



**STATUS OF SOIL AND WATER CONSERVATIONS AND ITS
IMPACTS ON SELECTED SOIL PROPERTIES AND CROP YIELD IN
OMO NADA DISTRICT, SOUTHWESTERN ETHIOPIA**

MSc THESIS

BY

ABDO RAYA ABADURA

JUNE, 2024

JIMMA, ETHIOPIA

**Status of Soil and Water Conservation and Its Impacts on Selected Soil
Properties and Crop Yield in Omo Nada District, Southwestern Ethiopia**

By

Abdo Raya Abadura

MSc. Thesis

**Submitted to Jimma University, College of Agriculture and Veterinary
Medicine, Department of Natural Resource Management, in Partial
Fulfillment of the Requirements for the Degree of Master of Science in
Specialization of Watershed Management**

Major Advisor: Amsalu Tilahun (Asst. Prof)

Co-Advisor: Abebe Nigussie (PhD)

June, 2024

Jimma, Ethiopia

APPROVAL SHEET

JIMMA UNIVERSITY

College of Agriculture and Veterinary Medicine, Department of Natural Resource
Management

Thesis submission for Request form (F-08)

Name of the Student: **Abdo Raya Abadura** ID No: **RM 3125/12**

Program of Study: **Degree of Masters of Science (MSc) in NRM specializing in Watershed
Management**

Title: Status of Soil and Water Conservation and Its Impact on Selected Soil Properties and
Crop Yield in Omo Nada District, Southwestern Ethiopia.

I declared that the thesis research work has not been done anywhere else before or is not part
of an ongoing work.

Name of the Student **Abdo Raya Abadura** Signature _____ Date ____/____/____

We have evaluated the contents of the thesis and found it to be satisfactory executed according
to the approved proposal, written according to the standard and format of the university, and
ready to be submitted. Hence, was recommended the thesis be submitted.

Major Advisor:

Name **Amsalu Tilahun** (Assit. Prof) Signature _____ Date ____/____/____

Co-Advisor:

Name **Abebe Nigussie** (PhD) Signature _____ Date ____/____/____

Internal Examiner (If Depends on the Verdict)

Name _____ Signature _____ Date ____/____/____

Decision/suggestion of Department _____ Date ____/____/____

Graduate Council (DGC) _____ Date ____/____/____

Chairperson, CGS _____ Date ____/____/____

DEDICATION

I dedicated this thesis to my parents for nursing me with affection and support, encouragement, patience, and contribution to the success of my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis, and compilation of this Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation. This thesis is submitted in partial fulfillment of the requirement for MSc Degree at Jimma University. It is deposited in Jimma University Library and is made available to borrowers under the rule of the Library. I solemnly declare that it has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate. A brief quotation from this thesis may be made without special permission provided that accurate and complete acknowledgment of the source is made. Request for permission for extended quotation from or reproduction of this Thesis in whole or in part may be granted by the head of the school or department when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

Name: Abdo Raya

Place: Jimma University

Date of Submission: _____

Signature: _____

BIOGRAPHICAL SKETCH

The author, Abdo Raya Abadura, was born on April 08/1988 G.C at Nada Sokote in Omo Nada district, Jimma Zone of Oromia National Regional State, Ethiopia. He attended primary education at Nada Primary School from 1996 to 2003 and joined Asendabo Secondary School from 2004 to 2005. Then, he joined Assella Agricultural, Technical, Vocational and Training College in 2006 and graduated with a Diploma in Natural Resources Management in July 2008. Soon after graduation, he was employed in Omo Nada district Agricultural and Rural Development Office and served as a development agent (DA). He joined Ambo University in 2014 and he graduated B.Sc. in Natural Resources Management in 2018. After graduation, he served at the Omo Nada district agricultural and rural development office as an expert in natural resources management from 2018 up to 2019. Then, he joined the school of graduate students at JUCAVM in September 2019/2020 to follow his MSc. Studies in natural resource management specialize in watershed management.

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude and appreciation to my major advisor, Mr. Amsalu Tilahun, for his continuous guidance and valuable advice and comments that enabled me to do this research result on the right path. I would like to express my appreciation and heartfelt gratitude to my Co-advisor, Dr. Abebe Nigussie, for his consistent guidance, encouragement, and for his constructive and valuable comments that shaped this thesis.

Further, I would like to extend my thanks to the local farmers for their cooperation and willingness to respond during the household survey, and to all Development Agents (DA) in my study area for their technical support during the whole data collection.

I highly acknowledge Omo Nada District for providing MSc sponsorship and available data, and Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) for funding my thesis and allowing the use of soil laboratory and material supporting for sample analysis.

I would like to express my special thanks to my father, Raya Abadura, and my mother, Zara She Imam, for their prayers, support, encouragement, patience, and love throughout my life. I would like to extend my deep sense of gratitude to my wife, Habiba Aba Bor, for overcoming many challenges to fulfill my vision and moral support, strength, and encouragement in completing my thesis. I would like to express my gratitude to my sister Layila Raya for her encouragement and moral support.

Finally, I would like to acknowledge all my friends, for their support from starting up to finishing time, fellows and individuals whom I did not mention, but contributed indirectly or directly to the successful completion of my study.

LIST OF ABBREVIATION

Av-P	Available Phosphorous
BD	Bulk Density
CEC	Cation Exchange Capacity
CSA	Central Statistical Agency of Ethiopia
EFAP	Ethiopia Forestry Action Program
EPA	Environmental Protection Authority
FAO	Food and Agricultural Organization
FGD	Focus Group Discussion
JUCAVM	Jimma University Agriculture and Veterinary Medicine
LULC	Land Use Land Cover
MOA	Minister of Agriculture
ONDANRO	Omo Nada District Agriculture and Natural Resource Office
PSWC	Physical Soil and Water Conservation
PSWCP	Physical Soil and Water Conservation Practices
SLMP	Sustainable Land Management Program
SNNPRS	Southern Nations Nationalities and Peoples of Regional State
SOC	Soil Organic Content
SOM	Soil Organic Matter
SWC	Soil and Water Conservation
SWCM	Soil and Water Conservation Measures
SWCS	Soil and Water Conservation Structures
TN	Total Nitrogen
WOCAT	World Overview of Conservation Approaches and Technologies

TABLE OF CONTENTS

DEDICATION	iii
STATEMENT OF THE AUTHOR	iv
BIOGRAPHICAL SKETCH	v
ACKNOWLEDGEMENTS.....	vi
LIST OF ABBREVIATION.....	vii
TABLE OF CONTENTS	viii
LIST OF TABLES	xi
ABSTRAC.....	xiv
1. INTRODUCTION	1
1.1 Background	1
1.2 Statement of the problem	4
1.3 Objective	5
1.3.1. General Objective.....	5
1.3.2. Specific objectives	5
1.4 Research Questions	5
1.5 Research Hypothesis	5
2. LITERATURE REVIEW	6
2.1. Importance of Soil and Water Conservation	6
2.2. Types of soil and water conservation practice	7
2.3. Soil and Water Conservation in Ethiopia	8
2.4. The Status of Soil and Water Conservation Measures in Ethiopia	9
2.4.1. Management and maintenance status of implemented structures	10
2.4.2. Current status of soil and water conservation measures	10
2.5. Impact of Soil and Water Conservation on Soil Properties.....	11
2.5.1. Soil physical properties	12
2.5.2. Soil chemical properties	13
2.6. Impact of Soil and Water Conservation Measures on Crop Yield	15
3. MATERIALS AND METHODS	17

3.1.	Description of the Study Area	17
3.1.1.	Location.....	17
3.1.2.	Topography	17
3.1.3.	Climate of the study area.....	18
3.1.4.	Soil type	19
3.1.5.	Land use and farming system of the study area	19
3.1.6.	Population	20
3.2.	Study Design	20
3.2.1.	Site selection	20
3.3.	Methods of Data Collection	21
3.3.1.	Field observation and measurement of the status of implemented SWC structures	21
3.3.2.	Soil sample collection	22
3.3.3.	Crop data collection	23
3.3.4.	Socioeconomic data collection.....	24
3.4.	Soil Laboratory Analysis.....	25
3.5.	Data Analysis	26
4.	RESULTS AND DISCUSSION	27
4.1.	Demographic and Socio-economic Characteristics of Respondents	27
4.1.1.	Age, sex, and educational status	27
4.1.2.	Family and land holding size, and land by slope category	28
4.1.3.	Livestock ownership of respondents.....	30
4.2.	Present Status of Implemented SWC Practices in the Study Area.....	31
4.2.1.	Present status, maintenance, and reasons for the destruction of SWC structures	31
4.2.2.	Farmers' perception of soil erosion and soil and water conservation practice ..	32
4.2.3.	Land ownership, the wealthy status of the farmer, and the age of structure.....	34
4.2.4.	General problems faced in sustaining SWC structures in the study area.....	35
4.2.5.	Status of SWC structures	35

4.3.	Impact of SWC Measures on Selected Soil Physicochemical Properties	38
4.3.1.	Impacts of slope classes and bund zones on soil physical properties	38
4.3.2.	Impacts of slope classes and soil bund zones on soil chemical properties	41
4.4.	Impact of Physical Soil and Water Conservation Measures on Crop Yield.....	47
5.	CONCLUSIONS AND RECOMMENDATIONS	49
5.1.	Conclusions	49
5.2.	Recommendation.....	50
6.	REFERENCES.....	51
7.	APPENDICES.....	67

LIST OF TABLES

Table 1: Sampling frame work of study site and respondent households	Error! Bookmark not defined.
Table 2: Sex, age and educational status of respondents	28
Table 3: Family and land holding size, and land by slope category of respondents.....	29
Table 4: Live stock holding of household across the three watersheds	30
Table 5: Erosion problem and trend of erosion in the study area.....	31
Table 6: Types of SWC implemented in sample watersheds....	Error! Bookmark not defined.
Table 7: Present status and Reason for the destruction of SWC structures ...	Error! Bookmark not defined.
Table 8: Land ownership, wealthy status of farmer and age of structure	34
Table 9: General Problems faced in sustaining SWC structures in the study area	35
Table 10: Field measurement of physical status of implemented soil bund ..	Error! Bookmark not defined.
Table 11: Field measurement of dimension of soil bund in relation to standard.....	Error! Bookmark not defined.
Table 12: Impact of slope classes on soil physical properties	39
Table 13: Impact of bund zones on soil physical properties.....	40
Table 14: Mean impacts of slope classes and bund zones on soil physical properties	41
Table 15: Impact of slope classes on soil chemical properties	422
Table 16: Impact of bund zones on soil chemical properties.....	433
Table 17: Mean impacts of slope classes and bund zones on soil chemical properties	445
Table 18: Impact of Soil and Water Conservation Measures on Crop Yield.....	47
Table 19: Impact of soil bund zone on grain yields of maize ...	Error! Bookmark not defined.

LIST OF FIGURES

Figure 1: Location map of study area	17
Figure 2: Topography of the study area	18
Figure 3: Soil map of the study area	19
Figure 4: Field measurement.....	22
Figure 5: Soil and crop data sampling field between two successive bunds .	Error! Bookmark not defined.

LIST OF APPENDIXES

Appendix 7.1: Questionnaire for Household Survey.....	67
Appendix 7.2: Pearson correlations of soil physicochemical properties.....	75
Appendix 7.3: Photo during Soil and Crop Yield Sampling from the Field.....	76
Appendix 7.4: Photo during focus group discussion and key informant interview.....	77
Appendix 7.5: During Soil Laboratory Analysis.....	78

ABSTRAC

Land degradation in the form of soil erosion is the major cause of low agricultural productivity and loss of soil nutrients in Ethiopia particularly in the study area. To reverse these problems, soil and water conservation measures were implemented in the different parts of our country including the study area. This study was conducted to assess the status of implemented SWC practices and their impact on selected soil physicochemical properties and crop yield in the study area. Three kebeles were selected purposely based on the availability of conservation structures and 184 households were selected by simple random sampling techniques, household survey, analysis of selected soil physiochemical properties, and crop yield assessment methods were used to carry out the study. The key informant and focus group discussion were used for the strength of the survey data. A total of 27 representative soil samples were collected from 0-20cm depth under three bund zones between two succeeding structures across three slopes with three replications. Core samples were collected for bulk density analysis. Data analysis was conducted using SPSS software version 20. The survey results show that the majority of farmers implemented soil bunds on their cropland. Concerning the status of implemented structures, maintenance problems, and reason for destruction as to land ownership, the wealthy status of the farmer, and the age of the structure, Problems faced in sustaining structures, were recognized. This study reveals significant differences in soil physicochemical properties under both slope classes and bund zones, with higher mean values of clay and silt soil at LS and DZ, and sand soil and BD at US and LZ, as well as higher mean values of pH, SOC, TN, Av-P, and CEC at LS classes, but pH, Av-P and CEC at DZ of soil bunds. The grain yield of maize for the deposition zone was higher by 17.3% than the middle zone of structures. The variation in soil physicochemical properties and crop yield between two consecutive structures across slope classes could be due to the removal of clay soil and organic matter from loss to depositional zones. Soil bunds had a positive impact on soil physicochemical properties and crop yield in the study area. The study suggests that it is important to maintain the structure to sustain the effectiveness and continuous technical support and follow-up after implementation should be given by government and natural resource experts.

Keywords: Soil erosion, Soil and water conservation structures, Slope classes, Soil bund, Soil property, Crop yield

1. INTRODUCTION

1.1 Background and Justification of the Study

Land degradation in the form of soil erosion is the major cause of low agricultural productivity and the loss of soil nutrients in Ethiopia (Haregeweyn *et al.*, 2015). Most of the soils in the country are highly degraded and affect all the physical and chemical properties of the soil (ATA, 2013; Lemenin *et al.*, 2005; Hurni *et al.*, 2010). Its problems are shown mainly in the form of soil erosion, gully formation, soil fertility loss, and crop yield reduction (Teramaj, 2015). In Ethiopia, about 32.1 million people are affected by soil erosion (Endalew *et al.*, 2015), and more than 30, 000 ha of the country's croplands are abandoned every year because cropping can no longer be supported in the highly eroded areas (Endalew *et al.*, 2015; Molla and Sisheber, 2017). Moreover, an estimated 2 billion m³ of topsoil is lost annually (Getachew *et al.*, 2016). About 50% of the total soil loss in Ethiopia occurred from cropland, in which more than 30 t ha⁻¹ yr⁻¹ of soil is eroded (Hurni, 1993; Haregeweyn *et al.*, 2015; FAO, 2019), and it is a cause of losses of soil fertility, reduce crop yield and thereby increase its risk of food security (Fikirie and Beyene, 2017).

By recognizing the impact of soil erosion after the 1973–1974 famine, the Ethiopian government has launched various campaigns on soil, land, and water conservation (Haregeweyn *et al.*, 2015). A total of 1,252,000 km of terraces and bunds were built, with 472 million trees planted (Osman and Sauerborn, 2001). The implementation developed a top-down, incentive-based (food-for-work) approach, with engineering measures taking priority (Shiferaw and Holden, 1999). However, due to the implementation method, this program was not long-lasting. The second step, a 30-day national community-based mobilization that began in 2010 with mass mobilization at the participatory watershed level, aimed at changing farmers' attitudes and ensuring that soil and water conservation systems are sustainable and efficient (Mekuriaw *et al.*, 2018). Without any incentives, over 15 million people participated, and over 3000 community watersheds were treated with biological and PSWC interventions each year (Dessalegn *et al.*, 2015).

Soil and water conservation (SWC) activities have been shown to enhance the physicochemical properties of soil in research studies (Mekuria *et al.*, 2006; Adimassu *et al.*, 2017; Teklu *et al.*,

2018). Sediment accumulated behind bunds provides suitable growing conditions for crops through the conservation of soil moisture and nutrients (Vancampenhout *et al.*, 2006; Dagneu *et al.*, 2015). It also improves crop growth and yield, increases fodder harvest, and farmers' income by reducing soil loss by sediment trapping (Amede, 2003; Wolka, 2015; Walie and Fisseha, 2016; Teklu *et al.*, 2018).

According to various reports, SWC interventions help to restore damaged materials on embankments. For instance, Etana (2020), found that Av-P of soils treated with level soil bund plots were higher than that of non-conserved plots with a mean value (7.13 ppm), and the lower mean value (5 ppm). The results reported by different authors (Gebiresilassie *et al.*, 2013; Dulo *et al.*, 2017; Solomon *et al.*, 2017 and Worku, 2017) indicated lower mean soil BD value in conserved farms than non-treated cultivated lands. The higher value of SOC on farm lands treated with SWC; and with increasing age of structures when compared to non-conserved land (Tadele *et al.* 2011; Dulo *et al.* 2017; Solomon *et al.* 2017). Ademe *et al.*, (2017) reported the increasing value of pH by 0.62% from upper to bottom terrace positions in farmlands treated with SWC measures. SWC had positive impact on grain and biomass yield and the increase of more than 25% for grain and 30% for biomass yields (Mekonen and Tesfahunegn, 2011). Similarly, Abay (2011) reported that yield was increased by 22 % on some farms and 15 fold on other farms within one year of bund/fanyajuu. Further, Gebreselassie *et al.*, (2009) reported crop grain yield increased by 29.8% at accumulation zone as compared to loss zone bund structures.

However, many SWC measures are implemented with design flaws, without proper design and maintenance, and do not match conservation requirements (Roes *et al.*, 2007). As a result, the anticipated outcomes of SWC measures are restricted, and the process of soil erosion and land degradation is not reversed as planned (Herweg and Ludi, 1999; Bakker *et al.*, 2008; Steenhuis *et al.*, 2008; Jemberu *et al.*, 2014). The failure of implemented structures was observed and reported frequently in most parts of the country that could be due to wrong SWC structures design specification and there was not done effective maintenance of the implemented SWC practice for its sustainability (Gizaw *et.al.* 2019). Furthermore, Fikirie and Beyene, (2017) reported that the implementation of structures are challenging, due to lack of integration of physical and biological measures, lack of considering socioeconomic profile, low perception

and participation of farmer, poor conservation design, inadequate maintenance, week monitoring and evaluation of SWC are major constraints for the implementation of soil and water conservation in Ethiopia.

Significant effort is being made to duplicate 'community-based participatory integrated watershed management' operations in districts across most of our country. As part of this endeavor, throughout the previous 10 years, a countrywide 30-day public work campaign for watershed management has been undertaken, and the activities are still underway in our country. Similarly, in Omo Nada district large scale of SWC structures (level and graded soil bunds, fanya juu, check dams, and other physical and biological measures) were implemented in different watersheds. Poor land management practices coupled with the rugged topography, erosive rainfall and more intense of gully and rill formation affected the agricultural practices in the study area (SLMP, 2010).

Recent studies conducted on SWC measures impact largely in view of soil fertility and crop yield in Jimma zone, southwestern Ethiopia. For example, the influence of participatory integrated watershed management on hydrology, the ecology, and socioeconomics at the Somodo watershed (Tesfaye *et al.*, 2018); evaluating technical standards of implemented SWC in jimma zone (Gizaw *et al.*, 2019). Studies have been done on soil fertility management and nutrient balance (Ababayehu, 2010); causes, consequences and solution of land degradation (SLMP, 2010); LULC dynamics and its impact (Amanuel, 2011); characterizing weathering intensity and trends of geological materials (Alemayehu *et al.*, 2014); soil fertility status and productivity trends along a toposequence (Siraj *et al.*, 2015). Therefore, this study was considering the current status of implemented soil and water conservation structures and their impacts on soil physicochemical properties and crop yield, in the study area.

1.2 Statement of the problem

Soil and water conservation in Ethiopia is considered today to be of top priority, not only to maintain and improve agricultural production but also to achieve food self-sufficiency. Appropriate SWC measures play an essential role in minimizing soil loss and its effects (Amsalu and de Graff, 2007; Bewket, 2007; Wolka, 2015). Investing in SWC measures enhances soil nutrients, fertility, and crop output (Mulat *et al.*, 2020).

Omo Nada district is one of the most affected districts by land degradation due to soil erosion and it has several watershed areas where there are extensive smallholder-based crop and livestock production systems. Presently, the public campaign works for the dissemination of SWC activities have also been implemented in the district. Still, there is an erosion effect due to material's transportation from the upper embankment and redistribution towards the lower embankment between the two successive structures, and there is also the destruction of conservation structures due to poor management like maintenance problems, free grazing, and some case cultivation of near bund in search of fertile soil in deposition area. Due to these problems, SWC structures promote erosion and cause redistributions of soil nutrients, which results in an impact on overall crop yields and spatial variations of yield.

However, the impact of physical soil and water conservation methods, as well as related management, on certain soil parameters and crop output has received little attention. Furthermore, the present state of applied soil and water conservation measures was not investigated in the majority of the study area's watersheds. The most common areas of study are crop yield, soil fertility, soil loss, and runoff. Thus, there is a lack of information about the status of SWC structures after implemented how many broken/damaged across slope classes and land ownership, the examination of their impacts on soil properties, and crop yield variations between two consecutive structures, and how many maintained and stabilized by biological SWC and measurement of the technical standards. But, evaluating SWC structures effect on soil properties and crop yield is essential for enhancing and improving the conservation effort, and to use the implemented structures in the sustainable manner. Therefore, this study was designed with the following objectives.

1.3 Objective

1.3.1. General Objective

To assess the status of soil and water conservation practices and examine its impact on selected soil physicochemical properties and crop yield in the study area.

1.3.2. Specific objectives

1. To assess the status of implemented soil and water conservation measures through mass mobilization and link with slope class and land ownership.
2. To examine the impacts of soil and water conservation measures on soil physicochemical properties.
3. To assess the spatial crop yield variations between consecutive physical soil and water conservation measures.

1.4 Research Questions

1. What is the status of implemented soil and water conservation measures through mass mobilization linked with slope class and land ownership?
2. Does soil and water conservation structures improve soil properties; pH, SOC, TN, Av. P, CEC, and Particle size distribution?
3. Does soil and water conservation practice crop yield in between two consecutive physical soil and water conservation structures?

1.5 Research Hypothesis

2. At least some of the implemented soil and water conservation structures may exist in a good management manner and implemented in accordance with standards.
3. Soil and water conservation measures could improve soil physicochemical properties.
4. Soil and water conservation measures (soil bund) may have a significant impact on maize grain yield.

2. LITERATURE REVIEW

2.1.Importance of Soil and Water Conservation

Since soil erosion is avoided or reduced to a tolerable level, and water is conserved for wise usage, soil and water conservation is important for long-term land productivity (Wubet *et al.*, 2013). According to reports, a significant portion of soil erosion (nearly half of all soil losses) occurs in cultivated fields, which account for just 13% of the country's land area and wash away an average of 42 tons of soil per hectare (Hurni *et al.*, 2007). EFAP (1993) also reported that the highest average soil loss occurred on lands that were once under cultivation but are now unproductive and have less vegetation cover, with an estimated annual loss of 1.9 to 3.5 billion tons of topsoil in Ethiopia's highlands. Because of the large amount of soil loss, the country has been named "one of Africa's and the world's most extreme erosion areas" (Hurni *et al.*, 2007). Due to excessive soil loss and other factors, the average crop yield per unit area was decreased. Since erosion takes away the most fertile part of the soil, namely the chemically active parts including organic matter and clay fractions, erosion is a major problem. It also degrades soil structure and moisture-holding ability by lowering soil depth, raising bulk density, crusting the soil, and reducing water infiltration (Woubet *et al.*, 2013).

As a result, SWC practices are significant, particularly in upland areas, because they can promote the development of a variety of ecosystem services that benefit both upstream and downstream. Physical soil and water management systems can help minimize soil loss by reducing overland water flow and increase yield by reducing moisture stress on plant growth by retaining rainwater that would otherwise be lost to runoff (Wagayehu, 2003). Downstream water quality benefits by reducing runoff and the need for chemical fertilizer inputs (CSA, 2007). It also aids in the conservation of soil's capacity to hold water, nutrients, and organic matter; farmers can substantially reduce agricultural water demand, reduce vulnerability to climate extremes such as drought and flooding, and increase soil carbon storage and productivity (Aylward, 2004). Soil organic matter, total nitrogen (N), usable phosphorus (P), bulk density, infiltration rate, and soil texture can all be dramatically improved with the right SWC practices (Demelash and Karl, 2010).

The steps are intended to intercept and minimize runoff velocity, pond and store runoff, transport runoff at non-erosive velocities, trap sediment and nutrients, encourage natural terrace

formation over time, protect the land from erosion, improve water, improve downstream, prevent flooding, reduce sedimentation, improve land fertility, and provide ecosystem services (Blanco and Lal, 2008). Bunds, check dams, micro-basins, and hillside terraces are among the main mechanical steps. Enclosure of degraded land from human and animal interferences, planting of tree seedlings on farmlands, afforestation, and plantations around homesteads and plantations in exclosures as enrichment to natural regeneration are examples of biological interventions (Mekuria *et al.*, 2011). The initiatives were planned to minimize soil erosion, preserve soil fertility, rehabilitate degraded lands, enhance microclimate, raise agricultural production and productivity, and restore the ecosystem (Vancampenhout *et al.* 2006; Bewket and Teferi, 2009).

2.2.Types of soil and water conservation practice

Soil and Water Conservation Practices (SWCP) are defined as activities at a local level that maintain or enhance the productive capacity of the land in areas affected by, or prone to, degradation (WOCAT, 2007). According to World Overview of Conservation Approaches and Technologies (WOCAT), SWCP is classified as agronomic, vegetative, structural, and /or management measures that prevent and control land degradation and enhance productivity in the field (WOCAT, 2007). Looking at land degradation caused by human activities, SWC technologies can be found everywhere in the world and can be described as good practices in agriculture.

Further, WOCAT distinguishes three stages of intervention: prevention, mitigation, or rehabilitation. The stage of intervention determines the treatment of the degraded land and also, which technology or conservation measures should be used. Prevention implies a treatment or an application of a technology that maintains natural resources and their environmental and productive function on land that may be prone to degradation (WOCAT, 2007). Mitigation means that the land is already degraded this on-going degradation has to be stopped because the impacts of this stage are already noticeable in the short term. The last stage of intervention, rehabilitation, is required when the land is already degraded to such an extent that the original use is no longer possible and the land has become practically unproductive. In this case, long-term and more costly investments are needed to have any impact” (WOCAT, 2007). Furthermore, WOCAT defines three conservation measures as follows:

1. Agronomic measures: such as conservation agriculture, manuring/composting, mixed cropping, mulching, etc. usually associated with annual crops, repeated routinely each season or in a rotational sequence, short duration and not permanent, often not zoned, do not lead to changes in slope profile, and normally independent of slope.
2. Structural measures: such as terraces (Banks, bunds, and other structures)-Often lead to a change in slope profile, long duration or permanent, carried out primarily to control runoff, wind velocity, and erosion, require substantial inputs of labor or money when first installed and can be aligned at a certain gradient.
3. Vegetative measures: such as grass strips, hedge barriers, windbreaks, or agroforestry involve the use of perennial grasses, shrubs, or trees, are of long duration, often lead to a change in slope profile, are often aligned along the contour or against the wind, and are often spaced according to slope.

2.3. Soil and Water Conservation in Ethiopia

Ethiopia has a long tradition of soil and water conservation; which has been used for centuries (Haregeweyn *et al.*, 2015). Farmers have long been aware of the problem of soil erosion and have developed several indigenous soil and water conservation practices that have helped agriculture thrive for centuries. For example, well-developed terracing structures in southern Ethiopia's Konso (FAO, 1990); different conservation practices in the Northern Highlands (Hoben, 1996); ditches in the Northern Shewa; and various techniques in the Eastern Highlands (Kebede *et al.*, 1996). In certain parts of Ethiopia, soil and water conservation activities are considered indigenous knowledge (Schaften, 2012). In Tigray and the Chercher Highlands, terracing was created as part of traditional agriculture. Indigenous SWC activities in Ethiopia are typically poorly recorded and ignored by SWC experts and policymakers (Abebe and Ketema, 2019).

Watershed management methods that incorporate SWC, increased natural resource use, and livelihood goals have been introduced in many micro-watersheds in Ethiopia since the early 1990s (Haregeweyn *et al.*, 2012a). Before the mid-1970s, however, institutionalized SWC activities in Ethiopia were very localized and negligible. The soil erosion issue was brought to the attention of the public, the government, and outside agencies during the 1973/74 drought. It was recognized that soil erosion and other destruction caused by poor land use, a growing

human and animal population, and environmental degradation in general led to the famine disaster to a large extent (Hurni, 1993). SWC became a priority of the Ethiopian government as a result of these facts, and its activities were institutionalized in the Ministry of Agriculture. The 1974 Land Reform Declaration and subsequent formation of the Peasant Associations defined roles and provided a mechanism for mobilizing resources for large-scale conservation projects. The government also worked hard to bring together a variety of international partners to develop and introduce SWC programs. This was the first step in Ethiopia's massive SWC embankment, which began in the mid-1970s, prioritizing mechanical steps and tree planting (Yeshambel, 2013).

2.4.The Status of Soil and Water Conservation Measures in Ethiopia

In every developing world recognizing the Framers 'willingness to use soil and water conservation practices is mandatory. Their willingness is highly dependent on their knowledge of the issue of soil erosion. Having a detailed understanding of both methods aids in the development of more effective techniques. Understanding farmers' perspectives on intervention and conservation practices would encourage other parties to design based on prior information (Geremaw, 2005). Plantation of trees, application of fertilizer, cut of drains, soil (stone) bunds, and fallow, contour plowing, drainage ditch, and leaving crop residues on the field are some of the erosion control methods used in Ethiopia (Trippathi and Singh, 1993; Herweg and Ludi, 1999; Shiferaw, 2005; Booker, 2009; MOA, 2015).

Soil Conservation: The prevention of erosion on cultivated land and other areas depends essentially on the reduction of soil detachment and runoff on the preservation of sufficient vegetation ground cover. Soil protection includes the different approaches used to mitigate soil erosion to avoid loss of soil nutrients and soil moisture and to enrich the nutrient status of the soil. The conservation techniques include terracing and others (Fitsum, 2002). A physical soil conservation practice is applicable to soil management using knowledge or art with the goal of protecting soil resources from exploitation. In addition, among those different applications, different structures are applied in different farm lands. However, these conservation applications depend on climate, soil type, vegetation cover, and level of economy (Shiferaw, 2005).

Water conservation: Water is a scarce resource due to irregular and insufficient rainfall, even though it is a year-round need for humans, animals, and plants (vegetation). Its presence has an effect on the existence and degree of human occupation, grazing patterns, and plant development. The key constraint to agricultural growth is the ever-increasing demand for water and the high cost of water development. Physical water management initiatives are structures that have been constructed to conserve water. This guards against damage caused by excessive runoff (Hurni, 1987).

2.4.1. Management and maintenance status of implemented structures

The physical SWC structures built in the area (on both private and public land) were suitable for the catchment. On the other hand, the applied system of private property has very little management and maintenance (Desta *et al.*, 2005). According to Wolancho (2015), the lack of regular maintenance is a challenge for SWC's campaign work in southern Ethiopia. In comparison to private ownership, public land has a very high level of structure management. The key informants reported that the structures on public land were subjected to regular maintenance through public engagement as part of an annual national campaign program. In contrast, the responsibility for preserving buildings on private property was the owner's mandate, and they were less involved in its upkeep.

2.4.2. Current status of soil and water conservation measures

Physical SWC systems have benefited productivity and ecosystem services, according to various studies conducted in low-potential areas (Kato *et al.* 2011; Lanckriet *et al.* 2014; Wolka and Negash 2014). They recognized that soil erosion damages cultivated and grazing lands, affecting crop yield and livestock production, much like farmers in low-potential areas. According to Kaspar *et al.* (2015), Ethiopia's annual soil loss rate is around 852.8 million Mg ha¹ y¹ across all land use types. As a result, the land is now deteriorated and is only suitable for some crop varieties, which was not the case a few years ago. Several studies found that by implementing SWC systems, average crop yields increased by 25% on sites in Ethiopia's northern low-potential areas (Nyssen *et al.* 2015; Mekonen and Tesfahunegn, 2011). Farmers' acceptance (or rejection) of SWC systems is conditioned by their perceptions of soil erosion and its effects (Alufah *et al.*, 2012). Farmers, on the other hand, are more concerned with

immediate benefits than with the long-term benefits of SWC systems. Similarly, Bezuayehu and Sterk (2010) and Amdihun *et al.* (2014) found that many high-potential area farmers are unable to adopt SWC initiatives unless they receive immediate financial benefits. Physical SWC structures increased land productivity after seven years in high-potential areas (Schmidt and Tadesse, 2012), but Bezuayehu and Sterk (2010) argued that physical SWC structures had no substantial effect on land productivity in high-potential areas. Physical SWC structures, on the other hand, can minimize soil erosion, hold soil in place, increase soil fertility and crop yield, and control and sustain stream and river flow in the long run. Hurni *et al.* (2005) discovered a connection between the use of SWC structures upstream and improved river flow downstream. The implementation of SWC steps was found to be influenced by knowledge of the various uses of SWC structures.

2.5.Impact of Soil and Water Conservation on Soil Properties

Soil is an extremely valuable natural resource. As a result, successful management is crucial for economic growth and development, as well as the production of food, fiber, and other necessities. Continuously cultivating the same land without proper and adequate nutrient management would most likely result in soil depletion (Wolka *et al.*, 2013). The aim of soil and water conservation is to get the most out of a given piece of land while keeping soil loss below a critical level and safeguarding the life-supporting ability of soils including soil quality, depth, structure, water holding capacity, and productivity. Soil bunds, for example, are used to manage runoff and erosion from crop fields by decreasing the slope length of the field, which decreases and prevents runoff velocity (Addisu, 2011). Bunds change the landscape by reducing the slope angle and volume.

Soil and water management practice increases soil properties by reducing runoff velocity since erosion washes soil down the slope in the absence of soil and water conservation. Soil erosion reduces base saturation and soil organic carbon (SOC) content, decreasing soil pH as a result. The abundance of phosphorus is influenced by the pH of the soil, which is poor for non-conserved agricultural land (Amare *et al.* 2013; Bekele *et al.* 2016). Soil physicochemical properties differed greatly in croplands with soil and water management practices (Bekele *et al.* 2016; Ademe *et al.* 2017; Alemayehu and Fisseha, 2018). According to Ademe *et al.* (2017),

soil and water conservation increases soil properties on conserved cropland (pH, K⁺, available P, SOC, TN, CEC, and clay content) compared to adjacent cropland that does not have soil and water conservation measures (pH, K⁺, available P, SOC, TN, CEC, and clay content). This demonstrates the beneficial effects of soil and water management activities on cropland nutrient status. As a consequence, altering soil erosion and deposition processes, has an effect on soil resources. As a result, the introduction of various SWC steps resulted in major differences in soil properties.

2.5.1. Soil physical properties

Soil Texture and Bulk Density

The particle size distribution of the soil affects the movement and availability of soil moisture, aeration, nutrient availability, and the soil's resistance to root penetration (FAO, 2000). It also has an effect on the physical properties of the soil that control aggregate stability and susceptibility to degradation. From upper to lower landscape locations, the sand content of cultivated farm plots decreased, while the clay content showed an increasing trend as the slope gradient decreased. Bogale *et al.*, (2021) also observed a significant difference in clay content at $p < 0.05$ with the highest fractions of (49.770% and 53.611%) at gentle slope and bottom spot of terrace position, respectively. Whereas, the highest fraction of sand content (32.278% and 34.639%) was recorded at the steep slope and upper terrace positions, respectively. The implementation of SWC measures affects soil bulk density, the relatively lower bulk density associated with treatments conserved with various measures could be attributed to the presence of significantly higher organic matter content in those treatments (Teramaj, 2015).

Management activities that affect soil cover, organic matter, soil structure, compaction, and porosity may also affect bulk density (Tadele *et al.*, 2011). The accumulation zone of the terraced watershed had higher concentrations of divalent basic cations than the loss zone, which may be attributed to the washing away of cations from the loss zone and accumulations in the deposition zone (Tadele, 2013). According to Aşkin and Zdemir (2010) and Chaudhari *et al.* (2013), sand content has a greater impact on soil bulk density than other soil properties. Demelash and Karl (2010); Bezabin *et al.*, (2016); Challa *et al.*, (2016); Dulo *et al.*, (2017) found that the mean value of bulk density in conserved areas with SWC practice was lower than

that in un-conserved areas, owing to the decomposition of plant biomasses on the conserved field increasing organic matter contents, lowering soil bulk density. In Ethiopia, Alemayehu and Fisseha, (2018) discovered that untreated farmland has a higher bulk density than conserved farmland. SWC can collect soil organic matter and change soil properties such as bulk density, and this innovation is consistent with the current study (Amare *et al.*, 2013); Low bulk density was observed for conserved croplands than non-conserved ones (Haweni, 2015).

2.5.2. Soil chemical properties

Soil organic matter and soil organic carbon

Soil erosion has an impact on soil productivity; most likely caused by deterioration in soil physical properties. In an eroded landscape the physical and chemical properties of the soils are changed (Arriaga and Lowery, 2003). SWC reduces the removal of fertile topsoil and improves soil moisture that favors crop growth; hence, increases crop residue input, which builds up soil organic carbon stock and plant nutrients on conserved cropland. SOM improves soil aggregate, which influences the total porosity of the soil and negatively affects soil bulk density (Amare *et al.* 2013; Bekele *et al.* 2016; Oldfield *et al.* 2018). SWC structures' primary functions are to substantially minimize soil loss and its effects. Many studies have suggested that SWC practices can help improve agricultural productivity. Grass strips, bench terraces, and fanya juu, according to Tenge *et al.* (2004), decreased soil loss by 40, 76, and 88 percent, respectively, as compared to land without those structures. According to FAO (1987), soil organic carbon (SOC), total nitrogen (NT), and usable phosphorus (P) were found to be significantly different at $p = 0.05$ between conserved and non-conserved watersheds.

Soil pH (Soil Reaction)

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. Soil reaction affects nutrient availability and toxicity, microbial activity, and root growth. The difference in the degree of soil loss between cropland treated with conservation measures and those simply cultivated without any means of protection at least to hold the soil in place can explain the relatively higher mean pH on soil bunds than the control (non-conserved plot) (Bezabih, 2015). The maximum pH values of 6.27 and 5.65 on bottom and upper landscape positions in

farmlands with SWC measures, respectively (Ademe *et al.*, 2017). Etana, (2020) also found the higher mean pH value (5) from the plots conserved by level soil bund and the lower mean (4) was from the plots non-conserved. Bekele *et al.* (2016) also confirmed that pH values were lower in steep slopes and higher in gentle slopes because high rainfall combined with steeper slopes could have increased leaching, soil erosion, and a reduction in soluble base cations, resulting in higher H⁺ activity.

Total Nitrogen (TN)

Nitrogen has a significant impact on soil fertility and is necessary for increasing output. Total nitrogen showed a rising tendency from a fairly steep slope to a gently sloping location, according to Aytenew (2015), which could be attributable to their downhill movement with runoff water from a higher slope position and accumulation at the lower slope position. The removal of organic matter from moderately steep slopes as a result of soil erosion and leaching to the down slope caused TN to vary significantly with slope position, with TN being higher in the lower slope position than in the higher slope position (Challa *et al.*, 2016). The C: N ratio was less than 16.6 for all of the soils in the study area, indicating that the mineralization process of soil organic matter might release accessible forms of N to the soil system, allowing for crop growth (Terefe and Lemma, 2016).

Available Phosphorous (Av-P)

Phosphorus in the soil is one of the most significant elements for energy transformation in agricultural output. Because soil organic matter may contribute to the existence of available P in the soil system, the variation in accessible P content among slope positions is paralleled with that of organic matter content (Aytenew, 2015). Due to the lower availability of organic matter content in the area, Hailu *et al.*, (2012) found that accessible phosphorous did not alter significantly with slope position. Wolka *et al.*, (2011), on the other hand, found that available P was variable due to differences in previous land degradation caused by continuous farming, extractive plant harvest, and soil erosion.

Cation Exchange Capacity (CEC)

CEC is a measurement of the magnitude of the negative charge per unit weight of soil, or the amount of exchangeable cations that a certain sample of soil can carry. In soils, cation exchange is a key process for maintaining and delivering plant nutrients, as well as adsorbing pollutants. According to Selassie *et al.* (2015), the presence of CEC varies depending on the slope location due to differences in clay and organic matter content of the soil. Clay and organic matter content adds to the existence of CEC. In addition, Challa *et al.* (2016) found that SWC methods increased soil CEC with a decrease in slope position in agriculture. The CEC was particularly high in the gently sloping area, which could be attributable to the clay's high specific surface area and organic matter content (Aytnew, 2015).

2.6. Impact of Soil and Water Conservation Measures on Crop Yield

Land degradation in the form of soil erosion has significant negative consequences on sustainable development through its on-site and off-site impact. In Ethiopia, one of the major causes of the downfall of many flourishing empires, including the ancient Axumite Kingdom, civilizations of Lalibela in the 14th century, and Gondar in the 17th century was land degradation. Consequently, SWC measures are implemented with functional principles of controlling erosion, improving infiltration, and maintaining or improving soil fertility thereby increasing yield (Young, 1989). Investments in SWC contribute to the intensification of the agricultural system which enhances food production and alleviates poverty. Terrace technologies control soil erosion by reducing the slope of the cultivated land and this facilitates the conservation of moisture for crop use, which leads to increased crop yields (Adgo and Teshome, 2010). Implementing SWC measures had a positive impact on grain and biomass yield and an increment of more than 25 percent for grain and 30 percent for biomass yields (Mekonen and Tesfahunegn, 2011). Wubet *et al.* (2013), also confirmed that SWC measures improved land suitability that further improves the yield of major crops.

Conservation measures can reduce yield variability in at least two ways. First, conservation can improve moisture retention during low-rainfall periods and thereby reduce moisture stress and enhance plant growth. Second, conservation technology can mitigate the consequences of flooding and thus can reduce associated crop damage and topsoil loss during high rainfall periods (Wolka *et al.*, 2013)., Guadie *et al.* (2020) found that the field treated by soil bunds and stone-faced soil bunds has a 34 percent grain yield advantage over untreated fields. Soil bunds

of different ages were able to improve soil properties that affect crop yield on conserved farmland. The croplands with soil bunds had improved the crop yield from 0.584 to 0.65 t ha⁻¹ which compensates for the financial cost expenses of building bunds (Nyssen *et al.*, 2007). Similarly, Abay (2011) reported that yield was increased by 22 % on some farms and 15-fold on other farms within one year of bund/fanyajuu construction and by >50 % after 3 years with similar farming practices. The average yield obtained from the accumulation zone had increased crop grain yield by 29.8 percent as compared to the loss zone; this might be due to the accumulation of soil organic matter and fertile topsoil above the bunds in the deposition zone of the bund (Gebreselassie *et al.*, 2009). Therefore, this implies that soil bunds reduce runoff velocity and hence soil erosion, and the practice maintains the productive capacity of the soil. In opposition, the finding of Kassie and Holden (2005) showed that physical conservation measures resulted in lower yield in a high-rainfall area of Ethiopian highlands, compared to plots without conservation measures.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted in Omo Nada district, Jimma Zone, Southwest Ethiopia. The district is located about 72 km away from Jimma town, and 294 km Southwest of Addis Ababa. Its location lies between $7^{\circ} 36' 00.87''$ - $7^{\circ} 41' 05.72''$ N latitude and $37^{\circ} 16' 55.88''$ - $37^{\circ} 14' 40.73''$ E longitude. The District is bordered by Omo Beyam district to the South, by Mancho and Dedo to the West, by Kersa to the North West, Tiro Afeta to the North, by Sokoru to the North East, and by the Omo River to the East which separates it from the SNNP (Figure 1).

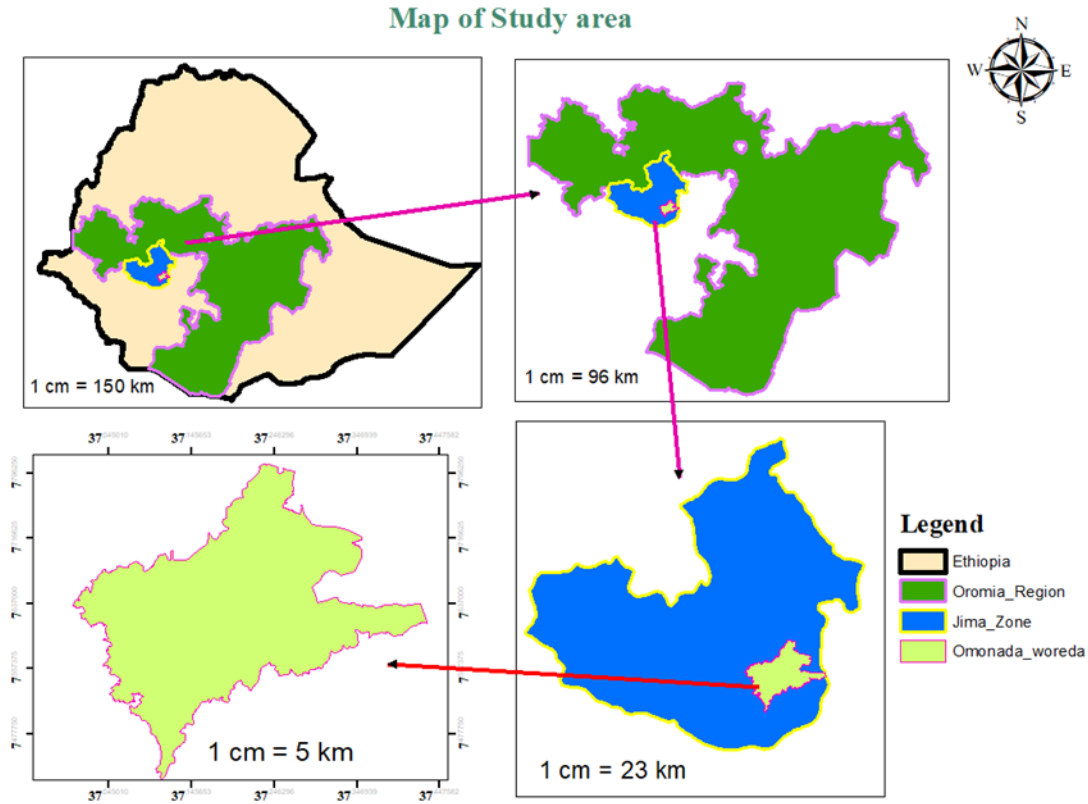


Figure 1: Location map of the study area

3.1.2. Topography

The topography of Omo Nada District is characterized by gentle, flat, and undulating topography (Alemayehu *et al.*, 2014). The upper part of the district is mostly a gentle slope.

The lower part is plain or flat and the drainage from the area typically flows into Gilgel Gibe Dam I. The altitude of the district ranges from 1017–2952 m a.s.l. The slope class categories and definitions of the district were made following the FAO guideline for soil profile description (FAO, 2006). The proportion of land with flat to gently sloping topography (0-2%) covers 4.85%, Gently sloping (2-5%) is 16.97%, sloping (5-10%) is 28.04%, strongly sloping (10-15%) is 19.01%, moderately steep (15-30) is 25.69% and steep slope (>30%) covers 5.44% of the land (Alemayehu *et al.*, 2014).

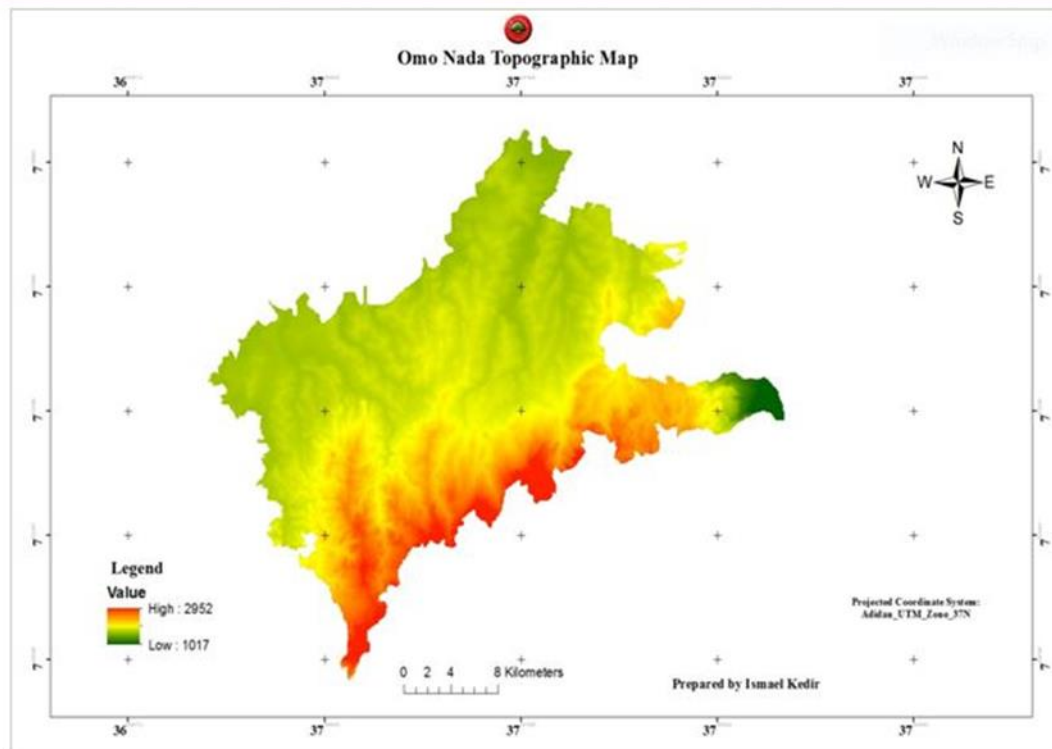


Figure 2: Topography of the study area (Source: ONDANRO, 2022)

3.1.3. Climate of the study area

The agro climate of the district covers 15% *Dega* (highland: > 2000 m a.s.l), 75% *Woina Dega* (midland: 1500–2000 m a.s.l), and 10% *Kola* (lowland: < 1500 m a.s.l.) area. The climatic condition is mostly wet *Woina Dega*, the mean annual rainfall ranging between 1280–1600 mm and the annual temperature varies within the range of a maximum of 25-30 °C and minimum of 12.4-15 °C (ONDANRO, 2022). According to SLMP (2010), the rainfall pattern in the study area is bimodal, with unpredictable short rains from March to April and the main season ranging

from June to September. The minimum and maximum annual rainfall ranges from 1066 to 1200mm with a mean annual temperature ranging from 18 to 25 °C.

3.1.4. Soil type

Soils of the study area are dominated by Dystric Fluvisols followed by Cromic Vertisols and Dystric Nitosols, some Orthic Acrisols, and Eutric Fluvisols (Alemayehu *et al.*, 2014). According to Van Rants' *et al.* (2010), the major reference soil groups in the Gilgel Gibe catchment are Nitosols, Acrisols, Ferralsols, Vertisols, and Planosols. All these soils have a significant level of clay and are dark reddish brown color (SLMP, 2010).

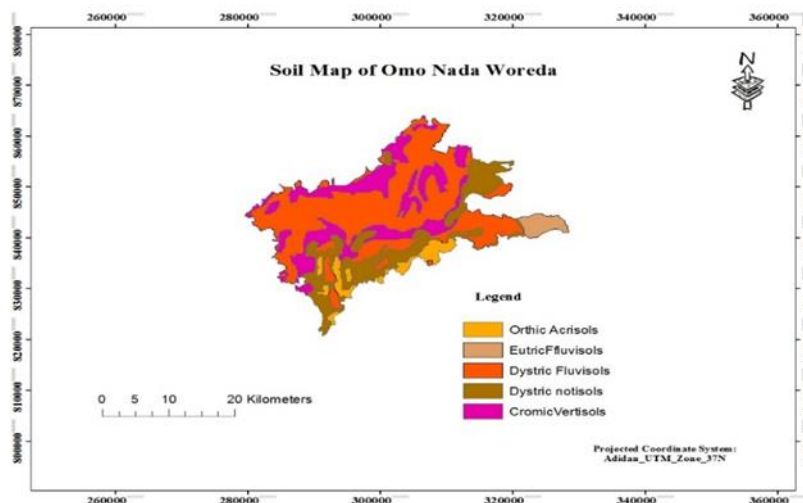


Figure 3: Soil classification map of the study area (Source: ONDANRO, 2022)

3.1.5. Land use and farming system of the study area

Types of land use change from time to time depending on socio-economic change. For instance, the grazing land, natural forest, and fallow lands are decreasing from time to time while cultivated and residential lands are increasing (ONDANRO, 2022). Accordingly, from the total area of the district 80,508.66 ha of land, the cultivated land (covered by annual and perennial crops) accounts for about 45,430.76 ha, the vegetation-covered land (forest, woodland, bush, and shrub) accounts for about 4,747.19 ha, and grazing land accounts about 17,743 ha,

construction 4,638.428 ha, and the land which is unusable for cultivation is 1,150.18 ha, as well other lands accounts about 6,799.09 ha. Of the total land coverage Cereal (86.7%), pulses (12.5%), and oil seeds occupy (0.8%) of the total cultivated land 43,997.43 hectares, and maize covers 63.3% of total cultivated land (ONDANRO, 2022).

Agriculture is the main economic source and a basis for the livelihood of the community in the study area. Major crops growing in the district are Maize (*Zea mays*), Teff (*Eragrostis tef*), Sorghum (*Sorghum bicolor*), Wheat (*Triticum vulgare*), Barley (*Hordeum vulgare*), and other pulse crops. The farming system is generally characterized by mixed subsistence farming, which includes crop production, livestock breeding, and, in some areas, cash crop production such as pepper. The study area has a large potential for crop production despite low rainfall, high crop diversification to cope with adverse weather, high-level utilization of modern agricultural packages (extension) such as improved seeds, fertilizers, and other related inputs, and high opportunities for off-farm employment. The majority of the land is flat or gently sloping, making it ideal for mechanization. There are some small-scale irrigation practices near the Nada, Beyam, Qawa, and Dima rivers using motor pumps, as well as Lake Gibe (Dam-I) for hydropower and fishing (ONDANRO, 2022).

3.1.6. Population

According to CSA (2010) report, the total population of the district is 198,618 which is an aggregate of 99,508 male and 99,110 female populations. The total number of households in the district is 22,681 which is an aggregate of 21,451 male and 1,230 female. From the total population, the numbers of the population living in rural areas and urban centers were 175,321 and 23,297 respectively. The average numbers of household size is 5.0 for the District.

3.2. Study Design

3.2.1. Site selection

To assess the status of physical soil and water conservation measures and examine its impact on some selected soil properties and crop yield Jogo, Kakali, and Yabeto watersheds which are located in Nada Chala, Chaleleka Donga and Lelisa Bula kebeles of Omo Nada District respectively, were selected purposively because of SWC structures with different ages and

slope classes are more available in these kebeles. The selection of these three watersheds was carried out in consultation with the District Watershed experts and the agriculture and natural resource office. These watersheds provide us an opportunity to find out the status of implemented physical SWC measures and to examine their impact on soil properties and variation of crop yield in the study area.

3.3.Methods of Data Collection

3.3.1. Field observation and measurement of the status of implemented SWC structures

Direct field observations and measurements of physical soil and water conservation structures implemented via mass-community mobilization that was used to assess the status of conservation practices in the study area such as soil bunds embankment height, embankment top width, embankment bottom width, ditch depth, ditch width and space between bunds were carried out using tape meter, water level, string (rope) and graduated poles. These field observations and measurements were conducted in nine fields in the three slope classes (three in upper slope, three in middle slope, and three in lower slope classes) to understand the realistic situation that exists in the watershed using a checklist and camera. During this field observation, additional information such as the trend, problems encountered after implementing soil and water conservation practices, and changed physical features such as how many broken/destroyed under different slope classes, different land ownership (communal and private), and how many (what percentage) maintained/repaired and stabilized by biological SWC were assessed.



Figure 4: Field measurement

3.3.2. Soil sample collection

To examine the impacts of soil and water conservation measures on selected soil physico-chemical properties soil samples were collected from the selected croplands with soil bunds found in different slope classes. Three inter-structural spaces between two successive structures were used as treatments in order to study their impact on selected soil properties and crop yield. The soil samples were collected at 0-20 cm depth (Laekemariam *et al.* 2016) for determination

of soil properties. The first soil sample was taken at 1.5 m distance from the upper bund structure (erosional area), whereas the third soil sample was also taken at 1.5 m distance away from the top of the bund structure (depositional area), following (Vancampenhout *et al.*, 2006 and Bogale *et al.*, 2020), and the second soil samples were collected at equidistance (at the center) between two successive structures. The collected samples were used to make a representative sample. In total 27 composite soil samples were collected from the three slope classes (3 slopes * 3 treatments (3 bund zones or sampling distance) * 3 replications).

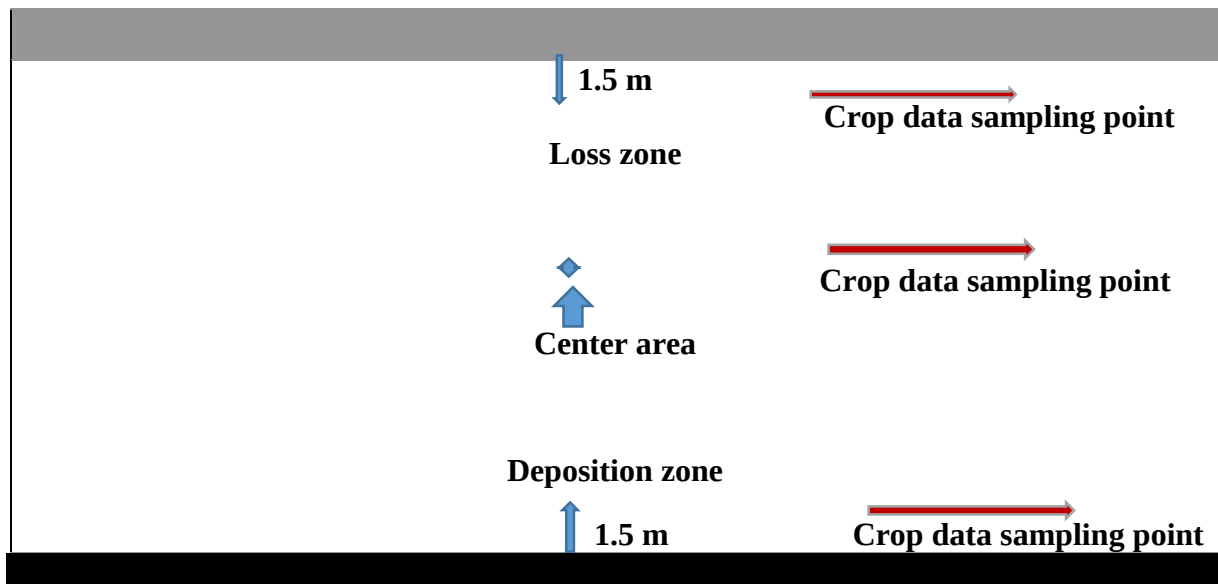


Figure 5: Soil and crop data sampling field between two successive bunds

3.3.3. Crop data collection

Croplands treated with physical soil and water conservation structures and established under different slope classes were selected to study spatial crop yield variations between two successive soil bunds, following the same procedures as soil sampling. Maize (*Zea mays*) was taken as a test crop since it is the dominant crop grown in the study area. Samples of grain yields were taken below the side of the erosion area (soil loss zone), middle zone (center), and on top side (deposition zone) between two successive soil bunds during harvesting time of the farmers by making transect walks from the upper to the lower part of the treated watersheds. A quadrant of one-meter square (1m * 1m) was used to take a sample. A total of 9 representative maize yield samples were collected from the three slope classes of the study area. Grain yield was measured in kilograms (kg) after threshing the seed yield from each cropland and then

converted to quintal per hectare per year. Sample plots in between the structures (middle zones) were used as a control.

3.3.4. Socioeconomic data collection

Socioeconomic data used to assess the status of implemented physical SWC measures in the study area were gathered from both primary and secondary sources. Both are intended to answer research questions about the current state of implemented SWC structures since 2012; demographic and socioeconomic data such as age, educational level, family and farm size, livestock ownership of respondents, and so on were collected. To supplement the primary data, the district agricultural office provided secondary data such as population and land use. Random sampling methods were used to select a representative household. From the 340 target population, 184 representative household heads were chosen at random. The household sample size is calculated using the simplified formula provided by (Yamane, 1967). Accordingly, the required sample size of the estimated result is at a 95% confidence level with a degree of variability of 0.5% and a Margin of error (Moe) 0.05% was used to obtain a sample size required which represents a true population:

$$n = \frac{N}{1 + N(e^2)} \quad \text{Where: } n = \text{is Sample size to be taken for the study}$$

N = is the total number of household heads e = is the desired margin of error

$$n = \frac{340}{1 + 340(0.05)} = 184$$

Table 1: Sampling frame work of study site and respondent households

Number	Kebele	Total number of target population	Respondent selected
1	Nada Chala	106	58
2	Chaleleka Donga	148	80
3	Lelisa Bula	86	46
Total		340	184

Source: Primary data, 2022

3.3.4.1. Focus group discussion (FGD)

Focus group discussion was used as an instrument to collect qualitative data in the study. For the FGD, a discussion of three groups, which contain a small group of six (6) members in each kebele three times ($6 * 3$) has participated based on socially respected and have better knowledge on the present and past environmental, social, economic, and status of SWC measures of the study area. FGD has focused on the opinions of farmers on the status of implemented SWC practices and their effects on soil productivity and crop yields. The data generated through FGDs were properly noted and transcribed using a template prepared for this purpose. The FGDs were also supported by written questions that were administered to each member on the beneficiaries of the practice related to the status of implemented SWC practices.

3.3.4.2.Key informants' interview (KII)

The informants, mainly the elders and experienced individuals on SWC measures were purposively selected and in-depth interview was conducted on the impact of PSWCP on soil properties and crop production. Accordingly, the interview was conducted with 3 kebele leaders, 3 DA (Development Agents), 3 Natural Resource experts of the district, 3 kebele managers, and 3 elders from each sampled kebeles to get a deeper understanding of the status of implemented SWC measures that have been practiced and their effects on soil productivity and crop production along with identifying farmer preference of conservation measures in the area. In total, 15 KII ($5 * 3$, a small group of five (5) members in each kebele) three times were conducted for this study. The KII were guided using a checklist prepared for this purpose, which include issues that need further explanation that can't covered through surveys and FGDs. The KII questionnaires were prepared according to their capacity to explain and understand more detail to explore more knowledge.

3.4.Soil Laboratory Analysis

The collected soil samples were transported to the Jimma University College of Agriculture and Veterinary Medicine soil analysis laboratory for determination of the physical and chemical properties. These samples were air dried, crushed with mortar and pestle, mixed well, and passed through a 2 mm sieve for the following physico-chemical analysis; organic matter content, total nitrogen, available phosphorous, soil pH, and CEC. Organic carbon content was determined by the wet oxidation method (Walkley, 1947). The determination of soil particle

size proportions was carried out by the hydrometer method described in Sakar and Haldar (2005). Following this, the determination of soil texture and textural classification were identified using an equilateral triangle suggested by the United States Department of Agriculture (USDA) (Osman, 2013). For bulk density determination, undisturbed soil samples were collected using a core sampler. The mass of the solids and water content of the core was measured by weighing the wet core and drying it to constant weight in an oven at 105°C for 24 hours (FAO, 2007). Soil pH was measured using the glass electrode method within a supernatant suspension of a 1:2.5 (soil: water on a mass-to-volume basis). The pH meter was calibrated with buffer solutions of pH 4 and 7. After 30 minutes of stirring, the pH was measured in the suspension by using a standard pH meter. Soil OC was determined by Walkley and Black's (1934) wet digestion method. TN was determined using the Kjeldahl digestion procedure (Bremner, 1996). Soil Av. P was analyzed using 0.5M sodium bicarbonate extraction solution of Bray method (Van Reeuwijk, 1993).

3.5.Data Analysis

The study included both qualitative and quantitative research methods. The collected data were analyzed by using Statistical Package for Social Science (SPSS) version 20.0. The presence of significant differences in soil physicochemical properties at different slope positions and soil bund zones due to SWC measures was tested by two-way ANOVA. The significance of differences between means of soil properties along slope classes and crop yields under conservation measures were used to determine SWC measures with sufficient evidence by using the LSD comparison method at a 0.05 significance level. P-values <0.05 were considered statistically significant. A household survey was analyzed using descriptive statistics. In addition, the Pearson correlation coefficient analysis was applied to determine the relationship between some soil parameters.

4. RESULTS AND DISCUSSION

4.1. Demographic and Socio-economic Characteristics of Respondents

4.1.1. Age, sex, and educational status

The majority of the sampled households 91.3% were male-headed households, while 8.7% of respondents were female-headed households (Table 2). The dominance of male respondents revealed that they were leading in the involvement of SWC practices. According to this result, most of the participants of soil and water conservation practices in the area were male-headed and there was no variation among the three study watersheds; this implies that the majority of females have little role in understanding the status of soil and water conservation practices. The result of this study is in line with Kibemo (2011) who stated that the majority of the people who participated in SWC practices were male-headed in Soro district, southern Ethiopia.

The average age of sampled respondents from the three watersheds was 41.40 with a minimum age of 25 and a maximum age of 68 (Table 2). Most of the household heads (86.4%) were in the age ranges of 31-45 (48.4%) and 46-65 (38.0%) years. Farmers in these age groups are expected to have a good understanding of soil erosion problems due to their access to information about soil and water conservation practices. Moreover, this group of people is an effective labor force to implement soil and water conservation practices. The other age groups that constitute 10.9% of the respondents are found in the age ranges of less than 30 years. The results of this study are in agreement with the findings of Assefa (2009) who reported that most of the farmers between the ages of 20-64 years contributed to soil and water conservation practices. The proportion of elderly farmers above the age of 65 (2.7%) years was lower in percentage, as old age affects their involvement in soil and water conservation practices due to their lack of ability in terms of labor. Kibemo (2011) also confirmed that aged farmers did not practice structural soil conservation in their fields. The majority of the interviewed household heads across the three watersheds were literate (51.1%). The maximum grade was 10 completed and the minimum grade was 1. Out of the 184 household heads questioned, about 48.9% were not able to read and write, 48.4% attended elementary school 1 up to 8 grade and the remaining 2.7% attended secondary school 9 up to 10 grade (Table 2). Better educated households have a more accurate perception of the soil erosion problem and more knowledge related to SWC and

can easily get involved in conservation activity. This suggestion is supported by (Fikiru, 2009) who reported that education enables farmers to use SWC measures in various ways of soil fertility improving practices.

Table 2: Sex, age, and educational status of respondents

Age			Education			Sex		
Category	F	P (%)	Category	F	P (%)	Category	F	P (%)
18-30	20	10.9	Illiterate	85	46.2	Male	168	91.3
31-45	89	48.4	1-8	96	51.1	Female	16	8.7
46-65	70	38.0	9-12	5	2.7			
Above 65	5	2.7						
Total	184	100.0		184	100.0		184	100.0

Where: F=Frequency, P=Percent

4.1.2. Family and land holding size, and land by slope category

The average family size of the sampled household heads was 5.89 with the largest family size 13 and the smallest 3 (Table 3). As indicated in Table 3 about 8.7%, 53.3%, 30.4% and 7.6% of the household heads had 1-3, 4-6, 7-10, and >10 family members, respectively. Accordingly, the majority of household heads (53.3%) who participated in the survey had 4-6 family members. This implies that a large number of family members have positive impacts on the implementation of SWC practices. The result of this study was comparable with the results of Atsbaha and Reddy (2014) who reported an average family size of 5.88 in Tigray, Ethiopia. Similarly, Kibemo (2011) and Ayalew (2014) reported that household heads with large family members have positive influences on practicing soil and water conservation measures. This means household heads with high working capacity may positively associate with soil and water conservation practices.

Concerning landholding size, almost all of the sampled farmers in the study area have their own land which ranged from 0.25 to 5 ha with an average of about 2.35 ha. From the sampled household heads 58.1% hold 1 to 2 ha of land, 17.4% of the respondents had 2.1 to 3 ha, 9.8%

owned less than 1 ha of land, 8.7% of the respondents owned 3.1 to 4 and only 6% of the respondents were owned greater than 4 ha of land (Table 3). Most of the agricultural land in the study area has been subdivided into small land plots. According to the Key informants and Focus group discussion, the farmers who hold large size of farmlands are positive towards soil and water conservation measures while those who hold small size of farms have negative approaches towards structural soil conservation measures because they have the perception that conservation structure consumes more land from crop production. Likewise, the study conducted in the Ethiopian highland watershed, indicated that farmers who have a larger farm are more likely to invest in soil conservation measures because they have the capital to do so (Amsalu and Graaff, 2007).

Based on the FAO (2006) slope classification topography of the study area is classified as gentle (3-8%), moderate (8-15%), and steep (15-30) categories. Out of the whole plots of sampled household heads about 14.7%, 30.4%, and 54.9% are gentle, moderate, and steep sloping, respectively (Table 3). The results of this study indicated that a farmer who operates a field with a steeper slope is more likely to accept the SWC measures. Focus group discussions also presented as the majority of the farmers have been cultivating erosion-prone areas. Key informant interviews also confirmed that farmers living on steep slopes are involved more in the continued use of SWC measures than those who own flats or gently sloping farmlands. The result of this study is in line with Birhanu and Meseret (2013) who reported that the slope position of a cropland encourages the implementation of soil conservation practices due to the steep slope being more vulnerable to soil erosion. Their results indicate that a farmer who had cropland with steep slopes was more used to implementing conservation measures. Similarly, Gebre and Weldemariam (2013) reported that the farmers who had cropland with steep slopes needed to perform more soil conservation activities than gently sloping.

Table 3: Family and land holding size, and land by slope category of respondents

Family			Land			Land by		
number			size (ha)			slope(ha)		
Category	F	P (%)	Category	F	P (%)	Category	F	P (%)
1-3	16	8.7	< 1	18	9.8	Flat	27	14.7

4-6	98	53.3	1-2	107	58.1	Gentle	56	30.4
7-10	56	30.4	2.1-3	32	17.4	Steep	101	54.9
>10	14	7.6	3.1-4	16	8.7			
			> 4	11	6.0			
Total	184	100.0		184	100.0		184	100.0

Where: F=Frequency, P=Percent

4.1.3. Livestock ownership of respondents

Farmers in the study area follow mixed agriculture in which livestock production is an important component. In general livestock ownership is one of the major assets of the households in the study area. Particularly, oxen serve as a source of labor for plowing while sheep and goats are very important sources of cash and food, and Equine is used for draft and transport (Table 4). The average livestock of sampled respondents from the three watersheds was 8.51 with a minimum of 1, and a maximum of 37 (Table 4). The composition of livestock was cattle accounted for 57.5%; sheep and goats 34% and Equine (horses, mules, and donkeys) 8.5% of the total. The majority of farmers stated that livestock contributed to the soil erosion process. This is due to the livestock in the area being challenged for removing physical conservation structures. This is mainly due to free grazing on farm plots after crop harvest. Woldeamlak (2003) and Belayneh (2005), found that an increase in livestock resulted in land degradation and thereby negatively impacted SWC because of overgrazing of land, destroying conservation structures. Shimeles (2012), also showed that the high livestock number has led to overgrazing.

Table 4: Livestock holding of households across the three watersheds

Types of livestock	Watersheds			Overall mean
	Kakali	Jogo	Yabeto	
Cattle	284	389	223	298.67
Sheep and Goat	229	178	130	179
Equine	59	42	33	44.67
Total	572	609	386	1,567

4.2. Present Status of Implemented SWC Practices in the Study Area

4.2.1. Present status, maintenance, and reasons for the destruction of SWC structures

Soil and water conservation measures have to be regularly maintained for their sustainable benefits. The result of this study indicated that there was no effective maintenance of the implemented SWC practice for its sustainability in the study area. Field observation during the transect walk also showed that there was no regular maintenance of conservation measures since implementation. The majority of respondents (75%) agreed that there was no maintenance activity once the structures were constructed; while (25%) agreed that there was maintenance of SWC structures after it was constructed (Table 5). The results of this current study were in line with Gizaw *et al.*, (2019) who reported that about 26.6, 21.1, and 12.2% of implemented conservation structures maintained from Sekoru, Manna, and Gomma districts respectively, in Jimma Zone, South-Western Ethiopia. In contrast, Meshesha and Fisseha (2018) reported the majority of the respondents (56.57%) maintained SWC structures at Akusti Micro Watershed, Northwest Ethiopia. As discussed above, the majority of respondents (94.0%) responded that the decreasing rate of soil erosion after SWC structures were done in the study area. On the contrary, they responded that the present status of implemented structures was partially removed (76.6%), while 7.1% of them replied that the structures were modified (adapted); whereas 7.6% and 8.7% replied that totally removed and not removed respectively. Farmer's response for the reasons for the destruction of structural SWC measures from their own farmland and communal land are lack of maintenance (39.6%) and free grazing (22.4%) followed by the need to benefit more lands (21.2%), not properly stabilized by biological measures (10.3%) and due to design problem (6.5%) (Table 5). Focus group discussion and Key informants confirmed that the major causes for the destruction of structural SWC practices were lack of maintenance, free grazing on communal land, and the need to benefit more land of private land. For these reasons, different structural soil and water conservation measures like soil bunds, fanya-juu, cut-off drains, etc.; were not practiced equally over all parts of the study area.

Table 5: Present status and Reason for the destruction of SWC structure

Present status of SWC			Reason for the destruction of bund			Maintenance status		
Category	F	P (%)	Category	F	P (%)	Category	F	P (%)
Totally removed	14	7.6	Lack maintenance	39	39.6	Yes	46	25
Partially removed	141	76.6	Design problem	12	6.5	No	138	75
No removed	16	8.7	Not properly stabilized	19	10.3			
Modified/adapted	13	7.1	To benefit more land	60	21.2			
			Free grazing	54	22.4			
Total	184	100.0		184	100.0		184	100.0

Where: F=Frequency, P=Percent

4.2.2. Farmers' perception of soil erosion and soil and water conservation practice

4.2.2.1. Erosion problem and trend

The survey result of this study indicated that the majority of the respondents in the sampled watersheds perceived soil erosion problems in their farmland (Table 6). Accordingly, about 95.7% of the farmers perceived the soil erosion problems in their farmland, while only 4.3% of farmers did not understand soil erosion problems in their farmland. Woldeamlak (2003) and Bewket (2007), also reported 98% and 98.4% of the surveyed farmers recognized that soil erosion was a problem in their farmlands respectively, in the northwestern highlands of Ethiopia. The result of this study was similar to Meshesha and Tripathi (2016) who reported similar results for farmer's perception of soil erosion and land degradation problems in the Beressa Watershed of Ethiopia. Soil erosion was a severe problem in the study areas, especially in croplands at upper and middle slope positions. Focus group discussions (FGD) also mentioned that even if the degree of erosion differs from cropland to cropland due to management practices and slope category they agreed on the occurrence of soil erosion on their farmlands.

Farmers were also asked to compare the problem of soil erosion on their cropland and surrounding area after conservation structures were done; accordingly, the majority of them (94.0%) recognized that the soil erosion trend had decreased after the implementation of SWC structures. While 3.3% said that the problem of soil erosion increased after the implementation of SWC structures and the remaining 2.7% said that the problem of soil erosion remained the same (no change) after SWC measures were done. The result of this study was in line with the

findings of Alemu *et al.* (2019) who reported (93.5%) confirmed that the soil erosion rate had decreased after the implementation of SWC in the Geshy sub-catchment, Gojeb River catchment, Ethiopia.

Table 6: Erosion problem and trend of erosion in the study area

Erosion problem			Trend of erosion		
Category	F	P (%)	Category	F	P (%)
Yes	176	95.7	Increasing	6	3.3
No	8	4.3	Decreasing	173	94.0
			No change	5	2.7
Total	184	100.0		184	100.0

Where: F=Frequency, P=Percent

4.2.2.2. Types of soil and water conservation implemented in the study area

Various physical soil and water conservation practices have been applied by the farmers using community participation approaches on their own farmlands and communal lands in the study area. Based on the results of the field survey (Table 7), 87% of sampled respondents implemented different types of structural SWC practices in their farmlands; which implies more availability of conservation structures in the study area. Soil bunds are the most dominant ones in the study area. The majority of respondents (75.5%) constructed soil bunds on their farmlands. In nearby areas, Gizaw *et al.* (2019), reported soil bunds constructed in 76.9% and 75.7% by Manna and Gomma districts respectively, in Jimma Zone, South-Western Ethiopia. During the interviews with focus group discussions and key informants, they also widely acknowledged the construction of soil bund structures as being an effective measures in arresting soil erosion and as having the potential to improve land productivity. Whereas 9.2% implement fanya-juu, 2.2% implement cut-off drains, 8.2% implement check dams and 4.9% implement other physical types of structures (Table 7).

Table 7: Types of SWC implemented in sample watersheds

Types of SWC implemented			Use of SWC structures		
Category	F	P (%)	Category	F	P (%)
Soil Bund	139	75.5	Yes	160	87
Fanya-juu	17	9.2	No	24	13
Cut-off drains	4	2.2			
Check dams	15	8.2			
Others	9	4.9			

Total	184	100.00	184	100.00
-------	-----	--------	-----	--------

Where: F=Frequency, P=Percent

4.2.3. Land ownership, the wealthy status of the farmer, and the age of structure

Concerning land ownership, the majority (57.6%) of the respondents said that conservation structures done through mass community mobilization are more damaged than private land, due to plowing by oxen for the need to benefit more lands and lack of maintenance, while 33.1% of the respondents said conservation structures were damaged from communal lands; due to free grazing on communal land and less care of the responsible body from kebele and district levels, and only 9.2% of the respondents said conservation structures from both lands are equally destroyed. Regarding with wealth status of the farmers, the majority (71.7%) of the respondents said that the implemented conservation structures more damaged the land of poor farmers, 7.6% of the respondents said that conservation structures more damaged the land of medium farmers, while 10.9% of the respondents said conservation structures were damaged from the land of rich farmers and the remaining 9.8% of the respondents said conservation structures from all farmers categories are equally broken. With regard to the duration age of structures, the majority (84.4%) of the farmers responded that the structures aged 7 years after implementation were more damaged due to duration structures, 3.8% of the respondents said that structures aged 3 years more damaged, while 3.8% of the respondents replied that the structures aged 5 years more damaged and the remaining 7.6% of the respondents said all implemented structures are equally destroyed.

Table 8: Land ownership, wealth status of farmer, and age of structure

Land ownership			Wealthy status			Duration age of structure		
Category	F	P (%)	Category	F	P (%)	Category	F	P (%)
private land	106	57.6	Rich farmers	20	10.9	3 years aged	7	3.8
communal land	61	33.1	Medium farmers	14	7.6	5 years aged	7	3.8
Both equally	17	9.2	Poor farmers	132	71.7	7 years aged	156	84.4
			All equally broke	18	9.8	All equally	14	7.6

Where: F=Frequency, P=Percent

4.2.4. General problems faced in sustaining SWC structures in the study area

Regarding with general problems faced in sustaining SWC structures in the study area, the majority (70.7%) of the respondents said that maintenance of SWC structures needs more labor and capital, 13% of the respondents said that lack of awareness on degradation and importance of SWC measures, while 8.7% of the respondents said extension education is not widely diffused and the remaining 3.3 and 4.3% of the respondents said problem of land tenure security and other difficulties respectively.

Table 9: General Problems faced in sustaining SWC structures in the study area

General problems faced in sustaining SWC		
Category	F	P (%)
Maintenance of SWCS needs more labor and capital	130	70.7
Lack of awareness degradation and importance of SWCM	24	13
The problem of land tenure security	6	3.3
Extension education is not widely diffused	16	8.7
Others	8	4.3
Total	184	100.0

Where: F=Frequency, P=Percent

4.2.5. Status of SWC structures

The field measurement result showed that the physical status of soil bunds implemented in the study area mostly broke from the sampled watersheds. With respect to slope gradients of conservation structures, 53.5%, 40.0%, and 48.14% of the structures constructed on private lands were broken from upper, middle, and lower slope classes, respectively. While 46.4%, 36.67%, and 40.74% of the structures constructed on communal lands were broken from upper, middle, and lower slope classes, respectively. A higher percentage of broken structures was observed at the upper slope position as compared to middle and lower slope gradients. This might be due to the siltation of a large number of bund channels and the destruction of the embankment by oxen during farm activities at the upper slope position. Field observation also showed that some of the structures implemented on private and communal lands were silted up and damaged. The overall percentages of destroyed structures stabilized by biological measures were 37.05% and 47.64% from private and communal lands at all slope classes, respectively.

This indicated that, less sustainability of implemented structures in the study area. The survey result also showed that the destruction of implemented structures might be lack of maintenance, design problems, not properly stabilized by biological measures, and overgrazing. As observed from the field and structural measurements soil bund structures were stabilized by biological conservation measures like Vetivar, Local (migira), and Elephant grasses. Concerning land ownership, the maximum number of structures broken from private land than communal lands in all slope classes. Generally, the management and maintenance of the structures in the study area were less on both communal and private lands.

Table 10: Field measurement of the physical status of the implemented SWC

Slope classes	Land ownership	Number of structures				
		Measured	Broken	%	Stabilized by biological conservation measures	%
US (15-30) %	Private land	28	15	53.5	13	46.42
	Communal land	28	13	46.4	9	32.14
	Total	56	28	50.0	22	39.28
MS (8-15) %	Private land	30	12	40.0	11	36.67
	Communal land	30	11	36.67	10	33.33
	Total	60	23	38.33	21	35.0
LS (3-8) %	Private land	27	13	48.14	12	44.44
	Communal land	27	11	40.74	8	29.62
	Total	54	24	44.44	20	37.03
Grand total		170	81	47.64	63	37.05

US: Upper Slope, MS: Middle Slope and Lower Slope

Field measurements on the basic components of soil bund showed that there are differences in constructed bund dimensions from expected standards for space between two successive bunds, height and bottom width of the embankment, ditch width, and ditch depth at the three slope classes (Table 11). Similarly, Meshesha and Birhanu (2015) showed that the structure of level soil bunds was not constructed in accordance with the standards in southwestern Ethiopia.

In private and communal lands the implemented soil bund embankment sizes (height and bottom width of embankment, ditch width, and ditch depth) were less than the standard required. The applied structures in the study area lack the capacity to control the top discharge that can be produced among two successive bunds when the constructed structure embankment sizes are less than normal. This might cause severe loss of soil to the field by starting rill and gully erosion. The problem was the structure implemented by the mass community mobilization

did not achieve the standard provided by the Ministry of Agriculture. Similarly, Bekele *et al.*, (2018) also showed that the structure of level soil bund components was not in accordance with the standards in the Lemo district, southwestern Ethiopia. Whereas, the space between the two successive bunds in the study area was more than the recommended bund space in the upper and lower slope classes, while the structures constructed in the middle slope fit the standard dimension. When physical SWC structures are done with large spacing more runoff can be generated causing over-topping.

The top width of the embankment in the three slope classes was constructed with a similar standard recommended by the Ministry of Agriculture. In relation to the width and depth of the soil bund ditches that are implemented in the study area were less than the considered design to hold and retain the produced runoff from the top of the field due to the overtopping problem (Table 11). Gizaw *et al.*, (2019) evaluated the technical standard in Jimma zone southwestern Ethiopia and reported that the implemented structure lacks the ability to hold the peak discharge that can be generated in between two consecutive bunds.

Table 11: Field measurement of the dimension of the implemented SWC

Slope classes	Bund Layouts	Measured value of soil bund across land ownership		Recommend by MOARD (2005)	Differences
		Private land	Communal		
US (15-30%)	SBB (m)	14.5	12.8	5-10	+3.65
	EH (m)	0.32	0.35	0.5	-0.165
	ETW (m)	0.28	0.29	0.3	0.015
	EBW (m)	1.22	1.31	1.6	-0.335
	DD (m)	0.39	0.38	0.5	-0.11
	DW (m)	0.41	0.43	0.5	-0.08
MS (8-15%)	SBB (m)	17.55	16.4	10-20	3.025
	EH (m)	0.42	0.45	0.5	-0.06
	ETW (m)	0.31	0.325	0.3	0.017
	EBW (m)	0.98	1.15	1.6	-0.53
	DD (m)	0.35	0.36	0.5	-0.14
	DW (m)	0.43	0.44	0.5	-0.06
LS (3-8%)	SBB (m)	26.5	23.7	20-25	+1.4
	EH (m)	0.48	0.47	0.5	-0.02
	ETW (m)	0.31	0.32	0.3	0.015
	EBW (m)	0.87	0.96	1.6	-0.68
	DD (m)	0.33	0.32	0.5	-0.17
	DW (m)	0.42	0.45	0.5	-0.065

US: Upper Slope, MS: Middle Slope, Lower Slope, and SBB: Space Between Bund, EH: Embankment Height, ETW: Embankment Top Width, EBW: Embankment Bottom Width, DD: Ditch Depth, DW: Ditch Width, + Sign: More than standard and – Sign: Less than standard.

4.3. Impact of SWC Measures on Selected Soil Physicochemical Properties

4.3.1. Impacts of slope classes and bund zones on soil physical properties

The result showed that particle size distribution (clay, silt, and sand) was significantly affected ($p < 0.05$) by slope classes. The highest mean values of clay and silt (50.11 and 33.11%) were recorded under the lower (3-8%) slope classes, while the lowest (38.92 and 26.56%) were found at upper (15-30%) slope classes, respectively. Conversely, the higher mean value of sand (34.52%) was observed at the upper slope class; and the lowest mean (16.78%) was observed under the lower slope classes (Table 12). The results of this study indicated that as slope class increases sand content increases while clay and silt content decreases. Similarly, Bezabih *et al.* (2016) showed that land position has a significant effect on soil texture through its influence on soil formation and erosion processes in Dedo District, Southwest Ethiopia. The result of this study agreed with the reports of Dejene (2017), who showed an increase in sand and a decline in silt and clay contents with an increase in slope gradient. Guadie *et al.* (2020) also reported higher sand fraction in the upper slope than the lower slope positions.

The results showed that the particle size distribution of the soil in the study area was significantly influenced at ($p < 0.05$) among soil bund zones. The highest mean values of clay and silt percent (51.33 and 31.11%) were perceived at deposition zones (1.5 m distance away from the top of the bund/depositional area); while the lowest percent (43.32 and 23.56%) were perceived at loss zones (1.5 m distance from the upper bund/erosional area), respectively. On the other hand, the higher mean of sand fraction (33.12%) was observed under loss zones; and the lowest mean (17.56%) was observed under deposition zones (Table 12). In line with this study, Bogale *et al.* (2021) reported a significant variation between bund zones in which the highest mean of clay soil percentage was recorded at the bottom spot of terrace position and the highest mean of sand soil portion under upper terrace position. In contrast, Bekele *et al.* (2018) reported that there was no significant difference ($P < 0.05$) among soil sample distance from bund in soil particle size distribution (clay, silt, and sand) fractions.

Table 12: Impact of slope classes on soil physical properties

Slope classes	Soil parameters				Textural Class
	BD (g cm ⁻³)	Sand (%)	Silt (%)	Clay (%)	
US	1.283±0.01 ^a	34.52±10.30 ^a	26.56±8.55 ^b	38.92±10.82 ^c	Clay
MS	1.099±0.01 ^b	26.44±7.89 ^b	27.23±8.77 ^b	46.33±12.88 ^b	Clay
LS	1.093±0.01 ^b	16.78±5.01 ^c	33.11±10.67 ^a	50.11±13.93 ^a	Clay loam
P. Value	0.012*	0.016*	0.009*	0.001*	

Data in the same row followed by different letters are significantly different from each other at a probability level of $p < 0.05$, US: Upper Slope, MS: Middle Slope, LS: Lower Slope, and BD: Bulk Density.

The interaction impact of slope class and bund zone on soil particle size distribution shows, a significant difference ($p < 0.05$) in clay portion at lower and upper slope classes. At the lower sloping position, the highest value of clay content (51.33%) was recorded at the deposition zone (1.5 m) away from the top of the soil bund and the lowest (40.00%) at the upper slope and loss zone (erosional area) of bund structure. The difference of clay particles among slope class and bund zone might be due to the affection of soil particles and the influence of soil bund practices. Bekele *et al.*, (2018) showed a significant difference in the interaction effect of slope position and soil sample distance from bund in clay and silt fractions. Furthermore, Bogale *et al.* (2021) also observed a significant difference in clay content with the highest fractions at the gentle slope and bottom spot of the terrace position, and the highest fractions of sand content at the steep slope and upper terrace position.

Soil bulk density (BD) showed a significant difference ($p < 0.05$) at different slope classes. The lowest (1.093 g cm³) bulk density as found under the lower slope class and the highest (1.283 g cm³) bulk density values were recorded in the upper slope class. As the slope gradient increases, BD increases by 0.19%, which could be associated with low soil organic matter content. The difference in soil bulk density among the slope class might be due to the disturbance of soil particles by water erosion and, the difference in organic carbon and clay fraction. The results agree with Bezabih *et al.*, (2016) who reported that there is a direct relation between soil bulk density with slope class.

Soil bulk density analysis showed significant variations with bund zones. The mean were in the variation of 1.17, 1.05 and 1.01g/cm³ at the loss zone, middle and deposition zones, respectively

(Table 12). It was higher at the loss zone of soil bund than middle and deposition zones. The results of soil BD in the study area indicate a decreasing trend by 0.12% from the loss zone (upper position) to the deposition zone (lower position) of soil bunds. Similarly, Hailu *et al.* (2020) reported a significant variation in the overall mean of bulk density among zones with the highest value at the loss zone in Somodo Watershed, Jimma Zone, and South Western Ethiopia. This might be washing away the organic matter from the upper slope position (loss zone) and accumulating in the lower position. Bogale *et al.* (2020) also explained that, the decreasing trend in soil bulk density value from the upper position to the lower position due to clearing away of the organic matter from the upper slope position (relative distance) and accumulated near the lower relative distance In the Case of Habru District. North Ethiopia.

Table 13: Impact of soil bund zones on soil physical properties

Bund zones	Soil parameters				Textural
	BD (g cm ⁻³)	Sand (%)	Silt (%)	Clay (%)	Class
LZ	1.17±0.01 ^a	33.12±7.33 ^a	23.56±3.56 ^b	43.32±12.04 ^c	Clay
MZ	1.10±0.01 ^b	23.78±3.33 ^b	25.89±5.86 ^b	47.33±13.78 ^b	Clay
DZ	1.05±0.01 ^b	17.56±5.24 ^c	31.11±9.01 ^a	51.33±14.27 ^a	Clay
P-value	0.019*	0.003*	0.003*	0.00**	

Data in the same column followed by different letters are significantly different from each other at a probability level of $p < 0.05$, LS: Loss Zone, MZ: Middle Zone, DZ: Deposition Zone, and BD: Bulk Density.

The interaction effect of soil bulk density was not significantly different at ($p > 0.05$) between slope class and bund zone. However, there were numerically different mean values between the slope class and bund zone. Accordingly, the highest (1.22 g m³) and the lowest mean (1.02 g m³) were recorded under the upper slope at the loss zone and under the lower slope respectively. The variation could be due to the existence of soil nutrients transported from the upper slope class and accumulated under lower classes. Similarly, Bogale *et al.* (2021) reported that there was no significant variation between slope gradient and terrace position in relation to their interaction effect. However, the lower bulk density from gentle slope gradient and bottom spot position were recorded, due to the presence of organic materials transported from the steeper slope.

The result showed soil BD had a significant relation and negative correlation with clay ($r = -0.462^{**}$), and soil OC ($r = -0.428^*$) contents. Regarding this, Hailu *et al.*, (2012) also reported that soil organic carbon affects soil bulk density due to soil deposition increased clay content, and accumulation of residues.

Table 14: Interaction impacts of slope classes and bund zones on soil physical properties

Slope classes	Bund zones	Soil parameters			
		BD (g/m-3)	Sand (%)	Silt (%)	Clay (%)
US	LZ	1.22±0.03 ^a	34.67±8.54 ^a	17.33±5.03 ^a	40.00±2.00 ^b
	MZ	1.18±0.02 ^a	32.00±7.33 ^a	18.67±1.15 ^a	46.33±2.30 ^a
	DZ	1.13±0.03 ^a	29.33±3.46 ^a	24.00±2.00 ^a	47.33±6.11 ^a
MS	LZ	1.20±0.03 ^a	23.33±5.03 ^a	20.67±4.02 ^a	46.33±4.08 ^b
	MZ	1.09±0.06 ^a	22.00±4.16 ^a	23.33±5.00 ^a	48.67±8.16 ^a
	DZ	1.04±0.06 ^a	19.33±2.34 ^a	28.67±7.03 ^a	49.33±8.08 ^a
LS	LZ	1.18±0.03 ^a	20.00±3.67 ^a	32.00±8.08 ^a	45.00±8.26 ^b
	MZ	1.15±0.01 ^a	18.00±2.00 ^a	32.67±9.86 ^a	50.67±10.31 ^a
	DZ	1.02±0.01 ^a	18.00±2.00 ^a	34.67±11.01 ^a	51.33±13.71 ^a
P-Value		0.22	0.20	0.42	0.031*

Data in the same column followed by different letters are significantly different from each other at a probability level of $p < 0.05$, US: Upper Slope, MS: Middle Slope, LS: Lower Slope, LS: Loss Zone, MZ: Middle Zone, DZ: Deposition Zone, and BD: Bulk Density.

4.3.2. Impacts of slope classes and soil bund zones on soil chemical properties

Soil reactions (pH)

The study found significant variations in soil pH across different slope classes. The mean values of soil pH were 5.42, 4.92, and 4.47 for the lower, middle, and upper slope classes, respectively (Table 15). The lowest mean value of pH was recorded at the upper slope (15-30%), and highest at the lower (5-10%) slope positions. This indicates that, as the slope gradient increases, soil pH decreases. This might be due to the increase in the slope position which facilitates soil erosion and the leaching of soluble base cations, thereby increasing the relative concentration of hydrogen ions in the soil and reducing soil pH. Mihrete, (2014) reported that the difference

in pH across the slope could be associated with the distribution of SOM and CEC in Simada district, northwest Ethiopia. Furthermore, Taressa (2017) also reported that soil on the upper slope had a significantly lower pH than their lower counterparts due to the accumulation of soluble cations on the lower slope.

There was a significant difference in soil pH with respect to bund zones of consecutive structures between the loss zone and deposition zone of soil bunds. The highest (5.09) mean value was observed at the lower bund zone (deposition) as compared to the middle (4.98) and upper (loss zone) (4.74) bund positions (Table 16). It may be due to sediment accumulation with soluble bases and organic matter received from the upper slope through erosion and leaching processes. Similarly, Etana, (2020) reported that the mean value of soil pH was significantly affected by the use of level soil bund at ($P < 0.05$).

Table 15: Impact of slope classes on soil chemical properties

Slope classes	Soil parameters				
	pH	SOC (%)	TN (%)	Av-P (ppm)	CEC(meq/100g)
US	4.47±0.22 ^c	2.03±0.51 ^c	0.21±0.03 ^c	7.04±3.25 ^b	20.23±5.06 ^c
MS	4.92±0.59 ^b	2.55±0.75 ^b	0.26±0.01 ^b	7.52±4.59 ^b	25.00±6.25 ^b
LS	5.42±0.36 ^a	2.83±0.73 ^a	0.30±0.02 ^a	8.33±5.75 ^a	28.37±7.10 ^a
P value	0.009*	0.004*	0.012*	0.016*	0.001*

Data in the same column followed by different letters are significantly different from each other at a probability level of $p < 0.05$, US: Upper Slope, MS: Middle Slope, LS: Lower Slope, pH: Soil reaction, SOC: Soil Organic Carbon, TN: Total Nitrogen, Av-P: Available Phosphorus, CEC: Cation Exchangeable Capacity.

The interaction effect of soil pH was significantly affected at ($p < 0.05$) with slope class and soil bund zones. The highest pH (5.67) values were observed under the lower slope class and the lowest (4.27) under the upper slope class of soil bund structures, respectively (Table 17). The difference might be due to the removal of basic cations which is related to excessive soil erosion and deposited at the lower slope class to cause a high amount of pH and EC. Similarly, Bogale *et al.* (2021) also reported the interaction effect of soil reaction as it significantly ($p < 0.05$) affected with slope gradient and terrace position with the observed highest pH values at gentle slope and bottom terrace position and the lowest at steep slope and upper spot of the terrace position. Soil pH was positively and highly significantly correlated with clay soil content at $r =$

0.771**, and also positively and significantly correlated with SOC% and CEC at $r = 0.337$ and $r = 0.466^*$, respectively.

Table 16: Impact of soil bund zones on soil chemical properties

Bund zones	Soil parameters				
	pH	SOC (%)	TN (%)	Av-P (ppm)	CEC(meq/100g)
LZ	4.74±0.75 ^b	2.32±0.58 ^a	0.253±.04 ^a	5.06±1.76 ^c	22.88±1.40 ^b
MZ	4.98±0.52 ^{ab}	2.32±0.70 ^a	0.252±.03 ^a	6.11±2.27 ^b	24.55±1.54 ^b
DZ	5.09±0.38 ^a	2.38±0.87 ^a	0.268±.04 ^a	7.17±3.76 ^a	29.55±1.65 ^a
P-value	0.017*	0.37	0.13	0.001*	0.023*

Data in the same column followed by different letters are significantly different from each other at a probability level of $p < 0.05$, LZ: Loss Zone, MZ: Middle Zone, DZ: Deposition Zone, pH: Soil reaction, SOC: Soil Organic Carbon, TN: Total Nitrogen, Av-P: Available Phosphorus, CEC: Cation Exchangeable Capacity.

Soil organic carbon (SOC)

The mean SOC (%) content was showed a significant difference at ($p < 0.05$) under slope classes. The highest mean value of soil OC (2.83%) was recorded at the lower slope class and the lowest (2.03%) was recorded at the upper slope class (Table 15). SOC in the study area for the three slope classes was categorized as medium according to Landon's (1991) soil carbon rating. This might be due to the removal of organic matter through erosion and runoff from the upper slope and accumulated in lower slope class. Aytenew, (2015) also reported that the lowest SOC under strongly sloping land, while the highest was observed under gently sloping land. The result of this study agreed with Bogale *et al.* (2021) who observed a significantly lower organic carbon content under steep slope gradient than gentle and moderate slopes. The analysis result of SOC did not show significant variation at ($p > 0.05$) between bund zones, and also interaction effect between slope classes and bund zones. Similarly, Bekele *et al.*, (2018) and Bogale *et al.*, (2021) reported a non-significant difference of SOC in relation to the interaction effect between slope gradients and terrace positions.

Total Nitrogen (TN)

The total nitrogen (TN) was a significant difference at ($p < 0.05$) among slope classes. The highest mean (0.30%) was observed at the lower slope and the lowest mean (0.21%) at the upper slope position. This might be due to reduced soil erosion and increased soil organic matter in the conserved croplands relatively the higher amount of TN may recorded. The contents of TN in the study were rated as medium according to Landon (1991), total nitrogen rating. Guadie *et al.*, (2020) also observed the highest mean value of TN in the lower slope gradient than in the higher slope gradients. Similarly, reports by Bogale *et al.* (2021) showed a higher value of total nitrogen at the bottom spot position and gentle slope gradient; due to the transportation of organic matter and clay soils near the inter-structural space area.

There was no significant variation among zones of soil bunds. The highest mean was (0.268%) found on deposition, while the middle (0.253%) and loss zones (0.252%) did not show significant variation mean values (Table 15). This might be due to the accumulation of organic matter under deposition zone that serves as a source of nitrogen. However, there was no significant difference between bund zones, and the interaction effect of slope class and bund zone. A similar finding was reported by Dagnachew *et al.* (2020) who appeared total nitrogen was not significantly varied with terrace position. The interaction effect of slope class with soil bund zones had a non-significant influence on soil total nitrogen. In line with this finding Bekele *et al.*, (2018) also reported the non-significant interaction effect between slope position and sample distance from soil bunds on total nitrogen. Total nitrogen (TN) was positively and strongly correlated with OC under the slope classes and bund zones of soil and water conservation practices. The relatively higher amount of TN in the lower slope class and deposition zone of soil bund may be due to its good mean of organic carbon content. The possible reason for this could be the removal of top soils by erosion from the upper than the lower position. Thus, it has a significant and positive relationship ($r = 0.562^{**}$) with soil organic carbon.

Table 17: Interaction impacts of slope classes and bund zones on soil chemical properties

Slope classes	Bund zones	Soil parameters				
		pH	SOC (%)	TN (%)	Av-P (ppm)	CEC(meq/100g)
US	LZ	4.30±0.22 ^b	1.96±0.03 ^a	0.20±0.04 ^a	5.63±0.90 ^a	19.40±2.68 ^a
	MZ	4.27±0.53 ^b	2.07±0.62 ^a	0.20±0.05 ^a	5.73±0.34 ^a	22.02±3.39 ^a

MS	DZ	5.29±0.14 ^a	2.28±0.87 ^a	0.24±0.02 ^a	6.25±0.80 ^a	22.74±2.27 ^a
	LZ	4.42±0.06 ^b	2.03±0.56 ^a	0.25±0.01 ^a	5.70±1.38 ^a	19.72±3.39 ^a
	MZ	5.21±0.41 ^a	2.37±0.82 ^a	0.26±0.01 ^a	5.74±5.11 ^a	22.08±4.79 ^a
LS	DZ	5.31±0.44 ^a	2.38±0.46 ^a	0.28±0.01 ^a	6.27±4.03 ^a	22.83±2.62 ^a
	LZ	4.69±0.14 ^c	2.19±0.38 ^a	0.30±0.02 ^a	5.73±1.17 ^a	21.45±3.47 ^a
	MZ	5.28±0.10 ^b	2.39±0.88 ^a	0.28±0.05 ^a	6.13±3.64 ^a	23.30±2.22 ^a
	DZ	5.67±0.44 ^a	2.41±0.84 ^a	0.33±0.02 ^a	6.51±3.45 ^a	23.78±2.46 ^a
P - value		0.016*	0.38	0.23	0.12	0.06

Data in the same column followed by different letters are significantly different from each other at a probability level of $p < 0.05$, US: Upper Slope, MS: Middle Slope, LS: Lower Slope, LS: Loss Zone, MZ: Middle Zone, DZ: Deposition Zone, pH: Soil reaction, SOC: Soil Organic Carbon, TN: Total Nitrogen, Av-P: Available Phosphorus, CEC: Cation Exchangeable Capacity.

Available phosphorus (Av-P)

Available phosphorous (Av-P) of the study area was significantly different at ($p > 0.05$) between slope classes. The mean values of Av-P were 8.33, 7.52, and 7.04 (ppm) for the lower, middle, and upper slope classes, respectively (Table 14). The content of Av-P in the soil of the study area was rated as medium, according to Landon's (1991) rating. The highest mean observed at the lower slope class compared to the middle and the upper slope classes might be due to the removal of topsoil and organic matter from the upper slope and resulting accumulation at the lower slope classes. Similarly, Bekele *et al.*, (2018) also observed the highest mean value of Av-P at gently sloping and the lowest at moderately steep sloping. Dejene (2017) and Ademe *et al.*, (2017) in the Weday watershed, in eastern Ethiopia and Wenago district, southern Ethiopia, respectively, also reported the effectiveness of SWC practices in improving soil properties.

A statistically significant difference was also found in Av-P between the inter-structural space of soil bunds; where the highest value was observed at the deposition zone (7.17 ppm) as compared to the middle part (6.11 ppm) and loss zones (5.06 ppm) (Table 15). The difference could be due to the transportation of soil particles with phosphorous through the erosion process and deposited in the lower bund zones. Significant differences in Av-P between deposition and loss zones were also reported by Amare *et al.* (2013) and Alemayehu and Fisseha, (2018) due to transportation in the upper parts and accumulation at the lower part. Similarly, Bogale *et al.*,

(2021) reported that significant accumulation of phosphorus at the bottom terrace position could be due to the inherent capacity of phosphorus to adhere with other soil materials and easily transported by erosion effect and accumulate due to structural barriers of conservation practice. The mean value of Av-P under lower slope class and deposition zone of bund is higher than that of the other slope classes and bund zones soil and water conservation practice. The soil Av-P also found a positive correlation with SOM (0.349**), and a strongly and positively correlated (0.776**) with soil pH.

Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC, meq/100 g) values showed a statistically significant difference ($p < 0.05$) at different slope classes. A mean value of 20.23, 28.02, and 28.37 (meq/100 g) was found at upper, middle, and lower slope classes, respectively (Table 14). The lowest value was found in the upper slope, and the highest in the lower slope class. This might be due to the dominant soil particles such as clay soil and soil organic matter, and their removal by erosion and leaching processes from the upper position of land and accumulating in the lower part of the land. Similarly, Bekele *et al.*, (2018) the highest CEC at lower slopes and the lowest at steep slope gradients; due to the high extent of clay soil and amount of OM in the soil, and their removal through runoff and erosion from the upper slope to lower slope gradients. This result is in line with the findings of Bogale *et al.* (2021), who reported that higher CEC values were found at a gentle slope gradient and the lower values were measured at a steep slope position in the case of Workamba Watershed, Debark District North Ethiopia.

The CEC value was also significant for bund zones of consecutive structures. The higher mean CEC value was observed under the depositional area (29.55 meq/100 g) than the middle zone (24.55 meq/100 g) and erosional area (22.88 meq/100 g) of soil bunds (Table 15). This indicates that the depositional zone is higher by 16.92% of CEC values than the middle zone. Bogale *et al.* (2021), also reported a higher CEC values for the bottom position terrace than the upper position terrace. This might be due to the loss of cations by runoff erosion from the higher sloping area (upper position) and concentrated in the lower slope (bottom) position. The value of CEC in both slope classes and bund zones in the study area was rated as medium based on the rating suggested by (Emiru and Gebrekidan, 2009). Cation exchange capacity (CEC) was not significantly different at ($p > 0.05$) in relation to the interaction effect of slope classes and

soil bund zones. The higher mean value of CEC found under lower slope class and deposition zone of bund than that of the other slope classes and bund zones soil and water conservation practice. The correlation showed a positive relation of cation exchange capacity with clay soil ($r = 0.679^{**}$) and soil organic carbon content ($r = 0.561^{**}$). Similar results by Bekele *et al.*, (2018) reported that the existence of high clay content and soil organic matter contributes to highest the content of cation exchange capacity in the lower sloping.

4.4. Impact of Physical Soil and Water Conservation Measures on Crop Yield

As shown in Table 18, the majority (85.3%) of the farmers perceived that SWC measures increased crop yield, while a small number of farmers 12% and 2.7% replied that SWC measures had no change and decreased, respectively. Similarly, Wondimu *et al.* (2022) reported that due to the construction of soil bunds, about 71% of the farmers perceived an increase in crop yield in southwest Ethiopia. As indicated in the result, major crops grown in the study area were 64.7, 10.9, 13, 7.1, and 4.3% maize, wheat, teff, sorghum and others including pulse crops, respectively.

Table 18: Impact of SWC measures on crop yield

Major crops grown in the area			Impact of SWC on crop yield		
Category	F	P (%)	Category	F	P (%)
Maize	119	64.7	Decreased	5	2.7
Wheat	20	10.9	No change	22	12
Teff	24	13	Increased	157	85.3
Sorghum	13	7.1			
Others	8	4.3			
Total	184	100.0		184	100.0

Where: F=Frequency, P=Percent

Maize (*Zea mays*) is the major cultivating crop in the study area. Maize production was significantly different between the two consecutive bund zones. Accordingly, the highest maize grain yield was recorded on the deposition zone of soil bund structures than the middle and loss zones (Table 19). Maize grain yield was higher by 17.3 and 29.61% on the deposition zone of soil bund structures than on the middle and loss zones of two successive structures along the slope, respectively. These might be due to conservation structures constructed and sediment deposited above the bund (soil accumulation area) as a result of sufficient nutrients and soil

moisture gained under the level soil bund. Similarly, Dimtsu *et al.*, (2018) reported that Barley and wheat grain yield was higher by 19.5 and 15.35 %, respectively on the accumulation zone of SWC structures than on the middle position of two consecutive SWC structures. Likewise, Amare *et al.* (2013) found that the grain yields of wheat and maize were significantly different between deposition and loss of structural zones. Challa *et al.* (2016), also reported that variation in grain yield may be due to soils actively eroded from the loss zone to the soil accumulation zone, making spatial variability in terms of moisture and nutrient availability within the inter-conserved space.

Table 19: Impact of soil bund zone on grain yields of maize

Crop type	Soil bund zone			
	Loss zone	Middle	Deposition	Overall mean
Maize (<i>Zea mays</i>)	3225kg/ha	3789kg/ha	4582kg/ha	3865.33kg/ha

Source: Field Measurement (2022)

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The survey revealed that 87% of respondents built soil bunds on their croplands, but most of these structures are poorly managed and maintained. Reasons for destroying structures included lack of maintenance, free grazing, and need to benefit more land. The study shows that soil bund practices positively impact soil physiochemical properties and maize grain yield, with significant differences between slope classes and bund zones. The differences in soil physicochemical properties (Clay, Silt, Sand and BD, and pH, SOC, TN, Av-P, and CEC) between slope classes were found to be statistically significant. With the exception of sand and BD concentrations, these parameters were also found to be higher in the lower slope classes than in the upper slope classes.

This study also shown the variation in soil physicochemical properties (Clay, Silt, sand and BD, and pH, Av-P, and CEC) and crop yield between bund zones, with deposition zones having the highest values. This is due to the removal of clay soil, organic matter, and other soil nutrients by erosion effects from loss to depositional zones. But the SOC and TN contents are not showed significant differences. The yield increased from loss to deposition zones were 3225kg/ha and 4582kg/ha, respectively. The result also showed that soil bunds have a beneficial role in preserving and improving the soil properties, thereby enhancing productivity. For clay soil and pH values, the interaction effect between slope classes and bund zones were varied significantly. This shows the importance of conservation practices to improve organic matter content in cropland. Soil bund intervention in the study area had observable positive effects on soil physicochemical properties and crop yield. Changing farmers' perceptions of the construction and maintenance of SWC structures and their role in saving soil from erosion and related impacts are important.

5.2.Recommendation

Based on the findings of this study, the following points were recommended as future research directions:

- Soil and water conservation measures in the study area should be practiced following the standard given by the Ministry of Agriculture and natural resource experts.
- Integrated conservation measures such as biological and mechanical measures should be run, and appropriate maintenance and management of implemented conservation structures should be more needed.
- Additional studies should be made to get more information about the soil fertility status of the cultivated land and the impacts of soil and water conservation consistent with the ages of conservation structures and agro ecological zones in the study area.

6. REFERENCES

- Abay. A., 2011. Construction of soil conservation structures for improvement of crops and soil productivity, Southern Ethiopia. *Journal of Environment and Earth Science*, 1(1), 21–29.
- Abebayehu, A., 2010. Soil Fertility Management and Nutrient Balance in Farm Components and Socioeconomic Groups: A Case Study in Selected Sites of Gilgel Gibe Catchment. *MSc Thesis, Hawassa University, Ethiopia*.
- Abebe Bezu and Ketema Tezera., 2019. Impacts of soil and water conservation on crop yield, soil properties, water resources, and carbon sequestration: A review. 10 (5), 103-113.
- Addisu Damtew, 2011. Benefit and challenge of adoption soil conservation techniques in Goromt watershed central Ethiopia, *Addis Ababa University, Ethiopia*.
- Ademe, Y., Kebede, T., Mullatu, A. and Shafi, T., 2017. Evaluation of the effectiveness of soil and water conservation practices on improving selected soil properties in Wonago district, Southern Ethiopia. *Soil Science and Environmental Management*, 8, 70-79.
- Adgo E, and Teshome A., 2010. Effects of long-term soil and water conservation on agricultural productivity: A case study of Anjeni watershed, Ethiopia. *IMAWES Working Paper* 17.
- Adimassu Z, Langan S, Johnston R, Mekuria W, and Amede T., 2017. Impacts of soil and water conservation practices on crop yield, run-off, soil loss and nutrient loss in Ethiopia: review and synthesis. *Environmental Management* 59, 87–101.
- Alemayehu Regassa, Van Daele, K., De Paepe, P., Dumon, M., Deckers, J., Asfawossen A, and Van Ranst, E., 2014. Characterizing weathering intensity and trends of geological materials in the Gilgel Gibe catchment, southwestern Ethiopia. *Journal of African Earth Science* 99, 568-580.
- Alemayehu, A.A., Getu, L.A. and Addis, H.K., 2020. Impacts of stone bunds on selected soil properties and crop yield in Gumara-Maksegnit watershed Northern Ethiopia. *Cogent Food and Agriculture*, 6(1), 1785777.

- Alemayehu, T., and Fisseha, G., 2018. Effects of soil and water conservation practices on selected soil physico-chemical properties in Debre-Yakob Micro-Watershed, Northwest Ethiopia. *Ethiopian Journal of Science and Technology*, 11 (1), 29-38.
- Alemu, M.D., Kebede, A., and Moges, A., 2019. Farmers' perception of soil erosion and Adoption of soil conservation technologies at Geshy sub-catchment, Gojeb River catchment, Ethiopia. *Agriculture Science* 10, 46–65.
- Ali M, and Surre K., 2012. Soil and water conservation management through Indigenous and traditional practices, Ethiopia. *Ethiopian Journal of Environmental Management*.54, 15.
- Alufah, S., Shisanya, C.A., and Obando, J.A., 2012. Analysis of factors influencing adoption of soil and water conservation technologies in Ngaciuma sub-catchment, Kenya. *African Journal of Basic Apply Science* 4 (5), 172–185.
- Amanuel Abate, 2011. Land Use Dynamics and Its Impact on Productivity. MSc. Thesis, Jimma University, Ethiopia. Analysis. *USA Agron. Part I*, No. 9.
- Amare T, Terefe A, Selassie YG, Yitaferu B, Wolfgramm B, and Hurni H., 2013. Soil properties and crop yields along the terraces and toposequence of Anjeni watershed, central highlands of Ethiopia. *Journal of Agricultural Science* 5(2), 134–144.
- Amdihun, A. E. Gebremariam, L. Rebelo, and Zeleke G., 2014. Suitability and scenario modeling to support soil and water conservation interventions in the Blue Nile Basin, *Ethiopia Environmental Systems Research*, 3, 1-13.
- Amede T., 2003. Restoring soil fertility in the highlands of east Africa through participatory research. International Center for Research in Agroforestry. *AHI brief no. A1*.
- Amsalu and De Graaff, 2004. Determinants of adoption and Continue Use of Stone terraces for soil and water Conservation in an Ethiopian Highland watershed. *Journal of Ecological Economics*, 2004; 61, 294–302.
- Amsalu, A. and De Graaff, J., 2007. Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. *Ecological economics*, 61(2), 294-302.

- Arriaga, F. J., and Lowery, B., 2003. Soil physical properties and crop productivity of an eroded soil amended with cattle manure. *Soil Science*, 168, 888-899.
- Aşkin T, and N. Özdemir. 2010. Soil bulk density as related to soil particle size distribution and organic matter content.
- Assefa M., 2009. Assessment of adaptation behavior of soils and water conservation practices in the Koga watershed, highlands of Ethiopia, at *Cornell University*.
- ATA (Ethiopian Agricultural Transformation Agency), 2013. Annual report 2013/2014: *Transforming agriculture in Ethiopia*.
- Ayalew, G., 2014. A geographic information system based soil loss and sediment estimation in Gerdi watershed, highlands of Ethiopia.
- Aylward, B., 2004. Land use, hydrological function and economic valuation. In M. Bonnell, and L. A. Bruijnzeel (Eds.), *Forests-water-people in the humid tropics*. Cambridge: *Cambridge University Press*.
- Aytenew, M., 2015. Effect of Slope Gradient on Selected Soil Physicochemical Properties of Dawja Watershed in Enebse SAR Midir District, Amhara National Regional State. *American Journal of Scientific and Industrial Research*, 6(4), 74-81.
- Bakker, M., Govers, G., Van Doorn, A., Quetier, F., Chouvardas, D., and Rounsevell, M., 2008. The response of soil erosion and sediment export to land use change in four areas of Europe: the importance of landscape pattern. *Geomorphology* 98, 213-226.
- Bamlaku, A., Nuppenau, E. and Boland, H., 2009. Technical Efficiency of Farming Systems across Agro- ecological Zones of Ethiopia. *Application of Stochastic Frontier Analysis*.
- Barber, R., 1984. An assessment of the dominant soil degradation processes in the highlands their impacts and hazards. Ethiopian highlands reclamation Study. Land use Planning and Regulator Department, Ministry of Agriculture, *Addis Ababa, Ethiopia*.
- Bekele, A., Aticho, A. and E., Kissi, 2018. Assessment of community based watershed management practices: emphasis on technical fitness of physical structures and its effect on soil properties in Lemo district, Southern Ethiopia. *Environmental Systems Research*, 7, 1-11.

- Bekele, M., Lemenih, M., and Regassa, A., 2016. The Effects of Integrated Soil Conservation Practices on Soil Physico-Chemical Properties: The Case of Menesibu District, West Ethiopia. *Journal of Natural Sciences Research*, 23, 35.
- Belayneh A., 2005. Land Degradation Assessment and Evaluation of Current Land Use and Soil Conservation Structures at Upper Chena Catchments, Southern Gundor, Ethiopia. MA Thesis (unpublished). Addis Ababa University. *Addis Ababa, Ethiopia*.
- Bewket W, and Teferi E., 2009. Assessment of soil erosion hazard and prioritization for treatment at the watershed level: A case study in the Chemoga watershed, Blue Nile Basin, Ethiopia. *Land Degradation and Development* 20, 609-622.
- Bewket, W., 2007. Soil and water conservation intervention with conventional technologies in northwestern highlands of Ethiopia: acceptance and adoption by farmers'. *Land Use Policy* 24 (2), 404–416.
- Bezabih, B., Aticho, A., Mossisa, T., and Dume, B., 2016. Journal of soil Sci. and Environmental management effect of land management practices on soil physicochemical properties in Gojeb sub-river Basin of Dedo District. *Southwest Ethiopia*, 7(10), 154–165.
- Bezabih, T., 2015. Effects of soil and Water Conservation Measures on Land Productivity and Crop Yield in Mirab Abaya Woreda of Southern Nation Nationalities and Peoples Region Ethiopia (Doctoral dissertation, *Haramaya University*).
- Bezuayehu, T., and Sterk, G., 2010. Land management, erosion problems and soil and water conservation in Fincha'a watershed, western Ethiopia. *Land Use Policy*, 27, 1027–1037.
- Birhanu, A. and Meseret, D., 2013. Structural soil and water conservation practices in Farta District, North Western Ethiopia: an investigation on factors influencing continued Use. *Science, Technology and Arts Research Journal*, 2(4), 114-121.
- Blanco H, and Lal R., 2008. Principles of Soil Conservation and Management. *Springer, New York*.
- Bogale M, Wondie G, and Shafi A., 2021. Effects of campaign-based soil and water conservation practice on soil properties: The case of Workamba Watershed, Debark

- District, and North Ethiopia. *Environmental and Natural Resource Journal*, 19(4), 292-301.
- Booker T., 2009. Tropical soil manual: A handbook for soil and agricultural land conservation in tropics and sub tropics. New York. *Longman scientific and technical publishers*.
- Bremmer J., 1996. Total nitrogen In: Spark DL (eds) *Methods of soils analysis and chemical method*, 2nd ed. American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin USA, 1085–1121.
- Challa A, Abdelkadir A, and Mengistu T., 2016. Effects of graded stone bunds on selected soil properties in the central highlands of Ethiopia. *International Journal Natural Resource and Ecological Management* 1(2), 42-50.
- Chaudhari, R., Ahire, V., Vidya, D., and Maity, S., 2013. Soil Bulk Density as related to Soil Texture, Organic Matter Content and available total Nutrients of Soil *International Journal of Scientific and Research Publications* 3, 123-131.
- CSA: (Central Statistical Agency of Ethiopia), 2010. Agricultural sample survey. Statistical Bulletin 468, October, 23-27. *CSA, Addis Ababa, Ethiopia*.
- Dagnachew M, Moges A, Kebede A, and Abebe A., 2020. Effects of Soil and Water Conservation Measures on Soil Quality Indicators: The Case of Geshy Sub-catchment, Gojeb River Catchment, Ethiopia. *Applied Environmental Soil Science*.
- Dagnew, D. C., Guzman, C. D., Zegeye, A. D., Tibebu, T. Y., Getaneh, M., Abate, S., Zemale, F. A., Ayana, E.K., Tilahun, S. A., and Steenhuis, T. S., 2015. Impact of conservation practices on runoff and soil loss in the sub-humid Ethiopian Highlands: The Debre Mawi watershed. *Journal of Hydrology and Hydromechanics*.
- Dejene, T., 2017. The Effectiveness of Stone Bund to Maintain Soil Physicochemical Properties: Case of Weday Watershed, East Ethiopia. *Civil Environmental Resource*, 9, 9–16.
- Demelash M and Stahr, K., 2010. Assessment of integrated soil and water conservation measures on key soil properties in South Gonder, North-Western Highlands of Ethiopia. *Journal of Soil Science and Environmental Management*, 1(7), 164-176.

- Derege Tsegaye, Atsushi Tsunekawa, Mitsuru Tsubo, and Nigussie Haregeweyn, 2012. Analysis of Dynamics and Hotspots of Soil Erosion and Its Management Scenarios: The case of the Central Rift Valley of Ethiopia. *International Journal of Sediment Research*, 27, 84–99.
- Dessalegn, C.D., Christian, D.G., Assefa, D.Z., Tigist, Y.T., Menelik, G., Solomon, A., Fasikaw, A.Z., Essayas, K.A., Seifu, A.T., and Tammo, S.S., 2015. Impact of conservation practices on runoff and soil loss in the sub-humid Ethiopian Highlands: The Debre Mawi watershed. *Journal of Hydrology and Hydromechanics*, 63, 210–219.
- Desta L, Carucci V, Wendem-Ageñehu A, and Abebe Y., 2005. Community-based Participatory Watershed Development: A Guideline. Federal Democratic Republic of Ethiopia Ministry of Agriculture and Rural Development, *Addis Ababa, Ethiopia*, 74.
- Dulo H, Feto E, and Fisiha G., 2017. Effects of soil bund on soil physical and chemical properties in Arsi Negelle woreda, Central Ethiopia. *African Journal Environmental Science and Technology* 11(10), 509–516.
- EFAP (Ethiopia Forestry Action Program), 1993. Draft Final Report, Volume II. The challenge for Development. Draft Final Report. *Addis Ababa, Ethiopia*, 78.
- Emiru, N. and H. Gebrekidan, 2009. Influence of land use changes and soil depth on cations exchange capacity and contents of exchangeable bases in the soils of Senbat Watershed, Western Ethiopia. *Ethiopian Journal Natural Resources*. 11, 195-206.
- Endalew, B. Muche, M. and Tadesse, S., 2015. Assessment of Food Security Situation in Ethiopia: A review. *Asian Journal of Agricultural Research*, 9(2): 55-68.
- Etana D. 2020. Effects of Level Soil Bund and Ages of Bund on Teff Productivity and Soil Properties: At, Nejo District, Oromia Region, Ethiopia. *SF Journal of Agricultural and Crop Management*. 1(2): 1008.
- FAO (Food and Agriculture Organization), 1987. Variation of land use and land cover effects on soil physicochemical characteristics and *soil enzyme activity*.
- FAO. 1990. The conservation and rehabilitation of African lands: *an international scheme*, ARC/90/4, (Accessed on February 10, 2016).

- FAO. 2000. Manual on Integrated Soil Management and Conservation Practices, Int. Institute of Tropical Agriculture (IITA) *Ibadan, Nigeria*.
- FAO. 2006. Guidelines for soil description. 4th edition. Rome, Food and Agriculture Organization of the United Nations, 97.
- FAO. 2007. Methods of analysis for soils of arid and semi-Arid Regions. *United Nations Rome, Italy, Rome*.
- FAO (2019). Proceedings of the Global Symposium on Soil Erosion 2019. *Rome*.
- Fikirie, K., and Beyene, T. M. (2017). Soil and Water Conservation Practices on Crop Productivity and its Economic Implications in Ethiopia: *Asian Journal of Agricultural Resource*. 11(4), 128-136.
- Fikiru Asefa, 2009. Assessment of Adoption Behavior of Soil and Water Conservation Practices in the Koga Watershed, *Highlands of Ethiopia*.
- Fitsum S., 2002. Contribution of fanyajuu and normal bund for crop production in Ethiopia *Addis Ababa, Ethiopia*, 83-84.
- Gachene C, and Kimaru G., 2003. Soil fertility and land productivity: a guide for extension workers in eastern Africa. *Nairobi, Kenya*.
- Gebireselassie, Y., Amdemariam, T., Haile, M., and C., Yamoah, 2009. Lessons from upstream soil conservation measures to mitigate soil erosion and its impact on upstream and downstream users of the Blue Nile River. Ethiopian Highlands: CP 19 *Project workshop Proceedings*, 171-183.
- Gebiresilassie Y, Amare T, Terefe A, Yitaferaru B, Wolfgramm B, and H., Hurni 2013. Soil properties and crop yields along the terraces and toposequence of Anjeni watershed, central highlands of Ethiopia. *Journal Agricultural Science* 5(2), 134–144.
- Gebre T, and D., Weldemariam 2013. Farmer’s perceptions and participation on mechanical soil and water conservation techniques in Kembata Tembaro Zone: the case of Kachabirra Woreda, Ethiopia. *Journal Advise Structure Geotech English*, 2(4), 118–131.

- Geremaw S., 2005. Improve soil and water conservation on farm land on high land of Ethiopia. *Addis Ababa, Ethiopia*; 83-84.
- Getachew, W.E., Getachew, F., Mulatie, M. and M., Assefa, 2016. Evaluation of technical standards of physical SWC practices and their role in soil loss reduction: The Case of Debre Mewi Watershed, North-west Ethiopia. *Landscape Dynamics, Soils and Hydrological Processes in Varied Climates, Springer Geography*.
- Gizaw T, Kalkidan F, Yalemtehay D, and H., Leta 2019. Evaluating Technical Standards of Implemented Soil and Water Conservation Technologies in Jimma Zone, South-Western Ethiopia. *Agriculture Research and Technology: Open Access*, 19(4):556100.
- Guadie, M., Molla, E., Mekonnen, M., and Cerdà, A., 2020. Effects of soil bund and stone-faced soil bund on soil physicochemical properties and crop yield under rain-fed conditions of *Northwest Ethiopia*. *Land*, 9(1), 1–15.
- Hailu W, Moges A, and Yimer F., 2012. The effects of ‘Fanya juu’ soil conservation structure on selected soil physical and chemical properties: the case of Goromti Watershed, western Ethiopia. *Resource Environment*, 2(4), 132–140.
- Hailu, L., Yimer, F. and T., Erkossa, 2020. Evaluation of the effectiveness of level soil bund and soil bund age on selected soil physicochemical properties in Somodo Watershed, Jimma Zone, Southwestern Ethiopia. *Journal of Degraded and Mining Lands Management*, 8(1), 2491.
- Haregeweyn N, Atsushi T, Jan N, Jean P, Mitsuru T, Tsegaye D, Adgo E, and F., Tegegne 2015. Soil erosion and conservation in Ethiopia: *Review Progress Physical Geography* 1-25.
- Haregeweyn N, Berhe A, and A., Tsunekawa 2012a. Integrated watershed management, an effective approach to curb land degradation: A case study of the Enabered watershed, northern Ethiopia. *Journal of Environmental Management* 50, 1219-1233.
- Haweni H., 2015. Effect of soil and water conservation on selected soil characteristics in Dimma Watershed, Central Ethiopia. *Addis Ababa University, Ethiopia*, 99.
- Herweg, K. and E., Ludi, 1999. The performance of selected soil and water conservation practices case studies from *Ethiopia and Eritrea*. *Catena* 36, 99– 114.

- Hoben, A., 1996. The cultural construction of environmental policy: paradigms and policies in Ethiopia. In: Leach, M., and Mearns, B., (Eds). *The lie of the land: Challenging received wisdom on the African Environment. The International African Institute, Villiers Publications, London.*
- Hurni H, Abate S, Bantider A, Debele B, Ludi E, Portner B, Yitaferu B, and G., Zeleke 2010. Land degradation and sustainable land management in the highlands of Ethiopia. In: Hurni H, North South, University of Berlin (5). *Geographical Bernensia. Berlin, Switzerland.*
- Hurni H., 1987. Erosion productivity conservation system in Ethiopia. In I placenta (Ed), soil conservation and productivity. Proc. of 4th Int. *soil conservation conference*; 654-674.
- Hurni H., 1993. Land degradation, famine, and land resource scenarios in Ethiopia, Cambridge University Press, *Cambridge*, 27-62.
- Hurni, H. K. Tato and G. Zeleke, 2005. The implications of changes in population, land use, and land management for surface runoff in the upper Nile Basin Area of Ethiopia. *Mountain Research Development*, 25, 147–154.
- Hurni, H., Bantider, A., Herweg, K., Portner, B., and H., Veit, 2007. Landscape transformation and sustainable development in Ethiopia. *University of Berlin, Switzerland*, 4-20.
- Jemberu, W., Ayele, B, and L., Tsegaye, 2014. Yield and water use efficiency of mulched drip irrigated onion in low land region of Amhara, north central Ethiopia. *Universal Journal of Agricultural Research* 2, 203-210.
- Kaspar H., Z. Gete, M. Kassie, B. Tegegne, T. Kassawmar, T. Ermias., and H. Hurni., 2015. Soil degradation and sustainable land management in the Rain fed agricultural areas of Ethiopia: An assessment of the economic implications Report for the Economics of *Land Degradation Initiative.*
- Kassie M, and Holden ST., 2005. Parametric and non-parametric estimation of soil conservation adoption impact on yield and yield risk. Paper presented at the 6th International Conference of the *European Society for Ecological Lisbon, Portugal.*

- Kato E., C. Ringler, M. and E., Yesuf, 2011. Bryan Soil and water conservation technologies: A buffer against production risk in the face of climate change? Insights from the Nile basin in *Ethiopia Agricultural Economics*, 42, 593-604.
- Kebede, A., Idris, K., and M., Semegn, 1996. The ‘flexibility’ of indigenous soil and water conservation techniques. Earth scan Publications, London.
- Kibemo Detamo, 2011. Farmers’ Perception on Soil Erosion and Their Use of Structural Soil Conservation Measures in *Soro District, Southern Ethiopia*.
- Laekemariam F, Kibret K, Mamo T, Karlton E, and H., Gebrekidan 2016. Physiographic characteristics of agricultural lands and farmers’ soil fertility management practices in Wolaita zone, Southern Ethiopia. *Environmental System Research*, 5, 24.
- Lanckriet S., B. Derudder, J. Naudts, H. Bauer, J. Deckers, M. Haile, and J. Nyssen., 2014. A political ecology perspective of land degradation in the North Ethiopian highlands *Land Degradation and Development*.
- Landon J., 1991. Tropical Soil Manual. A Hand book of Soil Survey and Agricultural Land Evaluation in the Tropical and Subtropical. *Longman Broak*, 447.
- Lemenin, E. Karlton and M. Olsson, 2005. “Assessing soil chemical and physical property responses to deforestation and subsequent cultivation in smallholders farming system in Ethiopia”, *Agricultural Ecosystem Environment*, 105, 373–386.
- Atsbaha M. T. and R. Reddy, 2014. Farmers’ Perception of Soil Erosion and Adoption of Soil Conservation Measures in Kolla Tembien Tabia Awotbkalsi, Tigray Regional State, *Ethiopia Haramaya University*.
- Mekonen K, and GB, Tesfahunegn 2011. Impact assessment of soil and water conservation measures at Medego watershed in Tigray, northern Ethiopia. *Maejo International Journal of Science and Technology*, 5(3), 312–330.
- Mekuria W, Veldkamp E, and MD, Corre 2011. Restoration of ecosystem carbon stocks following exclosure establishment in communal grazing lands in Tigray, Ethiopia. *Forest, Range and Wild land Soils*, 75(1), 1-11.

- Mekuria W, Veldkamp E, Mitiku H, Nyssen J, Muys B, and G., Kindeya 2006. Effectiveness of enclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. Department of Land Resources Management and Environmental Protection, Mekelle University, Mekelle, Ethiopia. *Journal of Arid Environment*, 69, 270–284.
- Mekuriaw A, Heinimann A, Zeleke G, and H., Hurni 2018. Factors influencing the adoption of physical soil and water conservation practices in the Ethiopian highlands. *International Soil and Water Conservation Research*, 6, 23-30.
- Meshesha M and K., Tripathi 2016. Farmer’s perception on soil erosion and land degradation problems and management practices in the Beressa Watershed of Ethiopia. *Journal of Water Resources and Ocean Science* 5 (5), 64-72.
- Meshesha, T.D and G., Fisseha, 2018. Effects of Soil and Water Conservation Practices on Selected Bio-physical, and Livelihood Attributes and Farmers Perception at Akusti Micro Watershed, Northwest Ethiopia. *Journal of Agriculture and Environmental Science*, 3 (2), 57-75.
- MOA. Ministry of Agriculture, 2015. *Annual report Retrieved on December*.
- MoARD, 2005. Community Based Participatory Watershed Development: A Guideline. *Addis Ababa Ethiopia*.
- Molla, T. and B., Sisheber, 2017. Estimating soil erosion risk and evaluating erosion control measures for soil conservation planning at Koga watershed in the highlands of Ethiopia. *Solid Earth*, 8: 13–25.
- Mulat, G., Eyayu, M., Mulatie, M. and C., Artemi, 2020. Effects of soil bund and stone-faced soil bund on soil physicochemical properties and crop yield under Rain –fed Conditions of North West Ethiopia.
- Nyssen J, Frankl A, Zenebe A, Deckers J, and J., Poesen 2015. Land management in the northern Ethiopian highlands: local and global perspectives: past, present, and future. *Land Degradation Development*, 26, 759–764.
- Nyssen J, Poesen J, Gebremichael D, Vancampenhout K, D’aes M, Yihdego G, GoversG, Leirs H, Moeyersons J, Naudts J, Haregeweyn N, Haile M, and Decke, 2007. Interdisciplinary

- on-site evaluation of stone bunds to control soil erosion on cropland in Northern Ethiopia. *Soil and Tillage Research*, 94(1), 151-163.
- Oldfield, E.E., Wood, S.A. and M.A., Bradford, 2018. Direct effects of soil OM on productivity mirror those observed with organic amendments. *Plant and Soil*, 423, 363-373.
- ONDANRO: Omo Nada District Agriculture and Natural Resource Office, 2021. *Unpublished Report*.
- Osman, K.T., 2013. Soils: principles, properties and management. Springer, Dordrecht.pia. Addis Ababa, Ethiopia: *Ethiopian Agricultural Transformation Agency (ATA)*.
- Osman, M., and P., Sauerborn, 2001. Soil and water conservation in Ethiopia: Experiences and lessons. *Journal of Soils and Sediments*, 1(2), 117–123.
- Roes, D., Kafiriti, E., Wellens, J., Deckers, J., Maertens, A., Mugogo, S., Dondeyne, K., and K., Descheemaeker 2007. Can soil bunds increase production of rain-fed lowland rice in southern Tanzania? *Agricultural Water Management*, 89, 230-238.
- Schmidt, E., and F., Tadesse, 2012. Household and plot level impact of sustainable land and watershed management practices in the Blue Nile. *Ethiopia strategy support program II Working Paper 42*.
- Selassie, Y.G., Anemut, F. and S., Addisu, 2015. The effects of land use types, management practices and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia. *Environmental Systems Research*, 4(1), 3.
- Sentís, 2002. Assessment of Environmental Impacts Derived of Soil and Water Conservation Practices. *12th ISCO Conference; Beijing*, 282-290.
- Shiferaw Bekele, and T.S., Holden, 1998. Resource degradation and adoption of land conservation technologies in the highlands of Ethiopia: A case study of Andit Tid, North Sheawa. *Agricultural Economics*, 18, 233-247.
- Shiferaw H., 2005. Resource degradation and adoption of land conservation technologies in the Ethiopia highland: case study in Andittid, *north shewa agri. economics*, 18, 233-47.
- Shiferaw, B. and S.T., Holden, 1999. Soil erosion and smallholders' conservation decisions in the highlands of Ethiopia. *World Development*, 27(4), 739-752.

- Shimeles D., 2012. Effectiveness of soil and water conservation measures for land restoration in the Wello area, *northern Ethiopian highlands. Dissertation.*
- Siraj Beshir, Mulugeta Lemeneh, and Endalkachew Kissi., 2015. Soil Fertility Status and Productivity Trends along a Toposequence: A Case of Gilgel Gibe Catchment in Nadda Assendabo Watershed, Southwest Ethiopia. *International Journal of Environmental Protection and Policy*, 3, 137-144.
- SLMP: (Sustainable Land Management Program), 2010. Causes, consequences and solution of land degradation in Omo Nada District: Annual report by SLMP woreda level. *Nada, Ethiopia.*
- Solomon H, James L, B., Woldeamilak 2017. Soil and water conservation effect on soil properties in the Middle Silluh Valley, northern Ethiopia. *Soil and Water Conservation Resource*, 5, 231–240.
- Steenhuis, T., Collic, A., Sileshi, B., Awulachew, A., Abdassalam, A., and Z., Eston, 2008. Modelling Erosion and Sedimentation in upper B Nile (Ethiopia). *Cornel University, Ithaca NY, USA.*
- Tadele A, Aemro T, Yihenew G, Birru Y, Bettina W, and H., Hurni 2013. Soil Properties and Crop Yields along the Terraces and Toposequence of Anjeni Watershed, Central Highlands of Ethiopia Ethiop. *Journal of Agricultural Research*, 5(2).
- Tadele A, Yihenew GS, Mitku H, and C., Yamoh 2011. Effect of soil and water conservation measures on selected soil physical and chemical properties and barley (*Hordeum spp.*) yield. *Journal of Environmental Science and Engineering*, 11, 1483-1495.
- Teklu E, Williams TO, and L., Fanuel 2018. Integrated soil, water and agronomic management effects on crop productivity and selected soil properties in Western Ethiopia. *International Soil and Water Conservation Research*, 6, 305–316.
- Tenge A.J., J. de Graaff and J.P. Hella, 2004. Social and Econ. Factors affecting adoption of soil and water conservation in West Usambara highlands, Tanzania. *Land Degradation Dev.* 15, 99-114.

- Teramaj B., 2015. Effect of SWC Measures on Land Productivity and Crop Yield in Mirab Abaya District of Southern Nations Nationalities and People's Region, Ethiopia, M.Sc. Thesis Haramaya University.
- Terefe, R and B., Lemma, 2016. Effect of different conservation agricultural practices on soil Physical and chemical properties, in Bako Tibe district, West Shoa, Ethiopia. *Journal of Humanities, Arts, Medicine and Sciences*, 2(1), 49-56.
- Tesfaye, G., Debebe, Y., T., Yakob, 2018. Impact of Participatory Integrated Watershed Management on Hydrological, Environment of Watershed and Socio-Economic, Case Study at Somodo Watershed, South Western Ethiopia. The *International Journal of Earth and Environmental Science*, 3 (1), 1-7.
- Tilahun, Y., 1996. "Impacts of conservation bunds on crop yields in Degua Tembien, northern Ethiopia", MSc Thesis, *Agricultural University of Norway, Norway*.
- Trippathi RP, and HP, Singh 1993. Soil erosion and conservation in Ethiopia. Regional soil conservation unit Swedish, international development authority; *Nairobi Kenya*.
- Van Ranst E, Tolossa A.R, Dumon M, Cornelis J-T and J., Deckers 2010. On the origin of planosols – the process offerrolysis revisited. 19th World Congress of Soil Science, Soil solutions for a *Changing World, Brisbane, Australia*.
- Van Reeuwijk, L. P., 1993. Procedures for soil analysis (3rd Ed.). Wageningen, the Netherlands: *International Soil Reference Center (ISRIC)*.
- Vancampenhout, K., Nyssen, J., Gebremichael, D., Deckers J., Poesen, J., Haile, M., and J., Moeyersons, 2006. Stone bunds for soil conservation northern Ethiopian highlands: Impacts on soil fertility and crop yield. *Soil and Tillage Research*, 90(1-3), 1-14.
- Wagayehu B., 2003. Economics of Soil and Water Conservation: Theory and Empirical Application to Subsistence Farming in the Eastern Ethiopian Highlands. Doctoral thesis *Swedish University of Agricultural Sciences, Uppsala*. ISSN 1401-6249, ISBN 91576-6433-1.
- Walie SD, and G., Fisseha 2016. Perception of farmers toward physical soil and water conservation structures in Wyebla Watershed, Northwest Ethiopia. *World Journal Agricultural Science*, 12(1), 57–63.

- Walkley A, and A., Black, 1934. Estimation of soil organic carbon in by the chromic acid titration method. *Soil Science*, 37(1), 29–38.
- WOCAT (World Overview of Conservation Approaches and Technologies), 2007. Where the land is greener-case studies and analysis of soil and water conservation initiatives worldwide. Editors: *Hanspeter Liniger and William Critchley*.
- Wolanco KW, 2015. Evaluating watershed management activities of campaign work in southern nations, nationalities and peoples’ regional state of Ethiopia. *Environ System Research*, 4, 6.
- Woldeamlak B., 2003. Towards Integrated Watershed Management in Highland Ethiopia: The Chemoga Watershed case Study; [PhD Thesis], Wageningen University, *Tropical Resource Management Papers*, No. 44, Wageningen.
- Wolka K, Moges A, and F., Yimer 2011. Effects of level soil bunds and stone bunds on soil properties and its implications for crop production: the case of Bokole watershed, Dawuro zone, Southern Ethiopia. *Agricultural Science*, 02, 357–363.
- Wolka K, Moges A, and F., Yimer 2013. Farmers’ perception of the effects of soil and water conservation structures on crop production: The case of Bokole watershed, Southern Ethiopia. *African Journal of Environmental Science and Technology*, 7(11), 990-1000.
- Wolka, K., 2015. Evaluating watershed management activities of campaign work in Southern Nations, Nationalities and Peoples’ Regional State of Ethiopia. *Environ System Res* 4:6.
- Wolka, K., and M., Negash, 2014. Farmers’ Adoption of SWC technology: A case study of the Bokole and Toni sub-watersheds, Southern Ethiopia. *Journal of Science*, 2 (1), 35–48.
- Wondimu, B., Alemayhu, M., and W., Kebede, 2022. Evaluating farmers’ perception on soil erosion and management of physical soil and water conservation measures in southwest Ethiopia. *Journal of Forestry and Natural Resources*, 1(2):39-53.
- Worku H., 2017. Impact of physical soil and water conservation structure on selected soil physicochemical properties in Gondar Zuriya Woreda. *Resource Environ*, 7(2), 40–48.

- Wubet G, Alemu TA, Birru Y, Yihenew G, Bettina W, and H., Hurni 2013. Impacts of Soil and Water Conservation on Land Suitability to Crops: The Case of Anjeni Watershed, Northwest Ethiopia. *Journal of Agricultural Science*, 5(2), 95.
- Yamane, Taro, 1967. Statistics Introductory Analysis, 2nd Ed., New York: *Harper and Row*.
- Yeshambel M., 2013. Indigenous knowledge practices in soil conservation at Konso people, South Western Ethiopia. *Journal of Agriculture and Environmental Sciences* 2(2), 1-10.
- Yibabe T, Kjell E, Tor-Gunnar V, and H., Mitiku 2002. Soil Conservation in *Tigray, Ethiopia*, *Noragric Report No. 5*.
- Young, A., 1989. Agroforestry for Soil Conservation. CAB International, *Wallingford, England*.

7. APPENDICES

APPENDIX 7.1: QUESTIONNAIRE

Questionnaire for Household Survey

Jimma University College of Agriculture and Veterinary Medicine Department of Natural Resource Management (M.Sc.) Watershed Management Program. A household-level questionnaire was developed to assess the status of soil and water conservation practices and their impact on selected soil properties and crop yield in Omo Nada District, Jimma zone, Oromia Regional State.

Name of Watershed: _____ Date of Interview _____ Ques. Code No _____

Name of Household head: _____

Household characteristics

1. Sex of household head: (1) Male (2) Female
2. Age of household head: _____ in year
3. Family size of households (in number) _____ in number
4. Educational status of the household: (1) Illiterate (2) 1-4 grade (3) 5-8 grade (4) 9-12 grade (5) Above
5. Marital status: (1) Single (2) Married (3) Divorced (4) Widowed/er
6. Household category in terms of wealth status: (1) Better-off (2) Medium (3) Poor
7. The size of the total area of cultivated land in hectares _____
8. What kind of slope of your cultivated land and how much of them use SWC measure?

Order	Slope type	Total hectare	Conserved land (%)
1	Flat (0-5%)		
2	Moderate /Gentle/ (6-15%)		
3	Steep slope (> 15%)		

9. Do you perceive that the slope has impact on productivity of your land? (1) Yes (2) No
10. Which land do you perceive more productive? (1) Flat (2) Moderate (3) Steeply sloping
11. What is the distance of your cultivation field from your home? (In minutes) _____
12. Livestock ownership: Write the number and types of livestock you own at this time?

Order	Type of livestock	Unit	Quantity
1	Total no of cattle owned	Number	
2	Total no of goats and sheep owned	“	
3	Total no of equine owned	“	
4	Total livestock owned	“	

Status of soil and water conservation practices

1. Do you believe soil erosion is a problem in your area? (1) Yes (2) No
2. If yes, what are the main causes of soil erosion? (Multiple responses are possible) (1) Steepness of the land (2) Soil being too erodible (3) Improper construction of SWC structures (4) Lack of maintenance for implemented SWC structures (5) Heavy rainfall/high run-off (6) Deforestation (7) Improper plow (8) Overgrazing (9) Others (specify) _____
3. What are the symptoms of the soil erosion problem? (Multiple response is possible) (1) Decrease soil depth (2) Decreasing productivity (3) Visible rill/gully formation (4) others specify_____
4. How do you see the rate of soil erosion on your cropland and surrounding area since community mobilization of 30 days of participation from year to year? (1) Increasing (2) decreasing (3) No change (4) I do not know (5) NA
5. If so, how do you rate the magnitude of the problem? (1) Very severe (2) Severe (3) Moderate (4) Low (5) Very low
6. Did you use physical SWC measures to control soil erosion? (1) Yes (2) No

- 6.1. If yes, which type of structural soil and water conservation measures do you practice on your cropland? (1) Soil bunds (2) fanaya-juu (3) stone bunds (4) Cut-off drains (5) Check dams (6) other if any _____
- 6.2. If No, what are the major problems in using SWC practices? (1) They reduce arable land (2) They are not suitable for plowing (3) they are expensive labor consuming (4) I do not believe they are important
7. How do you perceive the effectiveness of structural methods to control soil erosion? (1) Less effective (2) Effective (3) More effective (4) Do not know
8. What are those factors that have encouraged you to conserve your farmland by SWC measures? (1) Low crop productivity (2) Extension workers (3) Mass media (4) Neighbors (5) Others _____
9. What is the benefit of physical soil and water conservation measures? (1) Decrease erosion (2) Increase moisture content in the soil (3) Increase yield (4) Protect the land from erosion (5) If others, specify _____
10. To what extent have the SWC activities carried on so far decreased the degree of land degradation? (1) Highly decreased (2) Decreased (3) No change (4) Rather increased
11. If there is a change in environmental condition, what are the specific changes or improvements? (1) Change in temperature (2) Change in rain frequency (3) Increment of tree shades (4) Decrement of soil erosion (5) Others (specify) _____
12. Do SWC activities carried out can bring a significant improvement in your livelihood? (1) Yes (2) No
13. How do you summarize the benefit of soil and water conservation measures of the watershed in income generation? (1) Low (2) Medium (3) Maximum (4) Others (specify) _____
14. From the following Physical soil and water conservation structures which one was mostly practiced in your area? (1) Soil bunds (2) Fayna juu (3) Cut-off drains (4) Check dams
15. Are your SWC structures implemented in your cropland/surroundings maintained? (1) Yes (2) No (3)

15.1. If yes, who did the maintenance work? (1) Community participation (2) Family (3) Hired labor (4) Labor exchange; and how many percent (%) _____ maintained?

15.2. If No, what were the reasons (Why SWC structures not maintained)? (1) I have a shortage of labor (2) High maintenance cost (3) Lack of skill and knowledge (4) There was no need for maintenance (5) If Others _____

16. What is the present status of SWC measures: (1) Totally removed (2) partially (3) No removed (4) Modified (adapted)

17. If any of these is completely/partially damaged, what is the problem/reason?

(1) Lack of maintenance (2) design problem (3) structures by its own (4) Run off (5) Overgrazing (6) others specify _____

18. If the damage is Lack of maintenance, what is the reason? (1) Work is very tedious (2) High maintenances cost (3) It harbors rodents and moles (4) take more productive land (5) Inadequate household labor to maintenance (6) Neighbors are not willing to implement conservation measures (7) If Others _____

19. If the damage is run off/sheet, what is the reason? (1) Weakness of the structure done (2) strength of the run off (3) Old age of structures due to lack of maintenance (4) others, specify _____

20. How frequent do you maintain SWC structures? (1) Every year (2) Within two years (3) when damage happens (4) others, specify _____

21. If you have made any form of destruction of bunds, what is reason for the destruction? (1) Search for fertile soil (2) Planned to construct a new one (3) Reducing the bunds height (4) Need to benefit more land (5) Free grazing (6) Lack of values from the bunds (7) Destroying bad weeds (8) other (specify) _____

22. The status of broken/destroyed SWC structures:

22.1. Linking with land ownership, from implemented structures which one is more damaged?

(1) The structures implemented on private land (2) The structures implemented on communal land (3) Both are equally destroyed

22.2. Linking with slope classes, from implemented structures which one is more damaged?

(1) The structures implemented on the steep/high/slope (2) The structures implemented on the middle slope (3) The structures implemented on low/flat land (4) All are equally broken

22.3. Linking with ages of structures, from implemented structures which one is more damaged? (1) The structures aged 3 years after implementation (2) The structures aged 5 years after implementation (3) The structures aged 7 years after implementation (4) All are equally broken

22.4. Linking with educational status of farmers, from implemented structures which one is more damaged? (1) The structures implemented on the land of literate/knowledgeable/ farmers (2) the structures implemented on the land of illiterate/uneducated/ farmers (3) Both are equally destroyed

22.5. Linking with economic status of farmers, from implemented structures which one is more damaged? (1) The structures implemented on the land of Poor farmers (2) The structures implemented on the land of Medium farmers (3) The structures implemented on the land of Rich farmers (4) All are equally broken

23. How do you evaluate the maintenance of SWC structures after implementation? (1) Very good (2) Good (3) Not maintained

24. What Constraints of adopted method of soil and water conservation Indicators was common in your area from highest to lowest? (1) Constructing physical conservation (2) Increase place of rodents (3) Take high labor force (4) Decrease the size of the plots (5) Problem related to drainage (6) Difficult to plough and turn the oxen (7) if Others _____

25. What are the general problems faced in sustaining soil and water conservation structures? (1) SWC structures are area specific (2) Extension education is not widely diffused (3) Maintenance of SWC structures need more labor and capital (4) Lack of awareness about land degradation problems and importance of SWC measures (5) Problem of land tenure security (6) Shortage of land

Level of adoption of SWC practices

26. Perception of the farmer about soil erosion problem after the SWC measure is done (1) Aggravated (2) Remain constant (3) Improved

27. If there is reduction of soil fertility at your farmland, what Physical measures do you use to curb soil erosion problems? (1) Soil bunds (2) fanaya-juu (3) stone bunds (4) Cut-off drains (5) Check dams (6) Hill side terrace (7) other

28. Effect of inter-structural space (m) of fanya juu and soil bund SWC structures on selected soil properties (1) Lower slope class (2) Middle slope class (3) Upper slope class

Effects of SWC practices on crop yields

29. Do you think that there is a difference in your farm land area before and after the implementation of soil and water conservation (SWC) practices? (1) Yes (2) No

29.1. If your answer is “Yes”, what are those changes you noticed in your farm land? (1) Crop yield production (2) Soil fertility (3) Water availability 4) others if any _____

30. If there is a change in crop yield production, what are the specific changes or improvements? (1) Increment of the crop yield (2) Decrement of the crop yield

31. What is the level of crop productivity per hectare on the conserved land by soil and water conservation measures? _____

32. If there is a change in soil fertility, what are the specific changes or improvements you noticed? (1) Increment of soil thickness (2) Change of soil texture (3) Increment of moisture content

33. If there is a change in water availability, what are the specific changes or improvements you noticed? (1) Development of springs (2) Advent of new springs (3) Emergence and development of marshy areas

34. What crop do you grow on your conserved land? (1) Maize (2) Wheat (3) Teff (4) Beans (5) Vegetables (6) Fruits

35. What do you believe is the impact of SWC practices on crop yield? (1) Large increase (2) moderate increase (3) no change (4) large decrease (5) moderate decrease

I. Interview for Key Informants

1. How do you evaluate level of soil erosion year to year?

2. Do you believe that the SWCM carried on so far has decreased the degree of land degradation and plant/forest depletion?

3. What is the major cause of soil erosion?
4. What type of soil and water conservation structures are mainly implemented in your surrounding?
5. Do you believe that the SWCM carried out so far improved the livelihood of the community members/decreased poverty?
6. What is the extent of the tangible amount of social and economic benefit the community members received as individuals and groups (e.g. agricultural Yield, water supply, wood production, fodder, services etc.) resulted from SWC management?
7. How do you evaluate the status of the implemented SWC measures in your area?
8. How do you keep sustainability of the implemented conservation measures?
9. What are the major constraints to keep sustainability of the implemented conservation measures?
10. What is the present status of SWC measures? (1) Totally removed (2) partially (3) No removed (4) Modified (adapted)
11. How do you describe the status of broken SWC structures in your kebele?
12. Do SWC measures implemented in your farm land/surrounding maintained?
1. Yes 2. No
13. If yes, who did the maintenance work? (a) Community participation (b) Family (c) Hired labor (d) Labor exchange
14. What are the effects of SWC practices on crop yields? Please put down your explanation.

_____.
15. How SWC practices can increase crop yield?
_____.
16. What are the major factors for destruction of implemented SWC structures in your kebele?

17. How do you evaluate the effectiveness implemented SWC practices on soil properties and crop yield?

18. Is there significant difference between ages of soil and water conservation structures?

31. What is the level of crop productivity per hectare on conserved land per hectare in quintal?

II. Focus group discussion

1. What is the level of farmers' view regarding the implemented soil and water conservation measures?

Is there gender based variations? Is there age based variations? Are there house hold size based variations? Is there educational status based variations? Are there farm size based variations?

2. Which type of soil and water conservation measures are very common in your area?

3. Do you believe that the soil and water conservation practices implemented in your area have important benefits to the surrounding community? A. Yes B. No

4. If your answer for question 3 is "Yes" How and why it is important? What should be done to keep its sustainability?

5. If your answer for question 3 is "No" How and why it is not so important? What should be done to as a solution(s) to improve the soil and water conservation practices?

6. In your opinion, what are the major constraints to implement soil and water conservation measures in your area?

APPENDIX 2: Pearson correlations of soil physicochemical properties

Variables	PH	OC	OM	Av-P	TN	CEC	Clay	Silt	Sand	BD
PH	1									
OC	-.021	1								
OM	.105	.105	1							
Av-P	.776**	.039	.349**	1						
TN	.466*	.562**	-.022*	.549	1					
CEC	.070	.561**	.180	.079**	.021*	1				
Clay	.771**	-.106	.339**	.934	.609	.679**	1			
Silt	-.063	.033	-.254	-.006	-.062	-.646	.021	1		
Sand	.090	-.075	-.033	.082	.037	-.777	.081	.459	1	
BD	-.280	-.428*	-.296	-.471**	-.451*	-.018	-.462**	-.068	-.084	1

APPENDIX 3: During Soil and Crop Yield Sampling From the Field



APPENDIX 4: During focus group discussion and key informant interview



APPENDIX 5: During Soil Laboratory Analysis



