2025-05

Effects of Land Use Type and Land Management on Soil Quality Indicators in Gerda Watershed, Northwestern Ethiopia

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BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

GRADUATE PROGRAM

EFFECTS OF LAND USE TYPE AND LAND MANAGEMENT ON SOIL QUALITY INDICATORS IN GERDA WATERSHED, NORTHWESTERN ETHIOPIA

MSc Thesis

By:

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (MSC) IN SOIL CONSERVATION AND WATERSHED MANAGEMENT

May 2025

Bahir Dar, Ethiopia

Advisor: Dr. Derege Tsegaye (Associate professor)

THESIS APPROVAL SHEET

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As a member of the Board of Examiners of the Master of sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr. Dejen Mera** entitled **"Effects of Land use type and Land Management Practice on Soil Quality Indicators in Gerda Watershed, Dembecha District, Northwestern Ethiopia"**. We hereby certify that; **the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in Soil Conservation and Watershed Management.**

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DECLARATION

This is to certify that this thesis entitled "**Effects of Land Use Type and Land Management Practice on Soil Quality Indicators in Gerda Watershed, Dembecha District, Northwestern Ethiopia**" submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in "**Soil Conservation and Watershed Management**" to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Dejen Mera** (ID. No BDU 1500089) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for the award of any degree or diploma to the best of our knowledge and belief.

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Dr. Derege Tsegaye

Signature date 08\05\2025

ACKNOWLEDGEMENTS

First and foremost, I want to thank the almighty God and his mother, Saint Mary, who helped me from the beginning to the end of this thesis work. I want to express my heartfelt appreciation and special thanks to my advisor, Dr. Derege Tsegaye, for showing his interest in advising me when I selected him as my advisor and for his follow-up devotion of precious time, valuable suggestions, constructive comments, and systematic guidance to improve the content of this thesis starting from the planning stage of proposal writing to the completion of my research. He also deserves my utmost gratitude for the encouragement and on-time responses. I have always benefited from useful comments, suggestions, and constructive discussions. I extend my gratitude to Wolaita Sodo University for granting me study leave and guaranteeing my salary during the study period.

I sincerely acknowledge Bahir Dar University giving me the chance to confirm my studies. I would like to forward my great appreciation to Bahir Dar University NaRM staff, especially Dr. Mulatie Mekonen for his systematic guidance for this research, Mr. Mamaru Shitahun Soil Laboratory technician at Bahir Dar University, and Mr. Tadese Tolla Technician of soil physics at Bahir Dar University for their great support to soil analysis and moral encouragement to achieve the required objectives. Also, I would like to give my appreciation to Dembecha district agricultural office, NaRM experts specially Belete, who is a NaRM expert at Kurfa kebele, and Anjeni soil research experts specially Temesgen and Yigzaw Tadesse for giving material and other data. I am most deeply grateful to my parents, my grandmother Ayalnesh Simegn, my uncle Anteneh Tadege, and friends, especially Demeke Temesgen, Atalay Temesgen, Taye Getachew, Hailu Amare, Gebreyesus Tilahun, Desalegn Esubalew, Gizachew Wasse, Shumye Ali, Sahlemaryam Zeleke, Animaw Adiss and others who are not mentioned in this part for their involvement in helping me to strive towards the realization of my potentials, initiation, and encouragement, moral, and financial support.

DEDICATION

This thesis is dedicated to my grandmother, Ayalnesh Simegn, for her concern, prayer, patience, and love. Without her decision that allowed me to pass through modern education, in a situation where modern education was not significantly encouraged, I would have never been in my present position. I wish a long life for my grandma!

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CSA	Central Statistical Agency
DDOA	Dembecha District Office of Agriculture
EC	Electrical Conductivity
EHRS	Ethiopian Highland Reclamation Study
FAO	Food and Agricultural Organization
GDP	Growth Domestic Product
GLM	General Linear Model
LULC	Land Use Land Cover
LUT	Land Use Type
NaRM	Natural resource management
NRCS	Natural Resources Conservation Service
WAMS	Western Amhara Metrological Station
SLM	Sustainable Land Management
SLMP	Sustainable Land Management Program
SPSS	Statistical Package for Social Science
SQ	Soil Quality
SWC	Soil and water conservation
USDA	United States Department of Agriculture

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ABSTRACT

Soil fertility loss is a major global issue, especially in developing countries, including Ethiopia. This is a significant concern for sustainable agriculture, threatening food security and ecosystem health. To minimize soil quality loss and protect ecosystem health, The Ethiopian government implemented land management practices, such as soil and water conservation, area exclosure, and planting highland bamboo (Oldeania/Yushania Alpina), to protect steep slopes, prevent soil erosion, and generate income in the Dembecha district. However, there is insufficient research on how bamboo forests and area exclosure affect soil quality indicators in the northwestern highland of Ethiopia. Therefore, this study is conducted to evaluate the effects of bamboo forests on soil quality indicators and to evaluate the effectiveness of land management practices (area exclosure for grazing land and bamboo forest, and integrated soil and water conservation practice for cultivated land) on soil fertility in the Gerda watershed, Northwestern Ethiopia. Soil samples were collected from treated and untreated sites of cropland, grazing land, and bamboo forest in the upper and lower slope positions. The collected data were analyzed following standard statistical procedures concerning treatment, land use type, and slope position by using SPSS software. Land management practice, land use types, and topography significantly ($P < 0.05$ to $P < 0.001$) influence almost all physicochemical soil quality indicators. Higher clay (36.6%), pH (6.77), organic matter (11.46%), total N (0.39 %), available P (9.25 ppm), CEC (45.38 Cmol (+) kg^{-1}) were obtained from the treated bamboo forest at a lower slope. Relatively higher bulk density (1.36 g/cm^3) and sand content (54.33) were recorded from untreated cultivated land at the upper slope. This result implies that highly deteriorated soil quality indicators obtained from untreated cultivated land at the upper slope might be due to improper and intensive cultivation on steep slopes, and the application of inorganic fertilizer for a long period like urea, which leads to the removal of the fertile soil part. Generally, this result indicated that soil degradation can be minimized through enhancing land management practices like area exclosure, and integrated soil and water conservation practices to make sustainable agriculture in the watershed.

Keywords: Area exclosure, Bamboo Forest, cultivated land, Grazing land, Slope position, Physiochemical soil quality.

CHAPTER 1. INTRODUCTION

1.1 Background and Justification of the Study

Maintaining life and ecosystems depends on the integrity of the soil on our planet. However, the deterioration of soil fertility has emerged as a major global issue, especially in developing countries, including Ethiopia (Simachew Bantigegn, 2020). Soil quality loss, characterized by a decrease in soil fertility, is a significant concern for sustainable agriculture, threatening food security and ecosystem health. Soil quality is the ability of soil to perform essential living systems for preserving biological productivity, enhancing environmental quality, and upholding the health of plants and animals (Aklilu Abera and Desalegn Wana, 2023). So, the removal of soil fertility can affect environmental quality, biological productivity, and the health of plants and animals (Amare Aleminew and Melkamu Alemayehu, 2020).

Most developing countries including Ethiopia's economy is based mostly on agriculture, and smallholder farming techniques dominate this industry. In Ethiopia, agriculture accounts for 85% of all employment, 44% of the GDP, and 85% of export revenue in the nation (FAO, 2016). However, the population growth rate of the country and the availability of agricultural land is not proportional. Thus, increasing human population leads to the expansion of cultivated land and the decline of forest and pastureland to produce more food demand for human beings and less feed for the livestock populations. This resulted, in the expansion of land use conversion based on the conversion of the existing forest lands into cultivated lands and free grazing lands (Menberu Teshome, 2014). With the increase of human and livestock populations, temporary intensive expansion of farmland and grazing areas has begun to influence soil fertility (Binyam Alemu, 2015).

Inappropriate land use, overgrazing, intensive and continuous cultivation of land without proper management, and application of inorganic fertilizer for a long period led to soil erosion. Soil erosion is a gradual process caused by natural forces like water and wind, but human activities intensify it, resulting in detrimental effects on soil quality and agricultural productivity (Mulatie

Mekonnen *et al*., 2021). In Ethiopia, cultivated lands showed a continuously increasing trend at the expense of forests and grasslands over the last decades (Adimassu *et al*., 2020).

In Ethiopia, different studies were conducted to indicate the extent of soil loss due to land use change, Intensive and continuous cultivation of land without proper management, and overgrazing. The study by Hurni (1988) indicated that an average of about 42 t ha-1 yr-1 of soils were lost in Ethiopia from cultivated land due to poor soil management and population pressure. Another recent study by Bekele Tsegaye (2019) reported that the annual soil loss rate on average is about 42 tones/ha for croplands and up to 300 tones/ha in extreme cases. In the study by Mengesha Zerihun *et al*. (2018) in the study district Dembecha, the mean annual soil loss was estimated to be 49 t ha-1 yr-1 and a total annual soil loss of 526996 t yr-1.

Considering the severity of soil erosion and its associated consequences, conservation and restoration measures are essential to improve soil fertility and preserve biodiversity. Land management practices can change soil quality indicators or soil properties such as soil organic matter, soil structure, soil water holding capacity, soil bulk density, soil porosity, soil pH, and cation exchange capacity (Andualem Belay *et al*., 2025)

The government of Ethiopia launched different land management practices starting in the mid-1970s to minimize soil quality loss (Kindiye Ebabu *et al*., 2020). Integrated soil and water conservation practices, area exclosure, afforestation and agroforestry, and gully rehabilitation activities have been implemented in the Amhara region and in the study district to reduce soil erosion. In Ethiopia, forest ecosystems make both environmental (soil erosion control, soil fertility maintenance, and climate change mitigation) and economic (firewood collection, wild food collection, gum-resin production, and marketing) contributions to the country (Zebene Tadesse *et al*., 2023). In this case, Ethiopia has two indigenous bamboo species which are classified as forest type. These are lowland bamboo, *Oxytenanthera abyssinica* (A. Richard) Munro, and the highland bamboo, *Oldeania* or *Yushania alpina* (K. Schumann) (Kassahun Embaye, 2000). Especially highland bamboo is commonly cultivated and managed by farmers in various agroforestry systems. In the highland part of the study district farmers planted highland bamboo, *Oldeania,* or *Yushania alpina* (K. Schumann) to protect steep slopes, soils, and waterways, preventing soil erosion and cash crops (DDOA 2023). However, there is no study to indicate the influence of this bamboo forest on soil quality in the highland part of the country. Additionally, crop rotation and fallow or no tillage practices are applied in the study district.

Land management practice has a positive impact on soil quality indicators and key indicators of soil fertility. As such, it is reasonable to expect improved soil fertility from such practice (Asmare *et al*., 2023). Therefore, knowing about the influence of different specific land use types and their management practices on soil quality indicators should be used to devise plans for appropriate management practices to improve soil productivity and the sustainability of agricultural lands. So, this study aims to evaluate soil quality indicators under different land use types and land management practices.

1.2 Statement of the Problem

Ethiopia's land resources play a pivotal role in its economy, providing the foundation for agriculture, which is the backbone of the nation. However, these resources face significant challenges due to both natural and human factors. Especially, soil degradation, including depleted organic matter, erosion, acidity, and salinity, poses a significant challenge to sustained food security and agricultural growth in Ethiopia. Soil erosion and degradation have led to significant challenges in Ethiopia, impacting crop production and food security (Moges Tadesse Gedamu, 2020). Unsustainable land use practices (e.g. steep slope cultivation, overgrazing), population growth, and soil degradation have contributed to soil loss and decreased agricultural productivity in the country (Bekele Tsegaye, 2019; Desta *et al.*, 2021).

In the study area, Gerda Watershed, there was an increasing human population, and livestock production pressure, which can influence, the size of the landholding, create pressure on the available agricultural lands, and influence grassland. This in turn has forced farmers to expand their farming activity on marginal lands with steep slopes and also in areas that are covered by vegetation and Bamboo Forests. Moreover, deforestation, continuous cultivation without proper management, removal of crop residue, continuous application of inorganic fertilizer, and overgrazing are the features of the Gerda watershed. As a result, cultivated land and grazing are highly degraded, and erosion occurs, which leads to a loss of soil fertility.

On the other hand, to address these challenges, the Ethiopian government implements various land management practices (e.g., area closure, agroforestry, and integrated soil and water conservation) to minimize soil quality loss. In the study district SWC measures, fallow period, and crop rotation are mostly implemented on cultivated lands, and ex-closure is also implemented for grazing land. Bamboo plantation is also practiced to mitigate land degradation. These practices aim to protect steep slopes, soils, and waterways, preventing soil erosion, using cash crops, and promoting environmental sustainability (Dessalew Meseret, 2016).

To measure the effectiveness of land management practices, different research has been conducted in different parts of our country. Accordingly implementing land management practices can lead to improvements in soil quality indicators like soil organic carbon, soil organic matter, total nitrogen, available phosphorus, sulfur, boron, and cation exchange capacity (Aklilu Abera and Desalegn Wana, 2023). There was also a study in the lowland part of the study district by Melkamu Degu *et al*. (2019) which is the effect of soil and water conservation and crop rotation on soil properties. The findings of the study indicated that crop rotation and soil conservation practices have an influence on soil properties except for bulk density. The study by Yihenew G. Selassie *et al*. (2015) on the effect of land use type and management practice on soil physicochemical properties in a study district indicated that different land use type has a great influence on soil property and land management practices also have an effect on soil physicochemical properties.

However, previous research in the northwestern highlands of Ethiopia has not fully explored the effects of specific land use types and land management practices on soil quality indicators Therefore, this research aims to bridge this knowledge gap by investigating how different land use types (cultivated land, bamboo forest land, grazing land) and specific management practices (treated vs. untreated cultivated land, area exclosure vs. free grazing) influence key soil quality indicators in the Gerda Watershed. Furthermore, the results should be valuable for local farmers, land managers, and policymakers, as they can help inform land use planning and management practices that promote sustainable agriculture and environmental conservation.

1.3 Objective of the Study

1.3.1 General objective

The general objective of the study is to evaluate the impact of land use, management practices, and slope position on soil quality in the Gerda Watershed, northwestern Ethiopia.

1.3.2 Specific objectives

- To determine the impact of different land use types on key soil quality indicators in the Gerda watershed
- To evaluate the effectiveness of land management practices in improving soil quality (physical and chemical property)
- Investigate the influence of slope position (upper, lower) on soil quality indicators within each land use and management practice.

CHAPTER 2. LITERATURE REVIEW

2.1 Overview of Soil Quality Indicators

Soil quality indicators are measurements that assess the health of soil. They provide information on how well the soil can perform its functions, such as supporting plant growth, filtering water, and storing carbon. There are three main categories of soil quality indicators: chemical, physical, and biological (Bosch, 2021).

Chemical indicators measure the amount of nutrients and other chemicals in the soil. Some common chemical indicators include pH, organic matter content, nutrient availability (nitrogen, phosphorus, and potassium), cation exchange capacity (CEC), and electrical conductivity (EC). **Physical indicators** measure the physical properties of the soil, such as texture, structure, porosity, and water infiltration. These properties affect how well the soil can hold water and air, and how easily roots can grow through it (Clark *et al*., 1998).

Biological indicators measure the activity and abundance of soil organisms, such as earthworms, nematodes, and microbes. These organisms play an important role in decomposing organic matter, cycling nutrients, and improving soil structure. By measuring a combination of these indicators, scientists can get a good idea of how healthy soil is and how well it is functioning (Sparling, 2020).

2.2 Land Use Land Cover Change and Soil Quality in Ethiopia

Ethiopia's land cover and land use are incredibly diverse, ranging from lush highlands and deep valleys to arid plains and deserts. Land use and land cover (LULC) changes in the highlands of Ethiopia have resulted in significant transformations, particularly in the country's rural areas. Land use change by deforestation, urbanization or settlement, mining, expansion of cropland land, eucalyptus plantations, and grazing land is frequently practiced in the highlands of Ethiopia (Abdulbasit Hussein, 2023). The Ethiopian highlands once boasted extensive forest cover, but unfortunately, it has undergone a significant decline in recent decades, especially in the Amhara region. Between 2002 and 2022, Amhara experienced the loss of 116 hectares of humid primary forest, accounting for 4.2% of the region's overall tree cover reduction during that phase. Over this time, the humid primary forest's overall area in Amhara shrank by 1.2%. This translates to an annual loss of approximately 141,000 hectares. While deforestation rates have slowed down somewhat in recent years, the overall trend remains negative (Ed Holt, 2022).

2.2.1 Impact of bamboo forest on soil quality

Bamboo forests are ecosystems dominated by bamboo which is a rapidly growing woody grass. These forests are characterized by tall, slender stems that can reach significant heights and vary in species composition, density, and structure (Kassahun Embaye, 2000). These forests can be found in various regions, particularly in tropical and subtropical climates. Africa has 1,500,000 ha of which, Ethiopia has about 1 million Ha of high- and lowland bamboo, the latter being more dominant (850 000 ha). Thus, 67% of African bamboo resources and more than 7% of the world total are found in Ethiopia (Kassahun Embaye, 2000). Bamboo forests play a significant role in the ecosystem, providing habitat for wildlife and contributing to biodiversity. Bamboo forests also have several important effects on soil properties. Bamboo, with its rapid growth and widespread root system, enhances the physical, chemical, and biological properties of soil, limits soil erosion, and is ideal for the rapid rehabilitation of degraded lands. Nutrient cycling in bamboo forests attributed to its vigorous growth and litter production, has shown improvement in soil fertility. Generally, bamboo that grows in the wild plays a crucial role in nutrient build-up and soil fertility management (Gaikwad *et al*., 2022).

According to Venkatesh *et al*. (2005), mixed bamboo stands have higher levels of beneficial soil nutrients and superior soil properties, such as soil porosity, aeration, and bulk density than monoculture. Other studies have shown that soils under bamboo canopies exhibit better pH levels and nutrient retention compared to adjacent areas without bamboo (Zebene Tadesse *et al*., 2023). This effect is more pronounced in surface soils close to the bamboo culms, suggesting that nutrient recycling through litter fall and root turnover is effective.

2.3 Land Management Practices and Soil Quality in Ethiopia

Land management practices in Ethiopia have been crucial due to factors like land shortages, deforestation, unsustainable cultivation practices, and overgrazing leading to land degradation. Sustainable Land Management (SLM) practices are essential for addressing these issues and enhancing the productivity of natural resources. In Ethiopia, about 80% of the population depends directly on agriculture, making SLM critical for poverty eradication. The Sustainable Land Management Program (SLMP) in Ethiopia, launched in 2008, aimed to address significant developmental and environmental challenges in the country (Hou-Jones & Chung, 2019). Efforts to promote sustainable land management have been ongoing, with some successes and challenges. The labor-intensive nature of certain conservation practices and the negative impact on crop yield in high-rainfall areas have been noted as challenges to effective SLM implementation. Various studies have highlighted factors influencing the adoption of SLM practices by rural households, such as economic variables and the labor-intensive nature of physical conservation practices like terraces and bunds (Haftu Etsay *et al*., 2019).

While efforts have been made to promote sustainable land management in Ethiopia, there have been mixed results. The country faces challenges such as rapid population growth, deforestation, overgrazing, and inappropriate farming practices contributing to land degradation. Despite these challenges, ongoing research and programs aim to enhance the sustainability of land management practices in different regions of Ethiopia (Nebere *et al*., 2021).

2.4 Types of Land Management Practice

In Ethiopia, various types of land management practices are implemented to address land degradation and enhance agricultural productivity. Factors influencing the implementation of sustainable land management in Africa include weak incentive policies, poor legal frameworks, limited grazing land availability, and inadequate environmental knowledge (Hawi Bayisa *et al*., 2024). The Sustainable Land Management Program in Ethiopia focuses on stabilizing soils, improving water retention, enhancing tillage practices, building capacity for SLM practices, and securing land tenure for smallholder farmers (World Bank, 2020).

2.4.1 Soil and Water Conservation Measures

Soil and water conservation measures play a crucial role in combating land degradation and enhancing agricultural productivity in Ethiopia. Various techniques have been employed across the nation to address soil erosion, nutrient loss, and moisture retention. These include structural measures such as soil bunds, fanya juu, waterways, cutoff drains, grass strips, and check dams, as well as agronomic practices like contour farming and intercropping. Despite the widespread application of these strategies, the achievement of desired outcomes has fallen short of expectations. Factors hindering the full realization of benefits include intense labor requirements, poor design, insufficient land size, and socioeconomic limitations. Nonetheless, there have been instances of positive impacts on soil quality, crop yields, and fodder availability when these measures are effectively adopted (Mengie Belayneh *et al*., 2019; Negessa Gadisa and Tesfaye Midega, 2021).

The Ethiopian government has recognized the significance of soil and water conservation and has implemented extensive programs to promote these practices throughout the country. Despite initial progress, further improvements are needed to ensure long-term sustainability and resilience against land degradation (Negessa Gadisa and Tesfaye Midega, 2021).

2.4.2 Area closure

In Ethiopia, area closure is utilized as a land degradation control measure. Area exclosure is defined as degraded lands excluded from human and livestock interferences for rehabilitation (Wolde Mekuria *et al*., 2007). These closures aim to prevent further degradation and promote the recovery of vegetation cover in severely degraded areas. The government of Ethiopia has implemented sustainable land management interventions to address soil erosion and land degradation, investing significant resources in rehabilitation programs since the mid-1970s (Hailu Terefe *et al*., 2020). These interventions have shown positive impacts on selected soil properties in various regions of the country. By closing off degraded lands from human and animal activities, area closures play a crucial role in restoring ecosystems and combating land degradation in Ethiopia (Meseret Habtamu and Eyasu Elias, 2020).

Area closures, such as exclosure, in Ethiopia offer several benefits related to soil properties. The study by Kiros Abay *et al*.(2020) indicated that Converting open grazing lands to exclosure leads to significant improvements in cation exchange capacity (CEC), which increases from approximately 30.41 to 35.53 c mol/(+) kg, suggesting enhanced soil organic matter content and Exclosure increase soil nutrients by promoting the accumulation of decomposed plant materials, thereby enriching the soil. By limiting livestock access, exclosure prevents nutrient leaching or runoff, thus retaining essential elements within the ecosystem. It also As exclosure reduces human interference and promotes natural vegetative growth, it helps combat soil erosion, which is a major issue in Ethiopia (Tefera Mengistu *et al*., 2005).

2.5 Effect of Land Use Type and Land Management Practice on Physical Soil Quality Indicators

Soil appropriateness for engineering, environmental, and agricultural purposes is largely dependent on its physical characteristics. The physical characteristics of soil control how water and nutrients are moved, retained, and made available to plants. They also control how air and heat enter, exit, and circulate through the soil (William J. Chancellor, 2013). Soil physical properties change with changes in land use types and management practices. Soil physical properties may vary from one location to another and the application of organic and inorganic fertilizers, the intensity of cultivation, and the presence and the absence of crop residues are factors that contribute to physical properties (Haile *et al*., 2022).

2.5.1 Soil texture

Soil texture (such as loam, sandy loam, or clay) refers to the proportion of sand, silt, and clay-sized particles that make up the mineral fraction of the soil (Osman, 2013). Thus, soil texture determines soil workability, water-holding capacity, soil structure, and nutrient retention. Clay soils hold more water and nutrients as compared to sandy soils. A comparison of soil properties in different land uses reveals that forest land generally has higher clay content than cultivated land (Alemayehu Adugna and Assefa Abegaz, 2016; Chorom *et al*., 2009). Land use significantly influences soil composition, with potential implications for soil quality and fertility. Different research conducted that soil texture varies significantly under different land use types, management practices, and slope gradients. The mean value of sand in the non-forested land (cultivated outfields, homestead garden fields, and grazing land) was higher than the mean value of sand in the non-cultivated land (forest and grazing land) while the mean value of clay in the non-cultivated land was higher than the mean value of clay in the non-forested land (Belayneh Bufebo and Eyasu Elias, 2020). According to Melku Dagnachew *et al*. (2020), The clay fractions of cultivated land treated with SWC measures are significantly greater than those of cultivated land not treated with SWC measures. Soil physical properties are also impacted by area closure. The study by Tamrat Sinore and Solomon Umer (2021) reported that the highest mean value clay content was obtained from closed grazing land and the lowest mean value was recorded from free grazing land. In comparison, the free grazing area had the highest mean values of sand and silt, while the exclosure had the lowest mean values of sand and silt content.

2.5.2 Soil bulk density

The bulk density of soil is the oven-dry weight of soil per unit of volume at a specified moisture content, typically expressed in grams per cubic centimeter (USDA NRCS, 2019). Therefore, the organic matter concentration, compaction, and soil texture all affect the bulk density of the soil. Soil bulk density varies under different land use types, land management, and slop positions. The studies by Berhane Lema *et al*. (2019); Dereje Girma (2020); and Lechisa Takele *et al*.(2014) indicated that cultivated fields and grazing lands in Ethiopia have higher soil bulk density compared to forest lands and Lower soil bulk density values in the forest land as compared to cultivated and grazing lands. Deforestation and subsequent cultivation have been found to significantly increase soil bulk density and decrease pore space, soil carbon, and total nitrogen. Similarly, forest conversion to cultivation and grazing has been shown to reduce infiltration capacity and soil moisture content, while increasing dry bulk density (Dessie Assefa *et al*., 2017).

Generally, different studies suggest that bulk density is generally higher in cultivated land compared to forest and grazing lands, while soil fertility and total porosity decline as land use changes from forest to grazing and cultivated lands. So, the negative effects of land use change on soil quality and bulk density can be reversed through reforestation, which has been shown to restore soil quality and reduce bulk density (Berhanu Seyoum, 2016).

Slope position has a significant effect on soil bulk density. Studies have shown that soil bulk density varies with slope position due to factors such as soil texture, erosion, and deposition processes (Belayneh Bufebo *et al*., 2021). The steep slope had the greatest mean soil bulk density value (1.51 g/cm3), which was 12% and 7% higher than the slope gradients in the moderate (1.34 g/cm3) and gentle (1.27 g/cm3) areas, respectively (Mesfin Anteneh and Mohammed Assen, 2020).

2.6 Effect of Land Use Type and Land Management Practice on Chemical Soil Quality Indicators

Soil chemical properties are the result of different soil minerals' disintegration, decomposition, and weathering of soil parent materials over the geological period and are crucial for understanding soil fertility, plant growth, and overall soil health (McCauley *et al*., 2005). soil chemical properties are influenced by land use type, land management practices, and slope gradient. Good management like area closure for grazing and integrated soil and water conservation practices for cultivated land enhances soil fertility while improper management may irreversibly damage the soil environment (Dilnesa Bayle and Kelemu Muluye, 2023). In the highlands of our country Ethiopia, due to intensive land use and high population pressure, the land is severely degraded, and eroded and the nutrient status of most soils is decreasing (Negasi Solomon *et al*., 2024). Animal manure and crop residues, instead of being returned to the land, are largely used as fuel and livestock feed respectively (Nyssen *et al*., 2015). The most important soil chemical properties affected by land use and slope gradient include soil pH, soil OM, total nitrogen, available phosphorus, and cation exchange capacity (Kedir Merga *et al.*, 2023).

2.6.1 Soil pH

Soil pH is a measure of acidity or alkalinity and is an important environmental factor, particularly in soils (Addisu Mengist *et al*., 2023). Soil pH is a key determinant of nutrient availability and plant growth which is determined by the components of soil, including accumulated decaying vegetation, broken-up fragments of underlying rocks, and water that fills the spaces between solid soil particles (Kumar *et al*., 2014). Land use type and land management techniques have an impact on soil pH. Increased decomposition and altered microbial carbon cycling pathways are two effects of land use intensification on soil pH that can lead to carbon loss. Land use patterns have an impact on soil pH as well. Various land use systems lead to varying degrees of human land use activity, which in turn has varying consequences on the soil. Soil physicochemical qualities, including pH, can also be impacted by changes in land-use management techniques, such as cultivation of steep slopes, overgrazing, and no or restricted fallow periods. Consequently, Crop productivity and growth are significantly influenced by the pH of the soil, and maintaining adequate soil pH levels requires ongoing management (Achalu Chimdi *et al*., 2012; Yifru Abera & Taye Belachew, 2011).

The study by Addisu Mengist *et al.*, (2023) and Biyensa Gurmessa (2021) reported that the highest and the lowest mean value of soil pH were recorded under the forest and the cultivated land respectively, and the mean value of pH was lower in the cultivated land compared with grazing and forest covers, which indicates both forest and grazing LUTs were less acidic than the cultivated lands.

2.6.2 Soil organic matter

Soil organic matter (SOM) is the organic component of soil that includes decomposing plant and animal matter, soil microbe cellular structures, and compounds that soil microbes create. SOM plays a crucial role in improving soil structure, enhancing water retention, promoting soil biodiversity, absorbing and retaining pollutants, buffering soil chemistry, and cycling and storing plant nutrients (Osman, 2013).

Land use type, land management practice, and slope gradient have significant effects on soil organic matter in Ethiopia. Land management practices such as area closure, drainage practices, mechanical erosion control practices, and agronomic practices can have a significant impact on soil organic matter (Desta *et al*., 2021). Most cultivated soils in Ethiopia have low organic matter (OM) content due to the low availability of organic materials applied to the soil and the complete removal of biomass from the field. Soil degradation, depleted organic matter, topsoil erosion, acidity of soils, and soil salinity are considered serious challenges to sustained food security and agricultural growth in Ethiopia (Tilahun Chibsa and A. Asefa Ta, 2009). The highest mean value of soil organic matter has been recorded in forest land in Ethiopia, while grazing and cultivated land have lower values due to land-use changes or deforestation and the highest mean value of soil organic matter also has been recorded following the establishment of exclosure in Ethiopia, particularly in areas such as Cambisols and Luvisols, with effect sizes greater than two after 16 years (Haile *et al*., 2022).

2.6.3 Total Nitrogen

The quantity of nitrogen in the soil, which is a necessary ingredient for plant growth, is referred to as "soil nitrogen." land use type, land management practices, and slope gradient affect soil nitrogen content. Studies have demonstrated that variations in land use, such as agriculture versus grasslands or forest, lead to differences in soil organic carbon (SOC) and total nitrogen (TN) concentrations and stocks (Al-Kaisi *et al*., 2005). Additionally, slope gradient affects soil erosion, which in turn impacts nitrogen availability because steeper slopes increase erosion risk and may transport nitrogen away from the site. Furthermore, land management practices like deforestation, unsustainable farming methods, and steep slope cultivation contribute to the redistribution of soil nutrients, including nitrogen (L. B. Asmamaw and A. A. Mohammed, 2013). The highest total soil nitrogen content was recorded in natural forests and the lowest soil nitrogen content recorded in cultivated land may be due to continuous cultivation, soil erosion, plant uptake, and volatilization of N resulting from increased oxidation of nitrogenous compounds (Sabiela Fekad *et al*., 2020; Terefe Tolessa and Feyera Senbeta, 2018). Land management practices and slope position also influence total nitrogen content in Ethiopia. According to Elias Bojago *et al*.(2023), Soil bund treatment areas had much higher total nitrogen content (0.18%) than non-conserved plots (0.04%). The mean total nitrogen content of the soil bundle treated and control plots differed from that of the preserved plots, with the preserved plots having a greater mean value than the non-conserved plots.

2.6.4 Available phosphorus

Available phosphorus in soil refers to the amount of inorganic phosphorus dissolved in water/soil solution that is readily accessible to plants for uptake. It is one of the essential nutrients necessary for the growth and development of plants and its deficiency in soils restricts crop yields (Prasad & Chakraborty, 2019). The availability of phosphorus (P) in most Ethiopian soils has indeed been declining due to several factors, including soil acidification, fixation of P into non-plant-accessible forms, removal of crop residue, and soil erosion (Alemayehu Kiflu *et al*., 2017).

The phosphorus content of the soil was influenced by land use type, land management practice, and landscape positions. Therefore, forest land had the highest mean amount of accessible phosphorus (13.00 ppm), whereas grazing land had the lowest mean value (10.01 ppm). In cultivated land use categories, the mean value of accessible phosphorus was lower (9.52 ppm)(Belayneh Bufebo *et al*., 2021).

2.6.5 Cation exchange capacity

Cation exchange capacity (CEC) is a measure of the soil’s ability to hold positively charged ions or the total negative charges in the soil that adsorb plant nutrition cations like calcium ($Ca2+$), magnesium ($Mg2+$), and potassium ($K+$) is measured as the cation exchange capacity. As a result, a soil's CEC attribute characterizes its ability to provide nutritional cations to the soil solution for plant absorption. It is a very important soil property influencing soil structure stability, nutrient availability, soil pH, and the soil’s reaction to fertilizers and other ameliorants (Hazelton and Murphy, 2007).

The highest and lowest CEC values were found under natural forests and cultivated land, respectively. This may be higher organic matter content due to the accumulation of fallen leaves, dead trees, and other organic debris under forest land and depletion of organic matter through practices like plowing, tilling, and removal of crop residues under cultivated land. Depending on management techniques, and slope class cultivated land management like soil and water conservation practices have positive effects on CEC and grazing fields may also have variable CEC. Reduced organic matter and erosion are two consequences of overgrazing that are comparable to those seen in farmed areas. However, grazing lands can retain a respectable CEC if they are managed appropriately, with appropriate nitrogen inputs, and controlled (Mengie Belayneh *et al*., 2019; Yihenew G. Selassie *et al*., 2015).

CHAPTER 3. MATERIAL AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was conducted in the Gerda watershed which is located in Kurfa Kebele, Dembecha district, the west Gojjam zone of Amhara region Northwestern Ethiopia. The area is located at $10^0$38'0"N -$10^0$43'0" N latitude and 37°29'30" E- $37^0$33'30"E longitudes at the Dembecha district. Kurfa kebele is one of the kebeles from the district and is purposely selected based on the availability of land management practice. i.e. area closure, integrated soil and water conservation practices, and highland bamboo forest and plantation forests. The district is located 205 km away from Bahir Dar town which is the capital city of the Amhara region and 367 km Northwest of Addis Ababa. Geographically, the altitude of the watershed ranges from 2336 to 2574 meters above sea level.

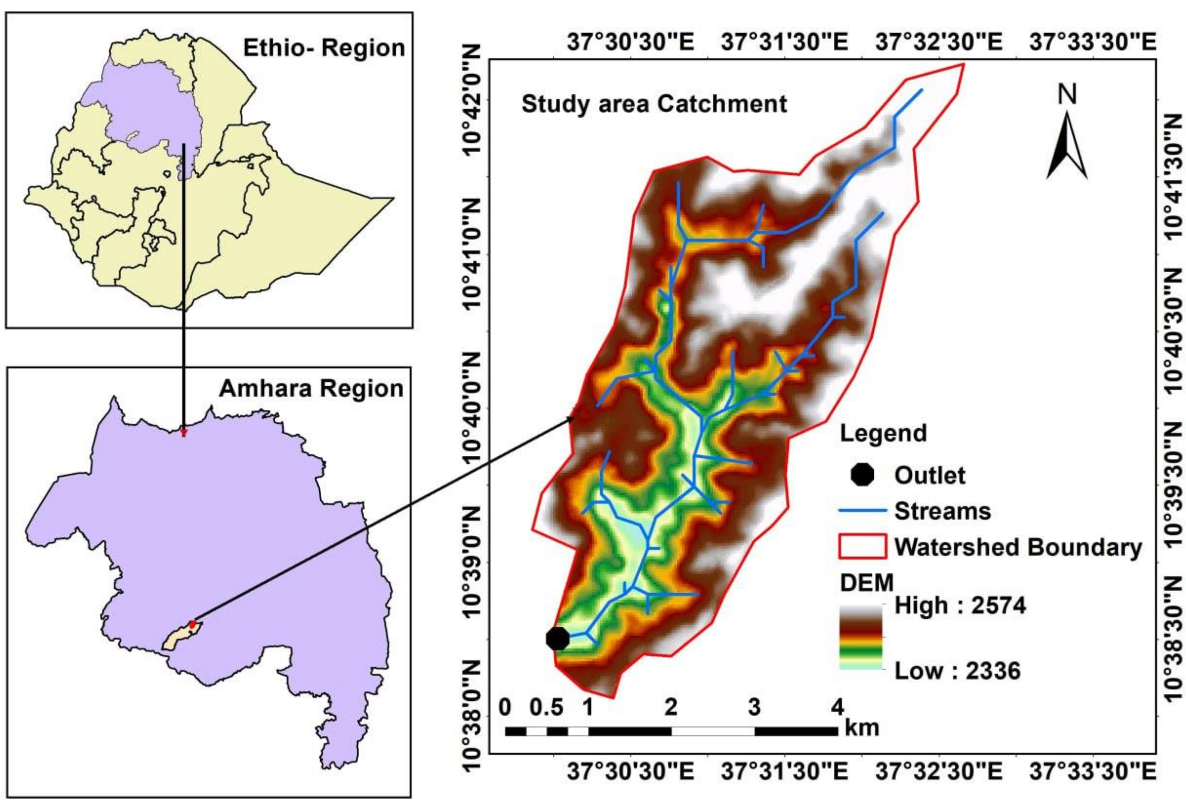

Figure 3.1 Location Map of Gerda Watershed

3.1.2 Population

Based on the 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA), Dembecha woreda had a total population of 151,023 of which 75559 were men and 75464 were women. Of this total population, 14 % (21143) were urban dwellers, whereas 86% (129880) were rural residents (DDOA, 2023). The total household of the watershed is 507, which is 484 male and 23 female-headed. The total population of the watershed is 1754, which is 782 males, and 972 females (DDOA, 2023).

3.1.3 Topography and Climate

Gerda watershed is characterized by gentle to slightly steep slope topography. The area of rainfall pattern is characterized by unimodal rainfall distribution with torrential and unpredictable rains that dominantly occur from May to October. However, the peak season was from June to September. The total average annual rainfall was 1495.4 mm. The mean annual minimum and maximum temperatures are 10.5 and 26.5^{0}c respectively (WAMS,2023).

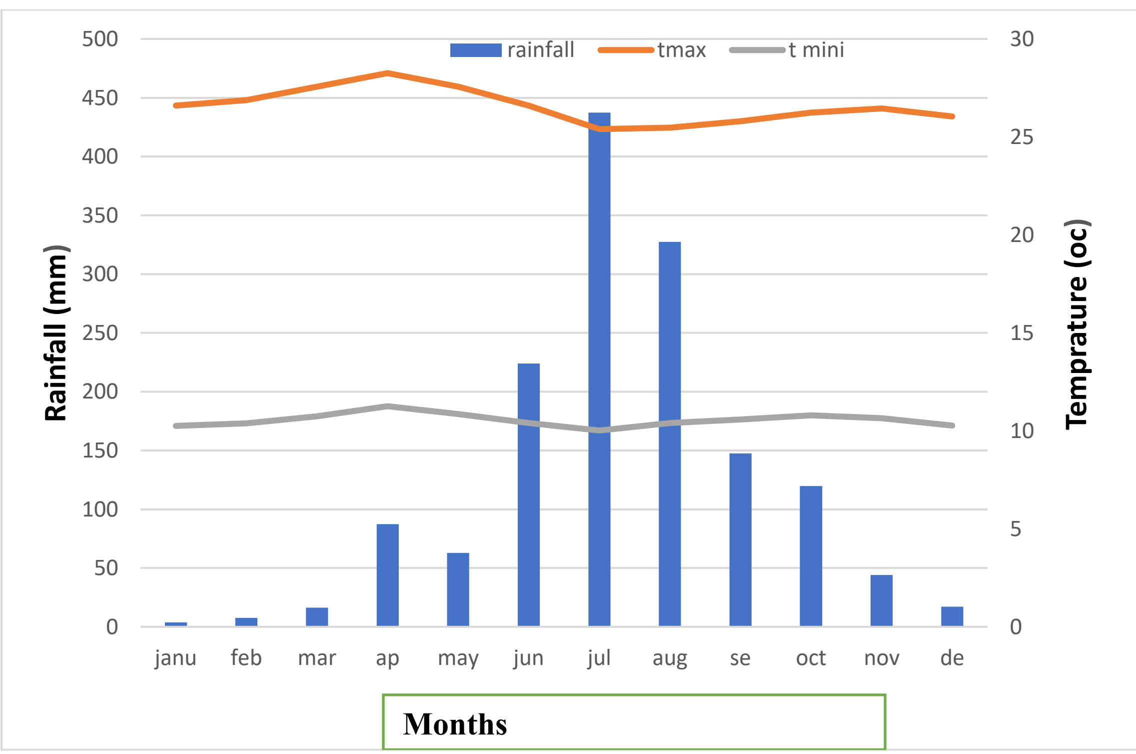

Figure 3.2 Mean annual rainfalls and temperatures in the study district

tmax: maximum temperature, tmin: minimum temperature

3.1.4 Land use type, land management practice, and farming system

The major land use and cover types found in the study area are mainly cropland, grazing land, shrubland, settlement, fallow land, bare/degraded land, forest land, bamboo forest, and eucalyptus plantations. Bamboo forest covers more than 19 hectares, and grazing land protected by area closures covers more than 5 hectares. Management practices are implemented to reduce soil degradation and fertility loss. For example, crop rotation, fallow periods, integrated soil water conservation, and agroforestry were implemented on cultivated land, and bamboo plantation and area enclosure were implemented on grazing and degraded land to facilitate rehabilitation and maintain fertility loss. The history of highland bamboo in the study area, especially Kurfa Kebele, has a long history (DDOA, 2023).

The farming system in the study watershed is typically mixed. Under mixed farming systems, farmers integrate both crop production and animal husbandry. Ploughing of the farm fields is carried out by traditional farm implements by oxen. Subsistence farming of mixed crop-livestock with maize (*Zea mays*), barley, finger milt, teff (*Eragrostis teff*), bean, pea, and barley under rain-fed conditions is the means of livelihood of the farming community. Cattle, horses, mules, and small ruminants comprise the major livestock classes raised by the community in the watershed (DDOA, 2023).

3.2 Sampling Site Selection, Soil Sampling, and Sample Preparation

Before soil sample collection, field observation and reconnaissance field survey were carried out, and informal group discussions with agricultural experts were made to identify representative land use types. A physical observation was made to ascertain the primary land use type and slope gradient within the representative study region's two slope positions, the upper and lower slopes. There are three land use types (bamboo forest, agricultural, and grazing land), and two conservation systems with and without management practice), area exclosure for grazing land and integrated soil and water conservation practices for cropland and both land use type and land management practice were considered under each slope gradient. The slope gradient was categorized by using a clinometer as a lower slope (2%–10%) and an upper slope (20%–30%).

3.2.1 Experimental design

Stratified random sampling was employed to gather data from the treated and untreated sites, upper and lower slope positions, and different land-use types at each slope position. Out of different land use types, only three land use types (bamboo forest, cultivated land, and grazing land) were purposely selected for this study. Different land management practices were also applied in the Gerda watershed, (area exclosure and integrated soil and water conservation practice was selected). Accordingly, three factors were involved in the study, namely three land use types (grazing land, cultivated land, and bamboo forest), two management practices (treated and untreated), and two slope classes (upper, and lower). The experiments have a total of twelve (12) treatments that were arranged in 3*2*2 factorial combinations.

Soil samples were collected after crop harvest (March 16 to April 22, 2024). These soil samples were taken from the selected land use type, land management practice, and slope position with three replications. At every sampling plot, 5 sub-samples from 0-20 cm depth were collected in the diagonal method from four corners and at the center of the plot. Accordingly, a total of 36 composites by auger and undisturbed samples by using a core sampler (3 LUT× 2 MGT×2 slope position and 3 replications) were collected from each plot (10m X 10m) from five spots within a depth of 0-20cm.

3.3 Soil Samples Preparation and Laboratory Analysis

The composite soil samples taken by auger were mixed and reduced to 1 kg properly bag-labeled with the appropriate information or field code of the sample and transported to the Bahir Dar soil laboratory. This composite soil sample was air-dried, crushed, and passed through a 2 mm sieve for the determination of most of the soil quality indicators. Undisturbed samples were also collected with a core sampler for the determination of bulk density. Finally, the soil samples were analyzed following standard analytical procedures.

3.3.1 Analysis of soil physical properties

From the major soil, physical properties known only as soil particle size distribution (texture) and bulk density were determined for this study. Particle size distribution was analyzed by the Bouyoucos hydrometer method (Bouyoucos, 1962). The textural class was determined by plotting the value of sand, silt, and clay to the “Marshall textural triangular coordinate” following the USDA system (Marshall, 1951). The bulk density (BD) of soil was estimated from undisturbed soil samples collected from each land use type, management practice, and slope position using a core sampler weighed at field moisture content, and then dried in an oven at 105^{o}C for 24 hours (Blake, G. R., & Hartge, 1986). The bulk density was calculated by dividing the masses of the oven-dry soils (g) by the respective volumes (cm3):

Bulk density (BD) = $\frac{M(g)}{V(cm3)}$

where M = Mass of oven-dry soil and

V = Volume of the soil

3.3.2. Analysis of soil chemical properties

Selected soil chemical properties such as pH, CEC, AP, TN, and organic matter were analyzed for this study. The soil pH-H2O was measured using a pH meter in a 1:2.5 ratio soil- water suspension as outlined by van Reeuwijk (1986). Soil organic carbon was determined by following the dichromate oxidation method as described by (Walkley, 1934). Moreover, the percent of soil OM was obtained by multiplying the percent soil OC by a factor of 1.724, following the assumption that the OM is composed of 58% carbon. Total nitrogen was determined using the micro Kjeldhal digestion, distillation, and titration procedure as described by Bremner JM (1982). While Available phosphorus was extracted by using the Olsen methods (Olsen, 1954). Finally, CEC was determined from an ammonium acetate saturated sample that was subsequently replaced by sodium from a percolated sodium chloride solution after the removal of excess ammonium by repeated washing with alcohol (Chapman, 1965).

3.4. Statistical Analysis

Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS), version 27.0. Depending on the distribution of the soil data, a three -way ANOVA and pairwise comparison were performed using the GLM procedure. This was done to test the significance of differences in soil properties, with land use type, land management practices, and slope position as the main factors, including their interactions. The general linear model (GLM) was used to determine the mean, standard error, F-values, and p-values, and to test the significance of differences between each soil property based on the specified independent variables. One-way ANOVA was used to analyze the mean values of the different physicochemical properties of soil as dependent variables. Where appropriate, a post-hoc multiple comparison test was used to compare the mean values of soil properties across land use types.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 Variations of Physical Soil Properties in Different Land Use Types, Management, and Topography

4.1.1 Soil texture

The result of this study indicated that there is a highly significant ($P<0.001$) in sand fraction and also a significant difference ($P \leq 0.05$) in clay and silt fraction among land use types. The highest mean value of sand was recorded (47.5%) in cultivated land followed by grazing land with a mean value of (46.2%) and Bamboo Forest (38.2%). The highest mean value of sand fraction recorded in cultivated land could be due to soil erosion, and intensive and improper cultivation which leads to the removal of the fertile soil part. The highest mean value clay and silt content (30%) was recorded in Bamboo Forests followed by grazing land (25%) and cultivated land (22.7%). This may be due to the failure of leaves and their underground root growth causes them to succeed other back wood types to keep soil particles intact, consequently, thereby preventing soil erosion and promoting water percolation (Kasu, 2023).

Table 4.1 Main effect of LUT, MGT, and slope on physical soil quality indicators.

Property	Sand (%)	Clay (%)	Silt (%)	BD g/cm^3)
LUT				
Grazing	46.2^b	25^a	28.8^b	1.23^b
Cultivated	47.5^a	22.7^b	29.8^{ab}	1.28^a
Bamboo forest	38.2^c	30^a	30.1^a	0.98^c
Mean	43.9	25.9	29.9	1.16
SE	0.37	0.5	0.51	0.012
F	187.34	52	7.8	180.06
P	.00	.00	.002	.00
SIGN	***	***	**	***

MGT				
Treated	39.4^{b}	30.7^{a}	30.4^{a}	1.03^{b}
Untreated	48.4^{a}	21.1^{b}	29.9^{a}	1.29^{a}
Mean	43.9	25.9	30.15	1.16
F	419.67	295.1	0.035	400.5
SE	0.43	0.4	0.42	0.01
P	.00	.00	0.85	.00
SIGN	***	***	NS	***
SLOPE				
Upper	47^{a}	23.5^{b}	29.5^{a}	1.24^{a}
Lower	40.9^{b}	28.3^{a}	30.8^{a}	1.07^{b}
Mean	43.95	25.9	30.15	1.15
SE	0.3	0.41	0.42	0.01
F	205.63	59.1	1.7	143.8
P	.00	0.026	0.24	.00
SIGN	***	*	NS	***

*Note BD, bulk density; LUT, land use type; MGT, management practice; Means within a column under each factor followed by the same letter are not statistically significant and Means followed by different letters along a column are statistically significant. ***, **, *, and NS indicate that the means are statistically significant at P < 0.001, 0.01, and 0.05 and no significance, respectively.*

The result of this study is in line with the study by Fikru Assefa *et al*. (2020) who reported that most soil physical properties were directly affected by land use types and soil under cultivated land had low fertility. The result of this study also agreed with the study by Kindiye Ebabu *et al*. (2020) who indicated that there was a significant difference in soil texture among different land use types and the highest mean value of sand content (42%) recorded from cultivated land at Aba Gerima agroecological zone. A similar result was also conducted by Venkatesh *et al*., (2005) reported that mixed bamboo stands have higher levels of beneficial soil nutrients and superior soil properties, such as soil porosity, aeration, and bulk density than monoculture. On the other hand, this study disagreed with the study by Zebene Tadesse *et al*. (2023) who obtained that soils under the natural lowland bamboo forest showed significantly higher sand and lower clay fractions than the soils on continuously cultivated lands. This may be because Highland bamboo forests could have different levels of organic matter accumulation, which can influence soil texture and water-holding capacity (Kassahun Embaye, 2000).

Soil texture is also influenced by land management practices and slope position. There was a statistically significant ($P<0.001$) difference in sand and clay fraction due to management practice and there was no significant difference in silt fraction. There was a slight difference in the mean value of silt content at a treated site (30.4%) and (29.9%) in an untreated site. The highest mean value of sand content (48.4%) and the lowest clay fraction (21.1%) were recorded from untreated sites. The reason might be the continuous grazing and trampling effect of livestock on grazing land and intensive cultivation and the removal of crop residue from cultivated land which is exposed to selective removal of the clay and silt fraction due to erosion.

The highest mean value of clay content (30.7%) and the lowest mean value of sand content (39.4%) were recorded from the treated site. In this case, the reason might be relatively low soil erosion at the treated site due to SWC in cultivated land, dense vegetation, and accumulation of vegetation litter and grass. This result agrees with Anteneh Asfaw *et al.* (2023) who reported the highest mean value of sand content (49.0%) and the highest mean value of clay content (31.8%) at open grazing land and closed grazing land respectively.

The finding of this study is also in line with that Melku Dagnachew *et al*. (2020) reported that Soils treated with SWC measures have significantly higher clay fractions compared with those without SWC measures. Conversely, silt fractions were significantly lower in cultivated lands with SWC than without SWC measures. The interaction effect of land use type and management practice shows a significant difference ($P \leq 0.05$) in the mean value of sand and silt content of the soil. Clay content is not shown to be statistically significant ($P > 0.05$) in the interaction effect of land use type and management practice.

Slope position is also a factor that can influence soil textural class. The result indicated that there was a significant difference ($P \leq 0.05$) in sand and clay content but there was no significant difference ($P > 0.05$) in silt content among slope positions. However, there was a very slight difference among the mean value of silt content due to slope position, with the highest mean value of silt content (30.8%) recorded in the lower slope, and the highest mean value of silt content (29.5%) recorded in the upper slope. The highest mean value of sand content (47.0%) and lowest clay content (23.5%) was recorded from the upper slope (20%–30%) and the highest clay content (28.3%) and lowest sand content (40.9%) recorded from the lower slope (2%–10%). The reason could be due to the high mean annual precipitation across the study area that might have selectively transported the fine soil fractions by runoff in the form of erosion while leaving the coarser fraction behind. A similar study conducted by Belayneh Bufebo *et al*. (2021) reported that there was a highly significant difference recorded among different slope classes. This study is also in line with Kedir Merga *et al*. (2023), who reported that the clay content was rising as the slope gradient decreased, whereas the sand content showed declining tendencies as the slope gradient decreased.

The interaction effect of land use type and slope class show a significant difference in the mean value of sand content ($P \leq 0.05$) and statistically significant ($P<.001$) due to the interaction effect of land use type, management practice, and slope position but haven't show significance in clay and silt content of soil.

Table 4.2 Interaction effect of land use type and management practice on soil quality indicators.

Property	Grazing	Cultivated	Bamboo forest	Mean	SE	F	P	SIGN
Treated								
Sand (%)	42.7^{a}	42.3^{a}	33.3^{b}	39.4	0.53	5.1	0.013	*
Clay (%)	30.2	27.3	34.5	30.6	0.71	0.47	0.63	NS
Silt (%)	27.2^{b}	30.3^{ab}	32.2^{a}	29.9	0.73	4.8	0.01	**
BD(g/cm^3)	1.1^{b}	1.23^{a}	0.73^{c}	1.02	0.17	74.8	.00	***
Untreated								
Sand (%)	49.7^{a}	52.7^{a}	43^{b}	48.5	0.53	5.1	0.013	*
Clay (%)	19.8^{b}	18^{b}	24.8^{a}	20.9	0.53	0.47	0.63	NS

Silt (%)	30.5^b	29.3^{ab}	31.5^a	30.4	0.73	4.8	0.01	**
BD(g/cm^3)	1.35^a	1.31^a	1.22^b	1.29	0.17	74.8	.00	***

*Note BD, bulk density; LUT, land use type; MGT management practice; Means within rows and columns followed by the same letter are not statistically significant and Means followed by different letters along rows and columns are statistically significant. ***, **, *, and NS indicate that the means within rows and columns differ significantly at $P < 0.001$, 0.01, and 0.05 and no significance, respectively.*

4.1.2 Bulk density

Bulk density was statistically significant ($P<0.001$) among land use types, management practices, and slope positions. The highest mean value of bulk density (1.28 g/cm^3) was recorded from cultivated land followed by grazing land (1.23 g/cm^3) and bamboo forest (0.98 g/cm^3). The upper landscape position had significantly higher bulk density than the lower landscape position. The low bulk density of the lower landscape position might be attributable to the high quantity of organic matter and clay content. Management practices also have impacts on soil health and soil property. In this study treated (1.03 g/cm^3) site had a higher significance difference regarding bulk density than the untreated site (1.29 g/cm^3).

The interaction effect of three factors (land use type, management practice, and slope position also showed statistically significant ($P<0.001$) variations in bulk density. The highest mean value of bulk density (1.49 g/cm^3) was recorded in the untreated upper grazing land and lower (0.58 g/cm^3) was recorded in the treated lower bamboo forest. The highest bulk density found on the open or free grazing land at the upper slope might be the trampling effect from domestic animals during grazing which leads to soil compaction and the low vegetation coverage exposure of the soil surface to direct raindrop impacts causes the soil compaction. The lower mean value of bulk density in the lower-treated bamboo forest could be due to better structure or aggregation and high soil porosity which can hold more water and increase available organic matter. Bulk density was significantly higher in the upper slope of untreated cultivated land as compared to lower treated cultivated land. The difference might be due to high soil erosion, low organic matter content, and low porosity in the untreated upper slope than the treated lower slope.

Table 4.3 Interaction effect of land use type with slope position on soil quality indicators.

Property	Grazing	Cultivated	Bamboo forest	Mean	SE	F	P	SIGN
Upper								
Sand (%)	50^{a}	49.8^{a}	41.2^{b}	46.9	0.53	4	0.032	*
Clay (%)	22.6	20.3	27.5	23.4	0.71	.00	1	NS
Silt (%)	27.3	29.8	31.3	29.5	0.73	.00	1	NS
BD	1.32^{a}	1.31^{a}	1.08^{b}	1.23	0.17	11.74	.00	***
Lower								
Sand (%)	42.3^{a}	45.1^{a}	34.8^{b}	40.7	0.53	4	0.032	*
Clay (%)	27.3	25	32.5	27.9	0.71	.00	1	NS
Silt (%)	30.3	29.8	32.3	30.3	0.73	.00	1	NS
BD	1.12^{a}	1.24^{a}	0.87^{b}	1.07	0.17	11.74	.00	***

*Note BD, bulk density; Means within the same rows and columns followed by the same letter are not statistically significant and Means followed by different letters along the same rows and columns are statistically significant. ***, **, *, and NS indicate that the means within rows and columns are significantly different at P < 0.001, 0.01, and 0.05 and have no significance, respectively.*

This result agreed with the finding by Kindiye Ebabu *et al*. (2020) who reported that bulk density decreased after the implementation of sustainable land management practices. Another similar result was also conducted by Dilnesa Bayle *et al*. (2023) reported that the maximum bulk density (1.44 g/cm^3) was found in the subsurface layer of grazing field soils at the top of the slope, while the lowest (1.20 g/cm^3) was found in the surface layer of cultivated land soils at the bottom of the slope.

4.2 Chemical Soil Quality Indicators Under Land Use Type, Management Practice, and Slope Position

4.2.1 Soil reaction (pH)

The mean value of soil reaction pH (H2O) was highly significant (P<0.001) among land use type, land management, and slope position. The highest mean value of soil pH (6.35) was obtained from bamboo forest land and the lowest mean value of pH (5.43) was recorded from cultivated land. This might be due to the removal of basic cations through intensive cultivation and the continuous use of acid-forming inorganic fertilizers. The highest mean value of pH from bamboo forest land could be related to the limited removal of basic cations through erosion and leaching. Bamboo, with its rapid growth and widespread root system, enhances the physical, chemical, and biological properties of soil, limits soil erosion, and is ideal for the rapid rehabilitation of degraded lands (Gaikwad *et al.*, 2022). This study agrees with the study conducted by Zebene Tadesse *et al.* (2023) who reported that soils under bamboo canopies exhibit better pH levels and nutrient retention compared to adjacent areas without bamboo.

Table 4.4 Main effects of LUT, MGT, and slope position on chemical soil quality indicators.

Property	$pH\text{-}H_2O$ **(1:2.5)**	OM (%)	TN (%)	AP (ppm)	CEC *Cmol (+) kg⁻*
LUT					
Grazing	5.68^b	2.54^b	0.16^b	4.15^b	32.69^b
Cultivated	5.43^c	1.26^c	0.08^c	3.71^c	28.12^c
Bamboo forest	6.34^a	7.07^a	0.22^a	6.46^a	38.13^a
Mean	5.81	3.62	0.15	4.77	32.9
SE	0.31	0.14	0.01	0.15	0.69
F	230.43	462.73	40.29	90.51	52.43
P	<0.001	<0.001	<0.001	<0.001	<0.001
SIGN	***	***	***	***	***
MGT					

Treated	6.04^{a}	5.04^{a}	0.24^{a}	6.03^{a}	35.89^{a}
Untreated	5.6^{b}	2.21^{b}	0.07^{b}	3.5^{b}	30.07^{b}
Mean	5.82	3.6	0.5	4.7	32.9
F	148.08	299.06	168.25	197.65	53.09
SE	0.25	0.11	0.01	0.12	0.56
P	.00	.00	.00	.00	.00
SIGN	***	***	***	***	***
SLOPE					
Upper	5.64^{b}	2.47^{b}	0.11^{b}	4.13^{b}	30.13^{b}
Lower	5.99^{a}	4.78^{a}	0.19^{a}	5.41^{a}	35.83^{a}
Mean	5.8	3.6	0.15	4.77	32.9
SE	0.02	0.11	0.01	0.12	0.56
F	94.53	198.07	47.09	50.79	51.00
P	.00	.00	.00	.00	.00
SIGN	***	***	***	***	***

*Note OM, organic matter; TN, total nitrogen; AP, available phosphorus; CEC, cation exchange capacity; LUT, land use type, MGT management practice; Means within a column under each factor followed by the same letter are not statistically significant and Means followed by different letters along a column are statistically significant. ***, **, *, and NS indicate that the means are statistically significant at P < 0.001, 0.01, and 0.05 and no significance, respectively.*

Land management practices like area closure, integrated soil and water conservation, and agroforestry practices can influence soil reaction. Based on the result of this study, there was a high significance (P<0.001) difference between treated and untreated sites. The highest mean value of soil reaction (6.04) was recorded from the treated site and the lowest mean value of pH (5.6) was obtained from the untreated site. This result is supported by other studies done in our country and parts of the world. This result agrees with the study by Tesfaye Tanto and Laekemariam Fanuel (2019) reported that the highest mean value of pH (6.60) was obtained from Integrated SWC after 5 years and the lowest mean value of pH value was recorded from untreated or control cultivated land. In a similar study by Tamrat Sinore and Solomon Umer (2021), the exclosure exhibited significantly ($p<0.05$) greater pH near the grazing area and concluded that exclosure is a realistic technique for restoring degraded landscapes and should be implemented as soon as possible.

Soil reaction is also affected by landscape positions. The result showed that there was a highly significant difference ($P<.001$) among the lower slope which had the highest mean value of pH (5.99) and the lowest mean value (5.64) at the upper slope. This result is in line with Dilnesa Bayle *et al*. (2023) who reported that the mean value of pH increased with in decreasing slope position. The reason could be due to basic cation depletion and removal as a result of persistent soil tillage and crop assimilation or soil erosion and leaching. pH value could not show a significant difference ($P>.05$) among the interaction effect of land use type and management practice. However, there is a slight difference in pH value for individual land use types and their management practice than untreated. pH value shows statistically significant ($P<.001$) among the interaction effect of land use type, management practice, and slope position. The highest mean value of pH (6.78) was obtained from treated lower bamboo forests and the lowest mean value of pH (5.16) was recorded from untreated upper cultivated land. The reason might be linked with intensive cultivation, the use of acid-forming inorganic chemicals, the removal of crop waste residue on cultivated land, and overgrazing on grazing land which can remove the availability of organic matter and basic cations in the soil.

Table 4.5 Interaction effect of land use type with management practice on chemical soil quality indicators.

Property	Treatment	Grazing	Cultivated	Bamboo forest	Mean	SE	F	P	SIG
pH-H_2O **(1:2.5)**	Treated	5.91	5.65	6.55	6.03	0.044	0.139	.87	NS
	Untreated	5.46	5.2	6.14	5.6				
OM (%)	Treated	3.83^{b}	1.65^{c}	9.65^{a}	5.01	0.2	59.79	.00	***

	Untreated	1.25^{b}	0.88^{c}	4.5^{a}	2.21				
TN (%)	Treated	0.26^{ab}	0.13^{b}	0.29^{a}	0.22	0.015	7.67	.003	**
	Untreated	0.05^{b}	0.03^{b}	0.14^{a}	0.07				
AP (ppm)	Treated	4.84^{b}	5.01^{b}	8.24^{a}	6.03	0.21	12.4	.00	***
	Untreated	3.46^{b}	2.41^{c}	4.68^{a}	3.51				
CEC *Cmol (+) kg^{-1}*	Treated	33.95^{ab}	31.25^{b}	42.49^{a}	35.89	0.97	5.07	0.015	*
	Untreated	31.43^{a}	25.00^{b}	33.78^{a}	30.07				

*Note OM, organic matter; TN, total nitrogen; AP, available phosphorus; CEC, cation exchange capacity; LUT, land use type, MGT management practice; Means within same rows and columns followed by the same letter are not statistically significant and Means followed by different letters along same rows and column are statistically significant. ***, **, *, and NS indicate that the means within rows and columns are significantly different at P < 0.001, 0.01, and 0.05 and no significance, respectively.*

4.2.2 Soil organic matter

Soil organic matter shows highly significant (P<.001) variation among land use types, land management practices, slope positions, and its interaction effect. The highest mean value of organic matter content (4.12) was obtained from the bamboo forest and lower organic matter content (0.74) in the cultivated land. The reason could be due to less soil degradation and accumulation and decomposition of organic matter through time in bamboo forests compared with grazing and cultivated land. Continuous cultivation for a long time leads to soil degradation and fertility loss. A similar study by Zebene Tadesse *et al*. (2023) reported that the SOC and TN values were significantly higher in natural bamboo forests than in cultivated lands.

Organic matter also shows highly significant (P<.001) variation among treatment conditions. The highest mean value of organic matter (2.94) was obtained from the treated site and the lowest (1.28) from the untreated site. The lowest mean value from untreated sites might be due to intensive cultivation without proper management practice in cultivated land and overgrazing on grazing land. This study is in line with the study by Kindiye Ebabu *et al*. (2020) who reported sensitive soil quality parameters (BD, SOC, TN, P_{av}) were noticeably improved three years after the implementation of the SLM practices. Another similar study by Anteneh Asfaw *et al*. (2023) reported that the highest mean value of organic carbon (2.13%) was obtained from area closure and the lowest mean value (1.64%) was observed from adjacent open grazing land.

The interaction effect of land use type, management practice, and slope position has shown highly significant variation (P<.001) in soil organic matter. The highest mean value of soil organic matter (11.46%) was recorded in treated lower bamboo forests, and the lowest (0.59%) in untreated upper cultivated land. The reason why the lowest organic matter recorded from untreated upper cultivated land could be due to the high amount of precipitation during the rainy season and Havey runoff which can form erosion and wash away organic matter. Soil organic matter content increases down the landscape due to lower landscape positions receiving high surface soil materials taken from the upper landscape positions.

4.2.3 Total Nitrogen

The total N contents of the soils were highly significant (P<.001) among land use type, and management practice, and had a significant interaction in its interaction effect. The highest mean value of total nitrogen content (0.22%) was obtained from bamboo forests followed by grazing land (0.16%) and cultivated land (0.87%). This result agrees with Belayneh Bufebo *et al.* (2021) who reported that the lowest mean value of total nitrogen was recorded followed by grazing land and forest land. In another similar study, Zebene Tadesse *et al*. (2023) reported that the highest amount of total nitrogen was obtained from natural bamboo forests than agricultural lands. Low total nitrogen content on cultivated land might be due to regular harvesting in which case the crops continuously remove the nutrients from the soil.

The mean value of total nitrogen was significantly (P<.001) affected by land management practice. The highest mean value of total nitrogen (0.24%) was recorded from the treated land and lowest (0.07%) was from the untreated land. The reason might be due to the decomposition of higher amounts of organic materials and there is minimal erosion due to management practice. This study is in line with the study by Hailu Terefe *et al*. (2020) who reported that the higher TN at the treated sub-watershed compared with the untreated sub-watershed.

Table 4.6 Interaction effect of land use type with slope position on chemical soil quality indicators.

Property	Grazing	Cultivated	Bamboo forest	Mean	SE	F	P	SIGN
Upper								
pH-H_2O **(1:2.5)**	5.55^{b}	5.34^{c}	6.04^{a}	5.64	0.036	12.48	.00	***
OM (%)	1.03^{c}	1.02^{c}	5.36^{a}	2.47	0.20	31.4	.00	***
TN (%)	0.11^{b}	0.075^{b}	0.28^{a}	0.15	0.015	7.32	0.005	**
AP (ppm)	3.22^{b}	3.56^{b}	5.63^{a}	4.13	0.219	7.32	0.003	**
CEC ***Cmol (+) kg^{-1}***	28.66	26.2	35.53	30.13	0.97	2.39	0.11	NS
Lower								
pH-H_2O **(1:2.5)**	5.82^{b}	5.52^{c}	6.64^{a}	5.99	0.036	12.48	.00	***
OM (%)	4.05^{b}	1.51^{c}	8.79^{a}	4.78	0.20	31.4	.00	***
TN (%)	0.20^{a}	0.1^{b}	0.15^{ab}	0.15	0.015	7.32	0.005	**
AP (ppm)	5.08^{b}	3.87^{c}	7.29^{a}	5.41	0.219	7.32	0.003	**
CEC ***Cmol (+) kg^{-1}***	36.71	30.05	40.74	35.8	0.97	2.39	0.11	NS

Note OM, organic matter; TN, total nitrogen; AP, available phosphorus; CEC, cation exchange capacity; LUT, land use type, MGT management practice; Means within same rows and *columns followed by the same letter are not statistically significant and Means followed by different letters along same rows and column are statistically significant. ***, **, *, and NS indicate that the means within rows and columns are significantly different at P < 0.001, 0.01, and 0.05 and no significance, respectively.*

Slope position and its interaction with land use type show high significance on the mean amount of total nitrogen. The highest mean value of total nitrogen (0.19%) was recorded from the lower slope and the lowest (0.11%) from the upper slope. The highest mean value of total nitrogen (0.39%) was obtained from treated lower-slope bamboo forests and the lowest (0.02%) from untreated upper-cultivated land. The reason might be due to the impact of erosion and the displacement of total nitrogen from upper slope positions to lower positions. This result agreed with the study by Belayneh Bufebo *et al*. (2021) who reported that the lower landscape position had the highest mean (0.17%) value of total nitrogen content followed by middle landscape positions (0.15%) and the lowest (0.12%) at the upper landscape position.

4.2.4 Available phosphorus

The results of this study indicated that the available phosphorus (P) was significantly($P<0.001$) affected by land use type, land management practices, and slope position. Based on land use type, the highest mean value (6.46 ppm) of available phosphorus (P) was recorded from highland bamboo forest followed by grazing land (4.15 ppm) and cultivated land (3.71 ppm). The reason could be that high organic matter content in forest soils contributed to the release of organic phosphorus and the lowest mean value obtained from cultivated land might be the impacts of fixation, abundant crop harvest, and erosion. The result of this study is in line with the study by Belayneh Bufebo *et al*. (2021) who reported that a higher mean value of available phosphorus (13.00 ppm) was found in forest land followed by grazing land (10.01 ppm) and cultivated land s (9.52 ppm).

Available phosphorus shows a highly significant difference ($P<0.001$) among treatment conditions of the land. The highest mean value of available phosphorus (6.03 ppm) was recorded from treated land and the lowest (3.51 ppm) was recorded from untreated land uses. The reason could be due to the decomposition of higher organic matter and due to minimum erosion, which can influence fertile soil. The current finding is in line with Damte Balcha *et al*. (2020) who reported that Available phosphorus under soil management practice is significantly higher than untreated. This result also agrees with the study by (Bedada *et al*., 2020) reported that there was a statistically higher mean value of available phosphorus obtained from closed areas than from free grazing land.

The slope is also a factor that has a significant influence on available phosphorus. The highest mean value of available phosphorus (5.41 ppm) was recorded from the lower slope and the lowest mean value of available phosphorus was (4.13 ppm) obtained from an upper slope. The reason for obtaining a lower mean value of available phosphorus might be due to the removal of phosphorus from the upper slope by erosion and deposit at the lower part. Similarly, Belayneh Bufebo *et al*. (2021) and Kedir Merga *et al*. (2023) reported that a significantly higher amount of available phosphorus was recorded on the lower slope than on the upper slope.

The interaction effect of land use type with management practices and land use type with slope position has shown highly significant variations ($P<.001$) and ($P<0.01$) respectively. There is also a highly ($P<.001$) significant difference between the interaction effect of land use type with management practice and slope position.

Table 4.7 Interaction effect of treated site with and slope position on chemical soil quality indicators.

MGT	Slope	LU	pH-H_2O **(1:2.5)**	OM (%)	TN (%)	AP (ppm)	CEC *Cmol (+) kg^{-}*
Treated	**Upper**	Grazing	5.79^{b}	1.25^{c}	0.21	3.56^{b}	29.53
		Cultivated	5.52^{c}	1.45^{c}	0.13	5.74^{ab}	28
		Bamboo	6.32^{a}	7.8^{a}	0.2	7.23^{a}	39.6
Mean			5.87	3.5	0.18	5.51	32.37
F			3.47	18.46	3.38	18.67	0.67
SE			0.062	0.28	0.02	0.31	1.38
P			0.04	.00	0.051	.00	0.51

SIGN			*	***	NS	***	NS
	Lower	Grazing	6.03^{b}	6.42^{b}	0.32	6.13^{b}	38.36
		Cultivated	5.79^{c}	1.85^{c}	0.14	4.29^{c}	34.5
		Bamboo	6.77^{a}	11.46^{a}	0.39	9.25^{a}	45.38
Mean			6.19	6.57	0.28	6.55	39.4
F			3.47	18.46	3.38	18.67	0.67
SE			0.062	0.28	0.02	0.31	1.38
P			0.04	.00	0.051	.00	0.51
SIGN			*	***	NS	***	NS

*Note OM, organic matter; TN, total nitrogen; AP, available phosphorus; CEC, cation exchange capacity; LUT, land use type, MGT management practice; Means within same rows and columns followed by the same letter are not statistically significant and Means followed by different letters along same rows and column are statistically significant. ***, **, *, and NS indicate that the means within rows and columns are significantly different at P < 0.001, 0.01, and 0.05 and no significance, respectively.*

4.2.5 Cation exchange capacity

The CEC values of the soils in the study area were significantly (P<.001) affected by land use, management, and slope position. The highest mean value of CEC 38.13*Cmol (+) kg*$^{-1}$ was obtained from bamboo forest and the lowest mean value of CEC 28.12*Cmol (+) kg*$^{-1}$ was found from cultivated land. The bamboo forest likely had a higher CEC may be due to its high level of organic matter, while the cultivated land likely had a lower CEC due to its lower level of organic matter and higher rate of erosion. This study is in line with the study conducted by Hailu Amare *et al*. (2024) who reported that land use type and slope position had a significant impact on soil CEC, with forest land having the highest CEC and cultivated land having the lowest CEC.

Land management practice also has a factor that significantly (P<.001) affects CEC values and the highest mean value (35.89 12*Cmol (+) kg*$^{-1}$) was found from treated land and the lowest mean value (30.0712*Cmol (+) kg*$^{-1}$) was obtained from untreated land. A similar study by

Anteneh Asfaw *et al*. (2023) reported that the cation exchange capacity was very highly significant ($P \leq 0.001$) and affected due to land management practices and the highest mean CEC value was found under area closure (48.8 meq/100g) while the lowest value (33.5 meq/100g) was found in adjacent open grazing land. This result is also in line with the study by Fikru Assefa *et al*. (2020) who reported that the highest amount of CEC was found from the treated site rather than the untreated site.

CEC value was also significantly ($P<.001$) affected by slope position and the highest mean value of CEC (35.83 *Cmol (+) kg*$^{-1}$) was obtained from the lower slope and the lowest mean value (30.13 *Cmol (+) kg*$^{-1}$) was obtained from the upper slope. The high CEC levels in lower slope positions might be due to the accumulation of clay, soil OM, and basic cations which come from the upper slope by erosion. Similar findings by Mulugeta Eshetu and Lemma Wogi, (2024) reported that the amount of CEC value was significantly higher at lower slopes than at upper and middle slope positions. The interaction effect of land use type with management practice has shown a significant difference($P<.05$) in the amount of CEC value.

Table 8 Interaction effect of untreated site with LUT and slope position on chemical soil quality indicators.

MGT	Slope	LU	pH-H_2O **(1:2.5)**	OM (%)	TN (%)	AP (ppm)	CEC ***Cmol (+) kg*** $^{-}$
Untreated	**Upper**	Grazing	5.31^b	0.82^c	0.012	2.89^b	27.8
		Cultivated	5.16^c	0.59^c	0.018	1.37^c	24.4
		Bamboo	5.78^a	2.89^a	0.1	4.03^a	31.46
Mean			5.41	1.43	0.04	2.76	27.88
F			3.47	18.46	3.38	18.67	0.67
SE			0.062	0.28	0.02	0.31	1.38
P			0.04	.00	0.051	.00	0.51
SIGN			*	***	NS	***	NS

	Lower	Grazing	5.61^{b}	1.68^{b}	0.09	4.03^{b}	35.07
P		Cultivated	5.25^{c}	1.16^{c}	0.05	3.45^{c}	25.61
SIGN		Bamboo	6.51^{a}	6.11^{a}	0.17	5.33^{a}	36.1
Mean			5.79	2.98	0.1	4.27	32.26
F			3.47	18.46	3.38	18.67	0.67
SE			0.062	0.28	0.02	0.31	1.38
P			0.04	.00	0.051	.00	0.51
SIGN			*	***	NS	***	NS

*Note OM, organic matter; TN, total nitrogen; AP, available phosphorus; CEC, cation exchange capacity; LUT, land use type, MGT management practice; Means within same rows and columns followed by the same letter are not statistically significant and Means followed by different letters along same rows and column are statistically significant. ***, **, *, and NS indicate that the means within rows and columns are significantly different at $P < 0.001$, 0.01, and 0.05 and no significance, respectively.*

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study examined the effect of land use type, land management practice, and slope position on soil quality indicators in the Gerda watershed, Northwest Ethiopia. The result showed that soil bulk density, sand content, amount of clay and silt, soil pH, OM, total nitrogen, available phosphorus, and amount of CEC showed significant differences among land use type, land management practice, and slope position. The amount of silt content hasn't shown a significant difference between land management practice and slope position. The highest amount of clay content, soil pH, organic matter, total nitrogen, available phosphorus, amount of CEC, and the lowest sand and bulk density were obtained from treated Bamboo forests at lower slopes. In contrast amount the lowest clay content, soil pH, organic matter, total nitrogen, available phosphorus, amount of CEC, and highest sand and bulk density were found from untreated cultivated land at the upper slope. Based on the study, better soil quality was obtained from bamboo forest according to land use type and treated lower slope based on land management practice and slope position.

5.2 Recommendations

Based on the result of this study, the following recommendations have been drawn for further consideration.

- Promote Bamboo Forest Expansion and Management: The study indicates that bamboo forests, especially when treated and located on lower slopes, exhibit superior soil quality. Therefore, a key recommendation is to actively promote the expansion of bamboo forests within the Gerda watershed. This can be achieved through reforestation initiatives, providing incentives to farmers for bamboo cultivation, and educating communities about the ecological and economic benefits of bamboo. Furthermore, existing bamboo forests should be managed with best management practices to maintain and enhance soil and ecosystem health.

- Implement Soil Conservation Practices on Cultivated Lands, Particularly on Upper Slopes

The study revealed that untreated cultivated lands, especially those on upper slopes, have the poorest soil quality. To address this, it is crucial to implement effective soil conservation practices. These practices could include terracing, contour plowing, cover cropping, and the application of organic amendments. Special attention should be given to upper slopes, as they are more prone to erosion and nutrient loss.

- Implement area exclosure on grazing land use type should be applied to enhance soil fertility and maintain ecosystem health.
- Further research could be conducted on the influence of bamboo forest on soil fertility based on different climatic condition and Argo- ecology zone.

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APPENDIX

Appendix Table 1 Mean monthly rainfall and Temperature of Dembecha District (2019_2023)

month	rainfall	Maximum temperature	Minimum temperature
January	3.75	26.6	10.26
February	7.675	26.88	10.38
March	16.3	27.575	10.75
April	87.45	28.26	11.26
may	62.725	27.56	10.86
June	224.05	26.6	10.4
July	437.5	25.4	10.02
Augst	327.425	25.48	10.4
September	147.525	25.8	10.575
October	119.65	26.24	10.8
November	44.125	26.45	10.65
December	17.225	26.05	10.275
annual mean	1495.4	26.57458	10.5525

Source: Western Amhara Metrological Agency (WAMA, 2023)

Bahir Dar University

College of Agriculture and Environmental Sciences

Department of Natural Resources Management

Soil and Plant Analysis Laboratory

Appendix Table 2 laboratory result of soil property

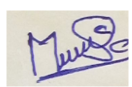
Laboratory Report

Client: Dejen Mera

No.	**Rep**	**pH-H_2O (1:2.5)**	**Bulk Density (g/cm^3)**	**% OC**	**% OM**	**% TN**	**Av. P (ppm)**	**CEC *Cmol (+) kg^{-1}***	**Texture (%)**		
									Sand	***Clay***	***Silt***
1	1	5.320	1.240	1.010	1.740	.024	3.860	35.200	46	23	31
2	1	5.270	1.270	.900	1.550	.160	5.340	30.000	46	25	29
3	1	6.540	1.000	3.830	6.600	.330	6.750	36.800	39	31	30
4	1	6.810	1.540	.420	.720	.015	2.540	27.800	54	18	28
5	1	5.740	1.270	.640	1.100	.052	3.470	25.800	51	20	29
6	1	5.150	1.170	3.750	6.470	.187	4.280	37.200	40	31	29
7	1	5.960	.590	6.710	11.560	.360	8.440	47.200	32	35	33
8	1	5.790	1.240	.970	1.670	.180	4.620	35.600	40	32	28
9	1	6.470	1.380	.350	.600	.013	1.260	25.300	55	18	27

10	1	5.470	1.290	1.330	2.290	.092	3.720	26.000	48	22	30
11	1	5.530	1.090	.740	1.270	.220	3.560	25.800	46	25	29
12	1	6.010	.940	4.790	8.200	.210	6.420	37.200	36	33	31
13	2	5.280	1.260	.980	1.690	.078	4.340	35.780	45	22	33
14	2	5.250	1.240	.860	1.480	.085	6.140	28.300	45	23	32
15	2	6.570	1.050	3.640	6.280	.290	6.430	38.700	38	33	29
16	2	6.780	1.470	.470	.810	.013	3.350	28.400	53	16	31
17	2	5.830	1.250	.630	1.080	.064	3.570	24.750	50	20	30
18	2	5.210	1.140	3.540	6.100	.177	5.760	32.400	38	27	35
19	2	5.830	.530	7.210	12.700	.340	9.750	45.300	33	37	30
20	2	5.730	1.220	1.080	1.860	.130	4.540	34.200	39	31	30
21	2	6.170	1.390	.370	.630	.018	1.320	23.400	54	17	29
22	2	5.320	1.280	1.740	2.990	.120	3.850	32.800	45	23	32
23	2	5.270	1.180	.670	1.150	.210	3.780	30.000	49	27	24
24	2	6.540	.850	4.000	6.890	.200	7.840	38.900	34	33	33
25	3	6.810	1.150	.940	1.620	.170	3.890	34.230	48	21	31
26	3	5.740	1.260	.780	1.340	.150	5.750	25.700	45	24	31

27	3	5.150	1.050	3.710	6.390	.340	5.210	39.600	38	34	28
28	3	5.960	1.450	.550	.940	.008	2.780	27.200	52	19	29
29	3	5.790	1.280	.770	1.320	.053	3.320	26.300	52	18	30
30	3	6.470	1.190	3.350	5.780	.172	5.950	38.700	38	28	34
31	3	5.470	.620	6.17	10.13	.490	9.570	43.640	30	37	33
32	3	5.530	1.180	1.18	2.030	.120	3.720	33.700	39	29	32
33	3	6.010	1.320	.320	.550	.022	1.550	24.500	54	15	31
34	3	5.280	1.270	1.98	3.410	.110	4.520	35.600	49	22	29
35	3	5.250	1.240	.780	1.340	.220	3.340	32.800	46	31	23
36	3	6.570	.900	4.890	8.430	.190	7.440	42.700	35	32	33

Name of chemist: Mamaru Shitahun Sign.  Date 18\11\2024

Checked By: Mamaru Shitahun Sign.  Date 18\11\2024

Approved By: ____________ Sign. ____________ Date ______________________

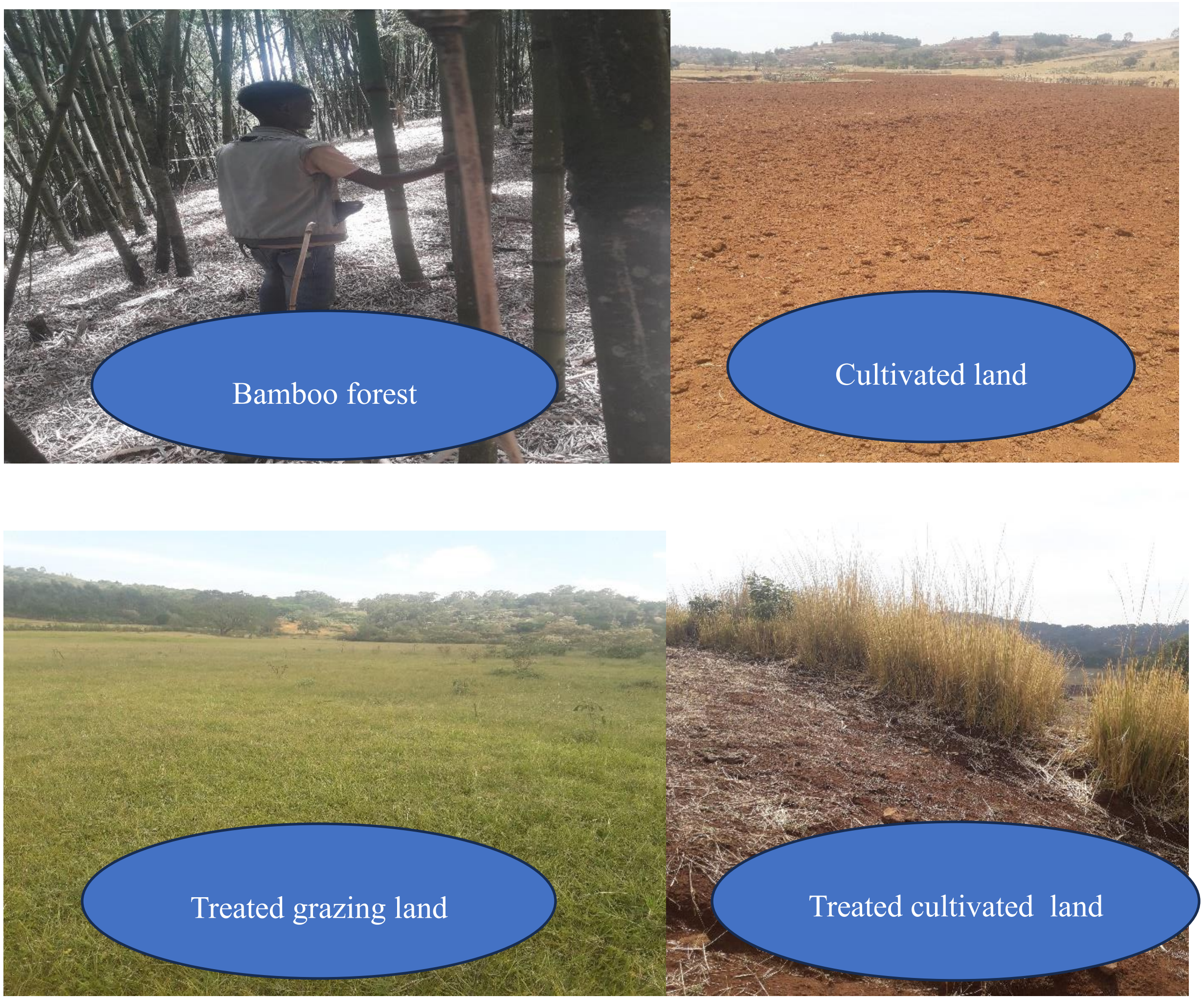


Photo taken by Dejen Mera from the study watershed, April 2024

Appendix Figure 1 Different land use types in the study watershed

Appendix Figure 2 Soil preparation and laboratory

AUTHOR'S BIOGRAPHY

The author was born on April 24, 1997, in Dembecha district, West Gojjam Administrative Zone, Amhara National Regional State, Ethiopia. He received his primary education at Godber and completed his secondary education at Dembecha Secondary School. In October 2019, he commenced his higher education at Wolaita Sodo University, Dawuro Campus, in the field of Natural Resource Management, culminating in the conferral of a Bachelor of Science (BSc) degree in August 2021. Subsequently, he served as a Graduate Assistant (GA_1) at Dawuro Campus from September 2022 to October 2023. In October 2023, the author joined Bahir Dar University to pursue a Master of Science (MSc) degree in Soil Conservation and Watershed Management. His current research focuses on the effects of land use type and land management practices on soil quality indicators within the Gerda watershed, Dembecha district, Northwestern Ethiopia.