



SCHOOL OF GRADUATE STUDIES

**EFFECTS OF SOIL AND WATER CONSERVATION
PRACTICES ON SOIL PHYSICOCHEMICAL PROPERTIES
UNDER DIFFERENT LAND USES IN KEBENA SPECIAL
DISTRICT, CENTRAL ETHIOPIA**

MSc. THESIS

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**Effects of Soil and Water Conservation Practices on Soil
Physicochemical Properties Under Different Land Uses in Kebena
Special District, Central Ethiopia**

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APPROVAL SHEET
SCHOOL OF GRADUATE STUDIES
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This is to certify that the thesis entitled “**Effects of Soil and Water Conservation Practices on Soil physicochemical Properties under Different Land Uses in Kebena Special District, Central Ehtiopia**” submitted in partial fulfillment of the requirements for the degree of Master's science with soil science, and has been carried out by Abdulrahman Ahmed Zeinu, under our supervision. Therefore we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Abdulrahman Ahmed Zeinu have read and evaluated his thesis entitled **“Effects of Soil and Water Conservation Practices on Soil physicochemical Properties under Different Land Uses in Kebena Special District, Central Ehtiopia”**, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree master's science in Soil Science.

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DEDICATION

This thesis is dedicated to my beloved wife, Kanzia Reshad, and my dear children, Abdulghar, Fawzan, and Huzaiifa Abdulrahman. I am profoundly grateful for the unwavering patience and support they have shown me throughout my studies and during the writing of this thesis.

DECLARATION

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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BIOGRAPHICAL SKETCH

The author was born on January 3, 1980, in Bariyo Kebele, Kebena special District, central Ethiopia. He attended elementary school from 1989 to 1996 at Edegetber Primary School. He then transferred to Goro General Secondary school and completed preparatory school.

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LIST OF ABBREVIATIONS AND ACRONYMS

CA	Central Agency
DAS	Development Agents
FFW	Food for Work
GIS	Geographic Information Systems
IK	Indigenous Knowledge
ITCZ	Inter-Tropical Convergence Zone
KSDANRS	Kebena Special District Agriculture and Natural Resource Sector
KSDFEDO	Kebena Special District Finance Economic Development Office
MOA	Ministry of Agriculture
NGO	Non-government Organization
NRM	Natural Resource Management.
OC	Organic Carbon
OM	Organic Matter
PAS	Peasant Association
PBS	Percentage Base Saturation
SNNPR	Southern Nations, Nationalities, and People's Region
SOM	Soil Organic Matter
SPSS	Statistical Package for Social Scientists
SWCP	Soil Water Conservation Practices
TN	Total Nitrogen

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EFFECTS OF SOIL AND WATER CONSERVATION PRACTICES ON SOIL PHYSICOCHEMICAL PROPERTIES UNDER DIFFERENT LAND USES IN KEBENA SPECIAL DISTRICT, CENTRAL EHTIOPIA

ABSTRACT

Soil erosion is among the foremost causes of declining soil resources in Ethiopia; the ever-increasing population has driven the populace to inhabit marginal frontiers worsening soil erosion and food insecurity. The purpose of the study was to assess the effect of land use types and soil and water conservation practices on soil properties in kebena area, central Ethiopia. A 3x2x2 factorial completely randomized block design (RCBD) was employed to investigate the impact of three land uses (grazing land, cultivated land, and plantation forest), two conservation practices (conserved and unconserved) and two soil depth (0-20 cm and 20- 40 cm) on soil physicochemical properties in Kebena special District, Central Ethiopia. The result showed that most of the selected soil physicochemical properties were affected by land use types and soil and water conservation measures. The highest clay (47.33%), moisture content(13.12%), soil pH (7.43), organic matter(5.91), organic carbon (3.60), total nitrogen (0.25), cation exchange capacity (29.26), available phosphorus(18ppm), exchangeable calcium (20.89 ppm), and magnesium (8.23 ppm) were recorded in the conserved plantation forest of the upper surface layer (0-20 cm). While the highest bulk density (1.37g/cm³) was recorded under unconserved cultivated land of the upper surface layer (0-20 cm). Further more, the interaction effects of land use types, conservation practices and soils depth was not significantly ($p < 0.05$) influenced exchangeable sodium and potassium. However, the highest exchangeable sodium was recorded at conserved plantation forest (0.9 ppm) and the plantation forest of lower surface layer (20-40 cm) (0.79ppm) and again the highest sodium (0.85 ppm) was recorded under conserved land of both upper and lower surface layer. These results underscore the critical need for widespread implementation of soil and water conservation practices in the study area. To enhance community adoption of these practices, further efforts are required to raise awareness and promote sustainable land management strategies that improve soil health and food security.

Keywords: *Conservation, Erosion, Landuse, Soil-Depth*

1. INTRODUCTION

1.1. Background

Soil erosion disturbs agricultural, environmental, and ecological functions performed by the soil (Dudiak *et al.*, 2019). It results in the depletion of soil fertility, decreased moisture storage capacity, and consequently reduced crop productivity (Abiy, W., 2022). In addition to the loss of soil fertility and crop yields, soil erosion also increases environmental pollution and sediment load in streams and rivers, thereby disturbing aquatic life, particularly fish (Boardman, 2006).. In the long run, soil erosion affects the socio-economic conditions of society by causing floods, silting of water reservoirs, and disruption (Mandal and Giri, 2021). Since soil formation takes millions of years approximately 1 cm every 100 to 400 years sustainable practices that conserve soil resources are essential (Pimentel *et al.*, 1995; Lal, 2001).

Soil erosion is particularly prominent in the highlands of Ethiopia, accounting for 43% of the total area (Desalegn *et al.*, 2018). The soils in these highlands are both fertile and crucial for supporting a significant proportion of the population; however, they are also highly prone to erosion (Haregeweyn *et al.*, 2017; Nyssen *et al.*, 2009). This erosion is mainly aggravated by land-use conflicts and topographic factors, as the rugged terrain contributes to the problem (Molla *et al.*, 2017). Abiy *et al.* (2015) in the Kaffa Zone of the southern region indicated that continuous farming, tillage on sloped land without conservation structures, deforestation, and frequent tillage—up to five times for some crops—are important factors aggravating soil erosion. Soil losses can reach 42 tons per hectare per year due to erosion, leading to a 30% decrease in yields and losses of 16-50% of rainwater each season, often in the form of floods that wash away the soil (Engdayehu *et al.*, 2016).

Soil erosion mainly occurs during the rainy season, manifesting as water erosion. Rills, gullies, and brown rivers filled with sediment indicate significant soil loss that disrupts agricultural production (Lal, R., 2001). Most erosion occurs on cultivated land in the form of sheet and rill erosion; however, it can also affect grasslands as gullies and forests if not properly managed (Milazzo, 2023).

Implementing soil and water conservation (SWC) practices in upland areas can foster various ecosystem services that provide upstream benefits (Meena, 2020). By maintaining or restoring the soil's capacity to retain water, nutrients, and organic matter, farmers can

dramatically reduce agricultural water demand, mitigate vulnerability to climate extremes such as droughts and flooding, and enhance soil carbon storage and productivity, all while decreasing runoff and the need for chemical fertilizers. Consequently, downstream water quality improves (Balasundram, 2023).

The detrimental effects of soil erosion have prompted efforts to implement sustainable SWC practices in Ethiopia's highlands (Bewket and Sterk, 2003). These practices include, but are not limited to, terracing, contour farming, and agroforestry (Amsalu and Graaff, 2007). While research has explored the efficacy of these practices in specific contexts, there remains a critical need to investigate the specific impact of SWC on soil physicochemical properties, particularly soil depth, across different land uses (Wolka, E., and Assefa, E. 2020).

Soil and water conservation initiatives have been carried out in Ethiopia for many years, notably by the Ministry of Agriculture. Over the past 40 years, large-scale activities have been implemented on cultivated land with contour bunds, on hillsides with afforestation terraces, and on degraded hills with hillside closures (Kohler and Hurni, 2022). Similar to other regions, SWC practices have been implemented in Kebena Special Woreda, Central Ethiopia for an extended period. However, gaps remain in effectively addressing the technological, economic, and social needs of local farmers. Therefore, this research addresses these gaps by focusing on the effects of SWC practices on selected soil physicochemical properties in Kebena Special District, Central Ethiopia. By analyzing the influence of different land uses, conservation practices, and soil depths, this study aims to provide valuable insights into optimizing SWC strategies for improved soil health, agricultural productivity, and overall environmental sustainability in the region..

1.2. Statements of the problem

Soil erosion is one of the most significant causes of declining soil resources in Ethiopia, which in turn affects agricultural productivity (Belayneh *et al.*, 2013). This problem is particularly pronounced in the highlands of Ethiopia (Pender & Gebremedhin, 2007). Additionally, the physicochemical properties of soil differ significantly between conserved and non-conserved practices in these highlands (Amsalu & de Graaff, 2007; Nyssen *et al.*, 2007). Rural communities living in degraded areas are exposed to severe soil erosion, land fragmentation, deforestation, and land pressure (Dessalegn, 2001; Yitaferu, 2007).

In Kebena Special Woreda, particularly in Sunika, Gerbaja and katibare Kebele, soil erosion is very high and poses a serious threat to land resources and agricultural productivity. To mitigate this issue, soil and water conservation measures have been implemented in the Kebena Special District watershed over the past two decades through community mass mobilization and free labor. However, the effects of these measures on soil properties have not been thoroughly evaluated, and the causes and impacts of the associated soil and water conservation measures and management practices remain unclear.

Therefore, understanding the effects of land use types and management practices on soil properties is essential for sustainable agricultural land management. This study aims to assess the impact of implemented soil and water conservation measures on soil properties in the Kebena Special District.

1.3. Objectives of the study

1.3.1. General objective

The overall objective of this study was to assess the effect of land use types, soil depth and SWC practice on soil physicochemical properties in Kebena Special District, Central Ethiopia.

1.3.2. Specific objectives

- To examine the physicochemical properties of soil in different land use types of the study area
- To examine the effects of SWC practices on soil physicochemical properties of the study area
- To examine the effect of soil depth on soil physicochemical properties of the study area

1.4. Research Questions

About the research objectives, the study tries to answer the following research questions:

- What were the status of selected physicochemical properties on different land use types of the study area? Soil in conserved and non-conserved land use?
- What was the effect of SWC practices on selected physicochemical properties of the study area?
- What was the effect of soil depth on soil physicochemical properties?

1.5. Significances of the Study

This study holds significant implications for improving soil health, agricultural productivity, and environmental sustainability in Kebena Special District, Central Ethiopia. By investigating the effects of soil and water conservation (SWC) practices on soil physicochemical properties in both conserved and unconserved areas, while considering variations in soil depth, this research contributed to a deeper understanding of the complex interactions between these factors.

The findings of this study provide valuable insights for various stakeholders. Farmers will benefit from practical information on the effectiveness of different SWC practices, enabling them to make informed decisions about land management and improve soil health on their farms. Agricultural extension workers will gain evidence-based recommendations to promote sustainable land management practices within the region, informing their programs and outreach efforts. Policymakers can utilize the research findings to develop and implement effective policies that promote soil and water conservation, ensuring the long-term sustainability of agricultural production and environmental health in Kebena Special District and similar agro-ecological zones.

Furthermore, this study will contribute to the growing body of knowledge on soil conservation in Ethiopia. By examining the relationship between SWC practices, soil depth, and soil physicochemical properties, it will provide a valuable foundation for future investigations into the effectiveness of SWC practices in different contexts and the development of more advanced strategies for soil management.

The findings of this study will not only benefit the local community in Kebena Special District but also have broader implications for promoting sustainable land management practices and improving agricultural productivity in Ethiopia and other similar regions facing soil erosion challenges.

2. LITERATURE REVIEW

2.1. Concepts of Soil and Water Conservation Practice

Soil Conservation is defined in different ways by different scholars Parisa, O. R. (2023). Defined Soil Conservation as the combination of appropriate land use and management practices that promote the productive and sustainable use of soils, reducing erosion and other forms of land degradation (Tadesse and Belay, 2004). Soil Conservation also defined as land resource degradation due to poor farming systems is the main environmental problem,

Soil and water conservation interventions are first a response to the perceived land degradation problem. Includes all forms of human actions to prevent and treat soil degradation Physical soil and water conservation practices are categorized: as traditional (indigenous) and improved practices. Whatever the measures might be, these measures aim to control runoff, improve soil fertility, and harvest water. Traditional conservation measures as farming practices that have evolved without any known outside institutional interventions. It has some soil conservation effects. Various mechanical, biological, and agronomic techniques used by farmers in various combinations are incorporated into the term. The traditional soil and water conservation (SWC) are simple structures of a short-term nature that could be reshuffled each year to make use of the soil captured above the structure and avoid rodent production. It may be difficult to conserve the soil and wisely use it during farmers' cultivation of land (Melkie, 2016).

2.2. Soil and Water Conservation Practices in Ethiopia

Soil conservation is the prevention of loss of the topmost layer of the soil from erosion or the prevention of reduced fertility. SWC is to prevent or at least reduce the effects of soil erosion while maintaining the soil quality (Graaff, 1993).

Soil and water conservation is at the top of development agendas in Africa. Virtually every project related to agriculture or the environment has a soil and water conservation component to it and environmental protection plans are being drawn up by African governments in which soil and water conservation figures are dominantly. This focus on soil and water conservation is due to its being perceived as a way to address both productivity and environmental sustainability questions (Mazzucatos, 2000).

Extensive land degradation in the Ethiopian Highlands jeopardizes rural livelihood. Intensified by increasing population pressure, a farmer is forced to expand their arable

land by deforestation thus worsening the soil erosion problem. Through the application of various soil conservation measures, farmers and authorities try to prevent further land degradation (Brenner *et al.*, 2013).

The Ethiopian government first recognized the severity of the soil degradation problem following the 1973/74 famines in Wolloss. The 1973/74 droughts drew also the attention of external donors to the land degradation problem and soon conservation became a priority. After the early 1970s, national efforts to conserve land intensified, these interventions largely relied on the mobilization of farm households and food for work (Berhanu and Swinton, 2003). The major benefits of erosion control are conserving water and retaining soil nutrients and organic matter, as well be maintaining soil depth and soil structure (Robert, 2012).

2.3. Soil and Water Conservation Practices in Central Ethiopia Region

Soil and water conservation techniques have been implemented by government organizations particularly by the regional bureau of agriculture, starting from region to district level. Moreover, various nongovernmental organizations including bilateral and multi-lateral organizations have implemented soil and water conservation techniques in highly degraded areas to halt the rapidly increasing land degradation specifically soil erosion. Apart from the exotic soil and water conservation techniques, indigenous soil and water conservation activities have been implemented by individual farmers with the aim of mitigating soil erosion, conserving soil moisture, and increasing soil fertility at the household farm level. Nevertheless, land degradation and soil erosion is still serious environmental and socio-economic threat to the region (Mandal, 2022).

Absence of integrating indigenous SWC: for centuries, Ethiopian farmers have an indigenous and traditional knowledge and skills to manage their farmland. In Southern Ethiopia, there are ample indigenous soil and water conservation techniques that enable farmers to manage and use their land. Farmers have typical agronomic soil and water conservation practices to conserve the soil, and moisture and to enrich soil fertility (Gete, 2000).

Some of the known agronomic practices are crop rotation, contour ploughing, mulching, manuring, strip cropping, agro-forestry practices, and life tree planting. The failure to integrate these rich practices into exotic soil and water conservation is one of the main constraints that exist in Woina- Dega and dega agro-ecological zones. High population

growth and density: as the Woina-dega climatic zone is suitable for settlement and agricultural practices; there is high population density. High population density forced the majority of farmers to depend on intensive farming for their substance which is a prime cause for less or no attention towards long-term soil and water conservation investment. This observation is supported by evidence that when incentives stopped, beneficiary farmers dismantled and/or abolished the constructed soil conservation works from communal and private land (Tute, 2022).

Current Situation of SWC in Central Ethiopia Region Since 2011, the Ethiopian government advocated collective action on physical soil and water conservation works and all regions are implementing the action by motivating and giving awareness to farmers. Collective action is one of the best participatory approaches which have its by-laws led by local leader assigned by the community itself. In Central Ethiopia Region, the first round of public massive SWC work was launched in January 2011 for consecutive 30 days, the second in February 2012, and the third round in March 2013 for 30 consecutive working days.

In this campaign program, farmers make a chain of development group whose farm is adjacent to the village level by developing good team spirit. Each kebele was divided into mini-watersheds in which farmers make a group and construct physical SWC in an agreed program with full responsibility, in the current community-based massive watershed management, people are actively participating in problem identification, planning, technology choice, designing and leveling, community by-laws settings, implementation, monitoring and evaluations and maintaining of the structures (Genene and Abiy, 2014).

2.4. Mismanagement of Farm Land

Practicing the major soil and water conservation both physical and biological conservation rather than practicing only alone few of construction of canals, terrace, inter cropping and other in combination to manage the soil fertility, increase crop production and managing natural resources to maintain safe environment, reduce climate change and in general reduce/halt land degradation increase the economic growth of the country as whole Feyera,D and Tsetadirgachew L.(2015).According the study indicated in four regions IWMI, (2018) working Paper182, more than ETB 25 billion (or approximately USD 1.2 billion) per year over the past 10 years. It is clear that large investments have been made in SWC activities in Ethiopia. However, the Outcomes in terms of impact on

yield and livelihood benefits are yet to be fully understood. A comprehensive assessment is needed to measure the impact of SWC activities on farmers' livelihoods and the environment.

Ethiopian farmers still continuing implementing unscientific way of cultivation. Wind and water erode the top soil. As a result of erosion much water could not percolate into the soil instead it is wasted as run-off (Kars, et al., 2022). Therefore, the soil cannot maintain the required amount of soil moisture. As a result of depletion of soil moisture and soil nutrients, the soil cannot sustain plant growth (Kumawat, A., et al., 2020).

Expansion of agriculture to sloping, shallow, and marginal lands is a common cause of soil erosion. Intensive agriculture and ploughing, wheel traffic, shifting cultivation, indiscriminate chemical input, irrigation with low quality water, and absence of vegetative cover degrade soils

Removal of crop residues for fodder and bio fuel and industrial uses reduces the amount of protective cover left on the soil surface below the level adequate to protect the soil against erosion. Intensive cultivation accelerates water runoff and exacerbates soil erosion, which transport nutrients and pesticides off-site, declining soil and water quality. (Singh and Nath, 2020).

2.5. The Role of Indigenous Soil and Water Conservation Practice

Indigenous knowledge of soil and water conservation practice are common in many parts of the country. Hence, many areas of the country's topsoil are under the severing condition of erosion. Indigenous practices have a considerable degree of sustainability with the local environment. Because of this, they have been developed in line with the laws of the natural ecological system. They are within the scope of the farmer's acquired or inherited culture, tradition, and knowledge (Belay, 1998; Yilkals, 2007).

Indigenous knowledge is important on three levels for the development process and it is important for the local community in which the bearers of such knowledge live and produce. Secondly, development partners such as CBO's, NGO's, private sector initiatives, government donors and local leaders need to recognize it in their interaction with the local community (Greneir, 1998; Habtemariam, 2013). Before corpora ting indigenous knowledge in their approaches, they need to understand it and critically validate it against the use of fullness for their intended objectives, and lastly IK forms parts of the global knowledge. In this context, it has value and relevance in itself IK can

be preserved, transferred, or adopted to ecological, social, cultural, and economic conditions of a particular community (Grenier, 1998, Yilkal,2007).

2.6. The Failure of Soil and Water Conservation Efforts in Ethiopia

Studies conducted in different parts of the country come up with different factors that explain the mid-level success of conservation initiatives. These studies attributed the mid-level success of the initiative to institutional and technological factors.

2.6.1. Institutional factors

During planning soil and water conservation intervention, a top-down approach was pursued where government officials told peasant association (kebele) what to do to get the food aid. This approach has local people little opportunities for discussion and participation on the initiative. Institutional inefficiencies in the development and delivery of relevant knowledge and assistance are asserted to be a major reason why conservation technologies are not adopted. Integration of SWC technologies into institutional, local information, and assistance networks can facilitate the adoption process (Baidu, 1999).

Land tenure is another variable that affects the adoption of soil and water conservation practice. Successful conservation practices need a land tenure system that gives a guarantee for continuous benefit to the farmer. Since land at present is under the control of the government it is unlikely to contribute positively to the adoption/continuous use of technology (Badeges, 2009).

2.6.2. Social factors

Personal characteristics of the household head like age, educational attainment, sex, and family size were hypothesized to influence the decision to adopt conservation practices. The age of a farmer can enhance or prevent the retention of conservation structures. With age, a farmer may get experience with his/her farm and can react in favor of the retention of structures. Exposure to education will increase the farmers' management capacity and reflect a better understanding of the benefits and constraints of soil and water conservation. Education also increases the ability to obtain and apply relevant information concerning the use of soil and water conservation practices. Education is thus hypothesized to increase the probability that a farmer will retain soil-water-conserving structures. The gender of a farmer is also hypothesized to affect the adoption of

conservation structures. Femal- headed or male-headed households can have different conservation behaviors. Thus, this variable can take both positive and negative signs.

2.6.3. Physical factors

Farm size is often related to the wealth of a farmer and is expected to be positively associated with the decision to retain conservation structures. Farmers having larger farm sizes can afford to leave the structures while the small farmers cannot and tend to destroy the structures to allow them to produce more. Steeper slope has been found to have a positive effect on the decision of SWC practices. Empirical studies in different parts of Ethiopia reported a positive and significant correlation between the slope of a farm and the decision to adopt SWC practices (Berhanu and Swinton, 2003). Farmers' plots with steep slopes are more involved in the continued use than those who own flat or gently sloping farmland. On steep slopes, farmers are constructing soil bunds and fanyajuon their farmland to prevent soil erosion. Distance of a plot from residential areas has negatively and significantly influenced the adoption of soil and water conservation practices by farmers (Abera, 2003).

2.6.4. Attitudinal factors

Perception of soil and water conservation practice recognizing it as a problem is an important factor that influences the application of erosion control practices. Thus, the perception variable is hypothesized to influence the retention of conservation structures positively. The role of perception of technology attributes in enhancing or eroding adoption decisions is well acknowledged. In this study, it is hypothesized that farmers' expectation of the effectiveness of conservation structures in retaining soil from erosion will have a positive effect on the retention of soil-water conserving structures (Bekeles and Holden, 1998).

2.6.5. Economic factors

Economic variables can play an important role in determining the adoption of SWC practices in the household. Among the economic factors, farm size is an important variable about the adoption of soil and water conservation (Aklilus and De Graaff, 2006). Farm size is one of the factors that affect farmer's decision to soil conservation technologies (Tadesse and Belay, 2004).

Especially physical structures like terraces imply a long payback period. While the investment costs of SWC are readily determined, measuring the benefits is more

problematic. Farm size is one of the factors that affect farmer's decision to soil conservation technologies (Akliluand DeGraaff, 2006). It implies that farmers with relatively larger land sizes had a better chance of adaptating to soil conservation technologies than farmers with smaller plots of land. The reason for the positive relation of farm size with adoption to the fact that conservation structures occupy part of the scarce land and due to this farmers with small plots of land could not afford to occupy part of their land with the structures (Bekele and Holden, 1998). Contrary to this, some studies have shown a negative correlation between farm size and adoption of SWC technologies.

2.7. Determinant Factors of Soil and Water Conservation Practice

Several factors are hypothesized to affect soil and water conservation effort. As indicated in the Journal of Agricultural and resource economics (2008). Reported that the perception of farmers on adopted conservation impacts positively on soil and water conservation practices and effort. The level of net farm income was expected to affect soil and water conservation effort because farmers with higher net income are less likely to be financially constrained to adopt soil and water conservation measures. Previous studies also have thrown that farmers who own their land are more likely to adopt soil-water conservation and expand more conservation efforts than those who do not own their land (Journal of Agriculture, 2008).

2.8. Status of Selected Soil Physical Properties

Soil physical fertility or soil structure can have as large an impact on plant growth as chemical fertility, as well as on the capability of the soil to resist degradation from processes such as compaction, surface sealing, and erosion under land management. Several suggested critical values for soil physical properties are presented in this section, but further discussion of soil physical fertility and soil structure is presented (Hazelton, P., & Murphy, B. 2016).

2.8.1. Soil texture

Soil texture forms the inherent property of soils and textural classes are not subject to easy modification in the field (Jaja.N, 2016). However, this property is subject to change under conditions of land use change which lead to varied soil management practices that may contribute indirectly to changes in particle size distribution (Ahukaemere et al., 2012). Soil texture determines a number of physical and chemical properties of soils. It

affects the infiltration and retention of water, soil aeration, absorption of nutrients, microbial activities, tillage, and irrigation practices (Delgado, A., & Gómez, J. A. (2016). It is also indicative of some other related soil features such as type of parent materials, homogeneity and heterogeneity within the profile, migration of clay, and intensity of weathering of soil material or the age of soil (Miler and Gradiner, 2001). The fine and medium textured (clay loam, silt clay loam, and silt loam) soils are favorable from an agricultural viewpoint because of their higher tension of available water, soil OM and exchangeable nutrient contents (Jaiswal, 2003). The same authors reported that soil relatively higher in clay content tends to be stabilized and retain more soil OM than those low in clay content. Under land use changes, which usually involve conversion from forest to cultivated lands, the soil protective cover loosens and erosion prevails. Whilst soil erosion takes place, fine particles are preferentially moved, resulting in a greater concentration of clay and silt in the sediments than in the original soil (Asefa, B. 2019). This ultimately caused to change in the particle size fraction composition of the original soil. This phenomenon is observed in Ethiopian highlands where severe erosion prevails. Over a very long period, pedogenic processes such as erosion, deposition, eluviation, and weathering can alter the textures of various soil horizons (Ahmed, 2002).

2.8.2. Bulk density

Bulk density is the weight of dry soil solids per unit volume of total soil including the pore space. Bulk density is a soil property required for calculating soil pore space, as an indicator of aeration status and water content. Bulk density normally decreases as mineral soils become finer in texture. Soils having low and high bulk densities exhibit favorable and poor physical conditions, respectively (Mulugeta *et al.*, 2019). Low bulk density values, generally below 1.3 gm/cm^3 indicate a porous soil condition (FAO, 2006). An increase in OM lowers bulk density while compaction increases bulk density. In swelling soils, bulk density decreases with an increase in moisture content and vice versa. Bulk densities of soil horizons are inversely related to the amount of pore space and soil OM which is highly influenced by land use and management practices (Melese, 2018). Any factor that influences soil pore space will also affect the bulk density. For instance, intensive cultivation increases bulk density resulting in a reduction of total porosity. Ayoubi *et al.* (2014) and Evrendilk *et al.* (2004) also reported that soils under cultivated lands had higher bulk densities than natural forest and grassland soils with an associated decrease in porosity. The study results of Mulugeta (2004) and Woldeamlak and

Stroosnijder (2005) revealed that the bulk density of cultivated soils was higher than the bulk density of forest soils. Hazelton and Murphy (2007) mention that the range of bulk density rating is, <1, 1-1.3, 1.3-1.6, 1.6-1.9, and >1.9 for very low, low, medium, high, and very high, respectively.

2.9. Effects of Soil and Water Conservation on Selected Soil Chemical Properties.

Soil chemical properties are the most important among the factors that determine the nutrient supplying power of the soil to the plants and microbes. The chemical reactions that occur in the soil affect processes leading to soil development and soil fertility build-up. Minerals inherited from the soil parent materials over time release chemical elements that undergo various changes and transformations within the soil (Zajícová *et al.*, 2019).

2.9.1. Soil pH

Soil reaction (usually expressed as pH value) is the degree of soil acidity or alkalinity, that is caused by a particular chemical, mineralogical, and/or biological environment. The fact that the high rainfall coupled with steeper slopes might have increased leaching, soil erosion, and a reduction in soluble base cations leading to higher H⁺ activity (Fantaw *et al.*, 2006). Soil reaction affects nutrient availability and toxicity, microbial activity, and root growth. Thus, it is one of the most important chemical characteristics of the soil solution because both higher plants and microorganisms respond so markedly to their chemical environment. Several soil fertility characteristics can be interpreted from soil pH.

The higher pH could have contributed to increased negative charge surfaces (of mineral or humic substances), consequently leading to a higher CEC and increased availability of phosphate ions (Tesfaye *et al.*, 2006). Both the clay and OM in soils act as a buffer against acidification making it possible for crops to grow in soils that would otherwise be too acidic or basic (Materechera and Mkhabela, 2001). In peat and muck soils and mineral soils containing large amounts of OM, organic acids contribute significantly to soil acidity. Within the normal range of soil pH, the two principal controlling factors are OM and the type and number of cations soil conservation practices influence soil pH and bring about changes in the soil microbial community structure and function. The advantages of conservation practices include reducing cultivation costs, allowing crop residues to act as an insulator, reducing soil temperature fluctuation, building up soil OM, and conserving soil moisture (Reji *et al.*, 2012).

In strongly acid soils, Al^{3+} becomes soluble and increases soil acidity, while in alkaline soils exchangeable basic cations tend to occupy the exchange site by replacing H^+ ions resulting in strongly alkaline soils. In moderately acid soils, H^+ contributes more to soil acidity than Al^{3+} ions, and hence soil acidity resulting in such soils is due to the excessive release of exchangeable H^+ ions from the soil exchange sites (Miller and Gardiner, 2001). Soil pH decreases with an increasing number of years in cultivation while almost all groups of soils tend to be slightly leached and become acidic in relation which results in declining soil chemical fertility (Jaiswal 2003). Jones Benton (2003) mentions that the range of soil pH rating as, < 4.5, 4.5 - 5.0, 5.1 - 5.5, 5.6 - 6.0, 6.1 - 6.5, 6.6 - 7.3, 7.4 - 7.8, 7.9 - 8.4, 8.5 - 9.0 and > 9.1 for extremely acidic, very strongly acidic, strongly acidic, moderately medium acidic, slightly acidic, neutral, slightly alkaline, moderately alkaline, strongly alkaline and very strongly alkaline.

2.9.2. Soil organic matter

Soil OM consists of dead plants, animal, microbes, and fungi or their parts, as well as animal and microbial waste products in various stages of decomposition. Eventually, all of these break down into humus, which is relatively stable in the soil (Getahun and Bobe, 2015). Soil OM is considered to be a key attribute of soil quality and is usually considered one of the most important properties of soils because of its impact on ecosystem sustainability and its effects on other soil physical, chemical, and biological characteristics (Abebe and Endalkachew, 2012).

Organic matter improves soil structural stability in addition to providing mineral nutrients for plants and microorganisms through the mineralization process or biochemical oxidation of organic substrates (Tilahun and Asefa, 2009). For this reason, soil OM content is the result of equilibrium between the processes supplying new organic inputs and the rate of mineralization of the existing OM (Nega and Heluf, 2013). Mineralization and immobilization are thus soil microbial processes governed by carbon availability, closely linked to soil OM content. The changes in land use impact soil OM pools and fluxes. The impact of land use change on OM content depends on several factors such as the old and new land use types, the soil type, management, and climate (Lantz *et al.*, 2001; Lettens *et al.*, 2004). These changes typically result in differing rates of soil erosion, aggregate formation, biological activity, and drainage all of which have a profound impact on OM accumulation and CO_2 evolution. However, forest and pasture lands make up the potential to build up large amounts of OM, whereas conversion of

natural ecosystems to croplands which results in a high rate of turnover lead to a declined level of OM (Lantz *et al.*, 2001; Batjes, 2004).

Most cultivated soils of Ethiopia are poor in OM contents due to the low amount of organic materials applied to the soil and complete removal of the biomass from the field (Yihenew, 2002), and due to severe deforestation, steep relief conditions, intensive cultivation and excessive erosion hazards (Eylachew, 2009). Uncultivated soils are higher in soil OM (both on surface and sub-surface soil) than those soils cultivated for years (Miller and Gardiner, 2001). In the forest, there is a continuous growth of plants and addition to three pools of OM; standing crop, forest floor, and soil. In the grassland ecosystem, much more of the OM is in the soil and much less occurs in the standing plants and grassland floor.

Materechera and Mkhabela (2001) showed that the most conspicuous soil property, which is influenced by land use and was strongly correlated with a wide range of other soil properties, is OM. It was significant to note especially the high correlation between OM and physical properties that define soil structural characteristics such as aggregate stability, bulk density, and water retention. This implies that OM may have been involved directly or indirectly in the process, which generates or modifies soil structure. This contribution reflects the importance of OM on soil productivity. The soil, which had higher OM, also had higher nutrient element concentrations. Furthermore, humus from OM decomposition combined with clay minerals to form an organomineral complex that increases the soil CEC from where plant roots can take up nutrients Mulugeta *et al.* (2019). Tekalign (1991) mentions that the range of organic matter rating is, < 0.86, 0.86 - 2.59, 2.59 - 5.17, and >5.17 for very low, low, medium, and high respectively.

2.9.3. Total Nitrogen

Nitrogen (N) is one of the most essential elements that is taken up by plants in the greatest quantity. After carbon, oxygen, and hydrogen, and considered to be one of the key crop growth limiting factors (Solomon *et al.*, 2006). Soil total N composed of inorganic (NH_4^+ and NO_3^-) and organic forms, is subject to change due to various factors. Management (cropping, fertilization, erosion, and leaching) and climatic conditions (temperature and moisture) determine the level and dynamics of N found in soils (Ashenafi *et al.*, 2010). Previous investigations on soil properties along landscapes

affected by long-term tillage indicate that soil total N and OC contents are lower in areas of soil removal than in areas of soil accumulation (Shimeles, 2006).

Wakene (2001) reported that there was a 30% and 76% depletion of total N from agricultural fields cultivated for 40 years and abandoned land, respectively, compared to the virgin land in the Bako area, Ethiopia. Average total N increased from cultivated to grazing and forest land soils, which gain declined with increasing depth from surface to sub-surface soils (Nega, 2006). The considerable reduction of TN in the continuously cultivated fields could be attributed to the rapid turnover (mineralization) of organic substrates derived from crop residue (root biomass) whenever added following intensive cultivation (McDonagh *et al.*, 2001). Moreover, the decline in soil OC and total N, although commonly expected following deforestation and conversion to farm fields, might have been exacerbated by the insufficient inputs of organic substrates from the farming system (Mulugeta, 2004). The same author also stated the levels of soil OC and TN in the surface soil were significantly lower, and declined increasingly with cultivation time in the farm fields, compared to the soil under the natural forest. Tekalign (1991) mentions that the range of total nitrogen rating is, < 0.05, 0.05 - 0.12, 0.12 - 0.25, and > 0.25 for low, medium, and high respectively.

2.9.4. Available Phosphorus

Phosphorus (P) is the most critical essential element next to nitrogen, in influencing plant growth and production across the world (Nega and Heluf, 2013). Unlike N, it is not supplied through biochemical fixation but must come from other sources to meet plant requirements. Hence, its deficiency is directly related to food security issues, especially in the tropics, where severe soil degradation is responsible for serious deterioration in soil quality (Solomon *et al.*, 2006).

Ethiopian soils particularly Nitisols and other acidic soils, are reported to have low P contents. This is due to not only the inherent low available content but also due to the high P fixation capacity of the soils (Yihenew, 2002). The highest concentration of available P was recorded in the surface soil of the intensively cultivated soil compared to the soil of the farmer's field and the virgin land in the Bako area (WakeneandHeluf, 2003). Several research results in Ethiopia indicated that most of the soils are known to have low P contents not only due to the inherently low available P content but also due to the high P fixation capacity of the soils (Mishra *et al.*, 2004; Wondwosen and Sheleme,

2011; Asmare *et al.*, 2015). According to Mishra *et al.* (2004) studies in most Ethiopian soils, Oxisols, Ultisols, Vertisols, and Alfisols are generally low in total P content.

The solubility and availability of P are largely determined by soil chemical characteristics such as soil reaction (pH), cation contents (Fe, Al, and Ca), and the total phosphate reserves of the soil. According to Asmare *et al.*, (2015) in acidic soils (pH <5.5), inorganic P, precipitates as Fe/Al-P secondary minerals and/or is adsorbed to the surfaces of Fe/Al oxides and clay minerals, finally P becomes less available. Olsen *et al.* (1954) mention that the range of Available phosphorus rating is, < 5, 5 - 9, 10 - 17, 18 – 25, and > 25 for very low, low, medium, high, and very high respectively.

2.9.5. Cation Exchange Capacity

Cation exchange capacity (CEC) is a measure of the soil's ability to retain and supply cation nutrients and expressed in centimole of charge per kilogram (cmolc/kg). Probably the most important and distinctive property of soils is that they can retain ions and release them slowly to the soil solution and plants. The cation exchange capacity (CEC) implies the capacity of a soil for ion exchange of cations between the soil solid and the soil solution (Ross *et al.*, 2008). CEC strongly influences nutrient availability, thus widely used in soil fertility evaluation and soil classification projects (Ufot *et al.*, 2016). The CEC of soil is strongly affected by the amount and type of clay, and the amount of OM present in the soil because both clay and colloidal OM are negatively charged and hence can act as anions to adsorb and hold positively charged ions (Teshome *et al.*, 2013). Higher CEC values are usually associated with humus compared to those exhibited by the inorganic clays (Lechisa *et al.*, 2014).

According to Hazelton and Murphy's (2007) classification, soils consisting of CEC values greater than 40 cmolc/kg are rated as very high, while the CEC values between 25 to 40, 12 to 25, and 6 to 12 cmolc/kg are rated as high, moderate and low, respectively. Cation exchange capacity increases with increasing soil OM, clay content, and soil pH (Aweke, 2005). He reported that the highest CEC value (56.70 cmolc/kg was recorded in the surface layer on the major soils of some dry land areas of northeast Ethiopia. Experimental results from organic amendments to coffee nursery media revealed that different organic sources and proportions significantly affected CEC. Hence, the highest and lowest CEC values of 36.00 - 27.88 cmolc/kg were obtained from undecomposed coffee husk plus farmyard manure and undecomposed coffee husk, respectively. In

general, CEC was much higher for the media composed of the decomposed materials than the undecomposed treatments singly or in combinations. Hazelton and Murphy (2007) set the rating of cation exchange capacity as, < 6, 6 – 12, 12 – 25, 25 – 40, and > 40 for very low, low, medium, high, and very high, respectively.

2.9.6. Exchangeable cations

The amounts of exchangeable bases (Na, K, Mg, and Ca) are important properties of soils as these not only indicate the existing nutrient status but can also be used to assess balances amongst cations (Abiyot and Alemayehu, 2016). The distribution of exchangeable basic cations in most agricultural soil is generally $\text{Ca}^{+2} > \text{Mg}^{+2} > \text{K}^+ > \text{Na}^+$ with a pH of 5.5 or more (Teshome *et al.*, 2013). Research works conducted on Ethiopian soils indicated that exchangeable Ca^{+2} and Mg^{+2} cations dominate the exchange sites of most soils and contribute higher to the total percent base saturation (Achalu *et al.*, 2012). Similarly, FAO (2006) indicated that in fertile soils of neutral soil reaction, about 75% of the adsorbed cations are Ca and Mg and only 3 – 5% is K. The largest portion (90 - 98%) of the total K present in the soil is found in a relatively unavailable form to plants, whereas only 1 to 2% of the soil K is readily available to plants.

In general, the K content of a given soil depends on the climatic conditions, degree of weathering, the intensity of cultivation, and the parent material from which the soil is formed. The response to K fertilizer is expected from most crops when the exchangeable K contents of the soil are below the critical (0.38 cmolc/kg) range, although different crops have different ranges of nutrient requirements. It is commonly believed that Ethiopian soils contain sufficient K and no deficiency problem for crop production. However, several research works by Shimeles (2006), Sintayehu *et al.* (2006), and Wondwosen and Sheleme (2011) revealed that K was deficient in various soil types (Umbrisols, Nitsols and Plinthols), which were subjected to intensive cultivation. Exchangeable calcium (Ca) and magnesium (Mg) are the dominant exchangeable cation in many soils, except alkaline soil that contain excess Na, and acidic soils which contain higher amounts of hydrogen and aluminum. Exchangeable Ca and Mg usually account for more than 60% of the exchangeable cations of soil at pH 5.5 or higher. The concentration of Ca in the soil varies from 1% or less (in non-calcareous soils) to 10% or more (in calcareous soils).

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Kebena Special district is found in the Central Ethiopia Regional States. Located 155 km Southwest of Addis Ababa along the Addis Ababa to Jimma asphalt highway.

Geographically bounded in the north by the Oromia regional state, in the south by Cheha District, in the west by Abashga District, and in the east by Muher-Akilel and Gedebano-Gutazer-Wolene District. It is located at geographical coordinates of 8° 15' 30" N to 8° 24' 30" N of latitude and 37° 44' E to 38° 5' E of longitude.

The district is 23 rural peasant associations and 1 urban dwellers association which are a total of 24 kebeles. The total area of the district is 34,000 hectares and is inhabited by 145,697 people with a crude density of 217 persons per sq. km. Among the total population 72,823, and 72,874 are males, and females respectively (Kebena Special District Administration Office, 2025).

The research site includes- Sunik Dincho Kebele (small administrative unit), which is far from Wolkite. located at approximate geographical coordinate of 8° 20' N - 8° 24' N latitude and 37° 53' E - 37° 59' E longitude, (Garbage) kebele, which is 27 km, from District center Wolkite located at approximate geographical coordinate of 8° 18' N - 8° 21' N latitude and 37° 56' E - 37° 59' E longitude. and (Katibre,) kebele, which is 21k.m, from District center Wolkite located at approximate geographical coordinate of 8° 16' N - 8° 18' N latitude and 37° 53' E - 37° 56' E longitude respectively (KSDFEDO, 2025).

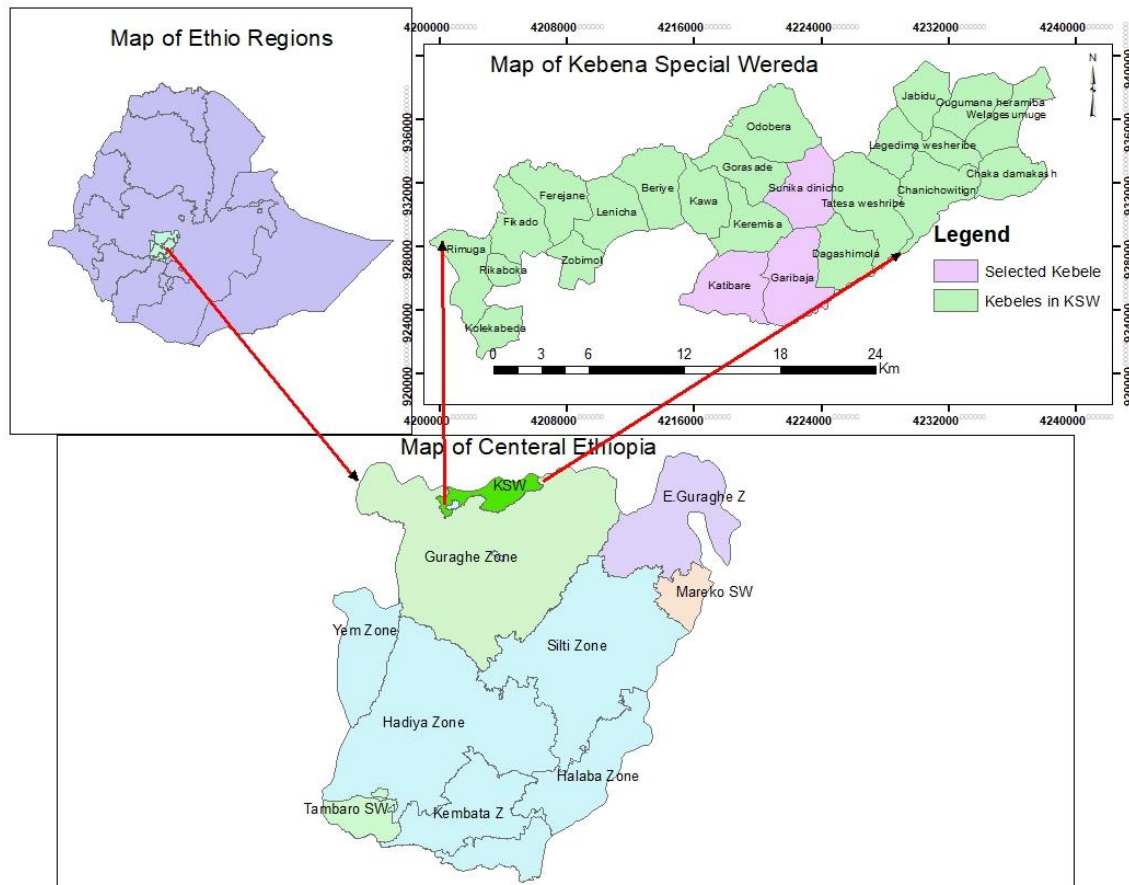


Figure 1. Map of the study area

3.1.2. Topography

The topography of Kebena special District is estimated to have two land features low Mountains 11% and irregular plain 89%. According to Genene *et al.*, (2014), Midlands’s agroecology is the intermediate climatic zone of Central Ethiopia that has a tropical sub-humid warm climate that lies between the ranges of 1500 to 2500 masl. It mainly includes the northern (Gurage). The digital elevation model of this District lies between 1663 to 2072 meters above sea level the slopes of Kebena Special District are between 0 - 50 percent. According to FAO (2006), the slope of farmland was classified as the area with flat to gently sloping (1 - 7%), strongly sloping (7 -15%), moderately steep (15 -30%), and steep to extremely steep (>30%) slopes.

3.1.3. Climate, and Hydrology

Kebena special District experiences four distinct seasonal weather patterns. The main wet season, known locally as Kiremt, stretches from June to August, followed by a minor rainy season (Mehir) from September to October. A short rainy season, called Belg,

occurs from March to May, while a predominantly dry season (Bega) extends from December to February.

The special District's climate is characterized by mid-lands (Weyna Dega) with an average annual rainfall ranging from 1200mm to 1400mm. Heavy rainfall concentrates from June to August, with a smaller amount of rain falling from March to May. The mean annual temperature ranges from 17.6°C to 20°C. The altitude of Kebena District varies between 1663 and 2072 meters above sea level (masl) (KSDNRMO, 2020).

3.1.4. Geology and Soil type

The study area's diverse soil landscape results from a complex interplay between local geology and climate. The bedrock's mineral composition significantly influences the chemical characteristics of developing soils, while varied climatic zones further modulate soil formation processes, leading to distinct soil types. Although a comprehensive soil survey is currently lacking, existing data from KSDANRO (2020) identifies three dominant soil types within the District. According to FAO/UNDP (1984), the most prevalent, covering approximately 65% of the study area is Vertisols ("Gamebla Bucha"). These are heavy clay soils characterized by a high percentage of 2:1 phyllosilicate clay minerals, primarily from the smectite group (e.g., montmorillonite), which imparts significant shrink-swell behavior. This results in deep cracking during dry periods, contributing to the heavy texture of these soils and leading to the development of a self-mulching surface.

3.1.5. Drainage and Water Resources

The present study area shares two main drainages Rebu and Wabe. Demekash and Bishewa (Legdima) are tributers of Wabe drainage flow throughout the year and Hebicha, Mukriba, and Dinicho are tributers of Rebu drainage flow only rainy season. Among 23 Kebeles, 13 Kebeles part of Rebu drainage and 10 kebeles parts of Wabe drainage. These four drainages have played an important role in people's day-to-day economic activities finally two main drainages join the Gibe drainage (KSDANRO, 2020).

3.1.6. Vegetation cover

various types of natural and cultivated vegetation existed in the study area. Key bahirzaf (*Eucalyptus camaldulesis*), Bisana (*Croton macrostachyus*), Warka (*Ficus Vaita*), Woira

(*Olea africana*), (*Cordia africana*) Zigiba (*Podocarpus talacta*) timber (*Eucalyptus*), and Acacia (*abyssinica*) variety of bushes and grass, etc. (KSDANRO, 2020).

3.1.7. Farming systems and socio-economics

The economic activities of the local society of the study area are used primarily mixed farming system that involves crop production and animal husbandry. The major development challenges of the area include the presence of high population pressure, poor productivity due to soil degradation, dependency on rain-fed agriculture, and poor socio-economic services.

Crop production is the first main economic activity of the study area, which includes Enset, potato, and maize. Tef and wheat. Cash crop (chat) and coffee. The major vegetables in the area are Potato, Cabbage, Onion, etc. Livestock rearing is the most important economic activity in the Dsworeda where cattle and goat rearing are common.

The major land use types in the study area are cultivated land, grazing land, and other covers the farm size varies below 0.1 ha. up to 10 hectares per household. In Kebena Special District 34,000-hectare total of land 28,363.7 hectares (83.40%) is cultivated yearly and perennial crops or used for various agronomic purposes (KSDANRO, 2020).

3.2. Research Methodology

3.2.1. Site selection and soil sampling technique

select representative sites and land use types for soil sampling. Prior to soil sample collection, a reconnaissance survey was conducted to identify locations that minimized differences in geologic, topographic, and climatic conditions among soil and water conservation types. This approach ensured a comparable baseline for evaluating the impact of conservation practices.

Three land use types (cultivated, grazing, and plantation forest), were considered for the study. Conserved and non-conserved plots were in close proximity to minimize potential variations due to differing environmental conditions.

Representative composite soil samples were taken at depths (0-20 cm and 20-40 cm) from each of three land use types and adjacent conserved and non conserved lands. Cultivated, grazing land, and plantation forest and land use types were organized within three

selected kebeles. After thorough mixing, by quartering method about 1 kg composite soil samples were taken for laboratory analysis. Generally, thirty-six composite soil samples were taken in the study areas. During collection of soil samples; dead plants, avoiding furrows, old manure, wet spots, areas near trees, and compost pits were excluded.

3.2.2. Soil Laboratory analysis

The composite soil samples were air-dried, ground, and sieved to pass through a 2 mm sieve for most physicochemical soil properties to make it ready for laboratory analysis. For the analysis of total nitrogen and organic carbon, soil samples were used with a 0.5 mm sieve size. The soil laboratory analysis was carried out at the Wolkite soil test and fertility improvement laboratory center. Selected soil physical and chemical properties such as soil particle size distribution, bulk density, soil pH, total nitrogen, organic carbon, available phosphorus, exchangeable bases, and cation exchange capacity were analyzed using standard laboratory procedures. Soil bulk density was determined by using the undisturbed core sampling method after drying the soil samples in an oven at 105°C to constant weights (Black, 1965).

Soil particle size determination was by proportions by the hydrometric method (Sakar and Haldar, 2005). Soil reaction (pH) was determined by a 1:2.5 soil: water ratio using a pH meter as described by (Olsen *et al.*, 1954). The soil organic carbon (SOC) concentration was determined by the Walkley and Black rapid titration method as described in Sakar and Haldar (2005). Soil organic matter (SOM) was determined by multiplying percent organic carbon by 1.724 (Jones, 2001).

Total nitrogen (TN) was determined with Kjeldahl methods (Sakar and Haldar, 2005). The available phosphorus (av. P) content was determined by the Olsen extraction method as described by Van Reeuwijk (2002). The exchangeable bases and CEC were determined by using the ammonium acetate method (Sakar and Haldar, 2005). Ca^{+2} , and Mg^{+2} , were determined by atomic absorption spectrophotometer, and the flame photometer method was used for the determination of Na^{+} and K^{+} .

3.3. Data Analysis

To investigate the effects of land use types and soil and water conservation practice on soil physicochemical properties, statistical analyses were performed using three-way analysis of variance (ANOVA). The ANOVA model was employed to test for significant

differences in soil physicochemical properties between conservation practice (conserved and non-conserved) and land use types across varying soil depths (0-20 cm, 20-40 cm).

The study employed a factorial randomized complete block design (RCBD) with three replications (blocks). Least significant difference (LSD) tests were conducted at a significance level of $p < 0.05$ to compare the means of different treatment groups. All statistical analyses were performed using the SAS statistical software package (SAS Institute Inc., Cary, NC, 2013).

4. RESULT AND DISCUSSION

4.1. The Effects of Land Uses, SWC, and Soil Depth on Soil Physical Properties

4.1.1. Soil Particle Size Distribution

The analysis of variance (ANOVA) revealed a statistically significant ($p < 0.05$) interaction effect of land use type, conservation practice and depth on clay content of the soil's (Appendix Table 1). This result indicated that their combined effects on soil clay content cannot be attributed to individual contributions alone. This study elucidates a complex interplay between land use, conservation practices, and soil depth in shaping soil clay content. Soil texture, considered an inherent soil property, is generally stable over short timescales. However, soil and water conservation practices can significantly influence the distribution and retention of clay particles within the soil profile, indirectly affecting the effective clay concentration in different soil horizons. Specifically, these practices (Johnson *et al.*, 2020).

The highest mean value of clay content (47.33%) was observed at the conserved plantation forest and upper soil depth (0-20cm) and the lowest (34.00%) was recorded under the cultivated unconserved surface soil and at the upper depth (0-20) (Table 4.1). This difference in the upper soil is consistent with a situation where conservation practices mitigate soil structure changes, reduce erosion and promote aggregation by organic matter, as is typical in uncultivated soils (Bronick and Lal, 2005). Teshome *et al.* (2013) noted that the high clay content in surface layers is attributed to abundant plant residues, which contribute to soil structure and stability. In the other hand, Mojiri *et al.* (2012) found that cultivated lands exhibited lower clay content compared to adjacent forest soils, highlighting the impact of land use on soil composition. Furthermore, Woldeamlak (2003), who suggested that under sparse vegetation, clay fractions are more susceptible to erosion and may be displaced down the soil profile. In unprotected lands, finer soil particles are selectively removed by erosion, resulting in a higher proportion of coarser particles, predominantly sand. This shift in soil texture is further exacerbated by deforestation, continuous cultivation, and intensive grazing, as reported by Mulugeta (2004) and Belayneh (2009).

The analysis of variance (ANOVA) disclosed that there was a non significant ($p < 0.05$) interaction effect of land use type, conservation practice and depth ; the interaction effects of of land use types and depth; conservation practices and depth in silt content of

the soil's. However, a significant difference ($p < 0.05$) in silt content was observed due to the interaction effects of land use types and conservation practices (Appendix Table 1).

The mean silt content was highest (32.27%) in the conserved plantation forest land, while it was notably lowest (19.93%) in conserved cultivated land (Table 4.2). These findings indicate that conservation practices in forested areas significantly enhance silt retention compared to cultivated lands.

Soil particle sizes are fundamental physical properties that can vary across different land use systems (Mohammed *et al.*, 2005). Supporting this, Demelash and Stahr (2010) and Mengistu *et al.* (2015) reported higher silt content was high in non-conserved rather than conserved land. This suggests that effective conservation practices play a crucial role in maintaining soil structure and fertility by preserving finer particles such as silt. The significant interaction between land use types and conservation practices highlights the importance of these factors in influencing silt content, with implications for soil health and agricultural productivity.

The analysis of variance revealed a highly significant interaction effect ($p < 0.01$) between land use types and conservation practices on the sand content of the soil (Appendix Table 1). The sand content varied between 35.14% and 28.69% across different soil samples. The highest sand content (35.14 %) was observed in the unconserved grazing land. In contrast, the lowest sand content was recorded in the conserved grazing land (28.69%) (Table 4.2). These findings align with Joas (2015), who reported a statistically significant difference in sand content due to various soil and water conservation (SWC) techniques employed in his study.

Table 4.1. Interaction effect of land use, conservation practices, and depth on soil physical property

Land use	Conservation practice	Depth	Clay (%)	Silt (%)	Sand (%)	BD (g/cm ³)	MC (%)
Grazing land	Conserved	0-20	42.14b	31.48a	28.69a	1.23e	11.89
Grazing land	Conserved	20-40	42.06b	38.68a	28.79a	1.23e	11.93
Grazing land	Unconserved	0-20	34.06f	30.80a	35.14a	1.30c	9.24
Grazing land	Unconserved	20-40	34.07f	30.80a	35.25a	1.30c	9.17
Plantation forest	Conserved	0-20	47.33a	20.81a	32.22a	1.22e	13.00
Plantation forest	Conserved	20-40	47.13a	20.80a	32.33a	1.20e	13.12
Plantation forest	Unconserved	0-20	37.22c	29.28a	33.33a	1.29c	9.42
Plantation forest	Unconserved	20-40	37.22c	29.33a	33.34a	1.27cd	9.59
Cultivated land	Conserved	0-20	35.30d	19.93a	29.55a	1.25d	11.05
Cultivated land	Conserved	20-40	35.20d	19.94a	29.56a	1.24d	11.48
Cultivated land	Unconserved	0-20	34.00f	32.93a	32.11a	1.37a	11.48
Cultivated land	Unconserved	20-40	34.72e	32.93a	32.11a	1.35b	8.82
P-value			*	Ns	Ns	***	*
CV			4.01	19.33	4.55	1.90	3.50

* = Significant at $P \leq 0.05$; Ns =Not Significant at $P \leq 0.05$; P = Probability

Table 4.2 Interaction effect of land uses and conservation practices on soil physical property

Land uses	Conservation practices	Clay (%)	Silt (%)	Sand (%)	BD (g/cm ³)	MC (%)
Grazing land	Conserved	42.14	31.47	28.69	1.23	11.91
Grazing land	Unconserved	34.06	30.8	35.14	1.30	9.20
Plantation forest	Conserved	47.13	32.93	32.22	1.25	8.70
Plantation forest	Unconserved	37.22	29.28	33.33	1.29	13.06
Cultivated land	Conserved	35.2	19.93	29.55	1.25	11.27
Cultivated land	Unconserved	34.72	20.81	32.105	1.37	9.50
P-value		*	*	**	**	*

* = Significant at $P \leq 0.05$; Ns =Not Significant at $P \leq 0.05$; P = Probability

4.1.2. Bulk density

Soil bulk density is a critical measure for assessing the degree of soil compaction, as it relates directly to pore spaces in the soil that influence water-holding capacity and aeration. The study result revealed that the interaction effects of land use, conservation practices, and soil depth had a highly significant impact on bulk density ($p < 0.001$). This study reveals a nuanced relationship between land use, conservation practices, and soil depth, demonstrating their interconnected influence on soil bulk density. The synergistic effect of these factors suggests that optimizing soil health requires a holistic approach. By integrating land use management and conservation strategies, it is possible effectively manipulate soil bulk density, paving the way for sustainable agricultural practices. The

highest mean bulk density (1.37 g/cm^3) was recorded in the lower surface of the unconserved cultivated land, whereas the lowest bulk density (1.20 g/cm^3) was found in the upper surface of the conserved plantation forest which is statistically on par with the lower surface of the same land (Table 4.1). This result suggests a relatively uniform soil structure throughout the upper soil profile in this land use. This contrasts with the expectation of higher bulk densities in subsoil horizons due to reduced organic matter inputs and increased compaction from overlying soil (Brady & Weil, 2016). However, several factors may account for this apparent anomaly. Firstly, the long-term presence of the plantation forest likely promotes the accumulation of organic matter not only in the topsoil but also in the upper portions of the subsoil through litter decomposition and root turnover (Johnson & Curtis, 2001; Post & Kwon, 2000). According to the rating system by Hazelton and Murphy (2007), the bulk density in the study area was classified as low to moderate.

Soleimani et al. (2019) noted that higher bulk density in cultivated land is often attributed to intensive tillage practices, which can temporarily loosen the tilled layer but ultimately lead to compaction and an increase in bulk density over time. Additionally, research by Islam and Weil (2000), Woldeamlak (2003), Mulugeta (2004), and Yihenew and Getachew (2013) indicated that lower bulk density in forested areas may result from higher clay content and the accumulation of organic matter. The reduced disturbance in these lands, compared to other land uses, further contributes to this phenomenon (Basaran *et al.*, 2006).

4.1.3. Moisture

The analysis of variance (ANOVA) showed that the interaction effects of land use, cultivation practices, and soil depth significantly influenced moisture content ($p < 0.05$). The highest mean moisture content (13.12%) was recorded in the lower surface of the conserved plantation forest, which was statistically comparable to the upper surface of the same forest type. Conversely, the lowest moisture content was observed in the upper surface of the unconserved grazing land (9.17 g/cm^3), which was statistically similar to that of the lower surface of the same land type (Table 4.1).

These findings indicate that moisture content is affected not only by land use type but also by conservation practices and soil depth and vice versa. The interplay of these factors significantly enhances soil moisture retention, which is crucial for crop productivity. Additionally, these results underscore the importance of integrating land use and

conservation practices to optimize soil moisture retention for sustainable agricultural outcomes.

Supporting this observation, Joas (2015) reported higher moisture levels in areas implementing soil and water conservation measures. Additionally, Stroosnijder and Hoogmoed (2004) noted that such practices effectively reduce runoff and evaporation, thereby increasing water infiltration into the soil.

4.2. Effects of SWC Practices on Soil Chemical Properties in Land Uses and Soil Depth

4.2.1. Soil PH

Soil pH is influenced by both anthropogenic and natural factors, including the leaching of exchangeable bases, acid rain, organic material decomposition, industrial fertilizer application, and farming practices (Papier Nik *et al.*, 2007). The analysis of variance revealed that soil pH was significantly ($p < 0.001$) affected by combined interactions of land use types, conservation practices, and depth (Table 4.3).

The highest mean pH value (7.43) was recorded in the upper layer of conserved plantation forest land, which was statistically comparable to the lower layer of the same land. In contrast, the lowest pH value (6.00) was found in the unconserved upper layer of the plantation forest, which was statistically similar to the unconserved lower layer (Table 4.3). This study highlights the critical role of all the three factors in maintaining soil pH, emphasizing the need for sustainable land management to mitigate soil acidification.

According to Tekalign (1991), the soil pH in this study area is classified as neutral to slightly acidic. Additionally, significant reductions in soil pH have been noted in soils cultivated over extended periods (Habtamu *et al.*, 2009).

4.2.2. Soil organic matter and organic carbon

The analysis of variance (ANOVA) results demonstrated a highly significant interaction among the three factors ($p < 0.001$), indicating that their combined effects on soil organic matter (SOM) levels cannot be attributed to individual contributions alone. This study elucidates a complex interplay between land use, conservation practices, and soil depth in shaping SOM.

The highest SOM content (5.91%) was recorded in the lower depth range (20-40 cm) of conserved plantation forest land, suggesting that conservation efforts, particularly within

forest ecosystems, significantly enhance SOM accumulation, especially in deeper soil layers.

The organic matter content in the soils examined ranged from high to medium, as classified by Birhanu (1980). Research by Wolde et al. (2007) in the Tigray region of Ethiopia indicated that SOM and nutrient levels in conserved areas differ markedly from those in adjacent unconserved lands. They found that the elevated SOM levels in plantation forest soils are likely due to the substantial presence of decomposed plant material.

Furthermore, Stroosnijder and Hoogmoed (2004) emphasized that rainwater conservation through soil and water conservation (SWC) structures promotes increased biomass production, which subsequently enhances SOM through litter fall and root decomposition.

The analysis of variance revealed that soil organic carbon (SOC) was significantly influenced by the interaction of land use types, conservation practices, and soil depth ($p < 0.01$).

Contrary to typical soil organic carbon (SOC) profiles where concentrations decrease with depth (Brady & Weil, 2016), this study found the highest SOC content (3.60%) at 20-40 cm depth in a conserved plantation forest (Table 3). This contradicts the usual topsoil SOC concentration from surface litter and root density (Brady & Weil, 2016), suggesting other factors are at play. One possibility is significant root biomass at depth in mature plantations, contributing SOC through root turnover (Jackson et al., 1996; Gale et al., 2000). Downward movement of dissolved organic carbon (DOC) and its stabilization in the subsoil may also enrich SOC (Kalbitz et al., 2000; Jardine et al., 1989). Conversely, the lowest SOC (1.81%) was at the surface of unconserved cultivated land, consistent with cultivation disrupting soil structure and accelerating decomposition (Lal, 2000). Regional studies (Yihenew et al., 2009; Kebede et al., 2011) support this, showing lower SOC in unconserved Ethiopian fields. This pattern indicates land management strongly influences SOC distribution, overriding typical vertical profiles.

Table 4.3. Interaction effect of land uses, conservation practices, and depth on selected soil chemical property

Land use	Conservation practice	Depth	pH (H ₂ O)	OM (%)	OC (%)	TN (%)	AP
Grazing land	Conserved	0-20	7.06	5.15	2.99	0.25	10.00
Grazing land	Conserved	20-40	7.03	5.13	2.98	0.22	10.00
Grazing land	Unconserved	0-20	6.02	3.47	2.01	0.17	8.00
Grazing land	Unconserved	20-40	6.03	3.41	2.05	0.13	8.00
Plantation forest	Conserved	0-20	7.43	5.19	3.01	0.26	18.00
Plantation forest	Conserved	20-40	7.26	5.91	3.60	0.25	18.00
Plantation forest	Unconserved	0-20	6.86	4.45	2.58	0.21	9.00
Plantation forest	Unconserved	20-40	6.80	4.20	2.44	0.19	9.00
Cultivated land	Conserved	0-20	6.86	4.93	2.97	0.23	9.16
Cultivated land	Conserved	20-40	6.70	5.11	2.90	0.21	9.10
Cultivated land	Unconserved	0-20	6.00	2.67	1.96	0.13	7.00
Cultivated land	Unconserved	20-40	6.02	2.40	1.81	0.11	7.00
CV			2.29	3.06	3.03	4.93	0.01

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$; *** = Significant at $P \leq 0.001$; NS = Not Significant; TN = Total Nitrogen; OM = Organic Matter; P = Probability.

4.2.3. Total nitrogen

The analysis of variance indicated a highly significant interaction effect ($p < 0.001$) among land use types, conservation practices, and soil depth on the total nitrogen content of the soil samples (Table 4.3). These findings suggest that the interaction effects of the three factors on total nitrogen cannot be explained by their individual contributions alone. This study reveals a complex interplay between land use, conservation practices, and soil depth in influencing total nitrogen levels.

The highest mean total nitrogen (TN) value (0.26%) was found in the soils of the conserved plantation forest at the upper soil surface (0-20 cm), while the lowest value (0.11%) was recorded in the soils of unconserved cultivated land at the lower depth (20-40 cm). The lower TN in unconserved farmland may be attributed to reduced organic matter content.

A study conducted by Mulugeta and Karl (2010) in southern Gondar demonstrated that cultivated lands implementing soil and water conservation (SWC) measures exhibited higher total nitrogen levels compared to unconserved lands. Similarly, Haweni (2015) reported that total nitrogen content in conserved lands of the Dimma watershed was greater than that in corresponding sites without conservation measures.

4.2.4. The status of available phosphorus

The study results indicated a highly significant interaction effect ($p < 0.001$) among land use types, conservation practices, and soil depth on available phosphorus (AP) (Table 4.3). The highest mean AP value (18.00 ppm) was recorded in both the upper and lower layers of the conserved plantation forest land, while the lowest AP value (7.00 ppm) was observed in the upper and lower surfaces of the unconserved cultivated land.

These findings suggest that the effects of conservation practices and soil depth on AP are not independent of the selected land use types, and vice versa. The interplay among land use types, conservation practices, and soil depth significantly influences AP levels in the soil samples.

Previous studies on soil properties along landscapes affected by long-term tillage have shown that soil AP content is typically lower in areas where soil has been eroded compared to areas where soil has accumulated (Ashenafi et al., 2010). Additionally, research by Worku et al. (2012) in the Goromti watershed of western Ethiopia indicated that available phosphorus levels did not significantly differ across various treatments and slope/depth gradients.

4.3. The Status of Exchangeable Bases

4.3.1. Calcium

Exchangeable bases (Na^+ , K^+ , Mg^{2+} , and Ca^{2+}) are critical indicators of soil nutrient status. Analysis of variance (ANOVA) disclosed a highly significant interaction ($p < 0.01$) among land use types, conservation practices, and soil depth influencing exchangeable calcium (Ca^{2+}) (Table 4.4). The highest mean calcium concentration (20.89 cmol/kg) was observed at the upper surface (0-20 cm) of the conserved plantation forest land, which was statistically on par to the lower surface (20-40 cm) of the same land type. In contrast, the lowest mean exchangeable calcium (16.42 cmol/kg) was recorded at the upper surface of unconserved cultivated land, which was statistically similar to the lower surface of the same land type.

These results indicate that the interplay of all three factors plays a crucial role in determining calcium levels in the soil samples. A study by Gebeyaw (2015) found that exchangeable Ca^{2+} levels are generally lower in cultivated lands compared to forest and

grazing lands, reinforcing the importance of land use management in maintaining soil nutrient levels.

4.3.2. Magnesium

Analysis of variance (ANOVA) revealed that exchangeable magnesium (Mg^{2+}) was highly significantly influenced ($p \leq 0.01$) by the interaction of land use types, conservation practices, and soil depth (Table 4). The highest exchangeable Mg^{2+} concentration (8.23 cmol/kg) was recorded in the upper surface of conserved plantation forests, which was statistically comparable to the same land use and conservation practice at the lower soil depth (20-40 cm). Conversely, the lowest concentration (5.81 cmol/kg) was observed in the unconserved cultivated land at both upper and lower soil depths (Table 4.4).

This disparity may be attributed to the removal of vegetation cover resulting from human and livestock interference, which depletes Mg^{2+} present in plant tissue and reduces the soil's cation adsorption capacity. Additionally, these findings indicate that the effects of land use types and conservation practices on exchangeable Mg^{2+} content are not independent of the chosen soil depth.

Overall, the combination of land use types, conservation practices, and soil depth significantly impacts the exchangeable Mg^{2+} content of the soil samples. According to FAO (2006) ratings, the exchangeable Mg values in this study area were classified as high. Fatwa et al. (2008) also reported that in the topsoil layer, the concentration of exchangeable Mg^{2+} was higher in protected areas compared to open grasslands.

4.3.3. Cation exchange capacity

The analysis of variance revealed that Cation exchange capacity (CEC) was significantly influenced by the interaction of land use, conservation practices, and soil depth ($p < 0.05$). The highest mean CEC value (29.26 cmol/kg) was observed at a depth of 20-40 cm in the conserved plantation forest land, which was statistically comparable to that at the same depth in conserved grazing land. Conversely, the lowest CEC (19.66 cmol/kg) was recorded at the lower soil surface of unconserved cultivated land (Table 4.4).

These results indicate that the relationship between land use types and CEC is intricately linked to conservation practices and soil depth, reflecting a complex interplay among these factors. According to Hazelton and Murphy (2007), CEC values in the study area range from high to very high.

Zhang et al. (2007) noted that soil chemical properties tend to be lower at higher elevations compared to lower landscape positions. Both clay and colloidal organic matter possess negative charges, enabling them to function as anions. Consequently, these materials, individually or as a clay-humus complex, can effectively absorb and retain positively charged ions. Therefore, soils rich in clay and organic matter exhibit higher CEC than sandy soils, which typically have lower organic matter content (Brady and Weil, 2002).

Table 4.4. Interaction effect of land uses, conservation, and depth on exchangeable bases

Land use	Conservation practice	Depth	CEC	Ca ⁺²	Mg ⁺²	Na ⁺	K ⁺	
Grazing land	Conserved	0-20	27.66	20.45	6.81	0.75a	0.66a	
Grazing land	Conserved	20-40	28.66	20.45	6.81	0.75a	0.50a	
Grazing land	Unconserved	0-20	21.30	16.43	6.09	0.36a	0.26a	
Grazing land	Unconserved	20-40	24.33	16.44	6.08	0.36a	0.56a	
Plantation forest	Conserved	0-20	27.00	20.89	8.23	0.90a	0.90a	
Plantation forest	Conserved	20-40	29.26	20.88	8.20	0.85a	0.88a	
Plantation forest	Unconserved	0-20	24.33	18.72	6.85	0.63a	0.83a	
Plantation forest	Unconserved	20-40	23.16	18.72	6.85	0.63a	0.86a	
Cultivated land	Conserved	0-20	26.76	18.49	6.74	0.84a	1.06a	
Cultivated land	Conserved	20-40	23.53	18.50	6.74	0.84a	0.83a	
Cultivated land	Unconserved	0-20	23.00	16.42	5.81	0.62a	0.26a	
Cultivated land	Unconserved	20-40	19.66	16.42	5.81	0.62a	0.23a	
			CV	0.86	0.28	0.01	9.62	5.83

NS= Not Significant * = Significant at $P \leq 0.05$; **= Significant at $P \leq 0.01$; *** = Significant at $P \leq 0.001$; P = Probability

4.3.4. Sodium

The combined interaction among land use types, conservation practices, and soil depth was not significant ($p < 0.05$) with respect to sodium content, as shown in Tables 4. However, the analysis of variance revealed a highly significant interaction effect ($p < 0.01$) between land use types and soil depth on the total sodium content of the soil samples (Table 4.4). The highest mean sodium (Na⁺) value (0.73%) was found in the lower soil depth of the plantation forest, while the lowest value (0.53%) was recorded in the upper soil depth of cultivated land.

Table 4.4 indicates a highly significant interaction effect ($p < 0.01$) between conservation practices and soil depth on sodium (Na⁺) content. Notably, conserved land exhibited a relatively high Na⁺ value of 0.85% at the upper surface, compared to the lower value of 0.41 cmol/kg in the non-conserved area (Table 4.4). This difference can be attributed to

conservation practices that reduce runoff and mitigate nutrient leaching. Fatwa et al. (2008) reported that Na⁺ concentrations were lower in cropland than in grazing and native forest areas.

Furthermore, the ANOVA indicated a significant interaction effect ($p < 0.05$) between conservation practices and land use on sodium (Na⁺) content. The highest mean Na⁺ value (0.90%) was found in the soils of the conserved plantation forest, while the lowest value (0.31%) was recorded in the soils of unconserved cultivated land. The relatively lower exchangeable Na⁺ values in unconserved areas are likely due to deforestation, leaching, limited recycling of dung and crop residues, and erosion, all of which contribute to the depletion of exchangeable bases in non-conserved agricultural lands.

As per the ratings of FAO (2006) ratings, the exchangeable Na⁺ contents in the study area under grazing land, unconserved land, and unconserved grazing land were classified as moderate, while those under forest land, cultivated land, conserved land, conserved grazing land, and both conserved and unconserved plantation forest and cultivated land were rated as high. Additionally, a similar study by Haweni (2015) in the Dimma watershed found that exchangeable sodium was not significantly affected by soil and water conservation practices and land slope.

Table 4.5. Interaction Effect of land uses, and conservation practices on exchangeable bases

Treatments			Na ⁺	K ⁺
Grazing land	Conserved;	Mean	0.88	0.58
Grazing land	Unconserved	Mean	0.36	0.41
Plantation Forest	Conserved;	Mean	0.90	1.01
Plantation Forest	Unconserved	Mean	0.55	0.85
Cultivated land	Conserved;	Mean	0.78	0.95
Cultivated land	Unconserved	Mean	0.31	0.25
P-value			*	*

Table 4.6. Interaction effect of land use types, and depth on exchangeable bases

Treatments	Depth	Mean	Na ⁺	K ⁺
Grazing land	0 -20	Mean	0.63	0.46
Grazing land	20-40	Mean	0.61	0.53
Plantation Forest	0-20	Mean	0.71	0.86
Plantation Forest	20-40	Mean	0.73	1.0
Cultivated land	0-20	Mean	0.53	0.66
Cultivated land	20-40	Mean	0.56	0.53
P-value			***	*

Where= P = Probability

Table 4.7. Interaction effect of conservation practices, and depth on exchangeable sodium

Treatments	Depth	Mean	Na ⁺
Conserved	0 -20	Mean	0.85
Conserved	20-40	Mean	0.85
Unconserved	0-20	Mean	0.40
Unconserved	20-40	Mean	0.42
P-value			**

4.3.5. Potassium

The result of the study revealed exchangeable potassium (K⁺) was significantly influenced ($p \leq 0.05$) by the main effects of land use types and conservation practices; however, it was not statistically significantly affected by soil depth (Tables 8). Among land use types, the highest mean K⁺ value (0.93 cmol/kg) was found in plantation forests, while the lowest value (0.50 cmol/kg) was recorded in grazing lands (Table 4.8). The elevated K⁺ concentration in plantation forests is likely related to their higher pH compared to cultivated land, which aligns with findings by Mesfin (2007) that reported higher K⁺ levels in soils with elevated pH values.

Additionally, the highest exchangeable K⁺ value (0.85 cmol/kg) was observed in conserved land, while the lowest was recorded in unconserved land (0.50 cmol/kg) (Table 4.8). This higher concentration of K⁺ in conserved farmland and protected forest areas can be attributed to the ability of vegetation to draw potassium from the subsoil (Bohn *et al.*, 2001).

There was no significant interaction effect ($p > 0.05$) among land use types, conservation practices, and soil depth on exchangeable K⁺ (Table 4.4). The highest exchangeable K⁺ value (1.01 cmol/kg) was noted under the interaction of conserved plantation forests, while the lowest value (0.25 cmol/kg) was recorded in unconserved cultivated land (Table 4.5). The relatively lower exchangeable K⁺ values in unconserved areas can be attributed

to factors such as deforestation, leaching, limited recycling of dung and crop residues, and erosion, which contribute to the depletion of exchangeable bases in non-conserved agricultural lands.

According to FAO (2006) ratings, the exchangeable K^+ values were classified as moderate in both the main effects of land use type and conservation practice, as well as soil depth (upper and lower), while conserved grazing land received a high rating in the study.

Table 4.8. The main effect of land uses, conservation practices, and depth on exchangeable bases

Treatment	Mean	Na^+	K^+
Grazing land	Mean	0.62b	0.50c
Plantation forest	Mean	0.80a	0.93a
Cultivated land	Mean	0.75b	0.60b
	P-value	**	*
Conservation practice			
Conserved	Mean	0.85a	0.85a
No conserved	Mean	0.41b	0.50b
	P-value	*	*
Depth			
0 – 20	Mean	0.62a	0.66a
20 – 40	Mean	0.63b	0.68a
	P-values	*	Ns

NS=Not Significant * = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$; *** = Significant at $P \leq 0.001$; Av. P = Available Phosphorus; TN = Total Nitrogen; OM = Organic Matter; P = Probability.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Land degradation poses a significant threat to food security and the livelihoods of farmers, resulting in reduced crop yields and substantial economic losses. The research findings demonstrate a complex interplay between land use types, conservation practices, and soil depth, highlighting the significant role of conservation measures particularly in the upper surface layer of plantation forests in enhancing soil quality. These measures improve critical soil properties such as clay content, moisture retention, and nutrient levels, while unconserved cultivated land of the lower surface layer lands marked deficiencies.

The findings demonstrate that the interaction effects of plantation forest, the upper soil and conserved land significantly promote higher levels of clay content, moisture content, soil organic matter (SOM), soil organic carbon, total nitrogen (TN), exchangeable bases specifically calcium and magnesium, and available phosphorus (AP). Furthermore, soil and water conservation measures positively impact the majority of soil physical and chemical properties.

These results underscore the necessity for sustainable land management practices to combat soil degradation and enhance agricultural productivity. Ongoing research is essential to further elucidate these relationships and develop effective conservation strategies tailored to specific ecosystems.

5.2. Recommendations

- ✓ **Implement Conservation Practices:** The woreda and farmers should adopt conservation practices, such as agroforestry and cover cropping, to enhance soil nutrient levels and prevent erosion.
- ✓ **Monitor Soil Health:** Regular soil testing should be conducted to monitor nutrient levels and adjust management practices accordingly, ensuring sustainable soil health over time.
- ✓ **Educate Stakeholders:** Providing education and resources to farmers about the benefits of soil conservation and sustainable land use can promote better land management practices.
- ✓ **Promote Organic Matter Recycling:** Encourage the recycling of organic materials, such as crop residues and animal manure, to improve soil organic matter and nutrient availability.

- ✓ **Research on Local Practices:** Further research should be conducted to assess the effectiveness of specific conservation practices tailored to local conditions and their long-term impacts on soil health.

By implementing these recommendations, stakeholders can work towards improving soil fertility, supporting sustainable agricultural practices, and ensuring long-term productivity of soil in the study area.

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7. APPENDIX

Appendix Table 1. Mean square value for physical soil properties

Source of variation	DF	BD (g cm ³)	MC (%)	Sand (%)	Silt (%)	Clay (%)
Replication	2	0.0005***	0.323ns	0.1944ns	0.3611ns	2.527ns
Land use	2	0.01**	0.05*	0.023*	0.0314*	0.001***
Con & Un co	1	0.04*	0.04*	0.00**	0.0139**	0.001*
Depth	1	0.0008**	0.04*	1.00ns	2.777ns	0.1111ns
LU * Cn &Un	2	0.002**	0.04*	0.0445**	0.0944*	0.0971*
LU &Depth	2	0.0002***	0.04*	0.250ns	11.194ns	2.86111ns
Cou&Unco*Depth	1	0.0002***	0.01**	0.23ns	58.777ns	0.777ns
LU*Con&Unc*Dep	2	0.0002***	0.01**	0.445ns	0.4471ns	0.049*
Error	22	0.0005	0.03	1.648	15.5429	4.0732
CV		1.90	3.50	4.55	9.33	4.01

* - significant at P=0.05; ** - significant at P=0.01; *** - significant at P ≤ 0.001; NS=Non-significant at P=0.05; BD = ;(%) Bulk Density MC (%) = Percent of Moisture continuity; Sand (%) percent of sand; Silt (%) = Percent of Silt; Clay (%) percent of Clay.

Appendix Table 2. Mean square of selected soil chemical Property for effects of soil and water conservation practice.

Source of variation	df	pH-H ₂ O %	OC %	OM %	TN	CEC
Replication	2	0.06*	0.0072***	0.021**	0.0001***	0.048*
Land use	2	0.03*	0.02*	0.003*	0.0047***	0.04*
Con& Unco	1	0.04*	0.03*	0.004*	0.0576*	0.042*
Depth	1	0.533ns	0.014**	0.0468*	0.0013***	0.042*
LU*Con &Unco	2	0.050*	0.4780NS	1.4202NS	0.0025***	0.39NS
LU&depth	2	0.001***	0.012**	0.0314**	0.00003***	0.0206*
Cou&Unco*dept	1	0.0136**	0.001***	0.00617**	0.0001***	0.006**
LU*Cou&Unco*depth	2	0.001***	0.003***	0.0102**	0.0003***	0.0319*
Error	22	0.023	0.011	0.018	0.0002	0.04151
CV		2.99	3.03	3.06	4.93	0.86

* - significant at P=0.05; ** - significant at P=0.01; *** - significant at P ≤ 0.001; NS=Non-significant at P=0.05; pH (H₂O) = Power of Hydrogen in the water solution; OC (%) = Percent of Organic Carbon; OM (%) percent of Organic Matter; TN (%) = Percent of Total Nitrogen; CEC (%) percent of Exchangeable Capacity.

Appendix Table 3. Mean square of Ap and exchangeable bases in Land use, soil depths and their interaction effect in soil water conservation study area.

Source of variation	DF	Av. P	Ca	Mg	Na	K
Replication	2	0.007*	1.17ns	0.80ns	0.002**	0.01*
Land USE	2	0.02*	0.03*	0.05*	0.04*	0.01*
Con & Un co	1	172.48ns	0.04*	0.044*	0.03*	0.06*
Depth	1	0.34*	0.01*	0.001**	0.001**	0.44ns
LU * Cn &Un	2	48.08ns	0.05*	0.036*	0.02*	0.028*
LU &Depth	2	0.001***	5.66ns	0.53ns	0.001**	0.05*
Cou& Unco*Depth	1	0.001***	1.29ns	0.04*	0.001**	0.05*
LU*Con & Unco*Depth	2	0.001***	0.01*	0.021*	0.45ns	0.05ns
Error	22	0.004	1.25ns	0.15	0.003	0.05
CV		0.01	0.28	0.01	9.62	5.83

* - significant at P=0.05; ** - significant at P=0.01; *** - significant at $P \leq 0.001$; NS=Non-significant at P=0.05; Av. P (mg/kg) = Available Phosphorus in milligram per kilogram; EX. Ca = Exchangeable Calcium; EX, Mg= Exchangeable Magnesium; EX, Na = Exchangeable Sodium; EX, K= Exchangeable Potassium

Appendix Table 4. Ratings of selected soil physicochemical properties.

Parameters	Rating					Sources
	Very low	Low	Moderate	High	Very High	
BD	<1	1-1.3	1.3-1.6	1.6-1.9	>1.9	
MC (%)						Hazelton and Murphy (2007)
PBS (%)	0-20	20-40	40-60	60-80		
OC (%)						
OM (%)	<0.86	0.86-2.57	2.57-5.17	>5.17		Tekalign (1991)
TN	-	<0.05	0.05-0.12	0.12-0.25	>0.25	
CEC (cmolc kg-1)	<6.0	<6.0-12-0	12.0-25.0	25.0 - 40.0	>40	Hazelton and Murphy (2007)
Soil Reaction		Rating of soil pH (H ₂ O)				
Extremely acidic		<4.5				
Very strongly acidic		4.5-5-0				
strongly acidic		5.1-5-5				
Moderately medium Acidic		5.6-6-0				
Slightly Acidic		6.1- 6-5				
Neutral		6.6 -7-3				
Slightly Alkaline		7.4- 7-8				
Moderately Alkaline		7.9- 8-4				
Strongly Alkaline		8.5 – 9-0				
Very strongly Alkaline		>9.1				

Source: Jones (2003)

Appendix Table 5. Ratings of selected soil Exchangeable base

Parameters	Rating					Sources
	Very low	Low	Moderate	High	Very High	
AV. P(Mg/Kg)	< 5	5-9	10-17	18-25	>25	Olsen <i>et al.</i> (1954)
Exch Ca (cmolckg ⁻¹)	< 2	2-5	5-10	10-20	> 20	FAO (2006)
Exch Mg (cmolc kg-1)	< 0.3	0.3-1	1-3	3-8	> 8	
Exch Na (cmolc kg-1)	< 0.1	0.1-0.3	0.3-0.7	0.7-2	> 2	
Exch K(cmolckg-1)	< 0.2	0.2-0.3	0.3-0.6	0.6-1.2	> 1.2	

Appendix Table 6. Composite soil samples taken points

Katibre Kebele							
Forest 01				Forest 02			
pin number	Easting x	Northing (y)	elevation	pin number	Easting x	Northing (y)	Elevation
1	0376233	0916128	18.70	1	0376222	0376222	18.66
2	0376221	09161151	18.73	2	0376202	0913302	18.64
3	0376200	0916145	18.73	3	0376179	0916322	18.67
4	0376175	0916133	18.77	4	0376162	0916346	18.65
5	0376186	0916105	18.70	5	0376185	0916357	18.62
6	0376209	0916084	18.75	6	0376216	0916363	18.68
7	0376224	0916062	18.72	7	0376243	0916367	18.71
8	0376244	0916048	18.71	8	0376260	0916387	18.72
9	0376215	0916035	18.70	9	0376249	0916410	18.71
10	0376186	0916029	18.66	10	0376239	0916427	18.68
11	0376151	0916018	18.64	11	0376244	0916439	18.69
12	0376142	0916013	18.66	12	0376261	0916447	18.71
13	0376164	0916002	18.68	13	0376266	0916454	18.72
14	0376175	0915993	18.68	14	0376256	0916466	18.69
15	0376186	0915980	18.66	15	0376246	0916480	18.69
16	0376201	0915953	18.63	16	0376268	0916496	18.79

Cultivated 01				cultivated 02			
pin number	Easting x	Northing (y)	Elevation	pin number	Easting x	Northing (y)	Elevation
1	0378418	0916289	18.99	1	0378623	0916228	18.98
2	0378436	0916303	18.97	2	0378593	0916206	18.98
3	0378450	0916325	18.97	3	0378555	0916177	18.97
4	0378467	0916344	18.97	4	0378341	0916207	18.99
5	0378481	0916361	18.98	5	0378527	0916235	18.96
6	0378502	0916391	18.99	6	0378519	0916258	18.96
7	0378520	0916368	18.01	7	0378496	09116244	18.98
8	0378532	0916333	18.99	8	0378469	0916231	18.99
9	0378537	0916303	18.99	9	0378442	0916220	18.99
10	0378542	0916283	18.99	10	0378431	0916244	18.98
11	0378570	0916300	18.97	11	0378419	0916272	18.98
12	0378588	0916321	18.98	12	0378408	0916298	18.98
13	0378610	0916316	18.99	13	0378398	0916311	18.97
14	0378625	0916290	18.98	14	0378382	0916296	18.96
15	0378638	0916266	18.98	15	0378365	0916881	18.96
16	0378641	0916246	18.98	16	0378472	0916785	18.98
Grazing non 01				Grazing 02			
pin number	Easting x	Northing (y)	elevation	pin number	Easting x	Northing (y)	Elevation
1	0378350	0916271	18.97	1	0378198	0916351	18.89
2	0378335	0916286	18.92	2	0378208	0916380	18.92
3	0378366	0916300	18.96	3	0378231	0916425	18.98
4	0378289	0916323	18.97	4	0378246	0916438	18.98
5	0378279	0916309	18.94	5	0378162	0916453	18.96
6	09378266	0916290	18.97	6	0378271	0916430	18.96
7	09378266	0916290	18.97	7	0378271	0916430	18.97
8	0378258	0378276	18.97	8	0378276	0916395	18.97
9	0378242	0916251	18.95	9	0378287	0916365	18.96
10	0378237	0916266	18.97	10	0378295	0916347	18.96
11	0378230	0916289	18.96	11	0378306	0916330	18.97
12	0378225	18.96	0378319	12	0916341	0916341	18.98
13	0378221	0916324	18.96	13	0378342	0916365	18.97
14	0378210	0916314	18.99	14	0378350	0916356	18.96
15	0378195	0916299	18.94	15	0378359	0916341	18.98
16	0378185	0916320	18.94	16	0377363	0916321	18.97

Garbage							
Forest 01				Forest 02			
pin number	Easting x	Northing (y)	elevation	pin number	Easting x	Northing (y)	Elevation
1	0381260	0916932	18.96	1	0381402	0916746	18.98
2	0381280	0916932	18.95	2	0381381	0916743	18.92
3	0381206	0916932	18.94	3	0381355	0916744	18.98
4	0381230	0916930	18.94	4	0381353	0916759	18.95
5	0381259	0916923	18.96	5	0381349	0916783	18.96
6	0381283	0916914	18.99	6	0381333	0916775	18.95
7	0381271	0916994	18.94	7	0381310	0916768	18.95
8	0381263	0916978	18.94	8	0381298	0916760	18.94
9	0381261	0916963	18.94	9	0381284	0916756	18.92
10	0381282	0916961	18.98	10	0389288	0916773	18.92
11	0381207	0916943	18.98	11	0381289	0916799	18.96
12	0381209	0916924	18.98	12	0381277	0916795	18.90
13	0381200	0916969	18.99	13	0381267	0916712	18.90
14	0381293	0916994	18.97	14	0381267	0916735	18.92
15	0381463	0916778	18.97	15	038250	0916735	18.98
16	0381394	091763	18.26	16	0381231	0916733	18.94
Cultivated 01				Cultivated 02			
pin number	Easting x	Northing (y)	elevation	pin number	Easting x	Northing (y)	Elevation
1	0381251	0916792	18.98	1	0381109	0917027	18.95
2	0381237	0916792	18.99	2	0381129	0917041	18.98
3	0381210	0918787	18.92	3	0381146	0917050	18.94
4	0381187	0916788	18.94	4	0381161	0917056	18.94
5	0381170	0916786	18.98	5	0381176	0917058	19.00
6	0381172	0916805	18.94	6	0381196	0917063	19.00
7	0381181	0916830	18.97	7	0381193	0917042	18.99
8	0381186	0916851	18.94	8	0381184	0917025	18.99
9	0381193	0916871	18.94	9	0381176	0917001	18.94
10	0381175	0916871	18.94	10	0381174	0916789	18.99
11	0381157	0916871	18.95	11	0381194	09167889	18.89
12	0381138	0916772	18.97	12	0381217	0916789	18.98
13	0381116	0916875	18.96	13	0381237	0916996	18.97
14	0381120	0916911	18.94	14	0381227	0916995	18.94
15	0381128	0916893	18.95	15	03812112	0916823	18.94
16	0381128	0916893	18.94	16	0381196	0916998	18.99
Grazing 01				Grazing non 02			
pin number	Easting x	Northing (y)	elevation	pin number	Easting x	Northing (y)	Elevation
1	0380978	0916648	18.96	1	0380951	091680	19.04
2	0380960	0916652	18.96	2	0380926	091602	19.04
3	0380931	0916657	18.98	3	0380907	091602	19.04
4	0380897	0916665	18.98	4	0380982	091602	18.89
5	0380912	0916675	18.98	5	0380981	091611	18.98
6	0380927	0916684	18.98	6	0380911	091629	18.95

7	0380949	0916699	18.98	7	0380925	091641	18.98
8	0380966	0916612	18.95	8	0380940	091662	18.04
9	0380944	0916621	18.95	9	0380928	091672	19.02
10	0380922	0916626	18.97	10	0380913	091678	19.02
11	0380903	0916626	18.94	11	0380998	0916888	19.00
12	0380887	0916638	18.98	12	0380910	091604	19.01
13	0380889	0916647	18.99	13	0380970	091616	19.08
14	0380907	0916660	18.98	14	0380927	091629	19.00
15	0380920	0916670	18.99	15	0380914	091638	19.004
16	0380937	0916684	18.900	16	0380901	091645	19.004

Sunik Kebele							
Forest 01				Forest 02			
pin number	Easting x	Northing (y)	elevation	pin number	Easting x	Northing (y)	Elevation
1	0382861	0921588	19.26	1	0383029	0921662	19.26
2	0382870	0921605	19.26	2	0383037	0921680	19.25
3	0382881	0921622	19.25	3	0383036	0921699	19.25
4	0382899	0921637	19.25	4	0383047	0921713	19.25
5	0382812	0921622	19.25	5	0383052	0921702	19.27
6	0382823	0921606	19.25	6	0383063	0921683	19.27
7	0382837	0921577	19.26	7	0383074	092164	19.26
8	0382847	0921561	19.27	8	0383087	0921677	19.24
9	0382859	0921555	19.24	9	0383100	0921695	19.24
10	0382868	0921575	19.23	10	0383111	0921715	19.25
11	0382900	0921572	19.24	11	0383122	0921729	19.27
12	038991	0921615	19.20	12	0383125	0921721	19.28
13	0382999	0921625	19.24	13	0383158	0921705	19.29
14	0383003	0921649	19.23	14	0383166	0921700	19.28
15	0383010	0921664	19.24	15	0383174	0921712	19.28
16	0383012	0921675	19.25	16	0383179	0921729	19.29
Cultivated 01				Cultivated 02			
pin number	Easting x	Northing (y)	elevation	pin number	Easting x	Northing (y)	Elevation
1	0383561	0921750	19.04	1	0383507	0921867	19.41
2	0383561	0921727	19.06	2	0383529	0921873	19.40
3	0383563	0921799	19.04	3	0383571	0921869	19.44
4	0383557	0921774	19.08	4	0383571	0921865	19.444
5	0383548	0921759	19.06	5	0383590	0921861	19.44
6	0383539	0921695	19.04	6	0383513	0921856	19.44
7	0383513	0921712	19.04	7	0383530	0921852	19.33
8	0383597	0921724	19.04	8	0383509	0921839	19.04
9	0383577	0921737	19.09	9	0383585	0921821	19.04
10	0383552	0921748	19.06	10	0383565	0921802	19.26
11	0383551	0921734	19.06	11	0383559	0921883	19.26
12	0383553	0921712	19.06	12	0383579	0921883	19.40
13	0383553	0921728	19.07	13	0383576	09211781	19.24
14	0383553	0921788	19.04	14	0383625	0921782	19.24

15	0383531	0921799	19.06	15	0383592	0921770	19.26
16	0383516	0921710	19.06	16	0383594	0921756	19.08
Grazing non 01				Grazing non 01			
pin number	Easting x	Northing (y)	elevation	pin number	Easting x	Northing (y)	Elevation
1	0383195	0921734	19.28	1	0383345	0921609	19.05
2	03833210	0921720	19.24	2	0383339	0921836	19.04
3	0383224	0921706	19.26	3	0383339	0921815	19.06
4	0383242	0921691	19.27	4	0383318	0921875	19.06
5	0383254	0921681	19.24	5	0383305	0921889	19.04
6	0383158	0921693	19.24	6	0383300	0921868	19.05
7	0383257	0921713	19.24	7	0383293	0921851	19.04
8	0383261	0921728	19.24	8	03833286	0921832	19.25
9	038273	0921728	19.24	9	0383274	0921814	19.28
10	0383184	0921693	19.26	10	0383265	0921796	19.24
11	0383299	0921693	19.25	11	0383260	0921783	19.26
12	0383308	0921684	19.24	12	0383251	0921796	19.04
13	0383314	0921702	19.27	13	0383251	0921814	19.04
14	0383315	0921725	19.28	14	0383257	0921831	19.20
15	0383330	0921727	19.29	15	0383255	0921851	19.21
16	0383347	0921719	19.28	16	0383251	0921872	19.21

Appendix 7. Some memorial photographs during field and laboratory work



7.1 Some field sample collection photos



7.2. Some laboratory analysis photo collections