Towards Land Degradation Neutrality: States, Achievements and Sustainability in Omo-Gibe River Basin, Ethiopia

Habtamu Dagne Bogale

A Dissertation Submitted to the

Center for Environment and Development Studies, College of Development Studies

Presented in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Development Studies (Environment and Development Studies)

Addis Ababa University,

Addis Ababa, Ethiopia

July 2023

Towards Land Degradation Neutrality: States, Achievements and Sustainability in Omo-Gibe River Basin, Ethiopia

Engdawork Assefa (Ph.D., Associate Professor), Center for Environment and Development, Addis Ababa University, Ethiopia

Ermais Tefferi (Ph.D., Associate professor), Center for Environment and Development, Addis Ababa University, Ethiopia

A Dissertation Submitted to the Center for Environment and Development Studies, College of Development Studies, Presented in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Development Studies (Environment and Development Studies) Addis Ababa University,

Addis Ababa, Ethiopia

July 2023

Declaration

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

Name:- Habtamu Dagne

Signature:

Date:

Place: Addis Ababa

Date of submission:

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

Supervisors' Name: Engdawork Assefa (Ph.D., Associate professor) and Ermais Tefferi (Ph.D., Associate professor)

Signature:

Date:

Dissertation Approval

Addis Ababa University

School of Graduate Studies

This is to certify that the dissertation prepared by Habtamu Dagne Bogale entitled: "Towards Land Degradation Neutrality: States, Achievements and Sustainability in Omo-Gibe River Basin, Ethiopia" and submitted in fulfillment of the requirement for the degree of doctor of philosophy (Environment and Development) compiles with the regulations of the university and meets the accepted standard concerning originality and quality.

Signed by the examiner committee:

Shimeles Damene	[signature]	19/7/2023
Chairman, examining committee	Signature	Date
Shitie Gatew (PhD)	[signature]	19 July 2023
External Examiner	Signature	Date
Mohammed Assen	[signature]	19/07/2023
Internal Examiner	Signature	Date
Engdawork Assefa	[signature]	19/07/2023
Major Advisor	Signature	Date
Ermias Teferi (PhD, Assoc. Prof)	[signature]	19/07/2023
Co- Advisor	Signature	Date

Dedication

To my Mother for her struggle and commitment to fulfill the family's needs. She gives her life for us.

Acknowledgment

First and foremost, I have accomplished my task thanks to Almighty God. The success of this study was due to the contributions of a wide range of individuals, groups, and organizations. It is with great pleasure that I acknowledge and express my deepest thanks to my supervisors, Dr. Engdawork Assefa and Dr. Ermias Teferi, for making this study possible. While writing my dissertation, they provided extensive professional guidance and taught me much about scientific research.

I also thank Addis Ababa University and Wachemo University for sponsoring my Ph.D. study. Thanks to all participants for their cooperation, includes farmers, development agents, NGOs, regional, zonal, worda, and kebele officials.

I thank my colleagues, Mohamed Seid, Belete Debebe, and Amare Tesefaw for their consistant support and feedback throughout the research process. My staff member Tsegaye Abie (Assistant professor) deserves a thank you for his comments and editorial support in publishing the article. And also, a great thanks to Alem Tesfaye (assistant professor) for his unlimited support in GIS activities.

My motivation and strength come from my lovely son, Eyoab. You are part of this dissertation work, and have sacrificed a lot to achieve my goal parallel with you. My deepest gratitude belongs to my loving and supportive wife, Samrawit Yayniwaga, and she provides unlimited inspiration and support to succeed in our goals. Without your support, I would not have completed this dissertation work.

Finally, I want to thank my strong mother, Nigestie Teshale. You dedicated your entire life to me and my sisters and brothers. I can only pray to God to give you a long and

healthy life. Dedicated to my late father, Dagne Bogale, who gave his entire life to help us reach this point, I extend my deepest gratitude.

List of Original Papers

This dissertation is based on four original papers derived from four different objectives.

i. Dagne Habtamu, Assefa Engdawork & Teferi Ermias (2023): Mapping and Quantifying Land Degradation in the Omo-Gibe River Basin, South-Western Ethiopia, *African Geographical Review*; 42(2). https://doi.org/10.1080/19376812.2022.2164023

ii. Dagne, Habtamu.; Assefa, Engdawork; Teferi, Ermias. Sustainable Use of Soil and Water Conservation Technologies and Its Determinants: The Case of the Handosha Watershed, Omo-Gibe River Basin, Ethiopia. *Earth* 2023, 4 (2), 315–330. https://doi.org/10.3390/earth4020017

iii. Dagne Habtamu, Assefa Engdawork & Teferi Ermias (2023): Evaluation of Land Degradation Neutrality for Sustainable Development in the Omo-Gibe River Basin, Southwest Ethiopia. Under review

iv. Dagne Habtamu, Assefa Engdawork & Teferi Ermias (2023): Stakeholders' perception towards land degradation neutrality and its implications for sustainable development: A case of Omo-Gibe River Basin, South-Western Ethiopia. Under review

Table of Contents

Contents

List of Tables

List of Figures

Acronyms/Abbreviations

AEZ	Agro Ecological Zone
AFSIS	African Soil Information Service
CALM	Climate Action through Land Scape Management
CHIRPS	Climate Hazards Group InfraRed precipitation with Station data
CQI	Climatic Quality Index
CSA	Central Statistics Agency
CSOs	Civil Society Organizations
DLDD	Desertification, Land Degradation, and Drought
DEM	Digital Elevation Model
DPSIR	Derived-Pressure-State-Impact-Response
EFAD	The European Federation of the Associations of Dietitians
ESA	Environmental Sensitivity Area
FAO	Food and Agricultural Organization
FGD	Focus Group Discussion
GEF	Global Environmental Facility
GIS	Geographic Information System
GIZ	The Germen Agency for International Cooperation
ISMF	Integrated Soil Management and Fertility
ISRIC	International Soil Reference and Information Center
LD	Land Degradation
LDN	Land Degradation Neutrality
LPD	Land Productivity Dynamics
LULC	Land Use Land Cover
MCA	Multi-Criteria Analysis

MEDALUS Mediterranean Desertification and Land Use

MQI Management Quality Index

NDVI Normalized Difference Vegetation Index

PV Percent Vegetation

REED+ Reducing Emissions from Deforestation and Forest Degradation

SCRP Soil Conservation Research Project

SDGs Sustainable Development Goals

SES Socio-Ecological System

SLM Sustainable Land Management

SLMP Sustainable Land Management Program

SOC Soil Organic Carbon

SQI Soil Quality Index

SWC Soil and Water Conservation

UNCCD United Nations Convention to Combat Desertification

USGS United States Geological Survey

VQI Vegetation Cover Quality Index

WOCAT World Overview of Conservation Approaches and Technologies,

ZNLD Zero Net Land Degradation

Towards Land Degradation Neutrality: States, Achievements and Sustainability in Omo-Gibe River Basin, Ethiopia

General Abstract

Its primary objective was to evaluate land management activities through Land degradation neutrality indicators to achieve sustainable development goals. Indicator 15.3.1 of the sustainable development goals calls for strengthening national capacities to perform quantitative assessments and mapping of degraded lands and map them to reverse current trends. This study used MEDALUS method, land degradation neutrality evaluation framework, and Heckman sample selection model for data analysis. The sample of 340 households were selected through a multistage sampling technique. The results indicated a high land degradation risk in 48% of the basin, which was evident in 36%. There was low potentials for land degradation in 15.8 percent of the area. Consequently, settlements (11.44%) and farmland (9.58%) significantly increased, while bushland (8.09%) and wetlands (5.29%) decreasedfrom 2000-2020. Land productivity has significantly declined due to changes in land cover and losses in soil organic carbon. The proportion of degraded land was 65.05% of 79000 km^2 of the basin. 235 (69.12%) households adopted soil bunds, but only 89 (37.87%) sustainably practiced soil bunds on their farm plots. The empirical results of the Heckman sample selection model showed that sustainable use of soil bund measures was significantly positively influenced by land tenure security, family size, and frequency of extension contact. In contrast, the distance between farm plots and home and farm plot size was affected negatively. The study found that farmers gain knowledge about soil erosion, SWC, LULC, and land productivity primarily from extension workers and specific training. However, most farmers and extension workers have littile information about SOC, LDN, and the SDGs. It has been concluded that spatial planning should focus on hotspot areas and implement locally based-sustainable land management practices. It should not only focus on the implementation and biophysical factors but also consider the socioeconomic interests of farmers to reach land degradation neutrality by 2030 at national and subnational levels.

Key words: *GIS, Heckman, LDN, MEDALUS, soil bund, Sustainable Development, SWC*

Chapter one: General Introduction

1.1. Background of the study

As defined by the international Science-Policy Platform on Biodiversity and Ecosystem Services, land degradation refers to various processes that reduce biodiversity, ecosystem functions, and ecosystem services (Montanarella et al., 2018). It is a global environmental and development issue and will remain high on the international agenda; that lowers the productivity of land resources' capacity, ecological integrity, and its effect on food security, the quality of life, and is linked to climate change in several ways (Eswaran et al., 2001; Omuto et al., 2014). According to United Nations Convention to Combat Desertification (2014), 52% of agricultural land, 40% of the landmass, 44% of food production, and nearly 1 billion hungry are affected by degradation in the least developed countries. In 2025, land degradation could lower global food output by 12%, resulting in a 30% increase in global food prices (UNCCD, 2014; FAO, 2017). Land degradation impacts up to two-thirds of Africa's productive land area (UN, 2013; Jones et al., 2013) and affects at least 485 million people, or 65% of the continent's total population (ECA, 2007). These hazards initiated different governmental and non-governmental organizations, such as; the world overview of conservation approaches and technologies (WOCAT) and the Network of civil society organizations (CSOs), to promote sustainable land management as a necessary shift from degrading the land to sustainable use and restoration (van Haren et al., 2019).

Maintaining and enhancing the ecological functions of land resources is the goal of sustainable land management, which aims to complement the frequently incompatible goals of intensified economic and social growth (Noe, 2014). Soil and water conservation as a strategy for sustainable land management has been reflected as a technical issue mainly focused on biophysical problems-oriented research such as climate, soils, topography, land use, and vegetation (Lötter et al., 2009). Halting and reversing land degradation is a high priority for transitioning to a more sustainable society. Several approaches are needed to restore degraded land depending on the nature, extent, and degree of the degradation (IUCN, 2015). Addressing the issue of land degradation has featured more prominently on the international agenda. In the last few years, various governmental and nongovernmental organizations have promoted sustainable land management to shift from degrading to more sustainable uses and restoration of land (van Haren et al., 2019).

The sustainable use of the land comes within the goals and objectives of Goal 15 (SDG 15) of the Sustainable Development Goals, which the world ratified in New York in September 2015 (UNCCD, 2015). As a result, the Land Degradation Neutrality (LDN) concept has emerged as a necessity to reconsider the effects of land degradation better and represents an urgent and compressive politically driven action to address land degradation (Okpara et al., 2018). It is a novel approach to addressing the issue (Cowie et al., 2018). To encourage a more effective political response to land degradation, "land degradation neutrality" was introduced into the global conversation. LDN is defined as “a state whereby the amount and quality of land resources necessary to support ecosystem functions and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems” (UNCCD, 2015). Building capacity to accomplish LDN was adopted as a target for Sustainable Development Goal 15 and is a significant objective of the UNCCD (UNCCD, 2016).

The UNCCD secretariat developed the concept of LDN and first came to the front at the United Nations General Assembly meeting on desertification, land degradation, and drought, which was held in New York on September 20th, 2011 (Gnacadja and Wiese, 2016). It became the outcome document of the Rio+20 conference in 2012 as part of the decision to “strive to achieve a land-degradation neutral world in the context of sustainable development” (UN, 2012). It is given explicit attention in sustainable development goal 15.3, targeting a ‘land degradation-neutral world’ (UNO, 2018). The concept was initially called “zero net land degradation” (ZNLD) and was defined during discussions about sustainable development goals (Grainger, 2015). The overall goals of LDN are to restore more land than that which is degraded, to improve the productivity of land resources through sustainable management and restoration of soil, water, and biodiversity, and to contribute to poverty reduction, food and water security, and climate change adaptation and mitigation (Gnacadja, 2015).

According to the UN, (2018) report, with a total of 119 participating countries, the level of technical engagement required to support national LDN target-setting processes effectively. Seventy-seven countries have established LDN targets and associated measures, and the governments have formally adopted. The range of LDN measures identified by participating countries varies according to their national circumstances, and all countries contextualized the LDN baseline by identifying drivers of land degradation, taking the legal and institutional environment and land degradation trends into account. Many countries mapped ongoing LDN-related initiatives at a country level and identified specific opportunities to upscale existing projects or develop new LDN implementation projects (UNCCD, 2019). Ethiopia also adopts this approach to reverse land degradation sustainably. Besides, the LDN program national report was developed in 2015, focusing on LDN to reverse land degradation in 2036 at the country level. This LDN program developed nine national voluntary targets with the strategies set by the LDN national working group to achieve an LDN environment throughout the country (FDRE, 2015).

LDN involves: preventing and reducing LD, restoring partly degraded land, and reclaiming vacant land (Chasek et al., 2015). Implementation will be measured and monitored within set targets and indicators. LDN is considered to be achieved when: "the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD, 2015). Achieving the goal requires the commitment of SLM practices to increase the sustainable provision of ecosystem goods and services to the human population. Also, it requires the development of systematic vigorous, and validated methods for tracing progress at a project, subnational and national scales (Gonzalez-Roglich et al., 2019). Further, the implementation of LDN needs a participatory approach in which multi-stakeholder engagement plays a vital role in promoting sustainable land management practices (Ştefãnescu & Ciuvăţ, 2018). Therefore, this study aimed to evaluated how land management activities achieve sustainable development goals through LDN indicators.

1.2. Statment of the problem

The impacts of land degradation are severe, particularly on poor people who depend heavily on natural resources in low-income countries (Nkonya et al., 2015). Africa is mainly vulnerable to land degradation and is the most severely affected region, with around 55% of the land at a high risk of further degradation (UNEP, 2015). Ethiopia has a severe land degradation issue that impacts agricultural output and food security (Muluneh et al., 2017). Significantly, the most common form of land degradation in Ethiopia is soil erosion by water which has accelerated over recent decades and has resulted in soil fertility loss, nutrient depletion, and biodiversity loss (Bekele & Drake, 2003; Gebreselassie et al., 2016). Recent studies indicated that the annual soil loss by water ranges from 16 to over 300 Mg ha^{-1} yr^{-1} in Ethiopia (Tesfaye et al., 2013). The soil loss in the country is about 852.8 million $Mgha^{-1}$ $year^{-1}$ on the whole land use type (Hurni et al., 2015). This indicates soil erosion remains a significant problem in large parts of Ethiopia, and it could worsen in the future because of the forecasted increase in population and extreme precipitation events throughout the 21^{st} century (Niang et al., 2014).

Despite a good potential for increased agricultural productivity, Southwest Ethiopia is also environmentally challenged, mainly due to deforestation, soil erosion, and nutrient depletion, which profoundly affect agricultural production and food security in the region (Tilahun et al., 2013). In the Omo-Gibe Basin, most of the catchment is occupied and cultivated by many smallholding farmers. However, poor land management practices coupled with the rugged topography, erosive rainfall regime in the area, and nutrient depletion create significant threats to the livelihood of the farmers (Negash et al., 2011). To reduce the impacts of surface runoff on soil erosion and sedimentation and increase land productivity, the Ethiopian government launched massive SWC programs beginning in the mid-1970s (Tesfaye et al., 2014; Haregeweyn et al., 2017).

Land degradation is a complicated issue; it calls for methodical thinking and coordinated solutions. Before any decisions should be made, it's helpful to know where actions should be taken. Previously, the involvement of the private sector, science, and civil society in land management-related issues was very weak. Thus, nowadays, these actors are essential in dealing with natural resource management issues. Therefore, to effectively and sustainably address the problems of land degradation in the country, it is more important to bring all the concerned stakeholders to one platform and actively involve them through the LDN approach (UNCCD, 2015). Multi-stakeholder engagement is essential for supporting sustainable land management practices, which is why LDN implementation calls for a participatory approach (Ştefãnescu & Ciuvăț, 2018). As a result, Ethiopia has adopted this strategy for sustainably reversing land degradation (FDRE, 2015). LDN is a new approach receiving considerable interest because of its potential to address land degradation. However, few empirical studies were conducted globally and in Ethiopia; for instance, the local perception of degradation and restoration processes for implementing LDN in the Gilgel-Abay watershed (Crossland et al., 2018). Besides, the LDN program national report was developed in 2015, focusing on LDN to reverse land degradation in 2036 at the country level (FDRE, 2015). However, studies are limited to a systematic comparison between SLM practices and the indicators proposed for monitoring LDN have been performed.

In Ethiopia, efforts have been made to quantify and map land degradation-prone areas. Most of them have focused on the physical forms of degradation and have applied single factors/parameters to monitor land degradation risk. However, other factors should also be considered to assess and quantify land degradation status. Consequently, it must be addressed through multiple factors analysis (MEDALUS) intergraded with GIS and remote sensing techniques.

In Ethiopia, assessments of LD and identifying areas sensitive to land degradation have become essential in policy and decision-making towards sustainable land management, consequently towards environmental stability and contributing to the performance of LDN. Therefore, the primary purpose of this study was to identify areas that are more sensitive to land degradation that needs urgent mitigation and evaluates the effectiveness of land management measures, indicators, and mechanisms of LDN at the Omo-Gibe River Basin, southwestern part of Ethiopia. This study employed a systematic framework considering spatial and temporal changes in land degradation. Also, at the same time, the factors influencing land management practices were taken into consideration. This study indicates whether LDN is likely to be achieved by the target date and allows corrective action to be taken if necessary.

1.3. Objective of the study

1.3.1. General Objective

The main objective of this study was to examine the Status, Achievements and Sustainability of Land Degradation Neutrality practices to achieve the sustainabel developments at the sub-national scale in the Omo-Gibe River basin, south Ethiopia.

1.3.2. Specific Objectives

Based upon the main objective, the specific objectives of this study were to:

i. Mapping and Quantify Land Degradation in the Omo-Gibe River Basin, SouthWest Ethiopia.
ii. Examine the Determinants of Farmers' Decisions on the Sustainable use of Soil and Water Conservation Technologies.
iii. Evaluate Land Degradation Neutrality achievements for Sustainable Development in the Omo-Gibe River Basin, Southwest Ethiopia.
iv. Evaluate the stakholders' perceptions towards land degradation neutrality in the Omo-Gibe River Basin, SouthWeste Ethiopia.

1.4. Research Questions

i. How can identify the area which is sensitive to land degradation?
ii. How do farmers' decisions influence the adoption and sustainable use of soil and water conservation measures?
iii. Are there any improvement changes in LULC, land productivity, and carbon stocking from 2000 to 2020?
iv. How did farmers and experts perceive land degradation neutrality (indicators, mechanisms, and achievements) and its implications for sustainable development?

1.5. Literature Review

1.5.1. Concepts of Land Degradation

Land degradation has long been the subject of scientific and political debate, so it is impossible to define land degradation precisely. Land degradation originates from soil degradation and is often used as a synonym for soil degradation (Environmental Assessment Report, 2003). Land degradation is defined by the United Nations as a reduction or loss of biological or economic productivity and complexity of rain-fed cropland, irrigated cropland or range, pasture, forest, and woodland. it corresponds to the reduction in the economic value of ecosystem services and goods derived from land as a result of anthropogenic activities or natural biophysical evolution (Thomas et al., 2019). Examples of forms of land degradation are erosion by water and wind, soil pollution and fertility decline, soil compaction, a decline of water quality, vegetation and loss of habitats, or soil sealing due to urbanization and construction (FAO, 2017). This study adapted the definition of land degradation as presented by Orr et al., (2017), which states that: “land degradation is the reduction or loss of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes arising from human activities. These definitions and explanations clearly show that land degradation is much more complex than soil degradation.

1.5.2. Emergency of Land Degradation Neutrality

The concept of land degradation neutrality was developed by the UNCCD secretariat and first came to the fore at the United Nations (UN) General Assembly meeting on desertification, land degradation, and drought (DLDD), which was held in New York on September 20th, 2011 (UNCCD, 2013). The concept was further discussed at events such as the 10th session of the UNCCD Conference of the Parties (COP) held in October 2011 in Changwon, Republic of Korea, and the preparatory process meetings of the United Nations Conference on Sustainable Development (UNCSD or Rio+20). LDN was mentioned in the Rio+20 conference outcome document as part of the decision to “strive to create a land degradation neutrality world in the context of sustainable development” with the understanding that “this should catalyze financial resources from a range of public and private sources" (UN, 2012). Recognizing the multiple benefits of halting and reversing land degradation, the concept of "zero net land degradation" was proposed at the 2012 UN Conference on Sustainable Development (Rio+20). This was reformulated as "strive to achieve a land degradation neutrality world" in the final outcome document and subsequently adopted by the United Nations general assembly as part of the Sustainable Development Goals, specifically, SDG target 15.3 (UNCCD, 2016). Achieving LDN through SLM underpins and catalyzes SDG 15 and 13 and their related targets.

1.5.3. Mechansims and Indicators to achieve Land Degradation Neutrality

The concept of land degradation neutrality acknowledges that arable land must be increased, or at least maintained. This is to ensure the delivery of goods and services provided by it and its interconnected ecosystems. With the vision, as proposed at the end of the 2012 UN Conference on Sustainable Development, to achieve a land degradation-neutral world, the signing parties agreed to expedite policy and laws to avoid or reduce land degradation and desertification. Furthermore, measures will be taken to reverse already degraded land to achieve a net loss of healthy and productive land (Orr et al., 2017). Each country will thereby develop its own national targets for land degradation neutrality based on baseline assessments as well as trends and drivers of land degradation in the respective region with the assistance of the LDN Target Setting Programme. The LDN response hierarchy provides guides for decision-makers in achieving LDN, based on the principle of: avoid- reduce- reverse. Parallel to LDN processes planning and setting targets, UNCCD is establishing a monitoring scheme, which is crucial for LDN success. The scheme is based on three land-based indicators and associated metrics (Orr et al., 2017; Vlek et al., 2017), which are used to monitor SDG 15.3 progress.

The methodological approach for LDN baseline assessment and monitoring is based on the UNCCD´s biophysical progress indicators that were approved by the Parties to the Convention in 2013 (COP 11). The three indicators for LDN are land cover, land productivity, and carbon stocks, whilst their corresponding metrics are land cover change, net primary productivity, and soil organic carbon (Orr et al., 2017). These three biophysical indicators can be used to monitor the quantity and quality of land-based natural capital and the ecosystem services that flow from that land base. Due to the limited availability of datasets for these metrics in some countries, UNCCD recommends a ‘tiered approach' for countries to compute the three indicators, which can use data from three levels (UNCCD, 2016). While the IAEG document suggests that 'areas with declining productivity and carbon stocks may be considered degraded' (suggesting that if two of the three indicators show a declining trend, the land is degraded), more recent documents provided by the UNCCD refer to a ‘one-out, all-out' approach. This means that ‘if any of the three indicator/metrics show a significant negative change, it is considered a loss (and conversely if at least one indicator/metric indicates a significant positive change and none show a significant negative change it is evaluated again)' (UNCCD, 2016).

1.5.4. Sustainable Land Mangment and Land Degradation Neutrality

SLM has been defined as “a knowledge-based approach that aims at integrating the management of land, water, biodiversity, and other environmental resources to meet human needs while sustaining ecosystem services and livelihoods” (World Bank, 2008). Today, SLM represents a holistic approach to long-term productive ecosystems by integrating biophysical, sociocultural, and economic needs and values (Schwilch, 2009). Ethiopian SLM practices/technologies can be grouped into two broad categories (indigenous and introduced), with different degrees of acceptability, area coverage, and benefits. Each category includes the following practices: physical soil and water conservation measures (dominant in the country), biological soil conservation measures, soil fertility improvement measures, agricultural water management measures, grassland management measures, and forestry and agroforestry measures (Zeleke et al., 2006).

According to Sanz et al.,(2017) stated SLM practices that increase productivity in grazing lands (such as adjusting grazing intensity, vegetation and animal waste management, prioritizing the use of indigenous species, permanent ground cover, agroforestry, fodder crops, water harvesting or integrated nutrient management) also show significant potential for land-based climate change mitigation and for addressing land degradation. Specifically, SLM technologies could improve livelihood outcomes for the poorest 10% of agricultural households in Central Asia (Gatzweiler & Von Braun, 2016). Each adopted SLM technology was found to increase the monetary value of per capita food consumption by 3 % for the poorest 10 % of agricultural households, while the effect is less pronounced for the richer categories of agricultural households (ibid).

1.5.5. Determinants of Soil and Water Conservation Measures

Since the 1950s, a lot of attention has been paid to the factors that determine farmers' soil conservation practice's adoption. According to Mekuriaw et al., (2018), 87% of the households sampled in the Ethiopian Highlands used physical SWC structures to keep the soil on their cultivated land and improve crop yields. However, the success and failure of SWC measures were determined by the different conditions of the study area. According to evidence from thousands of kilometers of Fanya Juu and normal bounds on agricultural land, these conservation structures have not been adopted and used sustainably by farmers (Fitsum et al., 2000). As Kessler, (2006) stated, the limited adoption and spreading of soil and water conservation practices is not only due to a technical problem but due to socioeconomic problems.

Besides, Tesfaye, et al., (2013) and Teshome et al., (2016), SWC technologies adoption rates differ considerably within Ethiopia since farmers' investments in SWC are influenced by their ecological, economic, and social impacts. Shiferaw & Holden, (1998) stated terrace technologies adoption varies due to diverse perceptions of farmers regarding the threat of soil erosion, household size, land and farm characteristics, and tenure insecurity. On the other hand, Amsalu & Graaff, (2006) revealed that the continued use of stone terraces in the Beressa watershed is influenced by actual technology profitability, slope, soil fertility, family size, farm size, and participation in off-farm work. This indicated, challenging to generalize about factors affecting the adoption of SWC technologies in different parts of the country. Therefore, the determinants of adoption in land management technology need empirical and local-specific study.

1.6. Conceptual Framework

Framing and addressing the environmental challenge of land degradation in terms of ‘neutrality’ adds a dimension not previously tackled in land degradation management policy. Achieving neutrality requires an approach that allows decision-makers to balance potential gains and losses regarding intent and results (Orr et al., 2017). Conceptualizing LDN, a system model was developed that describes the processes that sustain land-based ecosystem services, enhance the resilience of land-based natural capital and the populations that rely on it, and deliver human wellbeing (UNCCD, 2019). This study was conducted based on LDN conceptual framework. Figure 1 presents a system model for LDN as a causal framework relating the state of the land-based natural capital to the drivers and pressures, the consequent impacts, and human responses. This system model for LDN is intended to describe causal relationships, particularly how natural and social capital interacts, in a way that can help guide LDN policy-making (UNCCD, 2013).

Socio-ecological systems (SESs) are genuinely interconnected and co-evolving across spatial and temporal scales, where the ecological component provides essential services to society, such as a supply of food, fiber, energy, and drinking water. As a result, socio-ecological systems have become an emerging focus in scientific and policy arenas (Petrosillo et al., 2018). According to Orr et al., (2017), an SES context presumes that promoting and maintaining well-functioning land ecosystems depends not only on politically driven initiatives to avoid, reduce and reverse land degradation but also requires land managers/ institutions to ensure humans relate to care for, and value ecosystems under efficient allocation of rights and privileges across time and locations. In addition, Reed et al., (2015) sustainable land management (SLM) cannot be achieved separately from the livelihoods of land-dependent communities. As a result, integrated socio-ecological system (SES) approaches are needed to foster the achievement of LDN within a rapidly realigning global environmental change and sustainable development policy context (Okpara et al., 2018).

Figure 1 presents a system model for LDN as a causal framework relating the state of the land-based natural capital to the drivers and pressures, the consequent impacts, and human responses. The figure identifies the significant factors leading to land degradation and unsustainable land management practices.

Driving forces are the factors that motivate human activities and fulfill basic human needs (Maxim et al., 2009). In this study, the Driving forces include biophysical factors (geology, topography, soil properties, climate change, and drought) and socio-economic factors (Anthropogenic drivers are; population change, deforestation, land tenure security, urbanization, and ineffective land use policy).

Pressures are defined as human activities derived from the functioning of social and economic driving forces that induce environmental changes (Ibid). In this study, land management practices, negative land use change, unsustainable farming practices, and poor land use planning were the central pressures for land degradation.

In the Driver-Pressure-State-Impact- Response (DPSIR) model, ‘states’ change negatively because of land degradation in the study area. The state of the environmental quality changes negatively, like the quality of environments, quality of biodiversity, quality of soil, and vegetation quality decreasing due to land degradation. Conversely, environmental quality changes positively when the land becomes neutral from degradation using sustainable land management practices.

Changes in the quality and functioning of the ecosystem impact the welfare of humans, including the production of ecosystem goods and services and, ultimately, human well-being (Maxim et al., 2009). According to this study, land degradation neutrality activities with sustainable land management practices impact healthy ecosystems, food security, human wellbeing, land-based ecosystem services, land-based ecosystem functioning, and the improvement of agricultural productivity.

In the DPSIR framework, responses are actions taken by groups or individuals in society and government to prevent, compensate, and adapt to changes in the environment's state; and modify human behaviors (Yee et al., 2011). In the study river basin, LDN enabling policies, integrated land use planning, LDN intervention, LDN monitoring, and Sustainable use of SWC technologies are the essential responses or actions (Figure 1).

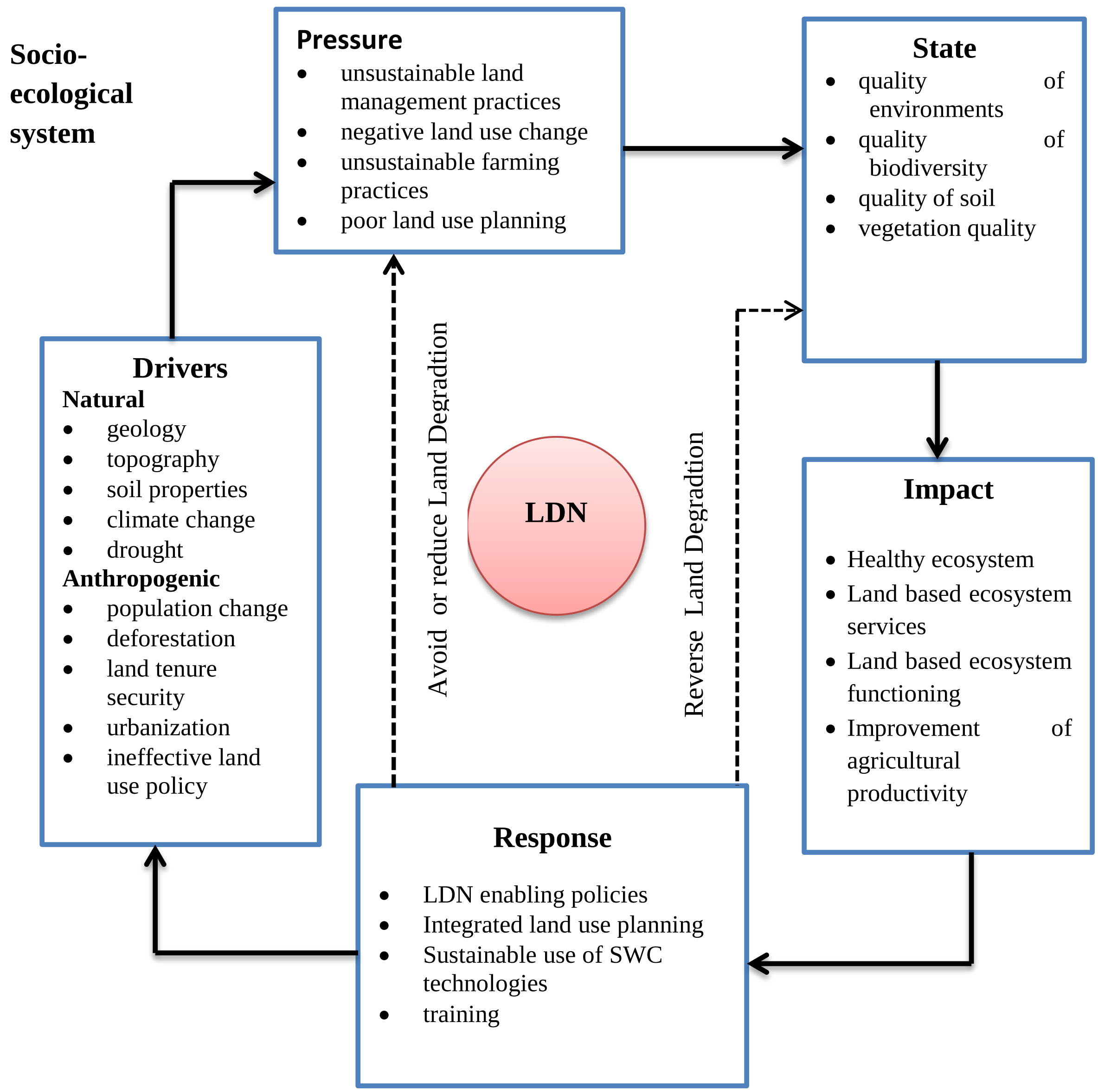

Figure 1: DPSIR conceptual framework within the socio-ecological system.

Solid arrows indicate cause-effect relationships; doted arrows indicate response relationships. Adapted from Orr et al., (2017)

1.7. Methodology

1.7.1. Study Area Description

The Omo Gibe River Basin is located in the southwest of Ethiopia, between 4°30' and 9°30' N and 35° and 38° E, which has a total area of around 79,000 km^2 (Figure 2). The altitude varies between 3625 and 235 m.a.s.l. The climate varies from a hot, arid climate in the south to a humid tropical climate in the highlands of the north and northwest part of the basin (Anose et al., 2021). It has two rainy seasons: the belg/spring and kiremt/summer (NMSA, 2001). The mean annual total rainfall is 1140 millimeters, with the annual average temperature of less than 17°C, but in the south lowlands, it exceeds 29°C. The river basin's overall mean annual flow is estimated to be around 16.6 BMC (MWRNMSA, 2001). The basin high land areas predominantly consist of deep, well-drained clayey soils with alluvial soils in the lower parts the basin.

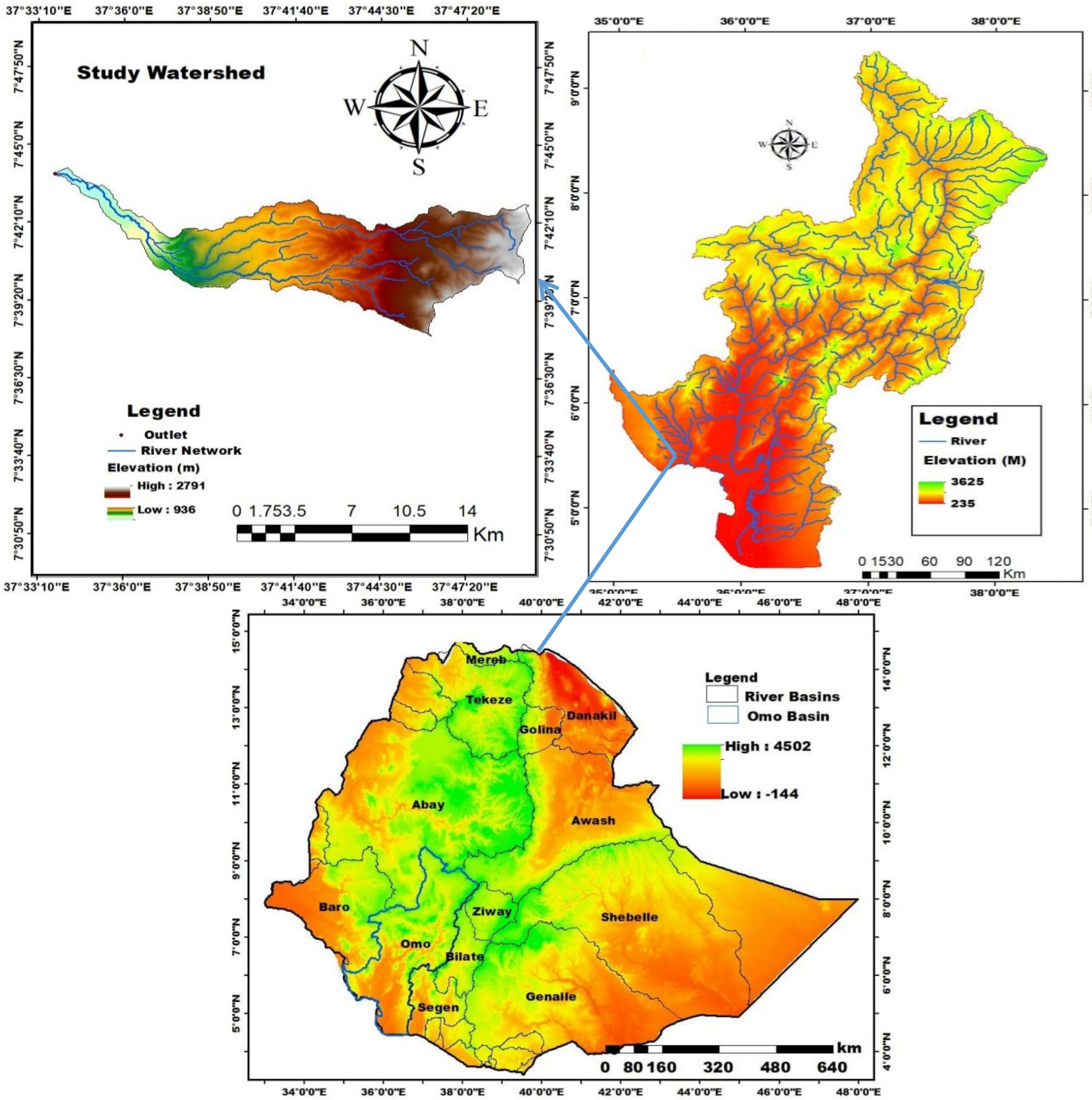

Figure 2: Study area map of Handosha watershed, Omo-gibe river basin, Ethiopia

The highlands have steep slopes with dissected hills, while the lowlands have relatively gentle and undulating slopes (MWRNMSA, 2001). Forest has the uppermost vegetation cover, with about half of the area being forested, grassland, or shrub. The Gibe, Gojeb, and Omo gorges are relatively unpopulated, with open woods and bush land extending across inaccessible areas. Around the eastern catchment, limit is where you find some of the basin's most heavily inhabited and farmed regions. The basin's southern part is lightly populated, with more natural vegetation. Nearly half of the country’s remaining natural forests are found in this region (MoWIE, 2002). Only 6.5 million people live in the basin, containing all or a portion of 80 weredas. As a result of the steep slope and tsetse fly infestation, there is little settlement around the reservoirs; it is mainly concentrated in the highland areas outside the valley. The area surrounding the cascade dams is entirely rural, and the population is arranged into tiny settlements (Tilahun, 2020). It currently provides three hydroelectric plants with 45% of the nation's hydroelectric power production (Negash et al., 2011).

This study was also conducted in the Handosha watershed, which is located in the Omo-gibe river basin, the southwest of Ethiopia, between 7^0 30’50” -7^0 47’50’’N and $37^0$33’10’’-37^0 47’20’’ E, which has a total area of around 12265 ha (Figure 9). Most of the area falls under the altitudinal range between 2200 to more than 2350masl having an annual average temperature and rainfall of 16-24^0C and 900-1200 mm, respectively. The climate consists of kola, w/dega, and dega.
The area is mainly characterized by a steep slope to undulated topography dissected by intermittent rivers and a slope percentage between 8% and greater than 50%. However, as indicated, 50% of the total area of the watershed lies between 30-50%, and 34% of the total area lies >50%. While the topography is variable, and the altitude of the watershed is relatively lower, ranging between meters above sea level. The highlands have steep slopes with dissected hills, while the lowlands have relatively gentle and undulating slopes (NMSA, 2001).

The dominant soil type in the study site is Litisol. They are deep, well-drained, red, and tropical soils. Besides, they are stable soils with favorable physical properties. Thus, they are the most productive soils for producing commonly gown food and plantation crops (FAO, 2006). The main annual crops grown under the rain-fed system are wheat, barely, and maze. They may be used for the cultivation of various standard crops, including *Enset*, potato, and vegetables. The area coverage of the land use system indicates that 69.8% is cultivated lands, 14.5% is forest lands, 8.4% is grazing lands, and 7.3% is others. Forest has the uppermost vegetation cover, with the area being forested, grassland, or shrub. The Gibe gorge is a relatively sparse vegetation cover, with open woods and bush land extending across inaccessible areas. The total population of the Handosha watershed covers 44,480 (21,230 males and 23,250 females) (CSA, 2021). The watershed is inhabited by a total of 8828 households, male-headed and 617 households are female-headed.

1.7.2. Materials and Methods

1.7.2.1. Research Design

According to Creswell (2018), there are three basic mixed methods designs: convergent mixed methods design, explanatory sequential mixed methods design, and exploratory mixed methods design. From these, in this study, the researcher used an explanatory sequential mixed methods design to assess the factors affecting the sustainability use of soil bund measures. The study was based on a solid quantitative background and followed supporting qualitative data. Besides, in this study, two-phase project is involved in which the researcher collects quantitative data in the first phase, analyzes the results, and then uses the results to plan (or build on to) the second, qualitative phase.

1.7.2.2. Data Source

The essential data for this study was gathered from prime and secondary sources. The Primary data for the study was collected from household surveys, and direct field observation. Secondary data sources were accessed from statistical abstracts (CSA), policy documents, Databases from the Soil conservation research project (SCRP), and FAO. Besides, data was collected from national, regional, and district-level agricultural and environmental offices.

1.7.2.3. Data Collection

The present study employed questionnaires, key informant interview and focus group discussions, and non-participant observation to collect data from household heads. Both open-ended and closed-ended type of survey questionnaire is developed to generate data on household circumstances such as age, education, family size, landholding size, land management, and the determinant factors for adopting introduced SWC technologies. The survey was conducted through a structured questionnaire in a specific period to obtain the factors that are determined SWC.

The key informant and land user in-depth interviews were conducted with some selected farmers and extension workers to understand farmers' knowledge towards SWC technologies. A direct observation (Transect walking) was also conducted to assess the SWC practices. Focus group discussion (FGD) was conducted with a group of farmers, and development agents. Challenges and limitations in building and repairing the structures and community commitment to replicate and repair the introduced structures were evaluated.

1.7.2.4. Sampling Design

In the present study, a Multi-stage systematic random sampling technique combining purposive and random sampling techniques was employed to collect primary data from the households. First, the Handosha watershed was selected purposely from the *Omo-Gibe* river basin catchments because this catchment boundary has some of the most densely populated and intensively farmed areas in the basin. On the other hand, the study watershed is one of the most intervened areas through various SWC and rehabilitation works by governmental and non-governmental organizations for several years. The watershed has three agro-climatic zones (*Dega, W/dega,* and *kola*). Then, one sample kebeles was selected randomly from each agro ecological zone. Finally, 340 sample households were selected from the households' lists of each kebeles through a systematic random sampling technique (Table 1).

For key informant interviews, 15 farmers (based on their farming experiences), 3 natural resources experts, and three kebele leaders were selected from each agro-climatic and participated in the interview. Focus group discussion was conducted using ten members of 3 groups in the society based on sex, age, and farming experiences from different agro-climatic. To determine the number of participants in the study, the following sample size determination formula was used, which was developed by Kothari, (2004):

$$n = \frac{z^2 * p * q * N}{e^2\,(N-1) + z^2 * P * q} \quad \ldots\ldots (1)$$

Where:

n is the desired sample size for the study; Z is the upper points $\alpha/2$ of standard normal distribution at 95% confidence level, which is equal to 1.96; p is the proportion of households (which is taken as 0.5 or 50%); e is an acceptable error at a given precision rate (assumed 5%); q is 1-p, and N is the total households in the Handosha watershed.

Table 1: Sample kebeles and number of sample households by agro-climatic

Sample *kebeles*	Total number of HHs		Sample households			Agro-climatic zone
	Male	Female	Male	Female	Total	
Hamola	1121		116	11	127	Dega (cool to humid)
Aste	954		99	8	107	W/dega (cool to sub-humid)
Gaseda	928		100	6	106	Kola (warm semiarid)
Total	3003		315	25	340	

Finally, Statistical analysis was performed using different software such as SPSS, STATA and Arc GIS, and ERDAS Imagine software are employed.

Table 2: Summery Tables of the study

Objectives	To Mapping and Quantifying Land Degradation in the Omo-Gibe River Basin, South-Western Ethiopia	To examine the determinants of farmers' decisions on the sustainable use of soil water conservation technologies	To Evaluate Land Degradation Neutrality achievements for Sustainable Development in the Omo-Gibe River Basin, Southwest Ethiopia	To evaluate the stakholdrs' perceptions towards land degradation neutrality in the Omo-Gibe River Basin, South-Western Ethiopia
Data type and sources	land use, digital elevation model (DEM), climate data, and soil data. The international soil data (ISRIC) and FAO, USGS CHIRPS	household surveys and direct field observation, (CSA), policy documents, and databases from SCRP, and FAO	ESA-CCI-LC dataset, MODIS NDVI, ISRIC, SOC data	household surveys and direct field observation, (CSA), policy documents, and databases from SCRP, and FAO, national, regional, and distict levels agricultural offices
Methods of data collection	Dowanload images from USGS Computed from DEM Derived from nearby meterology station	questionnaires, key informant interviews, focus group discussions, and non-participant observation	Dowanload images of 2000 and 2020 from USGS	questionnaires, key informant interviews, focus group discussions, and non-participant observation
Data analysis methods	SQI, VQI, CQI, MEDALUS, ESAI	Heckman selection model, Discript stastics	FAO classification system and supported by the LDN framework, NDVI, the carbon conservation coefficients associated with LC transitions	descriptive statistics, Logistic regression, Likert scale
Software	Arc GIS 10.4.1	STATA SE 14, SPSS Ver 25	Arc GIS 10.4.1, ERDAS IMAGINE	STATA SE 14, SPSS Ver 25
Towards Land Degradation Neutrality: States, Achievements and Sustainability in Omo-Gibe River Basin, Ethiopia				

1.8. Organization of the Study

This dissertation is organized into six chapters. **Chapter one** presents the general problem, review literature, the objectives, the research questions, the conceptual framework that shows the study design, and general methodology. Chapter two, chapter three, chapter four, and chapter five presented the central part of the dissertation. These chapters stand alone, and each consists of an introduction, methodology, results and discussions, and conclusions. **Chapter two** addresses Mapping and Quantifying Land Degradation. **Chapter three** deals with land degradation neutrality for sustainable development. **Chapter four** deals with the determinants of farmers' decisions on soil and water conservation technologies. **Chapter five** deals with the perceptions of land users and stakeholders towards land degradation neutrality, factors affecting their perception, and its implication for sustainable development. Finally, **chapter six** synthesizes the main findings of the main chapters of the study, research contribution, and their policy implications, and future research indication.

Chapter Two: Mapping and Quantifying Land Degradation in the Omo-Gibe River Basin, SouthWest Ethiopia

Abstract

In Ethiopia, land degradation is a serious ecological issue that has long affected socio-economic conditions. Recognizing the spatial pattern of land degradation promotes implementing area-specific sustainable land management. This study aimed to map and analyze the patterns of environmentally vulnerable regions to land degradation in the Omo-Gibe River Basin. GIS and remote sensing techniques were used to map land sensitivity to degradation. The multifactorial approach-MEDALUS method used three quality indicators- soil, climate, and vegetation- and nine parameters. About 48% of the basin was highly vulnerable to land degradation, and 36% showed clear signs of degradation. 15.8 percent of the area had a low potential for land degradation, due to heavy agricultural demands and inadequate plant cover. Spatially, land degradation was most prevalent in the eastern part of the basin, the south points (lower stream), and the north half of the basin (upper stream). Land management strategies should focus on severely degraded areas to achieve sustainable agriculture and hydroelectric energy production. Therefore, current land planning in the basin should focus on adopting conservation techniques in sensitive areas.

Keywords: *GIS, Indicators, Land Degradation, MEDALUS, Omo-gibe Basin,*

2.1. Introduction

As defined by the international Science-Policy Platform on Biodiversity and Ecosystem Services, land degradation refers to various processes that reduce biodiversity, ecosystem functions, and ecosystem services (Montanarella et al., 2018). It is a global environmental and development issue that lowers the productivity of land resources' capacity, ecological integrity, and human value and is linked to climate change in several ways (Omuto et al., 2014). Three billion people live on degraded lands, which accounts for 30% of the earth's surface (Nkonya et al., 2015). Thus, understanding the spatial pattern of land degradation is crucial for implementing area-specific sustainable land management.

The impacts of land degradation are severe, particularly on poor people who depend heavily on natural resources in low-income countries (Nkonya et al., 2015). Africa is mainly vulnerable to land degradation and is the most severely affected region, with around 55% of the land at a high risk of further degradation (UNEP, 2015). Ethiopia has a severe issue with land degradation that impacts agricultural output and food security (Muluneh et al., 2017). Significantly, the most common form of land degradation in Ethiopia is soil erosion by water which has accelerated over recent decades and has resulted in soil fertility and biodiversity loss (Bekele & Drake, 2003; Gebreselassie et al., 2016). Mainly, the Ethiopian highlands are influenced by severe land degradation due to deforestation, rainfall erosivity, steep slopes, overgrazing, and poor agricultural systems like agricultural stagnation techniques (Nyssen et al., 2015). Land degradation affects over 85% of Ethiopians in the highlands population and over 40 million hectares of land (Gebreselassie et al., 2016); soil loss is estimated to reach over 852.8 million Mg ha^{-1} yearly across all land use types (Hurni et al., 2015); 30.5% of the upper blue Nile basin is degraded to a high level (Ewunetu et al., 2021). As a result, land degradation is still a significant issue in many parts of Ethiopia, and it is likely to worsen in the future due to projected population growth and the recurrence of extreme precipitation events during the twenty-first century (Niang, et al., 2014).

Land degradation is a complicated issue; it calls for methodical thinking and coordinated solutions. Before any decisions should be made, it's helpful to know where actions should be taken. In Ethiopia, efforts have been made to quantify and map land degradation-prone areas. Most of them have focused on the physical forms of degradation, such as soil erosion and deforestation, and have applied single factors/parameters to monitor land degradation risk. However, soil texture, slope gradient, soil acidity, soil depth, soil organic carbon, rain fall, rainfall erosivity, percent vegetation cover, and erosion protection should also be considered to assess and quantify land degradation status.

Consequently, it must be addressed through multiple factors analysis intergraded with GIS and remote sensing techniques. MEDALUS-Mediterranean Desertification and Land Use Method is one of the world's most extensively applied methodologies for land degradation assessment due to its simplicity and flexibility, rapid deployment, and ability to update information on local conditions (Kosmas et al., 1999; Basso et al., 2000; Prăvălie et al., 2020). This model is unique from others in that the composite index, which is intended to be used as an integrated tool for complex systems analysis, is not restricted to model outcomes; it is instead the basis for further analysis of an area's environmental sensitivity in terms of its extent, nature, and character (Ferrara et al., 2020). According to Al-haidarey (2020), a survey of significant publications in international journals and reports from 1999 to 2018, this model was commonly employed globally and intended for use in various environments, demonstrating its significance around the globe. This method is based on the Environmental Sensitivity Area(ESA) principles, which are used to study land susceptibility to degradation using various indicators from a complex, multifactorial, and interdisciplinary perspective (Basso et al., 2000; Momirović et al., 2019). There have been a few studies at the national or regional level utilizing the MEDALUS model, such as (Teferi, 2019; Song et al., 2021) as well also (Ewunetu et al., 2021), which employed the MCA method in the upper blue Nile basin.

Therefore, this study aims to map and analyze the patterns of environmentally vulnerable regions to land degradation in the Omo-Gibe river basin in Ethiopia. The rationale for selecting the Gibe catchment is that it is heavily affected by landslides caused by a complex interaction of initiating, preparing, and triggering elements (Broothaerts et al., 2012). Furthermore, the majority of the catchment in the Omo-Gibe Basin is occupied and cultivated by a massive number of smallholder farmers. Poor land management methods and the area's rugged topography, erosive rainfall pattern, and nutrient depletion threaten farmers' livelihoods (Negash et al., 2011). Besides, the Gibe River is also a major tributary of the Omo-Gibe River Basin, and it is the primary water supplier for the Omo-Gibe cascade dam’s project. However, the reservoir's storage capacity has been threatened by soil erosion and subsequent sedimentation from upstream of the basin, which has resulted in siltation and nutrient enrichment, which have been significant problems in the reservoir (Devi et al., 2008; Negash et al., 2011).

The results of this model could help monitor spatiotemporal changes in land degradation worldwide, which have a similar circumstance. They could also be a starting point for sustainable development at a global level. Furthermore, the proposed model would enable a better understanding of the severe degradation areas in the Omo-Gibe River Basin, which will lead to more effective land management strategies to achieve sustainable agricultural production and hydroelectric power generation. Therefore, to prevent further land degradation and ensure the long-term viability of the Omo-Gibe cascade dams, current land use planning in the basin should focus on adopting conservation techniques in sensitive areas. By reducing siltation and sedimentation with land management practices, these area-specific Soil Water Conservation measures are valuable to the sustainability of Gibe dams. The study used a recent approach (MEDALUS) and used many indicators, taking into account its advantages for being applied for the first time in the study area and serving as a milestone for future research on land degradation.

2.2. Materials and Methods

2.2.1. Data Sources and Processing

Land degradation assessment and mapping are essential before implementing any land degradation prevention, restoration, and protection policies. Table 1 shows the leading indicators for assessing land degradation-affected areas. Nine geographically explicit datasets with varying spatial resolutions were gathered from various sources. The data in this study include land use, digital elevation model (DEM), climate, and soil data. The international soil reference and information center (ISRIC) and FAO soil portal's soil grid website provide soil texture classes, soil acidity, soil depth, and soil organic carbon (SOC) data. USGS provides data on vegetation cover, rainfall erosivity, topography, aspect, and slope gradient. erosivity and rainfall maps for the study area were created using CHIRPS data.

Table 3: Main characteristics of parameters and using indicators

Indicators	Parameters	Spatial resolution	Period	Data source
SQI	Soil texture class	250m	2019	African soil information service (AFSIS) (https://www.isric.org/projects/africa-soil-information-service-afsis)
	Slope gradient (%)	30m	2020	Computed from DEM (obtained from USGS) (https://earthexplorer.usgs.gov/)
	Soil acidity (pH)	250m	2019	FAO soils portal (https://www.fao.org/soils-portal/en/)
	Soil depth (cm)	250m	>>	FAO soils portal (https://www.fao.org/soils-portal/en/)
	Soil Organic Carbon (%)	250m	>>	ISRIC soil grids (https://www.isric.org/explore/soilgrids)
CQI	Rf (mm/yr)	5km	2020	CHIRPS (https://www.chc.ucsb.edu/data/chirps)
	Rainfall erosivity		2020	Derived from nearby metrology station data
VQI	Percent vegetation cover (Pv)	250m	2020	Sentinel 2A (https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/sentinel-2a/)
	Erosion protection	250m	2020	Sentinel-2A (https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/sentinel-2a/)

2.2.2. Environmental Sensitivity Area (ESA)

The ESA index, a multidimensional index made of partial indicators of climate, soil, vegetation, and management quality, is a unique product of this approach. This study used the MEDALUS approach with slight adjustments to fit it to the basin's setting. The methodology was validated and applied in the Mediterranean conditions (Kosmas et al., 1999; Salvati & Bajocco, 2011), but it was later applied in outside Mediterranean areas, such as Cabo Verde (De Pina Tavares et al., 2015); Brazilian northeast (Vieira et al., 2015); Serbia (Momirović et al., 2019) and southwestern Romania (Prăvălie et al., 2020). This model was used to identify locations in the Omo-Gibe basin sensitive to land degradation; it had not been previously employed in the study area.

Layers were chosen based on I) their proven association with land degradation processes, (ii) their ease of updating, and (iii) their availability at the highest geographic resolution achievable (Ferrara et al., 2020). The MEDALUS method uses an index of sensitivity (ESAs) derived from the geometric average of four indices (Soil quality index (SQI), climatic quality index (CQI), vegetation cover quality index (VQI), and management quality and human influence index (MQI)) (Kosmas et al., 1999). This study employed three environmental quality indexes because of data deficiency in anthropogenic factors (management index) due to the extensive study area coverage. The ESAs for land degradation were defined by merging three quality layers after determining indices for each layer. The data that defines the three primary layers is entered into a GIS, which generates compiled maps of ESAs for land degradation. The scores assigned to various parameters vary from 2 (best value) to 1 (worst value) (Kosmas et al., 1999; Basso et al., 2000).

The methodology adapts a two-phases process (Kosmas et al., 1999; Basso et al., 2000). The fundamental data layers are integrated into the first stage to provide three quality indicators for soil, climate, and vegetation by computing the geometric mean of the primary data layers:

$$Quality\left(X_{ij}\right) = (layer\_1ij * layer\_2ij * layer\_3ij * \ldots\ldots * layer \ldots nij)1/_{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where x represents the variable class (soil texture, soil depth, SOC, etc.), i and j represent the rows and columns of a single cell in the raster layer (i.e., the value associated with each considered geographical domain), and n is the number of layers (i.e., variables) employed. The environmental sensitivity region of each elementary unit is evaluated in the second stage using the quality layers:

$ESij = (quality\_\ 1ij * quality\_2ij\ *\ quality\ \_3ij)1/_3$……………. (3)

The final ESA index was computed according to the original procedure as a geometric mean of the three quality values recorded at each elementary pixel; (Equation 4):

$ESAij = (SQI_{ij} *\ CQI_{ij} * VQI_{ij})1/_3$ …………………………………. (4)

Where: i and j represent the rows and columns of a single cell in the raster layer.

2.2.3. Major Environmental Sensitivity Area Indicators

Soil quality indicators for mapping the sensitivity can be connected to available moisture and erosion tolerance. For this study, based on available data, soil texture class, soil depth, SOC,Soil acidity, and slope gradient were employed to examine the soil quality of the study area (Table 3). The digitalization of the soil map and the integration of survey analysis data for each soil type were used to create these maps. The results were graded according to the ranges reported by Kosmas *et al*. (1999) by relying on the attributes mentioned above; the soil quality indicator was obtained based on the geometric mean of the sub-indicators score values, calculated in the following way:

$SQI(Soil\ Quality\ Index) = (soil\ texture\ class * soil\ depth * slope\ gradient *$
$soil\ \ organic\ carbon * PH\ value)1/_5$…………………………………. (5)

Table 4: Quality indicators, parameters, description, assigned weighting indices of soil

Quality indicators	Parameters	Class	Description	Index
SQI	Soil texture class	L, SCL, SL, LS, CL	Good	2
		SC, SiL, SiCL	Moderate	1.6
		Si, C, SiC	Poor	1.2
		S	Very poor	1
	Soil depth (cm)	>75	Deep	2
		75-30	Moderate	1.8
		15-30	Shallow	1.6
		<15	Very shallow	1
	Slope Gradient (%)	<6	Very gentle to flat	2
		6-18	Gentle	1.5
		18-35	Steep	1.2
		>35	Very steep	1
	Soil pH value	< 5.5	Extremely acidic	1
		5.6-6.5	Moderately acidic	1.2
		6.6-7.4	Neutral	1.6
		>7.5	Alkaline	2
	Soil Organic Carbon (%)	>6	High	2
		2.1-6.0	Medium	1.4
		1.1-2.0	Low	1.2
		<1.0	Very low	1

N.B: L = loam, SCL = sandy clay loam, SL = sandy loam, LS = loamy sand, CL = clay loam, SC = sandy clay, SiL = silty loam, SiCL = silty clay loam, Si = silt, C = clay, SiC = silty clay, S = sand;

The assessment of climate quality was based on parameters that influence the amount of water available for plant growth. Rainfall and rainfall erosivity are sub-indices that make up the Climate Quality Index (Table 4). The climate data provided by the region's primary weather stations were used to create the rainfall and erosivity maps. In this study, CQI is calculated from the long-term records of meteorology stations in Ethiopia and nearby meteorological stations for 30 years of data (http://www.ethiomet.gov.et/).

$$CQI\ (Climate\ Quality\ Index) = (Rainfall * Rainfall\ erosivity)1/_2 \ldots \quad (6)$$

Table 5: Quality indicators, parameters, description, assigned weighting indices of Climate

Quality indicators	Parameters	Class	Description	Index
CQI	Rf (mm/yr)	>1200	high	2
		900-1200	Medium	1.6
		350-900	Low	1.2
		<350	Very low	1
	Rainfall erosivity	< 150	Very low	1
		151-350	Low	1.2
		351-700	Medium	1.6
		>700	High	2

Vegetation Quality Index (VQI)

Desertification and land degradation are both influenced by vegetation cover. The following main indications of desertification can be evaluated in connection to current natural or farmed percent vegetation cover (Pv) and erosion protection (Equation 8). In this research percent vegetation cover is computed from normalized difference vegetation index (NDVI), which is most commonly used for regional assessment of VQI (Prăvălie et al., 2020), obtained from sentinel 2A remote sensing data using the following equation (7):

$$P_v = (\frac{NDVI-NDVIs}{NDVI-NDVIs})^2 \ldots\ldots\ldots (7)$$

Based on the above information, the vegetation quality index is assessed in the following way:

$$VQI\ (Vegetation\ Quality\ Index) = (Percent\ Vegetation\ cover * Erosion\ protection)1/_2 \ldots\ldots\ldots (8)$$

The vegetation cover in the study area is classified based on satellite image classification for the specific year.

Table 6: Quality indicators, parameters, description, assigned weighting indices of vegetation

Quality indicators	Parameters	Class	Description	Index
VQI	Percent Vegetation cover (Pv) NDVI	<10	Very low	1
		10-30	Low	1.4
		30-50	moderate	1.6
		50-70	High	2
	Erosion protection	Agricultural lands, bare land	Low	2
		Marshland, Settlement area	moderate	1.4
		Forest, Shrub land, Woodland, Grassland	High	1

After completing the three indicators, the final result of the land degradation sensitivity index is obtained based on the formula (Equation 9). Area sensitivity to land degradation is used in environmental sensitivity indicators (soil quality, climate quality, and vegetation cover quality). To calculate the Environmental sensitivity areas index (ESAI), the three derived indices are multiplied geometrically as follows:

$ESA_{LD} = (SQI * CQI * VQI)1/_{3}$ ………………………………….. (9)

Subsequently, the geometric mean for all three quality indicators generates the environmental sensitivity to degradation map. ArcGIS 10.4.1 is utilized to analyze and prepare the layers of quality maps, using the geometric mean to integrate the individual indicator maps.

Figure 3 depicts the process flow for determining the land degradation sensitivity index. To pinpoint locations particularly vulnerable to land degradation, it demonstrates the relationship between the primary quality indicators and their sub-indicators as well as their geometric functions. The soil quality is measured by soil texture class, soil depth, slope gradient, soil PH value, and soil organic carbon content. Besides the overlaying of rainfall and rainfall erosivity, erosion protection and vegetation covers (PV) were used to illustrate vegetation quality in the research area. Finally, a comprehensive image of the area's sensitivity to land degradation in the Omo-Gibe river basin emerged by geometrically overlaying the main and sub-indicators.

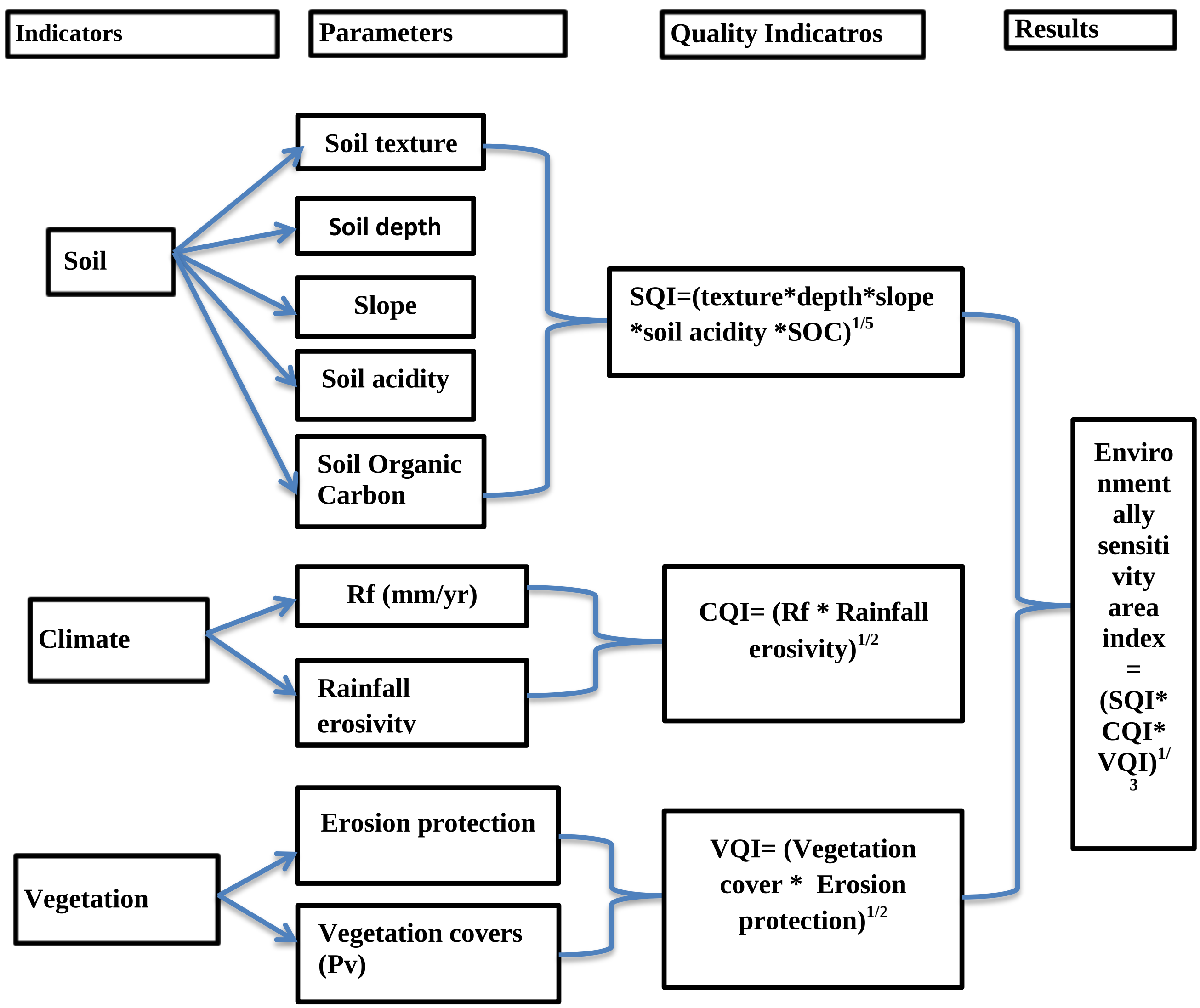

Figure 3: Flow chart shows the methodology of land degradation sensitivity indices

2.3. Results and Discussion

Each indicator used in the MEDALUS technique was calculated using a variety of spatial analysis functions and algebraic combination tools. The various indices SQI, CQI, and VQI are stored in maps in a matrix style, as seen in Figure 7. They are combined by the MEDALUS model (equation 4) to create a land degradation map (SLDI), which shows the potential for land degradation at each place.

2.3.1. Soil Quality Index (SQI)

Table 7 shows the outcome ranges for the three classes of soil quality in the Omo-Gibe river basin. Based on the results, suitable quality classes account for approximately 64.42 percent of the entire area.

Table 7: Ranges of the three classes of Soil Quality Index (SQI)

Class	Description	Index	Area (%)
1	High quality	2	64.42
2	Moderate quality	1-2	19.74
3	Low quality	1	15.84

The depth of the surface horizon was determined by examining soil profile samples (Table 4), which ranged from moderate to deep soil. In the research region, 82.5 percent of the soil depth ranges from moderate to profound. Thus, soils in the research area are still being sealed. According to the slope gradient map generated by the digital elevation model, places with a steep-to-gentle slope gradient dominate at 52.72 percent and 35.04 percent, respectively. This shows that the terrain morphology generally corresponds to plains to low mountains. Because the topography in the research area is mostly plateau and flat, the slope plays an influential role in soil erosion.

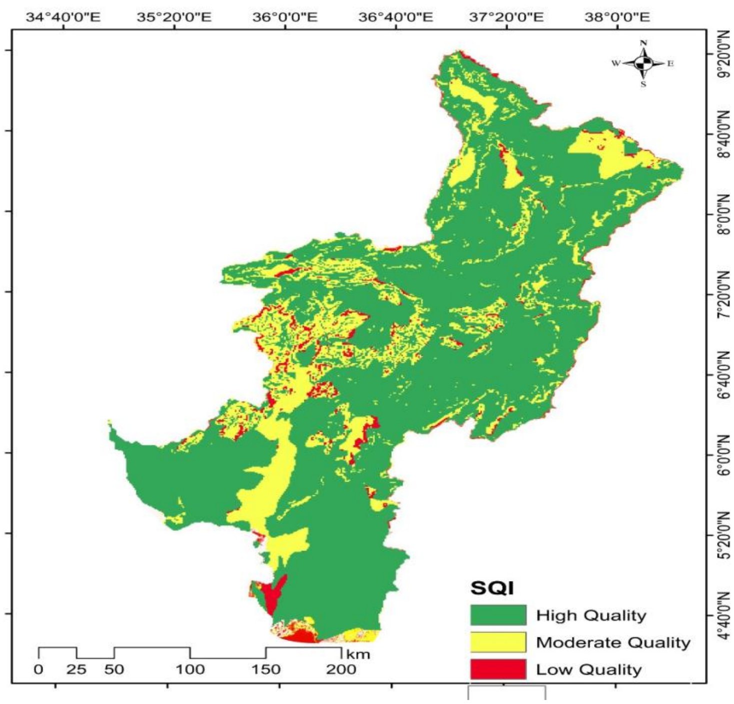

Figure 4: Soil Quality Map of Omo-Gibe River Basin related to land degradation risk

The high-quality index covers 64.42 percent of the area (Figure 4), dominated by the basin's central and eastern regions. The findings show that the study basin is dominated by a deep soil profile with extremely acidic composition. Loam and clay loam, sand and silty, and silty and clay and sand soil accounted for 56.6 percent, 0.4 percent, 42.6 percent, and 0.1 percent, respectively. As a result, favorable soil textures cover more than half of the study area. The soil of medium quality, on the other hand, accounts for 19.74 percent of the total. It is mainly found in the basin's northern and eastern regions and the valley.

Furthermore, low-quality soils, which are very susceptible to degradation, account for a small amount, estimated at 15.84 percent. They are found in steep slopes, medium soil texture class, and low soil organic carbon contents. These classes are less exposed to entropic pressure than other classes, which show good soil stability and are less vulnerable to land degradation.

2.3.2. Climate Quality Index (CQI)

Climate quality is a composite indicator measured using characteristics that influence plant water availability. In addition, climate hazards such as frost impede or prevent plant growth.

Table 8: Ranges of the three classes of Climate quality (CQI)

Class	Description	Index	Area (%)
1	High quality	2	76.7
2	Moderate quality	1-2	9
3	Low quality	1	14.2

Table 8 shows the scores for each sub-indexes class. Because of the importance of a semi-arid and sub-humid climate, the high rainfall class covers 81.5 percent of the entire basin.

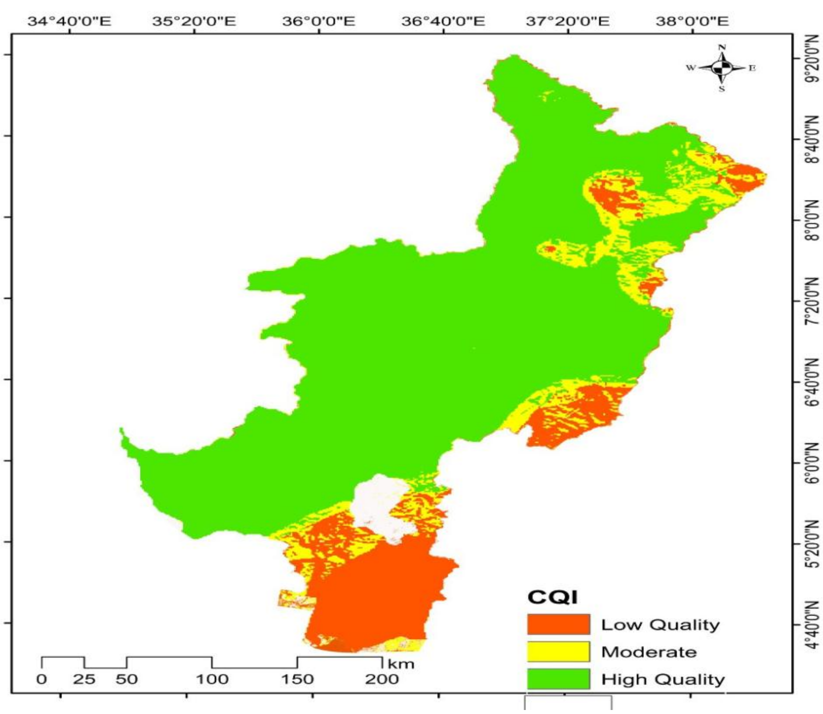

Figure 5: Climate Quality of Map of Omo-Gibe River Basin related to land degradation risk

As a result of the homogeneity of the rainfall and erosivity, the spatial variability is strongly correlated with the aspect sub-index. Figure 5 illustrates that a large portion of the basin has high (76.7%) and moderate (9%) quality climate areas, whereas bad quality climate areas account for 14.2 percent of the total land area around the northeast and southeast parts of the basin. This is primarily due to the high rates of rainfall that occur across much of the basin. Annual rainfall varies from 400 mm in the extreme south lowland to 1900 mm in the highland, averaging 1140 mm. Furthermore, the average annual temperature in the basin varies from less than 17^0c in the western highlands to more than 29^0c in the southern lowlands.

2.3.3. Vegetation Quality Index (VQI)

The VQI is calculated using the geometric mean of essential characteristics that directly or indirectly influence vegetation quality, such as vegetation cover and erosion protection (Table 9). These two variables have an impact on the quality of vegetation.

Table 9: Ranges of the three classes of Vegetation quality (VQI)

Class	Description	Index	Area (%)
1	High quality	2	59.17
2	Moderate quality	1-2	13.87
3	Low quality	1	26.96

The coverage sub-index shows that more than half of the area is well covered, which can be attributed to the basin's relatively medium forest cover. The presence of shrubs, herbs, grasses, and trees in this form of vegetation preserves the soil.

According to the findings, the high-quality class encompasses nearly 59.17 percent of the basin's total area, with the majority concentrated in the basin's west and southwest regions (Table 9). The map of the vegetation quality index (Figure 6) reveals that areas with good vegetation quality are concentrated in the basin's forest regions, accounting for nearly half of the total area. This class is dominated by forest vegetation, a natural barrier to soil erosion and drought. The intermediate quality class, on the other hand, covers 13.77 percent of the total area.

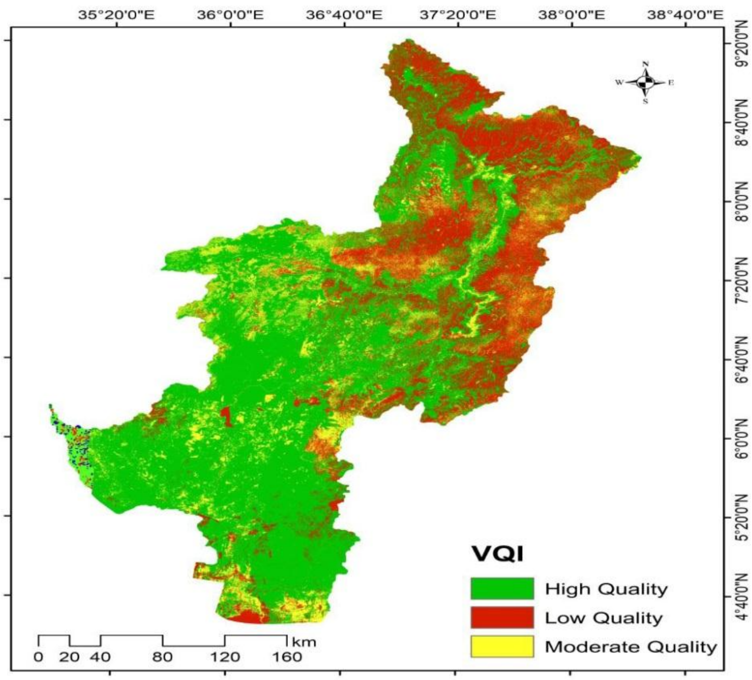

Figure 6: Vegetation Quality Map of Omo-Gibe River Basin related to land degradation risk

The poor and impoverished quality classes occupy a significant percentage of the research area, accounting for 26.96 percent; these lands are concentrated mainly in the upper basin (north) and middle basin (central) regions of the study area (Figure 6). This is because many of the Omo-Gibe basin includes vegetation incapable of buffering soil from erosion. Most of the area corresponds to cereal-growing areas or places with very sparse vegetation cover, where conditions for overland flow, erosion, and vulnerability to drought are favorable. Considering that vegetation cover is decreasing and is a critical component in soil erosion control on sloping terrain.

2.3.4. Environmentally Sensitive to Land Degradation (ESLD)

The final step involves matching physical environmental indicators (soil quality, climate quality, and vegetation quality) to define the many types of ESAs that can be used to combat land degradation.

Table 10: Summary results of sensitivity area of land degradation

Class	**Description**	**Index value**	**Area km^2**	**Area (%)**
Critical (30.9%)	Critical 3	>1.53	3980	5.2
	Critical 2	1.42-1.53	1720	2.3
	Critical 1	1.38-1.41	18040	23.4
Fragile (17%)	Fragile 3	1.33-1.37	515	0.7
	Fragile 2	1.27-1.32	11985	15.5
	Fragile 1	1.23-1.26	594	0.8
	Potential	1.17-1.22	28056	36.3
	Not affected	<1.17	12256	15.8

The complete testing and application of the ESAs methodology resulted in a final map of environmental sensitivity areas (Figure 7) in the context of land degradation, which provides a relatively good and clear picture of the critical levels of land degradation in the Omo-Gibe river basin, as well as the identification of less affected and fragile areas. The distribution of quality indicators demonstrates that the most relevant indicators are soil (64.42 percent) and climatic quality (76.7 percent), although vegetation quality is the decisive factor in land degradation in the research area (27%). Because of the dense vegetation in the research region, the low-quality rating is at its highest.

As specified above, Table 10 shows the ESAI ranges for each ESA type as well as three subclasses within each type. Each type of ESA is described on a three-point scale ranging from 3 (high sensitivity) to 1 (low sensitivity) to better integrate the boundaries of the following classes of ESAs (Kosmas et al., 1999). According to the value of the ESA index, the Omo-Gibe river basin is classified into eight categories: Critical 3, Critical 2, Critical 1, Fragile 3, Fragile 2, Fragile 1, Potential, and not affected (Table 10). The three quality indexes were mapped to identify the spatial distribution in the Omo-Gibe river basin. Figure 7 shows these quality indexes and a map of the Omo-Gibe river basin's environmentally sensitive areas to land degradation, which depicts the spatial distribution of each quality measure.

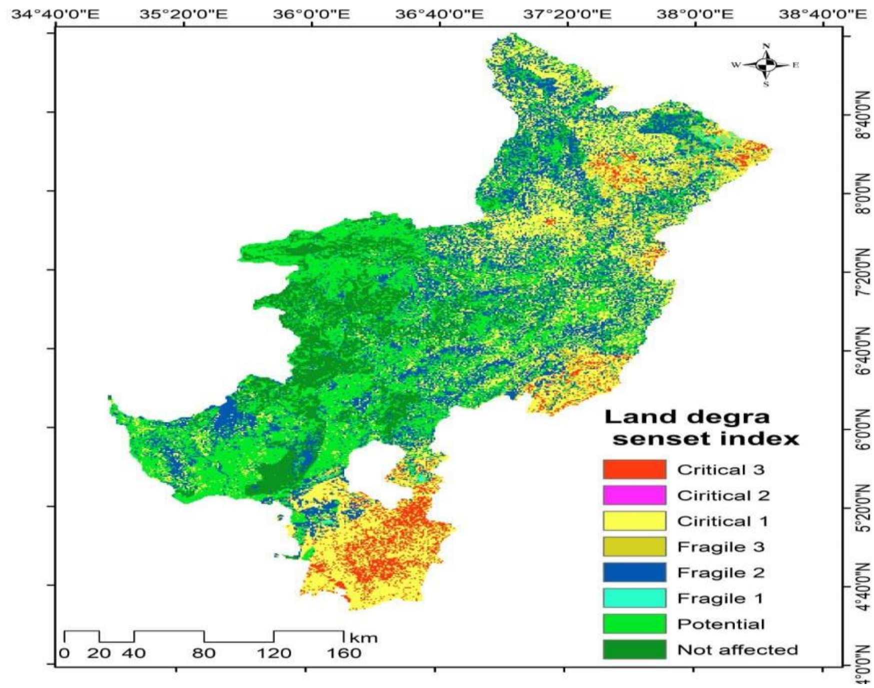

Figure 7: Map of Environmentally Sensitive Areas to land degradation for the Omo-Gibe River Basin

Many of the basin was classified as critical or fragile, with prospective or untreated classes. For instance, 36.3 and 15.8 percent of the basin are designated as potential and unaffected, respectively, with 30.9 percent classified as critical (with the majority of the basin classified as C1) and 17 percent designated as fragile (with large parts of the basin designated as F2) (Figure 8).

The critical areas (C1, C2, and C3) are primarily found in the basin's upper and lower reaches and include the Middle Eastern part of the basin (Figure 7). The primary contributor is the loss of natural vegetation, whereby the amount of vegetation cover increases water and soil conservation and protects against land degradation. For example, drainage from bare land can be high even during minor rainfall, whereas good plant cover reduces runoff from minor and moderate-intensity rains. As a result, a significant proportion of total water will penetrate the groundwater storage system, which is critical for crop production and grazing land. Similar results were reported in Serbia (Kadović et al., 2016).

Furthermore, the slope gradient significantly impacts this severe condition, particularly in the highlands. The steeper the slope gradient, the faster the runoff flow happens, resulting in increased erosion. This can be seen on the mountaintops, especially around the upper basin of the study area. Urbanization, grazing, and agricultural practices have all substantially impacted land degradation. Land degradation is also increased by natural factors such as climate change (low yearly precipitation mixed with high temperatures in the lower basin) in the study area. Generally, clay, low vegetation cover, steep slopes, overgrazing, and poor management result in a high sensitivity to land degradation.

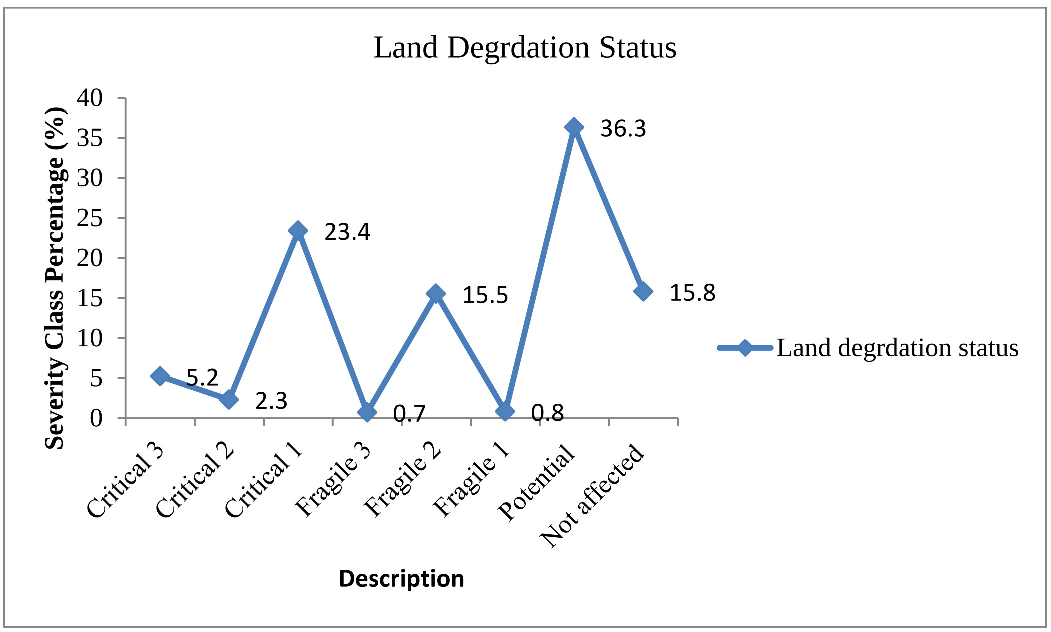

Figure 8: Area Percentages of the Sensitivity class with a Description

The fragile areas (F1, F2, and F3) are more common along the basin and reflect zones where soil quality parameters and climate are not critical in the aggregate but where a slight decrease in one of these elements might result in critical conditions. The potential and not-affected zones are primarily found in the western reaches and other locations with favorable temperature and soil conditions (flat and deep soils with high annual rainfall), healthy vegetation cover, and effective management. The agro-ecosystem of the Omo-Gibe river basin has undergone a considerable worsening in environmental conditions in terms of vulnerability to land degradation, as shown in Figure 7. Furthermore, the simultaneous interaction of vulnerable natural settings and anthropogenic influences leads to land deterioration in these areas. As a result, a large swath of the region has suffered negative impacts, such as a significant decrease in groundwater resources, land subsidence, and severe agricultural landscape fragmentation.

2.4. Conclusions and policy implications

Land degradation is one of Ethiopia's most pronounced challenges in sustainable rural development. This research is a case study in methodological approaches for assessment and mapping land degradation-prone areas. The results show that the MEDALUS model helps assess environmental sensitivity to land degradation in the study area. The analysis result of nine factors reveals that significant parts of the study area are severely vulnerable to degradation. The study found that land degradation was most prevalent in the Eastern part of the basin, the South points (lower stream), and the North half of the basin (upper stream). As a result, some of the basin's most populous and extensively cultivated areas are in the eastern catchment boundary.

In contrast, the southern portion is characterized by high runoff from the Omo River during the rainy season. During the wet season, the sparse vegetation cover, heavy rainfall, and steep slopes result in substantial overland flow. Moreover, the Omo-Gibe river basin agro-ecosystem has undergone a significantly worsening environmental circumstance vulnerable to land degradation. As a result, the Omo-Gibe cascade dam reservoirs are threatened by soil erosion and subsequent sedimentation from the Gilgel Gibe basin upstream. It requires the attention of a wide range of stakeholders. Therefore, the result of this study can serve as a guide for local decision-makers who can implement the essential land management techniques to address the issue of land degradation. Furthermore, the developed model can evaluate the quantity, intensity, and severity of different land degradation processes at the national, sub-national, and global levels.

Therefore, to prevent further land degradation and ensure the long-term viability of the Omo-Gibe cascade dams, current land planning in the basin should focus on adopting conservation techniques in sensitive areas. More research is required in various parts of Ethiopia to validate this method considering the weighted inclusion of other parameters/sub-indicators (for example, groundwater, wind, and social indicators) or those already used in the standard MEDALUS approach.

Finally, the low data access on socioeconomic factors, pedological factors (soil salinity, soil organic matter), climate factors (aridity, wind speed), socio-economic factors (rural households, poverty), and grazing land per hectare, vegetation type, groundwater limits the use of this model to assess and monitor land degradation in develping nations like Ethiopia.

Chapter Three: Sustainable use of Soil and Water Conservation Technologies and its Determinants: the case of the Omo-Gibe River Basin, Ethiopia

Abstract

For forty years, Ethiopia has promoted sustainable land management activities to enhance agricultural productivity. This study was intended to identify the factors determining farmers' adoption and continued use of soil bund measures in the Handosha watershed, Omo-Gibe river basin. Using Heckman sample selection model, a multistage sampling technique was used to select 340 households. 235 (69.12%) households adopted soil bunds, but only 89 (37.87%) of them sustainably practiced soil bunds on their farm plots. Most adopters widely practiced soil bunds (49.42%), followed by stone bunds (15.9%) and Fanyajuu (10%). The empirical results of the Heckman sample selection model showed that; farming experience, land tenure security, and perception of profitability of conservation measure affected the adoption of soil bunds positively significantly. Whereas farm plot size and participation in off-farm activities influenced the adoption of soil bund negatively significant. Sustainable use of soil bund measures was significantly influenced by land tenure security, family size, and frequency of extension contact, whereas the distance between farm plots and home and farm plot size were affected negatively. As a result, a design of agro-climatic based soil and water conservation (SWC) measures was essential in reducing farmland vulnerability to soil erosion and food insecurity. It has been concluded that conservation practices should not only focus on the implementation and biophysical factors but also consider the socioeconomic interests of the farmers to improve the sustainable use of conservation technologies.

Keywords: *Adoption, Heckman, Sample selection, Soil bund, Sustainability, SWC*

3.1. Introduction

Ethiopia is one of the most environmentally distressed countries suffering from land degradation in the form of water soil erosion, resulting in loss of soil fertility, nutrient depletion, biodiversity deterioration and seriously threatening livelihood of its people (Bekele & Drake, 2003; Nyssen et al., 2010). The country's soil erosion severity is intensified partly by intense rainfall and steep topography. In the Omo-Gibe Basin, most of the catchment is occupied and cultivated by many smallholding farmers. However, the rugged topography of the area, erosive rainfall regimes, and nutrient depletion pose significant threats to the livelihoods of farmers in the area (Negash, 2011), and the storage volume of Gibe dams' reservoir is threatened by the soil erosion and subsequent sedimentation from the catchment of Gibe basin (Negash, 2011). Therefore, investment in soil and water conservation (SWC) measures is decisive for sustaining natural resources and increasing resilience (Kumar et al., 2016; Bryan & Institute, 2009). The Ethiopian government launched massive soil and water conservation (SWC) programs beginning in the mid-1970s (Tesfaye et al., 2013; Haregeweyn et al., 2017b) in the highlands during the last four decades (Teshome et al., 2016) to reduce soil erosion and sedimentation from surface runoff, as well as to increase land productivity.

Several kilometers of soil and water conservation measures have been built on croplands throughout the country. According to Mekuriaw et al., (2018), 87% of the households sampled in the Ethiopian Highlands were using physical SWC structures to improve crop yield and keep soil on their cultivated land. However, the level of adoption of SWC measures varies from area to area, and the farmers have not sustainably used these conservation structures. The different conditions of the study area determined the achievement and failure of SWC measures. As Kessler, (2018) stated, in addition to technical issues, socio-economic issues also contribute to the limited adoption of soil and water conservation practices. Besides, Teshome et al., (2016) revealed that the adoption rates of SWC technologies vary considerably within Ethiopia because investments by farmers in SWC are influenced by ecological, economic, and social impacts of the SWC technologies. On the other hand, Amsalu & Graaff, (2006) revealed that the sustainable use of stone terraces in the Beressa watershed is influenced by actual technology profitability, slope gradient, soil fertility, family size, farm size, and participation in off-farm work. This indicated, challenging to generalize about factors affecting the adoption of SWC technologies in the country within variation agro-ecology, and no universally significant factors affecting the adoption of soil and water conservation measures across the regions (Kumar et al., 2021).

Furthermore, most of adoption studies in Ethiopia related with SWC practices were focusing on the pre-adoption (acceptance) and adoption stage than the continued use (post-adoption) for instance: (Bekele & Drake, 2003; Asfaw & Neka, 2017; Wolka et al., 2018; Mekuriaw et al., 201; Mengistu & Assefa, 2019; Sileshi et al., 2019). However, few studies (Amsalu & Graaff, 2006; Teshome et al., 2012; Teshome et al., 2016; Seid et al., 2022) were studied on also post-adoption stage (continued use). In the study area (Handosha watershed), a lot of NGOs projects such as sustainable land management program (SLMP), reducing emissions from deforestation and forest degradation (REED+), the European federation of associations of dietitians (EFAD), climate action through land scape management (CALM), the German Agency for International Cooperation (GIZ), integrated soil management and fertility (ISMF) found mainly focused on Sustainable land management. However, most of the farmers were supported by Safety Net Program by World Bank; as a result of food insecurity. It implies there are reasons behind the less effectiveness of sustainability of SWC practices. This raised a question, why this happing and enforced to conducted research on the factors determining the effectiveness of SWC practices. For devising an effective program and policy, and a better understanding of factors are responsible for enhancing level of adoption (Teshome et al., 2016).

Even with the vital role adopting SWC technologies plays in conserving the environment, very few studies have been conducted to analyze the factors affecting the sustainable use of SWC measures in either of their farm plots. As a result, we need location-specific target policies to ensure the sustainability of SWC. Hence, the determinants of the adoption process and its sustainability of conservation measures are highly useful and need empirical studies.

As part of this study, we utilized a sample section method named the Heckman selection model to take advantage of two-stage analysis and deal with the zero sample simultaneously. This selection model addresses unobserved heterogeneity and selectivity bias in conjunction with discrete, continuous modeling, which enhances the suitability of models (Xu et al., 2017). This model takes a two-step approach to zero-sample problems, accounting for heterogeneity and then investigating endogeneity.

Therefore, to address the gaps mentioned above and suggesting area specific appropriate sustainable land management measures based on farmers' preference, examining the significant environmental and socio-economic factors of soil bund measure for sustaining land productivity was necessary; this study was addressed to: (i) Are there any practices on adopting, continued use (sustainable) of sustainable land management (SLM)? (ii) How do farmers' decisions influence the adoption and sustainable use of soil bund measures? (iii) What are the determinants of the adoption and sustainability use of soil bund technology?

3.2. Materials and Methods

3.2.1. Model Specification

To investigate determinates' of farmers' adoption and continued use of SWC technologies, researchers used different sequential models. For instance, Paudel & Thapa, (2004) used a multi-stage processing model, Shiferaw & Holden, (1998)/; Amsalu & Graaff, (2006) employed a two-stage processing model, and Teshome et al., (2016) used five significant categories of the adoption process. The present study employed a two-stage processing model to examine the factors affecting farmers' continued use of soil bund measures. To optimize the advantages of two stages of analysis and simultaneously address the zero-sample problem, the Heckman selection model is employed in this study. Heckman selection model assumes that; (a) the error of both the selection and central equation are correlated and distributed normally, (b) explanatory variables in the selection equation are independent of the error term, (c) explanatory variables in the main equation are independent of the error term. Heckman selection models jointly handle discrete/continuous modeling, unobserved heterogeneity, and selectivity bias, which improve their appropriateness. The model provides a two-step solution to the zero-sample issue that enables it to consider heterogeneity before handling endogeneity (Teshome et al., 2012; Xu et al., 2017). In a two-stage process, the second adoption stage is a sub-sample of the first. Thus, it is likely that the second sub-sample (those who continued the technology) is non-random and necessarily different from the first (which included those who did not adopt SWC technology), and this creates a sample selection bias (Heckman, 1976). Consequently, the Heckman, a two-step maximum likelihood procedure, was used to correct this selection bias. The Heckman selection model assumes that there exists an underlying regression relationship, which consists of the latent equation given by:

$$yj = xj\beta + u1j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

Where y_j is the latent variable (the propensity to continued use of soil bund technology), x is a k-vector of explanatory variables, which include different factors hypothesized to affect sustained use, β is the parameter estimate, and u1j is an error term. Therefore, only the binary outcome given by the probit model is observed as;

$$yj^{probit} = (yj > 0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

The dependent variable is observed, if the observation j is observed in the selection equation:

$$yj^{select} = (zj\delta + u2j > 0) \ldots\ldots\ldots\ldots\ldots..(12)$$

$$u1 \sim N\ (0,1)$$

$$u2 \sim N\ (0,1)$$

$$corr\ (u1, u2) = \rho$$

where yj^{select} Is whether a farmer has adopted soil bund measure or not, z is an m vector of explanatory variables, which include different factors hypothesized to affect adoption; δ is the parameter estimate, u_{2j} is an error term, and u_1 and u_2 are error terms, which are typically distributed with mean zero and variance one. Thus, equation 12, the first stage of Heckman's two-step model, is the selection model, which represents the adoption of the SWC measure. The second stage is the outcome model (equation 10), which represents whether or not the farmer continued use of SWC measure. When the error terms from the selection and the outcome equations are correlated ($\rho \neq 0$), the standard probit techniques yield biased results (Deressa et al., 2011; Asrat & Simane, 2017). Hence, the Heckman probit selection model was employed to analyze the adoption and continued use of soil bund measures in the Omo-gibe river basin.

The relationship between the variables influencing the adoption and continuous usage of the soil bund measure of the Handosha watershed is depicted in Figure 9. This conceptual framework is organized following theories and the procedure for adopting SWC measures. Three stage of SWC technology adoptions are initial adoption, actual adoption, and post-adoption. This analytical framework considers the most essential socioeconomic, demographic, physical, and institutional factors that influence smallholder most important socioeconomic, demographic, physical and institutional factors that influence farmers' decisions about the adoption and sustainable usage of soil bunds. These parameters are anticipated to affect the usage of soil bund technology either favorably or unfavorably.

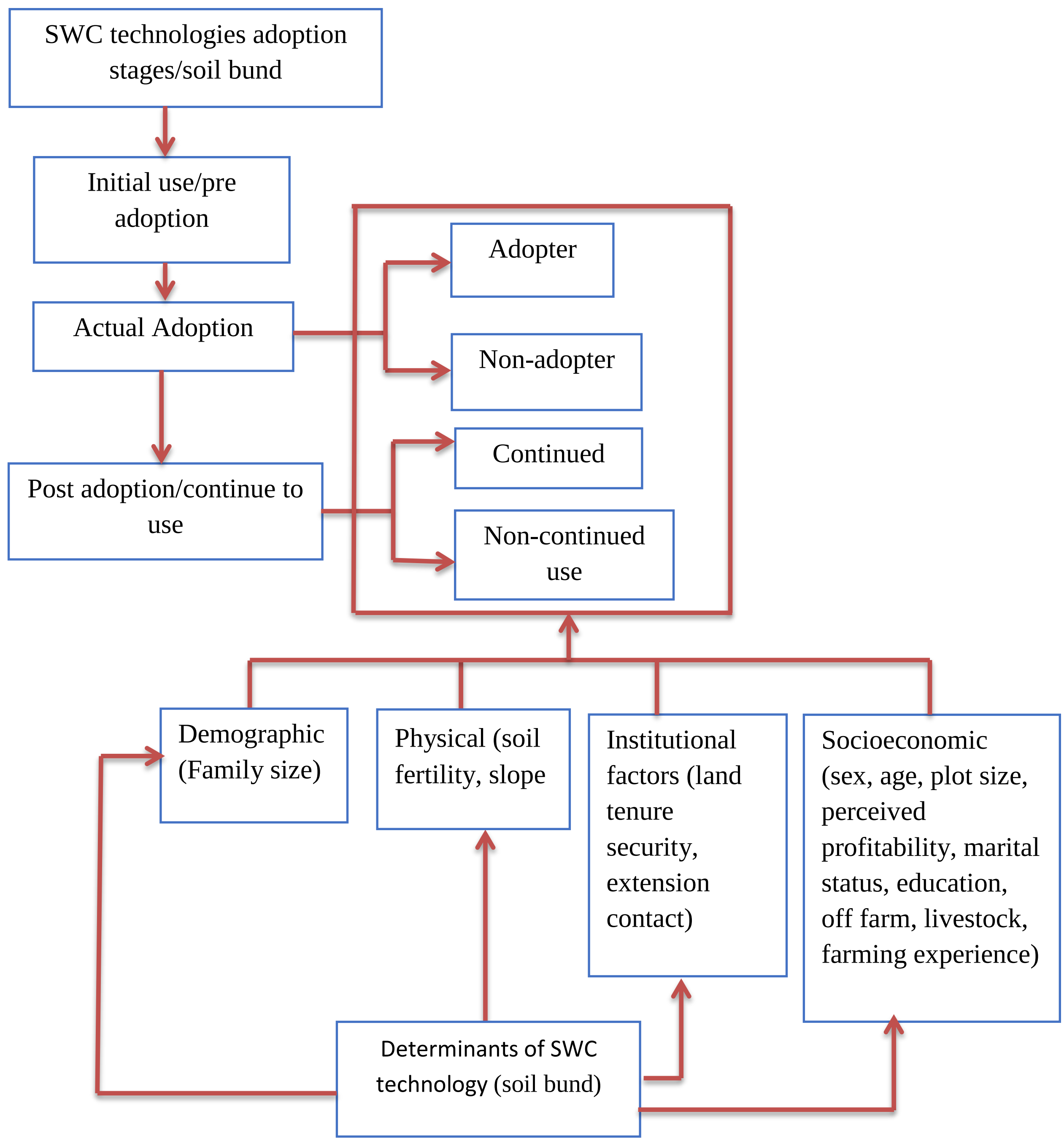

Figure 9: Conceptual framework of adoption and sustainable use of soil bund

3.2.2. Empirical Analysis and Variables

In the present study, the dependent variable for the selection equation is whether a farmer household adoption or not to soil bund measure. The dependent variable for the outcome equation is whether a farmer has sustainable use or not to SWC technology (user's decision behavior). These dependent variables are binomial variables captivating a discreet value adoption (1=adoption, 0=non-adoption) and (1=sustainable use, 0=non-sustainable use). A soil bund is a physical soil conservation and water harvesting structure built by farmers. The structure's design is 0.5m in height and 25cm in depth on average by digging a trench forming embankments or ridges (Mekuriaw et al., 2018).

In this study, Non-adopter/dis-adopters were abandoned the SWC measures/soil bund and/or never used soil bund on their plots. Actual adopters, whereby efforts or investments (in capital and labor) are made to implement SWC measures/soil bund on more than a trial basis established the initial SWC measures. Whereas post-adopter/ continued use, where existing SWC measures/soil bunds are used more than three subsequent years by maintaining and expanding new ones in other fields on their motivation (Amsalu & Graaff, 2006; Teshome et al., 2016).

Based on the different kinds of literature (Amsalu & Graaff, 2006; Teshome et al., 2012; de Graaff et al., 2008) and econometrics theory, the adoption status of farmers on soil and water conservation measures may depend on socioeconomic, demographic, physical, and institutional variables.

3.3. Results and Discussion

3.3.1. Socioeconomic Characteristics of Respondents

It was hypothesized that the adoption and sustainability of SWC measures were influenced by the demographic and socioeconomic characteristics of the survivors, which were included in Heckman selection models. Descriptive statics analysis shows sample households predominantly occur in the second stage rather than post- adoption. In the sample of households, 69.12 percent were actual adopters, while 26.2 percent were sustained users. Most adopters have implemented SWC measures, specifically soil bund measures, within a few years. Nevertheless, few of them have continued using soil bund measures over the last three years. As a result, 62.2% of the farmers failed to maintain or rapier soil bund conservation measures in their plots for the past years (Table 11).

92.76 percent and 88.51 percent of the 340 households surveyed were males and married continuing and non- continued users. The mean age of household for adopters and sustained users were 47.19 and 46.81 years, respectively. Family size was one of the most important factors influencing the sustainability of soil bund measures. A farmer's decision to adopt SLM practices is supposed to be influenced by the availability of labor in this family. Families with large households could provide the extra labor for adoption and continued use of SWC activities. A family size of 5 for the adopters and a family size of 6 for the sustained users was found in this study.

Table 11: Description of dependent and explanatory variables

Dependent variable	Description	Farmers' adoption status of soil bund							
		Adopt (%)		Non-adopt (%)		Sustainable (%)		Non-sustainable (%)	
Adoption of soil bund	Adoption of soil bund (dummy: takes the value of 1 if adopted and 0 otherwise)	69.1		30.9		26.2		42.9	
Explanatory variables	Description	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
SEX	Sex of respondent	0.051	0.221	0.124	0.331	0.067	0.252	0.076	0.266
AGE	Age of farmers (year) (Continues)	47.191	5.367	45.971	7.485	46.809	5.498	46.82	6.342
MARTSTAT	Marital status of respondents	0.221	0.729	0.238	0.802	0.213	0.715	0.232	0.767
EDUC	HH head educational status (dummay:1 = if illiterate, 0 = otherwise	1.647	1.392	1.781	1.359	1.921	1.772	1.6	1.206
FAMSIZE	HH Family size (N) (continues)	5	2.861	4	2.109	6	3.345	4	2.11
FARMSIZE	size of Farm (ha) (continues)	0.459	0.962	0.829	1.22	0.202	0.568	0.704	1.162
FARMEXP	HH head farming experience (in year) (continues)	21.995	6.393	17.133	7.56	21.652	6.129	20.084	7.433
PERPROF	Perceived profitability of technology (dummy; 1= if perceived profitability, 0= otherwise)	0.472	0.5	0.229	0.422	0.494	0.503	0.364	0.482
EXTCONT	Frequency of extension agents' Contacts (per month)	3.996	1.958	3.495	1.557	5.1	2.301	3.432	1.472
GENTSLOP	Gentle slope (1), not gentle (0)	0.417	0.494	0.457	0.5	0.393	0.491	0.44	0.497
MODERSTEP	Moderate steep slope (1), not moderate steep slope (0)	0.434	0.497	0.419	0.496	0.427	0.497	0.432	0.496
STEEPSLOP	Very steep slope (1), not steep (0)	0.523	0.5	0.343	0.477	0.5393	0.501	0.44	0.497
LOWFERT	Low fertility (1 if soil fertility is low, 0 otherwise)	0.468	0.5	0.571	0.497	0.405	0.494	0.536	0.499
MODFERT	Moderate fertility (1 if soil fertility is moderate, 0 otherwise)	0.319	0.467	0.219	0.416	0.326	0.471	0.272	0.446
HIGHFERT	High fertility (1 if soil fertility is high, 0 otherwise)	0.247	0.432	0.362	0.483	0.247	0.434	0.296	0.457
PLODIST	Mean Distance of farm plot from homestead (in a walking hours) (continues)	0.596	0.898	0.724	0.956	0.225	0.559	0.784	0.974
OFFFARM	Off-farm practice: yes (1), No (0)	0.043	0.202	0.619	0.488	0.043	0.208	0.28	0.449
LANDTUN	Land tenure security: yes (1), no (0)	0.817	0.388	0.019	0.137	0.989	0.106	0.424	0.495
LIVESTOC	Livestock Holding (in TLU) (continues)	8.179	3.457	8.114	3.614	7.978	3.141	8.2	3.613

The results also revealed that the average farmland size was 0.46 and 0.2 ha for adopters and sustained users, respectively. This implies that non-adopters and non-continued users have a larger farm land size than adopters and continued users. A typical farmer contacts an extension agent 3.99 (adopters) or 5.1 (sustained users) times per two months, which is a relatively high frequency compared to non-adopters or non-sustained users. This situation is the dominant feature for most parts of the country, which is supported by several studies: (Amsalu & Graaff, 2006; Sileshi et al., 2019).

In this study, farm plot characteristics are also considered; for instance, a farm plot distance has a significant implication for SWC practices. Those who lived close to their plots had the advantage of time and energy savings and were motivated to continue soil bund practices. For instance, sustained users took 13.5 minutes to reach their farming plots, while non-sustained users took 47.04 minutes. Most of the participants in the SWC practice earned money through livestock agriculture. According to the sampled households, the average number of livestock owned by adopters and sustainers was 8.18 TLUs and 7.98 TLUs, respectively. Tenure security influences land users' tendency and willingness to invest in SWC. In this study, the average adopters (0.82) and sustained users (0.99) of soil bund feel more tenure security than this non adopters (0.02) and non-continued users (0.42). Therefore, household investments or maintenance of soil and water conservation measures are more likely.

3.3.2. Dominant types of SWC Measures in the Handosha Watershed

Numerous farmers accepted and practiced some of the SWC structures due to incentives from NGOs, the perceived profitability of SWC activities, and pressure from government bodies. In the Handosha watershed, about 95.5% of the respondents used at least one SWC measure in their plots. The key SWC measures implemented in the study area include soil bunds, stone bunds, check-dams, fanyajuu, mulching and crop residues, and other mechanical and biological conservation measures. Most adopters widely practiced soil bunds (49.42%), followed by stone bunds (15.9%), fanyajuu (10%), mulching and crop residues (9.12%), and check-dams (5.59%). Others, such as area closure, deep trenching, and terracing, are implemented only in about 5.56 percent of the sampled households (Table 12 and Figure 10).

Table 12: Dominant types of SWC measures in the study area

SWC Types	Number	Percent
Soil bund	168	49.42
Stone bund	54	15.9
Check-dam	19	5.59
Fanyajuu	34	10
Mulching and crop residues	31	9.12
Other	19	5.56
Not implemented	15	4.41

Most farmers (69.1%) adopted a single conservation measure (soil bund) in one of their plots. The rest respondents used two or three SWC measures in their plots. This indicated that the respondents in the study area adopted improved SWC measures simultaneously. During FGD, they said that, due to the slope gradient and soil type and extension agents' recommendations, they were enforced and preferred to use soil bunds dominantly. Furthermore, the limited availability of rocks, limits the construction of stone bunds, resulting in this watershed's the extensively implemented was soil bund (Figure 10).

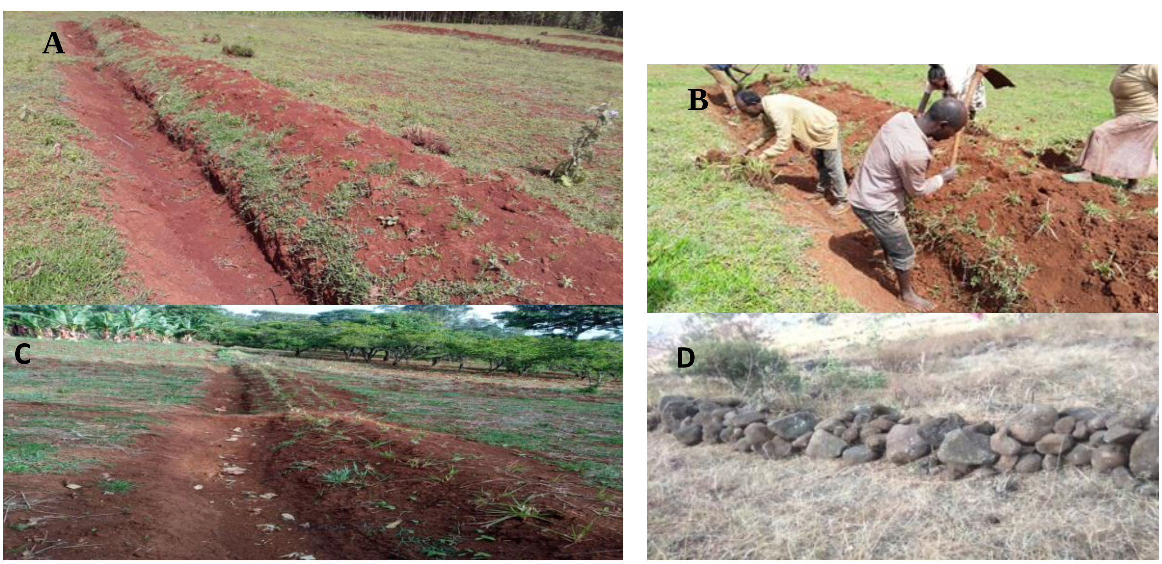

Figure 10: Soil bund structure in Handosha watershed

(A) soil bund on grazing land (B) soil bund construction by farmers (C) soil bund on farm land (D) stone bund structure: photo by researcher (2020)

3.3.3. Determinates for Adoption of Soil Bund

Farmers must decide how much effort they will put into implementing SWC measures once they accept them (Hurni & Zeleke, 2018). The Heckman sample selection model used a probit maximum likelihood estimation method as a first step. This was to identify factors influencing household adoption decisions. Several variables may influence households' technology adoption decisions. The sample selection model revealed that five of the 14 explanatory variables included in the model, namely farm experience, off-farm activities, farm size, land tenure, and perceived profit of soil bunds, significantly affected users' decisions to adopt in both a positive and negative way. According to the results of the selection model analysis of factors affecting the adoption of soil bund measures, farm experience, land tenure security, and perceived profitability are positively correlated. Farm size and off-farm activities affected soil bund adoption negatively (Table 13).

As hypothesized, farming experience on adoption is positive in the Handosha watershed. It indicates that the likelihood of adopting conservation practices is more farming experienced than few experiences. This is due to their long life of farming experience, which helps farmers change their perceptions about soil erosion impacts and understand the importance of SWC practices.

In the actual SWC adoption, farmland size has a negative and significant effect. Based on the results, an increase in cultivated land would increase the probability of adopting SWC measures by 43.8%. This is due to the potential increment of land size that may have been affected by land fragmentation and need intensive labor for conservation activities due to shortage labor, which is a limitation for the adoption of SWC for extensive holdings. It is consistent with the findings of (Teshome et al., 2012; Sileshi et al., 2019) and contrary to the results of (Amsalu & Graaff, 2006; Asfaw & Neka, 2017) that showed a positive relationship between farm size and soil bund adoption. In contrast, (F. Mengistu & Assefa, 2019) found that farm land size positively affected SWC measures adoption.

In the final adoption, farmers' perceptions of the profitability of SWC structures play a positive role. The result indicates that farmers who perceive SWC measures as profitable are 76.8% more likely to adopt soil bund measures. This is due to the farmers' perceived that implementing soil bund conservation technologies have profit increased productivity and encourage the adoption of soil bund measure in their farm plots. This result also aligns with (Amsalu & Graaff, 2006; Teshome et al., 2016). The effect of off-farm activities on the adoption of soil bunds is found to be significantly negative. This means most farmers are attracted by short-term labor market income from nearer towns and leave SWC activities due to time shortage. This finding is consistent with the findings of (Asfaw & Neka, 2017; Mengistu & Assefa, 2019), which found that farmers who practiced off-farm activities could not spend time on maintaining and modifying SWC measures. This finding is entirely against the finding of (Tiwari et al., 2008; Demelash & Stahr, 2010), which stated that off-farm income served as a source of cash to invest in SWC practices and support SWC technology adoption.

Land tenure security is a vital socioeconomic influence affecting farmers' decisions to adopt SWC practices. Tenure security is positively and strongly significant related to the actual adoption phase of soil bunds. The result shows that tenure security significantly increases the likelihood of actual adoption of soil bunds by 49.8%. This finding is consistent with the findings of (Teshome et al., 2016; Mengistu & Assefa, 2019) that they have concluded that as secure land tenure is an encouragement factor to adopt conservation technologies. On the contrary (Mekuriaw et al., 2018; Amsalu & Graaff, 2006) concluded that land tenure security was not an influencing factor for the adoption of SWC measures.

3.3.4. Determinates for Sustainable use of Soil Bund

In this study a sample selection problem was justifying using Heckman probit models with a value of *rho* significantly different from zero (Wald $x^2 = 169.81$, with $p<0.001$). As a result of this method, we can conclude that the covariate used in the regression model is appropriate and shows explanatory solid power. Table 13 shows that the fitted model is appropriate as indicated by the overall Wald chi^{2,} which is highly significant at $p<0.001$; this finding is consistent with that of (Heckman, 1976; Deressa et al., 2011).

In the probit estimates, the Inverse Mill's Ratio (Lambda) was calculated and included in the second stage of the selection model for analyzing the factors affecting the sustainability use of soil bund measure. Out of the variables entered into the model (12), 5 of them, namely family size, farm size, off-farm activity, land plot distance, land tenure security, and extension contact, were found to affect the sustainability of soil bund technology use significantly (Table 13). The results from the outcome model, which analyzes the factors affecting the continued use of soil bund measures, indicated that most of the explanatory variables affected the probability of sustainability. Variables that positively influenced the sustainable use of soil bund measures include family size, land tenure security, and frequency of extension contact. However, farm size and distance between farm plots were negatively related to sustainability.

This study indicates that family size had a positive and significant effect on SWC decision. This implies households with large family sizes are likely to continue using soil bund technology in either of their plots. In the Handosha water shade, households' family size increase by one; this increases the probability of continued SWC use by 5.7%. Due to quickly access of family members, labor would help more practicing conservation activities. A similar result also in Peru indicates that more labor is applied when the family is more prominent and thus, more family labor is available (Posthumus, 2005) but contrary to the results of (Amsalu & Graaff, 2006), which stated that labor is diverted away from conservation activities due to households keeping more livestock considerably involved in dung cake making and marketing.

The effect of farm size is found to be negative and significant on the continued use of SWC. The result indicates that a unit increase in cultivated land would increase the probability of sustaining the use of SWC measure decreased by 6.7%. This implies that sustainable use of the soil bund is likely to be lower with an increase in farm size due to a shortage of labor to cover the large farm size. Similarly, (Amsalu & Graaff, 2006; Asfaw & Neka, 2017) reported a negative relationship between farm size and the probability of continued soil bund practices due to lack of labor. A farm plot distance from a farmer's home significantly negatively affected soil bund sustainability measures. It indicates that a unit increase in the distance would make the probability of farmers continuing the use of soil bund measure decrease by 10.8%. Farmers whose plots were far from their homes didn't continue the use of soil bund measures due to time spent on travel than nearer plots, which is similar to the study (Tizale, 2007).

Table 13: Results of Heckman probit selection model

Explanatory variables	Adoption			Sustainability		
	Coefficients	**Std. err**	**z**	**Coefficients**	**Std. err**	**z**
SEX	-0.629	0.95	-0.66	0.089	0.109	0.81
MARTSTAT	-.053	0.342	-0.15	0.000	0.035	0.01
EDUCSTAT	0.123	0.131	0.94	0.026	0.018	1.48
FAMSIZE	-0.045	0.074	-0.61	0.057***	0.008	6.62
FARMEXP	0.053**	0.022	2.37	-0.002	0.004	-0.47
LOWFERT	-0.693	0.416	-1.67	-	-	-
HIGHFERT	-0.355	0.385	-0.92	-	-	-
GENSLOP	-	-	-	-0.093	0.049	-1.89
STEPSLOP	0.544	0.327	1.66	-	-	-
FARMSIZE	-0.438**	0.154	-2.85	-0.067**	0.028	-2.38
DISTANCE	-	-	-	-0.108***	0.03	-3.53
OFFFARM	-2.627***	0.46	-5.71	0.041	0.131	0.31
LIVESTOC	0.036	0.041	0.86	0.000	0.006	0.09
LANDTENU	3.411***	0.498	6.85	0.271**	0.112	2.43
PERPROF	0.768**	0.331	2.32	-	-	1.79
EXTCONT	-0.015	0.093	-0.16	0.091***	0.012	7.51
CONSTANT	-0.941	0.913	-1.03	-0.406	0.181	-2.24
Lambda	0.019	0.17				
Number of observation	340					
Censored observations	105					
Uncensored observations	235					
Wald ch^2	169.81 (p<0.001)					

***, ** and * indicate significance levels at 1%, 5% and 10%, respectively. Rho = 0.053, sigma = 0.355

Land tenure security is one of the most significant socioeconomic factors that affect farmers' decisions to continue soil and water conservation practices. Tenure security positively and significantly influences the sustainable use of soil bunds. The result indicates that tenure security significantly increases the likelihood of continued use of soil bunds by 27.1%. Farmers who cultivate their farmland are relatively more secure and willing to invest their labor and time in soil bund conservation measures on their farm lands. In the other case, during focus group discussion, farmers raised/said a significant number of households are migrating from rural to urban areas. As a result, they rented their land to other farmers, who only focused on the temporary productivity of the land rather than its sustainability and therefore did not maintain or modify soil bund measures.

In this study, the frequency of extension contact with farmers significantly positively affects the continued use of soil bund practices by 9.1%. This implies that farmers with access to extension services and information have a good awareness of soil erosion and conservation measures; as a result, they have the motivation to use soil bund measures either maintaining or modifying for an extended period. This finding is consistent with (Asfaw & Neka, 2017), which stated that as extension workers support farmers, the probability of using SWC technology sustainably through maintaining or modifying the technology increases. The Heckman selection model estimation also shows that sex, marital status, educational status, low fertility, high fertility, gentle slope, steep slope, and livestock show no significant effect on the adoption and sustainable use of soil bunds.

As shown in figure 11, soil bund measures were destroyed by run off and lack of treatment by land users around grazing land and on the farm plot. As a result of the aforementioned factors, soil bund technology practices failed to be sustainable in the watershed.

Figure 11; Failed soil bund structure filled by soil sediment

(A) and distracted soil bund structure filled by run-off (B) in the Handosha watershed. Photo by researcher

According to key informants, especially SLM experts, the absence of law enforcement after applying soil bund technology to their plots was another substantial factor hindering farmers' adoption of soil bund remedies. Due to this, most farmers eventually lost their SWC measures. Remittances are also a significant factor in the area's sustainable use of soil bund measures. Most rural households send one or more family members to South Africa and the Middle East. So, most young household members are waiting for remittances from their families rather than performing SWC activities or supporting their families in their daily lives. As a result, there is a labor shortage on their plots for the continued practice of bund measures.

3.4. Conclusion and Policy Implication

This study investigated factors affecting farmers' decisions related to adopting and sustainable use of soil bunds. Specifically, this study evaluated the socioeconomic and physical factors affecting households' decisions on the sustainability of SWC measures using the Heckman selection model.

In the Handosha watershed, there are a variety of influences that affect the use of soil bunds and their adoption. The study found nearly half of the socioeconomic and physical factors affected soil bund adoption and sustainability. Perceived profitability, land tenure security, and farm experience significantly influence soil bund adoption. However, farm size and participation in off –farm activities negatively contributed to soil bunds. Farmers' decisions to continue to use soil bund measures were much more strongly influenced by the frequency of extension contacts. They were also influenced by the size of farm plots, perceived land tenure security, and distance between the plot and their homes. Based on the Heckman selection model, analysis, access to extension services, and family size played a significant role in explaining the sustainability of soil bund technology practices. Land tenure security also significantly affects farmers' decisions on SWC measures. Conversely, farmers' decisions regarding the sustainability of soil bunding are negatively affected by the distance between farm plots and their homes and farm size. Generally, SWC measures are unlikely to be sustainable due to farmers' passive and forced participation in conservation activities. In addition, they require labor-intensive conservation methods.

Accordingly, this study recommends planning SWC measures based on local farmers' involvement and self-motivation for long-term soil and water conservation. To enhance the sustainability of SWC measures, policy makers and development workers must consider plot-level physical environments. They must also implement practices based on land users' interests. Based on this finding, appropriate policies and procedures need to be designed and implemented. Our findings suggest strengthening institutional and human capacity should be the focus of efforts to address soil erosion through SWC technologies. To control soil degradation and enhance farm productivity, farmers need to be educated and trained, and awareness should be created about soil erosion. Furthermore, national and local governments should establish post-adoption regulations on using SWC practices.

Chapter Four: Evaluation of Land Degradation Neutrality for Sustainable Development in the Omo-Gibe River Basin, Southwest Ethiopia

Abstract: The sustainable development goals, most notably indicator 15.3.1, call for strengthening national capacities to perform quantitative assessments and map degraded lands to stop and reverse current trends in land degradation. This study examined the status of land degradation neutrality achievements in the Omo-Gibe River basin, Ethiopia, based on changes in three indicators: land cover, land productivity, and soil organic carbon, between 2000 and 2020. As a result, settlements (11.44%) and farmland (9.58%) significantly increased, while bushland (8.09%) and wetlands (5.29%) decreased over 20 years. A major decline in land productivity has been observed due to adverse changes in Land Cover (LC) and losses in Soil Organic Carbon (SOC). The proportion of degraded land was 65.05% of 79000 km ^{2} *of the basin. However, a small part of the basin has improved or recovery of land. Therefore, spatial planning should focus on hotspot areas and implement locally based sustainable land management practices to reach land degradation neutrality by 2030 at national and subnational levels.*

Key word: *Land Cover, LDN, Land Productivity, SDG, Soil Organic Carbon*

4.1. Introduction

Land degradation, or the deterioration of land quality as a result of human activities, is a major global issue and will continue to be a high priority on the international agenda due to its impact on land productivity, the environment, food security, and quality of life (Eswaran et al., 2001; UN, 2022). The global extent of land degradation is estimated at between 20-40% of the total land area, directly affecting nearly half of the world's population, and affects 52 percent of agricultural land, 40% of the landmass, and 44% of food production (UNCCD, 2014; UN, 2022). In 2025, land degradation would lower global food output by 12%, resulting in a 30% increase in global food prices (FAO, 2017). Land degradation impacts up to two-thirds of Africa's productive land area (UN, 2013; Jones et al., 2013), and affects at least 65% of the continent's total population (ECA, 2007).

In Ethiopia, natural resources have been degraded for centuries (Hurni et al., 2010). A study by Gebreselassie et al. (2016) shows that 23 percent of the land area of Ethiopia is affected by land degradation. The country suffers from severe soil erosion caused by water and land degradation, especially in the highlands. In these areas, the landscape is exceptionally vulnerable to land degradation; there is tremendous population pressure, farmed steep areas, and rainfall is erosive (Bewket & Teferi, 2009). In the highlands, depending on land use, climatic and topographic characteristics, annual soil loss by water ranges from 16 to 300 tons per year (Tesfaye et al., 2014; Nkonya et al., 2015). Consequently, the Omo-Gibe basin loses 89.6 Mt of soil each year, with an estimated soil loss ranging from 0-279 tons per year (Girma & Gebre, 2020).

In the last few years, various governmental and nongovernmental organizations have promoted sustainable land management as a means of shifting from degrading to more sustainable uses and restoration of land (van Haren et al., 2019). As a result, the notion of land degradation neutrality (LDN) has been developed as a necessity for better considering the effects of land degradation and a politically driven approach and urgent action to solving land degradation (Okpara et al., 2018), and it is a novel approach to addressing the issue of land degradation (Cowie et al., 2018). Lately, the United Nations Convention to Combat Desertification (UNCCD) secretariat devised the concept of LDN in New York on September 20, 2011, which is a part of the Sustainable Development Goals (Gnacadja and Wiese, 2017) "strive to achieve a land-degradation-neutral world in the context of sustainable development" at the Rio+20 conference in 2012 (UN, 2013). LDN's overall goals are to repair more land than has been degraded and to increase land resource productivity (Gnacadja, 2015).

Various countries have found specific potential to scale up existing programs or build new LDN implementation projects by mapping active LDN-related initiatives at the country level (UNCCD, 2019). Multi-stakeholder engagement is essential for supporting sustainable land management practices, which is why LDN implementation calls for a participatory approach (Ştefãnescu & Ciuvăț, 2018). The idea of LDN is receiving much interest since it can address land degradation. As a result, Ethiopia has adopted this strategy for sustainably reversing land degradation (FDRE, 2015).

Numerous studies have evaluated the incidence of soil erosion, LD, and its affecting variables on national and subnational levels; however, most have focused on the drivers and effects of soil erosion (Hurni et al., 2010; Sonneveld et al., 2011; Gashaw et al., 2014) and there is little comprehensive quantification and potential risk of degradation. In this framework, three biophysical indicators: land cover (LC), land productivity dynamics (LPD), and soil organic carbon (SOC) dynamics, were used to determine the state of land degradation. For this, the "one out, all-out" (1OAO) principle from the United Nations Convention to Combat Desertification (UNCCD) suggested approach for LD evaluation was applied (Sims et al., 2021). This notion has been acknowledged and put into practice in several nations' national and regional land degradation assessments (Arroyo & Cervantes, 2022).

The LDN concept has been extensively researched since 2015 (Arroyo & Cervantes, 2022); the studies focused on applying the methodology at the national level (Stavi & Lal, 2015; Kust et al., 2017). Some of the results indicated that globally, the area of restored land was generally more extensive than that of degraded land (Guo & Gifford, 2002). In Ethiopia, the results show that agricultural land degradation increased within the study period (2003-2016) (Tilahun, 2020). Ethiopia’s current LDN national report follows UNCCD guidelines and the default dataset, assessed for the first 15 years (FDRE, 2015). According to our review, there are few published studies at the national and subnational level, and only Crossland et al. (2018) studied the local perception of LDN in the Gilgel-Abay watershed and the economics of LDN in Ethiopia (Tilahun, 2020).

The primary purpose of this study was to apply the LDN approach at the subnational level to determine the state and trends of land degradation in the Omo-Gibe River Basin, Ethiopia, from 2000-2020 based on the LDN framework analysis of positive and negative trends and modifications in the three indicators assessed over 20 years.

The relevance of this study is that it utilizes a methodology as a benchmark at the national and subnational levels, which forms the basis for efforts and public policies aimed at conserving, recovering, and restoring natural resources. This research provided an early indication of whether LDN would be reached by the deadline and, if not, what steps would be needed to remedy them. It also provided a valuable platform for the scientific analysis of the dynamics of land degradation at the subnational level to develop appropriate management practices for regenerating and rebuilding the study basin.

4.2. Materials and Methods

4.2.2. Methods

LDN indicators and related measures, such as land cover, land productivity, and carbon stock, were used to analyze and track the performance of land management operations in the research area (UNCCD, 2013). For various types of evaluations and other monitoring initiatives of land degradation, remote sensing has emerged as one of the most crucial techniques for LDN assessment (Aynekulu et al., 2017).

4.2.3. Data Source and Data Acquisition

Ethiopia's subnational land use/cover categories were obtained from European Space Agency’s Climate Change Initiative Land Cover (ESACCI-LC)(2000 & 2020). This study classified the multi-temporal land cover map based on the the ESA-CCI-LC dataset (Sims et al., 2019).

Earth’s observations of Annual Net Primary Productivity (ANPP) changes determine land productivity between years (Sims et al., 2021). This study used MODIS NDVI data products, averaged at 250 m pixel resolution, integrated over each calendar year from 2000-2020.

The International Soil Reference and Information Center's (ISRIC) ‘Soil Grids 250 m' dataset, which provides information on SOC concentration and depth in the upper 30 cm of the soil profile globally at 250 m spatial resolution, can be used to calculate a predicted SOC stock (Hengl et al., 2017). For this study, the mean SOC data for 2020 were obtained from ISRIC Soil Grids 250 m, Food and Agricultural Organization (FAO).

The ArcGIS 10.4.1 programs were used to process the data (geometric correction, radiometric calibration, atmospheric correction, mosaicking, and cropping before classification) and to determine the status and trend of the indicators.

4.2.4. Analysis of Land Cover (LC) Change (2000-2020)

Land cover data are crucial to estimate SDG indicators for goal 15, ‘Life on land’ since high-resolution land cover data with the up-to-date spatial and temporal resolution are crucial (Kussul et al., 2020). The LC was classified into nine land use categories supported by the LDN framework (Orr et al., 2017). Based on Anderson et al. (1976), the Omo-Gibe Basin's land use/land cover classification system is as in (Table 14). To examine land cover changes from 2000 to 2020, images were taken in January and February. A comparison of the old map with the current map was utilized to identify changes.

Table 14: Land Cover classification of the Omo-Gibe Basin

No.	Land cover class	Descriptions
1	Woodland	Land covered with relatively tall trees, at least have 20% canopy coverage, including integral open space and felled areas that are awaiting restocking.
2	Grassland	Small grasses are the predominant natural vegetation. It also includes land with scattered or patches of trees, and this land cover is used for grazing and browsing.
3	Shrub land	Land covered by small trees, bushes, and shrubs, and in some cases, such lands are mixed with grasses; It is less dense than the woodland.
4	Forest	a tree-crown areal density is stocked with trees capable of producing timber or other wood product and exert an influence on the climate or water regime.
5	Agricultural land	Areas allotted to extended rain-fed crop production and pastoral land
6	Settlement area	land covered by structures, which included towns and rural villages
7	Marshland	is dominated by herbaceous rather than woody plant species
8	River/water bodies	Lakes, rivers, and streams
9	Bare land	Land, which is mainly covered by bare soil and rock outcrops

Transitions from one land cover category to another throughout the research period were used to determine if a change was positive or negative. Then, it is computed that the land cover change enters a transition matrix that indicates whether transitions represent deterioration, stability, or improvement (Orr et al., 2017). ArcGIS 10.4.1 and ERDAS IMAGINE software were used for Land Use Land Cover (LULC) analysis and the creation of land use and land cover maps.

4.2.5. Determination of Land Productivity Dynamics (2000-2020)

Earth's observations of Annual Net Primary Productivity (ANPP) changes determine land productivity between years (Sims et al., 2021). The NDVI was determined by the arithmetic mean of the Omo-Gibe River basin in each year (2000-2021). Thus NDVI is calculated:

$$NDVI = \frac{NIR - Red}{NIR + Red} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (13)$$

Where: NDVI = normalized difference vegetation index, NIR = reflection from near-infrared wavelength region, RED = reflection from red wavelength region.

The index values range from -1 to +1 and are unit-less. Accordingly, a negative value of NDVI (value approaching -1) corresponding to water, low NDVI values (-0.1 to 0.1) are associated with arid areas of rock, sand, or snow, while intermediate values (0.2 to 0.3) represent shrub, woodland and grassland, and high values denote tropical and temperate rainforest (0.6 to 0.8) (Baskan et al., 2017). Then, the land productivity sub-indicator generated 5-qualitative classes of land productivity dynamics during the available time window from 2000 to 2020 (declining trend, early/moderate sign of decline, stable but stressed, stable not stressed, and increasing trend) (Ivits & Cherlet, 2013), to inform the type of degradation occurring in the study area. These qualitative classes do not directly correspond to quantitative measures of loss or gain biomass productivity; relatively, they measure the intensity and persistence of negative or positive trends and changes in vegetation cover over the observed period (UNCCD, 2018).

4.2.6. Soil Organic Carbon Stock (for 2020)

Soil organic carbon plays a vital role in the global carbon cycle (Sundarapandian & Subbiah, 2015). Predicted SOC stock can be determined using the "Soil Grids 250 m" dataset from the International Soil Reference and Information Center (ISRIC), depth in the top 30 cm of the soil profile globally at 250 m spatial resolution (Hengl et al., 2017). The SOC stock trend was determined by the arithmetic mean of the 2020 period of the study. The SOC of the study area in 2020 was estimated using the carbon conservation coefficients associated with LC transitions. Based on SOCs calculated per pixel in 2020, degradation in SOCs is defined as a loss, greater than 10% of the 2020 stock values (Sims et al., 2019).

4.2.7. State of Land Degradation (one out all out principles)

In this study, land degradation was analyzed using land degradation neutrality evaluation framework (Figure 12) to determine which regions have experienced degradation, have the possibility of restoration, and should receive priority for land conservation measures (Sims et al., 2021). The extent of deterioration observed in each of the goal periods (2020) is compared to the beginning period (2000); to determine whether this region is increasing or decreasing over time (Sims et al., 2021). For interpretation, the integration of results of the three global indicators should be based on a "one-out, all-out" approach where if any of the three indicators show a significant adverse change, it is considered a loss (and conversely, if at least one indicator shows a significant positive change and none shows a significant adverse change, it is considered again) (Borja et al., 2014) and neutrality is achieved when the area of losses equals the area of gains, across land use types. Finally, these indicators are integrated to establish the LDN baseline in the Omo-Gibe basin from 2000-2020 (Figure 12).

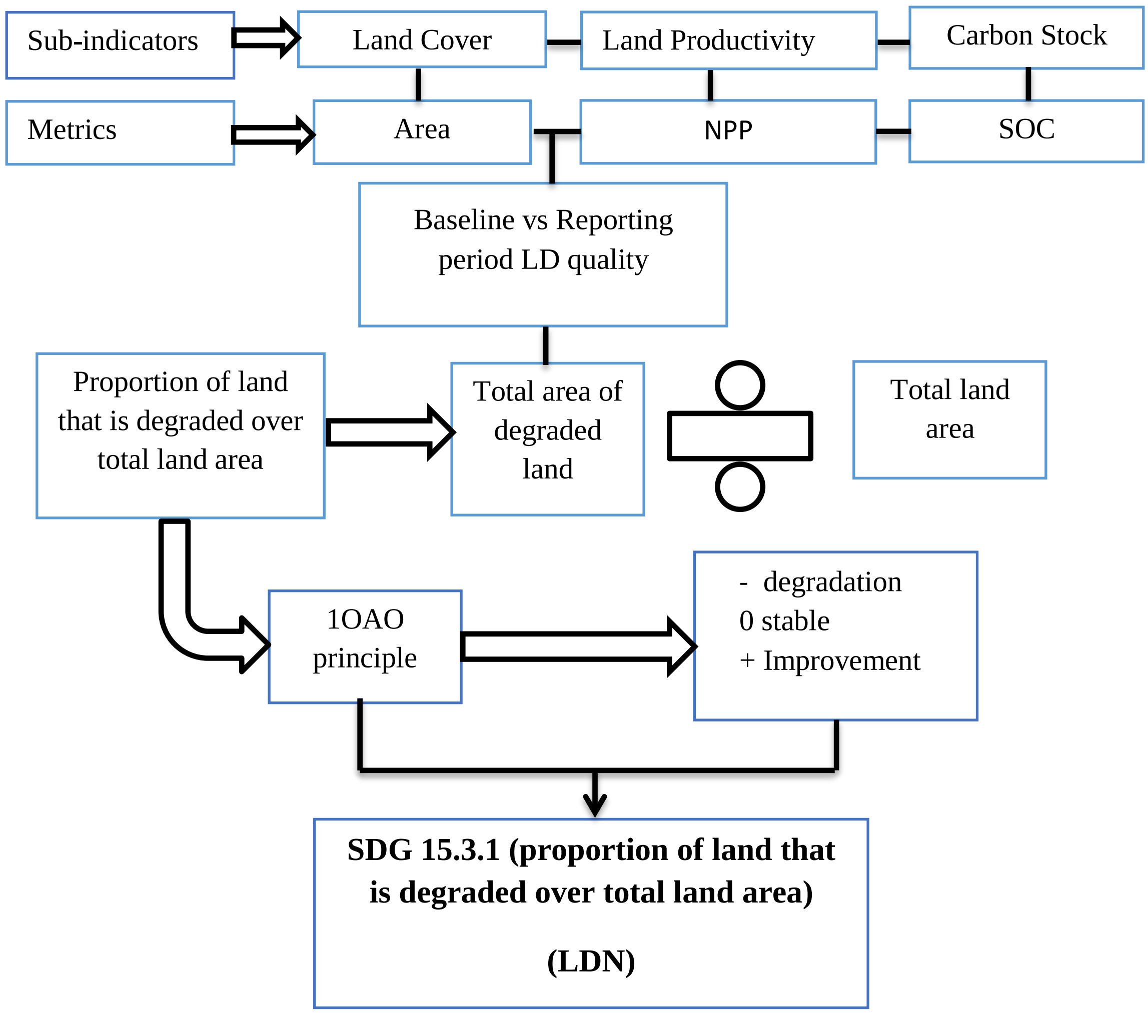

Figure 12: Land degradation neutrality framework of the Omo-Gibe River Basin,

4.3. Results and Discussion

The SDG 15.3.1 indicator was evaluated using standard employing three sub-indicators: LC transitions, LP decrease, and SOC loss.

4.3.1. Land Cover and Degradation Analysis

In 2000, the farmland category had a slight difference with settlement areas (0.79%); however, by 2020, settlement areas had increased their difference with farmland, which categorized the most prominent surface area coverage in the basin (11.44%). The results indicated that the settlement, farmland, and bare land areas represented net increases of 9041 km^2 (11.44%), 7566.57 km^2 (9.58%), and 1971.69 km^2 (2.5%) of the total area, respectively. However, the areas under woodland, grassland, bushland, forest, wetland, and water bodies decreased by 2368.31 km^2 (3%), 1947.24 km^2 (2.45%), 6392.02 km^2 (8.09%), 1151.81 km^2 (1.42%), and 2559.58 km^2 (3.24%), respectively (Table 15).

Table 15: Land covers and land cover changes (2000-2020).

Land cover	**2000**		**2020**		**Change**	
	$(km)^2$	**%**	**$(km)^2$**	**%**	**(km^2)**	**(%)**
Woodland	11390.17	14.42	9021.86	11.42	-2368.31	-3
Grassland	3159.30	3.99	1212.0	1.54	-1947.24	-2.45
bush land	9377.52	11.87	2985.5	3.78	-6392.02	-8.09
Forest	8517.04	10.78	7395.23	9.36	-1151.81	-1.42
Farm land	11797.44	14.93	19364.01	24.52	7566.57	9.58
Settlement	11173	14.14	20214	25.57	9041	11.44
Wetland	10246	12.96	6055.70	7.67	-4190.3	-5.29
water bodies	4551.22	5.76	1991.64	2.52	-2559.58	-3.24
Bare land	8788.31	11.12	10760	13.62	1971.69	2.5

Farmland expansion in the study area increased at the expanse of natural resources (shrub land, woodland, forest, grassland, and wetlands). These results may be explained by the fact that agriculture is the main economic activity in the study area as is for the nation (Mellor & Dorosh, 2010); agricultural land area increased from 30.7% (2000) to 33.6% (2018)[1] due to population expansion and land degradation. This finding supports the findings of Dagnachew et al. (2020); Kuma et al. (2022); Ewunetu et al. (2021); Arroyo & Cervantes (2022). Settlement expansion also significantly increased within a 20-year interval, at the expense of farmland, because of population growth and government-induced settlements (Dagnachew et al., 2020). In addition, this might include the construction of a number of developmental projects along with the Omo-Gibe River.

[1] https://data.worldbank.org/indicator/AG.LND.FRST.ZS?locations=ET

Furthermore, bare land also, increased significantly, particularly in the upper and eastern parts of the basin (Figure 13).

However, significant changes occurred in bushland, wetlands, and water bodies. These decreased by 6392.02 km^2 (8.09%), 4190.3 km^2 (5.29%), and 2559.58 km^2 (3.24%) from 2000 to 2020, respectively. This implies a decline in water resources from time to time; this may be due to climate change and a reduction in the Omo-Gibe River because of cascade dams during dry seasons, creating seasonal drought for those living in the lower Omo area. Consequently, sustainable water resource conservation activities need to be implemented. Forests, woodlands, and grasslands have also shown declining, mainly due to the expansion of farming in rural areas, and the national average shows a decline in natural forests from 18.5% (2000) to 15.1% (2020)[2].

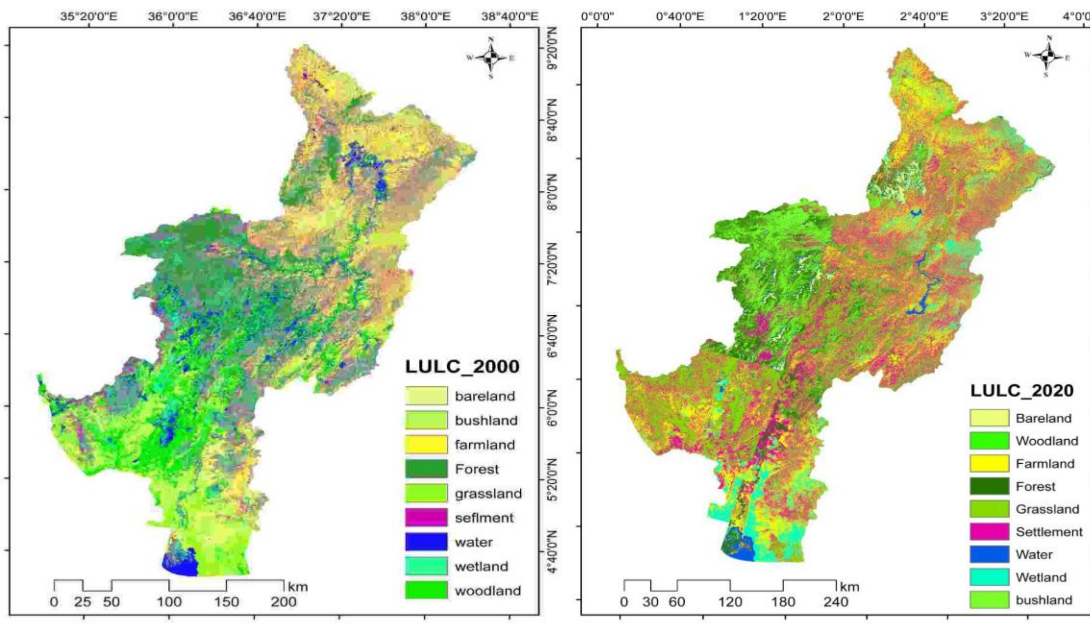

Figure 13: Spatial distribution of LC for 2000 and 2020 in the Omo-Gibe River basin.

LC maps for the Omo-gibe River basin for the years 2000, and 2020 show changes between baseline and target periods; in particular, the rose and yellow spots are potential hotspots where forests, woodlands, and grasslands become farmland and settlements. Spatially, agriculture and settlements were distributed mainly north-central with some additional areas all over the basin except for the south part; forest dominated the western

[2] https://data.worldbank.org/indicator/AG.LND.FRST.ZS?locations=ET

part of the basin with some areas in the center-west. Wetland areas naturally occur along the lower Omo River and along the basin's western and eastern extremities (Figure 13). This estimation coincides with the study of Toma et al. (2022); Dagnachew et al. (2020).

4.3.2. Detection of Land Productivity Dynamics

The LPD trends indicated a 20-year time series (2000 to 2020) of subnational NDVI observations. This study revealed that the LP sub-indicator degraded 67.27% of the area during 2000-2020 (Table 16). As a result, the LP component trend of 0.91% of the study area was declining; the remaining 31.81% and 34.55% of the study area were marked as showing "early signs of decline" and "stable but stressed" conditions, respectively (Figure 14). The study showed that green values vary inter-annually. For instance, an NDVI of 0.3-0.5 covered 14965.83 km^2 (18.94%) and 25131.72 km^2 (31.81%) of the total area in 2000 and 2020 respectively. Table 15 and Figure 14 show that from 2000-2020, the green area (or the area with increasing productivity) was 11057.58 km^2 (14%) and 9309.75 km^2 (11.79%). Over 60% of the study area was sparsely vegetated and highly susceptible to soil erosion. As of 2000 and 2020, 39.26% and 34.55% of the study basin revealed stable but stressed land productivity, respectively. The productivity of the area varies according to land cover and land use. However, the dominant label declined early and was stable but stressed throughout the observation period. Approximately, 2.21% of the study basin presented a noticeable increase in land productivity during the 2000-2020 period. The land productivity declined by 18.94% and 31.81% of the study basin in 2000 and 2020, respectively. A clear long-term land productivity decline was observed for small areas of 0.48% and 0.91% of the study area.

Table 16: Five classes of trends in land productivity (2000-2020)

NDVI	2000		2020		Change	
Description	**Area (km)^2**	**%**	**Area (km)^2**	**%**	**(km)^2**	**%**
Declining productivity	379.62	0.48	722.13	0.91	-342.51	-0.43
Early signs of decline	14965.83	18.94	25131.72	31.81	10165.89	12.87
Stable but stressed	31012.45	39.26	27295.93	34.55	-3716.52	-4.71
Stable, not stressed	21584.52	27.32	16540.47	20.94	-5044.05	-6.38
Increasing productivity	11057.58	14	9309.75	11.79	-1750.83	-2.21

As shown in Figure 14, the class declining productivity is assigned to areas with evidence of a decline in standing biomass over the 20-year observation period. It also demonstrates a current production efficiency that is below its potential. The areas in the upper and middle basin have relatively more territory under stress or display early signs of decline than other parts of the basin; where intensive agriculture exists has traditionally been a significant land use. The lower basin and Omo River valley region are where land productivity is declining.

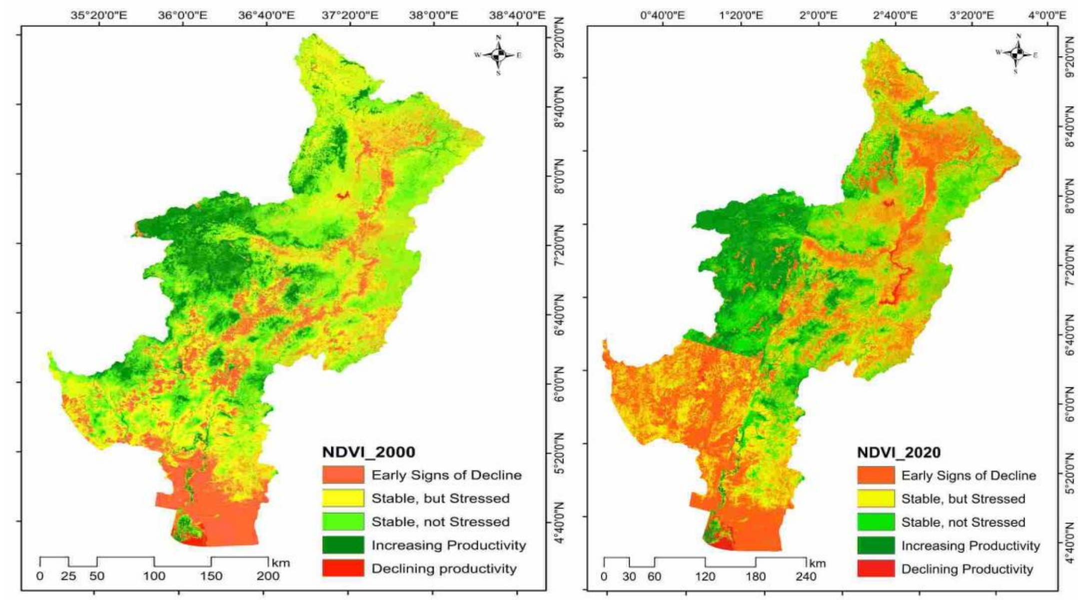

Figure 14: Land productivity dynamics calculated from 20 years of satellite-derived observations of land productivity

A decline, or its early signs, in land productivity, may be caused by droughts and floods due to Omo-Gibe cascade dams and climate change/variability. In densely populated areas, a decline in land productivity may be due to the loss of soil or productive land caused by over-cultivated and expanding infrastructure. In addition, overgrazing may cause a decline in land productivity, particularly in lower basins, where livestock is the basis for livelihood. All variations in the above-mentioned conditions were observed in the Omo-Gibe River Basin and mapped accordingly, as shown in Figure 14.

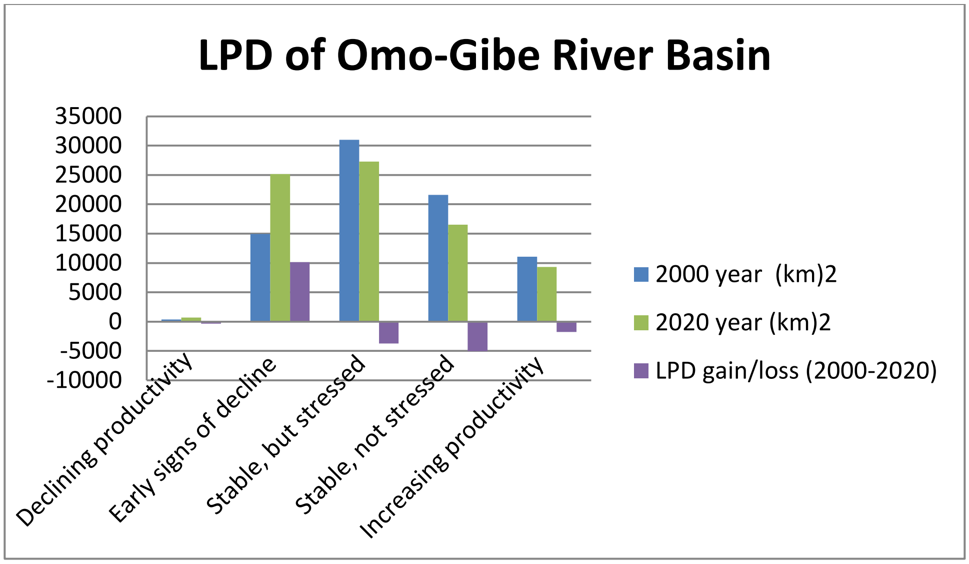

Figure 15: Total gains and losses of LPD for the Omo-Gibe River Basin from 2000 to 2020

Figure 15 shows the results of net land productivity change for 2000-2020. Generally, the declining class is concentrated mostly in the basin's northern and central arid and semiarid areas, especially the southwestern Omo Valley and the southern and southeastern parts (Figure 14). Several factors may contribute to these declines, including overgrazing, inadequate surface water during the dry season, soil erosion, and improper land management. In addition, fluvial soil concentrated erosion from upper stream, seasonal greenes (bareland during dry season), and dominant herbicious and grass vegetation type were the main factors.

4.3.3. Soil Organic Carbon Stock Status

The spatial distribution of SOC stocks shows that the highest concentrations between 78 and 140 tons per hectare were found in the forest areas (Figure 16). This zone has fertile and highly productive soils and is extensively covered by natural forest. According to Luke (2018), Ethiopia's average soil organic carbon ranges from 94 to 133 tons per hectare. In contrast, the lowest SOC concentration (less than 37 tons per hectare) coincides with cultivated land and grazing land areas, which were most prevalent in the southern and central parts of the basin (Figure 16). High SOC depilation rates were found in areas with high cultivation intensity in the central highlands and the lowland areas of semiarid climatic conditions. The lowest SOC content in cultivated soils could be due to reduced inputs of organic carbon and frequent tillage (Orgánico et al., 2011). The findings of this study are similar to those found in Van Beek et al. (2019) in the highlands of Ethiopia; and Amanuel et al. (2018) in the upper blue Nile River basin.

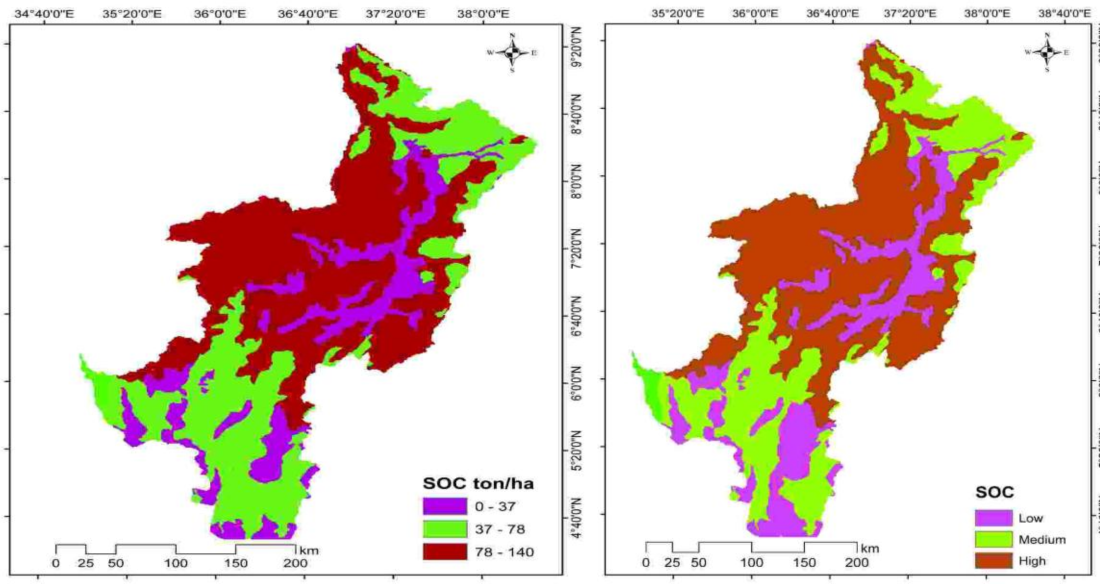

Figure 16: Topsoil (30cm) SOC stock map for the Omo-Gibe River basin.

4.3.4. The State of Land Degradation Neutrality

Dominantly, the omo-gibe river basin has experienced negative land cover change due to urbanization (uncontrolled land grabbing) and farmland expansion through clearing natural vegetation (Table 17).

Table 17: State of degradation for each indicator evaluated in the Omo-Gibe River Basin (2000 to 2020)

Status	**Land cover**		**Land productivity dynamics**		**Soil organic carbon**		**Total**	
	$(km)^2$	**%**	**$(km)^2$**	**%**	**$(km)^2$**	**%**	**$(km)^2$**	**%**
Degradation	47,798.93	60.6	25853.85	32.73	21816.6	27.64	51231.45	65.05
Stable	31,201.07	39.4	43836.4	55.59	47609.9	60.26	21735.4	27.51
Improvement	0.00	0.00	9309.75	11.69	9573.5	12.1	6033.15	7.44

*percentage of the total area of the basin (79,000 km^2)

Based on this study, from 2000 to 2020, LUCC estimated that the area of degraded land in the Omo-Gibe River Basin was 47,798.93 km^2 (60.6%), and the area of stable land was 31,201.07 km^2 (39.4%). The areas with decreased and increased NPP accounted for 25853.85km^2 (32.73%) and 9309.75 km^2 (11.69%), respectively, while the area with stable NPP accounted for 43836.4 km^2 (55.59%) of the total area. However, the degraded, stable, and improved SOC areas in the basin accounted for 27.64%, 60.26%, and 12.1% of the total land area, respectively.

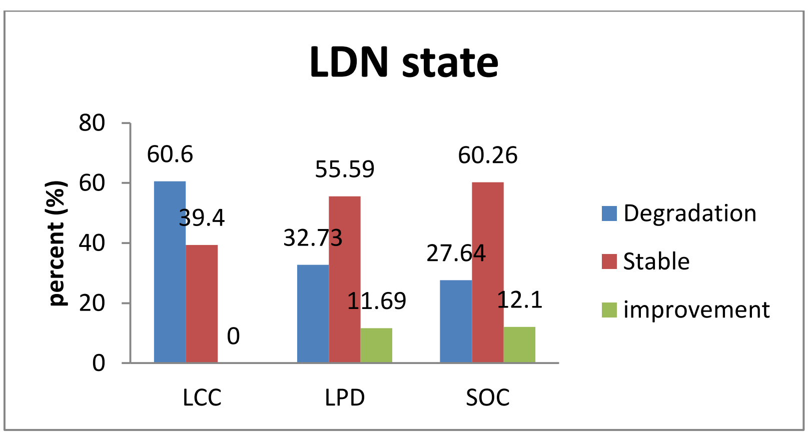

Figure 17: States of Land Degradation Neutrality

The indicator that presented the highest proportion of area with negative changes was LC, with 60.6% of the surface area. LPD followed this with 32.73% and with a proportion of

27.64% (Table 17, figure 17). Therefore, according to the results of the three indicators and taking into account the 1OAO approach, the actual degraded surface area was 65.05% (51231.45 km^2). Of the total potential degraded area, most occurred on bare land, with 13.62% potentially degraded, followed by forest and wetland, with 9.19% and 5.18%, respectively (Table 17).

However, there was some stability; the final result was a potentially degraded area because stability or restoration in any of the three indicators could not compensate for the degradation in another indicator. In this sense, the total degradation considering evaluating the three indicators, represented 65.5% of the Omo-Gibe River basin. This study revealed that the LC sub-indicator impacted LD in the study area by 60.6%; the remaining half was affected by the combination of SOC and LPD. Therefore, degradation occurred where SOC and NDVI were low, when forests-to-cropland and grassland transitions were becoming apparent, and where LPD was declining. Accordingly, Ethiopia may not be able to achieve its LDN target at the subnational level by 2030. Based on this study, it is clear that LDN assessment and identified indicators provided a helpful way to determine the time and resources required to achieve LDN for sustainable development at the global, national, and subnational levels during the target period.

4.4. Conclusions and Policy Implications

In the study we assessed the land cover change, land productivity, and SOC status of the Omo-Gibe River Basin, Ethiopia. The southern and northern parts of the region are experiencing stress and seeing a decline in vegetation cover. The NDVI range decreased from 2000 to 2020 as a consequence. A combination of livestock and drought could be responsible for the decline in vegetation well-being in the lower basin. Therefore, the southern part of the basin and the hotspots in the middle, north, and southeast require immediate action. This includes controlling overgrazing and releasing adequate amounts of water from upper stream dams, particularly during the dry season. In the basin, soil organic carbon levels were shallow, with the most significant potential found in the southwest and southeast, with a small area along the Omo-Gibe River.

As a result, increasing soil organic carbon content should be a significant focus for actions implemented to increase crop production in the northern and north-central parts of the basin. In conclusion, there were negative trends in the three indicators assessed. In the region, farmers should manage their soils in a way that helps increase soil organic carbon (SOC) levels. For example, they should leave crop residue on the field after harvest and use animal manure. The loss of vegetation should be minimized or prevented, and alternative energy and construction materials should be provided to communities.

The results will significantly contribute to policy development on land management, specifically on how to plan for implementing and monitoring LDN interventions. Finally, there is a need for more studies to clarify the relationship between climate change, land degradation, and regional LDN dynamics.

Chapter Five: Stakeholders' Perception towards Land Degradation Neutrality and Its implications for Sustainable Development: A case of Omo-Gibe River Basin, South-Western Ethiopia

Abstract

Developing and adapting locally appropriate strategies is likely constrained by a lack of understanding of local priorities. This study investigated farmers' perceptions of land degradation neutrality (indicators, mechanisms, and achievements) and its determinants. The study utilized an explanatory sequential mixed methods approach, including questionnaires, key informant interviews, and focus group descusions. A multi-stage systematic random sampling technique was used to select 340 samples from the total number of households. To analyze the data, a Likert scale, the logistic regression model, and a descriptive statistics were used. The study found that extension workers were the most frequently cited sources of information on soil erosion and conservation. Yet overall, the respondents showed a negative and neutral perception of Land Degradation Neutrality. In this study, 98.53% of the respondents perceived construction of Soil and Water Conservation structures on farm plots would reduce farm plot size. As a result, they are not interested in building SWC structures on their farm plots. According to this study, farmers' perceived insufficient labor availability (78.82%) and absence of incentives (54.41%) participation in the construction of SWC structures was the most dominant challenge in constructing SWC structures. The results revealed that land tenure security and contact with extension workers were positively associated with farmers' perceptions. However, participating in off-farm activities was associated with adverse effects. We concluded that the farmers' and extension workers' level of information about sustainable development goals, specifically land degradation neutrality and its indicators, was minimal. So, they need and should gain awareness through training and develop discussions in the local community union about indicators of Land Degradation Neutrality.

Key words: *Indicators, LDN, Likert scale, Logistic regression, SWC,*

5.1. Introduction

A significant component of the world's total land area-approximately 20-40% is considered degraded, consisting of croplands, dry lands, wetlands, forests, and grasslands (FAO, 2021). In response to the rapid depletion of our finite natural capital stocks, several countries have made commitments to restore degraded land by 2030 under the Rio Conventions (Sewell et al., 2020). Restoring ecosystems reverses global warming and biodiversity loss, protects nature's life support services, and reduces land degradation risks (UNCCD, 2022; Sewell et al., 2020). Additionally, restoration is imperative for achieving land degradation neutrality (LDN) and many Sustainable Development Goals (Sewell et al., 2020).

During the 70th session of the UN general assembly, 17 sustainable development goals (SDGs) were outlined (UNCCD, 2014), a guiding framework for global development from 2015 through 2030 following the expiration of the millennium development goals (MDGs) (United Nations, 2018), as a method of maintaining the well-being of both humans and the environment. This goal (goal 15: life on land) emphasizes preserving, restoring, and promoting healthy terrestrial ecosystems, managing forests sustainably, halting and reversing land degradation, and maintaining biodiversity (UNESCO, 2016). As a new approach to tackling land degradation, land degradation neutrality (LDN), defined as "a state in which land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems, is receiving considerable attention as a potential solution" (UNCCD, 2016).

The growing importance of protecting land-based natural capital has led to innovative solutions, such as land degradation neutrality, which seeks to maintain a state where the quantity and quality of land resources, essential for ecosystem survival, remain stable within specified temporal and spatial scales without compromising existing food supply (Akhtar-Schuster, et al. 2017; UNCCD, 2016). Several challenges have been identified regarding implementing LDN, primarily related to monitoring and assessing degradation and the scale at which to apply the concept (Akhtar-Schuster, et al., 2017; Stavi & Lal, 2015).

For LDN to be achieved, it is proposed that measures be taken to reduce and avoid the degradation of non-degraded land, and any anticipated loss of productive land must be offset by restoring already degraded land. To accomplish this, we need effective monitoring mechanisms that can identify degraded versus non-degraded land, identify land under degradation, and evaluate the effectiveness of interventions. While LDN commitments and compliance are reported and assessed at the national level, most of the current discourse focuses on its implementation and monitoring at the local level (Willemen et al., 2018; Luc Gnacadja and Liesl Wiese, 2016). Therefore, achieving LDN at the national level is an aggregate of local efforts.

Similarly, Cowie et al. (2018) and Orr et al. (2017) note that it is essential to implement LDN at the scale where land use decisions are made and develop locally appropriate LDN strategies based on complementary indicators. Land managers are unable to assess what different land management options can achieve; land users are unable to understand their decisions' impacts on ecosystem service provision; and this constraint could hinder LDN activities. While LDN targets and other restoration commitments must be aligned better across conventions and sustainable development goals, implementing these commitments also requires in-county action, notably more vital policies, enabling conditions, and an inclusive and bottom-up approach (WWF, 2022). As a result, Ethiopia has adopted this strategy for reversing land degradation sustainably and set a target to achieve SDGs up to 2030 based on UNCCD guidelines (FDRE, 2015).

Local communities have recently worked to restore degraded land in this area suffering from extensive soil erosion. Hoever, developing and adopting locally appropriate strategies is likely constrained by a lack of understanding of local priorities. This is due to involving land users in monitoring and assessing LDN Willemen et al., (2018). It also misses the opportunity to negotiate land management objectives and data verification on the ground. The present study was undertaken in response to the absence of studies evaluating perceptions of natural resources conservation and land degradation neutrality at local scales. It involved local land users in the assessment process. Therefore, it is essential to consider stockholder perceptions regarding land degradation neutrality. This includes their interests in ecosystem services and perceptions of land management sustainability implications.

In this study, the main objectives were explained as (i) better understanding of local perceptions of land degradation, restoration activities, and conservation measures; and (ii) examining farmers' perceptions of land degradation neutrality (indicators, mechanisms, and achievements) and its determinants. The findings of this research will significant for strategies to implement LDN at local scales would be developed, complementing the current UNCCD LDN framework.

5.2. Materials and Methods

5.2.1. Model Specification

In this study, descriptive statistics were used to calculate some socioeconomic variables' percentages and frequencies. A chi-square analysis was conducted to look for significant differences among the following variables: influence of age, number of household members, administrative responsibilities in kebeles, cattle ownership, education level, farmland area, frequency of development agents visits, perceived severity of soil erosion and workability of land degradation neutrality concepts. We used a logistic regression model to analyze the effect of different variables on farmers' perceptions. Studies of farmers' perceptions of conservation technologies have been conducted using this statistical tool (Moges & Taye, 2017; Sinore & Doboch, 2021). Using Logistic regression, it is possible to predict a discrete outcome using continuous, discrete, or dichotomous variables.

From the questionnaire survey response, the dependent variable (i.e., perception of Land degradation Neutrality) is a dichotomous discrete variable. The independent variables are a mixture of discrete and continuous. A computer program called statistical package for social studies (SPSS) version 20 was used to compile and analysis the data. A logistic regression model characterizing household perception (Argaw, 2005; Park, 2013; El Morr et al., 2022) as described as follows:

$$Pi = F(a + \beta xi) = \frac{1}{1+e^{-(a+\beta Xi)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where i denotes the i^{th} observation in the sample; Pi is the probability that an individual will make a particular choice given Xi; e is the base of natural logarithms and approximately equal to 2.718; Xi is a vector of exogenous; variables $\alpha \, and \, \beta$ are parameters of the model, $\beta, \beta 2 \ldots \ldots \ldots \ldots \ldots, \beta k$ are the coefficients associated with each explanatory variables X_1, X_2……, X_n. The above function can be rewritten as:

$$\ln\left[\frac{p}{1-p}\right] = \beta 0 + \beta 1 x 1 + \beta 2 x 2 + \ldots + \beta k x k \ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

where the quantity $p/(1-p)$ is the odds (likelihoods); $\beta 0$ is the intercept; $\beta 1, \beta 2 \ldots and \, \beta k$ are coefficients of the associated independent variables of X_1, X_2….X_k. it should be noted that the estimated coefficients reflect the effect of individual explanatory variables on its log of odds

$$\ln[\frac{p}{1-p}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (16)$$

This study focuses on independent variables expected to affect perceptions and behaviors related to LDN. Based on literature on farmers' we selected socioeconomic, physical, and institutional variables that may influence the perception of land users and experts toward SDGs, specifically LDN. According to table 18, dependent and explanatory variables are defined and measured in the logistic regression model.

Table 18: Definition and unit of measurements of dependent and explanatory variables

Variables	**Variable code**	**Variable type**	**Unit of measurement**	**Expected outcomes**
Dependent				
Perceptions of LDN	PERLDN	Dummy	1 if perceived and 0 otherwise	
Explanatory variables				
Sex of households HH	SEX	Dummy	1 if male; 0 otherwise	±
Age of HH	AGE	Continuous	Measured in years	±
HH head educational status	EDUC	Dummy	1 if literate; 0 otherwise	+
Family size	FAMSIZE	Continuous	Measured in number	±
Farm size	FARMSIZE	Continuous	Measured in hectars	+
Mean Distance of farm plot from the homestead	PLODIST	Continuous	Measured in walking in minuts	-
HH head farming experience	FARMEXP	Continuous	Measured in years	+
Frequency of extension agents Contacts	EXTCONT	Continuous	Measured in year	+
Slope	Slope gradient	Continuous	1 if steep slope; 0 otherwise	+
Land tenure security	LANDTUN	Dummy	1 if the farmer feels secure; 0 otherwise	+
Off-farm activities	OFFFARM	Dummy	1 if participated; 0 otherwise	-

5.3. Results and Discussion

5.3.1. Characteristics of the Respondents

Table 19 summarizes the socioeconomic characteristics of the respondents. Most of the participants in this study (92.6%) were male house heads. The majority of respondents were between 45 and 60 years old. The survey found that 33.53 percent of respondents participate in off-farm activities, while 66.18 percent feel secure about their land. A typical landholding size was 1.4ha, but ranges existed between 0.9ha and 3.5ha. About 39.12% of respondents have land between 1.5 and 2.0 hectares. It is estimated that 66.47 percent of the study watershed has a gentle slope, 59.12% of farmers contact extension experts three to five times per year.

Table 19: Socio-economic characteristics of the respondents in watershed

Variables	**Category**	**Response**	
		Frequency	Percent
Sex of households HH	Male	315	92.6
	Female	25	7.4
Age of HH	18-30	11	3.24
	30-45	128	37.65
	45-60	176	51.76
	>60	25	7.35
HH head educational status	Literate	32	9.41
	Illiterate	308	90.59
Family size	<3	84	24.71
	3-6	193	56.76
	<6	63	18.53
Farm size	<1	39	11.47
	1.0-1.5	75	22.06
	1.5-2.0	133	39.12
	2-3	78	22.94
	>3	15	4.41
Mean Distance of farm plot from the homestead	<20min	106	31.18
	20-40min	156	45.88
	40-60min	78	22.94
HH head farming experience	<10 years	42	12.35
	10-20	134	39.41
	<20	164	48.24
Frequency of extension agents Contacts	<3	89	26.18
	3-5	201	59.12
	5-8	39	11.47
	>8	11	3.23
Slope	Steep	114	33.53

	Gentle	226	66.47
Land tenure security	Feel secured	225	66.18
	Not feel security	115	33.82
Off-farm activities	Participated	114	33.53
	Not participated	226	66.47

5.3.2. Farmers' Sources of Information about Land Degradation Neutrality

According to this study, extension workers were the most frequently mentioned sources of information, followed by specific training and neighbors. The extension workers in the kebeles were the primary source of information about SWC (50.88%), soil erosion (46.47%), and land productivity (45%). A specific training event addressed items such as soil and water conservation, land use, land cover change, and soil erosion most commonly. Farmers in the study area have little knowledge of sustainable development goals (71.18%), land degradation neutrality (62.65%), and soil organic carbon (44.7%) (Table 20). During key informant interviews, the farmers have little information about the issues mentioned above, due to a lack of training and poor communication with development agents.

Table 20: Sources of information

Questions	No information about the topic		Specific training		Television		Extension Workers		Neighbors	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Soil erosion	-	-	124	36.47	5	1.47	158	46.47	53	15.59
SWC	-	-	145	42.65	13	3.82	173	50.88	9	2.65
LULCC	121	35.59	103	30.29	-	-	113	33.24	3	0.88
SOC	152	44.7	62	18.24	-	-	118	34.7	8	2.36
LP	75	22.06	57	16.76	17	5	153	45	38	11.18
LDN	213	62.65	48	14.12	7	2.06	61	17.94	11	3.23
SDGs	242	71.18	18	5.29	-		75	22.06	5	1.47

5.3.3. Farmers' Perceptions and their Motivation in SWC practices

Table 21 represents farmers' attitudes towards SWC and land degradation neutrality. As positive and negative statements were recorded accordingly. Most respondents' "Agree" and "Strongly Agree" responses are considered positive perceptions. The highest percentage of "strongly agree" responses by the farmers were society should be provided with frequent extension services (58%) and participation in SWC activities will increase land productivity (44.5%). This indicated that farmers know the value of extension services and the consequences associated with participation in SWC activities. The majority of the respondents also agreed with the fact that soil erosion is a significant problem in their farmland (53.5%). However, when asked about the necessity of raising awareness on LP, SOC, and LULC among the land users, there were mixed responses, with 47.5% of farmers responding "agree" and 23% responding "neutral." Yet overall, the respondents showed a low perception and neutral towards LDN.

Table 21: Summary of farmers' responses on SWC practices in the study area

#	Items	SD*(%)	D*(%)	N*(%)	A*(%)	SA*(%)
P1	Soil erosion is a significant problem in our farmland	9.5	11	9.5	53.5	16.5
P2	Because of soil erosion, the productivity of farm land become decreasing	3.5	16.5	2.5	48.5	29
P3	soil erosion can be controlled	18.5	23.5	8	29.5	20.5
P4	Participation in SWC activities Voluntarily	43	32.5	2	13.5	9
P5	To me, society should be provided with frequent extension services.	-	-	5	37	58
P6	To me, LP, SOC, and LULC are the main indicators of LDN	21.5	25.5	16.5	20	16.5
P7	To me, the final aim of LDN is provision services (food availability, water quality services)	14.5	23	48.5	9.5	4.5
P8	In my opinion, the final aim of LDN is regulating services (climate regulation, climate change mitigation, disaster risk reduction)	11.5	17	33.5	19.5	18.5
P9	To me, raising awareness on LP, SOC, and LULC among the land users is necessary	6.5	3.5	23	47.5	19.5
P10	The rising of using artificial fertilizers decreases SOC	25.5	18.5	13.5	23.5	19
P11	I believe that participation in SWC activities will increase land productivity.	-	15.5	6.5	33.5	44.5

*SD=strongly disagree, *D=disagree, *N=neutral, *A=agree, *SA=strongly agree

5.3.4. Perceptions towards Benefits and Challenges in practicing SWC structures

The descriptive statistics indicate that the farmers perceived that soil and water conservation activities would have the benefit of reducing runoff (78.82%), reducing soil loss from erosion (62.65%), and maintaining soil fertility (45%) (Table 22). In FGD, most participants agreed on the positive effects of SWC structures. Practically, SWC structures become a series of physical barriers against surface runoff and soil erosion (Mengistu et al., 2016). Despite the benefit of SWC practices, they perceived that SWC practices also would have challenges and limitations that discourage farmers' construction, repairing, and continued treatment. In this study, 98.53% of the respondents perceived construction of SWC structures on farm plots would reduce farm plot size. As a result, they are not interested in constructing SWC structures in their farm plots (Table 22).

On the other hand, 84.12% of the respondents perceived the demand for a high labor force for the construction of the SWC structure as a significant constraint because of the labor-intensive nature of the SWC structure. Difficult rapier and continued treatment were the other challenges related to SWC structures. During the construction of soil and water conservation measures, the farmers faced different challenges. According to this study, the farmers' perceived insufficient labor availability (78.82%) was the most dominant challenge in building SWC structures. From FGD, we concluded that higher labor demand for the SWC structures as a practical challenge that reduces the interest and motivation for their construction and repair. This study results is inline with the study of (Tefera & Sterk, 2010; Wolka et al., 2018). An absence of incentives (54.41%) during participation in the construction of SWC structure was another challenge. The farmers' said mostly the government bodies were ordering them to participate in the SWC campaign by force without convincing them, and they spent a lot of time on the construction of SWC structures without any incentives or sometimes minimum incentives. So, this may cause the farmers discourage and ineffective in their participation in the construction and maintaining of SWC structures. Based on our field observation, the constructed SWC structures are mostly destructed and failed. The finding showed that the main destruction causes were overtopping runoff (95.59%), free grazing by livestock, and land tillage activities.

Table 22: Perceived benefits and challenges in practicing SWC practices

Perceived benefits of SWC measures	Categories	Frequency	Percent
	Reduce runoff	268	78.82
	Reduce soil loss	213	62.65
	Maintain soil fertility	153	45
	Improve crop production	98	28.82
	Conservation soil moisture	73	21.47
Challenges in building SWC structures	Lack of awareness	52	15.29
	Lack of inputs	112	32.94
	Lack of materials	125	36.76
	Insufficient labor availability	298	78.82
	New skill demand	36	10.59
	No incentives	185	54.41
Problems related to SWC structures	Reduce farm plot size	335	98.53
	Difficult to repair and continued treatment	245	72.06
	Need a high labor force	286	84.12
	Suspicion on effectiveness	59	17.35
Causes for damages to SWC structures	Free grazing by livestock	165	48.53
	Overtopping runoff	325	95.59
	Land tillage activities	87	25.59

Note: the sum of % more than 100 was due to multiple responses

Different socioeconomic, biophysical, and institutional variables were hypothesized to affect the farmers’ and experts' perception of land degradation neutrality. A logistic regression model was used to analyze determinants of farmers’ perception of land degradation neutrality. The success of the overall predication by the logistic regression model indicates that the variables sufficiently explained the perception of farmers and experts on LDN, and there is a strong association between the perception and the group of the explanatory variables (R^2=0.64). A positive estimated coefficient in the model implies an increase in the farmers’ perception of soil erosion and conservation practices with increased explanatory variable value. In contrast, the negative estimated coefficient in the model implies decreasing perception with an increase in the value of the explanatory variable.

The results indicate that among the ten hypothesized explanatory variables included in the model, only five were found to have a significant influence on farmers' perception. These include, the age of the household head, farming experience, participating in off-farm activities, land tenure security, and contact with extension workers. Among these five variables, land tenure security and contact with extension workers were positively associated with farmers' perception, and the remaining age of the household head, farming experience, and participating in off-farm activity negatively associated (Table 23).

Table 23: Summary results of logistic regression analysis of farmers' perception (n=340)

Explanatory variables	Coefficient	Std. error	Odds ratio
SEX	0.58	0.97	1.58
AGE	-0.13***	0.04	0.86
FAMSIZ	0.14	0.11	1.17
FARMEXP	-0.09*	0.03	1.07
PLOTSIZ	0.17	0.68	1.39
SLOP	1.43	0.68	0.92
DISTA	0.09	0.37	1.08
OFFFARM	-2.64***	0.54	0.08
LANDTENU	6.78***	1.22	4.43
EXTCON	036**	0.13	1.41
Chi-square	265.49		
Log Likelihood	-73.22		
Nagelkerke (R^2)	0.64		
Number of observation	340		

***, **, *, significant at 0.01, 0.05, 0.1 probability levels, respectively

The logistic regression analysis results indicated that the respondents' age has a a negative and significant effect on farmers' perception at 1% significance level. The negative correlation between perception and age indicates that as the age of respondents increases their corresponding perception of indicators of LDN decrease. This could suggest that older farmers may be far from the recent concept and information of land degradation management practices than younger farmers. This finding was similar to the finding of Meseret & Amsalu, (2017); Meseret, (2014) in SWC practices.

Like that of the age of households, the farming experiences of the farmers are also another significant factor for the perception of farmers towards land degradation neutrality and their indicators. As hypothesized, the effect of farming experience on perception is positive. Which is the likelihood of accepting the concepts of land degradation neutrality is more among more farming experiencing than few experience, due to their long life farming experiences of farmers changing their perceptions about land degradation impacts and understanding the importance of sustainable land management practices. However, this study showed that the farmers with long life farming experience could not easily accept and implement the concepts of neutralizing the land from degradation. This may be due to our change resistance habit or ignorance of new ideas and technology and also indicated by old experienced farmers due to the absence of awareness creation training in the study area.

In the study area participating in off-farm activities is very common. This result also indicated that farmers' perception towards indicators of neutralizing land from degradation was negatively affected by their participation in farm activities at a significant level of ($P<0.01$). This indicated that farmers who participated in off-farm activities could not have sufficient time for training and gaining new information from the extension workers to update their awareness about land degradation and management. This may be because they give more attention and concern to daily income than sustainable land management practices and output.

The effect of extension contact on farmers' perception was a very important factor for farmers to have recent and updated awareness about land degradation and conservation. Farmers who have more contact with extension workers would acquire more updated information and develop their awernes about the indicators of land degradation neutrality and the means for reduction of land degradation. Similarly, plot ownership was found to have positive and significant ($P<0.01$) associated with farmers accepting the new concepts of neutralizing the land from degradation. This implies that the farmers who feel security of the land have a tray to pay attention and accept new information to manage their land than the rented or share cropped plots. The logistic regression model also showed that sex, family sizes, plot size, slopegradient, and plot distance have no significant effect on perceptions of farmers towards land degradation neutrality.

5.4. Conclusions and Policy implications

This study found that farmers learn most about soil erosion, SWC, LULC, and land productivity from extension workers and specific training. However, most farmers and extension workers were unaware of SC, LDN, and SDGs. Most respondents agreed that soil erosion was an essential problem on their farmland. However, they did not have a good perception of land degradation neutrality indicators. Several factors greatly influenced their perception. The main determinants include the gender of the household heads, their farming experience, their off-farm activities, and plot ownership. However, SWC structures are challenging to build due to labor shortages and lack of incentives, yet farmers believe these practices significantly reduce runoff and soil loss. Hence, NGOs and governments should provide financial support to them, primarily when they work on SWC practices. Although farmers perceive SWC practices to have different advantages, they also perceive them to reduce farm plot sizes and the difficulty of prolonged treatment and repair. Farmer practices that promote SWC were generally most beneficial to farmers in the study watershed. Farmers and extension workers had inferior information regarding sustainable development goals and specific land degradation neutrality (LDN). So, their perception of the SDGs, in particular, was minimal. Hence, they need and should gain awareness through training and discussions in the local community union regarding indicators of LDN and how to attain sustainable development goals.

Chapter Six: Synthesis

Land degradation is one of the world's most pressing environmental problems and will worsen without rapid remedial action. Globally, about 25 percent of the total land area has been degraded. The primary cause of land degradation in sub-Saharan Africa (SSA) is the expansion and intensification of agriculture to feed its growing population (Tully et al., 2015). According to Global Environmental Facility (GEF) (2019), all productivity landscapes from the drylands of Africa and Asia must be managed carefully and sustainably. To arrest and reverse land degradation and desertification, the UNCCD recognizes land degradation neutrality as a concept that can help communities, businesses, and governments reconcile the need to intensify food production without degrading land resources. Essentially, LDN is about managing land more sustainably to reduce degradation, while increasing rates of land restoration (UNCCD, 2014).

Further, before now, there has been very little involvement from the corporate sector, science, or civil society in matters relating to land management. Therefore, it is increasingly crucial to gather all relevant stakeholders on one platform and actively include them in the LDN strategy to effectively and sustainably address land degradation issues in the nation. Implementing LDN requires a participatory approach because multi-stakeholder engagement is crucial for supporting sustainable land management practices (Ştefănescu & Ciuvăț, 2018). In recent years, much research has been conducted regarding land degradation and sustainable land management practices. However, few studies have systematically addressed the issues of land degradation, sustainable land management practices, and sustaining the life expectancy of different megaprojects like hydroelectric dams using multiple indicators and parameters. Therefore, the main objective of this study was to identify areas more sensitive to land degradation that need urgent mitigation. In addition, it evaluated the effectiveness of land management measures, indicators, and mechanisms of LDN at the sub-national level using LDN conceptual framework. theoretical framework adapted from DPSIR contributed to this study linking land degradation, sustainable land management practices and effects with land users' perceptions.

This study discussed four main objectives with four independent chapters aimed to contribute to achieving sustainable goals, especially the neutralization of the land from degradation in 2030. To achieve these goals at the sub-national and national levels, we analyzed the areas sensitive to land degradation. We also analyzed sustainable land management practices and their determinants, the status of land degradation using three indicators, and farmers' perception of land degradation neutrality and its indicators. So, this part presented the sensitivity area to land degradation, soil and water technologies, and sustainability. It also presented land degradation neutrality and sustainable development, and land degradation neutrality and perceptions of stakeholders. The implications of this study; for policy development, sustainable agricultural development, and socioeconomic improvement of the country were discussed.

6.1. Environmental Sensitivity Area to Land Degradation

Land degradation is one of the major challenges in the Omo-gibe river basin. It is likely to get more severe due to projected population growth and extreme precipitation events, so it needs methodical thinking and coordinated solutions. The study area is heavily affected by landslides, and soil erosion and sedimentation threatening the reservoir's storage capacity. Due to its simplicity, flexibility, and ability to update information on local conditions, the MEDALUS method was employed in this study.

According to the ESA index, the basin is classified into eight categories, the study revealed that a significant portion of the basin is classified as critical or fragile, with large parts designated as untreated. Fragile areas are more common along the basin and reflect zones where soil quality parameters and climate are not critical in the aggregate. The study found that land degradation is most prevalent in the eastern part of the Omo-gibe river basin, the south points (lower basin), and the north half of the basin. Accordingly, the omo-gibe river basin agro-ecosystem has undergone a considerable worsening in environmental conditions due to unsustinable use of soil and water conservation techonolgies, resulting in severe degradation of the agro-ecosystem and severe agricultural land scape fragmentation. This resulted for high sedmentation and silitation on the gibe dams and creat critical condtions for highdroelctric energy production, difficulty for achiving sustinable developments in the country (**Chapeter 2 and 3**). This calls for sustainable land management practices in high land degradation sensitivity areas.

6.2. Soil and Water Technologies and Sustainability

In Ethiopia, soil and water conservation measures have been adopted differently. This is because the ecological, economic, and social impact of those SWC technologies influences investments in SWC technologies. Most studies focus on the pre-adoption (acceptance) and adoption stages rather than the continued use (post-adoption) stage. This raises the question: why are SWC practices not sustainable? Few studies have been conducted to analyze factors affecting sustainable SWC technology use. Location-specific target policies are needed to assure SWC sustainability. A variety of factors has hindered the implementation of those conservation structures on their farm plots. According to this study, nearly half of the socioeconomic and physical factors affect soil bund adoption and sustainability. Family size, extension contact, land tenure security (positively) and farm size, plot distance (negatively) determine the sustainability of SWC measure (**Chapter 3 and Chpater 4**). Therefore, to sustain agricultural productivity needs intensive attention and systematic planning for sustainable land management. As a result, first needs to assess the land which is neutralized from degradation by means of sustainable land management practices.

6.3. Land Degradation Neutrality, Stakeholders Perceptions, and Sustainable Development

LDN aims to repair more degraded land and increase land resource productivity. Various countries have found specific potential to scale existing programs or build new LDN implementation projects. Multi-stakeholder engagement is essential for supporting sustainable land management practices, and Ethiopia has adopted this strategy for reversing land degradation. The current study used three (LCC, LP, and SOC) biophysical indicators to evaluate the state of land degradation in the Omo-Gibe River basin from 2000 to 2020 using the "one out, all-out" (1OAO) principle. The Omo-Gibe River basin was potentially degraded because stability or restoration in any of the three indicators could not compensate for degradation in another indicator. Developing and adopting locally appropriate strategies is essential for successfully implementing local-based sustainable soil and water conservation activities. So, understanding the perception levels of stakeholders (farmers, development agents, and NGOs experts) about land degradation neutrality and its determinants is critical for the achievements of sustainable development(**Chapter 4 and Chapter 5**).

6.4. Contribution of the Study

The present study will make several noteworthy contributions to the community, policy makers, and academicians in several ways. The contribution will be conceptual/theoretical, empirical, and methodological.

Conceptual/theoretical contribution: this study will contribute by clarifying and contextualizing the concept of neutrality of land degradation, which is a new concept for reversing land degradation worldwide, specifically in Ethiopia. The study results will increase knowledge on the extent and patterns of land degradation, practices of SLM, and its effects on achieving SDG of LDN in the Omo-gibe basin. Besides, this study will provide a significant opportunity to advance the understanding of the status of land rehabilitation activities and farmers participating in conservation activities. Based on this information, the stakeholders may adjust their plan and program area-specific solutions based on the result to achieve sustainable development goals, specifically Land Degradation Neutrality (Goal 15.3) for improving the livelihood system of the society.

Empirical contribution: though much researchs on land degradation was produced, the problem is still aggravated. So, identifying the land degradation potential area through indexes and measuring the actual amount of soil organic carbon, land productivity, and land cover change, as well as capturing the perceptions of rural society towards land degradation neutrality and their activities of SLM, will be a significant contribution of this study. Additionally, this study will contribute by testing a theoretical linkage between SLM practices and reversing land degradation via indictors that have not been tested and by examining the effects of a potential moderator variable on the nature of the relationship between two constructs.

Methodological contribution: this study's environmental sensitivity index (soil index, vegetation index, climate index, soil erosion index, and management index) will be used locally to identify the area sensitive to land degradation. This model is new for the study area and a new insight towards the methodological aspects of land degradation. Also, this study will contribute new approaches to studying land degradation for sustainable development, which is a one-out all-out approach through the land degradation indicators at the sub-national level. As a result, the present study will reduce the potential problems with shared method variance through the insightful use of multiple measurement methods and increase the generalizability of the research through more appropriate sampling procedures.

Besides, the findings will contribute to agriculture, economics, environmental studies, etc. The methods used for this study may apply to other areas in the country that have approaching conditions in different aspects and elsewhere in the world. Therefore, this study will contribute to research on sustainable land management activities by demonstrating the finding, result, and methods in different areas. Furthermore, it will produce data to add input for the national-level program to combat land degradation and suggest the appropriate SLM technologies for the study area. Besides, this research will serve as a base for future studies as a source of information on related issues.

6.5. Recommendations

In light of the empirical Study, we have made the following policy development and amendment recommendations. The following suggestions may play a critical role in achieving sustainable development at the national and subnational levels.

i. The need to Motivate and consider the Interest of Farmers’ Participating in SWC Activities

It is one of the significant challenges of evolving technologies that users are unwilling to accept entirely. According to this study, SWC technologies are primarily accepted by farmers but not automatically or fully adopted. The primary indicator is that most farmers do not continue to use soil bunds in their plots. Due to political or economic reasons, farmers adopted soil bunds. This study revealed that SWC measures are unlikely to be sustainable due to farmers' passive and forced participation in conservation activities. The reason for this was the absence of participation in designing SWC structures and the lack of familiarity with top-down planning technologies without considering their interests. Accordingly, this study suggests that SWC measures should be planned based on farmers' self-motivation and participation/involvement. To enhance the sustainability of SWC measures, policy makers and development workers need to consider plot-level physical environments and land users' interests. As a result, agro-ecological SWC design was essential in reducing farmland vulnerability to soil erosion and food insecurity. In general, conservation practices should focus on both implementation and biophysical factors and farmers' socioeconomic interests, to improve sustainable use.

ii. Develop SWC measures of Post-adoption Follow-up Mechanisms.

In the study area, farmers accepted and implemented SWC technologies on a larger scale. Farmers are, however, less likely to reuse and renew soil bund structures for a long time. The researcher observed that the structures were damaged and destroyed. This study concluded that these challenges result from the absence of post- adoptive follow-up mechanisms. For example, some NGOs are developing post-adoption follow-up mechanisms, but after-SWC practices are still minimal. Policies and procedures need to be designed and implemented. Therefore, we also suggested that the national and local governments establish post-adoption rules and regulations and follow-up mechanisms for ensuring the continued use of SWC practices. Our findings suggest strengthening institutional and human capacity should be the focus of efforts to address soil erosion through SWC technologies.

iii. Government Investment in Intensive Training

Using any evolving technology requires intensive training and information management activities to create societal awareness. The SWC measures need awareness-building activities for land users and experts before implementation. This study found that most participants were adopting soil bunds for any reason. Nevertheless, most adopters did not continue to use this SWC structure (sustainable use) due to socio-economic and physical factors. One of the main gaps was the lack of training regarding the sustainable use of these technologies. The study area was home to several nonprofit organizations, but most of them implemented and practiced SWC technologies without considering the farmers' levels of awareness. In this regard, natural resource management experts, NGOs, and other interested organizations should provide continuous training for land users. This training should focus on the significant effects of the sustainable use of SWC practices.

To control soil degradation and enhance farm productivity, farmers need to be educated and trained, and awareness should be created about soil erosion.

The farmers in the study watershed were aware primarily of soil and water conservation benefits. However, farmers’ and extension workers' level of information about sustainable development goals, specifically LDN and its indicators, was minimal. So, they need and should gain awareness through training and develop discussions in the local community union about LDN indicators.

iv. Controlling Deforestation, Overgrazing, and Settlement Expansion

According to the study, the land cover has changed profoundly from 2000 to 2020. There was a profound change in land cover, with increased settlements, cropland, and bare lands. In contrast, a decrease in woodlands, forests, bushlands, and grasslands has been observed. It has been observed that water bodies and wetland areas have decreased slightly but significantly. The southern and northern parts of the region are experiencing stress and vegetation decline. A combination of livestock and drought could be responsible for the decline in vegetation well-being in the lower basin. Therefore, the southern part of the basin, as much as the hotspots in the middle, north, and southeast, require immediate action. This includes controlling overgrazing and releasing adequate amounts of water from upper stream dams, particularly during the dry season. The study area has extensive deforestation practices for commercial charcoal production. Therefore, vegetation loss should be minimized or prevented, and alternative energy and construction materials should be provided to communities.

v. Improving Land Productivity and Soil Organic Carbon through Sustainable Land Management Practices

In the basin, soil organic carbon levels were shallow, with the most significant potential in the southwest and southeast. There was a small area along the Omo-Gibe River. As a result, increasing soil organic carbon content should be a significant focus for actions implemented to increase crop production in the northern and north-central parts of the basin. Farmers should manage their soils to increase soil organic carbon (SOC) levels. For instance, they should leave crop residue on the field after harvest and use animal manure. Furthermore, crop fields should be cultivated with minimal tillage to preserve soil carbon. This makes it necessary to monitor and adequately plan for conservation and restoration measures at the subnational level.

vi. The Government bodies should Evaluate and Follow-up SDG Implementation

Sustainable development goal 15.3.1 aims to neutralize land degradation by 2030. The leading indicators for LDN are LCC, LP, and SOC, which are used nationally. Likewise, Ethiopia has set a target for this goal. The remaining time frame for achieving the SDGs is less than half the planned timeframe. However, this study discovered that, at the subnational level, there was a decline rather than an improvement in the three indicators assessed in Ethiopia. Therefore, spatial planning should focus on hotspot areas and implement locally based-sustainable land management practices. A follow-up and assessment mechanism should be in place to determine whether or not the set targets to reach land degradation neutrality by 2030 have been met by stakeholders at the national and subnational levels (federal, regional, and local).

vii. There Should be Afforestation and Reforestation activities

Despite the southwest parts of Ethiopia being covered by various vegetation, the analysis results of nine factors revealed that significant parts of the study area were severely vulnerable to degradation. The study found that land degradation was most prevalent in the Eastern part of the basin, the South points (lower stream), and the North half of the basin (upper stream). This is due to the basin's most populous and extensively cultivated areas at the eastern catchment boundary. In contrast, the southern portion is characterized by high Omo River runoff during the rainy season. During the wet season, sparse vegetation cover, heavy rainfall, and steep slopes result in substantial overland flows. As a result, the Omo-Gibe cascade dam reservoirs are threatened by soil erosion and sedimentation from the Gilgel Gibe basin upstream. It requires the attention of a wide range of stakeholders. Therefore, to prevent further land degradation and ensure the long-term viability of the Omo-Gibe cascade dams, current land planning in the basin should focus on conservation techniques in sensitive areas. In addition, federal, regional, and local governments should support extensive reforestation and aforestation programs. For instance, the NGOs founed in the basin should focus on covering the bare area with green plants, and engage in agro-forestry programs.

viii. Establishing actual Mitigation Mechanisms for Water shortage and Flooding in the Downstream community

The Gibe cascade dams and associated agricultural activities would drastically reduce the Omo-Gibe River flow and reduce annual floods. This water is essential to survival for pastoralists in the lower Omo basin. Study results revealed that soil erosion exposes the cascade dam reservoirs to siltation and sedimentation. This reduces the dam's water amount and leads to power rationing in the country. This is primarily during the dry season and in the rainy season. These significant changes would destroy the lower Omo basin natural resources systems, especially their grazing lands for livestock, riverbank cultivation, and fishing habitats. These conditions would produce massive hunger and widespread disease. Though the Gibe III dam environmental impact assessment document has mitigation mechanisms for those challenges, they are neither practical nor sufficient for pastureland survival. Therefore, the EEPCO must establish fair and equitable sharing of water resources with the pastoralist society in the lower basin. To satisfy the growing demand for water in the future, the ministry of water and energy should develop appropriate soil and water conservation activities integrated with basin development programs. In addition, the authority should have a systematic monitoring, auditing, and follow-up program about the socio-economic and environmental impacts of the Gibe basin cascade dams so that corrective measures can be taken. Consequently, life in the lower basin will be critical, as climate change is severe.

6.6. Limitations of the Study

Every research has some limitations, which is normal; this study also has limitations. In this study, lack of reliable data was a major limitation. Some parameters were employed when identifying areas sensitive to land degradation; however, additional parameters cannot be included due to costly and difficult to manage. Satellite images are essential for this study; Especially high-resolution satellite image was limited to access; it needed a high cost; however, it was difficult to buy due to research fund limitation. These limitations could point to the need for further research.

6.7. Future Research

Finally, this study has limited scope due to the above mentioned limitations, so the researchers recommend future research areas:

i. There is a need for more studies to clarify the relationship between climate change, land degradation, and regional LDN dynamics.
ii. The need to have considers other indicators in addition to LCC, LP, and SOC to make the study more relevant and significant.
iii. This study has a limited scope, focusing solely on the Omo-gibe river basin. Future researchers can apply the study models to areas with similar socio-economic and environmental conditions.
iv. This study assesses the status of land degradation neutrality activities in the basin from 2000 to 2020. We recommend that further research be conduct to establish the next ten years' status of the activities and evaluate the achievements of LDN up to 2030.

6.8. Ethical Consideration

Scientific investigations should place a lot of focus on ethical issues. The investigator has taken this into consideration. A particular focus was on ensuring and informing consent, maintaining confidentiality, and ensuring voluntary participation. The provision of information and communication was also respected ethically. To begin with, informed consent was obtained from participants prior to data collection. The purpose and nature of the study were briefly explained to the participants to assure their active participation in the process of data collection (questionnaires, FGDs, survey field observation information, and key informant interview). The investigators interfered and influenced interviewees, unauthorized communications were avoided. The procedural study was conducted in an ethical manner considering what would follow and respected accordingly at all stages of the study. Therefore, data collected from various sources were analyzed and interpreted according to the objectives.

References

Akhtar-Schuster, M, Stringer, Erlewein. (2017). Unpacking the concept of land degradation neutrality and addressing its operation through the Rio Conventions. Journal of Environmental Management. *Paper Knowledge. Toward a Media History of Documents*, 12–26.

Al-haidarey, M. J. S. (2020). Using Of Mediterranean Desertification And Land Use Model In Subtropics : *A Review. June. https://doi.org/10.37896/JXAT12.06/2032*

Amanuel, W., Yimer, F., & Karltun, E. (2018). Soil organic carbon variation in relation to land use changes: The case of Birr watershed, upper Blue Nile River Basin, Ethiopia. *Journal of Ecology and Environment, 42(1), 1–11. https://doi.org/10.1186/s41610-018-0076-1*

Amsalu, A., & Graaff, J. De. (2006). Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. *1. https://doi.org/10.1016/j.ecolecon.2006.01.014*

Anderson R., Ernest E., John T., and Richard E. (1976). A Land Use And Land Cover Classification System For Use With Remote Sensor Data.

Anose, F. A., Beketie, K. T., Terefe Zeleke, T., Yayeh Ayal, D., & Legese Feyisa, G. (2021). Spatio-temporal hydro-climate variability in Omo-Gibe river Basin, Ethiopia. Climate Services, 24, 100277. *https://doi.org/https://doi.org/10.1016/j.cliser.2021.100277*

Argaw, M. (2005). Forest conversion - soil degradation - farmers' perception nexus: Implications for sustainable land use in the southwest of Ethiopia. *Ecology and Development Series No . 26, 26*, 1–149.

Arroyo, I., & Cervantes, V. (2022). Land Degradation Neutrality : State and Trend of Degradation at the Subnational Level in Mexico.

Asfaw, D., & Neka, M. (2017). Factors affecting adoption of soil and water conservation practices: The case of Wereillu Woreda (District), South Wollo Zone, Amhara

Region, Ethiopia. *International Soil and Water Conservation Research, 5(4), 273–279. https://doi.org/10.1016/j.iswcr.2017.10.002*

Asrat, P., & Simane, B. (2017). Adaptation Benefits of Climate-Smart Agricultural Practices in the Blue Nile Basin: Empirical Evidence from North-West Ethiopia. *Climate Change Management, 45–59. https://doi.org/10.1007/978-3-319-49520-0_4*

Aynekulu, E., Lohbeck, M., Nijbroek, R., Ordóñez, J., Turner, K., Vågen, T.-G., & Winowiecki, L. A. (2017). Review of methodologies for land degradation neutrality baselines. Sub-national case studies from Costa Rica and Namibia. 58. *http://hdl.handle.net/10568/80563*

Baskan, O., Dengiz, O., & Demirag, İ. T. (2017). The land productivity dynamics trend as a tool for land degradation assessment in a dryland ecosystem. *Environmental Monitoring and Assessment, 189(5). https://doi.org/10.1007/s10661-017-5909-3*

Basso, F., Bove, E., Dumontet, S., Ferrara, A., Pisante, M., Quaranta, G., & Taberner, M. (2000). Evaluating environmental sensitivity at the basin scale through the use of geographic information systems and remotely sensed data: An example covering the Agri basin (Southern Italy). *Catena, 40(1), 19–35. https://doi.org/10.1016/S0341-8162(99)00062-4*

Bekele, W., & Drake, L. (2003). Soil and water conservation decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia: A case study of the Hunde-Lafto area. *Ecological Economics, 46(3), 437–451. https://doi.org/10.1016/S0921-8009(03)00166-6*

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. Land Degradation and Development, 20(6), 609–622. https://doi.org/10.1002/ldr.944*

Borja, A., Prins, T. C., Simboura, N., Andersen, J. H., Berg, T., Marques, J. C., Neto, J. M., Papadopoulou, N., Reker, J., Teixeira, H., & Uusitalo, L. (2014). Tales from a thousand and one ways to integrate marine ecosystem components when assessing the environmental status. *Frontiers in Marine Science, 1(DEC). https://doi.org/10.3389/fmars.2014.00072*

Broothaerts, N., Kissi, E., Poesen, J., Van Rompaey, A., Getahun, K., Van Ranst, E., & Diels, J. (2012). Spatial patterns, causes and consequences of landslides in the Gilgel Gibe catchment, SW Ethiopia. *Catena*, *97*(October), *127–136. https://doi.org/10.1016/j.catena.2012.05.011*

Bryan, E., & Institute, I. F. P. R. (2009). Soil and Water Conservation Technologies: A Buffer against Production Risk in the Face of Climate Change? Insights from the Nile Basin in Ethiopia, *IFPRI Discussion Paper 00871*. *June*.

Chasek, P., Safriel, U., Shikongo, S., & Fuhrman, V. F. (2015). Operationalizing Zero Net Land Degradation: The next stage in international efforts to combat desertification? *Journal of Arid Environments*, *112(PA), 5–13. https://doi.org/10.1016/j.jaridenv.2014.05.020*

Cowie, A. L., Orr, B. J., Castillo Sanchez, V. M., Chasek, P., Crossman, N. D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G. I., Minelli, S., Tengberg, A. E., Walter, S., & Welton, S. (2018). Land in balance: The scientific conceptual framework for Land Degradation Neutrality. *Environmental Science and Policy*, *79*(November), 25–35. *https://doi.org/10.1016/j.envsci.2017.10.011*

Cowie, A. L., Orr, B. J., Castillo, V. M., Chasek, P., Crossman, N. D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G. I., Minelli, S., Tengberg, A. E., Walter, S., & Welton, S. (2018). *Land in balance : The scientific conceptual framework for Land Degradation Neutrality*. *79(August 2017), 25–35. https://doi.org/10.1016/j.envsci.2017.10.011*

Creswell, J. W., & Creswell, J. D. (2018). Mixed Methods Procedures. In Research Defign: Qualitative, Quantitative, and Mixed M ethods Approaches.

Crossland, M., Winowiecki, L. A., Pagella, T., Hadgu, K., & Sinclair, F. (2018). Implications of variation in 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*

CSA. (2021). Federal Demographic Republic of Population Projection of Ethiopia from 2014 – 2017: Population Projection of Ethiopia for All Regions At Woreda Level from 2014-2017. *Central Statistical Agency (CSA)*, *August 2013*, 1–118.

Dagnachew, M., Kebede, A., Moges, A., & Abebe, A. (2020). Land use land cover changes and its drivers in gojeb river catchment, omo gibe basin, Ethiopia. *Journal of Agriculture and Environment for International Development*, *114*(1), 33–56. *https://doi.org/10.12895/jaeid.20201.842*

de Graaff, J., Amsalu, A., Bodnár, F., Kessler, A., Posthumus, H., & Tenge, A. (2008). Factors influencing adoption and continued use of long-term soil and water conservation measures in five developing countries. *Applied Geography*, *28*(4), 271–280. *https://doi.org/10.1016/j.apgeog.2008.05.001*

De Pina Tavares, J., Baptista, I., Ferreira, A. J. D., Amiotte-Suchet, P., Coelho, C., Gomes, S., Amoros, R., Dos Reis, E. A., Mendes, A. F., Costa, L., Bentub, J., & Varela, L. (2015). Assessment and mapping the sensitive areas to desertification in an insular Sahelian mountain region Case study of the Ribeira Seca Watershed, Santiago Island, Cabo Verde. Catena, 128(May 2015), 214–223. https://doi.org/10.1016/j.catena.2014.10.005

Demelash, M., & Stahr, K. (2010). Assessment of integrated soil and water conservation measures on key soil properties in South Gonder, North-Western Highlands of Ethiopia. *Journal of Soil Science and Environmental Management*, *1*(7), 164–176.

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *Journal of Agricultural Science*, *149*(1), *23–31*. *https://doi.org/10.1017/S0021859610000687*

Devi, R., Tesfahune, E., Legesse, W., Deboch, B., & Beyene, A. (2008). Assessment of siltation and nutrient enrichment of Gilgel Gibe dam, Southwest Ethiopia. *Bioresource Technology*, *99(5)*, *975–979*. *https://doi.org/10.1016/j.biortech.2007.03.013*

ECA. (2007). Africa Review Report on Drought and Desertification. *Fifth Meeting of the Africa Committee on Sustainable Development (ACSD-5). Addis Ababa 22-25 October 2007, November*, 71.

EEA Environmental Assessment Report. (2003). *Europe ' s environment : the third assessment* (Issue 10).

El Morr, C., Jammal, M., Ali-Hassan, H., & El-Hallak, W. (2022). Logistic Regression. *International Series in Operations Research and Management Science*, *334*, 231–249. *https://doi.org/10.1007/978-3-031-16990-8_7*

Eswaran, H., Lai, R., & Reich, P. (2001). Land degradation: An overview. Responses to Land Degradation. *Proc. 2nd. International Conference on Land Degradation and Desertification, KhonKaen, Thailand, 20–35.*

Ewunetu, A., Simane, B., Teferi, E., & Zaitchik, B. F. (2021). Mapping and quantifying comprehensive land degradation status using spatial multicriteria evaluation technique in the headwaters area of upper blue nile river. *Sustainability (Switzerland)*, *13*(4), 1–28. *https://doi.org/10.3390/su13042244*

FAO. (2006). Guidelines For Soil Description. In *Enhanced Recovery After Surgery* (Fourth edt). *https://doi.org/10.1007/978-3-030-33443-7_3*

FAO. (2017). The future of food and agriculture: trends and challenges, Rome. In The future of food and agriculture: trends and challenges (*Vol. 4, Issue 4). Ahttp://www.fao.org/3/a-https://ediss.uni goettingen.de/bitstream/han*

FAO. (2021). The state of the world's land and water resources for food and agriculture – Systems at breaking point. *Synthesis report 2021. Rome.*

FDRE. (2015). Federal Democratic Republic of Ethiopia Ethiopia - Land Degradation Neutrality National Report Target 6 : By 2026 ensure improved productivity of 72 , 766 ha of wetlands and water bodies through stopping uncompensated conversion of wetlands into cropping.

Ferrara, A., Kosmas, C., Salvati, L., Padula, A., Mancino, G., & Nole, A. (2020). Updating the MEDALUS- ESA Framework for Worldwide Land Degradation and

Desertification Assessment. *Land Degradation and Development*. *https://doi.org/10.1002/ldr.3559*

Fitsum, H., John, P., & Nega, G. (2000). Land degradation in the Highlands of Tigray and Strategies for Sustainable Land Management. *Policies for Sustainable Land Management in the Highlands of Ethiopia*, *30(July 1999), 2–75.*

Gashaw, T., Bantider, A., & G/Silassie, H. (2014). Land Degradation in Ethiopia: Causes, Impacts and Rehabilitation Techniques. *Journal of Environment and Earth Science*, *4*(9), 98–105. *http://www.iiste.org/Journals/index.php/JEES/article/viewFile/12963/13288*

Gatzweiler, F. W., & Von Braun, J. (2016). Technological and institutional innovations for marginalized smallholders in agricultural development. *Technological and Institutional Innovations for Marginalized Smallholders in Agricultural Development*, 1–435. *https://doi.org/10.1007/978-3-319-25718-1*

Gebreselassie, S., Kirui, O. K., & Mirzabaev, A. (2016). *Economics of Land Degradation and Improvement in Ethiopia BT - Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development* (E. Nkonya, A. Mirzabaev, & J. von Braun (eds.); pp. 401–430). *Springer International Publishing. https://doi.org/10.1007/978-3-319-19168-3_14*

GEF. (2019). *Land Degradation Neutrality: Guidelines for Gef Projects a Stap Document*.

Girma, R., & Gebre, E. (2020). Spatial modeling of erosion hotspots using GIS-RUSLE interface in Omo-Gibe river basin, Southern Ethiopia: implication for soil and water conservation planning. *Environmental Systems Research*, *9*(1). https://doi.org/10.1186/s40068-020-00180-7

Gnacadja, L. (2015). New challenges in science and policies to Combat Desertification. *Journal of Arid Environments*, *112*(PA), 1–4. *https://doi.org/10.1016/j.jaridenv.2014.10.010*

Gonzalez-Roglich, M., Zvoleff, A., Noon, M., Liniger, H., Fleiner, R., Harari, N., &

Garcia, C. (2019). Synergizing global tools to monitor progress towards land degradation neutrality: Trends.Earth and the World Overview of Conservation Approaches and Technologies sustainable land management database. *Environmental Science and Policy*, *93*(November 2018), 34–42. https://doi.org/10.1016/j.envsci.2018.12.019

Grainger, A. (2015). Is Land Degradation Neutrality feasible in dry areas? *Journal of Arid Environments*, *112*(PA), 14–24. https://doi.org/10.1016/j.jaridenv.2014.05.014

Guo, L.B.; Gifford, R. M. (2002). Soil carbon stocks and land use change: a meta analysis. *Global Change Biology*, *8*(4), 345–360; https://eurekamag.com/research/003/936/003936887.php

Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D. T., Fenta, A. A., Nyssen, J., & Adgo, E. (2017a). 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*, *574*, 95–108. https://doi.org/10.1016/j.scitotenv.2016.09.019

Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D. T., Fenta, A. A., Nyssen, J., & Adgo, E. (2017b). 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*, *574*(January 2017), 95–108. https://doi.org/10.1016/j.scitotenv.2016.09.019

Heckman, J. J. (1976). The Common Structure of Statistical Models of Truncation, Sample Selection and Limited Dependent Variables and a Simple Estimator for Such Models. *Annals of Economic and Social Measurement*, *5*(4), 475–492. http://ideas.repec.org/h/nbr/nberch/10491.html

Hengl, T., Mendes de Jesus, J., Heuvelink, G. B. M., Ruiperez Gonzalez, M., Kilibarda, M., Blagotić, A., Shangguan, W., Wright, M. N., Geng, X., Bauer-Marschallinger, B., Guevara, M. A., Vargas, R., MacMillan, R. A., Batjes, N. H., Leenaars, J. G. B., Ribeiro, E., Wheeler, I., Mantel, S., & Kempen, B. (2017). SoilGrids250m: Global gridded soil information based on machine learning. *PLOS ONE*, *12*(2), e0169748.

https://doi.org/10.1371/journal.pone.0169748

Hurni, H., Abate, S., Bantider, A., Debele, B., Ludi, E., Portner, B., Yitaferu, B., & Zeleke, and G. (2010). Land Degradation and Sustainable Land Management in the Highlands of Ethiopia. *Land Degradation and Development*, *9*(6), 529–542. https://doi.org/10.1002/(SICI)1099-145X(199811/12)9:6<529::AID-LDR313>3.0.CO;2-O

Hurni, H., & Zeleke, G. (2018). *Soil and Water - Conservation in Ethiopia* (Issue April).

Hurni, K., Zeleke, G., Kassie, M., Tegegne, B., Kassawmar, T., Teferi, E., Moges, A., Tadesse, D., Ahmed, M., Degu, Y., Kebebew, Z., Hodel, E., Amdihun, A., Mekuriaw, A., Debele, B., Deichert, G., & Hurni, H. (2015). The Economics of Land Degradation. Ethiopia Case Study. Soil Degradation and Sustainable Land Management in the Rainfed Agricultural Areas of Ethiopia: An Assessment of the Economic Implications. *Report for the Economcs of Land Degradation Initiative*, 94.

IUCN. (2015). *Land Degradation Neutrality: implications and opportunities for conservation, Technical Brief. November*, 19. https://portals.iucn.org/library/node/47869

Ivits, E., & Cherlet, M. (2013). *Land-productivity dynamics towards integrated assessment of land degradation at global scales*. https://doi.org/10.2788/59315

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., D., J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., L. R., P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., V., & Ranst, E., Yemefack, M. , Zougmoré R., (eds.). (2013). *Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg. 176 pp*. https://doi.org/10.2788/52319

Kadović, R., Bohajar, Y. A. M., Perović, V., Simić, S. B., Todosijević, M., Tošić, S., Mladan, M., Mladan, D., & Dovezenski, U. (2016). Land Sensitivity Analysis of Degradation using MEDALUS model: Case Study of Deliblato Sands, Serbia. *Archives of Environmental Protection*, *42*(4), 114–124. https://doi.org/10.1515/aep-

2016-0045

Kessler, A. (2018). *Decisive key-factors influencing farm households ' soil and water conservation investments*. *January 2006*. https://doi.org/10.1016/j.apgeog.2005.07.005

Kessler, C. A. (2006). Decisive key-factors influencing farm households' soil and water conservation investments. *Applied Geography*, *26*(1), 40–60. https://doi.org/10.1016/j.apgeog.2005.07.005

Kosmas, C., Kirkby, M. J., Geeson, N., & (Eds). (1999). *Medalus Project: Mediterranean Desertification and Land Use. Manual on Key Indicators of Desertification and Mapping Environmentally Sensitive Areas* (Issue November). http://www.kcl.ac.uk/projects/desertlinks/downloads/publicdownloads/ESA Manual.pdf

Kothari, C. R. (2004). Research methodology: Methods and techniques. In *Nucl. Phys.* (Vol. 13, Issue 1). New Age International (P), Ltd.Publishing.

Kuma, H. G., Feyessa, F. F., & Demissie, T. A. (2022). Heliyon Land-use / land-cover changes and implications in Southern Ethiopia : evidence from remote sensing and informants. *Heliyon*, *8*(March), e09071. https://doi.org/10.1016/j.heliyon.2022.e09071

Kumar, S., Raizada, A., Biswas, H., Srinivas, S., & Mondal, B. (2016). Application of indicators for identifying climate change vulnerable areas in semi-arid regions of India. *Ecological Indicators*, *70*, 507–517. https://doi.org/https://doi.org/10.1016/j.ecolind.2016.06.041

Kumar, S., Singh, D. R., Jha, G. K., Mondal, B., & Biswas, H. (2021). Key determinants of adoption of soil and water conservation measures: A review. *Indian Journal of Agricultural Sciences*, *91*(1), 8–15.

Kussul, N., Lavreniuk, M., Kolotii, A., Skakun, S., Rakoid, O., & Shumilo, L. (2020). A workflow for Sustainable Development Goals indicators assessment based on high-resolution satellite data. *International Journal of Digital Earth*, *13*(2), 309–321.

https://doi.org/10.1080/17538947.2019.1610807

Kust, G., Andreeva, O., & Cowie, A. (2017). Land Degradation Neutrality: Concept development, practical applications and assessment. *Journal of Environmental Management*, *195*, 16–24. https://doi.org/10.1016/j.jenvman.2016.10.043

Lötter, L., Stronkhorst, L. D., & Smith, H. J. (2009). Report : Sustainable Land Management Practices of South Africa. *Water*, *December*.

Luc Gnacadja and Liesl Wiese. (2016). Land Degradation Neutrality: Will Africa Achieve It? Institutional Solutions to Land Degradation and Restoration in Africa. In *Climate Change and Multi-Dimensional Sustainability in African Agriculture: Climate Change and Sustainability in Agriculture* (Issue November). https://doi.org/10.1007/978-3-319-41238-2

Luc Gnacadja and Liesl Wiese. (2017). *Land Degradation Neutrality : Will Africa Achieve It ? Institutional Solutions to Land Degradation and Restoration in Africa Chapter 5 Land Degradation Neutrality : Will Africa Achieve It ? Institutional Solutions to Land Degradation and Restoration in Af* (Issue November 2016). https://doi.org/10.1007/978-3-319-41238-2

Maxim, L., Spangenberg, J. H., & O'Connor, M. (2009). An analysis of risks for biodiversity under the DPSIR framework. *Ecological Economics*, *69*(1), 12–23. https://doi.org/10.1016/j.ecolecon.2009.03.017

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. https://doi.org/10.1016/j.iswcr.2017.12.006

Mellor, J. W., & Dorosh, P. (2010). Agriculture and the economic transformation of Ethiopia. *ESSP II Working Paper*. http://www.ifpri.org/sites/default/files/publications/esspwp010.pdf

Mengistu, D., Bewket, W., & Lal, R. (2016). Conservation Effects on Soil Quality and Climate Change Adaptability of Ethiopian Watersheds. *Land Degradation and*

Development, 27(6), 1603–1621. https://doi.org/10.1002/ldr.2376

Mengistu, F., & Assefa, E. (2019). Farmers' decision to adopt watershed management practices in Gibe basin, southwest Ethiopia. *International Soil and Water Conservation Research*, *7*(4), 376–387. https://doi.org/10.1016/j.iswcr.2019.08.006

Meseret, Desalew, & Amsalu, A. (2017). International Soil and Water Conservation Research Determinants of farmers ' perception to invest in soil and water conservation technologies in the North-Western Highlands of Ethiopia ☆. *International Soil and Water Conservation Research*, *5*(1), 56–61. https://doi.org/10.1016/j.iswcr.2017.02.003

Meseret, Dessalew. (2014). *Determinants of Farmers ' Perception of soil and water Conservation Practices on Cultivated Land in*. *2*(5), 1–9.

Ministry of Water Resources and the National Meteorological Services Agency. (2001). *Initial National Communication of Ethiopia to the United Nations Framework Convention on Climate Change*. *June*, 1–113.

Moges, D. M., & Taye, A. A. (2017). Determinants of farmers' perception to invest in soil and water conservation technologies in the North-Western Highlands of Ethiopia. *International Soil and Water Conservation Research*, *5*(1), 56–61. https://doi.org/10.1016/j.iswcr.2017.02.003

Momirović, N., Kadović, R., Perović, V., Marjanović, M., & Baumgertel, A. (2019). Spatial assessment of the areas sensitive to degradation in the rural area of the municipality Čukarica. *International Soil and Water Conservation Research*, *7*(1), 71–80. https://doi.org/10.1016/j.iswcr.2018.12.004

Montanarella, Luca; Scholes, R., and Brainich, A. (2018). Land degradation and restoration. In *Companion to Environmental Studies*. https://doi.org/10.4324/9781315640051-105

MoWIE. (2002). Water Sector Development Program - Main report. *Report*, *I*(October), 193.

Muluneh, A., Stroosnijder, L., Keesstra, S., & Biazin, B. (2017). Adapting to climate change for food security in the Rift Valley dry lands of Ethiopia: Supplemental irrigation, plant density and sowing date. *Journal of Agricultural Science*, *155*(5), 703–724. https://doi.org/10.1017/S0021859616000897

Negash, Teklu and Mesfin, K. (2011). Proceeding of the National Workshop in Integrated Watershed Management on Gibe - Omo Basin. *Proceeding of the National Workshop in Integrated Watershed Management on Gibe - Omo Basin*, 91.

Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. U. (2014). *Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. *January*.

Nkonya, E., Mirzabaev, A., & von Braun, J. (2015). Economics of land degradation and improvement - A global assessment for sustainable development. *Economics of Land Degradation and Improvement - A Global Assessment for Sustainable Development*, 1–686. https://doi.org/10.1007/978-3-319-19168-3

NMSA. (2001). Initial National Communication of Ethiopia to the United Nations Frame-Work Convention on Climate Change (UNFCCC). *Unpublished Technical Report*, *June*.

Noe, C. (2014). Reducing Land Degradation on the Highlands of Kilimanjaro Region: A Biogeographical Perspective. *Open Journal of Soil Science*, *04*(13), 437–445. https://doi.org/10.4236/ojss.2014.413043

Nyssen, J., Clymans, W., Descheemaeker, K., Poesen, J., Vandecasteele, I., Vanmaercke, M., Zenebe, A., Van Camp, M., Haile, M., Haregeweyn, N., Moeyersons, J., Martens, K., Gebreyohannes, T., Deckers, J., & Walraevens, K. (2010). Impact of soil and water conservation measures on catchment hydrological response-a case in north Ethiopia. *Hydrological Processes*, *24*(13), 1880–1895. https://doi.org/10.1002/hyp.7628

Nyssen, J., Poesen, J., Lanckriet, S., Jacob, M., Moeyersons, J., Haile, M., Haregeweyn, N., Munro, R. N., Descheemaeker, K., Adgo, E., Frankl, A., & Deckers, J. (2015).

Land Degradation in the Ethiopian Highlands. *World Geomorphological Landscapes*, *2011*, 369–385. https://doi.org/10.1007/978-94-017-8026-1_21

Okpara, U. T., Stringer, L. C., Akhtar-Schuster, M., Metternicht, G. I., Dallimer, M., & Requier-Desjardins, M. (2018). A social-ecological systems approach is necessary to achieve land degradation neutrality. *Environmental Science and Policy*, *89*(November), 59–66. https://doi.org/10.1016/j.envsci.2018.07.003

Omuto, C. T., Balint, Z., & Alim, M. S. (2014). A Framework for national assessment of land degradation in the drylands: A case study of somalia. *Land Degradation and Development*, *25*(2), 105–119. https://doi.org/10.1002/ldr.1151

Orgánico, C., Del, Y. N., & En, S. (2011). *Effects Of Landuse On Soil Organic Carbon And Nitrogen In Soils Of Bale, Southeastern Ethiopia*.

Orr, B. ., L, A., Cowie, V. M., Castillo Sanchez, P., Chasek, N. D., Crossman, A., Erlewein, G., Louwagie, M., Maron, G. I., Metternicht, S., Minelli, A. E., Tengberg, S., & Walter, S. (2017). Framework for Land Degradation Neutrality: A Report of the Science-Policy Interface. In *UNCCD-SPI Technical Series No.01*. https://knowledge.unccd.int/sites/default/files/2018-09/LDN_CF_report_web-english.pdf

Orr, B. J., Cowie, A. L., Castillo Sanchez, V. M., Chasek, P., Crossman, N. D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G. I., & Minelli, S. (2017). Scientific conceptual framework for land degradation neutrality. In *A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany* (Issue February).

Orr, B. J., Cowie, A. L., Castillo, V. M., Sanchez, P., Chasek, N. D., Crossman, Erlewein, A., Louwagie, G., Maron, M., Metternicht, G. I., Minelli, S., Tengberg, A. E., Walter, S., & Welton, S. (2017). Scientific Conceptual Framework for Land Degradation Neutrality. A report of the Science-Policy Interface. In *United Nations Convention to Combat Desertification - UNCCD*. https://www.unccd.int/sites/default/files/documents/2019-06/LDN_CF_report_web-english.pdf%0Ahttps://www2.unccd.int/sites/default/files/documents/2017-

08/LDN_CF_report_web-english.pdf

Park, H. A. (2013). An introduction to logistic regression: From basic concepts to interpretation with particular attention to nursing domain. *Journal of Korean Academy of Nursing*, *43*(2), 154–164. https://doi.org/10.4040/jkan.2013.43.2.154

Paudel, G. S., & Thapa, G. B. (2004). Impact of social, institutional and ecological factors on land management practices in mountain watersheds of Nepal. *Applied Geography*, *24*(1), 35–55. https://doi.org/10.1016/j.apgeog.2003.08.011

Petrosillo, I., Aretano, R., & Zurlini, G. (2018). Socioecological systems. *Encyclopedia of Ecology*, *October 2017*, 419–425. https://doi.org/10.1016/B978-0-12-409548-9.09518-X

Posthumus, H. (2005). Adoption of terraces in the Peruvian Andes. *Tropical Resource Management Papers, 72*, 216. https://edepot.wur.nl/18307

Prăvălie, R., Patriche, C., Săvulescu, I., Sîrodoev, I., Bandoc, G., & Sfîcă, L. (2020). Spatial assessment of land sensitivity to degradation across Romania. A quantitative approach based on the modified MEDALUS methodology. *Catena*, *187*(December 2019), 104407. https://doi.org/10.1016/j.catena.2019.104407

Prăvălie, R., Săvulescu, I., Patriche, C., Dumitraşcu, M., & Bandoc, G. (2017). Spatial assessment of land degradation sensitive areas in southwestern Romania using modified MEDALUS method. *Catena*, *153*, 114–130. https://doi.org/10.1016/j.catena.2017.02.011

Reed, M. S., Stringer, L. C., Dougill, A. J., Perkins, J. S., Atlhopheng, J. R., Mulale, K., & Favretto, N. (2015). Reorienting land degradation towards sustainable land management: Linking sustainable livelihoods with ecosystem services in rangeland systems. *Journal of Environmental Management*, *151*, 472–485. https://doi.org/10.1016/j.jenvman.2014.11.010

Salvati, L., & Bajocco, S. (2011). Land sensitivity to desertification across Italy: Past, present, and future. *Applied Geography*, *31*, 223–231. https://doi.org/10.1016/j.apgeog.2010.04.006

Sanz, M., de Vente, J. Chotte, M. Bernoux, G. Kust, I. Ruiz, M. Almagro, J.-A. Alloza, R. Vallejo, V. Castillo, A. Hebel, and M. A.-S. (2017). *Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation*.

SCHWILCH, F. B. A. H. L. (2009). Appraising and Selecting Conservation Measures To Mitigate Desertification And Land Degradation Based On Stakeholder Participation And Global Best Practices. *Land Degradation & Development*, *607*(July), 591–607. https://doi.org/10.1002/ldr

Seid, M., Simane, B., Teferi, E., & Azmeraw, A. (2022). Determinants of farmers' multiple-choice and sustainable use of indigenous land management practices in the Southern Rift Valley of Ethiopia. *Current Research in Environmental Sustainability*, *4*(April), 100158. https://doi.org/10.1016/j.crsust.2022.100158

Sewell, A., Esch, S. Van Der, & Lowenhardt, H. (2020). Goals and Commitments for the Restoration Decade. *PBL Policy Brief*. https://www.pbl.nl/sites/default/files/downloads/pbl-2020-goals-and-commitments-for-the-restoration-decade-3906.pdf

Shiferaw, B., & Holden, S. T. (1998). Resource degradation and adoption of land conservation technologies in the Ethiopian Highlands: A case study in Andit Tid, North Shewa. *Agricultural Economics*, *18*(3), 233–247. https://doi.org/10.1111/j.1574-0862.1998.tb00502.x

Sileshi, M., Kadigi, R., Mutabazi, K., & Sieber, S. (2019). Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia. *International Soil and Water Conservation Research*, *7*(4), 354–361. https://doi.org/10.1016/j.iswcr.2019.08.002

Sims, N.C., Green, C., Newnham, G. J., England, J. R., Held, A., Wulder, M. A., Herold, M., Cox, S. J. D., Huete, A. R., Kumar, L., Viscarra-Rossel, R. A., Roxburgh, S. H., & McKenzie, N. J. (2021). *Good Practice Guidance: SDG Indicator 15.3.1. Version 2.0* (Issue September). https://www.unccd.int/sites/default/files/relevant-links/2017-10/Good Practice Guidance_SDG Indicator 15.3.1_Version 1.0.pdf

Sims, N.C., Newnham, G. J., England, J. R., Guerschman, J., Cox, S. J. D., Roxburgh, S. H., Viscarra Rossel, R. A., Fritz, S., & Wheeler, I. (2021). Good Practice Guidance. SDG Indicator 15.3.1, Proportion of Land That Is Degraded Over Total Land Area. Version 2.0. In *United Nations Convention to Combat Desertification (UNCCD)* (Issue March).

Sims, Neil C., England, J. R., Newnham, G. J., Alexander, S., Green, C., Minelli, S., & Held, A. (2019). Developing good practice guidance for estimating land degradation in the context of the United Nations Sustainable Development Goals. *Environmental Science and Policy*, *92*(November 2018), 349–355. https://doi.org/10.1016/j.envsci.2018.10.014

Sinore, T., & Doboch, D. (2021). Effects of Soil and Water Conservation at Different Landscape Positions on Soil Properties and Farmers' Perception in Hobicheka Sub-Watershed, Southern Ethiopia. *Applied and Environmental Soil Science*, *2021*. https://doi.org/10.1155/2021/9295650

Song, C., Kim, W., Kim, J., Gebru, B. M., Adane, G. B., Choi, Y. E., & Lee, W.-K. (2021). Spatial assessment of land degradation using MEDALUS focusing on potential afforestation and reforestation areas in Ethiopia. *Land Degradation & Development*, *n/a*(n/a). https://doi.org/https://doi.org/10.1002/ldr.4130

Sonneveld, B. G. J. S., Keyzer, M. A., & Stroosnijder, L. (2011). Evaluating quantitative and qualitative models: An application for nationwide water erosion assessment in Ethiopia. *Environmental Modelling and Software*, *26*(10), 1161–1170. https://doi.org/10.1016/j.envsoft.2011.05.002

Stavi, I., & Lal, R. (2015). Achieving Zero Net Land Degradation: Challenges and opportunities. *Journal of Arid Environments*, *112*(PA), 44–51. https://doi.org/10.1016/j.jaridenv.2014.01.016

Ştefãnescu, M., & Ciuvăţ, L. A. (2018). Land degradation neutrality – A new pathway towards sustainable development in Romania. *Quality - Access to Success*, *19*(S1), 526–529.

Sundarapandian, S. M., & Subbiah, S. (2015). Diversity and tree population structure of tropical dry evergreen forests in Sivagangai district of Tamil Nadu, India. *Tropical Plant Research*, *2*(1), 36–46.

Tadesse, B. M. (2013). *Sustainable Land M anagement Program in Ethiopia " Linking Local REDD + Projects to National REDD + Strategies & Initiatives ."*

Tefera, B., & Sterk, G. (2010). Land management, erosion problems and soil and water conservation in Fincha'a watershed, western Ethiopia. *Land Use Policy*, *27*(4), 1027–1037. https://doi.org/10.1016/j.landusepol.2010.01.005

Teferi, E. (2019). *Mapping Land Degradation Based on the Composite Land Degradation Index for Ethiopia*. *June*.

Tesfaye, A., Negatu, W., Brouwer, R., and Van Der Zaag, P. (2014). UNDERSTANDING SOIL CONSERVATION DECISION OF FARMERS IN THE GEDEB WATERSHED, ETHIOPIA. In *Land Degradation and Development* (Vol. 25, Issue 1, pp. 71–79). https://doi.org/10.1002/ldr.2187

Tesfaye, G., Zerihun, M., Menfese, T. and Narayana, S. C. (2013). *Adoption of structural soil and water conservation technologies by small holder farmers in Adama Wereda, East Shewa, Ethiopia. International Journal of Advanced Structures and Geotechnical Engineering*.

Teshome, A., de Graaff, J., & 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, A., Graaff, J., Berresaw, M., & Stroosnijder, L. (2012). Role of institutional and socio-economic factors on adoption, dis-adoption and non-adoption of soil and water conservation technologies: Empirical evience from the North Western Ethiopia highlands. *Microbiology-Sgm, September 2015*.

Thomas, R. J., Quillérou, E., Stewart, N., Thomas, R. J., Quillérou, E., & Stewart, N. (2019). *The rewards of investing in sustainable land management To cite this* *version : HAL Id : hal-01954823 Economics of Land Degradation Initiative : A global strategy for sustainable land management*.

Tilahun, M. (2020). *The Economics of Land Degradation Neutrality in Ethiopia: Empirical Analyses and Policy Implications for the Sustainable Development Goals. March*.

Tilahun, S. A., Guzman, C. D., Zegeye, A. D., Engda, T. A., Collick, A. S., Rimmer, A., & Steenhuis, T. S. (2013). An efficient semi-distributed hillslope erosion model for the subhumid Ethiopian Highlands. *Hydrology and Earth System Sciences*, *17*(3), 1051–1063. https://doi.org/10.5194/hess-17-1051-2013

Tiwari, K. R., Sitaula, B. K., Nyborg, I. L. P., & Paudel, G. S. (2008). Determinants of farmers' adoption of improved soil conservation technology in a Middle Mountain Watershed of Central Nepal. *Environmental Management*, *42*(2), 210–222. https://doi.org/10.1007/s00267-008-9137-z

Tizale, C. Y. (2007). *The dynamics of soil degradation and incentives for optimal management in the Central Highlands of Ethiopia*. *February*.

Toma, M. B., Belete, M. D., & Ulsido, M. D. (2022). *Historical and future dynamics of land use land cover and its drivers in Ajora - Woybo watershed , Omo - Gibe basin , Ethiopia*. *April*, 1–27. https://doi.org/10.1111/nrm.12353

Tully, K., Sullivan, C., Weil, R., & Sanchez, P. (2015). The State of soil degradation in sub-Saharan Africa: Baselines, trajectories, and solutions. *Sustainability (Switzerland)*, *7*(6), 6523–6552. https://doi.org/10.3390/su7066523

UN. (2012). The future we want: Outcome document of the United Nations Conference on Sustainable Development. *United Nations*, 41. https://sustainabledevelopment.un.org/content/documents/733FutureWeWant.pdf

UN. (2013). *Convention to Combat Desertification Committee on Science and Technology Report of the Committee on Science and Technology on its third special session , held in Bonn from 9 to 12 April*. *June*.

UN (United Nations). (2018). *Progress made in setting voluntary national targets in* *support of land degradation neutrality implementation*. *April*.

UNCCD. (2013). *Report of the Conference of the Parties on its eleventh session, held in Windhoek from 16 to 27 September 2013 Part two: Action taken by the Conference of the Parties at its eleventh session Addendum*. *November 2013*. https://www.unccd.int/sites/default/files/sessions/documents/ICCD_COP11_23_Add.1/23add1eng.pdf

UNCCD. (2014). Desertification: The Invisible Frontline. *United Nations Convention to Combat Desertification*, 1–17. https://www.unccd.int/sites/default/files/documents/12112014_Invisible frontline_ENG.pdf

UNCCD. (2015). Integration of the Sustainable Development Goals and targets into the implementation of the United Nations Convention to Combat Desertification and the Intergovernmental Working Group report on land degradation neutrality. *Convention to Combat Desertification*, *11235*(July), 2–14. https://www.unccd.int/sites/default/files/inline-files/dec3-COP.12eng.pdf

UNCCD. (2016). *Nigeria Final report of the Land Degradation Neutrality Target Setting Programme*. *January*. https://knowledge.unccd.int/sites/default/files/ldn_targets/Nigeria LDN TSP Country Report.pdf

UNCCD. (2018). *Default data: methods and interpretation A guidance document for 2018 UNCCD reporting*. *February*, 54.

UNCCD. (2019). *Land-based Adaptation and Resilience*. isbn: 978-92-95043-84-8

UNCCD. (2022). Global Land Outlook, United Nations Convention to Combat Desertification. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, 1–20. https://doi.org/10.5822/978-1-61091-484-0_1

UNEP, E. I. &. (2015). *The Economics of Land Degradation in Africa: Benefits of Action Outweigh the Costs*. 151 pages. isbn: 978?92-808?6064-1%5CnThis ELD report was published with the support of the partner organisations of the ELD Initiative and Deutsche Gesellschaft fu?r Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Coop

UNESCO. (2016). Education for people and planet: Creating sustainable futures for all. In *The Global Education Monitoring Report 2nd Edition*. http://uis.unesco.org/sites/default/files/documents/education-for-people-and-planet-creating-sustainable-futures-for-all-gemr-2016-en.pdf

United Nations. (2018). *The 2030 Agenda and the Sustainable Development Goals An opportunity for Latin America and the Caribbean Thank you for your interest in this ECLAC publication*.

United Nations. (2022). Land , Climate and Development. *Global Climate & SDG Synergy Conference,Tokyo*,1–7. https://www.un.org/sites/un2.un.org/files/land_climate_and_development_by_unccd.pdf

United Nations Convention to Combat Desertification UNCCD. (2016). *Land Degradation Neutrality Target Setting Programme Land Degradation Neutrality Target Setting-A Technical Guide Draft for consultation during the Land Degradation Neutrality Target Setting Programme inception phase*. *May*.

UNO. (2018). The sustainable development goals report 2019. *United Nations Publication Issued by the Department of Economic and Social Affairs*, 64. https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report 2019_Spanish.pdf%0Ahttps://undocs.org/E/2019/68

UUNCCD. (2014). *Land Degradation Neutrality Resilience At Local, National and Regional Levels*. 24. http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/Land_Degrad_Neutrality_E_Web.pdf

Van Beek, C. L. (Christy), Elias, E., G. Selassie, Y., Gebresamuel, G., Tsegaye, A., Hundessa, F., Tolla, M., Mamuye, M., Yemane, G., & Mengistu, S. (2019). Soil organic matter depletion as a major threat to agricultural intensification in the highlands of Ethiopia. *Ethiopian Journal of Science and Technology*, *11*(3), 271. https://doi.org/10.4314/ejst.v11i3.5

van Haren, N., Fleiner, R., Liniger, H., & Harari, N. (2019). Contribution of community-based initiatives to the sustainable development goal of Land Degradation Neutrality. *Environmental Science and Policy*, *94*(November 2018), 211–219. https://doi.org/10.1016/j.envsci.2018.12.017

Vieira, R. M. S. P., Tomasella, J., Alvalá, R. C. S., Sestini, M. F., Affonso, A. G., Rodriguez, D. A., Barbosa, A. A., Cunha, A. P. M. A., Valles, G. F., Crepani, E., De Oliveira, S. B. P., De Souza, M. S. B., Calil, P. M., De Carvalho, M. A., Valeriano, D. M., Campello, F. C. B., & Santana, M. O. (2015). Identifying areas susceptible to desertification in the Brazilian northeast. *Solid Earth*, *6*(1), 347–360. https://doi.org/10.5194/se-6-347-2015

Vlek, P. L. G., Khamzina, A. & Tamene, L. (2017). Land degradation and the Sustainable Development Goals : Threats and potential remedies. *CIAT Publication No. 440. International Center for Tropical Agriculture (CIAT), Nairobi, Kenya*, 67.

Willemen, L., Crossman, N. D., Quatrini, S., Egoh, B., Kalaba, F. K., Mbilinyi, B., & de Groot, R. (2018). Identifying ecosystem service hotspots for targeting land degradation neutrality investments in south-eastern Africa. *Journal of Arid Environments*, *159*, 75–86. https://doi.org/10.1016/j.jaridenv.2017.05.009

Wolka, K., Sterk, G., Biazin, B., & Negash, M. (2018). Benefits, limitations and sustainability of soil and water conservation structures in Omo-Gibe basin, Southwest Ethiopia. *Land Use Policy*, *73*(December 2016), 1–10. https://doi.org/10.1016/j.landusepol.2018.01.025

World Bank. (2008). Sustainable Land Management Sourcebook. In *Sustainable Land Management Sourcebook*. https://doi.org/10.1596/978-0-8213-7432-0

WWF. (2022). *Towards Nature Positive – The Role of Restoration for Land Degradation Neutrality*.

Xu, X., Wong, S. C., Zhu, F., Pei, X., Huang, H., & Liu, Y. (2017). A Heckman selection model for the safety analysis of signalized intersections. *PLOS ONE*, *12*(7), 1–16. https://doi.org/10.1371/journal.pone.0181544

Yee, A. T. K., Corlett, R. T., Liew, S. C., & Tan, H. T. W. (2011). The vegetation of Singapore — an updated map. *Gardens' Bulletin Singapore*, *63*(1&2), 205–212.

Zeleke, G., Kassie, M., Pender, J., & Yesuf, M. (2006). *Stakeholder Analysis for Sustainable Land Management (SLM) in*. *January*.

Appendix: Survey Questionnaire

Dear Respondents:

My name is Habtamu Dagne. I am a postgraduate student (Ph.D.) at Addis Ababa university center for Environment and Development. Now I am conducting a study titled: **Towards Land Degradation Neutrality: States, Achievements and Sustainability in Omo-Gibe River Basin, Ethiopia**. The objective of this questionnaire is to collect primary data about land degradation, the status of land productivity, soil organic carbon, land cover change, land management activities, and their sustainability, socio-economic and other related information necessary to assess the current state of the farmland to achieve sustainable development. Therefore, you are kindly requested to respond freely and accurately to the success of this study. I would be grateful if you could provide me with the relevant information needed in this questionnaire. All information you provide will be confidential and used for academic purposes only.

Thank you in advance for your cooperation.

I. Basic Information Regarding Household Head

No.	Questions	Categories	Code	(✓) Remark
1.	Sex of respondent	Male	1	
		Female	2	
2.	Age of respondent?			
3.	What is the status of the respondent in the community?			
4.	What is the marital status of the respondent?	Married	1	
		Single	2	
		Divorced	3	
		Widowed	4	
5.	What is the highest education level of the respondent?	unable to read and write	1	
		Only able to read and write	2	
		First cycle primary education (grades 1-4)	3	
		Second cycle primary education (grades 5-8)	4	
		Secondary education (grades 9-10)	5	
		Preparatory education (Grades 10-12)	6	
		University/College and above	7	
6.	Type of occupation?	Farming	1	
		Trade	2	
		Handcraft	3	
		Gov't employee	4	
		Other (specify) _______________		

7.	farming experience (in a year)	______________________		
8.	Land slope	Gentle slope	1	
		Moderate	2	
		steep slope	3	
		Very steep slope	4	
9.	Soil type (color)	Gray color	1	
		Reddish color	2	
		Brown color	3	
		Black color	4	
10.	Mean Distance of farm plot from homestead (in walking hours)	_____________________		
11.	Frequency of extension agents Contacts	Once Per week	1	
		Once per month	2	
		More than one time per month	3	
		Once per year	4	
		No contact	5	
		Other (specify) _______________		
12.	Accesses to training	DAs	1	
		NRM experts	2	
		NGOs	3	
		Media	4	
		Neighbors	5	
		No access to training	6	
13.	Do you participate Off-farm work?	Yes	1	
		No	2	

II. Natural Capital

No	Question	Categories	Rank	(✓) Remark
14.	How many hectares/acres/pieces of farmland do you own?			
15.	How did you acquire this land?	Inherited	1	
		Bought land	2	
		Rented land	3	
		Others (Specify) _______________		
16.	Do you feel land tenure security?	yes	1	
		No	2	
17.	What is the type of land ownership?	Individual/Sole title	1	
		Communal	2	

		Rental	3	
		Allocation	4	
18.	How has the total area of your parcels change d compared to 10 years ago?	Increased	1	
		decreased	2	
		Remained the same	3	
19.	Why has the total area of your parcels increas ed?	Inherited	1	
		Bought more land	2	
		Bought more land	3	
		Others (Specify)	____________	
20.	Why has the total area of your parcels decrea sed?	Subdivided to children/ heirs	1	
		Sold	2	
		Stopped renting	3	
		Others (Specify)	___________	

21. What are the primary uses of the land? How has this changed over the last ten years?

Household land use types	Area of land (ha)	Changes (Increased or decreased)
Cropping		
Pasturing		
Forest/ woodland		
Others (Specify) ___________		

22. Which crops do you grow,and what are the household uses of significant crops? Tick accordingly

Crop type	Crop use		
	Consumption	Market	Others

23. How has the production of the major food crops changed over the last ten years?

Improved ☐ Decreased ☐ No Change ☐

24. Do you own livestock? Yes □ No □

25. Which type of livestock do you keep? What mode of feeding do you use? How has the size of livestock herds changed over the last ten years?

Animal type	Approximate number	Mode of grazing*	changes (increased, no change, or decreased)
Cattle			
Goat			
Sheep			
Donkey			
Poultry			
Others (specify)			

*Z-zero grazing, N- nomadic/free range, and T- tethering

26. Does the household own its grazing land(s)? Yes □ No □

    If 'YES,' what is the area of grazing land? …………………………..

    If 'NO' ,

    then on what basis is the grazing land being used? Rental □ Shared arrangem ent □ Open-access □

27. How far is the grazing land from the home? ……………………………………..

28. Has this distance to grazing lands changed in the last ten years? Explain Yes □ N o □

…………………………………………………………

No	Questions	Category	Rank	Remark
29.	What types of forests/woodlands are at a farm or community level?	Natural	1	
		Planted	2	
30.	What are the primary uses of forests/woo dlands?	Fuelwood	1	
		Fruits	2	
		Medicine	3	
		Honey	4	
		Livestock	5	
		Wild meat	6	

		Others (specify)----		
31.	What are the household sources of energy ?	Fuelwood	1	
		Electricity	2	
		Crop residues	3	
		Paraffin	4	
		Gas	5	
		Charcoal	6	
		Others (Specify) …………		
32.	Is the household self-sufficient in accessing fuel wood?	Yes	1	
		No	2	
33.	Where do you get fuel wood?	On-farm	1	
		Collect from forest	2	
		Market	3	
		Neighbors	4	
		Others (Specify) …………		
34.	How far do you travel to collect fuelwood ? ……………km			

35. What changes have been observed in forests/woodlands on your land and neighborhood?

Resource	Increased	Decreased	Remain the same
Natural forest			
Planted forest			

No	Questions	Category	Rank	Remark
36.	What are the reasons for the increase?	Afforestation	1	
		Restricted cutting	2	
		Other (specify)		
37.	What are the reasons for the decrease?	Fuel wood collection	1	
		Timber	2	
		Conversion to agriculture	3	

		Government excision	4	
		Growth of urban areas	5	
		Other (specify)		
38.	What goods or services have you gained or los t due to the changes in forests described above?			
39.	What adjustments has the household made to adapt to the changes discussed above?			

40. What are the primary sources and uses of water by the household? tick accordingly

Source	Domestic	Livestock	Irrigations	Others
Borehole				
Open wells				
Springs				
Piped				
Rives				
Dams				
Other (specify)				

No	Questions	Category	Remark
41.	How far do you travel to access water for the following u ses? (m/km/minutes)	Domestic	
		Livestock	
		Irrigation	
42.	What changes have occurred in the quantity of water sour ces listed above over the last ten years?	Increased	
		Decreased	
		No change	
	Explain the reasons for the change.		
43.	What changes have occurred in the quality of water sourc es listed above over the last ten years?	Improved	
		Decreased	
		No change	
	Explain the reasons for the change.		

III. States of Land Degradation

44. From your assessment, what is the status of the following land resources in your villa ge? tick accordingly

Resource	Improved	No change	Declined
Cropping land			
Grazing land			
Forested land			
Water resources			

45. What are the indicators of changes/trends mentioned above?

Resource	Indicators
Cropping land	
Grazing land	
Forested land	
Water resources	

46. Do you think that there is land degradation in your farmland?

☐ Yes ☐ No

47. If your answer is yes for Q45, when land degradation occurs on your farmland?

☐ In the last five years ☐ , In the last ten years ☐ , In the last fifteen years

☐ In the last twenty years

48. Which of the following types of land degradation is occurring in your farmland and neighborhood? How do you rate the degree of degradation?

A. Soil erosion	**Occurrence**	**Degree/magnitude**		
	Yes/No	Light	Moderate	Strong
Loss of topsoil				
River bank erosion				
Gully erosion				
Landslides				
Other (specify) ______________				
B. Chemical deterioration	Yes/No	Light	Moderate	Strong
Fertility decline				
Reduced organic matter content				
Acidification				

Other (specify) _____________				
C. Physical soil deterioration	Yes/No	Light	Moderate	Strong
Compaction				
Sealing and crusting				
Water logging				
Other (specify) _____________				
D. water degradation	Yes/No	Light	Moderate	Strong
Change in quantity of surface water				
Change groundwater				
The decline in surface water quality				
Decline groundwater quality				
Other (specify) _____________				
E. Biological Degradation	Yes/No	Light	Moderate	Strong
Reduction of vegetation cover				
Loss of habitats				
Diversity decline				
Increases in pests/diseases				
Other (specify) _____________				

No	Questions	Category	Remark
49.	How much of your farmland is damaged by land degradation in hectares?	<1 hectare of land	
		2 hectares of land	
		3 hectares of land	
		Above 4 hectares of land	
50.	Are you using chemical fertilizers to increase crop productivity?	Yes	
		No	
51.	If your answer is yes for Q no 49, when did you start to use artificial fertilizer?	In the last five years	
		In the last ten years	
		In the last fifteen years	
		Other (specify) __________	
52.	Which inputs do you use to i mprove soil fertility on your farm?	Fertilizer	
		Compost	
		Animal Manure	
		Lim	
		Other (specify) _________	
53.	Which of the following are the direct causes of land deg	Poor soil and crop management	
		Deforestation and removal of natural vegetation	

	radation in your locality?	Industrial activities and mining	
		Urbanization and infrastructure development	
		Overgrazing	
		Natural causes (changes in temperature, rainfall, and drought)	
		Other (specify) ________	
54.	What are the indirect cause s of land degradation in you r village?	High population pressure	
		Poverty	
		The weak land tenure system	
		Poor access to inputs (e.g. high input fertilizers pri ces)	
		Poor infrastructure	
		Lack of awareness, access to knowledge and suppo rt services	
		Poor governance / institutional	
		Other (specify) ________	

IV. Farmers' Decision on Land Management Technologies

55. Have you ever used traditional types of SWC measures on your plots?

☐ Yes ☐ No

If No for Q (54), what is/are the reason/s? ....

56. If yes, for Q (54), which type of traditional SWC measure do you construct?

☐ Traditional *ditches/boyi* ☐ *agdem mares/contour* plowing

☐ Others specify ....

57. Have you ever used introduced/ modern types of SWC measures on your plots?

☐ Yes ☐ No

If you say no for Q (56), what is/are the reason/ s? ....

58. If you say yes, Q (56), what modern SWC measures do you use?

☐ Stone bund ☐ soil bunds ☐ stone-faced ☐ check dams

☐ deep trench for harvesting water ☐ exclosure in degraded steep slopes

☐ Hillside terrace ☐ others, specify.. ....

59. What have you done with the soil and water conservation technologies introduced to the area?

☐ Never applied the technology in the field

☐ I applied but removed them completely

☐ Applied but removed them selectively

☐ Applied and maintained the conservation measures introduced

60. Specify the spread of the Technology in your locality:
    - ☐ evenly spread over an area (e.g. mulching, series of terraces, afforestation, micro-catchments)
    - ☐ applied at specific points/ concentrated on a small area (e.g. water points, dams, compost production pits, small stock stables, hydropower stations)
61. If the Technology is evenly spread over an area, indicate the approximate area covered:

☐ < 0.1 km^2 (10 ha)	☐ 100-1,000 km^2
☐ 0.1-1 km^2	☐ 1,000-10,000 km^2
☐ 1-10 km^2	☐ > 10,000 km^2
☐ 10-100 km^2	

62. Which mechanical soil conservation measure do you know?

☐ Terrace ☐ Water ways ☐ Cut of drain ☐ Check dams ☐ soil bund

☐ Stone bund ☐ funny juu ☐ Other specify _________________

63. Have you adopted soil bund on either of your farm plots?

☐ Yes ☐ No

64. Where slope gradients soil bunds are implemented?

☐ Steep ☐ Gentle ☐ Flat

65. Do you practice minting or modifying soil bund on one of your farm plots in the last three years?

☐ Yes ☐ No

66. Do you practice the following soil bund characteristics for the last three years?

Maintenance	☐ Yes	☐ No
Modification	☐ Yes	☐ No
Fertilizer	☐ Yes	☐ No
Compost	☐ Yes	☐ No
Manure	☐ Yes	☐ No

67. What is the present status of the SWC technology (soil bund)?

☐ in good condition ☐ , partially damaged ☐ , completely damaged

68. If any of these is entirely/partially damaged, what is the problem/ reason?

☐ Overgrazing ☐ design problem ☐ structures by its own ☐ purposefully

☐ Runoff ☐ others specify............... .

69. If the damage is purposefully for Q (87), what is the reason?

☐ Harbor pests ☐ hinder Oxen plowing, ☐ taking the more productive land, ☐ poor design of structures ☐ , poor initial construction of modern measures

☐ Others specify ....

70. What is the reason if the damage is run off/sheet erosion for Q (87)?

☐ Weakness of the structure done ☐ strength of the run off ☐ old age of structures due to lack of maintenance ☐ others, specify ....

71. How frequently do you maintain SWC structures?

☐ Every year ☐ within two years, ☐ when damage happens ☐ to others, specify …..

72. Are the maintenance and construction of SWC structures done at the same time or at different times with other farm activities? ☐ Same ☐ Different

73. What major problems do you face regarding SWC structures recommended by the Woreda Agricultural Office?

☐ Putting up conservation structures ☐ Labor competition with other farm activities

☐ Enforcement without willingness ☐ Others specify ....

74. How do you construct SWC structures/ technologies?

☐ With group ☐ family labor ☐ debo/wonfel ☐ others specify ....

75. Do you have the intention to implement SWC measures in the rest of your farmland currently untreated? ☐ Yes ☐ no, why? ....

76. Why do you construct SWC measures on your land?

☐ Forced to participate Currently untreated ☐ To get aid ☐ voluntarily, because of its benefit for us ☐ others, specify ....

77. What major problems do you face in establishing and using SWC technologies?

Problems/ constraints	Rank
High labor requirement	
Occupies cultivable land	
Favors the growth of pests and weeds	
Difficulty in plowing by oxen	
Overlap with other farm activities.	
Others, specify	

V.Farmers' Opinions on the Sustainability of Soil Conservation Measures

78. What is your opinion about the productivity of soil conservation measures introduced to the area compared to the traditional ones?

☐ Less productive than the traditional ones

☐ The same as the traditional conservation measures

☐ More productive than the traditional ones

79. What do you think about the ability of the introduced conservation measures to ensure sustainable yield compared to the traditional ones?

☐ Less able than the traditional ones

☐ The same as the traditional ones

☐ better than the traditional ones

80. Do you know the existence of improved soil and water conservation structures?

☐ Yes ☐ No

81. If yes, for Q 99, which types do you know? (Multiple answers is possible)

☐ Stone bunds ☐ Soil bund ☐ Cutoff drain ☐ Water way ☐ Fanya juu ☐ Planting of d/t tree ☐ NA

82. If yes, for Q 99, what is your source of information?

☐ Neighboring farmers ☐ Extension agents (DAs) ☐ NGOs ☐ From field days and Trainings ☐ Others, specify_____________ ☐ NA

83. Which of the following types of soil and water conservation measures are efficient in reducing the problem of soil erosion?

☐ Stone bund ☐ Soil bund ☐ Cut off drain ☐ Waterway

☐ Fanya juu ☐ Planting of d/t trees ☐ NA

84. Have you participated in community conservation activities this year?

☐ Yes ☐ No

85. Did you undertake the maintenance work on your own?

- ☐ Yes ☐ No

86. If no, for Q 104 what were the reasons for not doing?

- ☐ shortage of labor ☐ Lack of skill and knowledge ☐ Conservation structures were built without my knowledge and willingness
- ☐ I expect the land will be transferred to other farmers ☐ There was no need for maintenance

87. If the farmer did not use any improved conservation structures in all his plots, why did you not use them?

- ☐ No problem of soil erosion ☐ Shortage of labor ☐ Expecting that financial incentives will do the structures
- ☐ I feel that the land belongs to the government, and the government must maintain the land ☐ it reduces farmland ☐ I did not get an extension service
- ☐ Due to problems of rodents and other pests
- ☐ Others specify --

88. What do you think is the Main purpose(s) of SLM Technology? (Multiple answers is possible)

  - ☐ improve production (crop, fodder, wood/ fiber, water, energy)
  - ☐ reduce, prevent, and restore land degradation (soil, water, vegetation)
  - ☐ conserve ecosystem
  - ☐ protect a watershed/ downstream areas – in combination with other technologies
  - ☐ preserve/ improve biodiversity
  - ☐ reduce the risk of disasters (e.g. droughts, floods, landslides)
  - ☐ adapt to climate change/ extremes and its impacts (e.g. resilience to droughts, storms)
  - ☐ mitigate climate change and its impacts (e.g. through carbon sequestration)
  - ☐ create beneficial economic impact (e.g., increase income/ employment opportunities)
  - ☐ create beneficial social impact (e.g., reduce conflicts on natural resources, support marginalized groups)

☐ other purposes (specify): --
----

89. Do you identify the indicators and mechanisms of land degradation neutrality?

☐ Yes ☐ No

90. If your response is yes for q, no. 108, what are these indicators and mechanisms for land degradation neutrality?

----

91. To say there is LDN which indicators are observed in your environment?

☐ land cover change ☐ land productivity increase ☐ soil organic carbon increase

☐ bush encroachment ☐ other purposes (specify): ---------------------------------
--

92. What do you think about the final aim of land degradation neutrality? tick accordingly

Questions	Category	Remark
Provision service	Food availability	
	Water quality	
	Raw materials	
	Medical services	
Regulating service	Climate regulation	
	Climate change mitigation	
	Disaster risk reduction	
	Habitat regulation of pests and diseases	
	Water regulation	
Supporting service	Water cycling	
	Soil fertility	
Cultural services	Cultural heritage	
	Recreation tourism	

93. What do you think about the impact of soil bund conservation technology? tick accordingly

Perception statement	Number of response				
	Strongly agree	Agree	Neutral	This agree	Strongly disagree

Control soil erosion					
Reduce surface runoff					
Increase yield					
Increase fertility of the soil					
Increase soil water retention.					
Improve drinking water quality.					
Increase groundwater table					
Increase water availability for livestock.					
Increase product diversity					
Increase irrigation water availability.					
Improve water quality for livestock.					
Increase soil moisture					
Increase soil accumulation					
Reduce salinity					
Improvement of soil organic carbon					
food security/ self-sufficiency					
income Diversification					
Easily access agricultural inputs.					
Increase recreational opportunities					
Conflict mitigation					
Improvement of vegetation cover					
Increase plant diversity					
Increase animal diversity					
Reduces pests/ diseases					
Reduce flood impacts					
Reduce landslides/ debris flows.					
Reduce drought impacts					
Microclimate improvement					

94. Drivers of Land Use/Land Cover Change

Questions	Category	Remark
What are the Drivers of Land Use/Land Cover Change?	Agricultural land expansion	
	Urbanization and infrastructure development	
	Timber, fuelwood, and wood products	
	Resettlement	
	Grazing mismanagement	
	weak environmental considerations	

VI.Institutional support

95. Do you have access to an extension service? ☐ Yes ☐ No

96. If yes, who provides the extension service?

☐ Development agents (DAs) ☐ NGOs ☐ Others, specify ---------------
-

97. How often you were visited by DAs last year?

☐ Once per month ☐ , Twice per month ☐ , Three times per month

☐ Others, specify-___________________

98. How often have you obtained extension advice on soil and water conservation practices

☐ Once per month, ☐ twice, ☐ Three times per month ☐ , Once per three months ☐ , Twice per three months ☐ others, specify_____________________

99. Do you have contact with the SWC experts?

☐ Yes ☐ No

100. If your answer to question no. 117 is yes; how do you describe your contact with SWC experts?

☐ Very strong ☐ Good ☐ Limited ☐ None

101. Are you satisfied with the technical support you are receiving from extension officers?

☐ Yes ☐ No

102. If not why? --
----

103. Have you got any training for the last three years?

☐ YES ☐ NO

104. If yes, for how many days? __________days

105. Was the training useful? ☐ Yes ☐ No ☐ NA

106. If yes, I would like to know who provided you with the training.

☐ Extension workers ☐ Researchers ☐ Religion institutions ☐ NGOs

☐ others (specify) ---

107. What type of training have you obtained?

☐ Proper spacing for planting maize and beans ☐ Appropriate type of fertilizer to use and type ☐ Soil conservation measures ☐ Use of insecticides

☐ others (specify)---

108. Do you have access to credit?

☐ YES ☐ NO

109. If no, where did you obtain money for the construction/ implementation of soil conservation measures?

☐ Own financial ☐ Research project ☐ NGO ☐ Others (specify)

Thank You!