Heliyon 9 (2023) e18332

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Adoption of soil and water conservation technologies and its effects on soil properties: Evidences from Southwest Ethiopia

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ARTICLE INFO

Keywords:
Soil bund
Slope position
Conservation
Croplands
Soil erosion
Adoption

ABSTRACT

In Ethiopia, national wide soil and water conservation (SWC) is going on since 2010/11in all agro-climatic zones and farming systems. Therefore, this study evaluated the effects of soil bund on soil physico-chemical properties and factors determining farmers' decision on the adoption of SWC technologies in a watershed located in the sub-humid climate of southwest Ethiopia. Two sub-watersheds, namely Nada and Gulufa in the Gilgel Gibe I catchment, were selected for this study. Thirty-six soil samples were collected from non-conserved croplands and croplands conserved with soil bunds (older than 4 years) at three slope positions, namely lower (5–10%), middle (10–15%), and upper (>15%). Both composite and undisturbed top soil (0–30 cm) samples were collected and soil physicochemical properties were determined following standard laboratory procedures. The generated soil physicochemical data was analyzed using one-way ANOVA and the mean separation was carried out by the Tukey test using R-version 3.5.2. To generate survey data, 267 households were randomly selected from the two sub-watersheds and interviewed using a structured questionnaire. The collected survey data was analyzed using a binary logit model using STATA software version 13. The result showed that the implemented soil bund significantly ($p < 0.05$) improved soil BD, SMC, pH, SOC, TN and CEC at the three slope positions for both the Nada and Gulufa sub-watersheds. The binary logit model showed that personal, socio-economic, institutional, and physical factors influencing the decision of a farmer's adoption. This revealed the need to consider personal, socio-economic, institutional, and physical factors to enhance the willingness probability of adoption. Besides, the improvements in soil properties as a result of conservation practices can help to create awareness.

1. Introduction

Soil erosion and nutrient depletion caused by a poor farming system, combined with a lack of sustainable land management, have contributed to persistent food insecurity and poverty in humid and sub-humid tropical regions. Soil erosion is threatening crop production through loss of crucial soil nutrients from agricultural fields and by reducing per capita food biomass [1,2]. In developing countries, it further aggravates - persistent poverty and food insecurity [3] as well as significantly affects smallholders farmers livelihood and the national economy [4–6] since a significantly large number of the population is dependent on agriculture [7]. The

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https://doi.org/10.1016/j.heliyon.2023.e18332
Received 27 January 2022; Received in revised form 12 July 2023; Accepted 13 July 2023
Available online 16 July 2023
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estimated rate of soil losses from different land covers is about 1.493 billion tons per year, of which 672 million tons per year at a rate of 42 tons $ha^{-1}yr^{-1}$ is from cultivation land [8] which is far from the maximum tolerable limit of 22 ton $ha^{-1}yr^{-1}$ in Ethiopia [4]. Soil loss is estimated to reduce land productivity and/or crop yield at a rate of 1.5 to 2.2% per year from cultivation lands in the absence of soil and water conservation measures [9,10], as well as a 3% decrease in agricultural GDP [11,12]. Soil erosion is a major concern for Ethiopia, where agriculture accounts for 47% of GDP, employment for nearly 85% of the population and account for 84% of export revenues [13]. Besides, soil erosion poses a threat to downstream ecosystems and developments by depositing sediment load, reducing the benefit that would be gained from the development [14–19]. Tamene and Vlek [20] pointed out that the off-site effect of soil erosion causes rapid siltation of streams and reservoirs, accelerating the storage capacity loss of water harvesting schemes.

In Ethiopia, institutionalized natural resources management for the first time recognized and got policy attention in 1974 following the drought and devastating famine of that time [21]. However, for about four decades implementations of soil and water conservation (SWC) and afforestation through government and donors were limited to drought-prone areas of the country (i.e., mainly in the northern part of Ethiopia) for two reasons [22,23]. The two main reasons at the time were 1) Interest of donors who supported food for work and 2) Because of the misunderstanding that soil erosion is not a serious problem in high potential (i.e., high rainfall) areas. Implementation approach was in the form of food for work. Later on, national wide, implementation of community-based soil and water conservation practices were launched in 2010 due to the growing evidences on the impact of soil erosion on national economy and environment and the positive outcomes of SWC technologies and lesson drown from northern part of Ethiopia mainly Tigray regional state [23].

Soil and water conservation measures are expected to improve soil physical and chemical properties and thus increase agronomic yield, reduce surface runoff and soil erosion, and increase water yield in catchment. Despite such normal expectations and objectives, studies on the impacts of SWC on soil properties show large disparities. Some studies have reported improvements in soil properties including carbon sequestration [24] reduce runoff and soil erosion [25]and increase water yield [26]while others have also reported no significant impacts [27]. The large variations of SWC impacts could be due to 1) variations in ages of studied SWC measures, 2) types and proper design of SWC measures, 3) adoption variations and management of implemented SWC by farmers, 4) difference in agro-ecology/climate [28–30] 5) difference in methods of impact study among scientists. Sometimes good SWC technologies had negative impact, because of poor implementation. In Ethiopia, over the last 5 decades, large volumes of research finding are conducted on impacts of soil and water conservations on soil properties. However, almost all studies were conducted in northern parts of the countries where SWC implemented for long time and drought is major concern for livelihood. A better understanding of the constraints

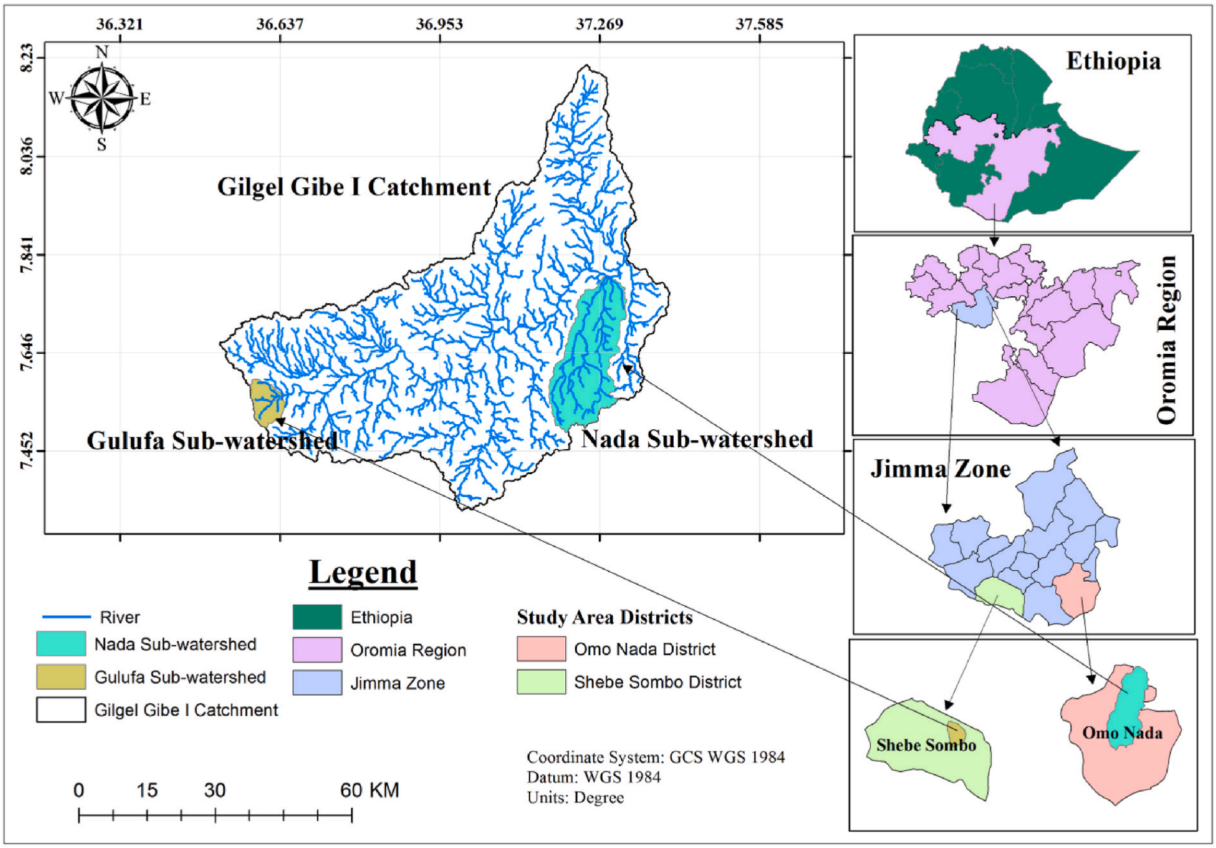

Fig. 1. Map of Nada sub-watershed and Gulufa sub-watershed.

that influence farmers' adoption behavior is thus critical for developing and transferring promising pro-poor policies that can stimulate and sustain SWC adoption and agricultural productivity. Little work has been done on the impacts of SWC on soil properties in sub-humid area of southwest Ethiopia. Additionally, mode of implementation of SWC and SWC technology types implemented are also different between the two agro-ecological regions (i.e., between high rainfall areas of southwest Ethiopia and drought prone northern parts).

However, there is limited research evidence regarding the effects of conservation practices such as soil bunds constructed via community mobilization on soil properties and the factors that determine farmers' adoption of the soil and water conservation

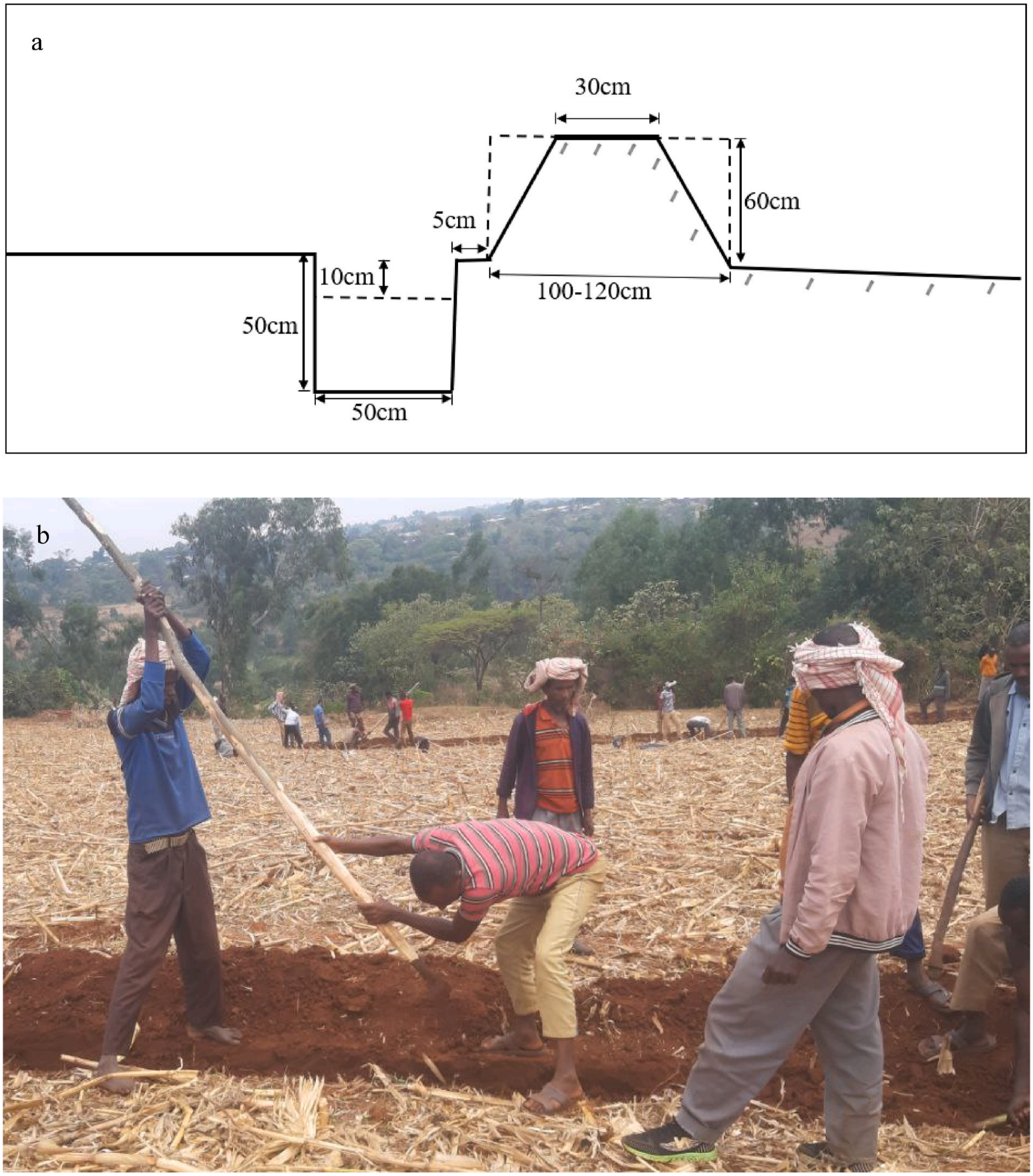

Fig. 2. Soil bund constructed through community participation (a) design of the soil bund (adopted from Refs. [31,33]) and (b) participation of farmers in constructing soil bund (Photo documented by Omo Nada district's agriculture and natural resource office).

technologies in southwestern Ethiopia. Therefore, the main objective of this study was to investigate the effects of SWC technologies on soil physicochemical properties and factors determining farmers' decisions on the adoption of SWC technologies in Nada and Gulufa sub-watersheds of southwest Ethiopia.

2. Materials and methods

2.1. Description of study areas

This study was conducted in Nada sub-watershed, and Gulufa sub-watershed which are parts of the Gilgel Gibe I catchment in Southwest Ethiopia (Fig. 1). The selection of the study watersheds was based on the potential of the community-based soil and water conservation practices and their existence in the Gilgel Gibe I catchment. The Nada sub-watershed is geographically located between 7°29′09″ to 7°47′52″ N latitude and 37^{0}10′00″ to 37°19′23″ E longitude. It is situated at an elevation ranging from a minimum of 1650 to a maximum of 3342 m. a.s.l. The area of the watershed covered 34901 ha. Gulufa sub-watershed is geographically located between 7°29′51″ to 7°35′42″ N latitude and 36°34′38″ to 36°38′52″ E longitude. It is situated at an elevation ranging from a minimum of 1911 to a maximum of 2638 m. a.s.l. The area covered by the watershed is 5526 ha. Both sub-watersheds are above 1500 m. a.s.l. and are parts of the Ethiopian highlands. The climate is humid, subtropical with a peak rainfall occurring between mid-June to mid-September (long rainy season) and within a smaller (short rainy season) from February to May, with mean annual rainfall of 1700 mm. The mean annual minimum and maximum temperature being 11 and 25 °C respectively.

2.2. Soil sampling and analysis techniques

Soil sampling plots were purposely selected both from conserved croplands with soil bunds and from non-conserved croplands without soil bund practices. Soil bund is the most dominantly practiced soil and water conservation technology on croplands in the study area for the last 8 years. The soil bunds were constructed by community mobilization (Fig. 2 b) as part of integrated participatory watershed management campaign. The design and specifications of the bunds were (Fig. 2 a) as per the guideline provided for development agents from ministry of agriculture and rural development (The former name of the current ministry of agriculture) [31–33]. Considering the land owner consent, the bunds were spaced with sufficient spaces between the bunds to make oxen pulling plough easy. The vertical interval ranges 1–2.5 m depending on the slope.

For this experiment, soil bund ages greater than four years old were purposely selected (Fig. 3). Croplands with and without soil bunds were classified into three based on slope class. The three slope classes include a lower slope position (5–10%), a medium slope position (10–15%), or an upper slope position (>15%). The purpose of classifying the landscape to three slope classes is based on the assumption that soils in the same slope class are more or less similar and thus soil sampling was under taken based on this slope category for both conserved and non-conserved croplands.

Fig. 3. Smallholder farmers' farmland in the landscape at the study site.

Both disturbed (composite) and undisturbed top soil (0–30 cm) samples were collected from February to May with three replications from each slope category of conserved farmlands and adjacent non-conserved farmlands from the two sub-watersheds for laboratory analysis. Furthermore, we collected composite soil samples (i.e., one soil sample consists of many sub samples) that are mixed or homogenized to be representative for large area. Composite samples were collected with a sharp-edged and closed, circular auger pushed manually down the soil profile after establishing 10 m × 10 m plots at the three slope positions for both watersheds considering the age of the soil bunds. A total of 36 composite soil samples (2 conservations x 3 slope positions x 3 replication x 2 sub-watershed) were collected in a random sampling technique for laboratory analysis.

Composite soil samples collected from experimental sites were transported to the soil laboratory for selected soil physicochemical analyses. The soil samples were air-dried at room temperature, grounded, homogenized, and passed through a 2 mm sieve before laboratory analysis. The analysis was carried out in the soil laboratory of Jimma University College of Agriculture and Veterinary Medicine following standard procedures as indicated in (Table 1).

2.3. Method of data collection for household survey

Cochran's [43] sample size determination method was used to randomly select 267 households in both sub-watershed areas. Structured questionnaires were used to collect demographic, socio-economic, institutional and physical farmland characteristics from sample households via face-to-face interview. Focus Group Discussion was conducted to collect qualitative information and to further strength the quantitative data. The discussion was made with experts, Development Agents (DAs) and office holders in the study area.

2.4. Statistical analysis

One-way analysis of variance (ANOVA) was used to test the significant difference of soil parameters due to soil and water conservation practices considering three slope positions at a $P < 0.05$ level of significance following the normality test using Shapiro-Wilk test. Mean separations were tested using the Tukey test and Pearson's correlation using R-software version 3.5.2.

Both descriptive and econometric model were used for household survey data analysis. Descriptive statistics like mean, standard deviation, percentage, frequency, minimum and maximum were executed. A binary logistic regression model was used to analyze factors determining the decision of farmers to adopt SWC practices which is a dichotomous dependent variable. The model helped to determine the influence of multiple explanatory variables on the dichotomous dependent variable. According to Tabachnick and Fidell [44], binary logit model can analyze a mix of independent variables such as continuous, discrete, and dichotomous and it is said to be useful (Table 2). Therefore, this model was used to determine factors influencing farmers' decision to adopt or not to adopt SWC technologies.

The logistic regression model can be specified as follows (equations (1) and (2)).

The response variable is a dichotomous variable that can be expressed as $Y = 0$ for non-adopters and $Y = 1$ for adopters.

$$Odds\ of\ adoption = \frac{probability\ of\ adoption\ (P_i)}{probability\ of\ nonadoption\ (P_0)} = \exp\ (Y)_i = \frac{P_i}{P_0}, P_0 = 1 - P_i$$

$$= > \exp\ (Y)_i = \frac{P_i}{1 - P_i} = \exp\ (Y_i)(1 - P_i) = P_i = exp\ (Y)_i - P_i \exp\ (Y)_i = P_i$$

$$P_i = \frac{\exp\ (Y_i)}{(1 + \exp(Y_i))} \tag{1}$$

Where, P_i is the probability of being adopter for the i^{th} household; exp is exponent; Y_i is a set of personal, socio-economic, institutional, and physical factors influencing adoption (X_i) and the disturbance term (ε_i) is expressed as:

Table 1
Summary of laboratory method and procedures used to determine soil physicochemical.

S/N	Parameters	Method or procedures
1.	Soil bulk density	Core method [34]
2.	Soil moisture content	Gravimetric method [34]
3.	Soil particle size distribution	Hydrometer
4.	soil textural class	United States Department of Agriculture (USDA) textural triangle [35]
5.	Soil pH	Potentiometrically using a standard pH meter (1:2.5 soil-to-water ratio) [36]
6.	Soil organic carbon (SOC %)	Walkley and Black wet digestion [37]
7.	Soil organic matter	Multiply SOC by 1.724 [37]
8.	Total nitrogen	Kjeldahl digestion and titration procedure
9.	Available phosphorus	spectrophotometer at a wavelength of 882 nm [38]
10.	Cation exchange capacity (CEC)	Ammonium acetate method
11.	Exchangeable acidity	Saturating the soil samples with potassium chloride solution and titrated with sodium hydroxide [39]
12.	Exchangeable aluminum	Atomic absorption a spectrophotometer (AAS) at 309.3 nm using acetylene flame [40]
13.	Exchangeable hydrogen	Difference between exchangeable acidity and exchangeable aluminum [41,42]

Table 2
Description of independent variables.

Variable name	Variable type	Variable description	Expected sign	Previous studies
Sex	Dummy	Sex of household head: 1 = male and 0 = female	+	[45]
Age	Continuous	Age of household head in a number of years	+/−	[46,47]
Family size	Discrete	Household's number of family members	+	[48]
Education	Discrete	Household head's education status in a number of years in school	+/−	[46,48]
Perception	Dummy	Perception of farmers on soil erosion seriousness: 1 = not a problem, 2 = a problem	+	[46]
Land size	Continuous	Total landholding size of the household in hectares	+/−	[49,50]
TLU	Continuous	Livestock ownership of household head in tropical livestock unit (TLU) in number	+	
Material	Dummy	Household material resource availability to construct soil and water conservation technologies "1" for if a household had material and "0" for if a household had no material	+	[51]
Responsibility	Dummy	Household head responsibility in kebele/social group "1" if responsible and "0" if not responsible	+	[52]
Extension	Dummy	Household head access to extension service "1" for if a household had extension service and "0" for if a household had no extension service	+	[47]
Distance	Continuous	Household's farmland distance from the local market in minutes	–	[53]
Slope	Dummy	The slope of farmland "1" if flat; "2″if steep	+	[54]
Workability	Dummy	The perception of the households on the construction of soil and water conservation technologies "1" for if difficult, "2" for if easy	+	[46]

$$Y_i = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i \tag{2}$$

$$\begin{aligned} L_i = \ln\left(\frac{Pi}{1-Pi}\right) = Y_i \\ = \beta_0 + \beta_1 Sex + \beta_2 Age + \beta_3 Family\ size + \beta_4 Education + \beta_5 Land\ size + \beta_6 TLU + \beta_7 Responsibility + \beta_8 Extension + \beta_9 Distance \\ + \beta_{10} Perception + \beta_{11} Slope + \beta_{12} Material + \beta_{13} Workability + \varepsilon_i \end{aligned}$$

Where L_i is the logit model; ln is the natural logarithm; β_0 is the intercept; β_i is the slope of variables in the model; $\beta_{1\text{-}13}$ is the slope of corresponding variables in the model and n is the number of explanatory variables.

The marginal effect is used to determine the influences of the independent variable per unit change on the dependent variable while everything else is constant. The computation of marginal effects is meaningful for the binary logit model because estimated parameter coefficients do not represent the magnitudes of the effects of independent variables on the categories of the dependent variable. In the logit model, the slope coefficient of a variable gives the change in the log of the odds associated with a unit change in that variable while holding all other variables constant. The logit model assumes that the log of the odds ratio is linearly related to X_i. Therefore, the marginal effects of changes in the explanatory variables are

$$\frac{\partial \Pr\ (Y = 1/X)}{\partial X} = \beta_i P_i (1 - P_i)$$

This is the rate of change in the probability of an event happening, where β_i is the (partial regression) coefficient of the ith regressor. But all the variables included in the analysis are involved in evaluating P_i. Accordingly, the marginal effects of the explanatory variables on the dependent variable are reported.

2.4.1. Definition of variables

In this study, adoption is treated as a dichotomous dependent variable that is 1 for if the farmer is used any of SWC measures at least on one of his/her farmland (adopter) and 0 for if the farmer has not used any SWC measures on any of his/her farmlands (non-adopter).

Before running the model, all the hypothesized explanatory variables were checked for the issue of multicollinearity. To check the multicollinearity problem, correlation matrices were used for all type explanatory variables. Accordingly, the relationship between explanatory variables less than correlation coefficient 0.8 is taken as a free of multicollinearity problem for both sub-watersheds (Table 3 and Table 4).

3. Results

3.1. The effect of soil and water conservation measures on soil physical properties

Community based constructed soil bunds have a significant effect on soil bulk density ($P < 0.05$) in both sub-watersheds. Lower soil bulk density (0.94 g/cm^3) and (1.00 g/cm^3) values were measured in conserved farm plots at lower slope positions of Nada sub-watershed and Gulufa sub-watershed, respectively, compared to relatively average higher soil bulk density (1.22 g/cm^3) and (1.47 g/cm^3) values measured at upper slope positions of non-conserved farmland plots in Nada sub-watershed and Gulufa sub-watershed respectively (Table 5). The overall mean of soil BD in the study areas (Nada and Gulufa sub-watersheds) covered with SWC practises at

Table 3
Correlation matrices of explanatory variables for Nada sub-watershed.

Variables	Sex	Age	Family size	Education status	Landholding size	TLU	Responsibility	Extension service	Distance from market	Perception	Slope	Material	Workability
Sex	1												
Age	.0359	1											
Family size	.1795	−.1125	1										
Education status	−.0124	−.0746	−.1559	1									
Landholding size	.03	−.0141	.1754	−.1486	1								
TLU	.0683	−.0272	.0592	−.1314	.1281	1							
Responsibility	.0263	−.0878	.052	.1895	−.2596	−.0771	1						
Extension service	.0816	−.0814	−.0213	.2842	.1354	−.1078	.3466	1					
Distance from market	.118	−.0007	.2756	−.4073	.2439	.2485	−.2949	−.2028	1				
Perception	.1179	−.2041	.0538	.2206	−.1674	−.0267	.4522	.2961	−.2241	1			
Slope	.2229	−.1049	−.0721	.0614	−.0789	.0273	.2294	.2868	−.0235	.2967	1		
Material	−.0094	−.0495	−.0698	.0942	−.196	−.0583	.5165	.2657	−.1487	.3849	.3142	1	
workability	.1017	−.2146	−.0532	.1977	−.1011	−.0886	.3873	.3079	−.2301	.4849	.2295	.2495	1

Table 4

Correlation matrices of explanatory variables for Gulufa sub-watershed.

Variables	Sex	Age	Family size	Education status	Landholding size	TLU	Responsibility	Extension service	Distance from market	Perception	Slope	Material	Workability
Sex	1												
Age	−.0788	1											
Family size	−.1894	.0547	1										
Education status	.0577	−.2895	.0211	1									
Landholding size	−.0495	.1743	.0876	−.3625	1								
TLU	−.0731	.0412	.0088	−.0837	.0901	1							
Responsibility	−.002	−.1919	−.0867	.3940	−.4513	.012	1						
Extension service	.0205	−.0232	−.0134	−.1458	−.0993	−.0257	.1464	1					
Distance from market	−.0356	.2909	−.0724	−.2529	.1917	−.0169	−.2066	−.0061	1				
Perception	−.0093	−.1157	.021	.2072	−.2096	.1359	.2812	.2261	−.1077	1			
Slope	.1736	−.1413	−.0406	.1867	−.2585	−.0103	.1874	.1267	−.1809	.1541	1		
Material	.0957	−.0789	−.0682	.1462	−.2414	.0114	.1931	.196	−.1566	.129	.2587	1	
Workability	.0775	−.2288	.0231	.3286	−.3234	−.0134	.3015	.1701	−.2027	.2676	.2307	.1644	1

adequate soil depth (0–30 cm) was lower than in the non-conserved areas. At both sites, the non-conserved plots had a significantly higher mean value of BD than the conserved plots.

Soil moisture content, a key attribute of agricultural production, was significantly ($P < 0.05$) influenced by conservation measures. At Gulufa sub-watershed and Nada sub-watershed, respectively, farm plots with soil bunds at lower slope positions had relatively higher mean soil moisture content, 42.99 and 36.25%, compared to 30.33 and 32.58% for non-conserved farm plots and the same slope positions (Table 5).

The soil textural fractions had showed significant variation with conservation and slope positions at ($P < 0.05$). The mean value of the sand and silt fractions was higher in the non-conserved farm plots than in the conserved farm plots (Table 5). However, clay fractions were observed to have the highest mean value at conserved farm plots than the non-conserved farm plots.

The sand fraction was higher on the upper slope than on the lower slope. However, the clay content of the upper slope was lower than that of the lower slope. The soil textural class has no variation with conservation and slope position variations in the Nada sub-watershed, which was clayey. However, in the case of the Gulufa sub-watershed, the soil textural class varied both with conservation and slope positions (Table 5). The clayey textural class was observed on conserved and lower slope position farmlands, whereas the clay loam soil textural class was observed on non-conserved, middle, and upper slope position farmlands.

3.2. The effect of soil and water conservation measures on soil chemical properties

The soil pH showed significant ($P < 0.05$) variation between farmlands with conservation measures and those without conservation measures. The mean values of soil pH measured were relatively higher (5.42) and (5.35) at the lower slope positions of the conserved farmlands as compared to the values measured at the upper slope positions for the non-conserved (4.35) and (4.32) farmlands in the Nada and Gulufa sub-watersheds, respectively (Table 6).

Results of the experiment indicated that both soil organic matter and total nitrogen were significantly ($P < 0.05$) influenced by the conservation and slope position of the farmlands in both the Nada and Gulufa sub-watersheds. The mean values of soil organic matter on conserved farmlands at the lower slope positions (3.47%) and (3.35%) were significantly higher as compared to (2.59%) and (2.60%) on non-conserved farmlands at the lower slope positions in the Nada and Gulufa sub-watershed, respectively. The lowest mean SOM (1.59%) was observed in non-conserved farmlands at the upper slope position in the Gulufa sub-watershed. Similarly, the mean value of total nitrogen of the soil on conserved farmland (0.17%) and (0.22%) was significantly higher as compared to (0.13%) and (0.11%) on non-conserved farmlands at the lower slope positions in the Nada and Gulufa sub-watersheds, respectively (Table 6).

Similarly, cation exchange capacity was significantly influenced by the implemented SWC measures and slope position of the farmlands. The mean values of cation exchange capacity on conserved farmlands (34.30 cmol (+)/kg) and (30.16 cmol (+)/kg) was significantly ($p < 0.05$) higher as compared to (30.06 cmol (+)/kg) and (24.57 cmol (+)/kg) non-conserved farmlands at the lower slope position in Nada and Gulufa sub-watersheds, respectively (Table 6). Although numerical higher in conserved farmland, there was no statistically significant difference in available phosphorus between conserved and non-conserved farmlands. Similarly, landscape position had no effect on available phosphorus at both study sites.

Table 5
The effect of soil bund on soil physical properties at different slope position.

Soil physical properties	Slope class	Nada sub-watershed		Gulufa sub-watershed	
		Conserved	Non-conserved	Conserved	Non-conserved
BD (g/cm^3)	Lower	0.94^b	1.09^a	1.00^b	1.31^a
	Middle	1.04^b	1.16^a	1.09^b	1.36^a
	Upper	1.12^b	1.22^a	1.20^b	1.47^a
SMC (%)	Lower	36.25^a	32.58^b	42.99^a	30.73^b
	Middle	34.20^a	31.32^b	37.11^a	27.08^b
	Upper	33.42^a	29.05^b	33.74^a	18.33^b
Clay (%)	Lower	59.33^a	48.67^b	50.00^a	39.60^b
	Middle	55.33^a	44.67^b	44.13^a	34.00^b
	Upper	53.33^a	40.67^b	41.73^a	29.33^b
Silt (%)	Lower	21.00^a	24.00^a	26.67^a	28.40^a
	Middle	15.33^b	25.33^a	29.53^b	32.40^a
	Upper	15.13^b	25.40^a	30.07^b	34.33^a
Sand (%)	Lower	19.67^b	27.33^a	23.33^b	32.00^a
	Middle	29.33^a	30.00^a	26.33^b	33.60^a
	Upper	31.53^b	33.93^a	28.20^b	36.33^a
Texture class		Clay	Clay	Clay	Clay loam

BD is top soil bulk density; SMC is gravimetric soil moisture content; Conserved is farmland conserved with soil bund; Non-conserved is farmland not conserved with any of soil and water conservation measures. Mean values followed by different letters (a,b) in the superscript along the same rows are for conservation difference within similar slope positions, and letters (a, b) in the subscript along the same column is slope difference is statistically different at $P \leq 0.05$.

Table 6
The effect of conservation and slope classes on soil chemical properties.

Soil chemical properties	Slope class	Nada sub-watershed		Gulufa sub-watershed	
		Conserved	Non-conserved	Conserved	Non-conserved
pH (H_2O)	Lower	5.42^a	4.70^b	5.35^a	4.96^b
	middle	5.02^a	4.49^b	5.19^a	4.67^b
	Upper	4.86^a	4.35^b	5.08^a	4.32^b
SOM (%)	Lower	3.47^a	2.59^b	4.35^a	2.60^b
	middle	2.94^a	2.24^b	3.43^a	2.13^b
	Upper	2.76^a	1.78^b	3.23^a	1.59^b
SOC (%)	Lower	2.02^a	1.50^b	2.52^a	1.51^b
	middle	1.70^a	1.30^b	1.99^a	1.24^b
	Upper	1.60^a	1.04^b	1.87^a	0.92^b
TN (%)	Lower	0.17^a	0.13^b	0.22^a	0.13^b
	middle	0.15^a	0.11^b	0.17^a	0.11^b
	Upper	0.14^a	0.09^b	0.16^a	0.08^b
CEC (cmol (+)/kg)	Lower	34.30^a	30.06^b	30.16^a	24.57^b
	middle	33.26^a	27.69^b	29.27^a	22.51^b
	Upper	31.50^a	26.24^b	26.99^a	19.99^b
Av.P (ppm)	Lower	23.46^a	18.78^a	18.20^a	13.33^a
	middle	20.57^a	17.34^a	15.41^a	10.89a
	Upper	17.43^a	14.69^a	13.40^a	10.27^a
EA (cmol (+)/kg)	Lower	0.72^b	1.38^b	0.64^b	1.34^a
	middle	1.13^b	1.53^b	0.79^b	1.52^a
	Upper	1.33^b	1.76^b	0.96^b	2.35^a
Al^{3+} (cmol (+)/kg)	Lower	0.43^a	1.02^a	0.35^b	1.09^a
	middle	0.76^a	1.29^a	0.63^b	1.19^a
	Upper	1.00^a	1.49^a	0.65^b	1.43^a
H^+ (cmol (+)/kg)	Lower	0.29^a	0.37^a	0.29^a	0.26^a
	middle	0.37^a	0.24^a	0.17^a	0.33^a
	Upper	0.33^a	0.27^a	0.30^b	0.93^a

pH – hydrogen ion concentration; SOC – soil organic carbon; SOM – soil organic matter; TN – total nitrogen; CEC – cation exchange capacity; Av. P – available phosphorus; EA – exchangeable acidity; Al^{3+} – exchangeable aluminum and H^+ – exchangeable hydrogen. Mean values followed by different letters (a, b, c) in the superscript along the same rows are for conservation difference within similar slope positions, and letters (a, b, c) in the subscript along the same column is slope difference are statistically different at $P \leq 0.05$. ppm is parts per million. 1 ppm = 1 mg/kg.

3.3. Determinants of farmers' decision to adopt soil and water conservation technologies

The results of predicted binary logit model coefficients, marginal effect, standard error, and their significance levels are presented in (Table 7). A positive coefficient was predicted for sex, family size, tropical livestock unit number (TLU), responsibility in kebele, access to extension services, perception of soil erosion seriousness, the slope of farmland, material resource availability, and workability of structures, implies an increase in these variables improves farmers adoption of SWC practices while the negative estimates for age, land size, and farmland distance from market indicate farmers willingness to adopt SWC measures decreases with increase in those

Table 7
Determinants of adoption of SWC practices in Nada and Gulufa sub-watersheds.

Variable	Nada sub-watershed				Gulufa sub-watershed			
	Coefficient	Marginal effect	Standard error	$P>\|Z\|$	Coefficient	Marginal effect	Standard error	$P>\|Z\|$
Sex	2.32	0.1099	3.96	0.558	1.54	0.065	3.09	0.62
Age	−0.068	−0.0032	0.048	0.16	−0.134	−0.0056	0.065	0.041^b
Family size	0.175	0.0083	0.182	0.338	0.125	0.0053	0.172	0.467
Education	−0.323	−0.0153	0.182	0.076^c	0.204	0.0086	0.217	0.349
Land size	−0.782	−0.0370	0.513	0.128	−2.52	−0.1061	1.09	0.022^b
TLU	0.551	0.0261	0.354	0.12	0.67	0.028	0.282	0.017^b
Responsibility	3.766	0.1783	1.144	0.001^a	2.43	0.1026	1.14	0.034^b
Extension	2.339	0.1107	1.046	0.025^b	1.79	0.076	1.37	0.19
Distance	−0.0099	0.00047	0.011	0.355	−0.029	−0.0013	0.014	0.038^b
Perception	2.22	0.1053	0.759	0.003^a	0.82	0.0346	0.438	0.061^c
Slope	0.168	0.0079	0.676	0.804	2.87	0.1211	1.64	0.079^c
Material	2.92	0.1384	0.997	0.003^a	1.30	0.055	1.12	0.242
Workability	0.19	0.0090	0.708	0.787	2.54	0.1068	0.75	0.001^a
Constant	−8.46		5.597	0.131	−9.67		5.81	0.096
Log likelihood = -22.09; Number of observation = 138; LR chi^2 (13) = 146.08; Prob > Chi^2 = 0.0000; Pseudo R^2 = 0.7678; overall classification = 96.38%.					*Log likelihood = -18.29; Number of observation = 129; LR chi^2 (13) = 137.37; Prob > Chi^2 = 0.00001; Pseudo R^2 = 0.7897; overall classification = 93.80%.*			

^{a}, ^{b}, ^{c} = significance at 1%, 5% and 10%, respectively.

explanatory variables in both sub-watersheds. On the other hand, education statuses of farmers influenced the decision to adopt SWC measures negatively in the Nada sub-watershed whereas; in the case of Gulufa sub-watershed, the education status of farmers influenced positively the decision to adopt SWC measures.

Responsibility in kebele, perception of soil erosion seriousness, and material resource availability have influenced the decision of farmers to adopt SWC in Nada sub-watershed while the workability of structures was influenced the farmers' decision in Gulufa sub-watershed at 1% significance level. Access to extension service influenced the farmers' decision to adopt SWC measures at a 5% significance level in Nada sub-watershed. The age of household head, landholding size, tropical livestock unit (TLU), social responsibility and farmland distance from the market determined farmers' decision to adopt SWC at 5% significance level in Gulufa sub-watershed. Education status also determined farmers' adoption decision in Nada sub-watershed at 10% significance level. At 10% significance level, the perception of farmers on soil erosion seriousness and farmland slope determined farmers' adoption decision in Gulufa sub-watershed.

The age of the household head has negatively influenced the decision of farmers to adopt soil and water conservation practices in Gulufa sub-watersheds at 5% significance level ($p = 0.041$). The marginal effect of the age of household head revealed that as one year increases there would decrease the probability to adopt SWC technologies by 0.56% keeping all other variables constant in Gulufa sub-watershed.

The education status of the household head was negative and significantly ($P = 0.076$) associated with the adoption of SWC technologies in Nada sub-watershed. One unit increase in the schooling year decreases the probability to adopt SWC measures by 1.53% keeping all other variables constant.

Household landholding size was negatively and significantly ($P = 0.022$) determined the adoption of SWC technologies in Gulufa sub-watershed. A one hectare increase in landholding size decreases the probability to adopt SWC technologies by 10.61% keeping all other variables constant in Gulufa sub-watershed.

The number of livestock in tropical livestock unit which is an indication of economic security and wealth status of the community, was positive and significant ($P = 0.017$) determined the adoption of SWC technologies in Gulufa sub-watershed. A one-unit increase in the number of tropical livestock units improves the probability to adopt SWC practices by 2.8% keeping other variables constant in Gulufa sub-watershed.

Responsibility in social affairs was positive and significantly related to the adoption of SWC technology in both sub-watersheds. The result shows that as household head became responsible to social affair their probability of SWC adoption improved by 17.83 and 10.26% keeping all other variables constant in the Nada sub-watershed and Gulufa sub-watershed, respectively.

Access to extension service was positive and significantly ($P = 0.025$) associated with the adoption of soil and water conservation practices in Nada sub-watershed. A change from lacking access to extension service to getting access to extension services improves the probability to adopt SWC technologies by 11.07% keeping other variables constant in the Nada sub-watershed.

The distance to local markets was negatively and significantly ($P = 0.038$) influenced the adoption of soil and water conservation practices in the Gulufa sub-watershed. A one unit increase in the distance of farmland from the local market decreases the probability of farmers to adopt SWC technologies by 0.13% keeping other variables constant in Gulufa sub-watershed.

The slope of the farmland was positive and significantly ($P = 0.079$) association to the adoption of SWC practices in the Gulufa sub-watershed. A one unit ordinal change of farmland slope from low to medium to high improves the probability to adopt SWC technologies by 12.11% keeping other variables constant in Gulufa sub-watershed.

The availability of material resources was positive and significantly ($P = 0.003$) associated to the adoption of SWC practices in the Nada sub-watershed. A change from not having a material resource for SWC to having a material resource that helps to construct SWC measures increases the probability of adopting SWC practices by 13.84% keeping other variables constant in the Nada sub-watershed.

The workability of structures (easiness/simplicity of structures to construct) had positive and significant ($P = 0.001$) relation to the adoption of SWC technologies in Gulufa sub-watershed. A unit ordinal change from difficult to easy increases the probability to adopt SWC practices by 10.68% keeping other variables constant in the Gulufa sub-watershed.

4. Discussion

4.1. The effect of soil and water conservation measures on soil physical properties

The lower soil bulk density measured in the conserved farmlands at the lower slope position suggests that the availability of relatively higher decay of plant residues, organic matter, and sediment resulted from conservation measures in conserved farm plots as compared to non-conserved farm plots because conservation measures decrease slope length and trap the topsoil that would be transported away through water erosion. The bulk density of a non-conserved farm plot was higher, which implies a lower content of organic matter and fine soil particles [24,30,55,56]. Soil BD was lower in conserved plots than in non-conserved plots, possibly due to significant differences in organic matter and moisture availability in conserved farms. Other researchers also reported that the mean value of BD in conserved areas with SWC practice is lower than that of non-conserved areas, owing to the decomposition of plant biomasses on the conserved field increasing organic matter contents, which reduces soil bulk density [27,57–60].

Relatively higher soil moisture contents under conserved farmlands implied the contribution of soil bunds to moisture conservation through direct moisture storage in the soil profiles by reducing runoff loss and increasing infiltration. The presence of more organic matter in conserved farm plots compared to non-conserved farm plots could also be attributed to higher soil moisture content measured at farm plots with soil bunds at lower slope positions. On the contrary, the lower content of moisture on non-conserved farm plots was due to relatively enhanced runoff velocity and reduced infiltration [30,61]. This reconfirms the role of SWC for climate change adaptation which was widely reported [62]. Beyond reducing runoff and soil erosion which is the primary goal of physical conservation measures, SWC had multidimensional benefits on environment and socio-economy if well planned and implemented.

Higher proportion of fine soil particles (clay fraction) was observed in both conserved and non-conserved farmlands. This high clay content is among common characteristic of highly weathered agricultural soil of humid Ethiopian highland [63]. Even though, higher clay fraction observed in conserved farmlands as compared to the respective non-conserved farmlands, this variation did not affect the soil textural classes which remained clay or clay loam in both watersheds. The observed lower clay fraction on non-conserved farm plots might be due to selectively transporting the fine fractions, leaving behind the coarser fraction because of the high mean annual precipitation over the study area or inherited heterogeneity in soil formation process. Previous studies have also reported significantly higher clay content in conserved farmland as compared to non-conserved farmland [29,30,55].

The higher SOC observed in the farmlands with soil bund could probably be accumulated and retained soil organic matter due to soil and water conservation measures. Whereas the lowest SOC on non-conserved farmlands might be attributed to the loss of top soil by water erosion due to lack of soil and water conservation structures. Similarly, the mean value of total nitrogen of the soil on conserved farmland (0.17%) and (0.22%) was significantly higher as compared to (0.13%) and (0.11%) on non-conserved farmlands at the lower slope positions in Nada and Gulufa sub-watersheds, respectively. This could be attributed to the lesser manifestation of soil erosion that resulted from the relatively higher availability of soil organic matter due to soil and water conservation measures. The lower amount of total nitrogen was observed on non-conserved farm plots, which might be due to intensive cultivation, serious erosion because of a lack of soil and water conservation structures and the lower addition of organic and inorganic fertilizer to the soil. Besides, the decrease in total nitrogen might be contributed by the decrease in soil organic carbon, which might have occurred due to intensive and continuous cultivation. This suggested that total nitrogen and soil organic carbon had a direct relationship, implying a decrease in total nitrogen was contributed by a decrease in organic carbon and vice versa [24,30,55,56,61,64]. On the other hand, the higher amount of organic matter measured at the lower slope positions might be attributed to the wetness of the lower slope positions rather than middle and upper slope positions which is directly related to soil moisture content, and transportation and deposition of soil organic matter to the lowest slope position through runoff and erosion processes [65].

Phosphorous is one of the most important macronutrients, the least accessible and hence the most frequently deficient nutrient in many agricultural soils. The magnitude of the problem is more pronounced in developing countries particularly in highly weathered tropical soils due to P fixation and low inputs. For instances, about 30% of the world's agricultural soils are characterized by P deficiency [66]. The numerically higher available P in conserved than non-conserved farmland in this study could be due to the higher soil organic matter in conserved farmlands. Furthermore, there could be change in soil management after implementation of SWC to enhance the benefits of SWC. Several literature sources discussed available phosphorous (Pav) in conserved and non-conserved farmlands and results were contradictory [24]. The inconsistency could be due to the various sources of P (fertilizer and organic sources) and the complex nature of P with soil minerals and soil reaction. For instance the soil pH during rainy season in tropics decreases due to leaching of basic cations and hence influences available P.

Following the rating of Landon (1991), CEC greater than 40 is categorized as very high, 26 to 40 as high, 13 to 25 as medium, 6 to 12 as low, and less than 6 as very low. According to this rating, the amount of CEC on conserved farmland was rated as high for both sub-watersheds, and on non-conserved farmlands, it was rated as high to medium in Nada and Gulufa sub-watersheds, respectively. This demonstrates a strong correlation between CEC and soil clay content, which influenced positively the availability of cation exchange capacity in the soil. - For example, high clay fraction content was observed on conserved and non-conserved farmlands of the Nada sub-watershed, which was attributed to the soil's high availability of CEC (Table 6).

The slope position influenced the amount of CEC. The highest amount of CEC was observed on the lower slope position, while the lowest was observed on the upper slope position in both sub-watersheds. This is due to the accumulation and deposition of basic cations on the lower slope positions by water erosion [24,30].

4.2. Determinants of farmers' decision to adopt soil and water conservation technologies

The result showed that responsibility in the kebele increases the opportunity to participate in various meetings and opportunities for obtaining newly introduced SWC technology. This implies that responsibility in the kebele created the opportunity to meet development agents, to ask and understand, and correspondingly increased the adoption of soil and water conservation technology [46,52].

On the other hand, those household heads whose landholding size was smaller are better in the management of farmlands. This is maybe due to the larger landholding size demand larger investment to hire labor due to the labor-intensive nature of constructing soil and water conservation structures [45,46]. In contradiction to this, [48,50,52]; reported that the positive relationship between farmland size and the probability to adopt soil and water conservation practices. Large land size is associated with greater wealth and increased availability of capital, which therefore increases the ability to afford the labor cost and increases the probability of investment in SWC practices.

Farmers' knowledge and perception regarding soil erosion severity play a great role in the likelihood to adopt or not adopting conservation practices. Accordingly, the perception of farmers on soil erosion problem seriousness was positive and significantly ($P = 0.003$ and $P = 0.061$) influenced their decisions to adopt SWC practices in the Nada sub-watershed and Gulufa sub-watershed, respectively. The ordinal change from no risk perception to severe problem perception of farmers enhances their probability to adopt SWC practices by 10.53 and 3.46% keeping other variables constant in Nada sub-watershed and Gulufa sub-watershed, respectively. This further implies that farmers who recognized soil erosion seriousness in constraining crop production were more likely to adopt SWC practices than those who did not perceive the problem [46,48,67].

5. Conclusion

This study aimed at investigating the effects of SWC technologies on soil physicochemical properties and factors determining farmers' decisions on the adoption of SWC technologies in Nada and Gulufa sub-watersheds of southwest Ethiopia. The study revealed that soil bund constructed on farmlands for soil and water conservation influenced some soil physical and chemical properties in both Nada and Gulufa sub-watersheds. The implemented soil bund improved soil properties such as soil bulk density, soil moisture content, pH, soil organic carbon, total nitrogen and cation exchange capacity at the three slope positions for both the Nada and Gulufa sub-watersheds. The improvements in soil properties can help to create awareness among small holder farmers. On the other hand, the binary logit model showed that personal, socio-economic, institutional, and physical factors influencing the decision of a farmer's adoption. Hence, it is important to consider personal, socio-economic, institutional, and physical factors to enhance the willingness probability of adoption. This study did not address short-term and long-term effect of soil and water conservation practices on soil nutrient balance, sediment budget, crop yield and biomass production.

Author contribution statement

Atnafu Degfe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Amsalu Tilahun; Yadeta Bekele & Bayu Dume: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Obsu Hirko Diriba: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors would like to thank Jimma University College of Agriculture and Veterinary Medicine for financial and logistics support. We are also thankful to our respondents for their willing in sharing their experiences with us. Finally, our gratitude goes to the field assists and soil laboratory technicians who wholeheartedly participated in data collection, soil sampling and laboratory analysis during the study period.

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