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Factors influencing household-level adoption of soil and water conservation practices among smallholder farmers: Application of Binary Logistic Regression

Alemayehu Abera [1], Wasihun Mengiste [2*], Melese Reda [2], Mohamed Abdu [1], Muhammed Adem [3], Abraham Woru Borku [4], Biniyam Assefa [2], Mamush Masha [1]

[1] Department of Geography and Environmental Studies, College of Social Science and Humanities, Mettu University, Mettu, Ethiopia

[2*] Department of Soil Resource and Watershed Management, College of Agriculture and Natural Resource Management, Gambella University, Gambella, Ethiopia

[3] Department of Geography and Environmental Studies, College of Social Science and Humanities, Debark University, Debark, Ethiopia

[4] Department of Geography and Environmental Studies, Arba Minch University, Arba Minch, Ethiopia

Abstract

The study examined the practices and factors affecting the adoption of soil and water conservation (SWC) measures in Mettu district. To achieve this, a cross-sectional survey design with a mixed-methods approach, specifically concurrent triangulation, was employed. A total of 341 households were selected using simple random sampling. Quantitative data were analyzed through descriptive and inferential statistics and a binary logistic regression model, while qualitative data were summarized, narrated, and interpreted. The findings revealed that the primary drivers of soil degradation in the area were deforestation (47.4%), steep slopes (79%), irregular and erosive rainfall (26.2%), land fragmentation (72%), overgrazing (88.2%), weak management practices (58.5%), and improper farming techniques (63.8%). Among these, overgrazing, steep slopes, and land fragmentation were the most influential factors. Indigenous soil conservation practices widely employed by farmers included crop rotation (85.5%), contour plowing (74.2%), fallowing (51%), mulching (77%), manuring (56.7%), and traditional cut-off drains (78Among the introduced soil and water conservation measures, vetiver grass (91.3%) emerged as the most widely adopted practice, followed by soil bunds (70%), hillside terraces (69.5%), agroforestry (40.5%), and micro-basins (38.2%). The binary logistic regression results revealed that gender, household age, education level, access to credit, and landholding size positively and significantly influenced farmers' decisions to adopt SWC practices. In contrast, longer distances between homes and farm plots significantly reduced the likelihood of adoption. Overall, strengthening farmers' awareness supported by coordinated efforts from relevant stakeholders is essential to advancing sustainable soil and water conservation in the district.

Keywords: Adoption; Binary logistic regression model; Cross-sectional design; Mixed research; SWC practices

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*Corresponding Author, E-mail: wasihunmengiste@gmu.edu.et

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Introduction

Africa possesses a natural environment that supports diverse life forms, including a wide range of crops. Agriculture remains the dominant sector and plays a major role in driving economic development across the continent (Belachew *et al.,* 2020). In particular, it is widely recognized as a key engine for economic growth and poverty reduction in Sub-Saharan Africa (SSA). However, despite its vital role in sustaining livelihoods, the sector faces persistent challenges, such as the degradation of natural resources and ongoing soil erosion (Belayneh *et al.,* 2017).

Ethiopia's fast-growing economy, as an agrarian nation, is confronted with comparable issues as a result of persisting land degradation and soil erosion (Wassie, 2020). This has lowered agricultural and livestock yield while increasing food insecurity and poverty (Dofee & Goshu, 2023). Land degradation presents a significant socioeconomic and environmental issue for Ethiopia. This problem arises from various factors, including inadequate agricultural methods, steeply sloped farmland, uneven terrain, unpredictable rainfall patterns, insufficient vegetation, severe soil erosion, and ineffective management of land resources (Awulachew *et al.,* 2009).

In Ethiopia, soil deterioration has reached a critical level (Wassie, 2020). The average yearly rate of soil loss in Ethiopia is estimated to be 12 tons/hectare/year, with rates exceeding 300 tons/hectare/year on steep slopes with little plant cover (Sahal *et al.,* 2023). The Ethiopian government (GoE) has taken significant steps to mitigate the impacts of land degradation. One of the methods has been to spread SWC techniques across the country (Wordofa *et al.,* 2020).

Ethiopia is a country with enormous water resources, diverse flora, wildlife, and significant sub terranean resource (Dondeyne *et al.,* 2024). Nonetheless, people's living standards remain low. Nigussie *et al.* (2017) noted that declining soil fertility and poor resource management in Ethiopia stem mainly from excessive pressure on land resources, various socioeconomic and institutional constraints, improper farming practices, large household sizes, small landholdings, and several other contributing factors. Human activity posed a significant danger to the natural resource base (mainly land, water, and soil) as well as ecological equilibrium in the Ethiopian highlands. This pressure, along with a variety of physical, socioeconomic, and demographic variables, has resulted in significant land degradation. Mettu Woreda in the Ilu Aba Bor Zone is one of the most severely damaged areas due to soil degradation. The most significant technical obstacles are soil erosion and decreased fertility. Thus, soil erosion is becoming more severe in Mattu as a result of the dissected topography and high rainfall during the wet season. As a result, not only does this problem affect agricultural output and revenue, but it also jeopardises family food security in the study region.

However, attempts to promote the technology so far appear to have had little influence on boosting the long-term adoption of conservation measures (Gadisa and Midega 2021). The limited effectiveness of these initiatives highlights the importance of better understanding the variables that hinder the adoption and long-term application of conservation strategies. Despite this, there has been little study on the factors that influence farmers' decisions to embrace SWC strategies. However, variables impacting farmers' practices of traditional and imported soil and water conservation methods have not been well investigated in the Mattu area, and they are frequently implemented poorly. Consequently, this study aimed to evaluate the soil and water conservation practices of farmers and to identify the factors that affect their adoption of both traditional and modern conservation measures implemented by farming households in the Mattu district. (Figure 1).

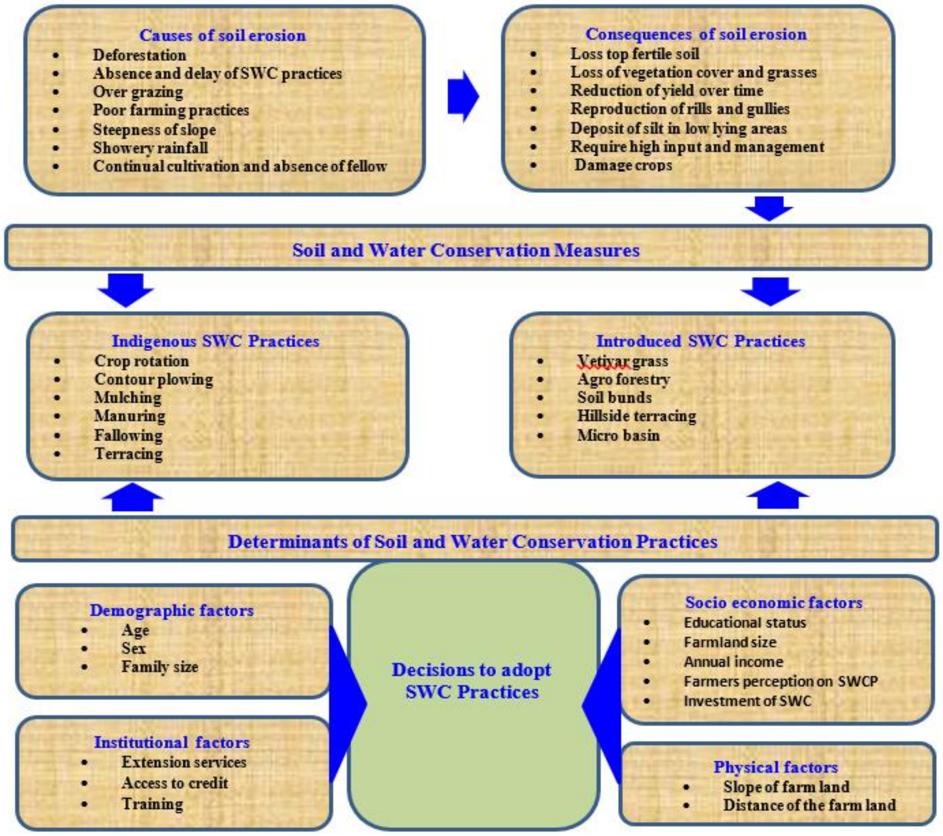

Figure 1. Conceptual framework

2. Research Methodology

2.1. Description of the Study Area

Mattu district is approximately 600 km southwest of Addis Ababa on the road to the Gambella area (Figure 2). Geographically, it is situated between 8° 23' - 8° 31' N latitude and 35° 20' - 35° 50' E longitude (Mattuu District Finance and Economic Development Office Department of Data and Information, 2023). The average yearly rainfall is 2000 millimetres. It has two rainy seasons: Kiremt and Beleg. Kiremt is the district's longest rainy season, lasting from June to August, while Belg is the shortest, lasting from March to May. The highest altitude/elevation in the district is 2,027 m, and the lowest elevation is 1,640 m. The district falls within the woina-dega agro-ecological zone, characterized by moderate temperatures ranging between 18°C and 24°C. The agro climatic zones of the district are sub-tropical, which is suitable for growing important crops such as maize, peas, millet, wheat, barley, ginger, oilseeds, vegetables, and potatoes. Mattu district agricultural practice is a mixed farming system. The district's principal cash crops are coffee, maize, sorghum, teff, wheat, barley, field peas, and beans. The district's geology includes loamy soil, which is important for agricultural cultivation, as well as various beneficial sands, volcanic rocks, and clay soils. The prevalent and important soils in the district range from black-brown vertisol to red sand soils. In the area, black-brown Vertisols are more fertile and productive than the dominant red soils. Although these soils offer a moderate capacity to retain moisture, they are highly susceptible to erosion, which gradually diminishes their agricultural productivity. In addition, the soil in the area was sticky and damp during the rainy season. Conversely, soils found on flatter slopes tend to have a greyish color and often experience waterlogging during the rainy season, although they are generally less vulnerable to erosion. Regarding population and socioeconomic conditions, the total number of households in the rural region comprising 29 peasant associations/kebeles and one town in the district is 13,493, with 11,825 (87.6%) males and 1,668 (12.4%) female-led households. Rural regions had a total population of 53,973, with 21,892 (40.6%) men and 32,081 (59.4%) females.

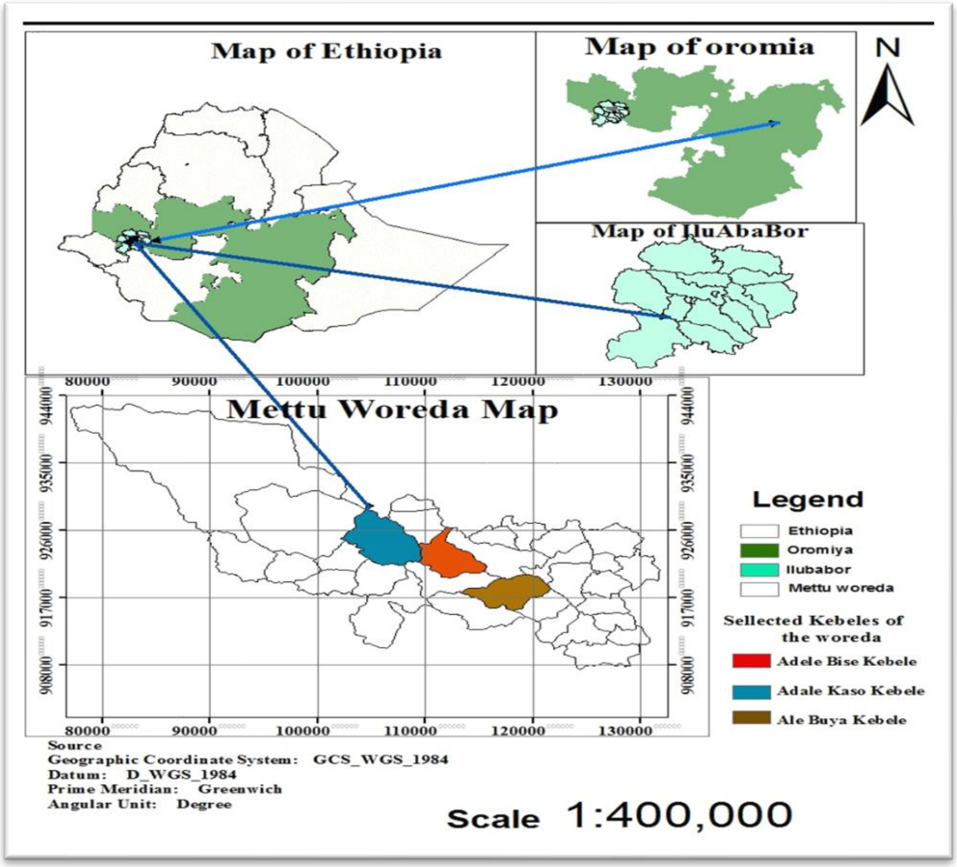

Figure 2. Location map of the study area

According to Mattu Woreda Agricultural and Natural Resource office and land administration office annual report (2023), Land Administration indicates that the Woreda covers an estimated 68,723 hectares. The district's land use and land cover are categorized as follows:

Table 1. Land use and land cover in Mattu Woreda

Land use	Area (hectares)	Percentage
Cultivated land and crop land	45,023.5	65.5%
Grass land	9,072.8	13.2 %
Forest land	10,665.9	15.5 %
Wetlands	1,399	2.03 %
Others	2,162	3.14 %
Total	68,723	100 %

2.2. Research Design and Approach

This study employed a cross-sectional survey design to achieve the intended objectives. In a cross-sectional survey research design, both quantitative and qualitative data were collected at a single point in time (Bryman 2008). A combination of qualitative and quantitative approaches was applied in the study. The quantitative analysis allowed the researcher to assess how indigenous and modern soil and water conservation practices relate to different influencing factors, such as demographic, socio-economic, institutional, and biophysical characteristics. The qualitative approach was employed to gather deeper insights and provide contextual explanations that complement and enhance the quantitative findings.

2.3. Data Source and Data Collection Techniques

Both qualitative and quantitative information were gathered from multiple sources. The study made use of primary as well as secondary data to ensure a comprehensive understanding of the topic, as the two sources enrich and support one another. Secondary data were obtained from a range of published and unpublished materials, including institutional records, reports, journal articles, conference papers, books, and other relevant literature. Primary data were collected through household surveys and reinforced with information from key informant interviews, structured questionnaires, focus group discussions, and direct field observations.

Semi-structured interviews were held with key informants to gather first-hand insights on the implementation of soil and water conservation measures and the factors affecting the adoption of newly introduced SWC practices. Interviews were conducted with one DA of each sample kebele, one model farmer, and one chairman of each sample kebele, as well as woreda and zone agriculture experts. This was accomplished by employing various data collection methods to triangulate the information gathered. Interviews were conducted with key informants, including community leaders such as kebele chairpersons, experienced and model farmers, development agents, agricultural extension workers, soil and water conservation experts, and the Agriculture and Natural Resource Officer from the Mattu Woreda. These participants were purposely selected because of their extensive experience and deep knowledge of soil and water conservation practices. The data collected from the interviews encompassed the various types of conservation measures (both traditional and modern) adopted by the farmers, as well as their extent and effectiveness.

A combination of open- and closed-ended questions was utilized to collect information on farmers' adoption of soil and water conservation (SWC) practices and the factors affecting their choices. The questionnaires were administered with the assistance of trained research aides and local development agents working in the kebeles, which enabled them to support respondents who had difficulty reading or writing. Model farmers were also included to provide insights into the conditions influencing SWC adoption and their conservation practices on both farmland and village surroundings. Their participation was proportionally drawn from the three kebeles Ale Buya, Adele Bse, and Adele Keso based on the survey data collected from sampled households.

A total of two FGDs were employed, each containing six members of the district's natural resource experts and elder farmers from sample kebeles. FGD participants were purposefully selected. The purpose of engaging group discussants is to identify the main themes of the study based on the ideas and perspectives shared by different groups. Purposive sampling is mainly based on their special engagement in the issues of SWC adoption practices, sufficient knowledge about the area, memorization of historical trends in adoption practices, and their major determinants.

Field observations were conducted to generate the required data. Farmers' soil and water conservation practices in the district, including grass strips, crop rotation, hillside terraces, soil bunds, micro-basins, contour farming, and agroforestry, were carefully observed. An observation was conducted through a transect walk with the development agent and kebele administrator in the selected kebele to gather essential physical information and identify the questions to be included in the survey. This method is effective for characterizing and understanding biophysical and terrain features, including topography, erosion status, types of traditional and modern soil and water conservation practices, land use, soil types, slope characteristics, and soil depth in the area.

2.4. Sample size and sampling Technique

A multi-stage sampling method was employed to select the participant households. In the initial stage, the study district was purposefully chosen based on its accessibility in terms of transportation and communication, as well as the severity of the issue under investigation. In the second stage, three kebeles (Ale Buya, Adele Bise, and Adele Keso) were purposively selected. The kebeles were chosen to represent the district in terms of problem severity, adoption of SWC practices, and socio-economic characteristics. In the third stage, household respondents from the three kebeles were chosen using simple random sampling, applying probability proportional to their population size. The total number of participants was calculated using the sample size determination formula proposed by Yemane (1967).

$$n = \left(\frac{N}{1 + N\,(0.e)^2}\right) \quad (1)$$

Where, n= sample, Ntotal population e= error term

Table 2. Sample Respondents of selected Kebeles of Mattu district

Kebles	Total hh heads	Adopter	Non-adopter	Total	SS of adopter	SS of non-adopter
Ale Buya	862	273	589	120	38	82
Adele Bise	486	219	267	44	20	24
AdeleKaso	984	284	700	177	48	129
Total	2332	776	1556	341	106	235

2.5. Method of Data Analysis

Data obtained from multiple sources were examined using both qualitative and quantitative approaches. Descriptive and inferential statistics were conducted with SPSS version 20. Questionnaire responses were summarized using descriptive measures such as percentages, frequencies, means, and standard deviations, with the results presented in tables. The chi-square test was employed to assess differences between expected and observed frequencies for categorical variables, whereas t-tests were conducted to compare the mean values of continuous variables between adopters and non-adopters. To identify the key factors affecting the adoption of soil and water conservation (SWC) practices in the study area, a binary logistic regression model was used. Moreover, qualitative data from interviews, focus group discussions, and field observations were analyzed to support and enrich the quantitative findings.

2.6. Binary logistic regression model specification

Birhan et al. (2009) note that binary logistic regression is a widely used statistical method for modeling the likelihood of two possible outcomes, such as adoption or non-adoption, based on a set of independent variables thought to influence the result. This study applied a binary logistic regression model to examine how demographic, socioeconomic, physical, and institutional factors affect farmers' decisions to adopt soil and water conservation (SWC) practices. This model is particularly applicable when the dependent variable is dichotomous, and the explanatory variables include both continuous and categorical types.

In the logistic regression model, the coefficients reflect how various factors influence the probability of an event in this case, adopting SWC measures where adopters are coded as 1 and non-adopters as 0. The dependent variable is expressed as the natural log of the odds of choosing to adopt. This binary setup allows examination of both the direction and strength of the relationships between the outcome variable and household-level predictors. A positive and statistically significant coefficient indicates that households with higher values for that particular variable are more likely to adopt SWC practices. Overall, the logistic model was used to determine the major factors affecting SWC adoption and to assess their contribution to the likelihood of being an adopter.

2.7. Description of Variables

Dependent Variable: In this research, the dependent variable represents whether or not soil and water conservation (SWC) measures were adopted. A logistic regression model was used since it is appropriate for examining binary response variables that indicate adoption decisions. In the analysis, farmers who implemented SWC practices on their own were coded as 1, while those who did not adopt them were coded as 0.

Independent Variables: The factors affecting farmers' decisions to adopt soil and water conservation (SWC) practices include demographic factors (age, gender, and family size), socio-economic factors (educational level, annual income, perception of SWC, farm size, and investment in SWC), physical factors (land slope and distance of farmland), and institutional factors (access to extension services and training) (Table 3).

Table 3. Definition of explanatory variables used in the model

Variables	Description of explanatory variables	Expected sign
Gender	1 if male, otherwise 0	+ve
Education level	1 if Illiterate, otherwise 0	+ve
Age	Years	-ve
Land holding size	Ha	+ve
Access to extension services	1 if accessed often, otherwise 0	+ve
Farmers perceptions	1 if high, 2 if medium, 3 if low awareness	+ve
Family size	Number	+ve
Annual income	Birr	+ ve
Distance to farm lands	Minutes	-ve
Investment in soil and water conservations	1 if yes, otherwise 0	+ve
Slope of farmland	1 if flat, 2 if moderate, 3 if steep	-ve
Training	1 yes, otherwise 0	+ve

3. Results and Discussion

3.1. Driving forces and consequences of soil erosion in the study area

Soil erosion poses a major threat to the social, economic, and environmental well-being of communities. Although it is a natural process occurring worldwide, its current rate has intensified to the extent that soil is being lost much faster than it is naturally replenished. In Ethiopia, the problem is particularly severe due to heavy rainfall and the country's rugged, highly dissected terrain, where about 70% of the highland area has slopes steeper than 30 percent. Additional pressures such as rapid population growth, farming on steep slopes, removal of natural vegetation, and excessive grazing further accelerate the erosion process (Tessema et al., 2020).

Similar to other areas of Ethiopia, soil erosion is very common in the Mattu woreda of the Ilu Aba Bora zone. This problem increases over time owing to several factors. The causes of soil erosion vary as they are related to various aspects of nature, such as climate, topography, and economic activities. The removal of topsoil is among the land degradation types and is caused by different practices of human beings and nature (Saljnikov *et al.,* 2021). The major causes of soil erosion mentioned by farmers in the study areas are erosive rains (existence of intensive rainfall), steep slopes (topography), limited use of soil conservation practices, damaged conservation structures, overgrazing, clearing of adjacent forests, improper farming practices, tillage, and continual cultivation, which makes the soil loose and bare (Figure 3).

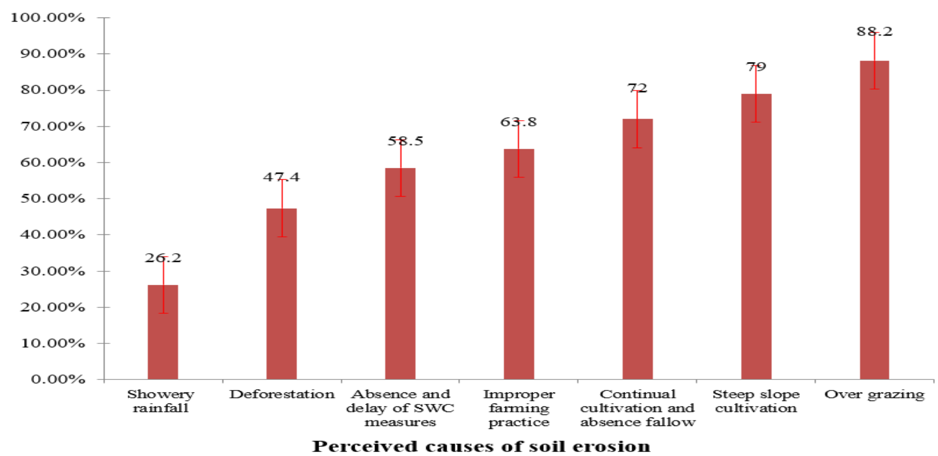

Figure 3. The Main causes of soil erosion in the study area

As indicated above, showery rainfall of the area, steep slope cultivation, deforestation, continual cultivation and absence of fallow, poor farming practice, and over-grazing are the main drivers of soil erosion in the study area.

Deforestation: vegetation shelters the soil from wind and decreases runoff, which in turn decreases the erosion of soil by running and rainwater. This means that the roots of the plant bind the soil together, interweave with other roots, and decrease soil erosion by rain and running water. This indicates that the removal of vegetation for agricultural land expansion increases the rate of surface erosion. The results of this study showed that deforestation or the removal of vegetation in the area is one of the major causes of soil erosion (Assefa & Bork, 2014). Data from key informants indicated that residents in the study area harvest forests for fuelwood, construction materials, and other forest products. Additionally, 47.4% of respondents identified deforestation or vegetation removal as a primary cause of soil erosion.

Steep slope cultivation: The velocity and amount of runoff increase as the slope angle increases. This means that the steeper the slope, the higher the risk of erosion. Soil erosion by water increased as the slope length increased because of the greater accumulation of runoff. The field survey results clearly showed that the steep topography of the study area was the cause of soil erosion (Chen *et al.,* 2022). Thus, it can be concluded that the steep slope of the land is the cause of soil erosion in the area.

Improper farming practice: This is a major cause of soil degradation. Information obtained from key informants, such as DAs, showed that most of the land in the area is steep, and some farmers practice improper farming activities. Some farmers plow their lands up and down on steeper slopes. However, such steep slope areas should be plowed through contour plowing (plowing sideways), which helps farmers reduce the rate of erosion on their farmland (Francaviglia *et al.,* 2023). Field survey results showed that improper farming practices are one of the causes of soil erosion in the area. Of the total, about 63.8% of the sample households reported that improper farming is the cause of soil erosion in the area.

Showery rainfall: Rainfall accounted for about 26.2% of the soil loss, particularly during seedbed preparation periods. According to key informants, when rainfall is high, farmland located on steep slopes is more prone to erosion.

Continuous cultivation and absence of fallowing: Intensive cultivation is one major cause for land degradation. As the area is intensively and continuously cultivated without fallowing, the top soil will be continuously removed by any erosion agent, especially water erosion. The survey result showed that the intensive continuous cultivation is the main cause as farmers are not using fallowing and cultivate continuously for a long period of time in the area.

Overgrazing: The result of this study showed that in the area, overgrazing is the cause of soil erosion. The majority (88.2 %) reported that it is the main cause for soil erosion in the area. Overall, the primary causes of soil erosion in the study area include deforestation, overgrazing, improper farming practices, cultivation on steep slopes, continuous cropping, and heavy rainfall.

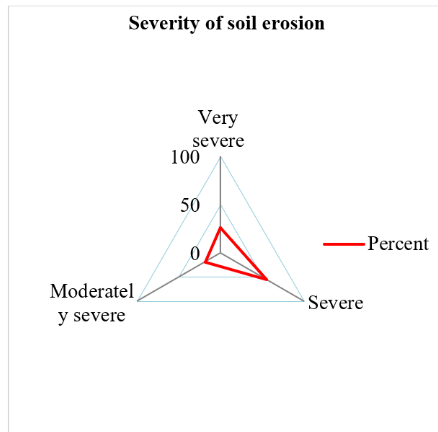

Figure 4. Respondents' perceived severity of soil erosion status in the area

As shown in Figure 4, over half of the respondents reported experiencing severe soil erosion on their farmlands. Specifically, 26.7% indicated that soil erosion was very severe, while 18.8% described it as moderately severe. Participants of key informants from the three kebeles and FGDs expressed that soil erosion is seriously affecting the livelihood of the local community. Most respondents recognized the effects of soil erosion on their farmlands prior to adopting the introduced structural soil and water conservation measures. Despite this awareness, the adoption of these techniques was limited, primarily due to poor farmland management, land fragmentation, and continued deforestation. As shown in Figure 5, reduction of yield over time, loss of top fertile soil/decrease soil fertility, deposit of silt in low-lying areas, reproduction of rills and gullies, and crop damage are the major consequences of soil erosion in the study area.

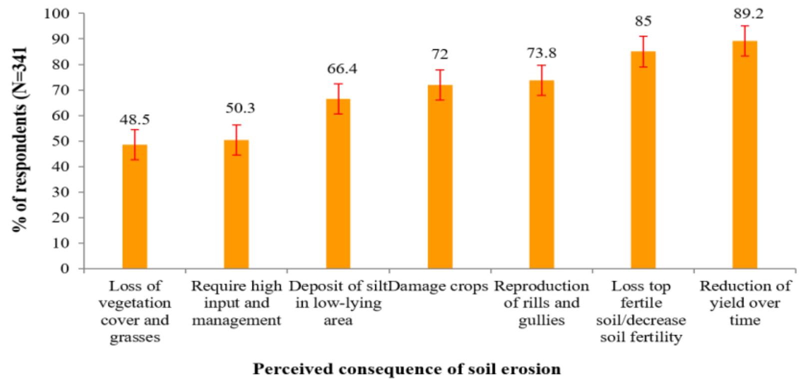

Figure 5. Major consequences of soil erosion in the area

3.2. Indigenous and adopted SWC techniques in the study area

3.2.1. Indigenous soil conservation methods

In Ethiopia, various indigenous land management practices have historically supported sustainable ecosystem management. However, the importance of these traditional knowledge systems in contemporary land management and their role in mitigating land degradation have often been overlooked. To address soil erosion, farmers have employed traditional SWC practices throughout their lives. In the Mattu district, farmers continue to use indigenous conservation methods to prevent soil erosion on their farmland. The field observations and focus group discussion results showed that manuring, fallowing, crop rotation, counter plowing, and traditional water methods are the major indigenous practices for soil fertility maintenance in the area under study.

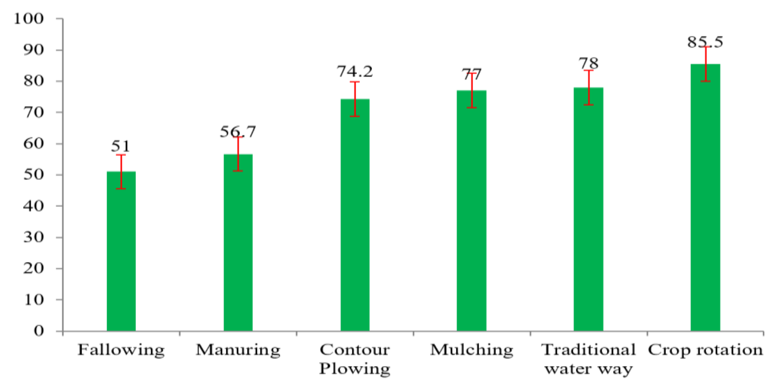

Figure 6. Indigenous soil conservation methods in the study area (Field survey, 2023)

Mulching: covers the surface with grass, crop residue, or other materials to reduce evaporation and erosion. Covering the soil with crop residues can reduce soil loss. As can be observed from Figure 6, the majority of the respondents (77 %) used mulching (leaving crop residue on their farmland), and the remaining 23% reported that they did not use mulching. Hence, mulching is used by people in the area to conserve their soil.

Traditional waterway: This structure is primarily built using an oxen-drawn plow; however, depending on the anticipated runoff, which is influenced by factors such as slope length and gradient, rainfall intensity, and the type of crop planted upstream, additional reinforcement with a hoe may be required. It is constructed along farm plots to safely channel runoff, directing excess water down the slope toward streams and rivers.

Crop rotation: cultivation of different crops: growing the same crop in the same field for successive years exhausts one particular kind of soil nutrient. Crop rotation involves growing different crops sequentially on the same field over time to maintain soil fertility. Information from focus group discussions and key informants indicates that this practice is particularly beneficial when leguminous crops are included in the rotation, as they help increase soil nitrogen content. The survey results also showed that about 85.3% of the respondents use such techniques in the area under study (see Figure 6), and that if they grow maize in one year, they will grow sorghum or other crops in the next year. Consistent with this finding, Belayneh et al. (2017) reported that cereal crops are often planted on the same farm plot only after two or more years, allowing other crops to be grown in the intervening seasons. This rotation helps the soil recover and replenish the nutrients depleted by the previous crops.

Fallowing: This practice involves leaving land unused once its nutrients are depleted. By allowing the soil to rest for a period, the land naturally restores the nutrients that were lost during cultivation. As can be seen from Figure 6, about 51% of the respondents used following, and only 49% of them did not use because of land shortage, as they reported during the survey. Farmers generally leave land fallow for one to two years so it can serve as grazing space and regenerate, depending on the size of their land and its natural recovery capacity. However, rising population pressure has reduced individual landholdings and grazing areas, making it harder for farmers to keep land fallow as before.

Manuring: This is a technique of using animal dung to add fertility to the soil. This means that farmers mix cow dung with soil by plowing the land. As can be seen from Figure 6, 56.7% of the respondents reported that they use manuring on their farmland that is found near their homes. The remaining 44.3% were not used because they had reported fewer cows. This practice is undertaken mainly in households with many livestock.

Contour Plowing: Many farmers extensively implement contour plowing in their fields. They claim that this practice helps reduce the swift downward flow of floodwaters and promotes the percolation of rainwater into the soil.

3.2.2. Adopted soil conservation methods in the study area

To mitigate the problems of soil erosion, the Government of Ethiopia and some Non-Governmental Organizations practiced different ecologically appropriate measures to introduce SWC measures starting from the 1970s in the northern highlands to sustain the traditional one. Similarly, farmers in Mattu District have practiced modern conservation measures to control soil erosion in their farmlands. Adoption refers to the decision by an economic unit to regularly implement a new technology or practice. Farmers who apply at least one of the newly introduced techniques are considered adopters. As shown in Figure 7, the major soil and water conservation practices adopted in the study area include hillside terracing, vetiver grass, soil bund, agroforestry, and others. However, the practical level of these technologies is very limited. This is mainly attributed to the lack of continuous follow-up, introduction, and awareness creation by agricultural offices and kebele agricultural agents, as well as the interest and attitude of the farmers.

Grass strips/Vetiver grass: A widely practiced grass strip method in the area is the use of vetiver grass technology. Vetiver grass offers a simple, practical, cost-effective, low-maintenance, and highly efficient solution for soil and water conservation, sediment control, land stabilization, and land rehabilitation. It is environmentally friendly, and when planted in single rows, forms hedge that slow and spread runoff, reduce soil erosion, conserve moisture, and trap sediments and agrochemicals on-site (Figure 8). The grass has an extremely deep and dense root system that firmly binds the soil, making it resistant to dislodgment under high water flow. Unlike other modern conservation methods, vetiver grass is widely visible across farmers' fields. It is a perennial that can grow up to two meters in height with roots extending three meters deep. It is highly adaptable to diverse soil types, including acidic, sodic, alkaline, and saline soils, and can withstand various climatic conditions, including drought and fire. Vetiver grass is commonly used for controlling soil erosion, stabilizing slopes, improving agricultural productivity, mitigating disasters, treating contaminated water, reclaiming wetland soils, reducing sedimentation, and enhancing water storage.

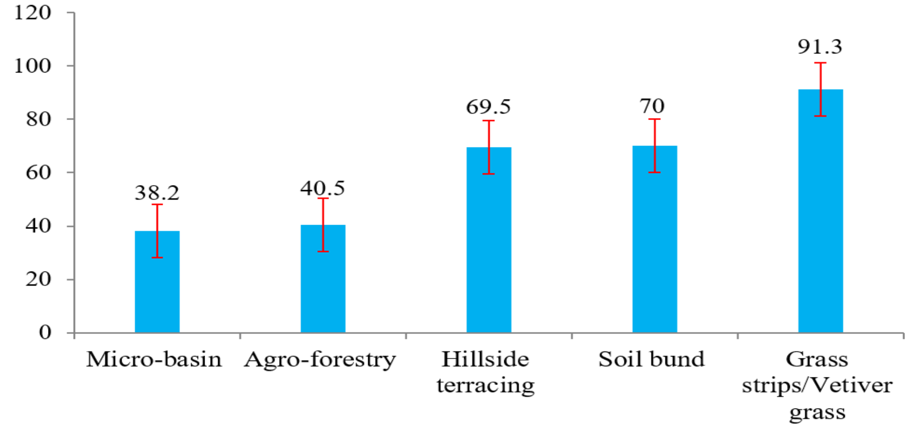

Figure 7. Soil conservation practices adopted in the study area

Due to its versatility and adaptability, most farmers have adopted vetiver grass, particularly because it requires relatively low labor. Interviews with farmers highlighted two main reasons for its adoption. First, vetiver hedges reduce overland flow during rains, retain nutrient-rich sediments on the farm, and protect soil fertility. Second, the grass provides fodder for livestock, either through direct grazing or cut-and-carry methods, which is particularly valuable for farmers with limited land. In such cases, dedicating part of the farm to vetiver strips allows for both soil and water conservation and livestock feeding. Overall, this method is an effective strategy for sustaining soil and water resources, enhancing food production, and supporting livestock management.

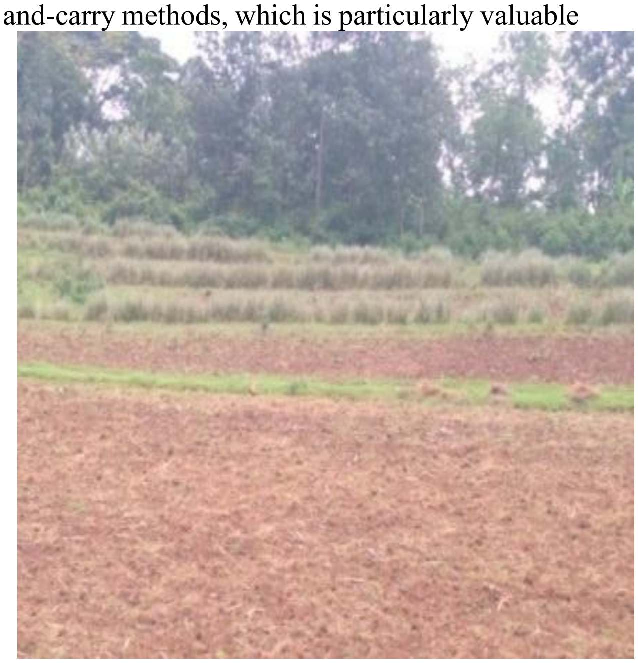

Figure 8. Vetivar grass of the study area (Source: Field photo, 2023)

Soil bund: A soil embankment, known as a level bund, is constructed along the contour with a basin on its upper side. This structure slows down or stops overland flow, thereby reducing soil erosion. Key informants indicated that level bunds typically measure 50–75 cm in height and 100–150 cm in bottom width, with a water retention basin on the upslope side. Tied ridges, placed approximately every 10 meters within the basin, prevent runoff from spilling sideways and channel overflow to a specific point along the bund. For slopes under 15%, the vertical spacing between bunds is 1 meter, whereas steeper slopes require spacing about 2.5 times the depth of the workable soil. These structures are commonly built on moderately sloping farmlands (Figure 9). This aligns with the findings of Yifru and Miheretu (2022), which showed that farmers' perception of erosion problems and soil and water conservation (SWC) practices significantly influences adoption. Survey results indicated that 70% of respondents had adopted soil bunds. In moderately sloped areas, farmers construct bunds to control erosion, which gradually stabilize as grasses grow on the risers. Compared to stone terraces, soil bunds require less labor and are easier to build, though stone bunds are limited in area. Level bunds help control runoff and erosion by shortening field slopes and reducing the velocity of water flow. According to WFP (2005), these structures are effective in preventing soil loss, retaining soil moisture, and ultimately improving farmland productivity.

Figure 9. Soil and stone bund structures of the study area (Source: Field photo, 2023)

Hillside Terracing: Another soil conservation practice observed in the study area is hillside terracing. According to key informants, this method involves creating leveled strips of land along the contour specifically for tree planting. Hillside terraces are typically up to 1 meter wide and are built at vertical intervals of 2–5 meters. These terraces are only constructed when there is a clear need to justify their use. Survey findings indicated that 69.5% of respondents practiced hillside terracing, while 29.5% did not (Figure 7). Farmers typically construct terraces on lower slopes to control erosion. Additionally, other soil conservation practices in the area include elephant grass strips, agroforestry, and micro-basins.

Figure 10. Hillsides terracing structures of the study area (Source: Field photo, 2023)

Key informant interviews and focus group discussions (FGDs) indicated that the use of both indigenous and introduced soil and water conservation measures is limited in the study area. Conservation activities are largely implemented through a top-down approach, with minimal farmer involvement in the planning and design stages, and little follow-up after the construction of structural conservation measures. FGD participants noted that soil bunds were sometimes built on flat farmland where they were unnecessary, and there was little effort to incorporate farmers' indigenous knowledge. On flat lands, induced bunds were closely spaced and narrow, making oxen plowing difficult, and in small landholdings, this reduced the cultivable area.

Agroforestry is another important practice, involving the intentional integration of perennial trees with crops and livestock within the same management unit. Survey results showed that 40.5% of respondents practiced agroforestry on their farms, particularly around homesteads, for multiple purposes (Figure 7). Key informants and FGD participants confirmed that agroforestry is common on farmer plots, with households planting trees such as mango, avocado, banana, and papaya. Field observations revealed that crops like maize and chat were cultivated alongside sugarcane, avocado, potato, pepper, and cabbage, with shrubs and trees often planted along soil and water conservation structures to support bunds (Figure 11). Edible fruit trees, including apple, suspania, and lucinia, were also used for forage while helping to protect soil from erosion. Agroforestry provides distinct benefits for soil and water conservation, including root stabilization, erosion control, and maintenance of soil fertility.

Figure 11. Agro-forestry practice of the study area (Source: Field photo, 2023)

Micro-basin: Small structures known as micro-basins are created by excavating half-circular basins for tree planting. These micro-basins vary in size depending on their purpose for water conservation; they tend to be smaller in moist agro-ecological zones and larger in arid areas. In the study area, there are some practices involving micro-basins for cultivating fruit trees; however, this practice is limited to a small number of farmers (Figure 11). During focus group discussion, the majority of the sample respondent farmers households indicated the practice is limited to specific farmers due to its perceived ecological irrelevance and farmers' low awareness of conservation structures.

Figure 12. Micro-basin structures of the study area (Source: Field photo, 2023)

Overall, information gathered from key informants and focus group discussion participants revealed that a variety of soil and water conservation practices are employed in the study area. Farmers utilize both traditional and improved technologies to combat land degradation, particularly soil erosion. These practices include applying manure, traditional water management techniques, constructing soil bunds, leaving crop residues in the fields, and practicing fallowing. The study found that farmers have adopted several technology options for soil and water conservation, such as hillside terracing, agroforestry, vetiver grass, and micro-basins.

3.3. Adoption status of soil and water conservation practices

Adopters and non-adopters differed in five of the hypothesized continuous variables (Table 4). The average ages of adopters and non-adopters were approximately 39 and 37 years, respectively. In terms of household size, adopters showed a slightly larger household size compared to non-adopters. The results in Table 4 indicate that, on average, adopters had 4.91 family members, while non-adopters had an average of 4.67 members, with the difference being statistically significant. This suggests that the adoption of soil and water conservation practices tends to increase with household size. This result aligns with the findings of Belachew (2020), which indicated that household size positively influenced the adoption of soil and water conservation (SWC) practices in the northwest Ethiopian highlands. Additionally, the table below reveals that adopters had a slightly larger farmland size compared to non-adopters. The descriptive statistics showed that adopters, on average, had 2.86 ha compared to 2.34 ha of non-adopter and the difference among the groups (adopters and non-adopters) was also statistically significant. This implies that as the size of farmland increase so does the adoption of soil and water conservation practices.

3.3.1. Analysis of factors influencing SWCP in Mattu district, Ethiopia

The proximity of farmland to farmers' homes plays an important role in their decision to implement soil and water conservation practices. As presented in Table 4, the average walking time from homesteads to the nearest farmland was

42.06 minutes for adopters and 48.64 minutes for non-adopters. The results show that adopters tended to have shorter distances to their fields than non-adopters, and this difference was statistically significant. This suggests that the likelihood of adopting soil and water conservation practices increases as the distance from farmers' residences to their farmland decreases. Interviews with key informants indicated that engaging in off-farm activities provides an additional income source, helping cover costs for home consumption products, agricultural fertilizers, livestock, clothing, and potentially hiring labor for soil conservation efforts. Farmers involved in off-farm activities had a higher likelihood of adopting soil and water conservation (SWC) practices compared to those who did not. Off-farm employment can improve liquidity (Anley et al. 2006).

Table 4. Continuous variables distinguishing adopters from non-adopters and t-test

Variables	Adoption Category of SWC practices				t-value
	Adopters		Non-adopters		
	Mean	Std.D	Mean	Std.D	
Age of the household (in years)	38.5	8.48	36.57	10.69	0.047*
Family size of the households (in numbers)	4.91	6.44	4.67	6.47	0.017*
Farmland size of the households (in hectares)	2.86	0.826	2.34	0.872	0.000**
Distance of farmland (in minutes)	42.06	6.52	48.64	8.12	0.037**
Annual income of the households (in Birr)	13,014.89	6.60	13,150.9	8.27	0.000**

Source: SPSS result *statistically significant at 1, 5, and 10 probability levels, respectively

Adopters and non-adopters also differed in seven hypothesized categorical explanatory variables (see Table 4). The survey results revealed that among male respondents, 49.9% were involved in SWC practices, with 48.08% being adopters and 53.8% non-adopters. Similarly, of the female respondents, representing 50.1%, 51.92% were adopters and 46.2% non-adopters of SWC practices. The chi-square analysis indicated that the differences between the two groups were not statistically significant, with a chi-square statistic of 1.278 and a p-value of 0.263, which is greater than the 0.05 significance level. Therefore, the observed and expected distributions do not differ significantly from the sampled 341 household heads, 38.7% were illiterate, 37.1% were adopters, and 62.9% were non-adopters of SWC practices. Of the 61.3% of literate households, 42.45% and 57.56% were adopters and non-adopters of SWC practices, respectively. Chi-square test (χ^2=6.028; P=0.018) revealed that the two groups were statistically significant. From this, one can easily state that SWC practice perceptions increased with the increase in the educational status of farmers' households. This is because educated farmers have more opportunities to access information and imitate and cope with technologies than illiterate farmers. The survey results indicate that better-educated households possess a more accurate understanding of soil erosion issues and greater knowledge related to soil and water conservation (SWC). Consequently, they are more likely to engage in conservation activities. The educational attainment of farmers significantly impacts their engagement in soil and water conservation practices. Higher literacy levels among farmers can lead to notable differences in the adoption of these conservation measures on their land, positively affecting overall soil conservation efforts.

Investment in soil and water conservation: Of the 51.6% of farmer household heads who supported investment in soil and water conservation practices, 62.12% were adopters, and 37.9% were non-adopters. Of the respondents, 48.4% did not decide to invest in soil and water conservation practices, and 28.3% and 71.7% were adopters and non-adopters, respectively. This suggests that, despite the long-term benefits of investing in soil and water conservation (SWC) practices, most farmers are cautious and readily recognize the seriousness of soil erosion. They respond to ongoing soil fertility loss, declining production, and changing climate conditions by applying the knowledge and skills passed down from their families on their lands. The chi-square test ($\chi2$ = 61.815; P = 0.000) also revealed that the two groups were statistically significant.

Table 5. Chi-square (χ2) analysis of categorical explanatory variables distinguishing Adopters and non-adopters and factors influencing SWC practices in Mattu District, Ethiopia

Independent Variables		Adopter		Non-adopter		χ^2-	P-
		No	%	No	%		
Gender	Male	113	48.08	57	53.8		
	Female	122	51.92	49	46.2		
	Total	235	100	106	100	1.278	0.263
Educational status	Illiterate	87	37.1	45	42.45		
	Literate	148	62.9	61	57.56		
	Total	235	1000	106	100	6.028	0.018*
Access to extension services	Yes	112	47.65	42	39.6		
	No	123	52.35	64	60.4		
	Total	235	100	106	100	5.401	0.021*
Training	Yes	90	38.3	52	49		
	No	145	61.7	54	51		
	Total	235		106	100	6.923	0.010**
Farmers Perceptions	High	130	55.32	40	37.7		
	Low	105	44.68	66	62.3		
	Total	235	100	106	100	27.236	0.000**
Slope of farm land	Flat	57	24.25	42	39.6		
	Moderately slope	106	45.1	41	38.7		
	Steep slope	72	30.6	23	21.7		
	Total	235	100	106	100	14.60	0.001**
Investment in soil and water conservations	Yes	146	62.12	30	28.3		
	No	89	37.9	76	71.7		
	Total	235	100	106	100	61.815	0.000**

Source: SPSS result *statistically significant at < 0.05 ** statistically significant at 0.001

Regarding training on SWC practice, out of 41.7% of respondents getting training on soil and water conservation practice, 38.3% are adopters and 61.7% are non-adopters. Of the 58.3% of respondents who had not accessed training, adopters of SWC measures were 49%, and 51% were non-adopters. This implies that farmers who have not accessed training have gained experience from their neighbours and, traditionally, from their elders or farmers adjacent to each other.

An interview held with some farmer households and FGD discussions with DA, Extension workers, and Woreda natural resource experts confirmed that the gap in training is the major constraint of SWC adoption in general. The chi-square test ($\chi2 = 6.923$; $P = 0.010$) also revealed access to training, influencing farmers' adoption decisions.

Access to agricultural extension services is an important component of the institutional support that helps farmers enhance their use of both traditional and modern soil and water conservation (SWC) practices. In this study, it was expected that farmers would receive such support through development agents (DAs), participation in field days, and brief training programs. The survey results in Table 5 revealed that about 45.2% of surveyed farmers sometimes received extension services, 47.65% and 52.35% were adopters and non-adopters of SWC measures, and about 54.8% of respondents usually received extension services, 39.6% and 60.4% were adopters and non-adopters of SWC practices, respectively. The chi-square test ($\chi2 = 5.401$; $P = 0.021$) revealed a statistically significant relationship between extension service contact and the adoption of soil and water conservation practices.

In contrast to the above result, agricultural experts and DAs of the sampled kebeles argued that they were serving and delivering the required service to the farmers as much as possible to achieve rural renovation and technology transfer in line with government interests.

The slope of the farmland is taken as an indicator of soil and water loss from farmlands. Out of 29.03%, 43.1%, and 27.85% of respondents owned flat, moderately sloped, and steep slope farmlands, 24.25%, 45.1%, and 30.6% were adopters, and 38.6%, 39.7%, and 21.7% were non-adopters of soil and water conservation practices, respectively. Farmers working on moderately sloped farmland were more aware of the risks of soil loss compared to those cultivating on steep or flat lands. The chi-square analysis (χ^2 = 14.60; P = 0.001) showed a statistically significant link between the slope of farmland and the adoption of soil and water conservation practices. This suggests that farmers with more erosion-prone land are more inclined to implement both traditional and modern SWC measures compared to those with less vulnerable farmland. Regarding farmers' perceptions of soil erosion and soil and water conservation (SWC) practices (see Table 5), it was revealed that out of 50.2% of respondents, 37.7% were adopters and 62.3% were non-adopters of SWC practices. Among the 49.8% of respondents who recognized soil erosion as a problem on their farmlands and acknowledged the importance of implementing SWC measures, 55.3% were adopters, while 44.68% were non-adopters.

These findings suggest that while recognizing the erosion issue is essential for adopting conservation practices, it is not sufficient on its own. Notably, some farmers who perceived no erosion threat on their farms still adopted SWC measures. Key informant interviews and focus group discussions confirmed that soil erosion significantly contributes to declining soil fertility, reduced production, and the emergence of rill and gully erosion, and noticeable surface runoff during the rainy season. The chi-square test (χ^2 = 27.236; P = 0.000) revealed a significant association between farmers' perception of erosion as a problem and their adoption of soil and water conservation practices.

3.4. Factors influencing the Adoption of SWC Practices in the study area

3.4.1. The binary logistic regression model result

The adoption of soil and water conservation (SWC) practices can be influenced by multiple factors across different areas. In Mattu District, the main factors affecting SWC adoption were examined by analyzing the dependent variable—adoption of SWC practices—against various explanatory variables. A logistic regression model was used to identify the factors that significantly influenced farmers' decisions to implement these practices. The estimated coefficients of the binary logistic regression model, along with Wald test results, standard errors, and significance levels, are presented in Table 6.

The dependent variable was examined in relation to various predictor or explanatory variables. The model was statistically significant (χ^2 = 149.527, p = 0.000), indicating strong explanatory power. The Nagelkerke R^2 value indicated that approximately 68.9% of the variation in SWC adoption was explained by the explanatory variables included in the analysis. Among the hypothesized factors, only those that were statistically significant are reported. The binary logistic regression results showed that gender, household age, educational level, distance to the farm plot, access to credit, and landholding size had a significant influence ($p < 0.05$) on households' decisions to adopt soil and water conservation practices in the study area (see Table 6).

Table 6. Result of the binary logistic regression model

Variable	B	S.E.	Wald	P-value	Exp(B)
Gender	.023	.211	1.330	. 002*	1.208
Age	.314	.112	2.106	.004*	1.222
Educational status	1.12	.055	.008	.000**	.611
Landholding size	1.233	1.41	2.020	.001**	.430
Access to extension	.331	.012	5.220	.561	1.01
Farm experience	.805	.376	4.241	.501	.321
Access to training	.146	.052	6.162	.457	1.153
Annual income	- .440	.004	4.31	.751	2.05
Distance from farm plot	-1.410	.220	.310	.008*	1.326
Access to credit	.796	.117	46.30	.000**	2.217
Constant	.421	.152	2.131	.352	1.231

Chi-square: 149.527; -2 Log likelihood: 312.04; Cox & Snell R Square: 0.266; Nagelkerke R Square: 0.689; P-value: 0.000. Source: SPSS result *statistically significant at < 0.05; ** statistically significant at 0.001.

Gender: The binary logistic regression results indicated that gender significantly impacts the adoption of soil and water conservation (SWC) practices, with a statistically positive relationship (β = 0.023, P = 0.002*). The Wald statistic of 1.330 suggested that male household heads were more engaged in adopting SWC practices, with an odds ratio of 1.208 compared to female heads. This finding implies that gender plays a noteworthy role in influencing the adoption of soil conservation practices.

The key informants explained that “this is due to gender stereotypes in the study area that disseminate the idea that SWC practices are the role of males, and most of the time female households spend their time doing various works in home, like cooking food, caring for children, and other non-economic household activities, and men are doing various work at field. As a result, females lack time to participate in SWC practices in their farmlands even if they wish to do so.”

Thus, one can conclude that gender influences soil and water conservation practices and that male households participate more in soil conservation activities than female households. Consistent with the findings of Asfaw and Neka (2017), male-headed households are more likely to adopt SWC practices than their counterparts.

Age: The age of farmers is one factor influencing their adoption of soil and water conservation measures. The model results indicated a positive and significant relationship between age and the adoption of soil and water conservation (SWC) practices, suggesting that age serves as a proxy for household farming experience. As households age, it is expected that they accumulate greater knowledge and experience related to farming. Similarly, Melese *et al.* (2019) noted that the positive effect of age indicates that older farmers gain valuable insights into the importance of land management over time. Amsalu and de Graaff (2007) also demonstrated that older farmers are more likely to adopt conservation practices compared to their younger counterparts, likely due to their greater experience in recognizing erosion issues and their typically lower participation in off-farm activities.

Educational status: It is hypothesized that farmers with higher educational attainment have a better understanding of the issues related to soil and water conservation and are more equipped to make informed decisions regarding the maintenance of conservation structures. The model results confirmed this hypothesis, demonstrating a significant relationship between educational status and the adoption of soil and water conservation (SWC) practices (β = 1.12, P = 0.000*). This indicates that education plays a crucial role in enhancing farmers' awareness and engagement in effective conservation practices. This suggests that education enhances households’ management capacity and their understanding of newly introduced SWC measures. Educated farmers are more likely to recognize the severity of soil erosion, actively seek information, and effectively implement the knowledge and skills passed down from their ancestors, as well as insights gained from extension services and other sources. Similarly, Asfaw and Neka (2017) found that better-educated farmers are more likely to adopt improved soil and water conservation practices compared to non-educated (illiterate) farmers.

Additionally, the binary logistic regression analysis revealed a positive and significant relationship between landholding size and the adoption of SWC practices, with a significance level of 5% (β = 1.233, P = 0.01). This shows that larger landholdings are associated with a greater likelihood of adopting these practices.

Land size is a critical factor influencing the adoption of soil conservation measures. Respondents with larger farmlands were more likely to engage in these practices, while those with smaller plots exhibited negative attitudes and a lack of trust in soil conservation measures. They also reported that participation in the planning and design of conservation programs was limited. In the study area, landholdings varied from less than one hectare to more than three hectares, with an average of 2.6 hectares per household. Many farmers expressed concerns that implementing conservation methods on small land areas was not advisable, a sentiment echoed by Zegeye *et al.* (2010).

Distance from Farm: Astatistically significant positive association was found between the distance of farmland from farmers' residences and the adoption of SWC practices (β = -1.410, P =

0.008). This indicates that households with farm plots closer to their homes are more likely to adopt SWC measures compared to those with plots further away. The odds ratio suggests that for every minute increase in distance from the farmer's home, the likelihood of adopting both indigenous and introduced SWC practices decreases. This finding implies that less time and energy are required to implement conservation measures on nearby farmlands. Consequently, farmers with plots situated far from their residences may be discouraged from conserving their lands. Supporting this conclusion, Zerssa *et al.* (2009) noted that distant farmlands receive less attention due to the increased time and effort needed for management. Similarly, Belachew *et al*. (2020) confirmed that greater distances negatively impact the adoption of soil and water conservation practices.

Access to credit significantly affects the adoption of soil and water conservation practices, as highlighted in numerous empirical studies. In this research, the impact of credit was assessed because it enables households to purchase agricultural inputs during critical periods. Given that most households in the study area are economically disadvantaged, access to credit services is viewed as a potential means of alleviating poverty and enhancing agricultural productivity. As anticipated, the results were positive and significant at the 1% level (β = 0.796, P = 0.000**), indicating that access to credit has a strong influence on the decision to adopt SWC practices.

5. Conclusions and Recommendations

5.1 Conclusions

Soil erosion is a common problem in different parts of Ethiopia, particularly in the Mattu District. Hence, this study aimed to assess soil erosion conditions and the application of suitable conservation practices in the study area. According to the major findings of the study area, removal of forest vegetation or deforestation, overgrazing, steep slope cultivation, showery rainfall, continual cultivation and absence of fallow, delay of SWC measures, and improper farming practices were found to be the main drivers of soil erosion, whereas reduction in yield over time, decrease in soil fertility, deposition of silt in low-lying areas, reproduction of rills and gullies, and crop damage were the major consequences of soil erosion in the study area. A range of soil and water conservation practices has been implemented to prevent land degradation, particularly soil erosion. In the study area, farmers use several traditional and improved soil and water conservation technologies. These technologies include the application of manure, traditional water methods, soil bunds, leaving crop residues in the field, and fallowing. The study found that farmers adopted various technological options for soil and water conservation, such as hillside terracing, agro-forestry, grass strips/vetiver grass, soil bunds, and micro-basins. The results of binary logistic regression analysis indicated that gender, age, educational status, distance to the farm plot, and landholding size significantly affected households' decisions to adopt soil and water conservation practices in the study area.

The implications of factors influencing the adoption of Soil and Water Conservation (SWC) practices for sustainable management and policy applications are essentially about identifying leverage points for effective intervention. In short, the main implication is that SWC policies must move beyond blanket technological promotion and incorporate the diverse socio-economic, institutional, and knowledge realities of the local land users to achieve high and sustained adoption rates.

5.2 Recommendations

The development policy and program intervention plan aimed at enhancing land productivity and protecting the environment through soil and water conservation strategies in the study district should consider the most significant variables related to the types of technologies and farmers' preferences. Based on the findings of this study, the following recommendations are proposed for improving soil and water conservation measures in the area:

✓ Minimize Forest Degradation: Address the major challenge of soil erosion caused by converting vegetated land to agricultural use. The government and stakeholders should work to reduce forest degradation, enhance productivity in the agricultural sector using modern technologies, provide necessary agricultural infrastructure, and promote off-farm activities.

- ✓ Enforce Watershed Protection Laws: The government should commit to enforcing laws around watershed management that protect soil and water conservation structures and ensure their sustainability. Shared Responsibility: All relevant government bodies and community members should share the responsibility for conserving soil and water resources in the area.
- ✓ Integration of Conservation Measures: While many farmers in Mattu Woreda practice improved SWC measures, integrating these with indigenous practices could yield better economic outcomes. SWC experts should consider local farmers' preferences when planning, designing, and implementing structural conservation measures.
- ✓ Strengthen Extension Systems: Extension systems for SWC activities should be expanded through development agents and other stakeholders. Consistent grassroots efforts are essential to minimize and halt soil erosion on farmers' plots, highlighting the impact of soil erosion on livelihoods, including future generations.
- ✓ Participatory Community Training: Community-level integrated training is crucial for young, laggard, and less experienced farmers, helping them develop better awareness and technical skills regarding soil erosion and the long-term benefits of investing in SWC practices.
- ✓ Focus on Soil Type and Slope: When implementing structural SWC technologies, farmers should prioritize soil types and slope characteristics that are relevant to the severity of erosion in the study area.
- ✓ Raise Awareness: Concerned bodies should educate farmers about soil erosion and conservation practices. Development agents, in collaboration with Woreda agricultural and administrative offices, should guide the community in minimizing forest degradation to reduce soil erosion. Local authorities should also encourage NGO involvement in conserving natural resources like soil, water, and forests.
- ✓ Improve Livestock Quality: There should be a focus on enhancing the quality of livestock and developing improved forage to increase income from livestock production.
- ✓ Promote Participatory Interventions: Authorities should implement participatory, locally adapted interventions, strengthen institutional and technical support, provide targeted economic incentives, and prioritize land tenure security.

Data Availability

All data pertinent to this study are included in the paper and its accompanying Supporting Information file.

Conflicts of Interest

This study was carried out collaboratively by all authors. Each author has read and approved the final manuscript. The authors declare that there are no conflicts of interest.

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Author Contributions

Wasihun Mengiste: Conceptualization, methodology, formal analysis and investigation, visualization, resources, writing-original draft preparation.
Alemayehu Abera: Conceptualization, methodology, formal analysis, and investigation.
Melese Reda: Conceptualization, methodology, formal analysis, and investigation, manuscript editing.
Muhammed Adem: Conceptualization, methodology, formal analysis, and investigation.
Abraham Woru Borku: Conceptualization, methodology, formal analysis, and investigation
Biniyam Assefa: Conceptualization, methodology, formal analysis, and investigation
Mamush Masha: Conceptualization, methodology, formal analysis, and investigation

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