceptual Framework

The livelihood of rural people is directly linked to the utilization of land resources for food, energy, and water production. These increasing pressures on the land resource bases coupled with poor land management, result in land degradation and reduces the livelihoods of those who depend on subsistence agriculture. The majority of the Ethiopian population (80%) relies on a mixed agricultural livelihood system, mainly a rain-fed and mixed crop-livestock husbandry system (Gebreselassie et al., 2016). The traditional system of land cultivation has led to the removal of the productive capacity of the topsoil hence a decline in land productivity, which has negative economic and environmental impacts. The demand for wood to build houses and for fuel contributes to the depletion of natural forest and vegetation cover. This results in an imbalance trend between the natural resource degradation and rehabilitation process. Thus, resource exploration results in deforestation and soil erosion and, this links to the livelihoods of the farming community in Ethiopia.

According to Amede and Belachew, (2001), there is a direct link between land degradation and rural livelihood through three paths. First, the decline in soil fertility as a result of land degradation decreases farm productivity and income. As crop/livestock production is the major source of household income in the poor country through nutrient depletion and poor water holding capacity affect the on-farm income significantly. Second, the decline in soil fertility affects the productivity of labour; degraded land requires more labour per unit area than fertile land. Thus, the cultivation of degraded land may reduce off-farm labour allocation at the household level. Thirdly, land degradation decreases the underground and above-ground biodiversity of the system, which in turn, affects the biochemical process of the rhizosphere and the vegetation cover.

6.2.2. Data Sources and Collection Methods

Data for the study were collected through open and close-ended questionnaires from 414 households from May to June 2018. The questionnaire covered ranges of demographic, topographic, plot, infrastructure, and institutional characteristics. It was also covered land users' perception of soil erosion and soil fertility trend. Besides, farmer's views on land degradation impact on crop production, livestock production, water resources, household energy, food security, income, and expenditure for the last 10 years were collected.

6.2.3. Data Analysis Methods

Collected data were summarized and organized by different methods. Quantitative data were analyzed using descriptive statistical methods such as frequency distribution, mean, and percentage using STATA14 and presented using different Tables and figures. While the data gathered from in-depth interviews, FGDs and observation were analyzed and described with simple narration and text analysis methods.

6.3. Results and Discussion

6.3.1. Farmers' View on Land Degradation Extent in north Gojjam Sub-basin

The land is a vital resource for human survival in the north Gojjam sub-basin because almost all rural community relies on a mixed crop-livestock production system. However, severe land degradation has been affected agriculture productivity. Regarding this, almost all respondents confirmed that land degradation is the main challenge of their living. As illustrated in Table 6.1, about 62.54% and 18% of the respondents reported that land degradation is highly and moderately affected farmland productivity, respectively. During FGDs and in-depth interviews, farmers reported that topsoil has been washed by runoff triggered by rugged topography, mainly in the spring season, when land is preparing for sowing seed. At this time tilled cultivated land and grazing land are bare. So, topsoil, crop residues, grass, and other organic matters are easily washed.

Table 6.1: Farmers' perception of land degradation in the north Gojjam sub-basin

Attributes	Dega Damot		Enarj Enauga		Andabet		Total	
	No	%	No	%	No	%	No	%
The current soil erosion in your cultivated land is_______________.								
High	82	74.79	90	65.49	87	51.97	259	62.54
Moderate	19	17.65	17	12.68	38	23	74	17.88
Low	6	5.88	22	15.49	35	21.08	63	15.23
I don't know	2	1.68	9	6.34	7	3.95	18	4.35
The rate of land degradation for the last 10 years in your cultivated land is________________.								
Has become increasing	53	48.74	79	57.04	80	48.03	212	51.21
Has become decreasing	18	16.81	13	9.15	19	11.18	50	12.08
No change	36	32.77	46	33.1	68	40.79	148	35.75
I don't know	2	1.68	2	1.41	-	-	4	0.97
In which land-use type degradation is more severe?								
Crop land	56	51.26	74	53.85	110	66.00	240	57.49
Grazing land	33	30.25	35	25.17	40	24.00	108	26.09
Forest land	20	18.49	26	18.88	13	8.00	60	14.73
All are the same	-	-	3	2.10	3	2.00	6	1.69
Where soil erosion is higher in your cultivated land?								
Near to residence	10	10.2	15	12.30	27	29.67	52	16.72
Faraway from residence	88	89.8	104	85.25	57	62.64	249	80.06
No difference	-	-	3	2.46	7	7.69	10	3.22

On the other hand, the majority (51.2%) of surveyed farmers reported that land degradation increasing while 12% of them confirmed as it was persistent for the last 10 years. But, the rest 35.7% of respondents reported that the land degradation rate was decreasing relative to before a decade. Besides, the majority of surveyed farmers acknowledged land degradation was more severe on cropland compared to other land-use types. More than half (57.49%) of them asserted that land degradation is severe on cereal cropland. While 26% of respondents argued that on grazing land use and the remaining (13.8%) on forest land (Table 6.1). Similarly, the in-depth interview farmers argued that the rate of soil erosion is higher on cropland than other land uses types on the same terrain. This result implies that land degradation in the north Gojjam sub-basin is severe on cereal cropland relative to other land-use types. Farmers recognized the variation of the soil erosion rate from plot to plot based on the distance from their residence. As Table 6.1 describes, the majority (80%) of the respondents replied that the soil erosion problem is less at the homestead. According to qualitative information, homestead land is less vulnerable to erosion because it is the nearest to families' eye and different household consumption and animal fodders remnants (such as straws, hay), and manure dumped on the nearest plot, thus, the infiltration rate is higher than farthest plots.

6.3.2. Farmers Perception on the Types of Land Degradation

In the study area, the main types of land degradation mentioned by local farmers were visible soil erosion and nutrient depletion to decline of crop yield. Local farmers used various indicators to evaluate degradation statuses, such as soil color, soil depth, plant root, rill and gully formation, and the impact on crop productivity. Besides, the surveyed farmers rated the severity of various land degradation types on their plots and the surrounding areas as increase, decrease, and no change trends for the last 10 years (Table 6.2). The finding shows that about 66.57% of respondents reported that the severity of rill erosion has been increasing while about 21% of respondents said that the rill erosion problem was decreasing. In contrast, about 12.35% reported as there was in change for the last 10 years. On the other hand, the development of deep incisions down to the subsoil was the other form of land degradation in the study area. In regard, about 50.6%, 33.4%, and 16% of the respondents confirmed that gully erosion has been decreasing, increasing and the no-change respectively, on their locality for the last 10 years. Similarly, during the field survey, we observed from small to large gullies on various land use types, particularly in communal grazing land that cutting from side to side in a different size.

Riverbank erosion was another indicator of land degradation in the north Gojjam sub-basin. Among the interviewed farmers, 57% indicated as there was increasing riverbank expansion in their locality for the last 10 years due to water erosion. About 19.37% of them noted the expansion of the streams and riverbank sides to other land use types has been decreased while about 23.54% of the respondents replied that as no change in the size of stream erosion. Similarly, farmers described that high livestock concentration resulted in reduced grass and crop residual that protect the soil surface from erosion. These causes for increased soil erosion rate. Moreover, farmers reported that vertical roads used by livestock and human were the other factor of gully erosion. Another cause for gully formation, as we observed in the field and confirmed by local farmers, was traditional drainage ditches (*fesses*), which created by individual farmers using oxen plow. Even if structural SWC was constructed on most plots, farmers used to intercept and divert runoff away from cropland to a waterway or other land-use types. As observed in chapter five, the RUSLE model result shows on average 46t $ha^{-1}yr^{-1}$ and a total of 65.21 million tons of topsoil have been lost annually from the north Gojjam sub-basin. Our finding is comparable to the studies conducted before a decade by (Amsalu and Graaff, 2006) at Beressa watershed, central highlands of Ethiopia and (Bewket and Sterk, 2002), at the Chemoga watershed northwestern Ethiopia, farmers reported that the main forms of soil erosion are rill and gully in their locality.

Soil fertility depletion is one of the key types of chemical land degradation indicators (Marques et al., 2016; Stavi and Lal, 2014). As regards this, about 72.5%, 18.5%, and 6.2% of surveyed farmers acknowledge that soil nutrient depletion has been increasing, decreased and no change, respectively, on their farmland for the last 10 years. Besides, most farmers during informal and formal discussion generalized that soil fertility has been depleting over time as a result of soil erosion, using manure and crop residue for domestic cooking and heating energy, free grazing, using crop residue for construction, absence of fallowing, meager farming, steep slope and using inappropriate SWC technology. On the other hand, local experts also associated soil nutrient depletion with local land preparation and cropping system.

On the other hand, soil acidity has been increasing for the last 10 years, mainly in the middle and upper parts of the sub-basin. But, most farmers do not use lime to reclaim soil acidity due to the scarcity of lime supply. This result is parallel to the geospatial analysis outcome (chapter five). This implies that the loss of nutrients and reduction of organic matter has been increased in the last 10 years due to various factors mentioned above. A similar result was reported before a decade at Beressa watershed, central highlands of Ethiopia by Amsalu and Graaff (2006). But, the result of this study is unlike the study conducted by Bewket (2012), most of the farmers included in the survey (>62%) perceived as their plots are a medium level of soil fertility in the Chemoga watershed.

Table 6.2 Perceived types and rate of land degradation for the last 10 years

Types of Degradation	Trends of Degradation (%)			
	Increase	Decrease	No change	Total
Rill erosion	66.57	21.08	12.35	100
Gully erosion	33.41	50.61	15.98	100
River/streambank erosion	57.09	19.37	23.54	100
Soil fertility decline	72.5	18.5	6.2	100
Soil depth	42.48	14.56	42.72	100
Soil compaction	39.08	20.15	40.53	100
Soil biodiversity	35.21	50.86	13.94	100
Vegetation cover	14.71	80.49	5.81	100

Physical land degradation (i.e. soil compaction and soil depth reduction) in our study area is the other problem. Regarding this, about 40.53% of respondents reported that there is no change in the state of soil compaction in the last 10 years. Only about 39% of the respondents as the soil compaction problem is increased and the remaining (14.8%) reported as it is decreasing (Table 6.2). Similarly, in FGDs frames explained as there is no such problem related to soil compaction on their farm field. But, farmers reported that due to soil compaction rainwater infiltration into the soil has been decreased and result in an increasing soil erosion rate. Table 6.2 shows that out of the total sample, about 42.48% of respondents perceived that soil depth reduction was increased on plots while about 14% replied that soil depth reduction was decreased in the last 10 years.

Likewise, the resulting in-depth interview shows that soil depth has been decreased attributable to the runoff water and continuous cultivation, particularly on steep slope lands. This implies that the reduction of soil depth is one of the problems of physical land abasement in the north Gojjam sub-basin and the result is similar to the fining of (Amsalu and Graaff, 2006), who reported that the loss of soil from cultivated field reduced the depth of the topsoil in the Beressa watershed.

There are different forms of biological land degradation include loss of soil biodiversity, the decline of biomass, and the increase of pests/diseases (Marques et al., 2016; Stavi & Lal, 2014). In our study area, 50.86% of respondents indicated that decreased in soil living things on their farmland while about 35.2% of the respondents replied that there was a severe decrease in soil living things in the last 10 years. Moreover, the majority (81%) of the respondents argued that vegetation covers in the study areas decreased in the last 10 years due to the plantation of eucalyptus trees. But, formal discussion participants replied that both fauna and flora have been declining through time on their farmland include fungi, algae, and a wide variety of large soil fauna, such as earthworms, ants, beetles, termites, insects, and burrowing rodents. This implies that biological land degradation in the sub-basin is the other implication of land degradation increased for the last 10 years.

6.3.3.The Impact of Land Degradation on Rural Livelihood

The impact of land degradation on rural living is severe as the majority of the population in the study area is heavily dependent on the mixing crop-livestock system. According to the local view, land degradation reduced crop productivity, livestock productivity, water resource, and natural firewood, household food access, and income, and these result in continuous persistent poverty in the last 10 years (Table 6.6).

6.3.3.1. Impacts on Crop Productivity

Crop production is determined by different factors in Ethiopia, these include climate variability, land quality, water availability, farm inputs, and practical knowledge of farmers (Mekuria and Mekonnen, 2018; Merga and Haji, 2019; Mussema et al., 2015). But, land degradation aggravated by climate extremes is the major challenge for the optimal crop yield. Regarding this, about 63.2% of the respondents reported as crop yield per hectare is decreasing compared to before a decade in the north Gojjam sub-basin (Table 6.6). Similarly, information from FGD and in-depth interview confirmed as land degradation is the primary challenge to produce potential crop productivity. They reported that, without external input such as chemical fertilizer/ manure/ compost, the current land does not support optimal crop production. Particularly, legumes and oilseed crops have been declining attributable to the reduction of soil fertility. Even in some areas cultivated lands are observed switched from crop production. Accordingly, farmers increasingly shifted from crop production to eucalyptus plantation, particularly in the highland parts of the sub-basin. The finding of this study agrees with the scientific observation of (Amsalu and Graaff, 2006), which found that the reduction of land productivity was perceived by almost all of the interviewed farm households in the Beressa watershed.

Table 6.3: Reasons for the decline of Agricultural production in the north Gojjam sub-basin

Reasons	Respondents (%) n= 269				
	Most Critical	Very Critical	Critical	Fairly Critical	Not critical
Loss of soil fertility	54.59	22.97	10.00	7.84	4.59
Drought/water shortage	30.00	25.41	26.49	13.24	4.86
Erratic rainfall	11.89	14.59	14.05	33.78	25.68
Scarcity of farmland	92.5	4.5	2.00	2.00	-
Crop diseases and /pests	15.95	15.41	9.73	20.27	38.65
Poor farming practices	11.38	15.45	10.57	20.05	42.55
Shortage of oxen	-	2.5	-	2.5	95.07
Water logging	22.76	12.11	57.38	7.26	0.48

Moreover, local land users were rated the drivers of crop yield reduction from the most critical to not critical ones on his/her farmland. Accordingly, scarcity of cultivated land and soil fertility depletion was acknowledged by 92.5% and 54.59`% respondents as the most critical factor for the reduction of crop production. Waterlogging and shortage of rainfall were also reported as the critical problems on crop reduction by 57.38% and 26.49% of the respondents, respectively. While erratic rainfall and crop disease are considered as fairly critical and not critical via 33.78% and

20.27% of the respondents, respectively for the decline of crop yield (Table 6.3). On the other hand, local experts' explained that land degradation causes the easy vulnerability of various crops to climate changes such as rainfall shortage, hailstorm, frost, runoff water, and crop diseases. In general, the result shows that soil degradation contributes to the low potential of crop productivity in the last 10 years. The result is comparable to the study conducted by Gashu and Muchie (2018), which found that land degradation affected crop production in Chilga district, Northwestern Ethiopia.

6.3.3.2. Impacts on Livestock Productivity

Livestock has a multi-faced role for rural living in Ethiopia (Dawit and Solomon, 2017; Mekuria and Mekonnen, 2018). Like elsewhere in Ethiopia, cattle are dominant in number in the north Gojjam sub-basin followed by sheep, goat, donkey, horse, and mule. According to local farmers, livestock in the study area is a central element for the whole farming activities include for draught power, transport, sources of cash for external farm inputs, and manure production. Livestock is the core source of living next to crop production because income from livestock is used to pay social, and government obligations as well as to purchase food crops during a food shortage. Small ruminants like sheep and goats and poultry are kept mostly by land-scarce poor farmers for commercial purposes. Sheep are common in the upper while goats are in the lower and middle parts of the sub-basin. On the other hand, livestock is directly used for food nutrition supply such as egg, meat, milk, and milk products (i.e. butter, cheese). Besides, livestock is one of the sources of dung for domestic fuel for food cooking in the study sub-basin. However, the productivity of livestock is declining over time as a result of land degradation. The feeding sources of the livestock population in the sub-basin primarily rely on natural pasture followed by crop residue. According to key informants, the feeding system in the rainy season is grazing while in the dry season is crop residue. But these feed resources are inadequate, and declining over time. The currently available grazing land is fragmented and highly degraded and located around homesteads, hillsides, wetland, roads, and waterside areas. This implies that the livestock feeding system still backward i.e. there is no improved and processed livestock feeding system in the study area.

On the other hand, land degradation results in a water shortage for livestock in the sub-basin. Water has become more severe in the last 10 years; springs, streams, and rivers have dehydrated and the existing ponds becoming empty. In the study sub-basin, farm households travel on average 35 minutes to access water for their livestock. As presented in Table 6.6, about 51.57%, 32.45% and 15.74% of the surveyed households reported that the impact of land degrading on livestock productivity is decreasing, increasing and no change in the last 10 years, respectively.

On the other hand, farmers in the study area were rated the drivers of livestock productivity reduction. Therefore, the shortage of grazing land ranked 1st while water shortage ranked 2nd level by the majority of respondents. Similarly, the majority of respondents rated the recurrent drought as the third factor for livestock quality reduction in the sub-basin (Table 6.4). Besides, most farmers during the in-depth interview also recognize that the impact of land degradation on livestock number and productivity has been increased over time. The quality and quantity of meat, milk, and milk production has been declining in the last 10 years. This results in the reduction of households' income and food access. The outcome also shows that land degradation results in physical deterioration, delaying of birth rate, and vulnerability to diseases of livestock in the study area. Similarly, the quality and quantity of livestock products, such as meat, milk, and milk products have been declining hopelessly for the last few decades in the study area. The finding of this study is similar to the study conducted by (Amsalu and Graaff, 2006), which found that livestock numbers have decreased in the Beressa watershed.

Table 6.4. Drivers of livestock productivity reduction since the last 10 years

Drivers	Rank by local farmers perception (%) n=414				
	1st	2nd	3rd	4th	5th
Water scarcity	10.33	55.5	35	-	-
Scarcity of grazing land	88.15	5.5	3.5	1.65	1.25
Labor shortage			3.04		97.02
Disease/ parasites	-	-	5.05	95.15	-
Drought	1.52	39	53.5	3.5	2.5
Average time to travel for accessing water for livestock in minute (Walking)					34.66

6.3.3.3. The Impact on Households' Income and Food Security

Persistent land degradation has been changed the community from surplus food to food deficit in the north Gojjam sub-basin. Regarding this, about 56.04% of the surveyed farmers in the north Gojjam sub-basin reported as their income is increasing in the last 10 years (Table 6.6). Similarly, farmers in the series FDGs discussion confirmed that the income of the majority has been increased as a result of the increasing market price of agricultural yield. However, their expenditure has been increased alarmingly due to increasing external agricultural inputs together with its price as well as government and other social duties. Agricultural inputs such as chemical fertilizer, pesticide, and medicine prices for livestock have been increased alarmingly through time. Therefore, the income of the household gained from agriculture has not compensated for the expenditure and debt. About this, a majority (86.44%) of the surveyed farmers reported that their household expenditure has been alarmingly increasing in the last 10 years (Table 6.6). The result of this study is in line with the study conducted by Holden and Shiferaw (2004) which reported that crop yield was reduced in the subsequent years due to the reduction of topsoil depth, and this has a direct impact on household income and food security.

Besides, about 69.57% of the surveyed farmers reported that their food supply has been decreasing for the last 10 years because of the reduction of land size and productivity, and increasing in farm input price (Table 6.6). Similarly, farmers in both formal and informal discussions reported that, unlike the previous period, in recent years the majority of households are only able to produce food to meet their family requirements and sometimes they suffer from food shortage. Local elders asserted that before 50 years we had harvested excess agricultural yield not only for family feeding but also for the market because we had enough and fertile cultivated land to produce crops and rear livestock effectively without any external input. Currently, attributable to soil nutrient depletion farmlands could not yield sufficient food crops for the increasing population and showed a large rate of malnourishment. Particularly, legume type (field pea, horse beans, and chickpeas) crop production highly decline in the study area. On the other hand, as we mentioned above food production from livestock such as meat, milk, butter, and others has been declined due to the low carrying of grazing land. The available food crops, livestock, and livestock products have been sold for purchasing external agricultural inputs to reclaim degraded cultivated land. This is the other reason for food shortage at home in the study area. This suggests that the food insecurity problem has been increasing in the north Gojjam sub-basin due to the reduction of agricultural production aggravated by land degradation. This result is comparable to the findings of (Ighodaro et al., 2016), who reported that land degradation, in the form of soil erosion, is affecting food security and rural livelihoods in South Africa.

6.3.3.4. The Impacts on Water Resources

According to the information obtained from district water resource development offices and intensive field observation, the north Gojjam sub-basin is the water tower of the region. The sub-basin is endowed with different clean water resources, such as springs, ponds, streams, and rivers. But surface water resources have been decreasing over time as a result of land degradation. The majority of FGD participants believed that land degradation has been increasing in the last 10 years. According to them the quantity and quality of water had been decreasing because of soil erosion, decreasing soil depth, deforestation, expansion of eucalyptus plantation, and decline rainfall patterns. They explain that soil cannot absorb much rainwater so that rainwater flow directly inters into streams and rivers by carrying fertile soil. Hence, springs, streams, and ponds have been drying and rivers become decrease. This result was confirmed by almost all survey respondents (53.6%), who reported that the volume and quality of water bodies in their surroundings has been decreasing over time (Table 6.6). Commonly, the community experienced three months of water scarcity, in the driest months (March to May). During this time, to fetch water for domestic use, but in some areas, households used hand pump water for domestic use in the recent decades. Generally, in history, although the north Gojjam sub-basin receives high rainfall, the local witness reported that water quality and quantity have been decreasing attributable to impacts of land degradation. From this, we can generalize that land degradation highly affected surface water resources in the north Gojjam sub-basin.

6.3.3.5. The impact on domestic cooking energy

In the north Gojjam sub-basin, population growth is resulting in increasing the pressures on natural forests attributable to increasing demand for firewood in the last 10 years. The majority (46.14%) of respondents said that degradation of natural forests results in firewood and burning material scarcity (Table 6.6) for the last 10 years. Almost all communities in the sub-basin rely on firewood, crop restudies, and dung for domestic energy for cooking and heating using the traditional three-stone stove. As a result, households in the sub-basin were forced to walk long distances to collect firewood from the nearby forests, and some farmers bought wood and used crop residues and animal dung for cooking and heating. On average, households walking 50 minutes to collect firewood (Table 6.8). Among the respondents, about 44.78% of the respondents were self-sufficient with firewood because they have eucalyptus trees. Even though in recent period energy-saving stoves were introduced only 20% of respondents were used (Table 6.5).

Table 6.5: Farmers' sources of energy in the north Gojjam sub-basin

Sources of energy	Rand by farmers perception (%) (n=414)				
	1st	2nd	3rd	4th	5th
Eucalyptus wood	52.05	17.26	10.77	11.54	8.76
Croup residue	22.5	48.54	24.36	2.83	2.62
indigenous trees	8.45	13.8	26.94	45.41	5.4
Animal dung	17	20.66	39.34	13.54	9.36
Others	0	0	0	26.79	74.21
Average distance to collect firewood			50.51 minutes		
Self-sufficient with firewood energy	Yes = 44.78		No = 55.22		
Energy-saving technology	Yes=20.80		No = 79.20		

In general, the above result shows that land degradation adversely affected the source of living for the community's livelihood in the north Gojjam sub-basin. Especially, it highly threatened crop yield, livestock production, surface water resources, and household cooking energy, income, and food security. This makes more of the households operate a subsistence level of living in the sub-basin. Besides, indirectly land degradation affects the livelihoods through ever-increasing external agricultural input requirements coupled with the rising price to reverse deteriorated soil to produce food crops. The other implication of this finding is that farmers in the study area are well perceived the adverse impacts of land degradation on their livelihoods. Farmers' perception of their environment provides critical evidence on the understanding of their farmland management practices (Amsalu and Graaff, 2006; Bewket, 2012; Legesse et al., 2012; Ouma and Sterk, 2006). Knowing the effect of land degradation on food security can motivate farmers to work out different strategies to reduce the impact or seek other alternatives to cope up with the problem. Besides, the recent level of poverty is seriously aggravated by low agricultural yield caused by abject land degradation in Ethiopia (Zeleke, 2002). This forces the community to live under a vicious circle of poverty with environmental degradation.

Table 6.6: Perceived impacts of land degradation on communities' living for the last 10 years

Livelihood strategies	Response (%) n = 414			
	Increasing	Decreasing	No change	I don't know
Crop productivity	21.7	65.05	10.77	2.48
Livestock productivity	32.45	51.57	15.74	0.24
Surface water quantity	16.18	53.62	29.23	0
Household cooking energy	42.27	46.14	10.00	1.59
Average household income	56.04	34.30	9.18	0
Average household expenditure	86.44	9.93	3.39	0.24
Food security/ availability	21.50	69.57	8.94	0

6.3.4. Farmers' Perception and practices on the Structural SWC Measures

Most farmers in the study area perceived and used one or more SWC technology to prevent soil erosion. During the time of the survey, most respondents replied that soil erosion can be prevented through the practicing of different SWC measures and applied at least one structural SWC measure on their farmland (Table 6.7). Contour plowing is not applied by all local farmers along with contouring. Rather, most farmers used the crisscross (up and down) farming system to mix the soils because they did not aware this farming system vulnerable to soil erosion. Traditional ditches are the major structural SWC measures used by all local people in the sub-basin to control soil; seed and fertilizers from runoff water. Though ditches are perceived by almost all respondents as preventing soil erosion, it is a cause for gully formation in the study area. Ditches are prepared for each crop season during the preparation of cropland before and after sowing seeds. The building of ditches is the simplest practice relative to other SWC measures.

Similarly, the cutoff drain is practiced by one or more farmers on upper cultivated lands. According to local farmers, particularly this measure constructed to protect the seed, soil, and fertilizer from runoff water which comes from grazing, forest, or other cultivated land before it enters into prepared land and turned to either waterway or other drainage systems. Like the cut of the drain, the waterway is mostly built by more than one framer to drain water downslope between their plots of land. It catches run-off water from various sources of conservation measures such as ditches and cut-off drains. And it reached runoff water into gullies, streams, and rivers. During the field survey, key informants explain that the width of the waterway depends on the steepness of the slope and length of the waterway, catchment area, and the amount of runoff water. A check dam is practiced to prevent different gullies and waterways from more expanded. It is built across the floor of the gully or waterway to slow down water flow and stops the gully from getting deeper and wider. Framers in the study area made a check dam from stone and wooden plots and branches. However, during transaction walking, we observed, the constricted check dams were seen being destroyed in different gully floors.

Soil bund is used by most farmers in the study area along contours with the excavated soil banked upslope were soil conservation measures that were introduced by the government's extension service. On the other hand, the stone bund is used in sloppy and stone available areas, especially, on communal grazing land. However, in some areas, both soil and stone bund technologies are properly managed and a lack of maintenance was observed in the sub-basin. Hillside terraces are used at degraded and shallow soil along the contours. As the name indicates, hillside terraces are mostly constructed on steeper land to control run-off, allow sufficient time for the filtration of water. Besides, community-based afforestation and reforestation were applied on communal lands, but, most planted trees are not gowning attributable to lack of follow-up after planting. Free grazing is another reason for the unsuccessful afforestation and reforestation in the sub-basin.

Table 6.7: Farmers' perception and practice in the north Gojjam sub-basin

Questions	Response (%) n=414	
	Yes	No
Can the current land degradation rate prevented using structural SWC measures	100	0
Have you applied any structural SWC measures on your farmland	96.39	3.61

6.4. Conclusion and Policy Implications

Land degradation is a great challenge for rural livelihoods in the Ethiopian Highland. This study assessed the impacts of land degradation on rural livelihood using local land users' view in the north Gojjam sub-basin. Data were collected from 414 randomly selected household heads, key informants, FGD participants, and field observation. The result shows that land abasement is one of the major threats to land productivity. Farmers reported that the magnitude of land abasement is high and the rate is increasing through time, especially on the cereal cropland during the spring season because cultivated land is bare at this time. The study shows that land degradation, in the form of soil erosion, soil nutrient depletion, soil acidity, and loss of vegetation cover, has been increasing for the last 10 years. Soil erosion in the form of rill and gully erosion is yet solved but, these erosion types have been increasing and result in higher topsoil loss.

The finding shows that land degradation has been continuing the adverse effects on both crop and livestock productivity, which is the main source of livelihood and food security in the north Gojjam sub-basin. Various water resources such as springs, ponds, and streams have been disappearing from the surface and rivers have been shrinking in the last 10 years. Besides, burning materials have been continuously declining, and accordingly, rural households are forced to walk a long distance to collect firewood. These cumulative effects of abject land degradation coupled with climate change and land shortage result in persistent poverty.

Therefore, based on the findings of this study, it is suggested that family planning is important to reduce the pressures on limited land resource bases. Farmers used expletive substances rain-fed farming system, therefore intensive farming should be implemented by promoting investment for agricultural sector transformation. It is very urgent to improve rural livelihood and food security as well as environmental rehabilitation to absorb the high population in the study area. Most farmers depend on cereal crop production, thus there should be government interventions for promoting the growth of cash crop-based agroforestry (vegetable and fruit) focus on both food productivity and environmental conservation.

Though livestock in the area is the key engine for agricultural activity and food security, productivity is very low. So it should be improved livestock heredities and feeding systems using forage technologies to generate a high yield from a few livestock. Promote technologies that substitute the livestock's role in the agriculture sector (i.e. transpiration, plowing, and harvesting). Besides, SLM activities should be integrated with the livestock fodder and growing of forage species on degraded lands. The rural community in the sub-basin is dependent on traditional biomass energy for cooking and heating. Therefore, energy-saving technologies and rural electricity should be promoted. To minimize soil erosion and soil fertility depletion, investing in high input and output of farming and landscape-friendly SWC technologies should be promoted. Generally, to cease the effect of land degradation on rural livelihood, the study suggested that land degradation in general and soil erosion, in particular, should be stopped and the degraded areas should be rehabilitated to achieve food security and sustainable development.

7. Relationship and Determinants of Sustainable Land Management Technologies in North Gojjam sub-Basin of the Upper Blue Nile, Ethiopia

Abstract

Sustainable land management (SLM) is the main policy issue in Ethiopia, however, the adoption and continuous use of SLM technologies remain low. This study investigates the causality and determinants of farmers' decision to adopt SLM technologies in the north Gojjam sub-basin of the upper Blue Nile. The study was based on the analysis of cross-sectional data collected from 414 randomly selected rural household heads, focus group discussions, and key informant interview participants. Descriptive statistics and Econometrics models (i.e. Multivariate probit and Poisson regression) were used to analyze the qualitative data while the content analysis method was used for quantitative data analysis. The result indicates that at least one type of SLM technology was implemented least on one plot by 94% of farm households in the north Gojjam sub-basin. The most widely used SLM technologies were inorganic fertilizer, soil bund, and animal manure. Most adopted SLM technologies are complemented each other. Farm size, family size, male-headed household, participation in local institutions, perception of soil erosion, livestock size, total income, and extension service increased the adoption probability of most SLM technologies. But, plot fragmentation, household head age, plot distance, off-farm income, market distance, and perceptive farmland as fertile discouraged the adoption probability of most SLM technologies. To scale up SLM technologies against land degradation should be considered several demographic characteristics, the capacity of farm households, and plot-level related factors integrated with the characteristics of SLM technologies to be adopted on the same farmland.

Keywords: *sustainable land management, adoption, determinants, multivariate, passion, North Gojjam sub-basin*

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7.1. Introduction

Land degradation is a major threat to improving rural livelihood strategies in Sub-Saharan African (SSA) countries, where the majority of the population depends on subsistence agriculture (Liniger et al., 2011; Zeweld et al., 2018; Le et al., 2016). In Ethiopia, agriculture is not only the leading economic sector but also a way to build the welfare of society (Gedefaw et al., 2018; Shiferaw and Holden, 2001). The agriculture sector is the main source of livelihood for more than 80% of the population (CSA, 2015), but agricultural productivity has been seriously threatened by abject land degradation in the form of soil erosion and soil nutrient depletion (Gedefaw et al., 2018; Hurni et al., 2010). The country has struggled to feed its growing population, and the problem may become more severe in the near future if agriculture yields are not increased (Hurni et al., 2010). The problem is particularly critical in the highland regions, where the majority of the population depends on crop-livestock mixed subsistence agriculture systems (Gebremedhin and Swinton, 2003; Hurni et al., 2010). The major causes of land degradation in the Ethiopian highlands are rapid population growth, climate variability, top-down planning systems, poor implementation of policies, limited use of SLM technologies, and frequent organizational restructuring (Hurni et al., 2010; Kassie et al., 2008).

Recognizing the need to slow and reverse land degradation to achieve food security, the Ethiopian government has prioritized the adoption of SLM technologies since the 1970s (Amsalu and de Graaff, 2007; Gebremedhin and Swinton, 2003). Over the past decades, various SLM development projects and strategies have been designed and employed by the government and through foreign initiatives (Abi et al., 2018; Teshome et al., 2016). Nevertheless, adoption rates and sustained use of SLM techniques have been below expectation (Amsalu and de Graaff, 2007; Gebremedhin and Swinton, 2003). As a result, the country continuously lost a tremendous amount of topsoil resources (Bewket and Teferi, 2009; Haregeweyn et al., 2017). Farmland cultivated without nutrient amendments and further reducing soil fertility status and widening yield gaps are continued (Platts and Leong, 2020). Focus on physical soil and water conservation (SWC) technologies, inappropriate installation of SLM technologies, top-down implementation approaches, and a lack of farmers’ motivation to invest on land management over the long run are among the reasons for these failures (Amsalu and de Graaff, 2007;Teshome et al., 2016).

Bearing in mind these constraints, the government of Ethiopia has gradually shifted to new SLM strategies, approaches, and technologies for smallholder farmers using extension agents and technical experts to realize access to infrastructure, training, sustainable energy resources, and agricultural technology inputs (FDRE,2010 and 2016; World Bank, 2020). Since 1995 the government has integrated several SLM technologies into agricultural extension packages through community mass mobilization at the watershed level (Abi et al, 2018; Teshome et al., 2016). These include the SLMP-I (2008–2013) and SLMP-II (2013–2018) (World Bank, 2020); Resilient Landscapes and Livelihoods Project (RLLP) (2019–2024); Climate Action through Landscape Management (CALM) Program (2019–2024); Making Environmental Resource to Enable Transition to More Sustainable Livelihood (MERET) project, Public Work Programme of the Productive Safety net Programme (PSNP) incorporated into the SLM program (World Bank, 2020). Similarly, the country has followed an agricultural production intensification approach to boost crop productivity on the smallholders through the application of modern agricultural inputs, primarily improved seed and fertilizer technologies to feed the rapidly increasing population (Dorosh and Rashid, 2013; Sime, 2018; Sisay et al., 2017). In Gojjam, watershed management based on mobilizing free labor was a common program. Despite the widespread implementation of SLM technologies, the adoption rate remains low.

Several studies have addressed factors affecting the household's decision on the adoption of SLM technologies in the Ethiopian highlands (Amsalu and de Graaff, 2007; Asfaw & Neka, 2017; Mekuriaw et al., 2018; Miheretu & Yimer, 2018; Teshome et al., 2016). But, the earlier studies have focused on a single technology and ignored complementarity and trade-offs between integrated SLM practices and missed important variables that were included in the SLM technology adoption program (Amsalu and de Graaff, 2007; Asfaw and Neka, 2017; Mekuriaw et al., 2018; Miheretu & Yimer, 2018; Teshome et al., 2016). Most of the studies modeled the implementation of SLM technologies as a binary: adopter and non-adopter. Such modeling approaches ignore the opportunity to capture the preference of land users' behavior from diverse SLM technologies and the simultaneous acceptance decision (Kassie et al., 2015; Murendo et al., 2019; Teklewold et al., 2019; Teklewold et al., 2013). Therefore, the present study is very important to show supplementary and complementary characteristics of adopted SLM technologies in addition to identifying socio-economic, demographic, institutional, and plot-related determinants of SLM technologies adoption by smallholders. Thus, the SLM technology adoption decision is inherently multivariate. In this case, the estimation of farmers' adoption behavior is essentially needed for consideration of the simultaneous and/or sequential decision-making process and the possible trade-off associated with the adopted SLM technologies. Nigussie et al. (2017) showed the determinants of simultaneous SLM technologies, but the study missed important variables, such as compost and improved seed technologies adoption factors. Hence, there is limited research conducted for a better understanding of the interrelationship between the adopted technologies and the determinants of farmers' decisions to adopt simultaneously. Therefore, we intended to analyze the relationship between the adopted SLM technologies and the key determinants of farmers' decision to adopt SLM technologies in the north Gojjam sub-basin of the upper Blue Nile. Explicitly, the paper addressed the following specific objectives: 1) to analyze major factors that affect farmers' decision to adopt SLM technologies. 2) to identify factors that affect farmers' decision to adopt a set of SLM technologies. 3) to show the interdependency of adopted SLM technologies.

The contributions of this paper are threefold: First, this would help to a better understanding of the determinants of the household's decision to adopt single and a set of SLM practices on farmland. Second, insight the interdependent and simultaneous characteristics of the adopted SLM technologies and third it also insight the adoption status for the Ethiopian Grand Renaissance Dam (GERD) because the area is the main sources of water for the dam and thus, knowing the determinants of Adoption of SLM technologies is very important.

7.2. Materials and Methods

7.2.1 Data Sources and Data Collection Methods

Cross-sectional data for this study were collected from 414 randomly selected household heads from January to May 2018 in the north Gojjam sub-basin of the Abbay basin. The questionnaire mainly covered demographic, topographic, plot, infrastructure, and institutional characteristics. Besides, it was covered farmers' perception of soil erosion and soil fertility status as well as types of land management practices being implemented by smallholder farmers in the sub-basin. The household survey was administered by well-trained enumerators under the close supervision and follow-up of the researcher and field assistance. Along with the survey information, qualitative data were collated to catch a variety of information and elucidate farmers' reasons for investing and not investing in the respective SLM technologies on their farmland. Moreover, to the survey, qualitative data were collected through key informant interviews and series FGD to get detailed information for the triangulation of the qualitative information.

7.2.2. Method of Data Analysis

The survey data were analyzed using descriptive statistics and econometric models. Descriptive statistics were used to describe survey households' socioeconomic characteristics, perception of soil erosion and fertility status, as well as SLM adoption status. A multivariate probit model was employed to analyze the interrelation of adopted SLM and the determinants of farmers' decision to adopt SLMs technologies, while the Poisson regression model was used to analyze the intensity of adopted SLM technologies in STATA14. Qualitative data obtained from the key informants and FGDs participants were analyzed using content analysis to triangulate the quantitative results.

7.2.2.1. Empirical Model Specification

Farm households always consider a set of technologies and they try to choose one or more of SLM technologies, which may be used simultaneously or sequentially to solve their farmland problem (Kassie et al., 2015; Murendo et al., 2019; Teklewold et al., 2013). The adoption of SLM technology is inherently multivariate. Thus, the use of the binary probit model is inefficient when adoption decisions are interrelated because the binary model ignores the correlation in the error terms of adoption equations (Murendo et al., 2019; Mwungu et al., 2016). Failure to capture this interdependence leads to unfair conclusions (Kassie et al., 2015; Mwungu et al.,2016). So, to analyze the causal relationships and determinants of farmers' SLM technology adoption, we deploy a multivariate probit (MVP) model following the procedures (Nigussie et al., 2017). This study comprises seven binary choice equations namely, soil bund, stone bund, compost, manure, improved seed[3], agroforestry, and inorganic fertilizer. Hence, we specified the study model as:

$$Y_{im}^{*} = \beta_m X_{im} + \varepsilon_{im} (\text{m=1, 2… 7}) \qquad (7.1)$$

$$Y_{im} = \{1\ if\ Y_{im}^{*} > 0\ and\ \ 0\ otherwis$$

[3] We consider improved seeds as SLM technology following the definition of Liniger et al. 2011.

Equation 7.1 is developed based on the assumption that a rational $\mathrm{i^{th}}$ farm household has a latent variable $\mathrm{Y_{im}^{*}}$ which captures unobserved preferences related to the $\mathrm{m^{th}}$ choice of SLM measures (m = 7 SLM technologies). X_{im} are several exogenous variables that determine SLM adoption, such as households' socioeconomic, demographic, institutional, and plot characteristics (Table 7.1). The coefficient of β_m is a set of parameters that reflect the effect of change in the vector of dependent variables. ε_{im} represent error terms following a multivariate normal distribution, each with a mean of zero and a variance-covariance matrix with values of 1 on diagonal and non-zero correlations as off-diagonal elements (Cappellari & Jenkins, 2003).

$$\text{Covariance matrix } (\epsilon_{i1} \ldots \epsilon_{i7}) \sim V = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} & \rho_{15} & \rho_{16} & \rho_{17} \\ \rho_{21} & 1 & \rho_{23} & \rho_{24} & \rho_{25} & \rho_{26} & \rho_{27} \\ \rho_{31} & \rho_{32} & 1 & \rho_{34} & \rho_{35} & \rho_{36} & \rho_{37} \\ \rho_{41} & \rho_{42} & \rho_{43} & 1 & \rho_{45} & \rho_{46} & \rho_{47} \\ \rho_{51} & \rho_{52} & \rho_{53} & \rho_{54} & 1 & \rho_{56} & \rho_{57} \\ \rho_{61} & \rho_{62} & \rho_{63} & \rho_{64} & \rho_{65} & 1 & \rho_{67} \\ \rho_{71} & \rho_{72} & \rho_{73} & \rho_{74} & \rho_{75} & \rho_{76} & 1 \end{bmatrix} \tag{7.2}$$

Where, $(\epsilon_{i1}, \epsilon_{i2}, \epsilon_{i3}, \epsilon_{i4}, \epsilon_{i5}, \epsilon_{i7})$ are denotes correlated disturbances, and ρ is a correlation parameter between SLM technologies in the model. A positive correlation shows a complementary among SLMs while a negative correlation depicts the substitution relationship between adopted SLM technologies (Kassie et al., 2015; Teklewold et al., 2013).

Poisson Regression Model (PRM) was used to analyze the determinants of farmers' decisions to adopt several SLM technologies. Because the number of SLM technologies is a count variable, ranging from 0 to 7 in our case. Following Ramírez (2000), the PRM model of the dependent variable ($\mathrm{y_i}$), which was constructed as the sum of the binary responses of the SLM measures implemented on the plot by the $\mathrm{i^{th}}$ rational farmer specified as:

$$E\,(y_i) = \beta x_i + \varepsilon_i \tag{7.3}$$

where $E\,(y_i)$ is the expected value of the dependent variable for the i^{th} rational farmer, β is the set of parameters that reflect the impact of change, x_i is a vector of observed variables, and ε_i refers to the error terms in the model result.

7.2.3. Concepts of Sustainable Land Management (SLM) Technologies

SLM is defined as a knowledge-based process that helps to integrate natural resource bases such as soil, water, forest, biodiversity, and environmental management to meet rising human food demand and sustainable ecosystem services. SLM technologies can be grouped as structural, agronomic, and vegetative management measures used to control soil erosion, reduce nutrient depletion, improve soil conservation and enhance productivity (Abi et al., 2018; Liniger et al., 2011). Farmers have been using various SLM technologies in the Ethiopian highlands (Abi et al., 2018; Teshome et al., 2016).

Structural SWC measures have been used to either been reducing the length of the slope of the land or to reduce runoff water. By doing this, the movement of water over the surface is stopped or slowed down, which will not cause erosion (Branca et al., 2013). From these types of SLM technologies, we considered both soil and stone bund. The agronomic SLM technology is aimed at production and conservation at a time (Liniger et al., 2011). From these types of technology, we included compost and manure applications as it was promoted by extension agents in the study area. The application of manure refers to the use of livestock waste by scattering on the surface of the plot or placing manure in the seed hole at the time of planting (Branca et al., 2013). Compost is an excellent soil fertility building technology which supplies a wide variety of plant nutrients. Farmers prepare compost from livestock dung, plant leaves, weeds, crop residues/ straws, topsoil, water, and other available organic materials. Similarly, chemical fertilizer application is usually done at the time of planting in the study area. Its application rate is higher relative to organic fertilizer, though, owing largely to financial liquidity constraints faced by poor smallholders. Application of agroforestry refers to planting multipurpose trees on the plot (Mganga et al., 2015), such as animal forage trees, planting trees on the bund, perennial fruit, shrubs, and buckthorn in the same management unit with cereal crops (Branca et al., 2013; Kirui and Mirzabaev, 2015).

7.2.4. Explanatory Variables Considered in this Study

The consideration of the hypothesized explanatory variables used in this study was drawn from the empirical literature on the determinants of SLM and agriculture technology adoption (Amsalu and de Graaff, 2007; Asfaw and Neka, 2017; Gebremedhin and Swinton, 2003; Kassie, et al., 2008; Kassie et al., 2015; Mengistu and Assefa, 2019; Teklewold et al., 2013; Teshome et al., 2016). These variables included in the model, were socioeconomic (i.e., age, gender, education, family size, dependent ratio); plot-specific attributes (i.e., plot size, distance to the residence, slope position, perceived soil erosion, and fertility status), SLM related training and advice, off-farm income, access to credit, livestock, and total income. The descriptions of the designated variables hypothesized direction of influence, and descriptive statistical measures are presented in Table 7.1.

7.3. Results and Discussion

7.3.1. Characteristics of the Respondents

Households' demographic, asset, institutional, and plot characteristics used in this study are presented in Table 7.1. The majority of the respondents were male-headed (83%) while the minority (17%) were female-headed mainly, divorced and widows. The average age of the study households was 50 years with a minimum of 22 years and a maximum of 85 years. The survey result indicates about 46.5% of respondents were illiterate while 54.5 % could be read and write, who attend formal and informal education. This shows that household heads' in the study area, have adequate farming experience, but a little bit of education status. The family size of the respondent ranged from 2 to 11 members and had a 5.38 mean family size with a 0.81 average dependency ratio.

The respondents' average landholding size was 1.03ha, ranging from 0.15 to 4 ha and, the plots are often not spatially adjacent. They cultivated on average 2.95 plots. Plot distance from the residence is an important factor influencing the adoption of SLMs because of increased transaction costs on the farthest plot, particularly the cost of transporting bulk materials such as manure and compost. The farthest plot usually receives less attention and less frequent monitoring in terms of watching and guarding (Kassie et al., 2015). In the study area, plots taking 58 minutes walking one-time round on average from the farmer's residence. Most plots were used for annual cereal-legume crop production. Almost all respondents received the current land certification card. According to an in-depth interview, a land certification card gives for the farmer to feel secured.

Table 7.1. Description of explanatory variables included in the model

Variable's name	Variable description (coding/units)	Exp. sign	Mean	SD
Gender	Household head gender type, 1= Male, female =0	±	0.82	0.38
Age	Age of the household head (years)	–	50.32	14.83
Education	Educational status of household head, (years)	+	1.56	0.68
Family size	Number of the family member (Number)	±	5.38	2.19
Dependency ratio	The ratio of members aged below 15 and above 64 to those aged between 15-64	–	0.81	0.73
Farm size	Area of cultivated land, (in ha)	±	1.03	0.71
Plot number	Land fragmentation, (Number)	–	2.95	1.81
Farm distance	Plot distance to the residence, (minutes of walking)	–	29.31	17.82
Steep slope	The slope of a plot perceived as a very steep=1	±	0.21	0.37
Moderate slope	The slope of a plot perceived as a moderate =1	±	0.43	0.49
Gentle Slope	The slope of a plot perceived as a gentle =1	+	0.36	0.48
Soil fertility	Farmland soil status perceived as good fertility =1	±	0.35	0.47
Soil erosion	Farmland perceived as high soil erosion=1	±	0.54	0.49
Market dis.	Plot distance to residence (minutes of walking)	–	122.04	57.69
Training	Household received SLM-related training =1	+	.39	.48
Extension serv.	Household received constructive SLM advice =1	+	0.62	.49
Media	Access to newspapers, own radio/TV/ mobile =1	+	0.35	.47
Membership	Participating in village clubs =1	+	0.87	0.34
Access to credit	Household received credit =1	+	0.34	0.48
TLU	Livestock herd size in TLU	±	4.13	2.66
Off-farm	If one of family members involved on off farm =1	±	0.18	0.81
Income	Household total annual cash income (ETB)	±	67 664.64	14556.47

Note: ± indicates a mixed result expectation. ETB is the Ethiopian Birr (currency).

Characteristics of farmland vary from flat to very steep slopes, and from very fertile to poor fertile soils. While evaluating the plots, on average, about 21 % of respondents replied that their farmland is a steep slope, 43% moderate slope whereas only 36% is the plain sloped. In the study area, about 35 % of the plot is perceived as fertile by land users. The majority of the farmlands were perceived as moderate to very severe eroded states. Access to extension service is a very important element of institutional support needed by farmers to enhance the use of SLM technologies. In the study area, the most important sources of information cited were through communication with relatives and neighbors, and the government's extension agents for improving farming production. For this purpose, three Development Agents (DAs) were assigned in each sample village/ kebeles in the study area. Thus, respondents were also asked to reply to the satisfaction of advising from experts, here about 62% of respondents reported as they have gotten constructive advice. Likewise, about 39 % of respondents attend SLM-related training on average about two times per year. Moreover, about 35% of respondents had their own radio/mobile. About 87 % of the sampled households were involved in a farmers' cooperative group. Farmers in the study area, on average walking two hours, to arrive at the nearest input-output market from their residence.

Livestock is a vital factor for farming activities in the study area. Farmers have different livestock, includes cattle, sheep, goats, horses, donkeys, mule, and poultry. Respondents possessed about 4.13 tropical livestock units (TLU). But, during the FGD and in-depth interview, farmers stated that there was a shortage of feed for their livestock, attributable to the decreasing size of grazing land and the decline carrying capacity of grazing land. Respondents had an average annual income of 67, 664.64 ETB (USD 1≈ETB 29) in the survey year. About 18% of respondents were engaged in off-farm activities. About 45% of the respondents had received credit from formal institutions, while about 34 % did not need any credit because they are wealthy or credit averse whereas the remaining 21% did not need credits.

7.3.2. The State of SLM Technology Adoption

Farmers in the north Gojjam sub-basin used various SLM technologies. But, based on the extension agent priority, seven SLM technologies were considered in this study, including soil bund, stone bund, manure, compost, inorganic fertilizer, improved seed, and agroforestry (Fig. 7.1). Among the total respondents, 69.1% used soil bund while 44.4% used stone bund. The spacing and depth of both soil and stone bunds construction vary from plot to plot depending on the slope and soil characteristics of the plot. The result of FGD and in-depth interview confirmed that structural SLM technologies were deliberately destroyed by farmers because it was considered as a shelter for rodents; barriers to plowing; occupied fertile cropland area and poor performance for controlling soil erosion.

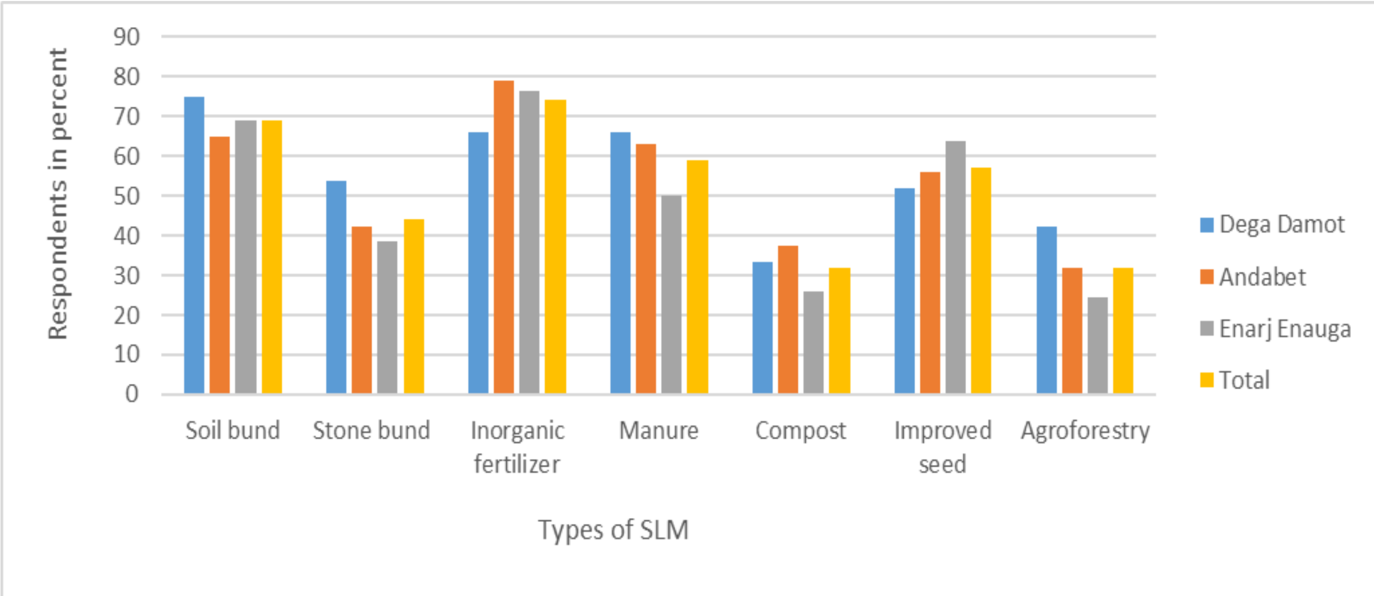


Figure 7.1. Type and extents of SLM practices across districts in the north Gojjam sub-basin

Inorganic fertilizer was used widely by 74.4% of the respondents. Most farmers used chemical fertilizer below the recommended amount due to a lack of finance to purchase and the inaccessibility of its supply. According to the in-depth interview, the use of manure was limited around the homesteads attributed to the shortage of manure. Of the total respondents, about 59% used manure in the study area at least on one plot. Similarly, compost application was used by a small number of respondents (32%) during the survey season, due to lack of awareness, shortage of inputs, and labor to prepare it. The improved seed was used by 57% of the respondents during the survey season at least on one plot of land. The interviewees argued that improved seed does not have access at the right time and right place to be used in the study area. The use of agroforestry practice on private farmland appears to remain very low in the north Gojjam sub-basin. It has been practiced by about 32% of respondents during the survey year. The majority of local peasants were not well-aware of agroforestry technology adoption and its benefit. Though soil acidity is a major problem in the sub-basin, the use of lime is very low due to shortage of supply and lack of farmers' knowledge about lime (i.e. in the district level: lime used by 3% of households in Dega Damot; 3% in Enarj enough districts). But lime was not used in Andabet district during the survey season. Generally, the result shows that structural and agroforestry SLM practices were more used in the

Dega Damot district, whereas inorganic fertilizer was implemented in Andabet district. Conversely, the improved seed was adopted more in the Enarj Enauga district. Of the seven SLM technologies, inorganic fertilizer was widely used followed by soil bund and manure.

7.3.3. Number of Adopted SLM Technologies

Among the Seven SLM technologies, land users used from zero to seven simultaneously on their plot in the north Gojjam sub-basin (Figure 7.2). The result shows that about 6% of the respondents have not applied any of the SLM technologies. This shows a few still used none of the 7 SLM technologies because they may be used other traditional SLM measures like a ditch. The result shows that about 18.8% of the respondents have adopted one SLM technology. Besides, 37.2% of them have used two SLM practices and only 20% of them used three types of SLM technologies. Soil bund and chemical fertile are the two technologies are frequently used by stallholder framers in the study area. About 10.1% and 6.7% of respondents applied four and five SLM technologies on their plots respectively. In sum, the result shows more than 94.2% of respondents in the study area used one or more SLM technology on their farmland during the survey season. This confirmed here was the interdependence between the adoption choice of SLM technologies. The result shows the intensity of the SLM adoption rate across the three districts was almost similar.

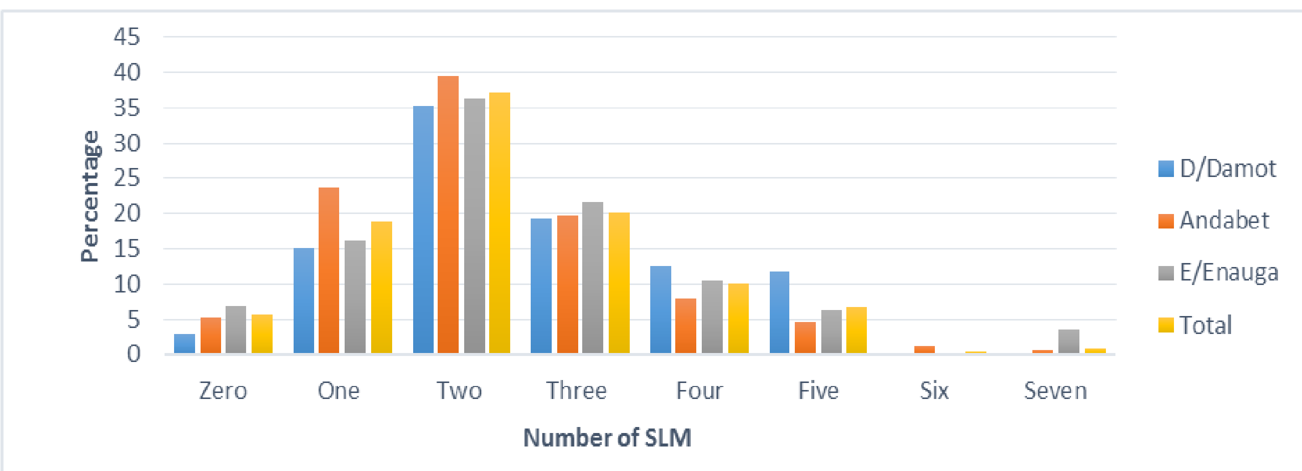


Figure 7.2. Number of SLM technologies adopted in the north Gojjam sub-basin

7.3.4. Empirical Results

Table 7.2 and Table 5.3 show MVP and PR model analysis results. The results of the PR model fit the data well because it is statistically significant at p = 0.00 with a log-likelihood ratio (X^2 (22) = 60.48) and Pseudo R^2 = 0.0685. Similarly, the choice of the MVP model is more justified by the significance likelihood ratio test (X^2 (21) = 108.76, P = 0.00), confirmed here the presence of interdependency among the adopted SLM technologies and to apply the MVP model in the data analysis process.

7.3.4.1. Relationship Among the Adopted SLM Technologies

The regression result in Table 7.2 shows that the presence of interdependence between the seven adopted SLM technologies in the north Gojjam sub-basin. Among the positive and significant correlations, the highest (0.8) is observed within an improved seed and inorganic fertilizer technologies. Soil bund and chemical fertilizer (0.6); improved seed and soil bund (0.4); soil bund and agroforestry (0.3); and compost and manure (0.7) are positively and significantly correlated. The results imply that the adoption of physical land management technology induces the application of short-run land management technologies in the north Gojjam sub-basin. Soil bund promotes the application of agroforestry like animal fodder and various plantation trees. Adoption of improved seed highly encouraged the use of chemical fertilizer. Moreover, farmers in the sub-basin used compost and manure jointly.

In contrast, there is a negative association among adopted technologies in the north Gojjam sub-basin. Manure and inorganic fertilizer (0.6); and compost and inorganic fertilizer (0.2) were correlated negatively and significantly. This implies that the two external agricultural inputs, inorganic and organic fertilizers, are not used by farmers in the sub-basin jointly. This shows that the application of chemical fertilizer is substituted by organic fertilizer (manure and/or compost). Because the application of organic fertilizer is labor-intensive whereas chemical fertilizer is capital-intensive and if farmers have the fund to purchase chemical fertilizers, may ignore the labor-intensive technologies (manure and compost). On the other hand, if farmers are endowed with sufficient labor, may not decide to use capital-intensive technologies, i.e., chemical fertilizer.

Generally, the results explain the fact that farmers are faced with the complementarity and substitutability of SLM technologies in the north Gojjam sub-basin. Most of the adopted SLM technologies correlated positively, which suggests the argument of farmers usually used a combination of long-term and short-term land management technologies. Farmers in the open discussion reported that, though not enough, they used a combination of SLM technologies in the study area. The results of this study are in line with the previous empirical studies of (Kassie et al., 2015; Mengistu & Assefa, 2019; Sileshi et al., 2019), who reported that farmers face various land degradation problems, and thus, they used more than one SLM technologies.

Table 7.2: Correlation coefficients of MVP regression result (Standard errors in bracket)

	ρ^{SOB}	ρ^{STB}	ρ^{MA}	ρ^{COM}	ρ^{FER}	ρ^{SED}	ρ^{AGR}
ρ^{SOB}	1						
ρ^{STB}	.029	1					
	(.116)						
ρ^{MA}	-.347	-.067	1				
	(.122)***	(.109)					
ρ^{COM}	-.091	-.115	.682	1			
	(.125)	(.105)	(.087)**				
ρ^{FER}	.573	.195	-.109	-.264	1		
	(.119)***	(.136)	(.129)**	(.136)**			
ρ^{SED}	.407	.157	.118	.005	.766	1	
	(.120)***	(.099)	(.102)	(.106)	(.072)***		
ρ^{AGR}	.296	.081	-.077	-.029	.065	.109	1
	(.119)**	(.105)	(.108)	(.109)	(.133)	(.109)	

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 = rho52 = rho62 = rho72 = rho43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho74 = rho65 = rho75 = rho76 = 0: chi2(21) = 108.76, Prob > chi2 **, *** significant at 10%, 5%, and 1% levels, respectively. SOB=soil bund, STB=stone bund, MA=manure, COM=compost, FER= chemical fertilizer, SED=improved seed and AGR= agroforestry.

7.3.4.2. Determinants of farmers' decision to adopt SLM technologies

The MVP and PR model results in Table 7.3 confirmed the influence of households' age on the adoption decision of SLM technology is mixed. Age encourages positively the adoption of inorganic fertilizer ($p < 0.05$) and agroforestry ($p < 0.05$). But, it discourages adoption probability of manure ($p < 0.01$) and compost ($p < 0.05$). This shows that older farmers are less likely to adopt labor-intensive technologies. This might be explained by the fact that younger farmers had a higher probability to adopt manure and compost than the elder ones, probably because younger farmers might be physically strong to collect, prepare and transport the bulk materials. In contrast, older farmers may have more assets to invest in inorganic fertilizer. This study is similar to the finding of Teklewold et al.(2013), (Kassie et al. (2011), and Saguye (2017), who reported that the age of the household head was negatively and significantly correlated with manure application. Miheretu and Yimer (2017) also confirmed that older farmers often invest more in chemical fertilizers because they have more assets than younger ones. Similarly, older farmers are more likely to adopt agroforestry because they have a larger farm size. The implication is that if farmers have small land sizes, they are reluctant to use agroforestry. The result is similar to the finding of Etsay et al. (2019), who found the age had negatively influenced the adoption of agroforestry because younger farmers have small farm sizes.

Gender of the household head has mixed results on the adoption probability of different SLM technologies (Table 7.3). A male-headed household is a more adopter of soil bund ($p< 0.1$), stone bund ($p< 0.05$), compost ($p < 0.1$) and a set of SLM practices ($p < 0.01$). The possible reasons are male-headed households are better exposed to SLM technology information and have more labor and assets to adopt than female-headed ones. Besides, females are tied to home-related tasks, such as taking care of their children and preparing their households' food. In the north Gojjam sub-basin, female farmers depend on the help of male farmers near them or relatives elsewhere to do their agricultural activities. But, females are more likely to apply manure ($p< 0.01$) than male ones. The evidence from qualitative information also shows that in the study area manure related works are female duty, and hence, this seems that females are more manure adopter in the sub-basin. Research conducted by Belay & Bewket (2013) consists of our finding that females were more concerned with animal manure to manage their farmland than male ones.

Education is an important instrument to enhance technology adoption decisions through acquiring knowledge and information for smallholder farmers (Beshir, 2014). The result this paper shows that household headed by those who attained a higher level of education is more likely to apply soil-bound ($p< 0.05$) and inorganic fertilizer ($p< 0.01$). The finding of a positive association between farmers' educational level and these SLM technology applications is consistent with findings of Asfaw and Neka (2017; Kassie et al. (2015), who identified that educational status has a positive influence on the farmers' decision to retain introduced SLM technology. Nevertheless, our study shows that level education was not more significant on a set of SLM technologies adoption in the north Gojjam sub-basin.

Family size has a positive effect on the adoption of soil bund ($P<0.01$), manure ($P<0.01$), compost ($p<0.1$), inorganic fertilizer ($p<0.05$), and many SLM technologies ($P<0.05$) in the north Gojjam sub-basin (Table 7.3). The result indicates that the abundance of labor supply through a larger family size has more probability to adopt several SLM technologies. This result is in line with the findings of Gebremedhin and Swinton (2003) and Miheretu and Yimer (2017), who stated that the presence of more household members favored the adoption of labor-demanded SLM technologies. The same view was also stressed by FGDs and key informant interviews in the north Gojjam sub-basin, explained here, there are no other options to produce family food in their locality other than subsistence agriculture. Consequently, the family labor force often engages in on-farm activities to produce more food.

Theoretically, the influence of farm size on SLM technology adoption decision is mixed. Implies that, larger farm size increases farmers' assets and reduces risk aversion. As a result, a household with a bigger farm is more likely to adopt SLM technology than having a small farm size. In contrast, a household with a small farm size is more likely to intensify production with more investing than their counterparts Saguye (2017) and Belay and Bewket (2013). A household that works a larger size of farmland needs high labor and time to build a conservation structure as well as to keep the fertility status of their plots. In this study, we found a mixed result from farm size on different SLMs adoption decisions. Farm size is positively and significantly correlated with the adoption of soil bund ($p<0.05$), stone bund ($p< 0.05$), inorganic fertilizer ($p<0.1$), agroforestry ($p<0.01$), and many SLM technologies ($p<0.1$). But, large land size decreases the application of compost ($p<0.1$) (Table 7.3). The result shows that structural SLM practices and agroforestry occupied land space, and the profit from conservation may not be enough to substitute for the decline in production due to the loss in the area used for conservation structures. Hence, farmers who have small land sizes are discouraged to adopt such SLM types. Instead, they used non-surface-occupied technologies (i.e., manure and compost). Similar results have been reported from other regions of the country by Amsalu and de Graaff (2017), Mengistu and Assefa (2017), and Ahmed et al. (2017) who reported that structural land management technology positively correlated with farm size.

The likelihood of farmers adopting soil bund ($P < 0.01$), manure ($P < 0.01$) compost ($P < 0.01$), and the number of SLM technologies ($P < 0.01$) declined with an increase in plot fragmentation (Table 7.3). This can be explained that land gets dispersed and fragmented usually creates wastage of time and labor. Because it is scattered in different locations and needs time to reach each plot. This is justified by the qualitative information that explained fragmented plots are challenged to install structural SLM measures and agroforestry because it causes quarrel with the adjacent farm owners unless he/she is willing to use similar technologies in addition to time and labor consumption. Our finding is similar to the result of Asfaw and Neka (2017), Bekele and Drake (2003). A large number of fragmented lands associated with small size discourage the adoption probability of structural SLM technologies.

The present study found a mixed result about the influence of topography on the adoption of different SLM technologies. Regarding this, we found that plots that are characterized by a gentle slope were found to be treated more by manure ($p<0.05$) and compost ($p< 0.05$). But, less likely to adopt a stone bund conservation structure ($p< 0.1$) (Table 7.4). Likewise, a significant and positive relationship was found between a moderate slope plot and soil bund measures. Similarly, the qualitative information confirmed that the use of soil bund on a very steep slope plot is more aggravated than soil erosion. But the stone bund is more important to cope with high runoff and soil loss. In this type of terrain, the application of manure and compost very low due to the reasons that more vulnerable to soil erosion emanated from high-speed runoff. To deter such erosion problems, farmers prefer to implement the stone bund, cutoff drain, and traditional ditches. Similar findings were reported by Gebremedhin & Swinton; Miheretu and Yime (2017), Sileshi et al. (2018); Kassie et al. (2015) found that structural SLM technologies are less widely applied at plain slope plots. It is expected that the better land user perceives the problem of land degradation, the better they can act to adopt SLM practices. But, this study found a negative relationship between the adoption probability of manure ($p<0.05$) and improved seed ($p<0.05$) with the farmers' perception of high soil fertility. The result might be farmers perceive good fertile plots produce better agricultural yield without external inputs, and they might be invested in infertile plots. Likewise, the adoption probability of soil bund ($P<0.01$), stone bund ($P<0.05$), and agroforestry ($p<0.05$) were increased with farmer perception about the severity of erosion, but less likely to adopt manure application ($p<0.01$). This implies that farmers who had already perceived their plots to have soil erosion problems more likely adopt structural SLM measures than those who did not.

Farm distance influences the choice of farmers' SLM adoption in different ways. The present study confirmed that plot distance affected negatively the use of manure ($p<0.1$), compost ($p<0.05$), and agroforestry ($p<0.01$), whereas positively associated with the use of soil bund ($p<0.01$) (Table 7.3). This implies that plots are located near the home of the owner have a higher chance of getting treatment with organic fertilizer and agroforestry than structural measures. The information from the qualitative result also shows that too far plots are challenged to transport compost and manure. Similarly, the adoption of agroforestry in the farthest plot is difficult due to free grazing.

The impact of market accessibility to adopt SLM technology in Ethiopia is unclear (Kassie et al., 2014). Regarding this, the result from MVP in this study shows that household lives close to the market more likely to use inorganic fertilizer ($p<0.05$), improved seed ($p<0.05$), and agroforestry ($p<0.05$) technologies, but less likely to adopt several SLM technologies. This finding is consistent with the studies conducted by Saguye (2017) and Teklewold et al. (2013), who stated that distance to the input-output market has a negative and significant effect on the adoption of land management technologies, reflecting transaction and access cost. Likewise, a household with more market access will tend to receive higher prices for their products and are more incited to invest in marketable technologies. Therefore, the adoption probability of agroforestry is motivated by the output market.

Training for farmers is a vital institutional factor that increases awareness about the benefits of SLM technology adoption. As predicted in Table 5.3, access to SLM related training increased the adoption probability of soil bund ($p< 0.01$), manure ($p < 0.1$), compost ($p < 0.01$), inorganic fertilizer ($p<0.05$), agroforestry ($p<0.01$) and a number of SLM technologies ($p<0.01$) on their farmland. But, access to training in the study area was found very low. Of the total respondents, about 39% have attended two formal SLM-related training in the survey season (Table 7.2). This suggests that SLM-related training and smallholder farmers are important factors for smallholder farmers to inspire the adoption of integrated SLM practices. This result is in line with the findings of Mengistu and Assefa (2017), Gebreselassie et al. (2016), and Saguye (2017), who reported that access to training increased the adoption probability of introduced SWC technologies.

Table 7.3: Determinants farmers' choice to adopt SLM technology: MVP and Poisson Results

Variables	Multivariate probit (MVP)							PRM
	Soil bund	Sone bund	Manure	Compost	Fertilizer	Imp. seed	Ag/forest	No. SLM
Age	-.043	.005	-.021	-.033	.016	-.004	.002	-.004
	(.094)	(.007)	(.008)***	(.008)***	(.010)**	(.006)	(0.01)**	(.003)
Gender	.218	.761	-1.04	.608	.523	.419	.255	.547
	(.289)*	(.319)**	(.328)***	(.318)*	(.330)	(.264)	(.313)	(185)***
Education	.116	-.081	.103	-.180	.893	.204	-.016	.009
	(.053)**	(.129)	(.136)	(.143)	(.215)**	(.125)	(.132)	(.063)
Household	.762	-006	.132	.0292	.127	.052	.020	.083
size	(.222)***	(.042)	(.050) ***	(.053)*	(.059)**	(.041)	(.045)	(.038)**
Farm size	.014	.325	.039	-.091	.061	.115	.920	.036
	(.006)**	(.162)**	(.045)	(053)**	(.057)*	(.164)	(.221)***	(.023)***
No of plots	-.173	-.036	-.105	-.164	.146	.028 (.057)	-.156	-.001
	(.78)**	(.057)	(.06)*	(.073)**	(.248)		(.067)	(.029)*
Plot	.014	-.000	-.011	-.617	-.002	-.010	-.015	-.004
distance	(.006)**	(.005)	(.005)*	(.258)**	(.005)	(.004)*	(.005)***	(.002)
Plain slope	.543	-.629	.543	.558	.278	.304	-.463	-.012
	(.342)	(.290)**	(.261)**	(.301)**	(.383)	(.242)	(.261)*	(.117)
Moderate	.677	.116	.157	.267	.155	.267	.025	-.036
Slop	(.287)**	(.186)	(.194)	(.291)	(.302)	(.182)	(.200)	(.095)
Soil	.138	.046	-.015	.088	-.362	-507	-.233	-.026
fertility	(.273)	(.247)	(.217)**	(.228)	(.348)	(.224)*	(.197)	(.103)
Soil	.947	.173	-.064	-.018	-.173	.360	.393	-.026
erosion	(.251)***	(.212)**	(.208)	(.211)**	(.279)	(.216)*	(.221)**	(.103)
Market	.000	.001	-.0004	.0001	.0017	-.031	-.0005	-.128
distance	(.001)	(.000)	(.0007)	(.000)	(.001)	(.014)**	(.0006)**	(.040)***
Training	.767	.045	.376	.688	.726	.449	.169	.206
	(.257)***	(.183)	(.197)*	(.198)***	(.262) ***	(.177)***	(.191)	(.094)***
Expert	.096	.129	-.249	.093	.020	-.091	.461	-.070
advise	(.249)	(.186)	(.199)	(.200)*	(.236)	(.163)**	(.205)**	(.095)
Media	.506	-.343	.023	.205	.418	.033	-.329	-.046
	(.349)	(.262)	(.279)*	(.302)	(.321)**	(.231)*	(.278)	(.157)
Farm coop.	.375	-.318	-.270	.213	.313	.033	-.411	-.046
	(.330)	(.262)	(.284)	(.319)	(.294)**	.234)**	(.275)	(.130)
Credit	.088	-.153	159	.088	.933	.011	-.197	-.074
	(.236)	(.175)	(.188)	(.191)	(.292)***	(.162)**	(.187)	(.090)
Livestock	-.017	.049	.342	.094	.124	.029	.008	.013
	(.046)	(.036)	(.051)***	(.412)**	(.048)**	(.036)	(.038)	(.017)
Off farm	-.001	-.000	-3.63e-06	-.00001	974	.0415	-.000	-.000
	(.000)***	(.000)	(.000)	(.00001)	(.377)**	(.028) *	(.000)	(.000)
Income	-2.58e-06	-6.52e-06	.00014	9.25e-07	.419	.0002	.00002	9.20e-06
	(.000)	(9.77e-06)	(8.98e-06)**	(.000)	(.184)**	(000) **	(9.80e-6)**	(4.85e-06)*
Constant	-1.77	-1.57	1.04	.960	.750	-.420	.133	.457
	(.837)**	(.680)**	(.692)	(.704)	(.875)**	(.629)	(.680)	(.361)
Wald chi²	(140) = 313.0							
Prob > chi²	0.000							

Significance * p < 0.1, ** p < 0.05 and *** p < 0.01, Number of obs = 258, Standard errors in parentheses

Contact with development agents (DAs) is another important institutional factor that positively influences the decision to adopt SLM technologies. We analyzed the relationship between farmers' satisfaction from experts' advice and the adoption probability of SLM technologies in the north

Gojjam sub-basin. The results show that advice from DAs increased the probability of compost ($p<0.1$), improved seed ($p<0.01$), and agroforestry ($p<0.05$) adoption rate (Table 7.3). Even if technical advising inspires farmers to adopt a combination of land management practices, we did not get a significant difference in the intensity of SLM technology adoption among those who get satisfactory advice from households and their counterparts in the north Gojjam sub-basin. Information is a vital input in making a good farming process and in the adoption of different technologies. Regarding this, we found that households who access mass media (radio/TV) have more probability to adopt manure ($p<0.1$), chemical fertilizer ($p<0.05$), and improved seed ($p<0.1$) (Table 5.3). The result implies that media increases the use of manure and purchased farm inputs, but has an insignificant effect on the use of structural SLM measures and agroforestry. The reason seems to be those who purchased farm inputs, included in the local broadcast program may be aware of farm households. On the other hand, farmers who are a member of traditional working cooperatively can acquire information about agricultural technologies. In line with this, the result of this study confirmed that farm cooperation is significantly and positively increased the adoption probability of stone bund ($p< 0.05$), chemical fertilizer ($p<0.05$), and improved seed ($p<0.01$) (Table 4). Similarly, farmers in the open interview agreed that the contribution of the social network for the resource sharing such as labor, finance, and knowledge exchange to implement SLM technologies. This suggests that to upscale the introduction of SLM practices, local institutions, and service providers have to encourage and assist farmers' cooperatives.

In the study area, the livelihoods of most farmers rely on mixed crop-livestock farming systems. And so, smallholders who have more livestock and large land size are more likely to have a higher output and income and are wealthier. Livestock is a basic part of the farming system and is very important for increasing the resilience of vulnerable poor people when exposed to crop failure, and income shocks. Manure and compost accessibility depends on the size of the herd a household owns. But, the livestock number might not be always a feasible solution for high manure production, introducing high-yield breeds and improved forage may intensify livestock products (Kassie et al., 2008).

As we hypothesized, livestock size increased the adoption probability of manure ($p<0.01$), compost ($p<0.05$), and chemical fertilizer ($p<0.05$) (Table 7.3) in the north Gojjam sub-basin, but less probability to use structural SLM technologies. Correspondingly, qualitative information confirmed that livestock is contributing to households' general wealth, serves as a source of draft power, manure, and transportation, and also sources of cash income to purchase external farm inputs like chemical fertilizer and improved seed. The result is consistent with findings of Kassie et al. (2013), Teklewold et al. (2019), Belay and Bewket 2013), who found that livestock had a significant and positive effect on the use of organic fertilizer.

Access to credit services has a mixed influence on the various adoption of SLM technologies. Regarding this, we found that access to formal credit increases the use of purchase agricultural inputs such as chemical fertilizer ($p<0.05$) and improved seed ($p<0.05$) (Table 7.3). This is consistent with the finding of Miheretu and Yimer (2017) and, Holden et al. (2004) who reported that access to credit has a positive impact on the likelihood of using inorganic fertilizers. This implies that farmers who have better access to credit inspire to invest in purchasing SLM technologies. On the other hand, the impacts of off-farm opportunities on several SLM technologies are theoretically ambiguous (Kassie,2008). Off-farm activity may enable households to access additional income to hire extra labor forces and purchase external agricultural inputs, but such opportunities may also discourage on-farm activities. Regarding this, the MVP analysis result (Table 7.3) shows that off-farm income has a negative and significant effect on the adoption of soil ($p<0.05$) and stone ($p<0.05$) bunds. But, off-farm income increased the probability of inorganic fertilizer ($p<0.01$) and improved seed ($p<0.1$) adoption rate. The result explained the fact that household head’s access to high off-farm income more likely to discourage the use of labor-intensive technologies, but inspired them to invest in the purchased once. Previous studies have consistently shown a negative relation between off-farm opportunity and the adoption of structural SLM technologies (Amsalu & de Graaff, 2007; Asfaw & Neka, 2017). But, our result showed a mixed result on different SLM technologies and implies the relationship between off-farm activities and SLM adoption decision depends on the type of SLM technologies.

The amount of modern farm input utilization, mainly fertilizer and improved seed, is positively associated with household aggregate income. The result of this study shows that farm households with high income were more likely to adopt manure ($p<0.05$), compost ($p<0.05$), inorganic fertilizer ($p<0.05$), improved seed ($p<0.05$), and a set of SLM technologies ($p<0.1$) (Table 7.3) technologies than those with low income. The result of the present study is similar to the finding of Kassie et al. (2013), which reported that farmers with high incomes are higher risk-taker behavior and have the capacity of testing new SLM technologies than those who have low income.

7.4. Conclusions and Policy Implication

The main objective of this study was to investigate the relationship between adopted SLM technologies and determinants of households' decision to adopt SLM technologies in the north Gojjam sub-basin, the upper Blue Nile. The result shows that about 94.19% of the respondents were implemented at least one type of SLM technology during the survey season in the north Gojjam sub-basin. The result of this study further indicated the adopted SLM technologies have complementary and supplementary relationships. The highest complementarity relation was observed between improved seed and inorganic fertilizer. This implies that the adoption of the improved seed depends on the supply of inorganic fertilizer and vis-a-vis. The adoption of purchasing farm inputs (i.e., chemical fertilizer and improved seed) depend on structural SLM technologies. Moreover, an increase in the proportion of soil bund promotes the application of agroforestry like plantation on soil bund. The two external agricultural inputs, inorganic and organic fertilizers, used by the smallholder farmers in the sub-basin, were proved to have reciprocal causation on one another. Most of the adopted technologies correlated positively, which confirmed the argument of rural farmers usually using a combination of long-term and short-term SLM technologies.

In addition to the reciprocal and simultaneous relationship between SLM technology application, several factors including farm size, family size, male-headed household, participating in local institutions, the participation of soil erosion, livestock size, income, and extension service have promoted the farmers' ability to adopt various SLM technologies. On the contrary, plot fragmentation, household age, plot distance, off-farm income, market distance, and perception of good soil fertility were discouraged the adoption probability of most SLM practices in the north Gojjam sub-basin. Likewise, the results of the present study show that the farm households' adoption probability on the number of SLM measures has been seen increasing with increasing family size, plot size, training, and income. But, decreased farmers' decisions with increased market distance and land fragmentation decreased the aggregate SLM technologies adoption probability.

Based on the results and lessons learned from this study, the following key policy implications and recommendations are drawn. The SLM technologies have complementary and substitutable characteristics to each other. Therefore, this should be considered to extend farmer choice on SLM technology adoption. The determinants of farmers' decision to adopt SLM technologies are directly related to demographic, socioeconomic, plot characteristics, and technologies in the sub-basin. Thus, this study suggests that policymakers and development agents' due attention to households' economic capacity, institutional support, and plot-level related factors in a combination with the characteristics of the SLM technologies to be adopted on their cultivated land. The adjacent landowners need to work together to prevent the land fragmentation problem. Moreover, to be facilitated effective SLM technology adoption, stockholders should be promoted environmental education in the community mass media; access SLM related training and education for farmers, providing satisfactory financial support, accessing agricultural external inputs such as seed and fertilizers at the right time and the right place and giving continuous constructive extension services. These will finally create self-motivated individual farmers who can persistently manage their farmlands.

8. Effect of Integrated Sustainable Land Management Technologies on Households' Food Security in the North Gojjam Sub-basin, Blue Nile River, Ethiopia

Abstract

sustainable land management is increasingly viewed as a major strategy to boost food security in Ethiopia. Standing from this logical ground, this study aimed to examine the impact of integrated sustainable land management (ISLM) technology adoption on household food security. The study depends on cross-sectional household-level data collected from randomly distributed 414 household heads in 3 districts. Endogenous switching regression (ESR) model supported by full information maximum likelihood (FIML) method was used to analyze quantitative data. The result shows that the adoption of ISLM technologies significantly increased rural household food security levels. Specifically, it increases household food consumption expenditure by ETB 38.3 (27%) relative to did not adopt. Similarly, it increases households' dietary diversity by 14.5% of the adopters. It also plays a significant role in reducing the food deficit period by one and half months, and food insecurity access scale by 46% points of the adopt than did not adopt. The finding of this paper shows that ISLM technology adoption has the potential to improve the well-being of rural farm households in the north Gojjam sub-basin. The policy implication is that the adoption of ISLM technology improves rural household food security and is used as a means of reducing rural poverty. Therefore, ISLM technology adoption should have been promoted in the study area and elsewhere by motivating land users through accessing external agricultural inputs at the right time and place to increase land productivity.

Keywords: *Technology Adoption, Sustainable Land Management, Food Security; Endogenous Switching Regression*

8.1. Introduction

Despite efforts that have been done to reduce global poverty and hunger over the past few decades, more than 795 million people are undernourished on a global scale (FAO et al., 2015). Among these, the majority live in developing countries, particularly in Africa (Lamourdia, 2015). In Africa, land degradation is the main threat to agricultural production and has severe implications for poverty, water, and food insecurity (ELD Initiative and UNEP, 2015). Land degradation coupled with climate change and poor land management has been affecting all facets of food security dimensions, i.e., availability, accessibility, utilization, and stability (FAO, 2017; Abebe, 2019; Teklewold et al., 2019). Against this, a lot of attention has been shifted towards the development of means and strategies of increasing agricultural production by empowering smallholder farmers to curb land degradation and boost food security (Nkonya et al., 2016). This is because most of the rural population's food security in Africa depends on subsistence agriculture characterizes by low-level use of technology (Biru et al., 2019).

In Ethiopia, the potential of an ecosystem for sustainable agricultural development has been threatened by abject land degradation (Kassie et al., 2010; Nkonya et al., 2016). Low agricultural productivity contributes to the base of food insecurity and extreme poverty in the country (Kassie et al., 2010). This result is that the country has remained dependent on foreign food aid and migration is common phenomenal. The country is one of the poorest in the world (Verkaart et al., 2017), nearly 33% of the rural population live below the national poverty line, and about 14% of the non-poor are vulnerable to poverty (World Bank, 2015). Vulnerability to food insecurity is a common problem in semiarid lowlands and mountainous highland areas where most people depend on unreliable rain-fed smallholder agriculture systems (Bayu, 2014). There is no exception in Gojjam, including the study area, which is well-known for the surplus agricultural production in the past (Simane et al., 2013; Zeleke and Hurni, 2001). In this region, soil degradation, climate change, fragile ecosystem, and poor land management are the key factor in the agricultural yield reduction in the last few decades. Because of these reasons, the community has changed from food surplus to food deficit (Ayele et al., 2020; Motbainor et al., 2016).

Ethiopia has followed an agricultural production intensification approach to boost agricultural productivity with a small farmland size through the application of modern agricultural inputs through promoting ISLM technologies, and this helps to feed the rapidly growing population (Dorosh and Rashid, 2013; Sime, 2018; Sisay et al., 2017). To achieve this, the government incorporates several programs and strategies. For example, the five-year Growth and Transformation Plans (GTP I and GTP II) of the country give special emphasis to the implementation of natural resources management through community mass mobilization at a watershed level (FDRE 2010; FDRE, 2016). The government promotes integrated SLM technologies, including soil fertility management, structural soil and water conservation (SWC) measures, and improved seed (Biru et al., 2019; Teklewold et al., 2019). Similarly, in the north Gojjam sub-basin, to curb land degradation and to increase land productivity, development agencies and the government have been implementing various SLM technologies for the last few decades.

Despite the program showing some positive progress over time, the impact of investments on household food security is not well documented in Ethiopia in general (Gebreselassie et al., 2016) and the north Gojjam sub-basin in particular. Accordingly, our central question is, do integrated SLM technologies adoption affect the food security of rural households who adopt? Regarding this, most previous studies focused on the welfare effect of single land management technology, and most of the results are inconsistent (Asfaw et al., 2012; Asrat and Simane, 2017; Kassie et al., 2018). To fill this gap, this paper systematically examines the impact of integrated SLM practices on household food security in high agricultural potential areas of the Ethiopian highlands where various conservation programs have been executed. Therefore, the main objective of this paper is to analyze the effects of integrated SLM technology adoption on rural household food security in the north Gojjam sub-basin of the upper Blue Nile.

Therefore, this paper will be contributed to several aspects of the existing literature on the impact of ISLM technology. First, the paper is very vital to the best of our knowledge about the effect of ISLM on adopter households' welfare, particularly on food security. Another benefit of this paper is important for informing policymakers and other development partners that could champion to enhance the usage and effectiveness of ISLM practices in smallholder production systems. Lastly, it may be contributed to future researchers for literature. For this purpose, endogenous switching treatment effect approach is used to control for selection bias while determining the effect of integrated SLM technologies on rural food security. This is established using data from a cross-sectional survey of rural farmers who engaged in the agricultural sector amid the challenges of land degradation.

8.2. Methodology

8.2.1. Data Sources and Data Collection Methods

Cross-sectional data for the study were collected through open and close-ended questionnaires in May and June 2018 from 414 randomly selected households, which are spatially distributed in different agro-climatic zones of the north Gojjam sub-basin. The questionnaire covered different demographic, topographic, plot, infrastructure, and institutional characteristics of surveyed households. It was also covered land users' perception of soil erosion and the fertility status of their farmland. Besides, subjective household food security measurements such as household food consumption expenditure (HFCE), household dietary diversity scale (HDDS), household food gap/deficit, and household food insecurity access scale (HFIAS). The survey was administered by well-trained enumerators under the close supervision and follow-up of the researcher and field assistance team. The survey period was free from fasting. In addition to the survey, qualitative data were collected from key informant interviews and FGD participants who were selected from different social groups to get detailed information for the triangulation of the qualitative data.

8.2.2. Methods of Data Analysis

In this study, quantitative data were analyzed using basic descriptive statistics and econometric methods. Descriptive statistics were employed to summarize the socio-economic, demographic, plot, assets, and institutional characteristics of the respondents included in the model. The econometrics model was used to address households' food security indicators. In doing so, we applied the ESR model to have insight on which type of household is more likely to benefit from the adoption of ISLM technologies using the FIML estimation technique.

8.2.2.1. Econometrics Model and Estimation Procedure

Quantifying the impact of land management technology on household food security through non-experimental observation is not a trivial task because it challenges for quantifying the counterfactual result (Asfaw et al., 2012; Kassie et al., 2007; Kassie et al., 2008). Besides, farmers are not randomly assigned in the two groups (adopters and non-adopters) rather, may make the adoption decision based on the predictable profit of the technology they adopt (Kassie et al., 2007; Kassie et al., 2008) and farmers in the choice of ISLM technologies may have different characteristics from those who did not adopt. Moreover, farmers' unobservable characteristics may affect both ISLM adoption decision and the welfare outcome. This leads to wrong conclusion on the estimation of adoption effect on household food security unless sample selection bias is considered (Kassie et al., 2008; Teklewold et al., 2019; Teklewold et al., 2013).

Widely used estimation methods for addressing such sample selection bias include propensity score matching (PSM), instrumental variable (IV), and Heckman two-stage selection (Abebe and Bekele, 2014; Zingiro et al., 2014). Each of these methods, however, has its limitations. For instance, both Heckman selection and IV methods tend to impose a functional form assumption by assuming that farmers' adoption has only an intercept shift and not a slope shift in the outcome variables (Khonje et al., 2015; Tambo and Wünscher, 2016). Though PSM tackles this problem by avoiding the functional form of assumption, it assumes that selection is based on observable variables, but there is likely to be unobserved heterogeneity because farmers' innate abilities, skills, and motivation are likely to influence their adoption behavior (Zingiro et al., 2014). To address these problems, we applied the ESR model. This approach is widely used in estimating the impact of farm technology adoption on rural households' welfare. The premise of this study is that farmers adopt ISLM technology when their utility of adopting is greater than the utility of non-adopt in the north Gojjam sub-basin. Considering this, the latent variables we specified following the method of (Biru et al., 2019; Lokshin & Sajaia, 2004; Teklewold et al., 2019).

$$S_h^*=\gamma Z_h + \varepsilon_h \quad \text{with} \quad S_h = (1\; if\; S_h^* > 0\; and\;\; 0\; otherwis) \qquad (8.1)$$

where, S_h^* is the unobservable variable and S_h is observable, i.e., the adoption of ISLM technology is equal to 1 if the farm household is an adopter (improved seed in any crop, compost, and/or manure and structural SWC simultaneously) and 0 otherwise. h is a subscript that represents the household head. Z_h denotes the vector of exogenous variables that affect the decision of adoption technology (Table 8.1). γ is the regression coefficient and ε_h is random error terms. As explained above, taking into consideration the sample selection bias on the participation of the ISLM technology adoption decision switching regression model was employed to estimate the impact of ISLM adoption on households' food security. In this study, therefore, two regime regressions models (for adopter and non-adopter) were specified as:

$$Y_{h1} = \beta_1 X_{h1} + u_{h1} \qquad \text{if } S_h = 1 \tag{8.2}$$

$$Y_{h0} = \beta_0 X_{h0} + u_{h0} \qquad \text{if } S_h = 0 \tag{8.3}$$

where Y_{h1} and Y_{h0} food security indicators for adopters and non-adopters while β_1 and β_0 are parameters to be estimated for the adopter and non-adopter regimes respectively. And u_{h1} and u_{h0} are error terms for equations 8.2 and 8.3 respectively. In this case, the three equation error terms (u_{h1}, u_{h0} and ε_h) are assumed to have a joint-normal distribution a mean vector of 0, and a covariance matrix specified following the equation used by (Lokshin and Sajaia, 2004):

$$\text{cover}(\varepsilon_h,\ u_{h1},\ u_{h0}) = \begin{bmatrix} \sigma^2_{\varepsilon_h} & \sigma_{\varepsilon_h u_{h1}} & \sigma_{\varepsilon_h u_{h0}} \\ \sigma_{\varepsilon_h u_{h1}} & \sigma^2_{h1} & . \\ \sigma_{\varepsilon_h u_{h0}} & . & \sigma^2_{h0} \end{bmatrix} \tag{7.4}$$

where $\sigma^2_{\varepsilon_h}$ = var(ε_h), which is supposed to be 1 as γ is only admirable up to a scale factor (Maddala,1983); σ^2_{h1} = var(u_{h1}), σ^2_{h0}=var(u_{h0}), covar (ε_h and u_{h1})=$\sigma_{h1\varepsilon h}$, covar (ε_h and $\sigma_{h0\varepsilon}$) = $\sigma_{\varepsilon_h u_{h0}}$. Since Y_{h1} and Y_{h0} are not observed at the same time, the covariance between u_{h1} *and* u_{h0} are not defined (Lokshin and Sajaia, 2004). The expected values of the error terms u_{h1} *and* u_{h0} can be specified following the work of (Asfaw et al., 2012; Tambo and Wünscher, 2016).

$$\text{E}\,(u_{h1} / S_h = 1) = \sigma_{\varepsilon_h u_{h1}}\left(\frac{\phi(\gamma Z_h)}{\Phi(\gamma Z_h)}\right) = \sigma_{\varepsilon_h u_{h1}} \lambda_{h1} \tag{8.5}$$

$$\text{E}\,(u_{h0} / S_h = 0) = \sigma_{\varepsilon_h u_{h0}}\left(\frac{-\phi(\gamma Z_h)}{1-\Phi(\gamma Z_h)}\right) = \sigma_{\varepsilon_h u_{h0}} \lambda_{h0} \tag{8.6}$$

where ϕ (.) is the standard normal probability density function and Φ (.) the standard normal cumulative density function, and $\lambda_{h1} = \frac{\phi(\gamma Z_h)}{\Phi(\gamma Z_h)}$ and $\lambda_{h0} = \frac{-\phi(\gamma Z_h)}{1-\Phi(\gamma Z_h)}$, where, λ_{h1} and λ_{h0} are the inverse mills ratio calculated from the selection equation. If the estimated covariance $\sigma_{\varepsilon_h u_{h1}}$ *and* $\sigma_{\varepsilon_h u_{h0}}$ are statistically significant, the decision to practice ISLM technologies and welfare outcomes are correlated and this is the evidence for endogenous switching that indicates the existence of sample selection bias. The outcome model is also known as a "switching regression model with endogenous switching" (Maddala, 1983). A widely used method to estimate self-selection is the two-stage instrumental variable procedure (Maddala, 1983). However, this technique is incorrect and highly criticized since it requires some adjustment to derive consistent standard errors and shows poor performance when there is high multi-collinearity between the covariates of the selection equation and the covariates of the outcome equation (Maddala,1983).

The appropriate and efficient method to estimate the ESR model is the FIML technique. This technique is preferable to other approaches in many instances. The FIML method estimates both selection and outcome equations simultaneously (Lokshin and Sajaia, 2004) using the *movestay* command in STATA (Lokshin and Sajaia, 2004). Besides, it allows to use of restrictions to be applied and permits the construction of likelihood ratio tests on the restriction variable (Lokshin and Sajaia, 2004) when similar variables affect the adoption decision (Z) and the subsequent outcome equations (X); absence of identification of the model will be a problem. For identification, we used exclusion restrictions i.e., we need at least one variable that affects farmers' adoption decisions, but it does not directly affect any of the households' food security indicators (Asmare et al., 2019; Lokshin and Sajaia, 2004). By considering the agricultural technology adoption literature on the significance of information access on farmers' agricultural technology adoption decisions, we used information access related to land management (Asmare et al., 2019; Lokshin and Sajaia, 2004; Tambo & Wünscher, 2016) for the instrumental variable. We proposed that farm households that do not face constraints in access to information on land management practices are more likely to understand the benefits of new technology and can adapt to their farmland. Accordingly, following the method used by (Lokshin and Sajaia, 2004; Tambo and Wünscher, 2016), the information access variable for the validation instrument was established by carrying out a falsification check. i.e. if a variable is a fitting choice instrument, it will affect the ISLM adoption choice, but not the food security indicators of non-adopter farm households.

8.2.2.2. The Estimation of Average Treatment Effects

In this section, we describe how the endogenous switching treatment regression model is used to compute the average treatment effect and counterfactual outcome (Asfaw et al., 2012; Asmare et al., 2019; Di Falco et al., 2011). ESR is very vital to compare the expected food security of rural farm households that adopted ISLM (8.7) to farm households that did not adopt (8.8). It is also used to investigate the expected farm households' food security in the counterfactual case, that is when farm households who had adopted did not adopt (8.9) and when farm households that had not adopted did adopt (8.10). The conditional expectation for household welfare in the four cases can be expressed mathematically as follows:

1. $\mathrm{E}\,(Y_{h1}\,/S_h = 1) = \beta_1 X_{h1} + \sigma_{\varepsilon_h u_{h1}} \lambda_{h1}$ if $S_h = 1$ (8.7)

2. $\mathrm{E}\,(Y_{h0}\,/S_h = 0) = \beta_0 X_{h0} + \sigma_{\varepsilon_h u_{h0}} \lambda_{h0}$ if $S_h = 0$ (8.8)

3. $\mathrm{E}\,(Y_{h0}\,/S_h = 1) = \beta_0 X_{h1} + \sigma_{\varepsilon_h u_{h0}} \lambda_{hp1}$ if $S_h = 1$ (8.9)

4. $\mathrm{E}\,(Y_{h1}\,/S_h = 0) = \beta_1 X_{h0} + \sigma_{\varepsilon_h u_{h1}} \lambda_{h0}$ if $S_h = 0$ (8.10)

Based on Heckman (2001), the effect of treatment 'to adopt' on the average treated (ATT) was calculated from the difference between that expected value of food security indicator outcome and counterfactual case (8.7 and 8.9).

$$\mathrm{E}\,(Y_{h1}/S_h = 1) - (Y_{h0}/S_h = 1) = X_{h1}(\beta_1 - \beta_0) + \lambda_{h1}(\sigma_{\varepsilon_h u_{h1}} - \sigma_{\varepsilon_h u_{h0}}) = \mathrm{ATT} \quad (8.11)$$

ATT represents the effect of integrated SLM technologies on the food security of the farm households that actually adopt the SLM technologies. Likewise, the impact of the treatment on untreated (ATU) estimated that it actually did not adopt did adopt (8.8 and 8.10).

$$\mathrm{E}\,(Y_{h1}/S_h = 0) - (Y_{h0}/S_h = 0) = X_{h0}(\beta_1 - \beta_0) + \lambda_{h0}(\sigma_{\varepsilon_h u_{h1}} - \sigma_{\varepsilon_h u_{h0}}) = \mathrm{ATU} \quad (8.12)$$

8.2.3. The Concept of Integrated Sustainable Land Management (ISLM)

The concept of SLM has developed as an important global environmental and economic development issue attributable to accelerating land degradation, including Ethiopia. SLM refers to the use of suitable technologies that farmers implement on their farmland to increase agricultural productivity through improving cultivated land (Liniger et al., 2011; Teklewold et al., 2019). SLM technologies can be grouped into structural, agronomic, vegetative management to reduce soil loss, control nutrient depletion, improve soil productivity respectively (Liniger et al., 2011). ISLM technology refers to the use of more than two suitable land management technologies adopted on one plot to increase the satisfaction of land users' needs (Liniger et al., 2011). This study focuses on the integration of different (i.e. structural, agronomic, and vegetative management), SLM technologies that are implemented in Ethiopia in general and in the north Gojjam sub-basin in particular to achieve rural households' food security. As presented in Table 8.1 about 53.5% of farmers adopt ISLM technologies on their farmland. Thus, in this paper, we evaluate the impact of ISLM technology adoption on household food security in the north Gojjam sub-basin.

8.2.4. Conceptualize and Measuring Methods of Food Security

The concept of food security has been used widely in different literature to measure households' welfare status (Tambo and Wünscher, 2016). A household is considered food secured if all family members have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life at all times (Russell et al., 2018). However, there is no unified measure of food security attributable to its complexity and multidimensionality (Ballard et al., 2011). Different researchers have used diverse methods ranging from caloric intake, dietary quality, and anthropometric estimates to capture the four pillars of food security: availability, accessibility, utilization, and stability. Most of these measures, however, are costly and time-consuming (Haen et al., 2011). But, in this study, we used to time-save and cost-effective standard food security measurement indicators, which are Household Food Consumption Expenditure (HFCE), Household Dietary Diversity Score (HDDS), household food gap, and Household Food Insecurity Access Scale (HFIAS).

The adoption of SLM technology is expected to affect household food consumption expenditure because most inhabitants in the study area are agro-based subsistence farmers (Simane et al., 2016). Therefore, we used HFCE as one indicator to evaluate the effect of ISLM on rural households' food security indicators. A 7-day recall period was used to capture household food consumption expenditure, and the result was reported in terms of the 2017/18 national average price, which is the Ethiopian Birr per adult equivalent (AE). Likewise, the use of ISLM technologies is expected to improve household food diet diversity by increasing agricultural productivity. HDDS can be described as the arithmetic sum of 12 food groups consumed by household members during the past 24 hours at home (Ngema et al., 2018). Following FAO-HDDS guideline, we used the following 12 food groups to measure food diet diversity, namely: cereals, roots and tubers, pulses/legumes/nuts, vegetables, fruits, fish and seafood, eggs, meat and poultry, milk and milk products, oils and fats, sweets/sugar/honey, and miscellaneous food items such as spices. As suggested by (Swindale & Bilinsky, 2006), we made sure that there were no special occasions such as funerals and fasting within the sampled households that might influence their food consumption pattern during the 24-hour survey period.

The food gap is another subjective measure of food security and refers to the number of months in the past 12 months that households have had difficulty satisfying their family food needs

(Tambo & Wünscher, 2016). Therefore, we used food gap measures to evaluate the effect of ISLM technology adoption on household food security in the north Gojjam sub-basin. The impact of ISLM was evaluated by another perception-based measure of food insecurity, HFIAS. The HFIAS consists of nine questions and three frequencies. When administered in a population-based household survey, it allows for estimating the percent of households affected by three different severities of hunger. The response to each question was coded: 0 = Never; 1 = Rarely (once or twice); 2 = Sometimes (three to ten); 3 = Often (more than ten) times in the past 30 days. The sum of these responses gives the HFIAS score, which ranges from 0 (no hunger) to 27 (severe hunger). Households were interviewed in March and June 2018 which is free from the fasting period of the lean season, and hence, it was an appropriate period to use the HFAIS in the north Gojjam sub-basin.

8.3. Results and Discussion

8.3.1. Characteristics of Sample Households

Table 8.1 presents the description, mean values, and standard deviation of the variables used in this study. These variables were selected based on agriculture and land management adoption literature which includes households' demographic, asset, institutional, and plot characteristics.
The description of each explanatory variable is presented in chapter seven of this dissertation. Moreover, the descriptive statistics of the outcome variables in Table 8.1 show that the average food consumption expenditure of the household was nearly ETB 149.69 per AE and the results of the descriptive statistics of the HDDS show respondents were found to have consumed an average of 6.03 food groups. The average household food insecurity accesses score (HFIAS) was estimated to 4.57 index shows that severe hunger is not common in the study area. Similarly, rural households in the north Gojjam sub-basin faced about 1.45 months of food gap/deficit.

Table 8.1: Definitions and description of selected variables used in the ESR model

Variables	Variable description (coding/units)	Mean	SD
Treatment variables			
ISLM adopter	Household used ISLM practices during the survey year	.535	.495
Independent variables			
Gender	Gender of household head (1= Male)	0.82	0.38
Age	Age of the household head (years)	50.32	14.83
Education	Educational status of household head (1= literate)	46.5	0.68
Family size	The number of a family member (Number)	5.31	2.19
Dependent ratio	The ratio of members aged below 15 and above 64 to those aged 15-64	0.81	0.73
Farm size	Area of cultivated land (in hectare)	1.03	0.71
Off-farm	Annual off-farm income received by the household, (in ETB)	2421.6	7078.8
Livestock	Livestock herd size in TLU	4.13	2.66
Parcel number	Land fragmentation, (number of plots)	2.95	1.81
Steep slope	Land perceived by the land user as very steep (1 =if yes)	0.18	0.47
Moderate Slope	Land perceived by the land user as moderate (1 =if yes)	0.45	0.49
Gentle Slope	Land perceived by the land user as gentle (1 =if yes)	0.36	0.48
Soil fertility	Land perceived by the land user as good fertile (1 =if yes)	0.35	0.37
Soil erosion	Land perceived by land user as high erosion (1 =if yes)	0.54	0.49
Market dis.	Input-output market distance from residence (in minutes of walking)	122.04	57.69
Farm distance	Plot distance to the residence in minutes of walking	29.31	17.82
Training	Household received SLM-related training (1 = if yes)	.39	.48
Extension	Household received SLM-related advice (1 = if yes)	0.62	.49
Media	Access to newspaper or radio/TV/ mobile (1 = if yes)	0.35	.47
Membership	Participating cooperation village (1 = if yes)	0.87	0.34
Credit access	Household received credit (1 = if yes)	0.34	0.48
Andabet	Household is located in Andabet District	0.31	0.46
Dega Damot	Household is located in Dega Damot District (1 = if yes)	0.29	0 .45
Enarj Enauga	Household is located in Enarj Enauga (1 = if yes)	0.33	0.47
Outcome variables			
HFCE	Total Food Consumption Expenditure Per EA (In ETB)	149.68	54.74
Food gap	Number of months of inadequate household food provisioning	1.45	1.77
HHS	Household Hunger Score	4.57	7.13
HDDS	Household Dietary Diversity Score	6.16	2.04

8.3.2. The Effect of ISLM Technology Adoption on Food Security

This section describes the effect of ISLM technology adoption on rural household food security obtained from the estimation of the FIML-ESR[4] model. As described above, four food security measurement indicators (i.e. HFCE, HDDS, household food gap, and HFIAS) to evaluate the effect of ISLM technology adoption on rural household food security using ESR model, and the results

[4] We use the "movestay" command of STATA to estimate the endogenous switching regression model by FIML (Lokshin & Sajaia, 2004)

are presented in Tables 8.2 and 8.3. ESR model contains the selection equation and the separate outcome equations of adopters and non-adopters that are evaluated at once (Asfaw et al., 2012; Di Falco et al., 2011; Tambo & Wünscher, 2016). The selection equation refers to the determinants of ISLM adoption (Table results are presented in appendix, Table A). In all food security measure equations, the correlation coefficient of error terms for the ISLM adopter ($\rho 1$) and non-adopter ($\rho 0$) model are statistically significant, except in the food gap, which shows that there is self-selection bias due to unobservable factors that occurred in the adoption decision. Thus, the use of the ESR model is appropriate in this study, which accounts for both observable and unobservable factors (Lokshin & Sajaia, 2004). The coefficients of the factors are not similar in all food security measures, which further confirm the presence of different samples and effects. Similarly, all variables that explain the food security of adopters do not affect the non-adopters and vice versa. In all ESR specifications, the variable representing the information constraint of the farmer on whether it is difficult to implement the ISLM technology is used as identifying instrument. The result shows positive and statistically significant in the adoption equations, but not in all outcomes (food security measures) (appendix, Table B). This satisfies the instrument relevance of all conditions in this model. The positive coefficient confirms that those households that have access to information are more likely to be ISLM adopters. As well, the significance of the likelihood ratio tests for independence of the equations also indicates that there is a joint dependence among the equations.

8.3.3.1. The determinant of food security on ISLM adopter and non-adopter households

To gain further understanding of the factors that affect the food security status of ISLM adoption on different groups, we examined the different socio-economic and plot characteristics related to food security indicators. As shown in Tables 8.2 and 8.3, land size and livestock assets increase the probability of HFCE and HDDS, and interestingly reduce the household food gap and HFIAS of both adopters and non-adopters. Farmers with larger farm sizes are not only more encouraged to produce food crops, but also gain more income through higher production of crop and livestock yield. According to the qualitative information, a household that has large farmland can produce many agricultural products and can consume much food and a diversity of food items. The result is consistent with the recent finding of (Teklewold et al., 2019), who conclude that large farm size increased the food security status of farm households in Eastern Ethiopia. Further, livestock has benefited through the quantity and diversity of food, either selling directly or their products. This shows that livestock is a key source of income to access food and to produce food items such as eggs, meat, milk, and milk products. Therefore, livestock assets influence food security positively without disaggregating the ISLM adopters and non-adopters. Furthermore, the outcome of the ESR model confirmed that gentle slope land with treated ISLM is increasing significantly HFCE and HDDS, and significantly reduce household food gap and HFIAS through increasing productivity (Table 8.2 and 8.3). This indicates that plain slope land is less vulnerable to erosion and suitable to produce household food. This finding underlies the justification given by (Biru et al., 2019; Kassie et al., 2013) who reported that land management with better land quality results in better productivity and increases the likelihood of household food security.

The ESR result shows that the household headed by a male correlated positively and significantly with HFCE and HDDS, and negatively and significantly with the household food gap and HFIAS of both adopters and non-adopters. The results show that female-headed households are more likely to have extra months of food inadequacy and their household members are more likely to experience food inaccessibility than male-headed whether they adopter or not. Regarding this, key informants reported that male-headed households have more likely to food diet diversity and consume more than female-headed households because they have the required labor force and information to access their family food. Moreover, in the study area, a female has limited access to land and other livelihood resources needed to produce for their family food. The result is in line with studies recently conducted by (Kassie et al.,2014), who found that female-headed households are more likely to be food insecure than male-headed households in Ethiopia.

Distance from the residence to farm input-output market is negatively and significantly correlated with the HFCE and HDDS of both adopters and non-adopters but positively correlated with household food gap and HFIAS. Similarly, the qualitative information from FGD shows that those farmers who are far away from the market may not get updated information to sell and purchase farm input-output produces from the market than their counterparts. Likewise, households headed by elders have decreased the food diet diversity of non-adopter farmers in the study area. Marital status, local cooperation, credit access, and off-farm activities are influenced positively and significantly HFCE of the adopters. Likewise, family size, education, training, and plot fragmentation are increased HDDS positively and significantly only by the adopters. Also, education and training reduced significantly the household food gap and HFIAS of the adopters.

Table 8.2. ESR results for household food consumption and dietary diversity

Variable	Household food consumption per AE (log)		Household food dietary diversity	
	ISLM adopter	ISLM non adopter	ISLM adopter	ISLM non adopter
Age	.001 (.002)	.000 (.002)	-.007 (.012)	-.025 (.008)***
Gender	.271 (.105)**	.355 (.075)***	1.755 (.644)**	1.797 (.509)***
Marital status	.149 (.064)**	.088 (.104)	.151 (.465)	1.165 (.524)**
Education	-.002 (.035)	-.018 (.036)	.382 (.239)**	.279 (.250)
Training	.040 (.059)	.005 (.074)	.433 (.092)**	.255 (.437)
Family size	-.011 (.012)	-.015 (.012)	.155 (.076)**	.045(.085)
Dependent ratio	.054 (.044)	.046 (.034)	-.091 (.273)	.223 (.192)
Land size	.038 (.046)**	.163 (.141)**	.185 (.098)**	. .148 (.098)*
Parcel number	-.002 (.014)	-.001(.016)	.012 (.086)*	.088 (.078)
Soil erosion	.040 (.051)	-.052 (.054)	-.529 (.352)	.425 (.334)
Soil fertility	.023 (.049)	.035 (.055)	-.254 (.343)	.342 (.378)
Gentle slope	.189 (.053)***	.073 (.064)	.733 (.428)*	.661 (.535)*
Moderate slope	-.022 (.075)	-.036 (.067)	.488 (.520)	.391 (.494)
Market distance	-.762 (.319)***	-.006 (.002)	-.005 (.002)**	.950 (.830)
Distance to road	.007 (.009)**	.009 (.009)	.009 (.009)***	.009 (.009)
Local membership	.012 (.006)**	.038 (.064)	.330 (.491)	-.037 (.419)
Credit access	.035 (.045)**	-.046 (.059)	-.408 (.296)	.321 (.289)
Off farm income	.001 (.002)**	.000 (.000)	.000 (.000)	-.000 (.000)
Livestock	.357(.084)***	.099(.132)**	.355 (.054)***	.100 (.052)*
Constant	4.767 (.342)***	4.587 (.222)***	4.46(1.68)***	3.112(1.09)***
$\ln\sigma_1$, $\ln\sigma_0$	-1.52 (.065)***	-1.112 (.087)***	.760 (1.803)	.372 (.112)***
ρ_1, ρ_0	-.484 (.285)**	-.045 (.527)**	.841(.373)**	-.178(.441)
LR test of indep. eqns.	4.67 ***		9.39 ***	
No observations	406		406	
Log likelihood	-255.56		-604.00	

***, **, * represent 1%, 5%, and 10% significance level, respectively. The number in brackets shows standard error.

Group and individual discussion participants reported that large family size through high labor force increased food production and consumption expenditure as well as diversified their food items by managing their cultivated land and generating more income from off-farm activates. This indicates that households with large family sizes are more likely to be food security than their counterparts.

On the other hand, land fragmentation increases households' food diet diversity, maybe farmers with a large number of plots may produce a variety of food items on different plots in the study area. The positive and significant effect of education and training on food diet diversity indicates that increase on farmers' knowledge on the accessing of a variety of food items from farmland as well as from the market to keep their health status but not in HFCE. These indicate that households' consumption expenditures may not always be parallel with food diet diversity. The finding of this paper is similar to the finding recently conducted by (Tambo and Wünscher 2016), who reported that training and education increased food security of farm innovation technology adopters in northern Ghana.

As observed in Table 8.3, there are noticeable differences across the two household food insecurity (i.e., food gap and HFIAS) determinants. For instance, land fragmentation, level of education, marital status, dependent ratio, credit access, and the age of the household head do not have a similar effect on the two food security indicator functions. The result also shows that households that have a higher age are subjected to a longer period of food shortage than youngers. Nonetheless, access to credit is more likely to reduce the food deficit period of the adopters. Those farmers who have farmland with a gentle slope are more likely to have the potential to decrease HFIAS than non-adopter groups. In other words, education, gentle slope farmland, training, and participating in a local cooperative have the probability to reduce HFIAS of the ISLM adopter group. The result shows that access to education and training reduces food insecurity of the ISLM technology adopters. Similarly, age and marital status have a probability to reduce HFIAS of the non-adopter farm groups.

Table 8.3: ESR results for food gap and household food insecurity access

Variable	Household Food gap/deficit		HFIAS	
	ISLM adopter	ISLM non-adopter	ISLM adopter	ISLM non-adopter
Age	-.011 (.008)	-.004 (.012)	-.012 (.031)	.054 (.031)*
Gender	-1.236 (.468)***	1.978 (.659)***	-7.21(1.92)***	-8.851(1.844)***
Marital status	-.006 (.009)	-.308 (.506)	-1.229 (1.100)	-3.972 (1.398)***
Education	.040 (.201)	.057 (.246)	-1.011(.589)**	-.853(.632)
Training	.169 (.167)	.225 (.146)	-1.226(.596)**	.818 (.505)
Family size	.097 (.058)	.000 (.097)	.206 (.205)	.148 (.224)
Dependent ratio	1.04 (.285)***	-.392 (.198)*	.026 (.116)	.283 (.100)
Land size	-.142 (.034)***	.136 (.066)**	-.054 (.133)**	-.014 (.227)***
Parcel number	.042 (.063)	.021 (.091)	.012 (.253)	.442 (.259)**
Soil erosion	-.038 (.214)	-.225 (.327)	.171 (.149)	-.089 (.206)
Soil fertility	-.060 (.157)	.183 (.283)	-.202 (.155)	.371 (.211)**
Gentle slope	-.006 (.214)**	-.472 (.405)	-.104(.263)***	-.704 (.373)*
Moderate slope	.523 (.466)	-.208 (.318)	-.199 (.200)	-.346 (.272)
Plot distance	-.008 (.007)	.011(.007)	-.003 (.004)	-.004 (.004)
Market distance	.234 (.135)**	.056 (.159)	.019 (.006)**	.008 (.006)
Group membership	.058 (.262)	.161 (.457)	-.517(.224)**	-.360 (.307)
Credit access	-.356 (.184)**	.429 (.275)	-.155 (6.656)	-.781 (.675)
Off farm income	.000 (.000)	.000 (.000)	-.000 (.000)	-.000 (.000)
Livestock	-.032 (.034)**	-.007 (.063)*	-.086(.026)***	.119 (.037)***
Constant	3.641(1.137)***	4.574 (1.014)***	.981 (.659)	-.085 (.496)
lnσ1, lnσ0	-.066 (.104)	.320 (.099)***	-.139 (.162)	-.088 (.093)
ρ1, ρ0	-.382 (.333)	.294 (.427)	-.858 (.484)**	.307(.339)
LR test of indep. eqns.	15.26***		25.10***	
Number of obs.	375		375	
Log likelihood	-845.58		-744.74	

***, **, * represent 1%, 5%, and 10% significance level, respectively. The number in brackets shows standard error.

8.3.3.2. Average ISLM technology Adoption Treatment Effects on Food Security

Table 8.4 presents the average treatment effect of the adoption on farm household food security. The Table illustrates that households who adopt ISLM technologies would have about ETB 38 (27%) HFCE per AE and 1(14.5%) HDDS more than if they did not adopt. Similarly, HFCE would have increased by ETB 25.4 (17.8%), and HDDS by 1.5 (33%) if non-adopters had adopted the ISLM technologies. This is the average variance in food diet diversity and food consumption expenditure of similar pairs of households that belong to different ISLM technologies adoption. The finding demonstrates that the adoption of ISLM technology significantly increases HFCE and HDDS of the north Gojjam sub-basin. The finding is similar to the study conducted by (Biru et al.,2019), who found that SLM adoption improved HDDS of the adopter farmers in Eastern Ethiopia. Similarly, ISLM adoption has also had an interesting effect on reducing the depth of food insecurity. Table 8.5 depicts the average effect of ISLM adoption on the household food gap/deficit and HFIAS in the north Gojjam sub-basin. The results show that ISLM technologies reduce the probability of household food gap and HFIAS on average by one and half months and 46% points respectively. Likewise, the household food gap would have reduced by one and half months, and HFIAS by 35.5% points if non-adopters had adopted the ISLM technologies on their plot.

Overall, the results show that the adoption of ISLM technologies increases the rural household's food security status. The finding confirmed that the adoption of ISLM increases household food security significantly (i.e., increased household food consumption expenditure, diversified food diets, and reduced food-deficit period and food insecurity access) in the north Gojjam sub-basin. The present study is similar to the recent empirical evidence conducted by (Kassie et al., 2018; Teklewold et al., 2019) in Ethiopia and elsewhere (Abdulai and Huffman, 2014; Tambo and Wünscher, 2016) revealed that the adoption of land management technology provides higher welfare returns for rural households.

Table 8.4: Average treatment effects: Endogenous switching regression model result

Welfare Outcome		Adoption decision		Treatment Effects
		To Adopt	Not to Adopt	
Food Consumption in AE (Birr)	Adopters	179.79	141.49	38.3***
	Non Adopters	167.68	142.29	25.39***
Household Dietary Diversity Score (HDDS)	Adopters	7.04	6.15	0.99 ***
	Non Adopters	6.04	4.53	1.51***
Food gap/deficit (months)	Adopters	0.92	2.04	-1.12***
	Non Adopters	1.04	2.07	-1.03***
Household Hunger Scale Score (HFIAS)	Adopters	2.99	5.54	-2.55***
	Non Adopters	3.08	4.79	-1.70***

Note: Statistical significance at the * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

8.4. Conclusions and Policy Implications

Sustainable land management and improving food security are among Ethiopian policy priorities. In this effort, the adoption of ISLM technologies is expected to play a vital role. The main objective of this paper is to evaluate the potential effect of ISLM technology adoption on a farm household food security based on cross-sectional household-level data. The potential effect of technology adoption along the determinants of household food security was estimated using FIML-ESR model to account for sample selection bias. The result shows that gender, land size, market and road distance, and livestock asset are the main determinants of all food security indicators without disaggregating the adopter status of the farmers. The study suggested that female households need special treatment to achieve their family food security. Further, rural infrastructure accessibility (i.e., market) is very important to improve the lifestyle of the rural people in the study area.

The farm households that did adopt ISLM had systematically different characteristics than the farm households that did not adopt. Specifically, the average household food diet diversity and household food consumption expenditure of the adopters were significantly higher than that of the non-adopters and significantly lower household food gap and food insecurity access scale. The adoption of ISLM provides a dual purpose for both household well-being improvement and ecosystem service health. This implies adoption of ISLM reduces land degradation; thus, increases the food security of farm households by increasing households' revenue and food production from mixing crop-livestock farming production. Accordingly, ISLM technologies should be scaled up in the north Gojjam sub-basin in particular and elsewhere in general. An important policy implication is that the current agricultural extension programs focus on the promotion and support of ISLM technology adoption to rescue rural farmers from food insecurity and poverty problems. It is important to stress that our finding does not suggest neglecting single SLM technology adoption, but strengthening the arguments of support for farmers to use various supplementary SLM technologies simultaneously on their farmland to increase food security status.

9. Synthesis

9.1. Introduction

In the north Gojjam sub-basin, land degradation process and response measures are complex and have spiral interaction due to several human and natural induce factors on the land resource bases, and this affects the majority of rural livelihood. Stockholders adopted and used various SLM technologies to control the drivers and pressures of land degradation; to adapt the state of land degradation; and to mitigate its impact on the rural livelihood. Such type of interaction is termed as '*the drivers, pressures, state, impacts and responses (DPSIR)*' (FAO, 2017). In this context, employing the DPSIR framework is very important to deliver knowledge and to communicate on the state and change of causal linkages regarding land degradation and response measureless. DPSIR framework is the potential environmental assessment tool that allows integrated GIS technologies and advanced econometric models for full analysis of land degradation and responses status (Agyemang et al., 2007). This systematic approach helps to identify the full range of empirical evidence from drivers to effective response indicators in a particular geographic area. Hence, following the specific objectives and DPSIR framework, the major findings derived from each chapter of this study are briefly summarized in the subsequent sections.

9.2. The State of Land Use and Land Cover Change (LULC)

In the north Gojjam sub-basin, a substantial LULC changes have been occurred from the period 1986 to 2017. Agricultural land cover was the most dominant, followed by grazing land and bush and shrubland during the study period. But, the former is very large than the later. Of the total area of the sub-basin, agricultural land shared about 58.22% in 1986, and 70.67% in 2017. This implies that agricultural land cover enormously increased by 21.38% from its original extent. Despite cultivating land size has been increased over time, landholding size per household has been decreased in the sub-basin, and on average households had a 1.05ha landholding size. Likewise, plantation forest cover has been increased by more than threefold (368.8%) areal extent from study baseline to end line, though water hangar eucalyptus plantation was the dominant of the plantation trees, particularly in the upper parts of the sub-basin (Ewunetu et al., 2021a).

In contrast, other LULC types shows a decreasing trend from the period 1986 to 2017: water bodies, forest land, bush and shrubland, grazing land and bare land by 50%, 41.7%, 38.4%, 28.9%, and 7.9% of areal extent, respectively. Natural forests have been diminished and is currently observed in churches, riverbanks, and hillside areas. Major indigenous tree species have been abjectly declined and some are reached to extinct. Similarly, 25% of bush and shrubland covers have been converted to other land cover types during this period. Similarly, substantial grazing land cover has been converted to agriculture and plantation forest covers. These results in increasing of bare land cover in the sub-basin for the last 31 years (Ewunetu et al., 2021a).

In general, agriculture land cover has experienced the highest gain (19.98%), while grazing land revealed the highest loss (14.56%) from the period of 1986 to 2017. Most stability and persistency were observed on the agricultural land cover. This may be the result of its largest cover in the study period. About 34.57% of the landscape extent experienced the transition from one category to another cover types in last the 31 years. Out of this, about 15.3% attributable to the net change while 19.27% due to swap change. The outcome showed that swap change is greater than the net change during the study period, saying that the importance of the swapping component in LULC change in the sub-basin (Ewunetu et al., 2021a).

9.3. The State of Comprehensive Land Degradation

Land degradation is a complex environmental problem resulting from human and natural-induced factors in the north Gojjam sub-basin. Accordingly, to map and quantify diverse land degradation indicators into a single indicator, we followed the standardized classification technique in ArcGIS10.5 and the hierarchical spatial MCA method. The analysis was using a combination of different land degradation indexes including, physical (soil erosion, soil compaction, soil drainage, and soil depth indexes), biological (vegetation cover and soil organic matter indexes), and chemical (soil acidity) indicators. The rate of soil loss was estimated using the RUSLE model taking into account the basic factors of soil loss: topography, soil characteristics, rainfall, land cover, and local land management measures (Ewunetu et al., 2021b).

The RUSLE model result reveals that soil erosion is very high and affected any part of the sub-basin. On average 46 t $ha^{-1}yr^{-1}$ or a total of 65.21million tons of topsoil has been lost from the sub-basin annually. Besides, about 45.3% of the sub-basin was evaluated to be at high and very high soil loss risk in the sub-basin. Similarly, the four groups of physical degradation indicators (soil erosion, soil compaction, soil drainage, and soil depth indexes) overlay analysis result shows that about 80.2% of the sub-basin is characterized as having a moderate level of physical land degradation. On the other hand, the finding of soil adjusted vegetation index (SAVI) analysis result confirmed that the majority of the sub-basin subjected to moderate (60.26%) and high (20.87%) level of land degradation/moderate and low vegetation cover and a large area (72.56%) of sub-basin is characterized by low soil organic matter content (Ewunetu et al., 2021b). The finding shows that about 30.78%, 60.13%, and 4.7% of the sub-basin were moderately, highly, and very highly biologically degraded, respectively. This indicates that more than half of the sub-basin was biologically degraded. Likewise, the status of chemical degradation for about 55.8%, 39%, and 4% of the sub-basin was grouped as low, moderate, and high levels respectively. This implies that more than one-third of the sub-basin was moderately and highly affected by soil acidity. The combined spatial MCA of biological, physical, and chemical land degradation indicators shows that about 1.14%, 32%, 35.4%, and 30.5% of the sub-basin exhibited very low, low, moderate, and high degradation level, respectively. The spatial MCA result indicates that biological, physical, and chemical degradation was contributed to land degradation vulnerability from the most to the least, respectively in the north Gojjam sub-basin. Overall, the combined degradation analysis shows that more than 60% of the sub-basin was moderate to highly degraded (Ewunetu et al., 2021b). The result confirmed that land degradation in general and soil erosion in particular still a significant problem in the north Gojjam sub-basin.

9.4. Key Drivers of Land Degradation

Indirect driving forces/root causes for LULC change and land degradation in north Gojjam sub-basin are various. But, rapid population grow is the leading root causes, as it causes for continuous land resources scarcity and continuous farmland fragmentation, farmland scarcity and agricultural land encroachment at the expense of natural vegetation and grazing land covers. Likewise, it causes for increasing demand for firewood and construction materials, and other household furniture materials (Ewunetu et al., 2021a). On the other hand, poverty was the other underlined/ root cause of land degradation in the sub-basin. Due to the absence of other alternative sources of income generation, farmers always poorly used limited land resources for living. In the sub-basin, there are no many alternative renewable household energy sources to substitute biomass energy (like electric, solar, and biogas), even in the towns. On the other hand, the livelihood of many poor people depends on selling firewood and charcoal production. Mainly, women collecting firewood from natural forests and animal dung from fields to sell in the near market. Similarly, poor males engaged in charcoal making and timber production activities to generate income. Likewise, lack of community awareness and attitude on sustainable resources management; low implementation of environmental rules and regulations, low level of extension services were the other main root causes for landscape change and natural resource degradation in the north Gojjam sub-basin (Ewunetu et al., 2021a).

9.5. Key Pressures of Land Degradation

Land degradation is driven by several factors in the north Gojjam sub-basin. The most critical drivers are associated with population growth and poor natural resource management. Expansion of agriculture land, using biomass for cooking energy, charcoal production, cutting trees for construction materials, and furniture making, and selling firewood are major direct causes for landscape change and land degradation (Ewunetu et al., 2021a). Over and free grazing is the other major direct cause of landscape change and land degradation in the sub-basin. The low productive livestock number has been increasing coupled with population growth, though the trends have been declined per household head. Free grazing is the main cause for crop residual clearance from agriculture land after harvest and challenged the adoption of biological land management measures. The grazing system has been shifted to bush and shrublands attributable to grazing land scarcity in the study area. Domestic fuel energy is the other driving force of natural resource degradation in the study area. Almost all communities used biomass, particularly firewood followed by livestock dung, and crop residue for cooking, heating, and lighting, mainly in the rural area. Poor agricultural activities such as cultivating very steep land, and marginal land, plowing ups and downs (cress-cross tillage), and poor grazing are key reasons for soil erosion and natural resource degradation in the study area. Above and beyond, misuse of land management technologies and poor irrigation systems are the other factors for the conversion of productive land to poor land. Erratic rainfall, erosive soil, and rugged topography are also other direct biophysical factors that contributing to land degradation in the study sub-basin (Ewunetu et al., 2021a).

9.6. Impacts of Land Degradation on Rural Livelihood

Land degradation was the central challenge for achieving sustainable livelihood in the north Gojjam sub-basin. The result shows that farmers perceived land degradation as an acute problem and has been increasing its severity for the last 10 years in the form of soil erosion, soil nutrient depletion, loss of soil biodiversity, and increasing of soil acidity. The assessment shows that soil erosion was perceived in the form of rill and gully erosion in the sub-basin. Regarding this, land users acknowledged that gullies and streambanks have been encroaching on productive crops and grazing land areas. Farmers reported that land degradation coupled with farmland scarcity and climate change reduced crop and livestock productivity (Chapter 6). On the other hand, farmers reported that external agriculture inputs such as chemical fertilizers and limestone demand have been increasing over the last 10 years to solve the low soil fertility and soil acidity problem. Likewise, reduction of crop residues, grazing land size, and decline of grazing land carrying capacity result in livestock productivity reduction for the last 10 years (Chapter 6).

Likewise, households' sources of energy such as firewood, crop residue, and dung have been declining continually. This has forced the community to travel long distances and spend a significant amount of time to collect firewood for domestic use. Nonetheless, recently, most farmers planted eucalyptus trees to minimizing the problem of firewood scarcity and construction materials. Besides, various water resources such as springs, ponds, and streams have been disappearing from the earth's surface and river water have been reduced due to land degradation (Chapter 6). The cumulative effects result in the decline of communities' income and food security.

9.7. Responses Against Land Degradation

In the north Gojjam sub-basin smallholder farmers implement various land management practices in response to severe land degradation problem though the implementation is not to the adequate level owing to various impeding factors. These include soil bund, stone bund, hillside terrace, check dam, traditional ditches, waterways, chemical fertilizer, manure, agroforestry, afforestation, and reforestation. The result shows about 94.2% of respondents reported as they implemented at least one type of SLM technology on one plot of land in addition to traditional ditches during the survey season. The most widely used SLM measures next to traditional ditches were inorganic fertilizer (65%), soil bunds (53.8%), and animal manure (50.5%) in the north Gojjam sub-basin (Ewunetu et al., 2021c).

9.7.1. Relationship and Determinants of SLM Technologies Adoption

In the north Gojjam sub-basin, the adoption of SLM technologies have both complementary and supplementary relationships. Most of the adopted SLM technologies are complementary while some are supplementary (Ewunetu et al., 2021c). The highest complementarity was observed between improved seed and chemical fertilizer. This implies that the adoption of improved seed depends on the supply of chemical fertilizer and vice versa. Furthermore, the adoption of purchasing farm inputs (i.e., chemical fertilizer and improved seed) depend on structural SLM technologies, mainly on soil bunds. A strong complementary was also observed between the use of soil bunds and the adoption of agroforestry technologies. Substitutability, meanwhile, was found for soil fertility inputs: farmers tended to apply either chemical fertilizer or organic fertilizer on their farmland. This shows that the application of chemical fertilizer is substituted by organic fertilizer (manure and compost). Because, the application of organic fertilizer is labor-intensive while chemical fertilizer is capital intensive and if smallholder farmers have the fund to purchase chemical fertilizers, they may ignore the labor-intensive organic fertilizer (manure and compost). On the other hand, if farmers are endowed with sufficient labor and manure resources they may not decide to use capital-intensive technology i.e. chemical fertilizer. In the main, the result explains the fact that smallholder farmers faced the complementarity and substitutability of SLM technologies in the north Gojjam sub-basin when they decide to adopt.

Turning to the drivers of SLM practices, factors positively associated with increased likelihood to implement at least one SLM practice include farm size, family size, male household head, participation in local institutions, perception of soil erosion, number of livestock, household income, and presence of extension service. On the other hand, plot fragmentation, household age, plot distance, off-farm income, market distance, and farmers' perception of good soil fertility, meanwhile, were negatively associated with the adoption of most SLM practices. The probability of a household adopting multiple SLM measures was higher for larger family size, larger plot size, participation in training, and household income. Market distance and land fragmentation were associated with decreased likelihood to adopt multiple SLM technologies in the north Gojjam sub-basin (Ewunetu et al., 2021c).

9.7.2. Effect of ISLM Technology Adoption on Households' Food Security

In north Gojjam sub-basin, in the process of ensuring natural resources management and to improve rural food security, many efforts have been invested to adopt different SLM strategies through promoting smallholder farmers. The potential effect of technology adoption along the determinants of household food security was estimated using FIML-ESR model to account for sample selection bias (Chapter 8). The result shows that gender, land size, market and road distance, and livestock asset are increased all food security indicators without disaggregating the SLM adopter status of the farmers. Furthermore, rural infrastructure accessibility (i.e., market) is very important to improve the lifestyle of the rural people in the sub-basin (Chapter 8).

The model result shows that the adoption of ISLM technology significantly increases rural household food security in the north Gojjam sub-basin. Specifically, the adoption of ISLM technology increases households' food consumption expenditure by ETB 38.3 (27%) relative to did not adopt ISLM technologies. Similarly, it increases households' dietary diversity by 14.5% of the adopt than did not adopt. ISLM adoption also plays a significant role in reducing households' food gap period by one and half months, and household food insecurity access scale by 46% points of the adopt than did not adopt. In general, the finding of this study shows that a combination of SLM adoption is very important to improve smallholder farmers' food security. This result happened due to an increasing households' income and food access through the improvement of cultivated land productive capacity to produce better agricultural yield than non-adapter. Therefore, there is the need to encourage farmers to adopt ISLM to boost rural households' welfare in the north Gojjam sub-basin (Chapter 8).

9.8. Conclusions

Land degradation is one of the major environmental problems and has been affecting the socio-economic wellbeing of the community in the north Gojjam sub-basin**.** The present study shows that the north Gojjam sub-basin has been experiencing significant LULC changes for the last few 31years. The major changes were due to the expansion of agricultural land and plantation forests and a sharp decline of grazing and natural vegetation land covers. The key drivers of these changes were population growth, common property right, persistent poverty, weak enforcement of rules and low level of extension service, and lack of public awareness. On the other hand, the main proximate reasons for landscape change and land degradation were deforestation, cropland and settlement expansion, poor grazing, using biomass for cooking and heating, erosive soil, rugged topography, and erratic rainfall.

Most parts of the sub-basin suffered from high soil erosion. More than 50% of the sub-basin was vulnerable to high and very high soil loss risk. The majority of the sub-basin is moderately affected by soil acidity and physical deterioration of land quality, but biological land degradation was considered to be a more important factor in land degradation than chemical or physical indicators. The result of the combined land degradation indicators confirmed that more than 50% of the sub-basin is subjected to moderately to highly degradation. Similarly, farmers perceived land degradation as one of the major environmental problems in their locality and they acknowledged that the magnitude is high and the rate is increasing for the last 10 years in the form of soil erosion, soil nutrient depilation, the decline of vegetation cover, and increasing of soil acidity. The finding confirmed that the communities have been changed from food surplus to food-deficit because of land degradation that affected crop and livestock productivity, and reduced quantity of surface water and fuelwood.

The finding shows that at least one type of SLM technology was implemented on any one plot of land in the sub-basin to control land degradation. The most widely used technologies are chemical fertilizer, soil bund, and animal manure. Most of the adopted SLM technologies were complementary each other. Farm size, family size, male-headed household, local institutions, perception of soil erosion, livestock size, total income, and extension service increased the adoption probability of most SLM technologies. But, plot fragmentation, household age, plot distance, off-farm income, market distance, and perception of good fertile soil discourage the adoption probability of SLM technologies. The research concludes that the adoption of ISLM technology improves rural household food security and is used as a means of reducing rural poverty.

9.9. Recommendations

Based on the findings of the research, we draw the following policy recommendations for sustainable development in the North Gojjam sub-basin.

- The present study revealed that LULC has been adversely affecting the ecosystem services stability in the north Gojjam sub-basin. Therefore, the drivers for LULC change should be controlled, and sustainable resources use is required. Otherwise, these resources will soon be lost and will no longer be able to play their role in socio-economic development and environmental sustainability.
- In order to reverse alarming land degradation rate, an integrated SLM approach including structural, biological, and agronomic land management measures is needed to maintain land productivity and economic development. Mainly, lime application and organic fertilizer (compost, manure, and mulching) application are very important to reverse soil acidity and to improve soil fertility status. Moreover, the portfolio of SLM technologies available to farmers exhibits both complementarities and substitutability. Therefore, the relationships between SLM technologies should be considered when promoting any specific SLM technology to farmers by development agents and land managers.
- Off-farm employment alternatives to reduce the pressure on the agricultural land resource by pulling out the surplus agricultural labor and increasing farmers' income to invest in land management technologies is highly needed in the north Gojjam sub-basin for more sustainable farming systems.
- The major sources of energy in the study area are firewood, animal dung, and crop residues. This contributes to ongoing land degradation in the sub-basin. Therefore, to address the problems sustainable energy sources and energy-saving stove technologies are needed to minimize biomass energy consumption in the sub-basin.
- The adoption of agroforestry and economically vital multi-purpose perennial crops should be introduced and promoted to reverse land degradation in the sub-basin. This requires the collaboration of all the stakeholders to rehabilitate degraded areas and to minimize the current degradation rate as well as to improve ecosystem health and maintain sustainable development in the study area. Furthermore, the study found that afforestation and reforestation program to rehabilitate the degraded area is not effective in several areas of the sub-basin. As a result, attention should be given to the survival rate of trees after planting and promoting indigenous tree plantation, instead of merely planting water hunger eucalyptus tree in the north Gojjam sub-basin to achieve sustainable ecosystem services.

- Farmland fragmentation is one of the key challenges to adopt physical SLM measures in the north Gojjam sub-basin. As a result, clustering of neighboring landowners is needed to work together on SLM to reduce the negative impact that land fragmentation has on SLM adoption.
- Smallholder framer's decision to adopt SLM technologies is directly related to their demographics, socioeconomic conditions, and plot characteristics. As a result, these factors should be standard considerations for extension efforts and SLM-oriented development strategies for specific technologies and holistic land management initiatives. Moreover, environmental education, access to media, access to SLM-related training and education, financial support for SLM activities, regular extension communication for smallholders, and timeliness of availability of agricultural inputs are necessary for a more successful implementation of SLM technologies.
- Implementing integrated SLM technologies has a great potential to improve rural households' welfare through improving agricultural productivity. As a result, integrated SLM practices should be promoted in the study area through inspiring land users with extension services and accessing timeline external agricultural inputs.

Based on the limitations and findings of this study, we propose the following key research areas in the future:

- The RUSLE model only considers rill and inter-rill erosion by rainfall water. Thus, future researchers should consider gully and river bank erosion in the north Gojjam sub-basin.
- The study assesses the current status of land degradation using biological, physical and chemical land degradation indicators. Therefore, future researchers should be considered trends/change using time serious data to see land degradation change indicators through time. Furthermore, the study did not assesse land degradation status based on agroecosystem and/or livelihood zones. Thus, future researchers have to be consider these research gap.
- Identify local adaptable perennial crop/ multipurpose trees to adopt in the north Gojjam sub-basin to maintain sustainable ecosystem health. And assessing farmers' perception of the effect of a eucalyptus plantation on the sustainable ecosystem services.

- Analyzing the challenges of adopting improved livestock bread and a modern feeding system to improve livestock productivity and to minimize livestock pressure on land resources.
- Assessing the long-term SLM technology adoption on households' welfare using panel socioeconomic data.
- Exploring feasible livelihood diversification strategies to minimize population pressure from agricultural land.

References

Abate, E., Hussein S., Mark L. & Mengistu F. (2017). Soil acidity under multiple land-uses: assessment of perceived causes and indicators, and nutrient dynamics in small-holders mixed-farming system of northwest Ethiopia, Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 67:2, 134-147, DOI:10.1080/09064710.2016.1230227

Abdelmoneim, H., Reda, M., & Moghazy, H. M. (2020). Evaluation of TRMM 3B42V7 and CHIRPS Satellite Precipitation Products as an Input for Hydrological Model over Eastern Nile Basin. *Earth Systems and Environment*, (0123456789). https://doi.org/10.1007/s41748-020-00185-3

Abdelrahman, M. A. E., Natarajan, A., & Hegde, R. (2016). Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamarajanagar district , Karnataka , India. *The Egyptian Journal of Remote Sensing and Space Sciences*, *19*(1), 125–141. https://doi.org/10.1016/j.ejrs.2016.02.001

Abdelrahman, M. A. E., Natarajan, A., Hegde, R., & Prakash, S. S. (2018). The Egyptian Journal of Remote Sensing and Space Sciences Assessment of land degradation using comprehensive geostatistical approach and remote sensing data in GIS-model builder. *The Egyptian Journal of Remote Sensing and Space Sciences*, (xxxx). https://doi.org/10.1016/j.ejrs.2018.03.002

Abdulai, A., & Huffman, W. (2014). The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Economics*, *90*(1), 26–43. https://doi.org/10.3368/le.90.1.26

Abebe, G. (2019). *A Survey Data Description on Food Insecurity Factors, Farmers ' Coping and Adaptation Strategies in the Sidama Zone of Southern Ethiopia*. (August).

Abebe, Y., & Bekele, A. (2014). The Impact of Soil and Water Conservation Program on the Income and Productivity of Farm Households in Adama District, Ethiopia. *Science, Technology and Arts Research Journal*, *3*(3), 198. https://doi.org/10.4314/star.v3i3.32

Abi, M. (2018). *Understanding the Spontaneous Spreading of Stone Bunds in Ethiopia : Implications for Sustainable Land Management sustainability Understanding the Spontaneous Spreading of Stone Bunds in Ethiopia : Implications for Sustainable Land Management*. (July). https://doi.org/10.3390/su10082666

Agegnehu, G., & Yirga, C. (2019). Soil Acidity Management; Ethiopian Institute of Agriculture Research: Addis Ababa, Ethiopia, 2019; ISBN 9789994466597. .

Agidew, A. meta A., & Singh, K. N. (2018). Determinants of food insecurity in the rural farm households in South Wollo Zone of Ethiopia: the case of the Teleyayen sub-watershed. *Agricultural and Food Economics*, *6*(1). https://doi.org/10.1186/s40100-018-0106-4

Agyemang, I. (2012). *Assessing the driving forces of environmental degradation in Northern Ghana : Community truthing approach*. *4*(May), 59–68. https://doi.org/10.5897/AJHC12.005

Agyemang, I., Mcdonald, A., & Carver, S. (2007). *Application of the DPSIR framework to environmental degradation assessment in northern Ghana*. *31*, 212–225.

Akinnagbe, O. M. (2011). Farmers' Perception of the Effects of Land Degradation on Agricultural Activities in Ethiope East Local Government Area of Delta State, Nigeria. Agriculturae Conspectus Scientificus Vol. 76 (2011) No. 2 (135-141)

Alemu, B. The effect of land use land cover change on land degradation in the highlands of Ethiopia. Environ. Earth Sci. 2015, 5,1–13.

Alemu, Z. A., Ahmed, A. A., Yalew, A. W., & Simanie, B. (2017). Spatial variations of household food insecurity in East Gojjam Zone, Amhara Region, Ethiopia: Implications for agroecosystem-based interventions. *Agriculture and Food Security*, *6*(1), 1–9. https://doi.org/10.1186/s40066-017-0113-9

Amede, T. (2003). Opportunities and Challenges in Reversing Land Degradation: The regional experience. In Natural Resource Degradation and Environmental Concerns in the Amhara National Regional State: Impact on Food Security; Amede, T., Ed.; Ethiopian Soils Science Society: Bahir Dar, Ethiopia, pp. 173–183.

Amede. T, Takele B, and Endris G (2001). Reversing the degradation of arable land in the Ethiopian highlands. Managing Africa 's Soils No.23. International center for Research in agro forestry. Pp 1-20.

Amsalu, A. (2006). *Caring for the Land: Best practices in soil and water conservation in Beressa*.

Amsalu, A., & de Graaff, J. (2007). Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. *Ecological Economics*, *61*(2–3), 294–302. https://doi.org/10.1016/j.ecolecon.2006.01.014

Amsalu, A., & Graaff, J. De. (2006). *Farmers ' Views of Soil Erosion Problems and their Conservation Knowledge at Beressa Watershed , Central Highlands of Ethiopia Farmers ' views of soil erosion problems and their conservation knowledge at Beressa watershed , central highlands of Ethiopia*. (December 2013). https://doi.org/10.1007/s10460-005-5872-4

Amsalu, T., & Mengaw, A. (2014). *GIS Based Soil Loss Estimation Using RUSLE Model : The Case of Jabi Tehinan Woreda ,*. 616–626.

Amuti, T., & Luo, G. (2014). Analysis of land cover change and its driving forces in a desert oasis landscape of Xinjiang, northwest China. *Solid Earth*, *5*(2), 1071–1085. https://doi.org/10.5194/se-5-1071-2014

Ananda, J., & Herath, G. (2009). A critical review of multi-criteria decision-making methods with special reference to forest management and planning. *Ecological Economics*, *68*(10), 2535–2548. https://doi.org/10.1016/j.ecolecon.2009.05.010

Anderson, B. J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (2001). A Land Use and Land Cover Classification System for Use with Remote Sensor Data. 2001.

Asfaw, D., & Neka, M. (2017). *International Soil and Water Conservation Research Factors affecting adoption of soil and water conservation practices : The case of Wereillu Woreda (District), South Wollo Zone, Amhara Region, Ethiopia*. *5*, 273–279.

Asfaw, S., Shiferaw, B., Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food Policy*, *37*(3), 283–295. https://doi.org/10.1016/j.foodpol.2012.02.013

Ashtiani, B., Haghighirad, F., Makui, A., Montazer, G. (2009). Extension of fuzzy TOPSIS method based on interval-valued fuzzy sets. Appl. Soft Comput. 9, 457–461.

Asmare, F., Teklewold, H., & Mekonnen, A. (2019). The effect of climate change adaptation strategy on farm households welfare in the Nile basin of Ethiopia: Is there synergy or trade-offs? *International Journal of Climate Change Strategies and Management*, *11*(4), 518–535. https://doi.org/10.1108/IJCCSM-10-2017-0192

Asrat, P., & Simane, B. (2017). Household - and plot-level impacts of sustainable land management practices in the face of climate variability and change : empirical evidence from Dabus Sub-basin, Blue Nile River, Ethiopia. *Agriculture & Food Security*, 1–12. https://doi.org/10.1186/s40066-017-0148-y

ASTM. (2001). American Society for Testing Materials, soil bulk density classes. Available online: https://www.sciencedirect.com/ topics/earth-and-planetary-sciences/bulk-density

Ayele, A. W., Kassa, M., Fentahun, Y., & Edmealem, H. (2020). *Prevalence and associated factors for rural households food insecurity in selected districts of east Gojjam zone, northern Ethiopia : a cross-sectional study*. 1–13.

Bai, Z.G., Dent, D.L., Olsson, L., Shaepman, M.E. (2008). Global assessment of land degradation and improvement. Identification by remote sensing. Report 2008/01. ISRIC-World Soil Information, Wageningen, NL.

Ballard, T., Deitchler, M., & Ballard, T. (2011). *Household Hunger Scale : Indicator Definition and Measurement Guide Household Hunger Scale : Indicator Definition and Measurement Guide*. (August).

Batar, A. K., Watanabe, T., & Kumar, A. (2017). *Assessment of Land-Use / Land-Cover Change and Forest Fragmentation in the Garhwal Himalayan Region of India*. 1–16. https://doi.org/10.3390/environments4020034

Begum Irfan, Z., Jo, A. A., & Mondal, M. (2016). Urbanization as a Land use change driver of Forest Ecosystem: Land-Use Pattern Change Analyzed for the Indore city. *American Journal of Engineering Research*, (57), 2320–2847. Retrieved from www.ajer.org

Behavior, P., Badariah, T., Ahmad, T., & Nordin, M. S. (2014). *University Students ' Subjective Knowledge of Green Computing and*. *7*(2), 1–11. https://doi.org/10.5539/Abstract

Bekele, W. (2003). Economics of Soil and Water Conservation. *Acta Universitatis Agriculturae Sueciae Agraria (Economic Department of Uppsala University)*. Retrieved from http://diss-epsilon.slu.se:8080/archive/00000362/01/Agraria411.pdf

Bekele, W., & Drake, L. (2015). *Soil and water conservation decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia : a case study of the Hunde-Lafto area Soil and water conser v action decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia*. (July). https://doi.org/10.13140/RG.2.1.2334.3200

Belachew, O., & Iqbal Zuberi, M. (2015). Perception of Climate Change and Livelihood of a Farming Community of Maruf Kebele, Central Oromia, Ethiopia. *American Journal of Climate Change*, *04*(03), 269–281. https://doi.org/10.4236/ajcc.2015.43022

Belal, A. B., Sciences, S., Sciences, S., & Abu-hashim, M. (2015). *Land Evaluation Based on GIS-Spatial Multi-Criteria Evaluation (SMCE) for Agricultural Development in Dry Wadi , Eastern Desert,*. (November). https://doi.org/10.3923/ijss.2015.100.116

Belay, M., & Bewket, W. (2013). *Farmers ' livelihood assets and adoption of sustainable land management practices in north- western highlands of Ethiopia Farmers ' livelihood assets and adoption of sustainable land management practices in north- western highlands of Ethiopia*. *7233*. https://doi.org/10.1080/00207233.2013.774773

Belay, T. T. (2014). *Perception of farmers on soil erosion and conservation practices in Dejen District , Ethiopia*. *2*(6), 224–229. https://doi.org/10.11648/j.ijepp.20140206.15

Belayneh, M., Yirgu, T., & Tsegaye, D. (2020). *Runoff and soil loss responses of cultivated land managed with graded soil bunds of different ages in the Upper Blue Nile basin ,*.

Berry, L., Olson, J., & Campbell, D. (2003). Assessing the Extent, Cost and Impact of Land Degradation At the National Level: Findings and Lessons Learned From Seven Pilot Case Studies. *A Case Study Prepared for the Food and Agriculture Organization of the United Nations Retrieved from Httpwww Fao Org*, (March), 28. https://doi.org/10.1016/j.tcb.2005.07.004

Beshir, H. (2014). Economics of Soil and Water Conservation : the Case of Smallholder Farmers in North Eastern Highlands of Ethiopia. *The Experiment*, *23*(3), 1611–1627.

Bewket, W. (2003). Towards integrated watershed management in highland Ethiopia: the Chemoga watershed case study. *Towards Integrated Watershed Management in Highland Ethiopia: The Chemoga Watershed Case Study*, 169-pp. https://doi.org/10.1007/sl

Bewket, W, & Teferi, E. (2009). *Assessment of Soil Erosion Hazard and Prioritization for Treatment at the Watershed Level : Case Study in the Chemoga Watershed , Blue Nile Basin , Ethiopia*. *622*, 609–622. https://doi.org/10.1002/ldr

Bewket, W. (2007). Soil and water conservation intervention with conventional technologies in northwestern highlands of Ethiopia: Acceptance and adoption by farmers. *Land Use Policy*, *24*(2), 404–416. https://doi.org/10.1016/j.landusepol.2006.05.004

Bewket, W. (2012). *Farmers ' Knowledge of Soil Erosion and Control Measures in the Northwestern Highlands of Ethiopia*. (November 2014), 37–41. https://doi.org/10.1080/19376812.2011.10539143

Bewket, W, & Abebe, S. (2016). *Land-use and land-cover change and its environmental* *implications in a tropical highland watershed, Ethiopia Land-use and land-cover change and its watershed, Ethiopia*. *7233*(December). https://doi.org/10.1080/00207233.2012.755765

Bewket, Woldeamlak, & Sterk, G. (2015). *Assessment of soil erosion in cultivated fields using a survey methodology for rills in the Chemoga watershed, Ethiopia Assessment of soil erosion in cultivated fields using a survey methodology for rills in the Chemoga watershed, Ethiopia*. (January 2003). https://doi.org/10.1016/S0167-8809(03)00127-0

Bhagat, V., Arts, A., & Ahmednagar, D.-. (2014). *Agriculture Water Balance of Micro-Watershed Using GIS Techniques*. (July). https://doi.org/10.18005/JESR0201001

Birhane, E., Ashfare, H., Almaw, A., & Hishe, H. (2018). *Land use land cover changes along topographic gradients in Hugumburda national forest priority area, Northern Ethiopia Remote Sensing Applications : Society and Environment Land use land cover changes along topographic gradients in Hugumburda national fo*. (November). https://doi.org/10.1016/j.rsase.2018.10.017

Biru, W. D., Zeller, M., & Loos, T. K. (2019). The Impact of Agricultural Technologies on Poverty and Vulnerability of Smallholders in Ethiopia: A Panel Data Analysis. *Social Indicators Research*, (490). https://doi.org/10.1007/s11205-019-02166-0

Bhushan, N.; Rai, K. Strategic Decision Making: Applying the Analytic Hierarchy Process, 4th ed.; Springer: New York, NY, USA, 2004; p. 172.

Branca, G., Lipper, L., & Mccarthy, N. (2013). *Food security, climate change, and sustainable land management. A review*. 635–650. https://doi.org/10.1007/s13593-013-0133-1

Borrow, C.J. (1965). Land Degradation: Development and Breakdown of Terrestrial Environments. London: Cambridge University Press.

Boserup, E.(1981). The Population and Technology: Study of Long Term Trends, Chicago.

Bulletin, H. G. (2009). *The global problem of land degradation and desertification*. *58*(1), 19–31.

Butt, A., Shabbir, R., Ahmad, S. S., & Aziz, N. (2015). Land-use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan. *Egyptian Journal of Remote Sensing and Space Science*, *18*(2), 251–259. https://doi.org/10.1016/j.ejrs.2015.07.003

Cappellari, L., & Jenkins, S. P. (2003). *Multivariate probit regression using simulated maximum likelihood*. (3), 278–294.

Carr, E. R., Wingard, P. M., Yorty, S. C., Thompson, M. C., Jensen, N. K., Roberson, J., … Thompson, M. C. (2016). *Applying DPSIR to sustainable development Applying DPSIR to sustainable development*. *4509*(November). https://doi.org/10.1080/13504500709469753

Carver, S. J., & Carver, S. J. (2007). *Integrating multi-criteria evaluation with geographical information systems*. *3798*. https://doi.org/10.1080/02693799108927858

Cassells, D. (1995). *LAND DEGRADATION AND REHABILITATION IN ETHIOPIA : A REASSESSMENT By Jan Bojo and David Cassells and*.

Central Intelligence Agency (CIA). (2018). *The world fact book*. https://www.cia.gov/library/publications/download/download-2018/index.html. [Accessed January 21 2020].

Challa, M., & Tilahun, U. (2014). Determinants and Impacts of Modern Agricultural Technology Adoption in West Wollega: The Case of Gulliso District. Journal of Biology, Agriculture and Healthcare, 4(20), 63–77.

Chabrillat, S. (2014). *Land Degradation Indicators : Spectral indices Land Degradation Indicators : Spectral indices*. (September 2006).

Chabrillat, S. (2015). Land Degradation Indicators : Spectral indices. *Annals of Arid Zone*, *45*(August), 331–354. https://doi.org/10.1177/0278364907079279

Chander, G., & Markham, B. (2003). *Revised Landsat-5 TM Radiometric Calibration Procedures and Postcalibration Dynamic Ranges*. *41*(11), 2674–2677.

Chander, G., Markham, B. L., Helder, D. L., & Ali, E.-. (2009). Remote Sensing of Environment Summary of current radiometric calibration coefficients for Landsat MSS , TM , ETM + , and EO-1 ALI sensors. *Remote Sensing of Environment*, *113*(5), 893–903. https://doi.org/10.1016/j.rse.2009.01.007

Chanyalew, D., Adenew, B. & Mellor, J (2016) Ethiopia‟s Agricultural Sector Policy and Investment Framework (PIF). Ministry of Agriculture and Rural Development, FDRE, Addis Ababa

Cheruto, M. C., Kauti, M. K., Kisangau, P. D., & Kariuki, P. (2016). *Journal of Remote Sensing & GIS Assessment of Land Use and Land Cover Change Using GIS and Remote Sensing Techniques : A Case Study of Makueni County, Kenya*. *5*(4). https://doi.org/10.4175/2469-4134.1000175

Creswell, J.W. (2009). Qualitative, Quantitative, and Mixed Methods Approaches. (3rd ed.). SAGE Publications, Inc. USA.

Crossland, M., Ann, L., Pagella, T., Hadgu, K., & Sinclair, F. (2018). Implications of variation in the local perception of degradation and restoration processes for implementing land degradation neutrality. *Environmental Development*, *28*(September), 42–54. https://doi.org/10.1016/j.envdev.2018.09.005

Commission for Africa (2016). Our Common Interest. Report of the Commission for Africa

Congalton R. (1991). A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens. Environ. 37, 35–46, doi:10.1016/0034-4257(91)90048-B.

CSA. (1994). The 1994 Population and Housing Census of Ethiopia; Results at Country Level: Summery Report; Central Statistical Authority (CSA): Addis Ababa, Ethiopia

CSA. (1996). *The 1994 population and housing census of Ethiopia. Central Statistical Agency*: Addis Ababa.

CSA. (2007). "*The Population and Housing Census of Ethiopia; Results at a Country Level,"*. Office of Population and Housing Census Commission, Central Statistical Authority, Addis Ababa, Ethiopia.

CSA. (2013). *Federal Democratic Republic of Ethiopia (FDRE). Population projection of Ethiopia for all regions: At Wereda level from 2014-2017.* Addis Ababa, Ethiopia.

CSA. (2014). Agricultural sample survey: report on livestock and livestock characteristics (private peasant holdings). *Volume II Statistical Bulletin*, Addis Ababa, Ethiopia

CSA. (2016). Agricultural sample survey 2015/2016, volume II Report on Livestock and livestock characteristics (private peasant holdings). Addis Ababa, Ethiopia: Central Statistical Agency.

Dawit, A., & Solomon, B. (2017). *Status and challenges of smallholder dairy cattle production in the highlands of Original article Status and challenges of smallholder dairy cattle production in the highlands of Bale, Southeast Ethiopia*. (June 2015). https://doi.org/10.14196/aa.v4i12.2074

Demeke, B. (2003). Factors influencing the adoption of soil conservation practices in North western Ethiopia. Institute of Rural Development University of Goettingen D-37073 Gottingen-Waldweg 26.

Dereje Guteta & Assefa Abegaz (2015): Determinants of Integrated Soil Fertility Management adoption under annual cropping system in Arsamma watershed, southwestern Ethiopian Highlands, African Geographical Review, DOI:10.1080/19376812.2015.1088390

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 825–842. https://doi.org/10.1093/ajae/aar006

Dibala, W.T.; Demissie, T.A.; Miegel, K. (2019). Drivers and implications of land use/land cover dynamics in finchaa catchment, Northwestern Ethiopia. Land 2020, 9, 113.

District, D., Munthali, M. G., Davis, N., Adeola, A. M., & Botai, J. O. (2019). *Local Perception of Drivers of Land-Use and Land-Cover Change Dynamics sustainability Local Perception of Drivers of Land-Use and Land-Cover Change Dynamics across Dedza District, Central Malawi Region*. (February), 0–25. https://doi.org/10.3390/su11030832

Dorosh, P. A., & Rashid, S. (2013). *Food and Agriculture in Ethiopia: Progress and Policy Challenges*.

Dubale, P. (2001). Soil and Water Resources and Degradation Factors Affecting Productivity in Ethiopian Highland Agro-Ecosystems. *Northeast African Studies, 8*(1), 27–51. https://doi.org/10.1353/nas.2005.0015

Eastman, J.R. (2012). Multi-criteria evaluation and GIS. Geogr. Inf. Syst.1, 493–502.

Economy of Land Degradation (ELD) Initiative. (2013).The Rewards of Investing in Sustainable Land Management. Interim Report for the Economics of Land Degradation Initiative: A Global Strategy for Sustainable Land Management. 2013. Available online: www.eld-initiative.org.

EFAP (Ethiopian Forestry Action Program). (1994). Ministry of Natural Resources Development and Environmental Protection, Volume 2 and 3, Final Report, EFAP Secretariat, Addis Ababa

El-gammal, M.I.; Ali, R.R.; Samra, R.M.A. Science Direct GIS-based land degradation risk assessment of Damietta governorate, Egypt. Egypt J. Basic Appl. Sci 2015, 2, 183–189.

Ellis, E. C. (2011). Anthropogenic transformation of the terrestrial biosphere. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *369*(1938), 1010–1035. https://doi.org/10.1098/rsta.2010.0331

Esa, E., Assen, M., & Legass, A. (2018). Implications of land use / cover dynamics on soil erosion potential of agricultural watershed , northwestern highlands of Ethiopia. *Environmental Systems Research*. https://doi.org/10.1186/s40068-018-0122-0

Ethiopian Agricultural Transformation Agency(ATA). (2017) Soil Fertility Status and Fertilizer Recommendation Atlas for Amhara Regional State; Ethiopian, ATA: Addis Ababa, Ethiopia,

Etsay, H., Negash, T., & Aregay, M. (2019). *Factors that influence the implementation of sustainable land management practices by rural households in Tigrai region, Ethiopia*. (May). https://doi.org/10.1186/s13717-019-0166-8

Eswaran, H., R. Lal and P.F. Reich. 2001. Land degradation: an overview. In: Bridges, E.M., I.D. Hannam, L.R. Oldeman, F.W.T. Pening de Vries, S.J. Scherr, and S. Sompatpanit(eds.). Responses to Land Degradation. Proc. 2nd. International Conference on Land Degradation and Desertification, Khon Kaen, Thailand. Oxford Press, New Delhi, India.

Eva, H. D., Brink, A., & Simonetti, D. (2006). *MONITORING LAND COVER DYNAMICS IN SUB-SAHARAN AFRICA Institute for Environment and Sustainability*.

Evans, J., Geerken, R. (2004). Discrimination between climate and human-induced dryland degradation. Journal of Arid Environments 57: 535-554.

Ewunetu, A., Simane, B., Teferi, E., & Zaitchik, B. F. (2021a). Land Cover Change in the Blue Nile River Headwaters: Farmers’ Perceptions, Pressures, and Satellite-Based Mapping. *Land*, *10*(1), 68. https://doi.org/10.3390/land10010068

Ewunetu, A., Simane, B., & Teferi, E. (2021b). *Mapping and Quantifying Comprehensive Land Degradation Status Using Spatial Multicriteria Evaluation Technique in the Headwaters Area of Upper Blue Nile River*.

Ewunetu, A.; Simane, B.;Teferi, E.; Zaitchik, B.F. (2011c). Relationships and the Determinants of Sustainable Land Management Technologies in North Gojjam Sub-Basin, Upper Blue Nile, Ethiopia. Sustainability 2021, 13, 6365. https://doi.org/10.3390/su13116365

Fairhead, J., & Leach, M. (1995). *False Forest History, Complicit Social Analysis : Rethinking Some West African Environmental Narratives*. *23*(6), 1023–1035.

FAO. (1986). *Ethiopian Highlands Reclamation Study, Final Report, Volume 1*. 289. https://doi.org/10.1111/j.1365-2036.2004.02009.x

FAO. (2003). Data Sets, Indicators and Methods to Assess Land Degradation in Drylands. Rome, Italy.

FAO. (2004). The methodological framework for land degradation assessment in dry lands (LADA) (simplified version): Report on a consultancy as visiting scientist by rural Ponce-Hernandez with Parviz Koohafkan, FAO-UN, land, and water development division. Rome, Italy

FAO. (2010). Sustainable Crop Production Intensification through an Ecosystem Approach: Capturing Efficiency through Ecosystem Services and Management, FAO Committee on Agriculture, June 16-19 2010(COAG/2010/3), Available at: www.fao.org/docrep/meeting/018/K8079E01.pdf.

FAO. (2011). Sustainable Land Management in Practice: Guidelines and Best Practices for Sub-Saharan Africa, field application, A TerrAfrica Partnership Publication

FAO. (2013). Land degradation assessment in dry lands: Questionnaire for mapping land degradation and sustainable land management (QM), Rome, Italy

FAO .(2014). Science to Support Climate-Smart Agricultural Development: Concepts and Results from the MICCA Pilot Projects in East Africa, Mitigation of Climate Change in Agriculture, Series 10, Rome

FAO. (2017). Sustainable Land Management (SLM) in practice in the Kagera Basin: Lessons learned for scaling up at landscape level - Results of the Kagera Transboundary Agro-ecosystem Management Project (Kagera TAMP). Food and Agriculture Organization of the United Nations, Rome, Italy. 440 pp.

Farhan, Y., & Nawaiseh, S. (2015a). Spatial assessment of soil erosion risk using RUSLE and GIS techniques Spatial assessment of soil erosion risk using RUSLE and GIS techniques. *Environmental Earth Sciences*, (September). https://doi.org/10.1007/s12665-015-4430-7

Farhan, Y., & Nawaiseh, S. (2015b). Spatial assessment of soil erosion risk using RUSLE and GIS techniques Spatial assessment of soil erosion risk using RUSLE and GIS techniques. *Environmental Earth Sciences*, (March 2016). https://doi.org/10.1007/s12665-015-4430-7

Federal Democratic Republic of Ethiopia (FDRE). (2010). Growth and Transformation Plan (2010/11–2014/15); the Federal Democratic Republic of Ethiopia, Ministry of Finance and Economic Development: Addis Ababa, Ethiopia, 2010; Volume 1, p. 127.

Federal Democratic Republic of Ethiopia (FDRE).(2016) Growth and Transformation Plan II (GTP) II) (2015/16-2019/20); FederalDemocratic Republic of Ethiopia, National Planning

Commission: Addis Ababa, Ethiopia, Volume 1

Fcderal Democratic Republic of Ethiopia(EDRE).(2005). Rural Land Administration and Land Use Proclamation, 11th Year No. 44 Addis Ababa-15th July

Federici, S., Tubiello, F. N., Salvatore, M., Jacobs, H., & Schmidhuber, J. (2015). Forest Ecology and Management New estimates of CO 2 forest emissions and removals : 1990 – 2015 q. *Forest Ecology and Management*, *352*, 89–98. https://doi.org/10.1016/j.foreco.2015.04.022

Finvers, M.A., (2008). Application of DPSIR for analysis of soil protection issues and an assessment of British Columbia's soil protection legislation. Cranfield University, UK

Fiona, F (2003). Engaging Eden vol, II women, gender, ICPDP in Africa; lesson learned and experience shared; Intervention institution for environmental and development endsleighsret, London WCIHDD, HED wild life and development series No. 17.

Fonji, S. F., & Taff, G. N. (2014). *Using satellite data to monitor land-use land-cover change in North-eastern Latvia*. 1–15.

Ganasri, B. P., & Ramesh, H. (2016a). Geoscience Frontiers Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. *Geoscience Frontiers*, *7*(6), 953–961. https://doi.org/10.1016/j.gsf.2015.10.007

Ganasri, B. P., & Ramesh, H. (2016b). *Geoscience Frontiers Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin*. *7*, 0–8. https://doi.org/10.1016/j.gsf.2015.10.007

Gashaw, T., Bantider, A., & Silassie, H. G. (2014). *Land Degradation in Ethiopia : Causes, Impacts and Rehabilitation Techniques*. *4*(9), 98–105.

Gashaw, T., Tulu, T., & Argaw, M. (2017). Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia. *Environmental Systems Research*, 1–14. https://doi.org/10.1186/s40068-016-0078-x

Gashaw, T., Tulu, T., Argaw, M., & Worqlul, A. W. (2017). Evaluation and prediction of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. *Environmental Systems Research*. https://doi.org/10.1186/s40068-017-0094-5

Gashu, K., & Muchie, Y. (2018). Rethink the interlink between land degradation and livelihood of rural communities in Chilga district, Northwest Ethiopia. *Journal of Ecology and Environment*, *42*(1), 1–11. https://doi.org/10.1186/s41610-018-0077-0

Gebrehiwot, S.G.; Bewket,W.; Gardenas, A.I.; Bishop, K.(2014). Forest cover change over four decades in the Blue Nile Basin, Ethiopia: Comparison of three watersheds. Reg. Environ. Chang. 14, 253–266

Gebremedhin, B., & Swinton, S. M. (2003). *Investment in soil conservation in northern Ethiopia : the role of land tenure security and public programs*. *5150*.

Gebreselassie, S. (2016). *Economics of Land Degradation and Improvement in Ethiopia Economics of Land Degradation and Improvement in Ethiopia*. https://doi.org/10.1007/978-3-319-19168-3

Gebru, T. D. (2016). *Deforestation in Ethiopia : Causes, Impacts, and Remedy*. *4*(2), 204–209.

Gedefaw, M., Denghua, Y., Hao, W., Alemu, B., Chanie, M., Agitew, G., & Yildiz, F. (2018). Evaluation of adoption behavior of soil and water conservation practices in the Simein Mountain National Park, Highlands of Ethiopia. *Cogent Food & Agriculture*, *4*(1), 1–10. https://doi.org/10.1080/23311932.2018.1513782

Gessesse, B.; Bewket, W. (2014). Drivers and implications of land use and land cover change in the central highlands of Ethiopia: Evidence from remote sensing and socio-demographic data integration. Ethiop. J. Soc. Sci. Humanit.10, 1–23.

Gessesew, W. S. (2017). *Application of DPSIR Framework for Assessment of Land Degradation : A Review*. 1–7. https://doi.org/10.31031/APDV.2017.01.000522

Gibbs, H. K., & Salmon, J. M. (2015). *Mapping the world's degraded lands*. *57*, 12–21.

Golla, A. S. (2019). *Soil Acidity and its Management Options in Ethiopia : A Review*. *07*(11), 1429–1440. https://doi.org/10.18535/ijsrm/v7i11.em01

Guteta, D., & Abegaz, A. (2015). Determinants of Integrated Soil Fertility Management adoption under annual cropping system in Arsamma watershed, southwestern Ethiopian Highlands. African Geographical Review, 35(2), 95–116. doi:10.1080/19376812.2015.1088390

Haen, H. De, Klasen, S., & Qaim, M. (2011). What do we know ? Metrics for food insecurity and undernutrition What do we know ? Metrics for food insecurity and undernutrition. *Food Policy*, *36*(6), 760–769. https://doi.org/10.1016/j.foodpol.2011.08.003

Hailemariam, S. N., Soromessa, T., & Teketay, D. (2016). *Land Use and Land Cover Change in the Bale*. https://doi.org/10.3390/land5040041

Hailu, B. T., Eiji, E., Heiskanen, J., & Pellikka, P. (2015). Reconstructing pre-agricultural expansion vegetation cover of Ethiopia Reconstructing pre-agricultural expansion vegetation cover of Ethiopia. *Applied Geography*, *62*(June), 357–365. https://doi.org/10.1016/j.apgeog.2015.05.013

Hajkowicz, S. (2007). *A comparison of multiple criteria analysis and unaided approaches to environmental decision making*. *10*, 177–184. https://doi.org/10.1016/j.envsci.2006.09.003

Hajkowicz, S., & Higgins, A. (2008). *A comparison of multiple criteria analysis techniques for water resource management*. *184*, 255–265. https://doi.org/10.1016/j.ejor.2006.10.045

Hano, A. I. A. (2013). *Assessment of Impacts of Changes in Land Use Patterns on Land Degradation/Desertification in the Semi-arid Zone of White Nile State, Sudan, by Means of Remote Sensing and GIS.*

Haque, I., & Basak, R. (2017). The Egyptian Journal of Remote Sensing and Space Sciences Land cover change detection using GIS and remote sensing techniques : A Spatio-temporal study on Tanguar Haor , Sunamganj , Bangladesh. *The Egyptian Journal of Remote Sensing and Space Sciences*, *20*(2), 251–263. https://doi.org/10.1016/j.ejrs.2016.12.003

Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Tsegaye, D., Almaw, A., … Adgo, E. (2017). Science of the Total Environment Comprehensive assessment of soil erosion risk for better land use planning in river basins : Case study of the Upper Blue Nile River. *Science of the Total Environment, The*, *574*, 95–108. https://doi.org/10.1016/j.scitotenv.2016.09.019

Heckman, J.J., Tobias, J.L. and Vytlacil, E.J. (2001). "Four Parameters of Interest in the Evaluation of Social Programs," Southern Economic Journal 68(2):210-233.

Herweg, K., Ludi, E. (1999). The performance of selected soil and water conservation measures—Case studies from Ethiopia and Eritrea. Catena, 36, 99–114.

Hengl, T., Jesus, J. M. De, Heuvelink, G. B. M., Ruiperez, M., Kilibarda, M., Blagoti, A., … Kempen, B. (2017). *SoilGrids250m : Global gridded soil information based on machine learning*. https://doi.org/10.1371/journal.pone.0169748

Hill, J., Stellmes, M., Udelhoven, T., Röder, A., & Sommer, S. (2008). *Mediterranean desertification and land degradation. Global and Planetary Change, 64(3-4), 146–157.* doi: 10.1016/j.gloplacha.2008.10.005

Holden, S., & Shiferaw, B. (2004). Land degradation, drought and food security in a less-favored area in the Ethiopian highlands: A bio-economic model with market imperfections. *Agricultural Economics*, *30*(1), 31–49. https://doi.org/10.1016/j.agecon.2002.09.001

Huete, A.R. (1988). A soil-adjusted vegetation index (SAVI). Remote Sens. Environ, 25, 295–309.

Hudson, P. F., & Alcántara-Ayala, I. (2006). *Ancient and modern perspectives on land degradation. CATENA, 65(2), 102–106.* doi: 10.1016/j.catena.2005.11.003

Hurni, H. (1985). Erosion-productivity-conservation systems in Ethiopia. In Proceedings of the 4th International Conference on Soil Conservation, Maracay, Venezuela, 3–9.

Hurni H (1987) Erosion–productivity–conservation systems in Ethiopia. Proceedings of the fourth international conference on soil conservation. Maracy, Venezuela, pp2-20

Hurni, H. (1998). *Agro-ecological belts of Ethiopia. Explanatory notes on three maps at a scale of, 1(1,000,000).* Soil Conservation Research Programme Ethiopia.

Hurni, H. (1993). Land degradation, famine, and land resource scenarios in Ethiopia. In World Soil Erosion and Conservation; Pimentel, D., Ed.; Cambridge University Press: Cambridge, UK, pp. 27–62.

Hurni, H. (2016). *Erosion-productivity-conservation systems in Ethiopia Conservation Systems in Ethiopia IV International Conference on*. (January 1985).

Hurni, H., Bantider, A., Debele, B., & Ludi, E. (2010). *Land degradation and sustainable land management in the Highlands of Land Degradation and Sustainable Land Management in the Highlands of Ethiopia*. (January). https://doi.org/10.13140/2.1.3976.5449

Ighodaro, I. D., Lategan, F. S., & Mupindu, W. (2016). *The Impact of Soil Erosion as a Food Security and Rural Livelihoods Risk in South Africa*. *8*(8), 1–12. https://doi.org/10.5539/jas.v8n8p1

Ismail, M. H., & Jusoff, K. (2008). *Assessment-Based from Reference Dataset*. 527–533.

Jafari, S., & Zaredar, N. (2010). *Land Suitability Analysis using Multi-Attribute Decision Making Approach*. *1*(5), 441–445.

Jaiswal, R. K., Ghosh, N. C., Galkate, R. V, & Thomas, T. (2015). Multi-Criteria Decision Analysis (MCDA) for the watershed. *Aquatic Procedia*, *4*(Icwrcoe), 1553–1560. https://doi.org/10.1016/j.aqpro.2015.02.201

Jobbágy, E. G., & Jackson, R. B. (2001). *The distribution of soil nutrients with depth : global patterns and the imprint of plants*. 51–52.

Joshi, A. P. K., Wani, S. P., Chopde, V. K., Foster, J., & Study, A. C. (2019). *Farmers ' Perception of Land Degradation : A Case Study Farmers ' Perception of Land Degradation*. *31*(26).

Kangalawe, R. Y. M., & Lyimo, J. G. (2010). *Population dynamics, rural livelihoods, and environmental degradation : some experiences from Tanzania*. 985–997. https://doi.org/10.1007/s10668-010-9235-y

Kassie, M., Holden, S., Köhlin, G., & Bluffstone, R. (2008). *Environment for Development Economics of Soil Conservation Adoption in High-Rainfall Areas of the Ethiopian Highlands*. (March).

Kassie, M., Holden, S., Köhlin, G., Kassie, M., Holden, S., Köhlin, G., & Bluffstone, R. (2009). *WORKING PAPERS IN ECONOMICS No 400 Economics of Soil Conservation Adoption in High-Rainfall Areas of the Ethiopian Highlands Randy Bluffstone October 2009 ISSN 1403-2473 (print) ISSN 1403-2465 (online) Economics of Soil Conservation Adoption in High-R*. *2473*(400).

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Technological Forecasting & Social Change Adoption of interrelated sustainable agricultural practices in smallholder systems : Evidence from rural Tanzania. *Technological Forecasting & Social Change*, *80*(3), 525–540. https://doi.org/10.1016/j.techfore.2012.08.007

Kassie, M., Marenya, P., Tessema, Y., Jaleta, M., Zeng, D., Erenstein, O., & Rahut, D. (2018). *Measuring Farm and Market Level Economic Impacts of Improved Maize Production Technologies in Ethiopia : Evidence from Panel Data*. *69*(1), 76–95. https://doi.org/10.1111/1477-9552.12221

Kassie, M., Ndiritu, S. W., & Stage, J. (2014). What Determines Gender Inequality in Household Food Security in Kenya? Application of Exogenous Switching Treatment Regression.

World Development, *56*, 153–171. https://doi.org/10.1016/j.worlddev.2013.10.025

Kassie, M., Pender, J., Yesuf, M., Kohlin, G., Bluffstone, R., & Mulugeta, E. (2007). *Impact of Soil Conservation on Crop Production in the Northern Ethiopian Highlands*. (December).

Kassie, M., Pender, J., Yesuf, M., Kohlin, G., Bluffstone, R., & Mulugeta, E. (2008). Estimating returns to soil conservation adoption in the northern Ethiopian highlands. *Agricultural Economics*, *38*(2), 213–232. https://doi.org/10.1111/j.1574-0862.2008.00295.x

Kassie, M., Shiferaw, B., & Muricho, G. (2011). Agricultural Technology, Crop Income, and Poverty Alleviation in Uganda. *World Development*, *39*(10), 1784–1795. https://doi.org/10.1016/j.worlddev.2011.04.023

Kassie, M., Teklewold, H., & Jaleta, M. (2015). Land Use Policy Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, *42*, 400–411. https://doi.org/10.1016/j.landusepol.2014.08.016

Kassie, M., Yesuf, M., & Köhlin, G. (2008). *Environment for Development The Role of Production Risk in Sustainable Land- Management Technology Adoption in the Ethiopian Highlands*. (April).

Kassie, M., Zikhali, P., & Pender, J. (2010). *The Economics of Sustainable Land Management Practices in the Ethiopian Highlands*. https://doi.org/10.1111/j.1477-9552.2010.00263.x

Kerr, J., & Pender, J. (2005). *Farmers ' Perceptions of Soil Erosion and Its Consequences in India' S Semiarid Tropics*. *271*(March), 257–271.

Khan, Z. R., Midega, C. A. O., Pittchar, J. O., Murage, A. W., Birkett, M. A., Bruce, T. J. A., … Tja, B. (2020). *Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020*.

Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of Adoption and Impacts of Improved Maize Varieties in Eastern Zambia. *World Development*, *66*(Icv), 695 706-706. https://doi.org/10.1016/j.worlddev.2014.09.008

Khoshabi, P., Nejati, E., Ahmadi, S. F., Chegini, A., Makui, A., & Ghousi, R. (2020). Developing a multi-criteria decision-making approach to compare types of classroom furniture considering mismatches for anthropometric measures of university students. *PLoS ONE, 15*(9 September), 1–25. https://doi.org/10.1371/journal.pone.0239297

Kiage, L. M. (2013). *Perspectives on the assumed causes of land degradation in the rangelands of Sub-Saharan Africa*. https://doi.org/10.1177/0309133313492543

Kindu, M., Schneider, T., Teketay, D., & Knoke, T. (2013). *Land Use / Land Cover Change Analysis Using Object-Based Classification Approach in Munessa-Shashemene Landscape of*. 2411–2435. https://doi.org/10.3390/rs5052411

Kirui, Oliver K. (2017). *Drivers of Sustainable Land Management in Eastern Africa*. (May), 1–18. https://doi.org/10.20944/preprints201705.0007.v1

Kirui, O. K, & Mirzabaev, A. (2015). Drivers of land degradation and adoption of multiple sustainable land management practices. *International Conference of Agricultural Economists (ICAE)*. Retrieved from https://ageconsearch.umn.edu/bitstream/212008/2/Kirui-Drivers of land degradation and adoption of multiple sustainable land management practices-1021.pdf

Kirui, O.K. (2016). *Economics of Land Degradation, Sustainable Land Management and Poverty in Eastern Africa - The Extent, Drivers, Costs and Impacts*. Retrieved from http://hss.ulb.uni-bonn.de/2016/4355/4355.pdf

Kleemann, J., Baysal, G., Bulley, H. N. N., & Fürst, C. (2017). Assessing driving forces of land use and land cover change by a mixed-method approach in north-eastern Ghana, West Africa. *Journal of Environmental Management*, *196*, 411–442. https://doi.org/10.1016/j.jenvman.2017.01.053

Kouli, M., & Soupios, P. (2009). *Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece*. 483–497. https://doi.org/10.1007/s00254-008-1318-9

Kothari, C.R. (2004). Research Methodology: Method and Techniques (2ed), New Age International Publisher, New Delhi

Kristensen, P. (2004). *The DPSIR Framework*. National Environmental Research Institute, Denmark Department of Policy Analysis European Topic Centre on Water, European Environment Agency, and Paper presented at the 27-29 September 2004 workshop on a comprehensive/detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nairobi, Kenya

Laflen, J. M., & Flanagan, D. C. (2013). The development of U 鄙 S 鄙 soil erosion prediction and modeling 1摇 Introduction 2摇 Empirical soil erosion prediction in the United States. *International Soil and Water Conservation Research*, *1*(2), 1–11. https://doi.org/10.1016/S2095-6339(15)30034-4

Lal, R. 1994. Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. *Soil Tillage Research*,27, 1–8.

Lal, R. (2012). *Zero Net Land Degradation : A New Sustainable Development Goal for Rio + 20*. (May), 1–30.

Lal, R. (2015). *Restoring Soil Quality to Mitigate Soil Degradation*. 5875–5895. https://doi.org/10.3390/su7055875

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of Land Use And Land Cover Change in Tropical Regions. *Annual Review of Environment and Resources, 28*(1), 205–241. https://doi.org/10.1146/annurev.energy.28.050302.105459

Lamourdia, T. (2015). *Status and Trends in Land Degradation in Africa Status and Trends in Land Degradation in Africa*. (November 2007). https://doi.org/10.1007/978-3-540-72438-4

Lanckriet, S., Derudder, B., Naudts, J., Bauer, H., Deckers, J., Haile, M., & Nyssen, J. (2014). *A*

Political Ecology Perspective of Land Degradation in the North Ethiopian Highlands. Land Degradation & Development, 26(5), 521–530. doi:10.1002/ldr.2278

Le, Q. B., Nkonya, E., & Mirzabaev, A. (2016). *Biomass productivity-based Mapping of Global Land Degradation Hotspots*. 55–84. https://doi.org/10.1007/978-3-319-19168-3

Legesse, B., Ayele, Y., & Bewket, W. (2012). Smallholder Farmers' Perceptions and Adaptation to Climate Variability and Climate Change in Doba District, West Hararghe, Ethiopia. *Asian Journal of Empirical Research*, *3*(3), 251–265.

Li, J., Lewis, J., Rowland, J., Tappan, G., & Tieszen, L. L. (2004). *Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series*. 1–18. https://doi.org/10.1016/j.jaridenv.2004.03.019

Liniger, H., van Lynden, G., Nachtergaele, F., Schwilch, G. (2008). A questionnaire for mapping land degradation and sustainable land management. 40p.

Liniger, H.P., Gurtner, M., Studer, R.M., Hauert, C. (2011). Sustainable Land Management in Practice-Guidelines and Best Practices For Sub-Saharan Africa. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO); FAO: Rome, Italy, 2011; 243p

Lokshin, M., & Sajaia, Z. (2004). Maximum Likelihood Estimation of Endogenous Switching Regression Models. *The Stata Journal: Promoting Communications on Statistics and Stata*, *4*(3), 282–289. https://doi.org/10.1177/1536867x0400400306

Lorenz, K. (2019). *Soil organic carbon stock as an indicator for monitoring land and soil degradation in relation to United Nations ' Sustainable Development Goals*. (December 2017), 824–838. https://doi.org/10.1002/ldr.3270

Lu, D., Batistella, M., & Moran, P. M. E. (2007). *Mapping and Monitoring Land Degradation Risks in the Western Brazilian Amazon Using Multitemporal Landsat TM / ETM Þ ImageS*. *54*, 41–54.

MA. (2005). Ecosystems and Human Well-Being: Synthesis; Island Press: Washington, DC, USA.

Mairura, F. S., Mugendi, D. N., Mwanje, J. I., Ramisch, J. J., Mbugua, P. K., & Chianu, J. N. (2008). *Scientific Evaluation Of Smallholder Land Use Knowledge In Central Kenya*. *90*(July 2007), 77–90. https://doi.org/10.1002/ldr

Mekuriaw, A., Heinimann, A., Zeleke, G., & Hurni, H. (2018). Factors influencing the adoption of physical soil and water conservation practices in the Ethiopian highlands. International Soil and Water Conservation Research, 6(1), 23–30. doi: 10.1016/j.iswcr.2017.12.006

Manikandan AD, Kurian VM. (2016). Theory and Practical Implication of Land Degradation and Livelihood: Case of Attappady Region in Kerala.; XXVI (1):85-104. doi:10.1177/1018529120160103

Malczewski, J. (2007). *GIS - based multicriteria decision analysis : a survey of the literature*.

8816. https://doi.org/10.1080/13658810600661508

Marczyk G. DeMatteo D and Festinger D. (2005). Essentials of Research Design and Methodology, John Wiley and Sons, Inc. Hoboken, New Jersey.

Marques, M. J., Schwilch, G., Lauterburg, N., Crittenden, S., Tesfai, M., Stolte, J., … Panagopoulos, T. (2016). *Multifaceted Impacts of Sustainable Land Management in Drylands : A Review*. (i). https://doi.org/10.3390/su8020177

Masoudi, M., Jokar, P., & Pradhan, B. (2018). A new approach for land degradation and desertification assessment using geospatial techniques. *Natural Hazards and Earth System Sciences*, *18*(4), 1133–1140. https://doi.org/10.5194/nhess-18-1133-2018

Mekuria, W., & Mekonnen, K. (2018). Determinants of crop-livestock diversification in the mixed farming systems: Evidence from central highlands of Ethiopia. *Agriculture and Food Security*, *7*(1), 1–15. https://doi.org/10.1186/s40066-018-0212-2

Mekuriaw, A., Heinimann, A., Zeleke, G., & Hurni, H. (2018). *International Soil and Water Conservation Research Factors in fl uencing the adoption of physical soil and water conservation practices in the Ethiopian highlands*. *6*, 23–30.

Menbere, S., & Box, P. O. (2014). *Livestock Production Constrains Priorities and its Determinant Factors in Mixed Farming System of Southern Ethiopia*. *10*(4), 169–177. https://doi.org/10.5829/idosi.wjas.2014.10.4.914

Mengistu, F., & Assefa, E. (2019). *International Soil and Water Conservation Research Farmers ' decision to adopt watershed management practices in Gibe basin , southwest Ethiopia*. (xxxx).

Merrey, D.J., Gebreselassie, T. (2011). Promoting Improved Rainwater and Land Management in the Blue Nile (Abay) basin of Ethiopia. In NBDC Technical Report 1; ILRI: Nairobi, Kenya, 2011.

Meseret, D., & Gangadhara, M. H. (2017). Integration of geospatial technologies with RUSLE for analysis of land use/cover change impact on soil erosion : a case study in Rib watershed, northwestern highland Ethiopia. *Environmental Earth Sciences*, *76*(22), 1–14. https://doi.org/10.1007/s12665-017-7109-4

Mganga, K. Z., Musimba, N. K. R., & Nyariki, D. M. (2015). Combining Sustainable Land Management Technologies to Combat Land Degradation and Improve Rural Livelihoods in Semi-arid Lands in Kenya. *Environmental Management*, *56*(6), 1538–1548. https://doi.org/10.1007/s00267-015-0579-9

Miheretu, B. A., & Yimer, A. A. (2018). *Estimating soil loss for sustainable land management planning at the Gelana sub-watershed, northern highlands of Ethiopia*. *5124*. https://doi.org/10.1080/15715124.2017.1351978

Miheretu, B. A., & Yimer, A. A. (2017). *Determinants of farmers ' adoption of land management practices in Gelana sub- watershed of Northern highlands of*. https://doi.org/10.1186/s13717-017-0085-5

Miller, R. (2003). A-Z Social Research. A Book. SAGE Publication Limited. London, UK.

Mishra, A. K., Deep, S., & Choudhary, A. (2015). Identification of suitable sites for organic farming using AHP & GIS. *The Egyptian Journal of Remote Sensing and Space Sciences*, *18*(2), 181–193. https://doi.org/10.1016/j.ejrs.2015.06.005

MoA & ILRI. (2013). Animal production vision and strategy for Ethiopia. *Ethiopia Livestock Master Plan Background Paper*, (Ministry of Agriculture and International Livestock Research Institute.). Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/67250/LMP_animalproduction_2013.pdf?sequence=1

Moges, A.; Holden, N. M. (2007). Farmers' Perceptions of Soil Erosion and Soil Fertility Loss in Southern Ethiopia. *Land Degradation and Development*, 18: 543–554.https://doi.org/10.1002/ldr.795

Mokhtarian, M.N.; Sadi-nezhad, S.; Makui, A. (2014). A new flexible and reliable interval-valued fuzzy VIKOR method based on uncertainty risk reduction in the decision-making process: An application for determining a suitable location for digging some pits for municipal wet waste landfill. Comput. Ind. Eng. 78, 213–233.

Molla, T., & Sisheber, B. (2016). *Estimating Soil Erosion Risk and Evaluating Erosion Control Measures for Soil Conservation Planning at Koga Watershed, Highlands of Ethiopia*. (September), 1–23. https://doi.org/10.5194/se-2016-120

Molla, T., & Sisheber, B. (2017). *Estimating soil erosion risk and evaluating erosion control measures for soil conservation planning at Koga watershed in the highlands of*. (2014), 13–25. https://doi.org/10.5194/se-8-13-2017

Moore, I. D., & Wilson, J. P. (1992). *Length-slope factors for the Revised Universal Soil Loss Equation : Simplified method of estimation*. (October), 423–428.

Motbainor, A., Worku, A., & Kumie, A. (2016a). Level and determinants of food insecurity in East and West Gojjam zones of Amhara Region, Ethiopia: A community based comparative cross-sectional study. *BMC Public Health*, *16*(1). https://doi.org/10.1186/s12889-016-3186-7

Motbainor, A., Worku, A., & Kumie, A. (2016b). Level and determinants of food insecurity in East and West Gojjam zones of Amhara Region, Ethiopia : a community-based comparative cross-sectional study. *BMC Public Health*, 1–13. https://doi.org/10.1186/s12889-016-3186-7

Muloo, M. S., Kioko, K. M., & M, K. J. (2019). *Effects of Land Degradation on Agricultural Land Use : A Case Study of Smallholder Farmers Indigenous Knowledge on Land Use Planning and Management in Kalama Division, Machakos County*. *34*(3), 1–15. https://doi.org/10.9734/CJAST/2019/v34i330134

Murendo, C., Gwara, S., Mpofu, N., Pedzisa, T., & Chivenge, P. (2019). *The adoption of a portfolio of sustainable agricultural practices by smallholder farmers in Zimbabwe The adoption of a portfolio of sustainable agricultural practices by smallholder ... The adoption* *of a portfolio of sustainable agricultural practices by s*.

Munthali, M.G.; Davis, N.; Adeola, A.M.; Botai, J.O. (2019). Local perception of drivers of land-use and land-cover change dynamics across Dedza district, central Malawi region. Sustainability, 11, 832.

Mussema, R., Belay, K., Alemu, D., & Rashid, S. (2015). Determinants of crop diversification in Ethiopia: Evidence from Oromia region. *Ethiopian Journal of Agricultural Sciences*, *25*(2), 65–76.

Mwungu, C. M., Mwongera, C., Shikuku, K. M., Acosta, M., & Läderach, P. (n.d.). *Determinants of Adoption of Climate-Smart Agriculture Technologies at Farm Plot Level : An Assessment from Southern Tanzania*.

Nachtergaele, F.; Velthuizen, H.; Van Verelst, L.; Batjes, N.H.; Dijkshoorn, J.A.; Engelen, V.W.P.; van Fischer, G.; Montanarella, L.; Petri, M.; Prieler, S. Harmonized World Soil Database. Version 1.0. 2009. Available online: http://www.fao.org/nr/water/docs/ Harm-World-Soil-DBv7cv.pdf

Nawaz, M. F., & Bourrié, G. (2013). *Soil compaction impact and modeling. A review*. 291–309. https://doi.org/10.1007/s13593-011-0071-8

Ngema, P. Z., Sibanda, M., & Musemwa, L. (2018). *Household Food Security Status and Its Determinants in Maphumulo Local Municipality, South Africa*. 1–23. https://doi.org/10.3390/su10093307

NCSS (National Conservation Strategy Secretariat). 1991. *Economic Assessment of Land Degradation in the Ethiopian Highlands: A Case Study.* Addis Ababa: NCSS.

Nellemann, C. (2009). The Environmental Food Crisis: The Environment's Role in Averting Future Food Crises: A UNEP Rapid Response Assessment. UNEP/Earth Print.

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., & Adgo, E. (2017). *Land Use Policy Factors in fl uencing small-scale farmers ' adoption of sustainable land management technologies in north-western Ethiopia*. *67*(May 2016), 57–64. https://doi.org/10.1016/j.landusepol.2017.05.024

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Nohmi, M., Tsubo, M., … Abele, S. (2017). Farmers' Perception about Soil Erosion in Ethiopia. *Land Degradation and Development*, *28*(2), 401–411. https://doi.org/10.1002/ldr.2647

Nkonya, E.; von Braun, J.; Mirzabaev, A.; Le, Q.B.; Kwon, H.Y.; Kirui, O. (2013). Economics of Land Degradation Initiative: Methods and Approach for Global and National Assessments; ZEF—Discussion Papers on Development Policy No. 183; Center for Development Research: Bonn, Germany, p. 41.

Nkonya, E., Johnson, T., Kwon, H. Y., & Kato, E. (2016). *Economics of Land Degradation in Sub-Saharan Africa*. https://doi.org/10.1007/978-3-319-19168-3

Nyssen, J., Poesen, J., & Deckers, J. (2009). Land degradation and soil and water conservation in tropical highlands. *Soil and Tillage Research*, *103*(2), 197–202. https://doi.org/10.1016/j.still.2008.08.002

Obalum, S. E., Buri, M. M., Nwite, J. C., Watanabe, Y., Igwe, C. A., & Wakatsuki, T. (2012). *Soil Degradation-Induced Decline in Productivity of Sub-Saharan African Soils : The Prospects of Looking Downwards the Lowlands with the Sawah Ecotechnology*. *2012*. https://doi.org/10.1155/2012/673926

Oldeman, L.R., Hakkeling, R.T.A., Sombroek, W.G. (1991). World Map of the status of human-induced degradation: An explanatory note. ISRIC, Wageningen, The Netherlands/UNEP, Nairobi, Kenya

Oldeman, L. R. (1992). *Global Extent of Soil Degradation*. 19–36.

Oldeman, L. The Global Extent of Soil Degradation. (1994). In ISRIC Bi-Annual Report 1991–1992; International Soil Reference and Information Centre: Wageningen, The Netherlands, pp. 19–36.

Oldeman, L.; van Lynden, G. (1996). Revisiting the Glasod Methodology; Working Paper and Preprint, 96/03; International Soil Reference and Information Centre: Wageningen, The Netherlands.

Olsson, L., & Tengberg, A. (2018). *Monitoring and Assessing Land Degradation to Support Sustainable Development A background to the use of the land*. (May). https://doi.org/10.13140/RG.2.2.11055.84642

Oo, O., Sl, G., & Do, G. (2017). *Journal of Remote Sensing & GIS Analyzing the Rate of Land Use and Land Cover Change and Determining the Causes of Forest Cover Change in Gog District , Gambella Regional*. *6*(4). https://doi.org/10.4172/2469-4134.1000219

Orchard, S. E., Stringer, L. C., & Manyatsi, A. M. (2017). Farmer Perceptions and Responses to Soil Degradation in Swaziland. *Land Degradation and Development*, *28*(1), 46–56. https://doi.org/10.1002/ldr.2595

Orhan, I., Sener, B., & Atici, T. (2003). Fatty acid distribution in the lipoid extracts of various algae. *Chemistry of Natural Compounds*, *39*(2), 167–170. https://doi.org/10.1023/A:1024805712396

Ouma, B., & Sterk, G. (2006). *Farmers ' identification of erosion indicators and related erosion damage in the Central Highlands of Kenya*. *65*, 292–301. https://doi.org/10.1016/j.catena.2005.12.004

Osman, K.T. (2013) Soil Degradation, Conservation and Remediation; Springer: New York, NY, USA.

Park, Q.N.; Mucova, R.; Leal, W. (2018). Assessment of land use and land cover changes from 1979 to 2017 and biodiversity & land management approach in Quirimbas National Park, Northern Mozambique, Africa. Glob. Ecol. Conserv. 16, e00447.

Panagos, P., Borrelli, P., Meusburger, K., Zanden, E. H. Van Der, Poesen, J., & Alewell, C.

(2015). ScienceDirect Modelling the effect of support practices (P -factor) on the reduction of soil erosion by water at European scale. *Environmental Science and Policy, 51*, 23–34. https://doi.org/10.1016/j.envsci.2015.03.012

Pender, J., & Gebremedhin, B. (2004). *Strategies to Improve Land Management, Crop Production and Household Income in the Highlands of Tigray, Northern Ethiopia*.

Pender, J. L., & Gebremedhin, B. (2006). *Land management, crop production, and household income in the highlands of Tigray, northern Ethiopia: An econometric analysis*. Retrieved from https://hdl.handle.net/10568/50774

Renard, K.G.; Yoder, D.C.; Lightle, D.T.; Dabney, S.M. (2011) Universal soil loss equation and revised universal soil loss equation. In Handbook of Erosion Modelling, 1st ed.; Morgan, R.P.C., Nearing, M.A., Eds.; Blackwell Publishing Ltd.: New York, NY, USA.

Reynolds, J. F., Smith, D. M. S., Lambin, E. F., Turner, B. L., Mortimore, M., Batterbury, S. P. J., Walker, B. (2007). Global Desertification: Building a Science for Dryland Development. Science, 316(5826), 847–851. doi:10.1126/science.1131634

Pimentel, D., & Burgess, M. (2013). Soil Erosion Threatens Food Production. *Agriculture, 3*(3), 443–463. https://doi.org/10.3390/agriculture3030443

Pontius, R. G., Shusas, E., & Mceachern, M. (2004). *Detecting important categorical land changes while accounting for persistence*. *101*, 251–268. https://doi.org/10.1016/j.agee.2003.09.008

Platts, M.J. and Leong,Y.Y.(2020). Soil Fertility Is a Productive Capital Asset. Agricultural Sceiences, II,744-776. http://doi.org/10.4236/as.2020.118049

Prasad, V. S., & Kousalya, P. (2017). *Role of Consistency in Analytic Hierarchy Process – Consistency Improvement Methods*. https://doi.org/10.17485/ijst/2017/v10i29/100784

Purcell, T. W. (1998). *Indigenous knowledge and applied anthropology : Questions of definition and di ...*

Puyravaud, J. (2003). *Standardizing the calculation of the annual rate of deforestation*. *177*, 593–596.

Qi, J., Chehbouni, A., Huete, A. R., Kerr, Y. H., & Sorooshian, S. (1994). *A Modified Soil Adjusted Vegetation Index*. *4257*(May). https://doi.org/10.1016/0034-4257(94)90134-1

Rabia, Ahmed H, & Terribile, F. (2013). *Introducing a New Parametric Concept for Land Suitability Assessment*. (June 2014). https://doi.org/10.7763/IJESD.2013.V4.295

Rabia, Ahmed Harb, & Rabia, A. H. (2012). *GIS Spatial Modeling for Land Degradation Assessment in Tigray, Ethiopia.*

Rahman, R., Shi, Z. H., & Chongfa, C. (2009). *Soil erosion hazard evaluation — An integrated use of remote sensing, GIS, and statistical approaches with biophysical parameters towards management strategies*. *220*, 1724–1734. https://doi.org/10.1016/j.ecolmodel.2009.04.004

Ravnborg, H. M. (2003). Poverty and Environmental Degradation in the Nicaraguan Hillsides. World Development, 31(11), 1933–1946. doi: 10.1016/j.worlddev.2003.06.005

Reed, M. S., & Dougill, A. J. (2002). *Participatory selection process for indicators of rangeland condition in the Kalahari*. *168*(3), 224–234.

Reis, S. (2008). *Analyzing Land Use/Land Cover Changes Using Remote Sensing and GIS in Rize, North-East Turkey*. 6188–6202. https://doi.org/10.3390/s8106188

Renard, K. G., & Foster, G. R. (1985). *Managing Rangeland Soil Resources : The Universal Soil Loss Equation*. *7*(3).

Reusing, M., Schneider, T., & Ammer, U. (2017). *Modeling soil loss rates in the Ethiopian Highlands by integration of high-resolution MOMS-02 / D2- stereo-data in a GIS*. *1161*(February). https://doi.org/10.1080/014311600209797

Richards, J. A., Sensing, R., & Image, D. (2013). *Correcting and Registering Images*. https://doi.org/10.1007/978-3-642-30062-2

Romkens, M.M.; Young, R.A.; Poesen, J.A.; McCool, D.K.; El-Swaify, S.A.; Bradford, J.M. (1997). Soil erodibility factor (K.). In Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE); Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., Eds.; U.S. Government Printing Office: Washington, DC, USA, 1997; pp. 65–100.

Russell, J., Lechner, A., Hanich, Q., Delisle, A., Campbell, B., & Charlton, K. (2018). Assessing food security using household consumption expenditure surveys (HCES): A scoping literature review. *Public Health Nutrition*, *21*(12), 2200–2210. https://doi.org/10.1017/S136898001800068X

Rwanga, S. S., & Ndambuki, J. M. (2017). *Accuracy Assessment of Land Use / Land Cover Classification Using Remote Sensing and GIS*. *2017*, 611–622. https://doi.org/10.4236/ijg.2017.84033

Saaty, T.; Vargas, L. (2001). Methods, Concepts, and Applications of the Analytic Hierarchy Process; Kluwer Academic Publishers: Boston, MA, USA.

Saaty, T. L. (2008). *The Analytic Hierarchy Process; McGraw-Hill: New York, NY, USA.*

Sadik-zada, E. R. (2020). *Natural resources, technological progress, and economic modernization*. (July), 1–24. https://doi.org/10.1111/rode.12716

Saguye, T. S. (2017). *Analysis of farmers ' perception on the impact of land degradation hazard on agricultural land productivity in Jeldu district in West Shewa Zone, Oromia , Ethiopia*. *9*(June), 111–123. https://doi.org/10.5897/JAERD2017.0854

Saguye, T. S. (2017c). Determinants of Adoption of Sustainable Land Management (SLM) Practices among Smallholder Farmers' in Jeldu District, West Shewa Zone, Oromia Region, Ethiopia. *Global Journal of Science Frontier Research: H Environment & Earth Science*, *17*(5), 111–127. Retrieved from https://globaljournals.org/GJSFR_Volume17/5-

Determinants-of-Adoption.pdf

Saguye, T. S. (2018). Analysis of Farmers' Perception on the Impact of Land Degradation Hazard on Agricultural Land Productivity in Jeldu District in West. 8(2), 20–33. https://doi.org/10.5539/eer.v8n2p20

Sałabun, W., Ziemba, P., & Wątróbski, J. (2016). The rank reversals paradox in management decisions: The comparison of the AHP and COMET methods. *Smart Innovation, Systems, and Technologies*, *56*, 181–191. https://doi.org/10.1007/978-3-319-39630-9_15

Sarin, R.K. Multi-attribute Utility Theory. (2013). In Encyclopedia of Operations Research and Management Science; Gass, S.I., Fu, M.C., Eds.; Springer: Boston, MA, USA, pp. 1004–1006.

Scharsich, V., Mtata, K., Hauhs, M., Lange, H., & Bogner, C. (2017). Remote Sensing of Environment Analysing land cover and land-use change in the Matobo National Park and surroundings in Zimbabwe. *Remote Sensing of Environment*, *194*, 278–286. https://doi.org/10.1016/j.rse.2017.03.037

Scherr, S. J. (2000). A downward spiral? Research evidence on the relationship between poverty and natural resource degradation. Food Policy, 25, 479–498

Scherr, S. J. & Hazell, P. B. R. (1994). . EPTD discussion papers 1, International Food Policy Research Institute (IFPRI).1200 Seventeenth Street, N.W. Washington, D.C. 20036-3006 U.S.A.

Schmidt, E., & Tadesse, F. (2019). *The impact of sustainable land management on household crop production in the Blue Nile Basin, Ethiopia*. (January 2018), 777–787. https://doi.org/10.1002/ldr.3266

Selassie, Y.G.; Belay, Y. (2013). Costs of Nutrient Losses in Priceless Soils Eroded from the Highlands of Northwestern Ethiopia. J. Agric. Sci, 5, 7.

Şener, Ş., Şener, E., Nas, B., & Karagüzel, R. (2010). Combining AHP with GIS for landfill site selection: A case study in the Lake Beyşehir catchment area (Konya, Turkey). *Waste Management*, *30*(11), 2037–2046. https://doi.org/10.1016/j.wasman.2010.05.024

Sileshi, M., Kadigi, R., Mutabazi, K., & Sieber, S. (2019). *Impact of soil and water conservation practices on household vulnerability to food insecurity in eastern Ethiopia: endogenous switching regression and propensity score matching approach. Food Security.* doi:10.1007/s12571-019-00943-w

Shiferaw, B., & Holden, S. T. (1998). *Resource degradation and adoption of land conservation technologies 1n the Ethiopian Highlands : A case study in Andit Tid , North Shewa*. *18* (March 1990), 233–247.

Shiferaw, B., & Holden, S. T. (2001). Farm-level benefits to investments for mitigating land degradation: Empirical evidence from Ethiopia. *Environment and Development Economics*, *6*(3), 335–358. https://doi.org/10.1017/S1355770X01000195

Shimeles, D. (2012). *Effectiveness of soil and water conservation measures for land restoration in the Wello area, northern Ethiopian highlands*. 150.

Sileshi, M., Kadigi, R., Mutabazi, K., & Sieber, S. (2019). *International Soil and Water Conservation Research Determinants for the adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia*. (xxxx).

Sileshi, T., UN, Models, P., Use, W., Information, W., Degradation, L., … Livelihood, T. (2012). Characterization and Atlas of the Blue Nile Basin and its Sub basins. *International Water Management Institute*, *6*(August), 1–81. https://doi.org/10.5251/abjna.2015.6.5.123.133

Simane, B., Zaitchik, B. F., & Foltz, J. D. (2016). *Agroecosystem specific climate vulnerability analysis : application of the livelihood vulnerability index to a tropical highland region*. 39–65. https://doi.org/10.1007/s11027-014-9568-1

Simane, B., Zaitchik, B. F., & Mesfin, D. (2012). *Building Climate Resilience in the Blue Nile / Abay Highlands : A Framework for Action*. 610–631. https://doi.org/10.3390/ijerph9020610

Simane, B., Zaitchik, B. F., & Ozdogan, M. (2013). *Agroecosystem Analysis of the Choke Mountain*. 592–616. https://doi.org/10.3390/su5020592

Sime, G. (2018). *Sustainability of Improved Crop Varieties and Agricultural Practices : A Case Study in the Central Rift Valley of Ethiopia*. https://doi.org/10.3390/agriculture8110177

Sisay, D. T., Verhees, F. J. H. M., Trijp, H. C. M. Van, Tsegaye, D., Verhees, F. J. H. M., & Van, H. C. M. (2017). *Seed producer cooperatives in the Ethiopian seed sector and their role in seed supply improvement : A review*. *7528*. https://doi.org/10.1080/15427528.2017.1303800

Smeets, E., Weterings, R., Centre, T. N. O., Bosch, P., Büchele, M., & Gee, D. (n.d.). *Environmental indicators : Typology and overview Prepared by Project Managers :* (25).

Song, X.; Du, L.; Kou, C.; Ma, Y. Assessment of soil erosion in the water source area of the Danjiangkou reservoir using USLE and GIS. In Proceedings of the Second 73 International Conference on Information Computing and Applications, Qinhuangdao, China, 28–31 October 2011; Springer: Berlin/Heidelberg, Germany, pp. 57–64.

Stavi, I., & Lal, R. (2014). Achieving Zero Net Land Degradation : Challenges and opportunities Achieving Zero Net Land Degradation : Challenges and opportunities. *Journal of Arid Environments*, *112*(October 2017), 44–51. https://doi.org/10.1016/j.jaridenv.2014.01.016

Stringer, L. C. (n.d.). *Global land and soil degradation : soil challenges*. *44*(0).

Stringer, L. C., & Dougill, A. J. (2013). Channelling science into policy : Enabling best practices from research on land degradation and sustainable land management in dryland Africa. *Journal of Environmental Management*, *114*, 328–335. https://doi.org/10.1016/j.jenvman.2012.10.025

Stocking, M., Murnaghan, N. (2001). Handbook for the field assessment of land degradation.

Earth scan Publishers Ltd. London.

Swindale, A., & Bilinsky, P. (2006). *Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide | Food and Nutrition Technical Assistance III Project (FANTA)*. Retrieved from http://www.fantaproject.org/monitoring-and-evaluation/household-dietary-diversity-score

Taddese, G. (2001). *Land Degradation : A Challenge to Ethiopia*. *27*(6), 815–824. https://doi.org/10.1007/s002670010190

Tadesse, M., & Belay, K. (2004). *Factors Influencing Adoption of Soil Conservation Measures in Southern Ethiopia : The Case of Gununo Area*. *105*(1), 49–62.

Tambo, J., & Wünscher, T. (2016). Beyond adoption: welfare effects of farmer innovation behavior in Ghana. *Center for Development Research (ZEF)*, (216), 1–30.

Tamene, L., Adimassu, Z., Aynekulu, E., & Yaekob, T. (2017). International Soil and Water Conservation Research Estimating landscape susceptibility to soil erosion using a GIS-based approach in Northern Ethiopia. *International Soil and Water Conservation Research*, *5*(3), 221–230. https://doi.org/10.1016/j.iswcr.2017.05.002

Tamene, L.; Le, B.Q. (2015). Estimating soil erosion in sub-Saharan Africa based on landscape similarity mapping and using the revised universal soil loss equation (RUSLE). Nutr. Cycl. Agroecosyst.

Teferi, E., Bewket, W., Uhlenbrook, S., & Wenninger, J. (2013). Understanding recent land use and land cover dynamics in the source region of the Upper Blue Nile, Ethiopia: Spatially explicit statistical modeling of systematic transitions. *Agriculture, Ecosystems and Environment*, *165*, 98–117. https://doi.org/10.1016/j.agee.2012.11.007

Teketay, D. (2001). Deforestation, wood land famine and environmental degradation in Ethiopia high land ecosystem urgent to action. Northeast Afr. Stud. 2001, 8, 53–76.

Teklewold, H., Gebrehiwot, T., & Bezabih, M. (2019). *Climate-smart agricultural practices and gender-differentiated nutrition outcome : An empirical evidence from Ethiopia*. *122*, 38–53.

Teklewold, H., Kassie, M., & Shiferaw, B. (2013). *Adoption of Multiple Sustainable Agricultural Practices in Rural Ethiopia*. *64*(3), 597–623. https://doi.org/10.1111/1477-9552.12011

Tesfaye, S., Guyassa, E., Raj, A. J., Birhane, E., & Wondim, G. T. (2014). *Land Use and Land Cover Change, and Woody Vegetation Diversity in Human Driven Landscape of Gilgel Tekeze Catchment, Northern Ethiopia*. *2014*.

Teshome, A., Graaff, J. De, & Kassie, M. (2016). Household-Level Determinants of Soil and Water Conservation Adoption Phases : Evidence from North-Western Ethiopian Highlands. *Environmental Management*, *57*(3), 620–636. https://doi.org/10.1007/s00267-015-0635-5

Teshome, Y. B., & Bayu, T. Y. (2014). *An Agro-Ecological Assessment of Household Food Insecurity in Mid-Deme Catchment, South-western*. *2*(2), 19–27.

Tiruneh, G., & Ayalew, M. (2015). *SOIL LOSS ESTIMATION USING GEOGRAPHIC INFORMATION SYSTEM IN ENFRAZ WATERSHED FOR SOIL CONSERVATION PLANNING IN HIGHLANDS OF ETHIOPIA*. *5*(2), 21–30.

Torres, L., Abraham, E. M., Rubio, C., & Barbero-sierra, C. (2015). *DESERTIFICATION RESEARCH IN ARGENTINA*. *440*, 433–440.

Tsegaye, D., Moe, S. R., Vedeld, P., & Aynekulu, E. (2010). Agriculture, Ecosystems and Environment Land-use / cover dynamics in Northern Afar rangelands, Ethiopia. *"Agriculture, Ecosystems and Environment," 139*(1–2), 174–180. https://doi.org/10.1016/j.agee.2010.07.017

UNCCD, (2013b). Refinement of the Set of Impact Indicators on Strategic Objectives 1, 2, and 3 Recommendations of the ad hoc Advisory Group of Technical Experts. ICCD/COP (11) /CST/2.

UNCCD. (2013a). *Economic assessment of desertification, sustainable land management and resilience of arid, semi-arid and dry sub-humid areas* 9-12 April 2013 - Bonn, Germany

UNCCD. (2015). Climate change and land degradation: Bridging knowledge and stakeholders Outcomes. In Proceedings of the UNCCD 3rd Scientific Conference, Cancun, Mexico, 9-12 March 2015.

UNEP .(2015). The Economics of Land Degradation in Africa, ELD Initiative, Bonn, Germany Available from www.eld-initiative.org

USDA. (2008). Bulk Density. Soil Quality Indicators, USDA Natural Resources Conservation Service. Available online: www.nrcs.

USDA. (2017). Soil Quality Indicators, USDA Natural Resources Conservation Service. Available online: www.nrcs.usda.gov.

Utuk, I. O., & Ph, D. (2015). *Land Degradation : A Threat to Food Security : A Global Assessment*. *5*(8), 13–22.

Verkaart, S., Munyua, B. G., Mausch, K., & Michler, J. D. (2017). *Welfare impacts of improved chickpea adoption : A pathway for rural development in Ethiopia ? 66*, 50–61.

Walmsley, J. A. Y. J. (2002). *Framework for Measuring Sustainable Development in Catchment Systems*. *29*(2), 195–206. https://doi.org/10.1007/s00267-001-0020-4

Warren, A. (2002). *Land degradation is contextual. Land Degradation & Development, 13(6), 449–459.* doi:10.1002/ldr.532 \

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: Micro-level evidence from Kenya. *Agriculture and Food Security*, *7*(1), 1–14. https://doi.org/10.1186/s40066-018-0230-0

Wischmeier, W.H.; Smith, D.D. (1978). Predicting Rainfall Erosion Losses: A Guide to Conservation Planning; Agriculture Handbook No. 537; Department of Agriculture: Washington, DC, USA.

Woodhouse, P., Howlett, D., & Rigby, D. (2000). *Sustainability Indicators for Natural Resource Management & Policy A Framework for Research on Sustainability Indicators for Agriculture and Rural Livelihoods*. 1–39.

Wordofa, M.G., Okoyo, E.N. & Erkalo, E. (2020). Factors influencing adoption of improved structural soil and water conservation measures in Eastern Ethiopia. *Environ Syst Res* 9**,** 13. https://doi.org/10.1186/s40068-020-00175-4

World Bank. (2006). Sustainable Land Management: Challenges, Opportunities, and Trade-Offs, Washington, DC

World Bank. (2008). Sustainable land management sourcebook: Agriculture and rural development, The World Bank, Washington DC 20433

World Bank. (2005). *Well-being and poverty in Ethiopia: The role of agriculture and agency. Document of the World Bank. Report No. 29468-ET*.

World Bank. (2020). International development association project appraisal document on a proposed credit. Report No: PAD2484. Available online: http://documents1.worldbank.org/curated/en/671621533180654816/pdf/ETHIOPIA-PAD-07112018.pdf (accessed on 20/03/2018)

Xie, L. W., Zhong, J., Chen, F. F., Cao, F. X., Li, J. J., & Wu, L. C. (2015). *Evaluation of soil fertility in the succession of karst rocky desertification using principal component analysis*. 515–524. https://doi.org/10.5194/se-6-515-2015

Yalew, S.G.; Mul, M.L.; Van Griensven, A.; Teferi, E.; Priess, J. (2012) Land-Use Change Modelling in the Upper Blue Nile Basin. Environments, 3, 21.

Yang, X., Gray, J., Chapman, G., Zhu, Q., Tulau, M., & McInnes-Clarke, S. (2018). Digital mapping of soil erodibility for water erosion in New South Wales, Australia. *Soil Research, 56*(2), 158–170. https://doi.org/10.1071/SR17058

Yesuph, A. Y., & Dagnew, A. B. (2019). Soil erosion mapping and severity analysis based on RUSLE model and local perception in the Beshillo Catchment of the Blue Nile Basin, *Environmental Systems Research*, 1–21. https://doi.org/10.1186/s40068-019-0145-1

Yilma, A. D., & Awulachew, S. B. (2009). *Characterization and Atlas of the Blue Nile Basin and its Sub basins*.

Yifru, G.S.; Miheretu, B.A. (2021). Farmers' adoption of soil and water conservation practices: The case of Lege-Lafto Watershed, Dessie Zuria District, South Wollo, Ethiopia. Research square. https://doi.org/10.21203/rs.3.rs-522567/v1

Young, N.E., Anderson, R.S., Chignell, S.M., Vorster, A.G., Lawrence, R., and Evangelista, P.H. (2017). A survival guide to Landsat preprocessing. Ecology 2017, 98, 920–932.

Zegeye, A. D., Steenhuis, T. S., Blake, R. W., Kidnau, S., Collick, A. S., & Dadgari, F. (2010). *Assessment of soil erosion processes and farmer perception of land conservation in Debre Mewi watershed near Lake Tana, Ethiopia. Ecohydrology & Hydrobiology, 10(2-4), 297–306.* doi:10.2478/v10104-011-0013-8

Zeleke, G. (2000). Landscape Dynamics and Soil Erosion Process Modeling in the North-Western Ethiopian Highlands; University of Bern: Bern, Switzerland.

Zeleke, A. G., & Hurni, H. (2001). *Implications of Land Use and Land Cover Dynamics for Mountain Resource Degradation in the Northwestern Ethiopian Highlands Implications of Land Use and Land Cover Dynamics for Mountain Resource Degradation in the Northwestern Ethiopian Highlands*. *21*(May), 184–191.

Zeleke, G. (2007). *Conceptual Framework of RUL with special Emphasis on water and pollutant flow analysis Global Mountain Programme (GMP) The major drive of the RUL Initiative – Global perspective*.

Zerihun, M., Mohammedyasin, M. S., Sewnet, D., Adem, A. A., & Lakew, M. (2018). Assessment of soil erosion using RUSLE, GIS, and remote sensing in NW Ethiopia. *Geoderma Regional*, (March). https://doi.org/10.1016/j.geodrs.2018.01.002

Zewdie, W., & Csaplovics, E. (2016). *Identifying Categorical Land Use Transition and Land Degradation in Northwestern Drylands of Ethiopia*. https://doi.org/10.3390/rs8050408

Zewdie, W., & Csaplovies, E. (2017). *Remote Sensing-based multi-temporal land cover classification and change detection in northwestern Ethiopia Remote Sensing-based multi-temporal land cover classification and change detection in northwestern Ethiopia*. *7254*. https://doi.org/10.5721/EuJRS20154808

Zeweld, W.; Van Huylenbroeck, G.; Tesfay, G.; Azadi, H. (2018). Impacts of Socio-Psychological Factors on Actual Adoption of Sustainable Land Management Practices in Dryland and Water Stressed Areas. Sustainability, 1-23. doi:10.3390/su10092963

Zia-ur-rehman, M., Murtaza, G., Qayyum, M. F., Rizwan, M., & Ali, S. (2016). *Degraded Soils : Origin, Types and Management Degraded Soils : Origin, Types and Management*. https://doi.org/10.1007/978-3-319-34451-5

Zingiro, A., Okello, J. J., & Guthiga, P. M. (2014). Assessment of adoption and impact of rainwater harvesting technologies on rural farm household income: the case of rainwater harvesting ponds in Rwanda. *Environment, Development, and Sustainability*, *16*(6), 1281–1298. https://doi.org/10.1007/s10668-014-9527-8

Zolekar, R. B., & Bhagat, V. S. (2015). Multi-criteria land suitability analysis for agriculture in the hilly zone : Remote sensing and GIS approach. *Computers and Electronics in Agriculture*, *118*, 300–321. https://doi.org/10.1016/j.compag.2015.09.016

Appendices

A. Household Survey Questionnaire

School of Graduate Studies

College of Development Studies

Center for Environment and Development

Dear respondent: the main purpose of this study is to understand land degradation status, its impact on rural livelihood, and the response to improve households' welfare in the north Gojjam basin. However, the success of this study highly depends on your genuine and honest response. Thus, the information you provide is highly valuable for the finding of this study. We assure that your information confidentially never disseminates to any other body by any means. Hence, you are kindly requested to answer all items. Thank you for your cooperation!

Questionnaire No ________ Date of interview: Date ____ Month______ Year: 2018;

Start time________ End time_______

Interviewed by_____________________ Checked by _____________________

Date ________Month________ Year; 2018

Household head identification					
1	Name of the household head (optional)		4	Enumeration District	
2	Enumeration basin		5	Enumeration kebele	
3	Enumeration agro-ecology		4	Enumeration village	

Part one: Household Demographic Characteristics

1. Gender: 0. Male 1. Female

2. Age of household head in year ________________________

3. Educational status in a year___________________________________

4. Marital status: 1. Single 2. Married 3. Divorced 4. Widowed

5. Your household composition:

Age category	Gender		Education (use number)				
	Male	Female	Illiterate	Write and read	Elementary(1-8)	Secondary(9-12)	Tertiary
≤ 14 years							
14-65 years							
≥ 65years							

Part Two: Types of Crop, Production, Income, and Expenditure

Could you, tell us your crop type, production and income in the last 12 months

No	Crop type (use code below)	Types of seed 1=improved 2=local	Land Size in ha	Amount of seed in Kg	Total crop production in quintal	Total consumption in quintal	Total amount sold in quintal	Total price
1								
2								
3								
4								
5								
6								
7								
8								

Types of crop: 1. Wheat, 2. Barley, 3. Maize, 4. Teff, 5. Lentil, 6. Bean, 7. Pea, 8. Sorghum, 9. vetch, 10. Chickpea, 11. Potato, 12. Fruit, 13. Others____

Part Three: Types of livestock and income

1. Do you have livestock? 1= Yes B=No (if you said yes, could you, tell us livestock type, income, expenditure and production

No	Livestock Type	Total number in the last 10 year		Total current number		Number sold during last 12 months	Value of Birr from sell during last 12 months
		Local breed	Improved breed	Local breed	Improved breed		
1	Oxen						
2	Cows						
3	Bulls						
4	Heifers						
5	Calves						
6	Sheep						
7	Goats						
8	Horses						
9	Mules						
10	Donkeys						
11	Poultry						
12	Bee colony						
13	Others						

Why sold your livestock?	1. For purchasing food	2. Due to shortage of feed/grazing	3. For purchasing agricultural inputs	4.To pay taxes and others social duets	5. For education fee	6.Others--
Put (√) mark						

2. What is/are the main feeding source(s) of your livestock?

Type	1.Common grazing	2.Private grazing	3.Hay/ crop residue	4. Forest /bush land	5.Cut and carry systems	6.If other____	
Put √ mark							
What are the key challenges for your livestock in the last 10 years?			1. Shortage of water	3. Shortage of pasture	4. Shortage of labor	5. Disease	6.Others
How is the trend of grazing land size in your locality in the last 10 years?					1. Increasing; 2. Decreasing; 3. No change		
How is the trend of water availability for livestock in your locality in the last 10 years?					1. Increasing; 2. Decreasing; 3. No change		
The average time to travel for accessing water for your livestock is __________							

Part Four: Other Household Income Generating Activities

1. Based on your household income; please fill the following table with an appropriate value.

Types of activity	Value income in Birr for the last 12 months	Types of activity	Value of income in Birr for the last 12 months
Sales of eucalyptus tree		Seft net program involvement	
From handcraft		Daily wage /casual work	
Sales of firewood /charcoal/cow dung		Sale of honey	
Land rent		Petty trading	

Sales of grass and/ or throw		If others	

2. Your household's expenditure since the last 10 years is_____.

   1. Increasing 2. Decreasing 3. The same

3. Over the last 12 months, has the household income been sufficient to cover the basic needs of your household such as food, medicines, clothes, fertilizer, and education expenditure?

   1= Yes 0 = No

Part Six: Household landholding size and other characteristics

1. Could you, please tell us about your land characteristics for the last 10 years, based on your perception?

Parcel No.	Ownership right 1. Owned 2. Rented 3. Crop sharing 4. Others	Land size/ha	Walking time in a minute to reach from home	Slope of land 1.Sloppy 2. Moderate 3. Gentle	Soil fertility status 1.Fertile 2.Moderate 3. Less fertile	Degree of soil erosion: 1.Low 2.Moderate 3. Sever	How did you acquire your land? (use below code)	Do you have 1st and 2nd certificates for your land? 1=Yes 0=No
1								
2								
3								
4								
5								
6								
7								
8								

Land acquiring: 1. Inherited; 2. from government 3. By clearing of natural forest 4. If others

5. The average size of own land in the last 10 years is: 1. Increased 2. Decreased 3. No change

6. Why the size of your parcels decreased? 1. Given to children 2. Degradation 3. Taken by the government 4. Others________
7. How do you see the productivity of your farmland for the last 10 years?
   1. Increased 2. Decreased 3. No change
8. Is your piece of land being enough to feed your family throughout the year?
   1 =Yes 0=No
9. Could you tell us about the average soil degradation status on your farmland based on your perception?

Type of degradation	The Rate degradation in the last 10 years			The severity of degradation in the last 10 years		
State of soil erosion	Increasing	Decreasing	No change	1. low	2. medium	3. high
Sheet erosion						
Gully erosion						
Riverbank/stream erosion						
State of soil physical degradation						
Soil compaction						
Soil depth						
Sealing and crusting						
Biological degradation						
Losses of vegetation cover						
Reduces biodiversity in the soil						
If others						

Part Nine: Causes of land Degradation (driver indicator)

1. Is land degradation an environmental problem in your locality? 1=Yes 0= No
2. If your answer is yes, what are the land degradation deriving forces and pressures in your locality?

Part Ten: Perception on the impacts of land degradation on rural livelihood

1. Could you tell us the impact of land degradation based on the following information?

1. How do you perceive the total cope productivity since the last 10 years?	Increased	Decrease	No change	
2. How do you perceive animal production (milk per caw, meat production….) in the last 10 years?				
3. How do you perceive surface water availability/quantity in the last 10 years?				
4. How do you perceive on amount of your income in the last 10 years?				
5. How do you perceive household cooking energy availability/quantity in the last 10 years?				
6. How do you perceive the cost of agricultural production input in the last 10 years?				
7. How do you perceive food security in the last 10 years?				
8. What are the reasons for decline of Agriculture production?	1=Yes 0=No	Extent of impact		
		Low	Moderate	High
1. Loss of soil fertility/soil erosion				
2.Drought/water shortage				
3. Erratic rainfall/unexpected rain				
4. Farm land shortage/scarcity of farm land				
5.Crop diseases and pests				
6. poor farming practices				
7. shortage of oxen				

8. Water logging				
9. Continuous cropping/absence of fallowing				
9. If others				

Part eleven: Farmers’ SLM technology adoption (Response indicator)

Did you adopt the following SLM technologies on your farmland? 1= Yes; 0= No

Plot No	Types SLM technologies (if your answer is yeas put √)										
	Improved seed	Compost	Animal manure	Chemical Fertilizer	Crop rotation	Soil bund	Stone bund	modern faring tool	Planting on bund	Agronomy	Others
1											
2											
3											
4											
5											
6											
7											
8											

Part Twelve: Tree planting and sources of domestic energy of the household

Do you plant a tree in the last 10 years?			1=Yes; 0= No					
If you planted, for what purpose?	For construction	For SWC	For selling	For fuel	For fruit	livestock fodder	For Bee	If other
Put ′ × ′for yes								
What types of trees do you plant?			____					
Do you have a plan to plant a eucalyptus tree in the future time?			1=Yes; 0= No (if your answer is what is the reason_____________					
If you have a plan to plant in the future, where it will be planted?			1. At homestead; 2. At gullies; 3. Near streams/water bodies;4. At cropland 5. Near cropland; 6.If others____________					
What is the source of domestic fuel energy for your household?	Type	Eucalyptus	Animal dung	Crop residue	Forest	If others		
	Rank							

How do you perceive the supply of fuelwood for the last 10 years?	Increasing	Decreasing	No change
Do you self-sufficient in cooking energy?			1=Yes; 0= No
Do your household used energy-saving technology?			1=Yes; 0= No
If you said yes, what types of energy-saving technology your households use?		1. Improved stave; 2. Biogas 3. Solar blue;4. Electric stove	

1	Do you get information about sustainable land resources management practices from expertise in the last 12 months?	1= Yes 0 = No
2	Do you satisfy with the experts' advice?	1= Yes 0 = No
3	Have you got training about SLM practices in the last 12 months?	1= Yes 0 = No
5	Did you get information about market prices of agricultural inputs and outputs?	1= Yes 0 = No
6	If yes, what are the sources of information about market prices?	1. Development agent; 2.Woreda NR experts; 3. Friends; 4.Radio; 5.Newspaper; 6. church/mosque; 7.Others________

Access to infrastructure service and market					
Walking time in minutes from home to reach_____	weather road _________	tarmac road----	farm input & output market ________	district town-----	DA office

Part thirteen: Credit Access and Services

1. Did you receive credit during the last 12 months? 1=Yes 0=No (please go to question number 2&3)
2. Total amount in Birr_______ and if in kind, please estimate the total amount in terms of Birr_________

For what purpose you obtained credit?	1= Yes 0 = No	From where you obtained credit?	1= Yes 0 = No	Why didn't obtain credit?	1= Yes 0 = No
1.To purchase agricultural inputs		1.from Amhara credit & saving		1. no need	
2. To pay education expenses		2.From commercial bank		2. too expensive	
3. To purchase family food		3. From Private bank		3. absence of guaranty	
4. To buy livestock		10. From money lenders		4. Not available	
5.To pay tax and social obligation		5.If others____		5. if others	
6. To build house					

7. If others__________					

Par fourteen: Food Security

1. Have you faced food security problem? 1= Yes 0= No
2. How many months in the last 12 months did your household have faced for food deficit /gap____________________________?
3. Pleas list the months that your household have faced for food shortage/gap____
4. Household Food Insecurity Access Scale (HFIAS)Measure *(1=rarely (once or twice); 2=Sometimes (3 to 10 times);3=Often (more than 10 times)*

No	Equation/ item	1=Yes			0=No
		1	2	3	
1	In the past month, did you worry that your household would not have enough food?				
	If you said yes, how often did this happen?				
2	In the past month, where you or any of your household members not able to eat the kinds of food you preferred due to lack of resources?				
	If you said yes, how often did this happen?				
3	In the past month, did you or any other household member eat just a few kinds of food day after day due to lack of resources?				
	If you said yes, how often did this happen?				
4	In the past month, did you or any household member eat food that you preferred not to eat due to a lack of resources to obtain other types of food?				
	If you said yes, how often did this happen?				
5	In the past month, did you or any other household member eat a smaller meal than you felt you needed due to a shortage of enough food?				
	If you said yes, how often did this happen?				

6	In the past month, did you or any other household member eat fewer meals in a day because there was a shortage of enough food?				
	If you said yes, how often did this happen?				
7	In the past month, was there ever no food to eat of any kind in your house because of a lack of resources to get food?				
	If you said yes, how often did this happen?				
8	In the past month, did you or any household member go to sleep at night hungry because there was not enough food?				
	If you said yes, how often did this happen?				
9	In the past month, did you or any household member go a whole day without eating anything because there was not enough food?				
	If you said yes, how often did this happen?				

2. Household Dietary Diversity Score (HDDS) Measure

Now I would like to ask you about the types of foods that you or anyone else in your household ate or/and drank yesterday during the day and at night in the home

No	Food Group	Examples	1=Yes; 0= No
1	Cereals/grains	Food prepared from cereal (maize, barley, wheat, teff, sorghum, rice, oats, or any other grains or foods made from these group) e.g. enjera, bread, porridge, or other grain products	
2	Root and tubers	Food from potatoes, ginger, yam, or other foods made from roots	
3	Vegetables	pumpkin, carrot, tomato, onion, pepper, cabbage, chili, and other related foods	
4	Fruits	Lemon, orange, apple, mango, papaya, banana, and 100% fruit juice made from these	
5	Meat	Meat from animal, chicken, and other birds	

6	Legumes/pulses/ nuts	beans, peas, nuts, lentil, chickpea, or foods made from these	
7	Egg	eggs from chicken or any other birds	
8	Fish	fresh or dried fish or foods made from fish	
9	Milk & milk products	milk, cheese, other milk products	
10	Oil &/ fats	oil, fats, or butter added to food (water) or used for cooking/preparing	
11	Sweets	sugar, honey, sweetened soda or sweetened juice drinks, sugary foods such as chocolates, candies, cookies, and cakes	
12	Spices/condiments, beverages	Food made from spices (black pepper, salt)/condiments, coffee, tea, alcoholic beverages	

Section 3: Household Consumption Expenditure

Food Consumption expenditure (During the past 7 days)

Food, Beverage, and Tobacco	Value of consumption out of purchases **(**ETB**)**	Value of consumption out of home produce **(**ERB**)**	Value if received in-kind/free **(**ETB**)**
Cereals			
Roots, Tubers, Plantain			
Legumes and Nuts			
Fruits			
Vegetables			
Meat and Egg			
Oils and Fats/Milk and Milk products			

B. Questionnaires for focus group discussion participants

1. Is land degradation environmental problem in your locality in the form of soil and vegetation degradation? what the cause of

   1.1. soil erosion____

   1.2.Soil compaction____

   1.3.Poor soil drainage____

   1.4.Reduction of soil depth_______________________________________

   1.5.Soil fertility reduction _______________________________________

   1.6. Increasing of soil acidity ____________________________________

2. Last and rank key driving forces and preserves of LULC change.

No	Main driving forces LULC	Rank
1		
2		
3		
4		
5		
6		
7		
8		

No	Main pressures forces LULC	Rank
1		
2		
3		
4		
5		
6		
7		
8		

3. Is land degradation affected the communities' livelihood in your locality? 1= Yes 0=No

No	Livelihood types	Increasing	The same	Decreasing	Rank
1	Crop productivity				

2	Livestock productivity				
3	Household cooking energy				
4.	Net income				
5	Food security				
6	Surface water availability				

4. What are SLM technologies that the community used by the community in your locality?
5. What are government rules and community by-laws for land resources management in your area? Are they effective?
6. Are the introduced SLM technologies improved the communities' food security, income, and expenditure? Explain clearly
7. Why farmers dis-adopt the introduced SLM technologies from their farmland in your area?

C. Questionnaires for key informant interviewee

1. Are there any changes in land use/ land cover (forestland, cropland, grazing, shrub, and bare land) patterns in your locality through your life experience?
   a. Which type of land use size is increased, decreased, or remains the same?
   b. What is the rate of change in each land use and cover type?
2. What are the key causes of change? And how they are causes for degradation?
3. What is your perception of the rate of soil erosion in your surrounding?
4. Explain the trend of surface water (rivers, streams, and springs) quantity and quality throughout your life?
5. Is the currently available land enough for the community to produces yield to feed households throughout the year? Explain the reason?
6. Explain the impact of land degradation on apicultural productivity based on your experience?
7. What are the actions/responses taken by stockholders against land degradation?
8. What are government rules and community by-laws for land resources management in your area? Are they effective?
9. Are the introduced SLM technologies improved the communities' food security, income, and expenditure? Explain clearly
10. Why farmers dis-adopt the introduced SLM technologies from their farmland in your area?

D. Checklist for Data Collection through Transect walking

1. The current state of land resources
2. Key driver and pressures of land resources change
3. Key livelihood strategies
4. Sustainable land management technologies practiced in different land use and land cover

Table 7- Land use/land cover transition matrices of north Gojjam Basin

1986/1994	CS	WB	BR	GL	FL	PL	BSL	Total	Loss
CS	46.74	0.01	0.22	7.07	0.22	0.59	3.37	58.22	11.48
WB	0.01	0.05	0.01	0.00	0.00	0.00	0.01	0.08	0.03
BR	1.74	0.02	0.68	0.22	0.00	0.00	0.49	3.16	2.48
GL	9.47	0.00	1.51	9.89	0.01	0.13	0.42	21.43	11.54
FL	0.22	0.00	0.00	0.40	1.13	0.19	0.96	2.91	1.78
PL	0.00	0.00	0.00	0.07	0.05	0.39	0.03	0.77	0.38
BSL	3.32	0.00	0.22	2.67	0.70	0.27	6.25	13.43	7.18
Total	61.71	0.09	2.65	20.33	2.11	1.58	11.54	100	34.87
Gain	14.97	0.04	1.97	10.44	0.98	1.19	5.29	34.88	
1994/2007									
CL	49.29	0.02	1.08	5.58	0.24	1.82	3.69	61.71	12.43
WB	0.03	0.04	0.01	0	0	0	0	0.09	0.05
BR	1.86	0.01	0.33	0.31	0	0	0.13	2.65	2.31
GL	9.47	0	0.17	8.15	0.2	0.76	1.58	20.33	12.18
FL	0.27	0	0	0.04	0.93	0	0.87	2.11	1.18
PL	0.39	0	0	0.24	0	0.62	0.33	1.58	0.96
BSL	5.22	0	0.05	0.77	0.76	0.27	4.46	11.54	7.07
Total	66.53	0.08	1.64	15.09	2.26	3.34	11.07	100	36.17
Gain	17.24	0.04	1.31	6.94	1.33	2.72	6.61	36.17	
2007/2017									
CL	55.26	0.01	2.02	4.84	0.29	1.14	2.97	66.53	11.27

WB	0.02	0.02	0.02	0	0.01	0	0	0.08	0.06
BR	1.19	0	0.41	0.02	0	0	0.01	1.64	1.23
GL	7.07	0	0.4	6.38	0.04	0.46	0.74	15.09	8.71
FL	0.46	0	0	0.13	0.56	0.48	0.62	2.26	1.7
PL	2.08	0	0	0.24	0.08	0.66	0.28	3.34	2.68
BSL	4.58	0	0.05	0.89	1.09	0.87	3.59	11.07	7.48
Total	70.67	0.04	2.91	12.5	2.07	3.61	8.21	100	33.13
Gain	15.62	0.02	2.5	6.12	1.51	2.74	4.62	33.13	

Table A: First stage results of the FIML-ESR models

Variables	**1[a]**	**2**	**3**	**4**	**5**	**4**
Age	-.002(.007)	-.002(.007)	.110(.046)**	-.003 (.008)	-.001(.007)	.001 (.009)
Gender	.745(.331)***	.744(.333)**	.673(.335)**	.827(.332)**	.661(.343)***	.158 (.543)**
HH size	.106 (.046)**	.109(.046)**	.111 (.046)	.106(.045)**	.100 (.046)**	.068 (.057)
Education	.299(.131)**	.308(.132)**	.311(.133)**	.274(.127)**	.297 (.133)**	.129 (.165) **
Plot size	.106 (.045)**	.070(.172)**	.101(.170)**	.016 (.167)	.106(.171)**	.152(.212)
Plot distance	-.001 (.005)	-.002 (.006)	-.001(.005)	-.001 (.005)	-.006 (.058)	.043 (.059)
Parcel No	.039 (.059)	037 (.059)	.034 (.061)	.045 (.058)	.027(.061)	-.002(.007)
Soil fertility	-.332 (.228)	-.353 (.229)	-.321(.236)	-.397 (.227)	-.328(.233)	-.193(.270)
Gentle slope	.193 (.285)	.211 (.284)	.263 (.292)	.095 (.284)	.245(.289)	-.316 (.310)
Moderate slope	.717 (.277)**	.743(.278)**	.682(.279)**	.674 (.277)**	.687(.279)**	.223 (.249)
Soil erosion	.114 (.264)**	.394(.220)**	.428 (.225)	.409 (.217)**	.396(.224)**	888 (.535)*
Livestock	-.272(.245)	.057(.038)	-.209 (.216)	.058 (.036)	.054(.037)	.025 (.050)**
Credit access	.008 (.012)	-.217 (.185)	-.186 (.189)	-.199 (.186)	-.1869(.187)	-.136 (.236)
Off farm	-.000(.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)	-.000 (.000)
Cooperation	-.229(.289)	-.291 (.285)	-.231 (.293)	-.264 (.284)	-.280 (.292)	-.351(.419)
Market distance	.084 (.116)	.092(.117)	-.457 (.399)	.001(.001)	-.067(.126)**	.001 (.001)
Training	.504(.193)***	.070(.172)**	.558(.19)***	.499(.181)***	.474(.193)***	.650(.220)***

Dega Damot	-.457(.164)**	-.317 (.211)	-.417.232)**	-.277(.213)	-.305(.213)	-.305(.213)
Enarj Enauga	-.204(.154)	-.132(.195)	-.298 (.214)	-.306(.214)	-.336(.218)	-.336 (.218)
Constant	-1.168(.297)	- 1.79(.891)**	- 1.71(.871)**	-1.54 .868)**	-1.569(.891)*	-1.24(.883)

***, **, * represent <0.01, < 0.05, and < 0.1 significance level, respectively. Values in parentheses are standard errors. [a] Models 1 to 7 refer to first-stage estimates for farm income, household income, consumption expenditure, food gap, HHS, food consumption expenditure, and HDDS, respectively.

Table B: Falsification test

Variable	**(1)[a]**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
SLM related Information	.144 (.101)	(.056) (.102)	.085 (.065)	-.002 (.078)	.125 (.195)	-.094 (.261)
Constant	7.842 (.412)***	8.323 (.416)***	4.438 (.157)***	1.316 (.216)	2.233 (.445)***	2.398 (.907)
Wald X2 /F-Stat	4.16***	3.40***	7.87***	68.68***	143.86 ***	96.24**
No. of observation	358	355	355	355	355	

***, **, * represent <0.01, < 0.05, and < 0.1 significance level, respectively. Values in parentheses are standard errors. [a] Models 1 to 6 refer to farm income, household income, HFCE, HDDS, food gap and HFIAS, respectively. Models 1‒3 & 6: Ordinary Least Squares. Model 4 and 5: Poisson Regression. Model 6: Negative Binomial Regression. We control for other variables but only report parameters for the variable of interest.

Table C. variance influence factors for multivariate probit model

Variables	VIF	1/VIF
Age	1.26	0.79
Gender	1.18	0.85
HH size	1.36	0.74
Education	1.19	0.84
Plot size	1.80	0.56
Plot distance	1.18	0.85
Parcel No	1.61	0.62
Soil fertility	1.49	0.67
Gentle slope	1.30	0.77
Moderate slope	1.33	0.75
Soil erosion	1.45	0.69
Livestock	1.59	0.63
Credit access	1.11	0.90
Off farm	1.34	0.75
Cooperation	1.14	0.88
Market distance	1.07	0.94

Training	1.27	0.79
Dega Damot	1.18	0.85
Enarj Enauga	1.12	0.89
Mean VIF	1.31	

Table D. Conversion factor of various classes of livestock to TLU

No	Animal Category	Tropical Livestock Unit (TLU)
1	Calf	0.25
2	Donkey (young)	0.35
3	Weaned calf	0.34
4	Heifer	0.75
5	Goat/sheep (adult)	0.13
6	Cow and ox	1.0
7	Goats/sheep (young)	0.06
8	Horse	1.10
9	Donkey (adult)	0.70
10	Chicken	0.013

Source: Strock et al. (1991)

Table E. Conversion factor for Adult Equivalent (AE)

Age group	Sex	
	Male	Female
<10	0.60	0.60
10-13	0.90	0.80
14-16	1.00	0.75
17-50	1.00	0.75
>50	1.00	0.75

Source: Strock et al. (1991)

Appendix F:

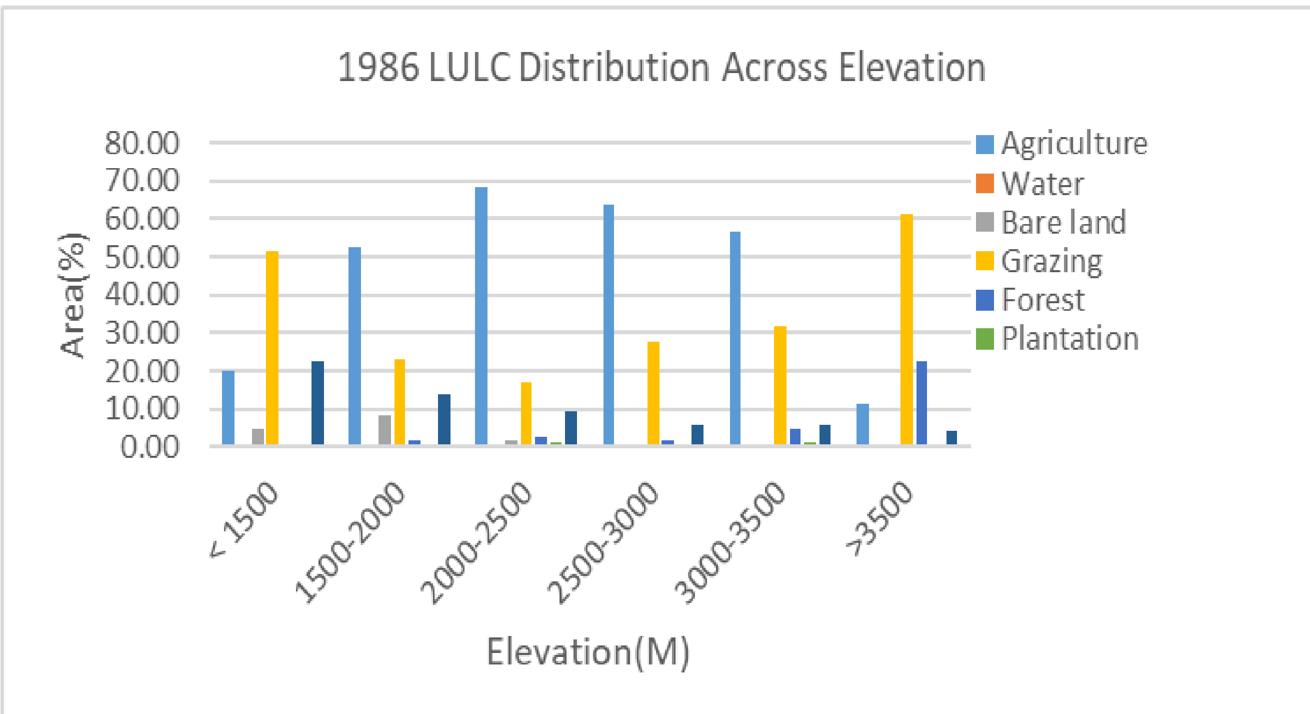


Figure A. The 1986LULC distribution across altitude

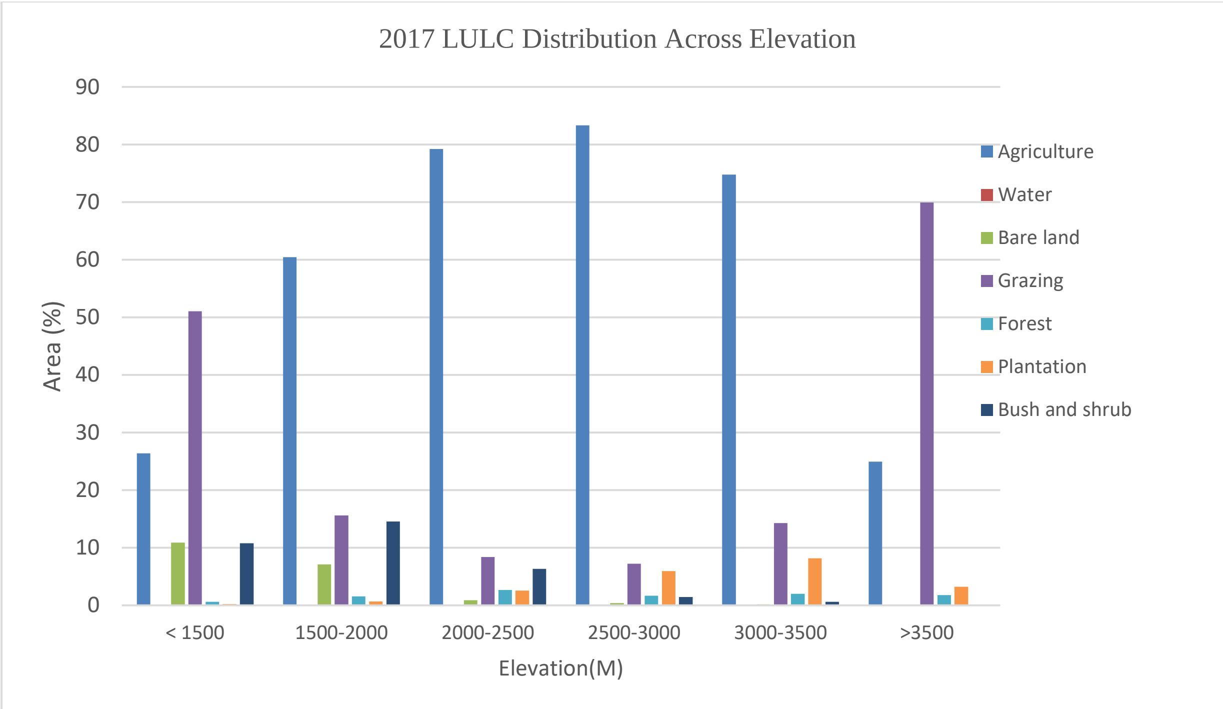


Figure B. The 2017 LULC distribution across altitude.

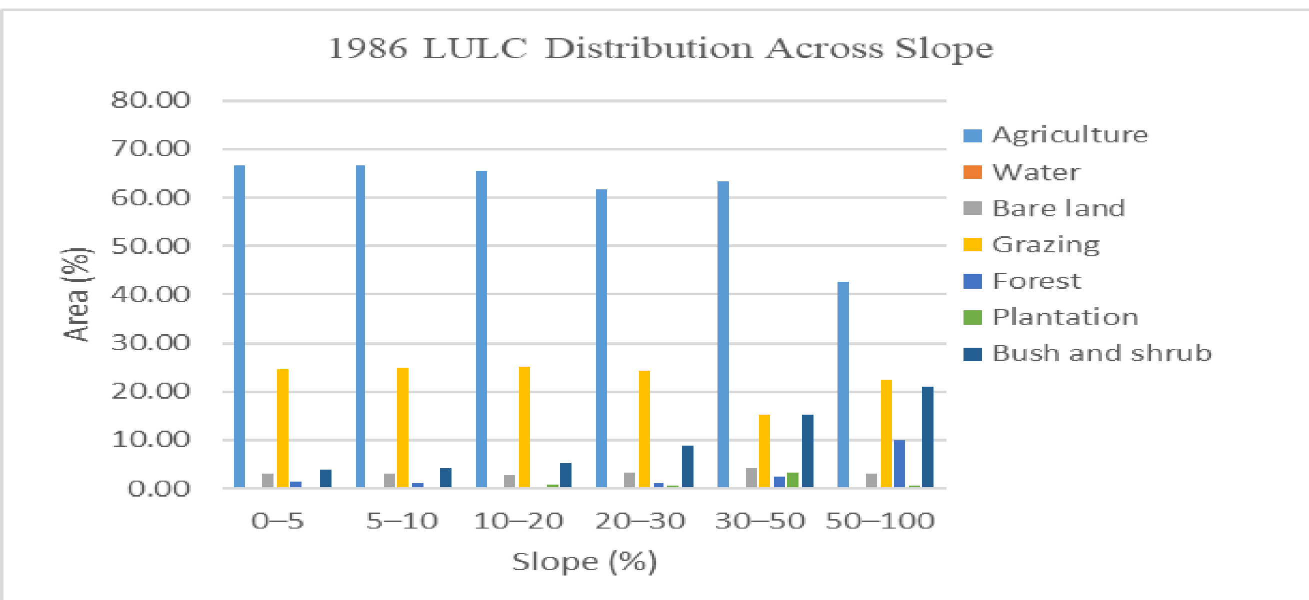


Figure C. The Distribution of LULC across the Slope in 1986

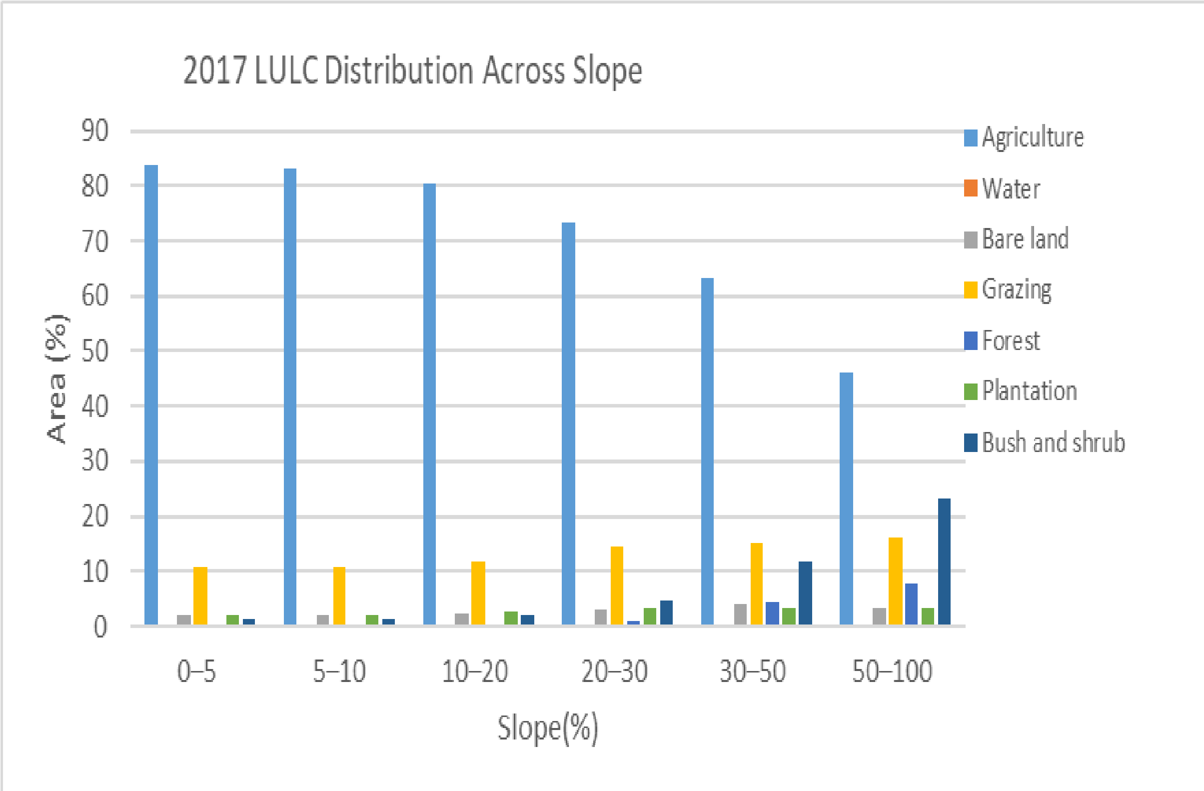
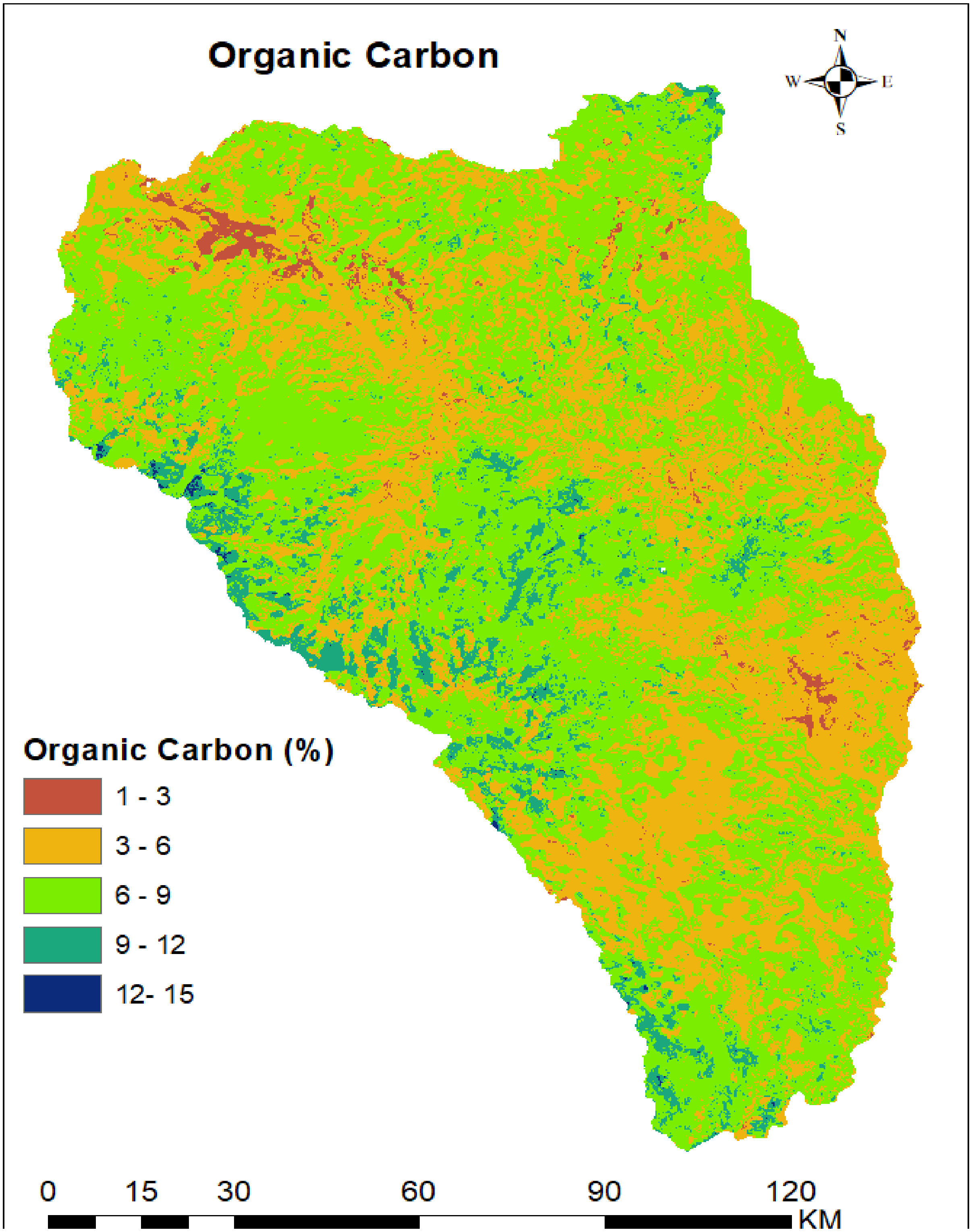


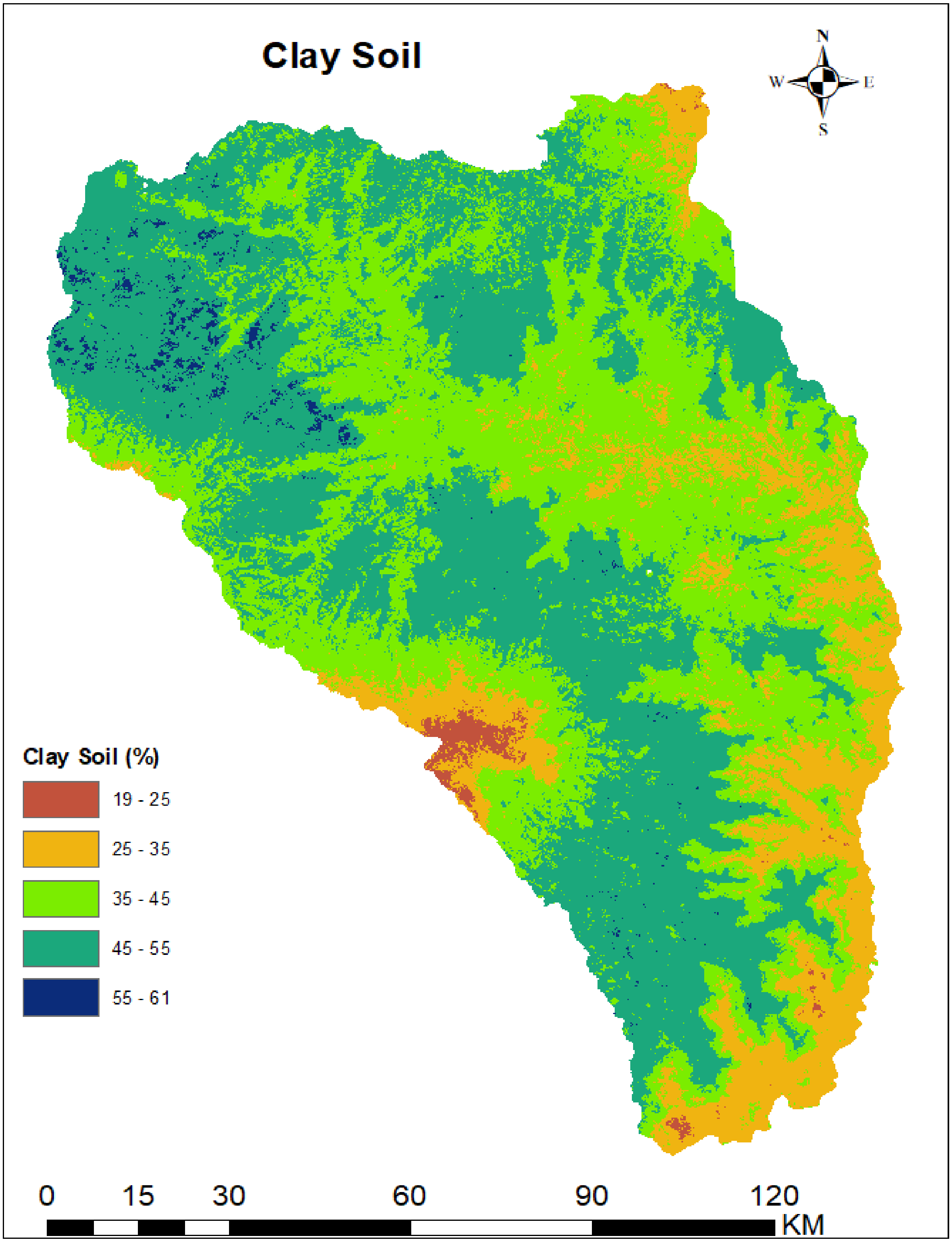
Figure E. The Distribution of LULC across the Slope in 2017

Figure F. Soil organic carbon



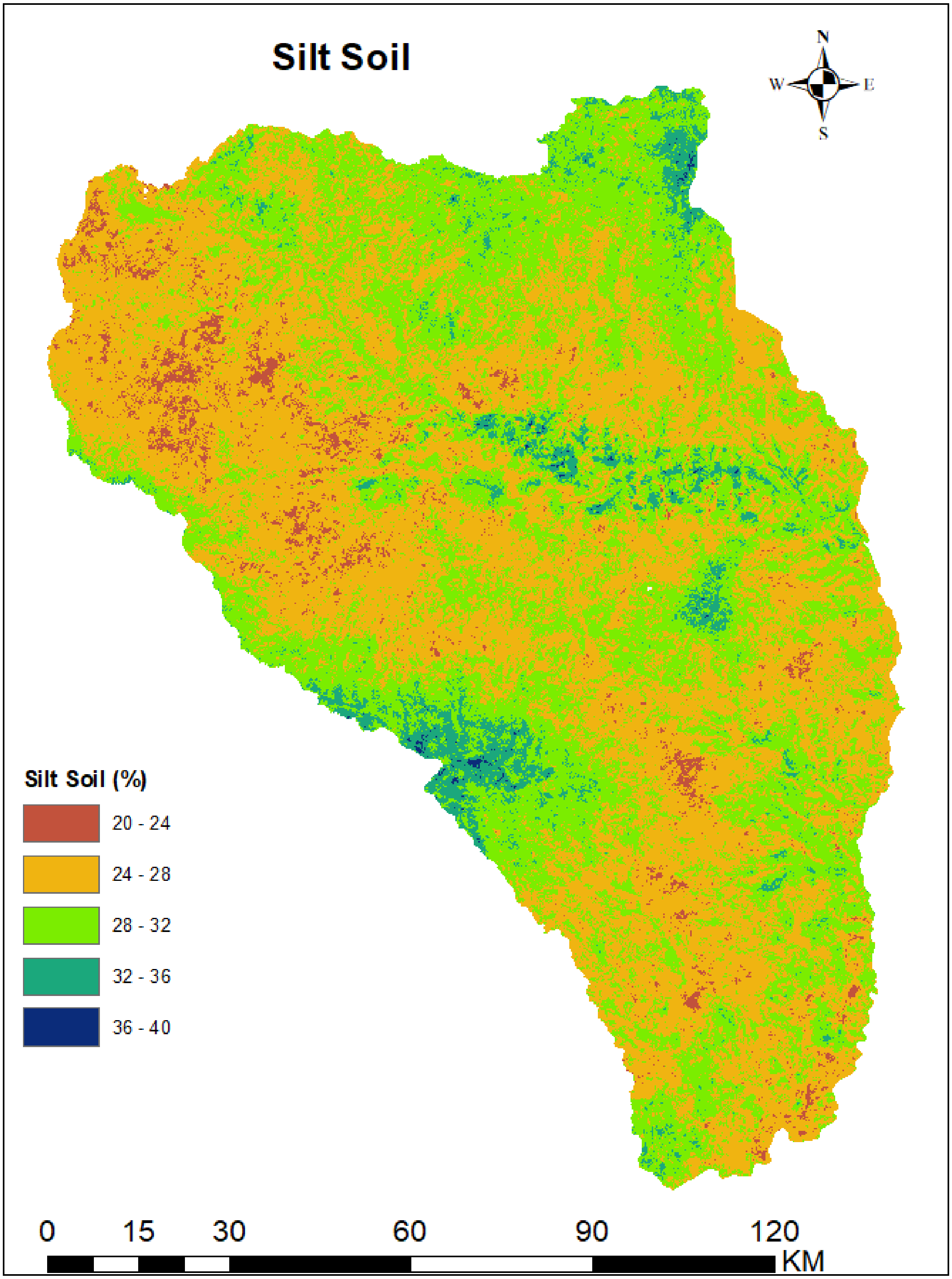
Source: (Hengl et al., 2017)

Figure G. Clay Soil



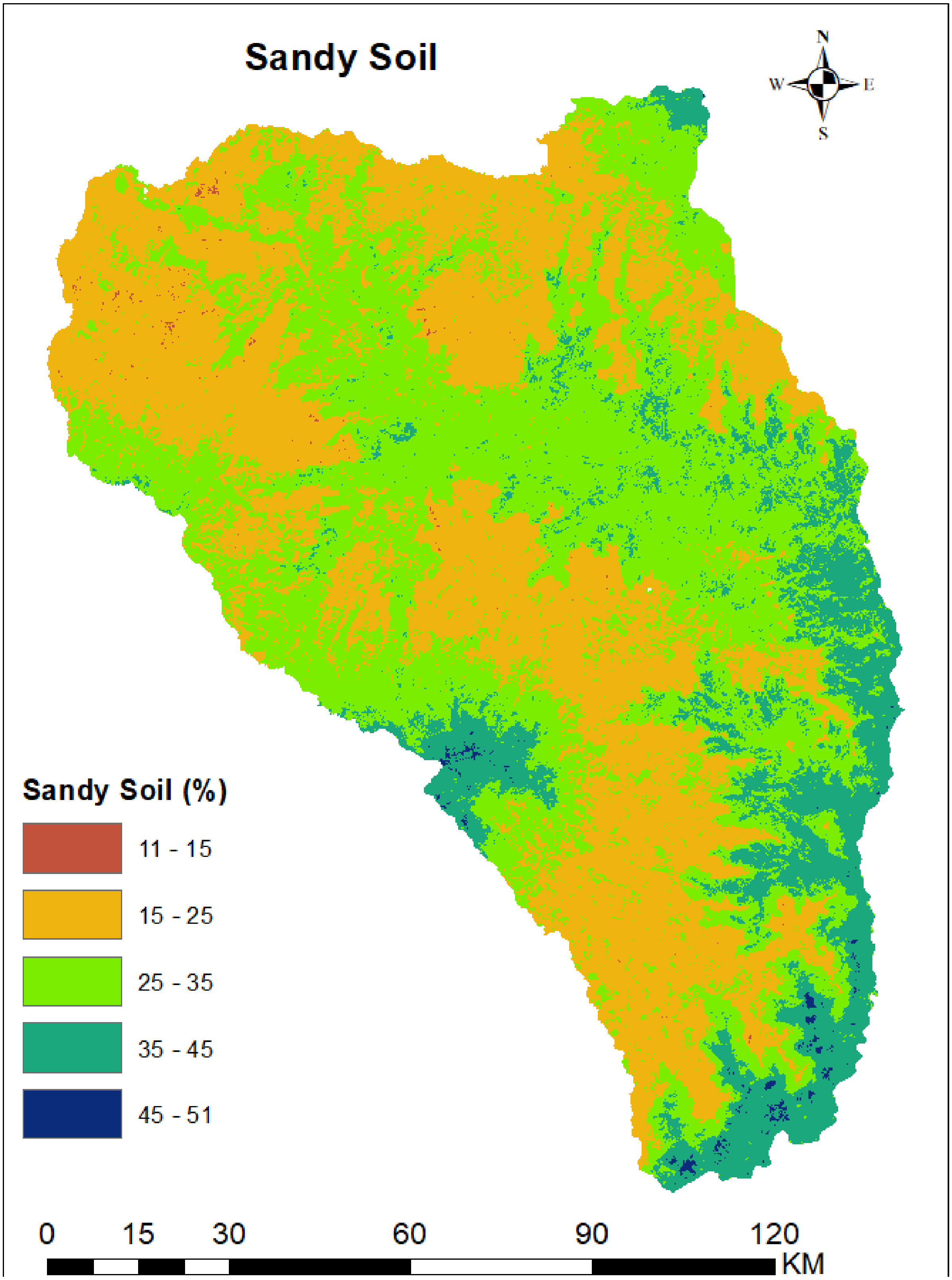
Source: (Hengl et al., 2017)

Figure H. Silt Soil



Source: (Hengl et al., 2017)

Figure I. Sandy Soil



Source: (Hengl et al., 2017)