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Sustainable Use of Soil and Water Conservation Technologies and Its Determinants: The Case of the Handosha Watershed, Omo-Gibe River Basin, Ethiopia

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Abstract: For the past forty years, Ethiopia has been promoting sustainable land management activities to enhance agricultural productivity. This study was intended to identify the factors determining farmers' adoption and continued use of soil bund measures in the Handosha watershed, Omo-Gibe river basin. A multistage sampling technique was used to select 340 households using the Heckman sample selection model. A total of 235 (69.12%) households adopted soil bunds, but only 89 (37.87%) of them were sustainably practicing soil bunds on their farm plots. Most adopters widely practiced soil bunds (49.42%), followed by stone bund (15.9%), and Fanyajuu (10%). The empirical results of the Heckman sample selection model showed that the farming experience, land tenure security, and perception of profitability of conservation measures were significantly positively affected the adoption of soil bund. Whereas, farm plot size and participation in off farm activities significantly negatively influenced the adoption of soil bund. Sustainable use of soil bund measures were significantly positively influenced by land tenure security, family size, and frequency of extension contact, whereas the distance between farm plots and home, and farm plot size were negatively affected. As a result, a design of agro-ecological-based soil and water conservation (SWC) measures was essential in reducing farmland vulnerability to soil erosion and food insecurity. It has been concluded that conservation practices should not only focus on the implementation and biophysical factors but also consider the socioeconomic interests of the farmers to improve the sustainable use of conservation technologies.

Keywords: soil bund; Heckman; sample selection; SWC; adoption; sustainability

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1. Introduction

Ethiopia is one of the most environmentally distressed countries, which suffers land degradation in the form of water-induced soil erosion, resulting in loss of soil fertility, nutrient depilation, and biodiversity deterioration, thereby seriously threatening livelihoods [1,2]. The severity of soil erosion in the country is accredited partly to the intense rainfall and steep topography. In the Omo-Gibe Basin, the majority of the catchment is occupied and cultivated by a large number of smallholding farmers. However, the rugged topography of the area, erosive rainfall regimes, and nutrient depilation pose major threats to the livelihoods of farmers in the area [3] and the storage volume of the Gibe dams' reservoir is threated by the soil erosion and subsequent sedimentation from the catchment of the Gibe basin [3]. Therefore, investment for soil and water conservation (SWC) measures is decisive for sustaining natural resources and for increasing resilience [4,5]. The Ethiopian government launched massive soil and water conservation (SWC) programs beginning in the mid-1970s [6,7] in the highlands, and have maintained them over the last four decades [8], to reduce soil erosion and sedimentation from surface runoff, as well as to increase land productivity.

There have been several kilometers of soil and water conservation measures built on croplands throughout the country. According to [9], 87% of the households sampled in the Ethiopian Highlands were using physical SWC structures to improve crop yield and keep soil on their cultivated land. However, the level of adoption of SWC measures varies from area to area and these conservation structures have not been sustainably used by the farmers. The achievement and failure of SWC measures were determined by the different conditions of the study area. As [10] stated, in addition to technical issues, socio-economic issues also contribute to the limited adoption of soil and water conservation practices. Furthermore, [6,8] revealed that the adoption rates of SWC technologies vary considerably within Ethiopia because investments by farmers in SWC technologies are influenced by the ecological, economic, and social impacts of those SWC technologies. On the other hand, [11] revealed that the sustainable use of stone terraces in the Beressa watershed is influenced by actual technology profitability, slope, soil fertility, family size, farm size, and participation in off-farm work. This indicated that it is difficult to generalize about factors affecting the adoption of SWC technologies in the country, considering the variations in agro-ecology and the fact that there are no universally significant factors affecting the adoption of soil and water conservation measures across the regions [12].

Furthermore, most of the adoption studies in Ethiopia related to SWC practices focused on the pre-adoption (acceptance) and adoption stage rather than the continued use (post-adoption) stage, for instance: [1,9,13–16]. However, few studies [8,11,17,18] also focused on the post adoption stage (continued use). In the study area (Handosha watershed), many NGO projects such as the Sustainable Land Management Program (SLMP), Reducing Emissions from Deforestation and Forest Degradation (REED+), the European Federation of the Associations of Dietitians (EFAD), Climate Action through Landscape Management (CALM), the German Agency for International Cooperation (GIZ), and Integrated Soil Management and Fertility (ISMF) mostly focused on sustainable land management. However, most of the farmers were supported by the World Bank's safety net program, as a result of food insecurity. This implies there are reasons behind the reduced sustainability of SWC practices. This raised a question: why is this happening? This question inspired research on the factors determining the effectiveness of SWC practices in order to devise an effective program and policy, and to obtain a better understanding of the factors responsible for enhancing the level of adoption [8].

Even considering the vital role the adoption of SWC technologies plays in conserving the environment, very few studies have been conducted to analyze the factors affecting the sustainable use of SWC measures or of their farm plots. As a result, location-specific target policies are needed to assure the sustainability of SWC practices. Hence, the determinants of the adoption process and of the sustainability of conservation measures are highly useful and need empirical studies.

As part of this study, we utilized a sample section method named the Heckman selection model in order to take advantage of two-stage analysis and deal with the zero sample at the same time. This selection model addresses both unobserved heterogeneity and selectivity bias, in conjunction with discrete, continuous modeling, which enhances the suitability of models [19]. This model takes a two-step approach to zero-sample problems, first accounting for heterogeneity and then investigating edogeneity.

Therefore, to address the aforementioned gaps and suggest area-specific appropriate sustainable land management measures based on farmers' preference, it was necessary to examine the significant environmental and socio-economic factors of soil bund measure for sustaining the land productivity. This study addressed: (i) Are there any strategies to promote the adoption and continued use (sustainable) of sustainable land management (SLM) practices? (ii) How do farmers' decisions influence the adoption and sustainable use of soil bund measures? (iii) What are the determinants of the adoption and sustainable use of soil bund technology? Hence, to achieve the objectives, the Heckman sample selection model was employed.

2. Materials and Methods

2.1. Description of the Study Area

This study was conducted in the Handosha watershed, which is located in the Omo-Gibe river basin, the southwest of Ethiopia, between 7°30′50″–7°47′50″ N and 37°33′10″–37°47′20″ E, which has a total area of around 12,265 ha (Figure 1). The majority of the area falls under altitudinal range between 2200 to more than 2350 masl, having an annual average temperature and rainfall of 16–24 °C and 900–1200 mm, respectively. The climate consists of kola, w/dega, dega.

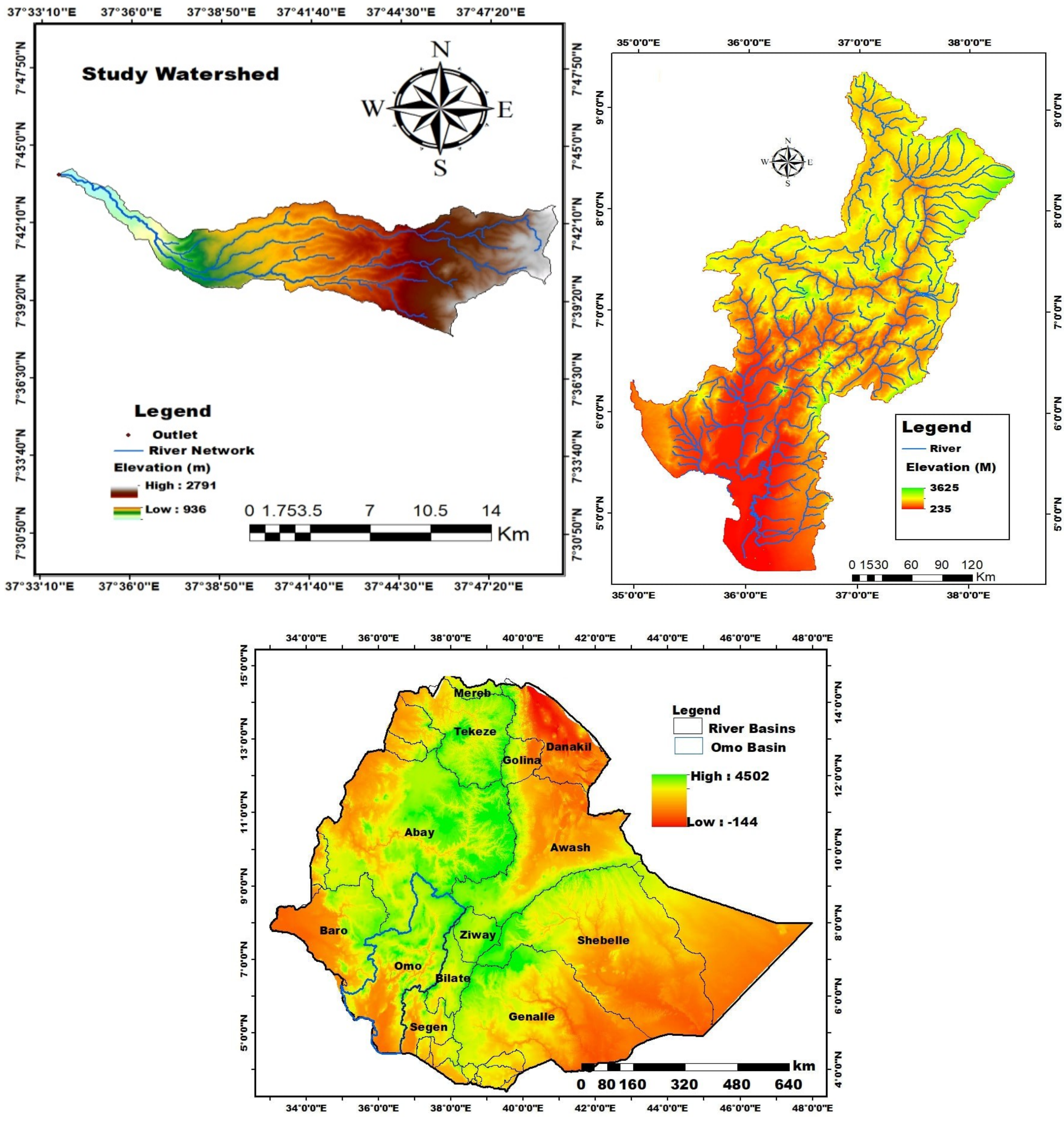

Figure 1. Study area map of the Handosha watershed, Omo-Gibe river basin, Ethiopia.

The area is mainly characterized by steep slopes to undulated topography, dissected by intermittent rivers and a slope percentage between 8% up to greater than 50%. However, as indicated, 50% of the total area of the watershed lies between 30–50% and 34% of the total area of the watershed lies >50%. While the topography is variable and the altitude of the watershed is relatively lower, ranging between meters above sea level. The highlands have steep slopes with dissected hills, whilst the lowlands have relatively gentle and undulating slopes [20].

The dominant soil type in the experimental site is Litisol. These are deep, well-drained, red, and tropical soils. Furthermore, they are stable soils with favorable physical properties. Thus, they are the most productive soils to produce the commonly grown food and plantation crops [21]. The main annual crops grown in the area under the rain-fed system are wheat, barley, and maize. They may be used for cultivation of various standard crops including enset, potatoes, and vegetables. The area coverage of the land use system indicates that 69.8% are cultivated lands, 14.5% are forest lands, 8.4% are grazing lands and 7.3% are others. Forest has the uppermost vegetation cover, with the area being forested, grassland, or shrub. The Gibe gorge has relatively sparse vegetation cover, with open woods and bush land extending across inaccessible areas. The total population of the Handosha watershed covers 44,480 (21,230 males and 23,250 females) [22]. The watershed is inhabited by a total of 8828 households that are male headed and 617 households that are female headed.

2.2. Research Design

According to [23], mixed-method designs can be grouped into three categories: convergent mixed methods, sequential mixed methods, and exploratory mixed methods. To assess the factors affecting the sustainible use of soil bund measure, the researcher applied an explanatory sequential mixed-methods approach to the study. There is a strong quantitative background to the study as well as qualitative data that supports it. Furthermore, in this study, two-stage analysis is involved, in which the researcher collects quantitative data in the first phase, analyzes the results, and then uses the results to plan the second, quantitative phase.

2.3. Data Source

The essential data for this study was gathered from primary and secondary sources. The primary data for the study was collected from household surveys and direct field observation. Secondary data sources were accessed from statistical abstracts (CSA), policy documents, databases from the Soil Conservation Research Project (SCRP) and FAO. Furthermore, data were collected from national-, regional-, and district-level agricultural and environmental offices.

2.4. Data Collection

The researcher employed questionnaires, key informant interviews, focus group discussions, and non-participant observations to collect data from household heads. Both open-ended and closed-ended types of survey questionnaires were developed to generate data on household circumstances such as age, education, family size, landholding size, land management, and the determinant factors for adopting the introduced SWC technologies. The surveys were conducted through a structured questionnaire during a specific period to obtain the factors that determined the use of SWC measures.

Key informant and land user, in-depth interviews were conducted with some selected farmers and extension workers to understand the knowledge of farmers regarding SWC technologies. A direct observation (transect walking) was also carried out to assess the SWC practices. Focus group discussion (FGD) was conducted with a group of farmers and development agents.

2.5. Sampling Design

In the present study, a multi-stage systematic random sampling technique combining purposive and random sampling techniques was employed to collect primary data from the households. First, the Handosha watershed was selected purposely from the Omo-

Gibe river basin upper catchments because this catchment boundary has some of the most densely populated and intensively farmed areas in the basin. Additionally, the study watershed has been one of the most intervened areas through various SWC and rehabilitation works by governmental and non-governmental organizations for several years. Second, the watershed was categorized in to three agro-climatic zones (dega, w/dega, and kola) using stratified sampling techniques. Then, one sample kebele was selected randomly from each agro-ecological zone. Finally, 340 sample households were selected from the households' lists of kebeles through a systematic random sampling technique (Table 1).

Table 1. Sample kebeles and number of sample households by agro-ecology.

Sample Kebeles with Agro-Ecology	Total Number of HHs	Sample Households Based on Agro-Ecology			
		Adopters	Non Adopters	Continued Used	Non-Continued Used
Hamola (*Dega*)	1121	93	34	34	59
Aste (*W/dega*)	954	74	33	30	44
Gaseda (*Kola*)	928	68	38	25	43
Total	3003	235	105	89	146
Total sample			340		

For key informant interviews, 15 farmers (based on their farming experiences), 3 natural resources experts, and 3 kebele leaders were selected from each agro-ecology to participate in the interview. Focus group discussion was conducted using 10 members of 3 groups of the society based on sex, age, and farming experiences from different agro-ecologies. To determine the number of participants in the study, the following sample size determination formula was used, which was developed by [24]:

$$n = \frac{z^2 * p * q * N}{e^2\ (N-1) +\ z^2 * P * q} \tag{1}$$

where, n is the desired sample size for the study; Z is the upper points $\alpha/2$ of standard normal distribution at 95% confidence level, which is equal to 1.96; p is the proportion of households (which is taken as 0.5 or 50%); e is acceptable error at a given precision rate (assumed 5%); q is 1-p, and N is the total number of households in the Handosha watershed.

2.6. Model Specification

To investigate the determinants of farmers' adoption and continued use of SWC technologies, researchers used different sequential models. For instance, [25] used a multi-stage processing model, whereas [11,26] employed a two-stage processing model, and [8] used five major categories of adoption process. The present study employed a two-stage processing model to examine the factors affecting farmers' continued use of soil bund measures. To optimize the advantages of two stages of analysis and simultaneously address the zero-sample problem, the Heckman selection model is employed in this study. The Heckman selection model assumes that: (a) error of both selection and main equation are correlated and distributed normally, (b) explanatory variables in selection equation are independent of the error term, (c) explanatory variables in main equation are independent of the error term. Heckman selection models jointly handle discrete/continuous modeling, unobserved heterogeneity, and selectivity bias, which improve their appropriateness. The model provides a two-step solution to the zero-sample issue that enables it to take into account heterogeneity before handling endogeneity [19,27]. In a two-stage process, the second stage of adoption is a sub-sample of the first. Thus, it is likely that the second sub-sample (those who continued the technology) is non-random and necessarily different from the first (which included those who did not adopt SWC technology), and this creates a sample selection bias [28]. Consequently, the Heckman selection model features a two-step maximum likelihood procedure, which was used to correct for this selection bias. The

Heckman selection model assumes that there exists an underlying regression relationship, which consists of the latent equation given by:

$$yj = xj\beta + u1j \quad (2)$$

where, yj is the latent variable (the propensity to continue use of soil bund technology), x is a k-vector of explanatory variables, which include different factors hypothesized to affect sustained use, β is the parameter estimate, and $u1j$ is an error term. Therefore, only the binary outcome given by the probit model is observed as:

$$yj^{probit} = (yj > 0) \quad (3)$$

The dependent variable is observed only if the observation j is observed in the selection equation:

$$yj^{select} = (zj\delta + u2j > 0) \quad (4)$$

$$u1 \sim N\,(0,1)$$

$$u2 \sim N\,(0,1)$$

$$corr\,(u1,\ u2) = \rho$$

where, yj^{select} is whether a farmer has adopted soil bund measures or not, z is an m vector of explanatory variables, which include different factors hypothesized to affect adoption; δ is the parameter estimate, $u2j$ is an error term, and $u1$ and $u2$ are error terms, which are normally distributed with mean zero and variance one. Thus, Equation (4), the first stage of Heckman's two-step model, is the selection model, which represents the adoption of SWC measures. The second stage is the outcome model (Equation (2)), which represents whether the farmer continued use of SWC measures or not. When the error terms from the selection and the outcome equations are correlated ($\rho \neq 0$), the standard probit techniques yield biased results [29,30]. Hence, the Heckman probit selection model was employed to analyze the adoption and continued use of soil bund measures in the Omo-Gibe river basin.

The relationship between the variables influencing the adoption and continuous usage of soil bund measures in the Handosha watershed is depicted in Figure 2. This conceptual framework is organized in accordance with theories and the procedure for adopting SWC measures. The three stages of SWC technology adoptions are initial adoption, actual adoption, and post-adoption. This analytical framework takes into account the most important socioeconomic, demographic, physical, and institutional factors that influence farmers' decisions about the adoption and sustainable usage of soil bunds. These parameters are anticipated to affect the usage of soil bund technology either favorably or unfavorably.

2.7. Empirical Analysis and Variables

In the present study, the dependent variable for the selection equation is whether a farmer's household does or does not adopt soil bund measures. The dependent variable for the outcome equation is whether a farmer does or does not have sustainable use of SWC technology (user's decision behavior). These dependent variables are binomial variables captivating a discreet value adoption (1 = adoption, 0 = non-adoption) and (1 = sustainable use, 0 = non-sustainable use). A soil bund is a physical soil-conservation and water-harvesting structure built by farmers. The design of the structure is 0.5 m height and 25 cm depth, on average, by digging a trench forming embankments or ridges [31].

In this study, non-adopter/dis-adopters abounded the SWC measures/soil bunds and/or never used soil bunds on any of their plots. Actual adopters, whereby efforts or investments (in capital and labor) are made to implement SWC measures/soil bunds on more than a trial basis established the initial SWC measures. Whereas, post adopter/continued use, where existing SWC measures/soil bunds are used for more than 3 subsequent years by maintaining and expanding new ones on other fields based on their own motivations [8,11].

Based on the different kinds of literature [11,17,32] and econometrics theories, the adoption status of farmers for soil and water conservation measures may depend on socioeconomic, demographic, physical, and institutional variables. The key socio-economic and institutional variables expected to influence the investments in the soil bund measures that were investigated in this study are discussed briefly below (Table 2).

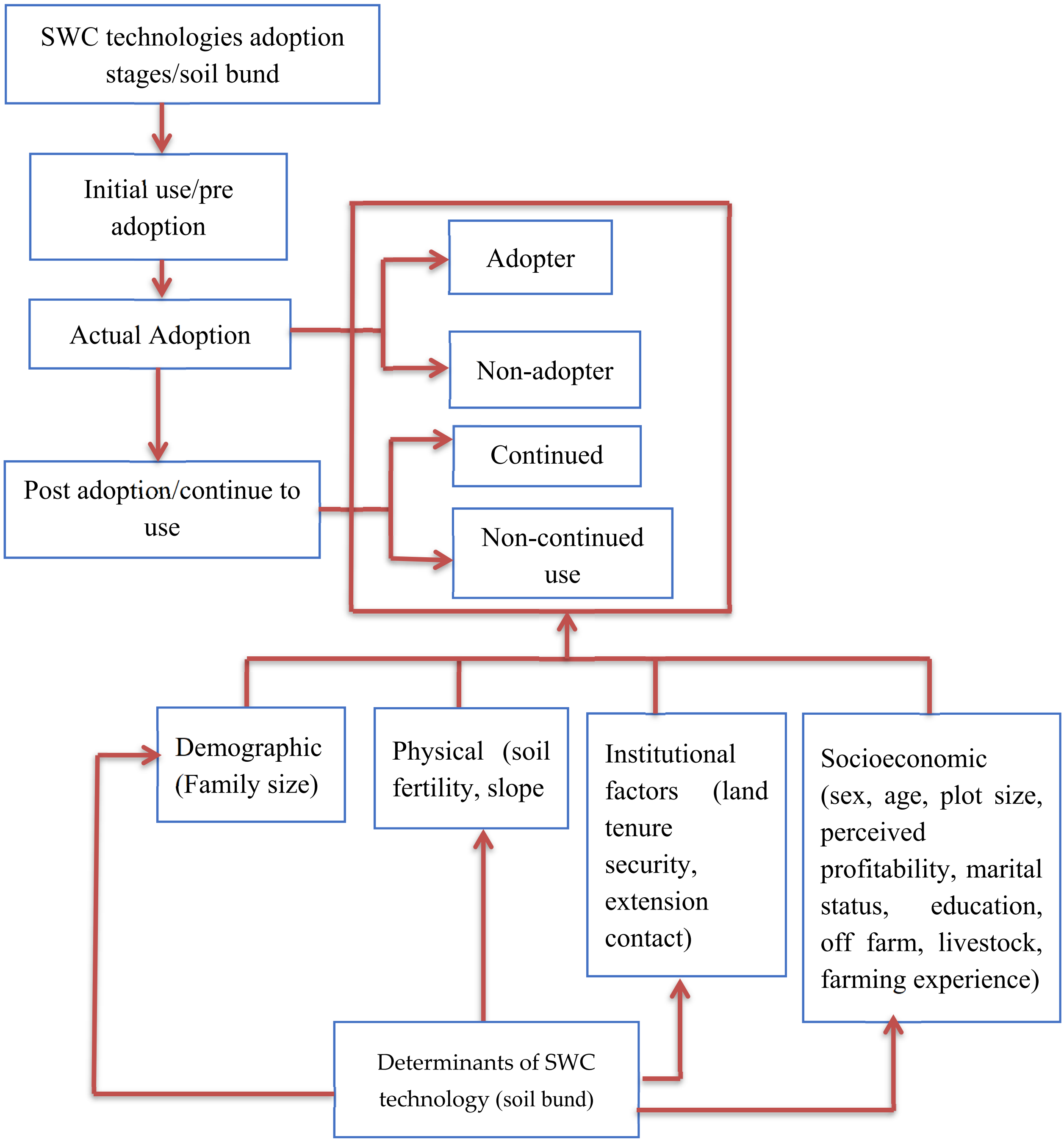

Figure 2. Conceptual framework of adoption and sustainable use of soil bund.

Table 2. Description dependent and explanatory variables.

Dependent Variable	Description	Farmers Adoption Status of Soil Bund							
		Adopt (%)		Non-Adopt (%)		Sustainable (%)		Non-Sustainable (%)	
Adoption of soil bund	Adoption of soil bund (dummy: takes the value of 1 if adopted and 0 otherwise)	69.1		30.9		26.2		42.9	
Explanatory variables	Description	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
SEX	Sex of respondent	0.051	0.221	0.124	0.331	0.067	0.252	0.076	0.266
AGE	Age of farmers (year) (Continues)	47.191	5.367	45.971	7.485	46.809	5.498	46.82	6.342
MARTSTAT	Marital status of respondents	0.221	0.729	0.238	0.802	0.213	0.715	0.232	0.767
EDUC	HH head educational status (dummy: 1 = if illiterate, 0 = otherwise	1.647	1.392	1.781	1.359	1.921	1.772	1.6	1.206
FAMSIZE	HH Family size (*N*) (continues)	5	2.861	4	2.109	6	3.345	4	2.11
FARMSIZE	Size of Farm (ha) (continues)	0.459	0.962	0.829	1.22	0.202	0.568	0.704	1.162
FARMEXP	HH head farming experience (in year) (continues)	21.995	6.393	17.133	7.56	21.652	6.129	20.084	7.433
PERPROF	Perceived profitability of technology (dummy: 1 = if perceived profitability, 0 = otherwise)	0.472	0.5	0.229	0.422	0.494	0.503	0.364	0.482
EXTCONT	Frequency of extension agents Contacts (per month)	3.996	1.958	3.495	1.557	5.1	2.301	3.432	1.472
GENTSLOP	Gentle slope (1), not gentle (0)	0.417	0.494	0.457	0.5	0.393	0.491	0.44	0.497
MODERSTEP	Moderate steep slope (1), not moderate steep slope (0)	0.434	0.497	0.419	0.496	0.427	0.497	0.432	0.496
STEEPSLOP	Very steep slope (1), not steep (0)	0.523	0.5	0.343	0.477	0.5393	0.501	0.44	0.497
LOWFERT	Low fertility (1 if soil fertility is low, 0 otherwise)	0.468	0.5	0.571	0.497	0.405	0.494	0.536	0.499
MODFERT	Moderate fertility (1 if soil fertility is moderate, 0 otherwise)	0.319	0.467	0.219	0.416	0.326	0.471	0.272	0.446
HIGHFERT	High fertility (1 if soil fertility is high, 0 otherwise)	0.247	0.432	0.362	0.483	0.247	0.434	0.296	0.457
PLODIST	Mean Distance of farm plot from homestead (in walking hour) (continues)	0.596	0.898	0.724	0.956	0.225	0.559	0.784	0.974
OFFFARM	Off farm practice: yes (1), No (0)	0.043	0.202	0.619	0.488	0.043	0.208	0.28	0.449
LANDTUN	Land tenure security: yes (1), no (0)	0.817	0.388	0.019	0.137	0.989	0.106	0.424	0.495
LIVESTOC	Livestock Holding (in TLU) (continues)	8.179	3.457	8.114	3.614	7.978	3.141	8.2	3.613

3. Results and Discussion

3.1. Socioeconomic Characteristics of Respondents

It was hypothesized that the adoption and sustainability of SWC measures was influenced by the demographic and socioeconomic characteristics of the survivors, which were included in the Heckman selection models.

Descriptive statics analysis shows the sample households predominantly occur in the second stage rather than in post-adoption. In the sample of households, 69.12 percent were actual adopters, while 26.2 percent were sustained users. The majority of the actual adopters have implemented SWC measures, specifically soil bund measures, within the few years. Nevertheless, few of them continued the use of soil bund measures over the last three years. As a result, 62.2% of the farmers failed to maintain or repair soil bund conservation measures in their plots over the past years (Table 2).

92.76 percent and 88.51 percent of the 340 households surveyed were males, and married continuing and non-continuing users. The mean age of household for adopters and sustained users were 47.191 and 46.809 years, respectively. Family size was found to be one of the most important factors influencing the sustainability of soil bund measures. A farmers' decision to adopt SLM practices is supposed to be influenced by the availability of labor in their family. For adoption and continued use of SWC activities, families with large households could provide the extra labor. A family size of five for the adopters and family size of six for the sustained users was found in this study.

The results also revealed that average farmland size was 0.46 and 0.2 ha for both adopters and sustained users, respectively. This implies that non-adopters and non-continuing users have a larger farmland size than adopters and continuing users. A typical farmer contacts an extension agent 3.99 (adopters) or 5.1 (sustained users) times every two months, which is a relatively high frequency compared to non-adopters or non-sustained users. This is the dominant situation for most parts of the country, which is supported by several studies, including: [11,15].

In this study, farm plot characteristics also considered, for instance, a farm plot's distance has significant implication for SWC practices. Those who lived close to their plots had the advantage of time and energy savings and were motivated to continue soil bund practices. For instance, sustained users took 13.5 min to reach their farming plots, while non-sustained users took 47.04 min. Most of the participants in the SWC practice earned money through livestock agriculture. According to the sampled households, the average number of livestock owned by adopters and sustainers was 8.18 TLUs and 7.98 TLUs, respectively. Tenure security influences land users' tendency and willingness to invest in SWC. In this study, the average adopters (0.82) and sustained users (0.99) of soil bunds feel more tenure security than dis-adopters (0.02) and non-continued users (0.42). Therefore, household investments or maintenance of soil and water conservation measures are more likely.

3.2. Dominant Types of SWC Measures in the Handosha Watershed

Numerous farmers accepted and practiced some of the SWC structures due to incentive from NGOs, the perceived profitability of SWC activities, and pressure from government bodies. In the Handosha watershed, about 95.5% the respondents used at least one SWC measure in their plots. The key SWC measures implemented in the study area include soil bunds, stone bunds, check-dams, fanyajuu, mulching and crop residues, and other mechanical and biological conservation measures. Most adopters widely practiced soil bunds (49.42%), followed by stone bunds (15.9%), fanyajuu (10%), mulching and crop residues (9.12%), and check-dams (5.59%). Others, such as area closure, deep trenching, and terracing, are implemented only in about 5.56 percent of the total sampled households (Table 3 and Figure 3).

Table 3. Dominant types of SWC measures in the study area.

SWC Types	Number	Percent
Soil bund	168	49.42
Stone bund	54	15.9
Check-dam	19	5.59
Fanyajuu	34	10
Mulching and crop residues	31	9.12
Other	19	5.56
Not implemented	15	4.41

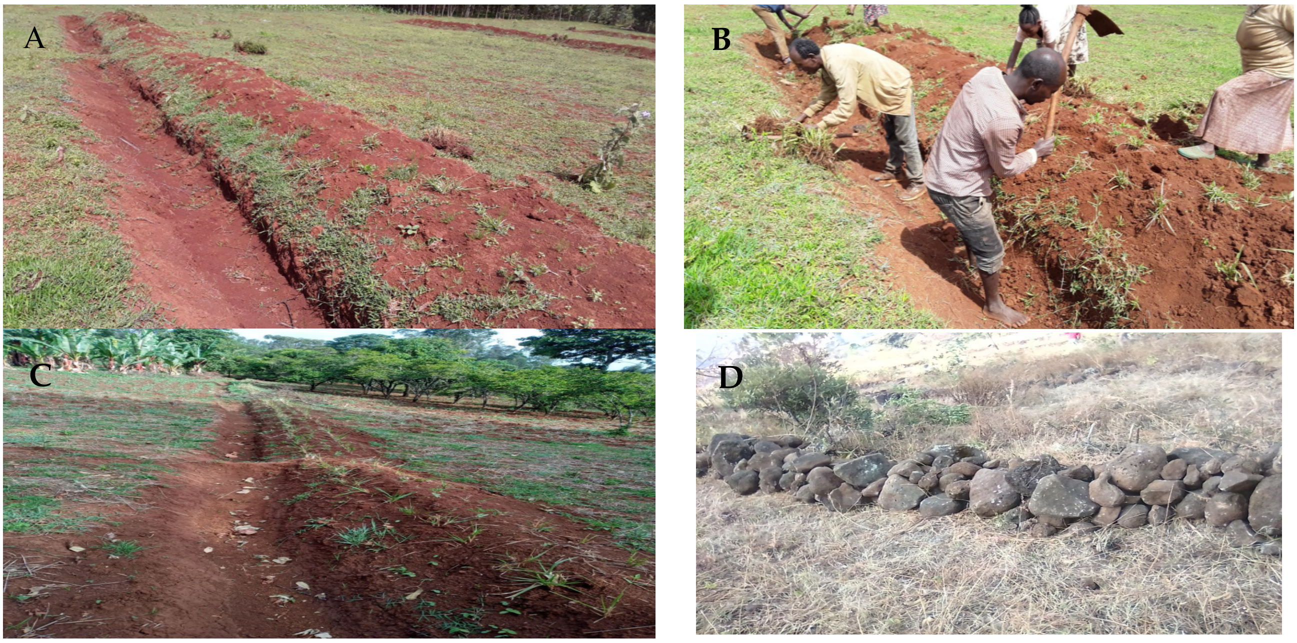

Figure 3. Soil bund structures in the Handosha watershed: (**A**) soil bund on grazing land, (**B**) soil bund construction by farmers, (**C**) soil bund on farm land, (**D**) stone bund structure. Photo by researcher.

Most farmers (69.1%) adopted a single conservation measure (soil bund) in one of their plots. The rest of the respondents used two or three SWC measures in their plots. This indicated that the respondents in the study area adopted improved SWC measures simultaneously. During FGD, they said that due to the slope and soil type, as well as extension agents' recommendations, these measures were enforced and they preferred to use soil bunds dominantly. Furthermore, the limited availability of rocks, which limits the construction of stone bunds, resulted in this watershed extensively implementing soil bunds (Figure 3).

3.3. Determinates for Adoption of Soil Bund

Farmers must decide how much effort they will put into implementing SWC measures once they accept them [31]. A probit maximum likelihood estimation method was used as a first step in the Heckman sample selection model. This was to identify factors influencing household adoption decisions. There are several variables that may influence households' technology adoption decisions. The sample selection model revealed that five of the fourteen explanatory variables included in the model, namely farm experience, off-farm activities, farm size, land tenure, and perceived profit of soil bunds, significantly affected users' decisions to adopt in both a positive and negative way. According to the results of the selection model analysis of factors affecting the adoption of soil bund measures, farm experience, land tenure security, and perceived profitability are positively correlated with adoption of the measures. Farm size and off-farm activities affected soil bund adoption negatively (Table 4).

Table 4. Results of Heckman probit selection model.

Explanatory Variables	Adoption			Sustainability		
	Coefficients	Std. err	z	Coefficients	Std. err	z
SEX	−0.629	0.95	−0.66	0.089	0.109	0.81
MARTSTAT	−0.053	0.342	−0.15	0.000	0.035	0.01
EDUCSTAT	0.123	0.131	0.94	0.026	0.018	1.48
FAMSIZE	−0.045	0.074	−0.61	0.057 ***	0.008	6.62
FARMEXP	0.053 **	0.022	2.37	−0.002	0.004	−0.47
LOWFERT	−0.693	0.416	−1.67	-	-	-
HIGHFERT	−0.355	0.385	−0.92	-	-	-
GENSLOP	-	-	-	−0.093	0.049	−1.89
STEPSLOP	0.544	0.327	1.66	-	-	-
FARMSIZE	−0.438 **	0.154	−2.85	−0.067 **	0.028	−2.38
DISTANCE	-	-	-	−0.108 ***	0.03	−3.53
OFFFARM	−2.627 ***	0.46	−5.71	0.041	0.131	0.31
LIVESTOC	0.036	0.041	0.86	0.000	0.006	0.09
LANDTENU	3.411 ***	0.498	6.85	0.271 **	0.112	2.43
PERPROF	0.768 **	0.331	2.32	-	-	1.79
EXTCONT	−0.015	0.093	−0.16	0.091 ***	0.012	7.51
CONSTANT	−0.941	0.913	−1.03	−0.406	0.181	−2.24
Lambda	0.019	0.17				
Number of observation	340					
Censored observations	105					
Uncensored observations	235					
Wald ch^2	169.81 ($p < 0.001$)					

***, ** indicate significance levels at 1%, 5%, respectively. Rho = 0.053, sigma = 0.355.

As hypothesized, the influence of farming experience on adoption is positive in the Handosha watershed. This indicates that the likelihood of adoption of conservation practices is greater for experienced farmers than for those with little experience. This is due to their life-long farming experience, which helps farmers change their perceptions about the impacts of soil erosion and helps them understand the importance of SWC practices.

Regarding actual SWC adoption, farmland size has a negative and significant effect. Based on the results, an increase in cultivated land would increase the probability of SWC measures being adopted by 43.8%. This is due to the incremental potential that land size may have been affected by land fragmentation, and would therefore need intensive labor for conservation activities as a result of labor shortage, which is a limitation for the adoption of SWC for large holdings. This is consistent with findings of [15,17] and contrary to the results of [11,16], which showed a negative relationship between farm size and soil bund adoption. In contrast, [14] found that farmland size positively affected the adoption of SWC measures.

In the final adoption, farmers' perceptions of the profitability of SWC structures play a positive role. The result indicates that farmers who perceive SWC measures to be profitable are 76.8% more likely to adopt soil bund measures. This is due to the farmers perceiving that implementing soil bund conservation technologies will increase profits and productivity, and therefore, they encourage the adoption of soil bund measures in their farm plots. This result is also in line with [8,11]. The effect of off farm activities on the adoption of soil bunds is found to be significantly negative. This means most farmers are attracted by short-term labor market income from nearer towns and leave SWC activities due to time shortage. This finding is consistent with the findings of [14,16], which found that farmers who practiced off-farm activities were unable to spend time maintaining and modifying SWC measures. This finding is completely against the finding of [33,34], which stated that off-farm income served as a source of cash to invest in SWC practices and support the adoption of SWC technology.

Land tenure security is one of the vital socioeconomic influences that affect farmers' decisions to adopt SWC practices. Tenure security is positively and strongly significantly related to the actual adoption phase of soil bunds. The result shows that tenure security significantly increases the likelihood of actual adoption of soil bunds by 49.8%. This finding is consistent with the findings of [8,14], who concluded that secured land tenure is an encouraging factor for the adoption of conservation technologies. To the contrary, [9,11] concluded that land tenure security was not an influencing factor for the adoption of SWC measures.

3.4. Determinates for Sustainable Use of Soil Bund

In this study, a sample selection problem was found, justifying the use of Heckman probit models with a value of rho significantly different from zero (Wald x^2 = 169.81, with $p < 0.001$). As a result of this method, we can conclude that the covariate used in the regression model is appropriate and shows strong explanatory power. Table 4 shows that the fitted model is appropriate, as indicated by the overall Wald chi^2, which is highly significant at $p < 0.001$; this finding is consistent with that of [28,29].

Using the probit estimates, the Inverse Mill's Ratio (Lambda) was calculated and included in the second stage of the selection model for analyzing the factors affecting the sustainability use of soil bund measures. Out of the variables entered into the model (twelve), six of them, namely, family size, farm size, off farm activity, land plot distance, land tenure security, and extension contact, were found to significantly affect the sustainability of soil bund technology use (Table 4). The results from the outcome model, which analyzes the factors affecting the continued use of soil bund measures, indicated that most of the explanatory variables affected the probability of sustainability. Variables that positively influenced the sustainable use of soil bund measures include family size, land tenure security, and frequency of extension contact. However, farm size and distance between farm plots were negatively related to sustainability.

This study indicates that family size had a positive and significant effect on the decision to use SWC measures. This implies that households with large family size are likely to continue using soil bund technology practice either of their plots. In the Handosha watershed, household family size is increased by one, which increases the probability of continued SWC use by 5.7%. Due to the fact that easy access to the labor of family members would help increase the practice of conservation activities. A similar result was also found in Peru, implying that more labor is applied when the family is larger and thus more family labor is available [35]. However, this is contrary to the results of [11], which stated that labor is diverted away from conservation activities due to households keeping more livestock, which are considerably involved in dung cake making and marketing.

The effect of farm size is found to be negative and significant on the continued use of SWC measures. The result indicates that a unit increase in cultivated land would decrease the probability of sustaining use of SWC measures by 6.7%. This implies that sustainable use of soil bunds is likely to be lower with an increase in farm size due to a shortage of labor required to cover the large farm size. Similarly, [11,16] reported a negative relationship between farm size and the probability of continued soil bund practices due to lack of labor. A farm plot's distance from a farmer's home showed a significant negative effect on soil bund sustainability measures. This indicates that a unit increase in distance would decrease the probability of farmers continuing the use of soil bund measures by 10.8%. Farmers whose plots were far from their home did not continue the use of soil bund measures due to the time spent on travel as opposed to nearer plots, which is similar to the study of [36].

Land tenure security is one of the most significant socioeconomic factors that affect farmers' decisions to continue soil and water conservation practices. Tenure security positively and significantly influences the sustainable use of soil bunds. The result indicates that tenure security significantly increases the likelihood of the continued use of soil bunds by 27.1%. Farmers who cultivate their own farmland are relatively more secure and are willing to invest their labor and time in soil bund conservation measures on their farmlands. In the other case, during focus group discussion, farmers said that there was a significant number of households migrating from rural to urban areas. This implies that as a result, they rented their land to other farmers, who only focused on the temporary productivity of the land rather than its sustainability, and therefore, did not maintain or modify soil bund measures.

In this study, the frequency of extension contacts with farmers shows a significant positive effect on the continued use of soil bund practices by 10.8%. This implies that farmers with access to extension services and information have good awareness of soil erosion and conservation measures, and as a result, they are motivated to use soil bund measures to either maintain or modify their land for a long period of time. This finding is consistent with [16], who stated that as farmers are supported by extension workers, the probability of using SWC technology sustainably through maintaining or modifying the technology increases. The Heckman selection model estimation also shows that sex, marital status, educational status, low fertility, high fertility, gentle slope, steep slope, and livestock show no significant effect on both the adoption and sustainable use of soil bunds.

As shown in Figure 4, soil bund measures were destroyed by run-off and lack of treatment by land users around grazing land and on the farm plot. Moreover, as a result of the aforementioned factors, soil bund technology practices failed to be sustainable in the watershed.

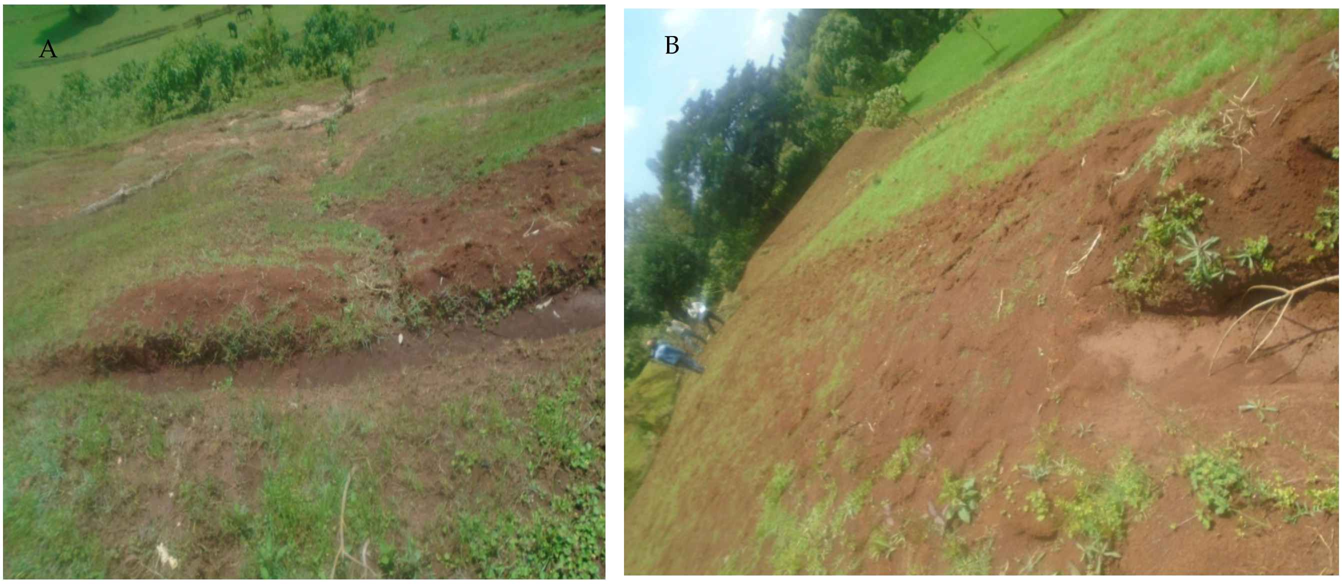

Figure 4. Failed soil bund structure filled by soil sediment (**A**) and distracted soil bund structure filled by run-off (**B**) in the Handosha watershed. Photo by researcher.

According to key informants, especially SLM experts, the absence of law enforcement after applying soil bund technology to their plots was another substantial factor hindering farmers' adoption of soil bund remedies. Due to this, most farmers eventually lost their SWC measures. Remittances are also a significant factor in the sustainable use of soil bund measures in the area. Most rural households send one or more family members to South Africa and the Middle East. Thus, most young household members are waiting for remittances from their families rather than performing SWC activities or supporting their families in their daily lives. As a result, there is a labor shortage on their plots for the continued practice of bund measures.

4. Conclusions and Policy Implication

This study investigated factors affecting farmers' decisions related to the adoption and sustainable use of soil bunds. It was conducted in the Handosha watershed in the Omo-Gibe river basin. Several studies have investigated farmers' decisions about soil and water conservation measures using different models; however, most of them focused on the acceptance and adoption stages of technology adoption. Specifically, this study evaluated the socioeconomic and physical factors affecting households' decisions regarding the sustainability of SWC measures using the Heckman selection model.

A multistage sampling method was used to select 340 sample households from three agro-ecological zones. There were 235 adopters and 105 non-adopters in the total sample; only 89 adopters practiced sustainable soil bunding on one or both of their farm plots. According to our analysis, most of the explanatory variables influenced the adoption of soil bund measures and their sustainability. In addition to socioeconomic factors, physical factors influenced farmers' decisions on the practice of soil bund measures.

In the Handosha watershed, there are a variety of influences that affect the use of soil bunds and their adoption. The study found that nearly half of socioeconomic and physical factors affected soil bund adoption and sustainability. Soil bund adoption is significantly influenced by perceived profitability, land tenure security, and farm experience. However, farm size and participation in off-farm activities negatively contributed to soil bund adoption. Farmers' decisions to continue to use soil bund measures were much more strongly influenced by the frequency of extension contacts. They were also influenced by the size of farm plots, perceived land tenure security, and distance between the plot and their homes. Based on the Heckman selection model analysis, access to extension services and family size played significant roles in explaining the sustainability of soil bund technology practices. Farmers' decisions on SWC measures are also significantly affected by land tenure security. Conversely, farmers' decisions regarding the sustainability of soil bunds are negatively affected by the distance between farm plots and their homes, and farm size. Generally, SWC measures are unlikely to be sustainable due to the passive and forced participation of farmers in conservation activities. In addition they require labor-intensive practices for conservation methods.

Accordingly, this study recommends planning SWC measures based on local farmers' involvement and self-motivation for long-term soil and water conservation. To enhance the sustainability of SWC measures, it is essential that policy makers and development workers take plot-level physical environments into account. They must also implement practices based on land users' interests. Based on this finding, appropriate policies and procedures need to be designed and implemented. Our findings suggest that strengthening institutional and human capacity should be the focus of efforts to address soil erosion through SWC technologies. In order to control soil degradation and enhance farm productivity, farmers need to be educated and trained, and awareness should be created about soil erosion. Furthermore, national and local governments should establish post-adoption regulations on the continued use of SWC practices.

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