

Smallholder farmers' choice of portfolios of sustainable land management practices in the Upper Blue Nile Basin, Ethiopia

Gashaw Tenna Alemu

gtenna@yahoo.com

Bahir Dar University

Zerihun Nigussie

Bahir Dar University

Zemen Ayalew

Bahir Dar University

Tsehay Kelemework

Bahir Dar University

Zewdu Berhanie Ayele

Bahir Dar University

Eric Ndemo Okoyo

Haramaya University

Dessalegn Molla

Alliance of Bioversity International and CIAT, Africa – Addis Ababa Office

Research Article

Keywords: land degradation, sustainable land management, land-use policy, factor analysis, seemingly unrelated regression

Posted Date: October 28th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11204548/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

1 **Smallholder farmers' choice of portfolios of sustainable land management practices in the**
2 **Upper Blue Nile Basin, Ethiopia**

3 Gashaw Tenna Alemu^{a*}, Zerihun Nigussie^a, Zemen Ayalew^a, Tsehay Kelemework^a, Zewdu
4 Berhanie Ayele^a, Dessalegn Molla^b, Eric Ndemo Okoyo^c

5 ^aCollege of Agriculture and Environmental Sciences, Bahir Dar University, P.O. Box 5501, Bahir
6 Dar, Ethiopia

7 ^bAlliance of Bioversity International and CIAT, Africa – Addis Ababa Office, P.O. Box 5689,
8 Addis Ababa, Ethiopia

9 ^cCollege of Agriculture and Environmental Sciences, Haramaya University, P.O.Box 138, Dire
10 Dawa, Ethiopia

11 *Corresponding author: College of Agriculture and Environmental Sciences, Bahir Dar
12 University, P.O. Box 5501, Bahir Dar, Ethiopia. E-mail address:
13 gtenna@yahoo.com/gashaw.tenna@bdu.edu.et (G.T. Alemu)

14 **Abstract**

Land degradation, which emerges from the unsustainable use of natural resources, still poses great challenges in the Upper Blue Nile Basin of Ethiopia. This study analyzes smallholder farmers' adoption of sustainable land management (SLM) practices and factors that determine their selection of SLM practice portfolios. Primary data were collected from randomly selected farm households (n=300) and were analyzed using factor analysis and a seemingly unrelated regression (SUR) econometric model. The findings revealed that only around 39% of households practiced SLM, but less than a quarter practiced sustainably. There were significantly wide variations in the adoption level across the study areas. Based on the estimated SUR econometric model results, decision-making related to different SLM practice portfolios was influenced by various socioeconomic, institutional, and policy factors. In particular, farmers who perceived their land-use policies as creating uncertainty for future returns from investment in SLM did not practice soil conservation and runoff management practices that had an impact on long-term land productivity. The results show how necessary it is to create a favorable land-use policy framework and devise relevant strategies that will promote the widespread use of SLM practices among smallholder farmers.

Keywords: land degradation; sustainable land management; land-use policy; factor analysis; seemingly unrelated regression.

1. Introduction

Globally, increasing agricultural production, reducing poverty, and ensuring sustainable management of natural resources are important goals. Meeting them, however, requires overcoming the challenges posed by land degradation (LD) [1]. LD is a serious global threat posing a major challenge to both humans and nature [2]. Approximately 30% of the global land area and 40% of land in developing countries is degraded, affecting 3.2 billion people globally [3]. Likewise, sub-Saharan Africa has experienced a disproportionately higher rate of LD [4]. In East Africa, for instance, the gross soil loss due to water erosion is on the order of 4 billion t yr⁻¹, 50% of which originates from croplands in Ethiopia [5]. LD in the form of soil erosion and nutrient depletion is a major concern in Ethiopia too, where about 25% of the country's land area is moderately to severely eroded [6]. In Ethiopia, the average soil loss from cultivated land was estimated at 42 t ha⁻¹ yr⁻¹ [7]. As one of the 10 major basins in the country, the Upper Blue Nile Basin (UBNB) is a good example of a severely degrading area in Ethiopia. Haregeweyn, Tsunekawa (8) estimated a gross soil loss of 473 Mt yr⁻¹ from the basin, and over 77% of the basin's area is experiencing moderate to very severe soil erosion risk. This ongoing LD reduces the country's land productivity by 2.2% annually [9], and the associated cost accounts for approximately 2% and 3% of the national and agricultural gross domestic product per annum, respectively [10]. The agricultural sector is mainly regulated by smallholder farmers whose livelihoods are predominantly reliant on agriculture, and a fast-growing population, erratic rainfall, and poverty have resulted in high levels of LD that threaten agricultural productivity [11].

LD takes a variety of forms and is driven by several biophysical, institutional, and socio-economic factors, including the inefficient use of resources, fragile economic growth, and failure of policy to address practical actions [12]. Humans have modified the environment for millennia in response to changing climatic conditions, demographic, social, and economic pressures [13], but the level of degradation has accelerated dramatically in recent decades [12]. As a result, LD presents a significant challenge to the human's ability to achieve environmental sustainability and realize the outcomes of diverse Sustainable Development Goals (SDGs), especially those with reference to food (SDGs 1 and 2), health (SDG 3), water (SDG 6), climate (SDG 13), and land management (SDG 15) [12, 14]. Addressing LD would play a prime role in achieving those SDGs and is supposedly also indirectly relevant for other SDGs [15]. Generally, there is a shared global

understanding that a key factor in achieving many of the SDGs is the improvement of land use and management, reversing the current trend of increasing LD, and preventing further degradation [16]. Hence, there is increasing evidence that curbing LD in smallholder farming settings, like Ethiopia, relies on the quest for sustainable land management (SLM) practices [17].

In an effort to curb soil erosion and nutrient depletion, the government of Ethiopia, together with some non-governmental organizations have been implementing a series of SLM programs since the 1970s. Some of the major programs that have been implemented include food-for-work programs (1973–2002), management of environmental resources to enable a transition to more sustainable livelihoods (2003–2015), productive safety net programs (2005–present), community-based watershed development (1998–present), and the national SLM program (2008–2018) [18]. These programs have aimed at combating LD, protecting natural resources, and restoring soil fertility by considering complex societal problems [17]. Some reports have indicated that these programs have mainly achieved their objectives in reducing LD and improving crop productivity in the dryland areas of northern Ethiopia [19, 20]. Although similar programs have been promoted in high-rainfall areas, they have not achieved the desired outcomes and are still underway with a debatable amount of success [21]. It is only recently that a growing body of case studies from northwestern Ethiopia has shown some positive outcomes of SLM practices in reducing LD and improving land productivity [1, 22]. Kassie, Teklewold (23) determined that about 40.2% of Ethiopian farmers adopted SLM practices, including soil and water conservation measures, manure use, crop diversification, improved seed, chemical fertilizer, and minimum tillage. In semi-arid areas of Ethiopia, Kassie, Zikhali (24) reported that about 36.8%, 23.6% and 17% of farmers adopted conservation tillage, chemical fertilizer and manure use, respectively. In the northern highlands of Ethiopia, Miheretu and Yimer (25) noted that 35.8% and 23.3% of farmers applied stone bund and chemical fertilizers, respectively. Likewise, Teshome, de Graaff (26) reported that about 44%, 26%, and 71% of farmers used bunds, organic fertilizers, and inorganic fertilizers, respectively, in northwestern Ethiopia. In general, the SLM programs implemented so far across the country have achieved some success in facilitating and promoting the widespread use of SLM practices among smallholder farmers [18]; however, there is still scope for further improvement.

Using binary or multivariate analyses^a, many studies have provided valuable insights into factors that influence smallholder farmers' adoption of SLM practices for one or a few SLM practices in Ethiopia [27-30]. Accordingly, these studies have shown that farmers' use of SLM practices vary with location, slope, erosion severity, soil, sex, age, and resource endowment [28]; extension communication [30]; and land-use policy and tenure arrangement. Likewise, farmers' perception of LD severity influences their decisions to use SLM practices [29]. Smallholder farmers' perceived changes in climate also influence their use of SLM practices [31]. Moreover, the existing state-run land-use policy and its governance have been shown to constrain farmers from expanding their knowledge of SLM practices, hence discouraging them from investing in these practices if their land tenure is insecure and therefore altering land productivity [32]. Generally, the potential reasons for the limited uptake of SLM practices are often traced to various socio-economic conditions, farm characteristics, and biophysical and institutional conditions [33].

Despite enhancing our understanding of smallholder farmers' SLM adoption behavior, the existing studies of the UBNB have three primary limitations. First, they do not sufficiently cover the full diversity and extent of SLM practices being implemented by smallholder farmers. They disproportionately focus on physical SLM measures that have been promoted by external programs for relatively long periods in the region [34] and do not emphasize traditional SLM practices [35]. Second, previous studies have not considered the full range of smallholder farmers' choices as a package of SLM practices [36] composed of physical, agronomic, agroforestry, horticultural, and other related practices, all of which may enhance crop productivity and net farm revenues. Third, previous studies have generally followed a simple dummy scaling approach (a value of 1 is assigned if the SLM practice is applied and 0 otherwise) in lieu of developing a weighted composite use index indicator for portfolios of SLM practices.

In light of this background, the goals of this study were to (1) assess heterogeneity in the choice of portfolios of SLM practices and (2) analyze factors influencing farmers' choice of portfolios of SLM practices in the UBNB. The results of this research should help to identify the most dominant and regularly utilized portfolios of SLM practices as well as identify factors that might help to enhance their extent of use. More specifically, the analysis of factors influencing farmers' extent of use of SLM practices could help to gain insights into why smallholder farmers often refrain

^a A dummy approach that takes one if the farmer adopts each single SLM practice, and zero otherwise.

from investing in SLM practices, and thereby inform the design, support, and promotion of appropriate technologies relative to farmers' resources and livelihood strategies. It should also help develop strategies to improve their investments in SLM practices on their farmlands.

2. Material and methods

2.1. Study sites

The research purposely targeted three watersheds located in the UBNB of Ethiopia: the Aba Gerima and Guder watersheds in the Bahir Dar Zuria and Fagita Lekoma districts, respectively, of the Amhara Region and the Dibatie watershed in the Dibatie district of the Benishangul Gumuz Region (Figure 1). The Guder, Aba Gerima, and Dibatie watersheds are 765 ha, 719 ha, and 700 ha in area, respectively, and their elevations are 1800–2900 m a.s.l. (Guder), 1922–2250 m a.s.l. (Aba Gerima), and 1479–1709 m a.s.l. (Dibatie). The annual rainfall amounts are 1951–3424 mm (Guder), 895–2037 mm (Aba Gerima), and 850–1200 mm (Dibatie), and their respective annual temperature ranges are 9.4–25 °C, 13–27 °C, and 25–32 °C. In general, the three watersheds are in the humid subtropical (Aba Gerima), moist subtropical (Guder), and tropical hot humid (Dibatie) agro-ecological zones [28].

Different SLM programs have been implemented in the three watersheds. Smallholder farmers in each area have participated in regular government-driven soil and water conservation activities. In addition, farmers in Aba Gerima have been supported through a Swiss program called the Water and Land Resource Center, and farmers in Guder have received support from the World Bank–sponsored Sustainable Land Management Program and the Service in Mission Project. Dibatie has not received any form of external assistance [37]. The livelihood of the watershed communities is based on a mixed crop-livestock system. Farmers in Guder and Aba Gerima have shifted from cultivating annual crops to cultivating acacia (*Acacia decurrens*) and khat (*Catha edulis*), respectively, whereas farmers in Dibatie have cultivated groundnuts as a cash crop. The major staple crops are teff, finger millet, wheat, and maize in Aba Gerima; barley, teff, wheat, and potatoes in Guder; and finger millet, teff, and maize in Dibatie. The major livestock produced are cattle, sheep, goats, and donkeys in Aba Gerima; cattle, sheep, donkeys, and horses in Guder; and cattle, sheep, goats, and donkeys in Dibatie [38].

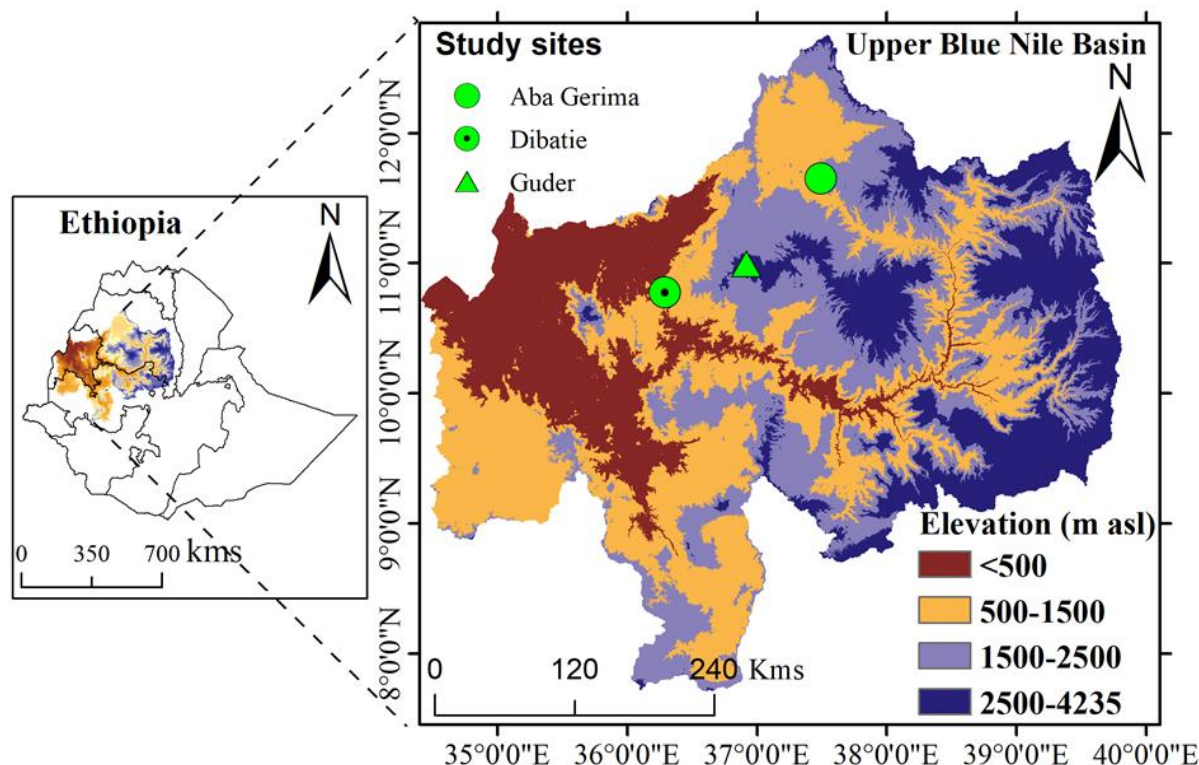


Figure 1. Location map of the study sites in the UBNB, Ethiopia.

2.2. Sampling, data type, and methods of data collection

In this study, we employed a cross-sectional survey research design. The survey was divided into two phases. In the first phase, a series of field appraisals, involving field observations, informal interviews, and focus group discussions (FGDs), were employed to gain an understanding of LD problems, how farmers perceive LD and policies being promoted toward its management, and the portfolios of SLM practices being implemented by smallholder farmers. In total, 30 in-depth individual interviews with key informants and three FGDs were conducted (10 interviews and one FGD at each watershed). FGDs were held with a group of seven people (i.e., four males and three females) who were selected purposely from each watershed. We used a checklist with a list of questions to support our interviews and group discussions. Following this step, a draft survey questionnaire was designed. The content of the questionnaire focused on three main issues: (1) socio-economic and demographic data, farm characteristics, and biophysical and institutional conditions; (2) farmers' perceptions of LD, land-use policy's perceived economic risks and tenure

security, and causes of climate change; and (3) farmers' adopted SLM practices and the extent of their implementation. Before we initiated the formal survey, the interview questions were pilot-tested with 30 farmers. The responses from the pilot test were helpful to ensure the clarity and adequacy of the information sought while avoiding ambiguity in the survey questions.

The second phase was the formal survey. Following the preparation of the final survey questionnaire, a sampling frame consisting of farm household heads from the farming communities in the three watersheds were prepared. The lists of households were obtained from local agriculture offices affiliated with each watershed. Then, the sampling units for this study were drawn first by purposely selecting the Aba Gerima, Guder, and Dibatie watersheds to represent medium, higher, and lower elevation watersheds, respectively, within the UBNB. Following this, 300 households (100 from each watershed) were selected for the formal survey ensuing a simple random sampling procedure. The fieldwork was undertaken in February and March 2018. The formal survey was administered using face-to-face interviews conducted by well-trained data enumerators, who were supervised by the researchers. Interviews were carried out in Amharic (the local language).

Information on the extent of use of SLM practices was gathered by asking the respondents (1) whether they implemented a spectrum of SLM technologies in any of their farmlands (yes/no) and (2) if their answer was yes, they were asked the extent to which they implemented them. A three-point Likert scale (occasionally, sometimes, always) was used to quantify the responses. Classification of responses into these scales was made in consultation with participants of the FGDs and interviews with key informants and local extension workers. Accordingly, a response of "always" refers to a situation where a household has been constantly using existing portfolios of SLM practices for at least 4 years during the past 5 years. Responses of "sometimes" and "occasionally" refer to cases where a household has been using the prevailing SLM practices for at least 2 years and 1 year, respectively.

2.3. Data analysis

For the descriptive analysis of the status and extent of use of SLM practices, we took the aggregate value of the status of use and the proportion of farmers who always used the prevailing SLM practices, respectively. The status of use was the percentage of the total farmers that used any amount of the existing portfolios of SLM practices, while the extent of use indicated the proportion

of the total farmers that either always, sometimes, or occasionally used any amount of SLM practices. After the descriptive analysis, the survey data were analyzed following two multivariate statistical procedures. First, factor analysis (FA) was employed to extract the dominant dimensions of SLM practices and develop an SLM use index based on the extracted scoring coefficients. Analysis of variance (ANOVA) was employed to see the variations in the SLM use index across the three watersheds. Second, Zellner's estimation technique for seemingly unrelated regression (SUR) was employed to analyze factors influencing smallholder farmers' choice of portfolios of SLM practices. Data management and analyses were performed using Stata ver. 15.1 (Stata Corp LP, College Station, TX, USA).

2.3.1. Factor analysis

We used FA to generate distinct portfolios of SLM practices employed by farmers from the survey data. FA is usually carried out to reduce a large set of observed variables into a smaller orthogonal set of factors [39]. Following the methods of Beavers, Lounsbury (40), prior to employing the FA approach, we carried out Bartlett's sphericity test and the Kaiser-Meyer-Olkin measure of sample adequacy to ascertain the appropriateness of using the variables as inputs to the FA procedure. We then conducted orthogonal rotation (Varimax) method to facilitate the selection of the factors without any multicollinearity effect. Principal factor components (PFCs) with factor score loadings of ≥ 0.4 (absolute terms) were extracted for further analysis. These loadings indicate how well the factors represent the actual data and account for the variance in the observed variables. Kaiser's criterion (i.e., the eigenvalue rule) was used to identify the common factors retained to create a weighted SLM use index^b variable. Thus, after FA, 18 SLM practices were extracted within five PFC portfolios that had eigenvalues of ≥ 1 (using Kaiser's criterion). FA was also employed to develop indices for explanatory variables such as media exposure (Appendix Table [AT] A), LD perception (AT B), perceptions of tenure security and economic risks (AT C), and climate change perception (AT D). After developing the indices, to simplify the analysis and interpretation of results, the LD perception index and the perceptions of tenure security and economic risks index were changed to categorical variables based on their interquartile ranges.

^b $\sum Sc \times P$, where Sc is the degree of scoring coefficient (column 6 in Table 2) and P is the proportion of farmers who used each SLM practice (column 2 in Table 2, AT E) in each retained factor or PFC (column 1 in Table 2).

2.3.2. Econometric model specification

Paudel and Thapa (41) analyzed the composite adoption index of 10 SLM practices in Nepal by using the ordinary least squares (OLS) method. Paudel and Thapa (41), however, allocated equal proportions for each SLM practice regardless of the farmers' frequency of use. Developing a composite use index that incorporates the proportion and relative frequency of use of each SLM practice would be advantageous as it helps to identify the most frequently used components of the package and rank them by their contribution scores. Accordingly, we developed an index based on each SLM practice's degree of scoring coefficient. The five FA-extracted use index values were then used as dependent variables to analyze the determinants of smallholder farmers' choice of portfolios of SLM practices.

We can estimate the five equations independently by using OLS to obtain consistent and unbiased parameter estimates. In a single OLS estimation method, the correlation of error terms is ignored; that is, the error terms of the five equations would not be correlated. From this research perspective, this means the decision to use one PFC of SLM practices does not affect the decision to use the other portfolios of SLM practices. However, this assumption is contradictory to reality in a smallholder farming system where a household applies portfolios of SLM practices. In this situation, OLS estimation would be inefficient because it would ignore the correlation of error terms across equations.

Using a system estimator has the advantage of increased estimation efficiency because information on the different equations is combined [42]. Accordingly, we used the Zellner (43) method of SUR to overcome the potential drawback of error-term correlations among the dependent variables. Zellner (43) initially developed this model for estimating the number of equations (i.e., $p > 1$ dependent variables with various explanatory variables in each model) by taking into consideration the correlation of error terms; that is, $E(\varepsilon_{in}\varepsilon_{jn}) \neq 0$, where ε_{in} and ε_{jn} are the error terms of the n^{th} observation of equations i and j , respectively. Following Zellner (43) and Greene (44), the SUR model equation can be specified as:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_p \end{bmatrix} = \begin{bmatrix} x_1 & 0 & 0 & 0 \\ 0 & x_2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & x_p \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_p \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_p \end{bmatrix} \quad (1)$$

$$Y = X\beta + \varepsilon, \quad (2)$$

where $Y = (y'_1, y'_2, \dots, y'_p)'$ is a vector of five dependent variables, X is a block diagonal design matrix with the i^{th} design matrix x_i on the i^{th} block, $\beta = (\beta'_1, \beta'_2, \dots, \beta'_p)'$ is the vector of the loaded coefficient vectors of all equations, the total number of parameters estimated for all p sub-models is $K = \sum_{i=1}^p k_i$, and $\varepsilon = (\varepsilon'_1, \varepsilon'_2, \dots, \varepsilon'_p)'$ is the vector of the loaded error vectors of all equations.

In single OLS estimations, the parameter estimates can be obtained as $\beta^{OLS} = (X'X)^{-1}X'Y$. The SUR estimator is obtained as $\beta^{SUR} = [X'\Omega^{-1}X]^{-1} [X'\Omega^{-1}Y]$, where Ω^{-1} is a weighting matrix based on the covariance matrix of the error terms $\Sigma = [\sigma_{ij}]$ and the elements of the covariance matrix $\sigma_{ij} = E[\varepsilon_{in}\varepsilon_{jn}]$, where ε_{in} and ε_{jn} are the error terms of the n^{th} observation of equations i and j , respectively. Finally, the inverse of the weighting matrix can be calculated by $\Omega = \Sigma \otimes I_N$, where I_N is the $N \times N$ identity matrix and $\otimes$ denotes the Kronecker product. However, because the true error terms (ε) are unknown, they are often replaced by observed residuals (e.g., obtained from OLS estimates; i.e., $\hat{\varepsilon}_i = y_i - X_i\beta_i^{OLS}$) so that the elements of the covariance matrix can be specified as follows [45]:

$$\hat{\sigma}_{ij} = \frac{\hat{\varepsilon}_i \hat{\varepsilon}_j}{N} \quad (3)$$

The Breusch and Pagan test of independence can be used to verify the appropriateness of the SUR model by checking whether the error terms of the five equations are correlated. It has a χ^2 statistic (a Lagrange multiplier, λ) with $P(P-1)/2$ degrees of freedom [46]:

$$\lambda = N \sum_{p=1}^P \sum_{n=1}^{p-1} r_{pn}^2, \quad (4)$$

where r_{pn} is the estimated correlation between the residuals of the P equations and N is the number of observations.

If the equations are independent, no efficiency can be gained by using the SUR [44]. But if the residuals of the five equations are independent (i.e., uncorrelated and homoscedastic), OLS regression can yield unbiased estimates [45].

2.3.3. Identification of SLM practices and selection of variables

Dependent variables

In this study, SLM practices refer to a range of measures adapted to local social, economic, and biophysical conditions intended to protect, conserve, and sustainably use resources and restore degraded land resources [47]. The continuous index values of the extracted PFCs, which are obtained after FA, were used as dependent variables. The dependent variables, therefore, represent the five PFC categories of SLM practices (Table 3). These five categories were defined as follows. (1) Agronomic practices comprise procedures that are implemented to improve crop productivity; reduce, prevent, and reverse LD; and create a beneficial economic impact on croplands through improving inputs use and yields. The agronomic knowledge also helps farmers in taking good care of the environment by improving soil quality, water usage and crop management [48]. The practices considered here include the use of improved crop varieties, crop rotation, applications of agronomic knowledge, following a basic crop calendar, and contour cultivation. (2) Horticultural practices comprise procedures such as the planting of horticultural crops in conjunction with the use of compost and irrigation. These practices are implemented to improve productivity by increasing soil fertility [48]. (3) Agroforestry practices include the application of agroforestry methods, as well as the use of forestry/nursery techniques, trenches, and the cut-and-carry system. As a biological measure, these can stand alone or be combined with physical structures. Agroforestry practices are aimed at increasing the infiltration capacity of the soil, reducing LD, and increasing land productivity [49, 50]. (4) Soil conservation practices comprise measures that are implemented in croplands, often to change the slope profile and to reduce the flow of runoff so that the water can drain into the soil, thereby retaining the soil [51]. The soil conservation measures considered here include the use of stone bunds, soil bunds, and stone-faced soil bunds. (5) Runoff control practices are usually employed to safely control excess runoff from farmlands before it damages or destroys structures used for soil conservation practices [51]. These measures include check dams, cutoff drains, and waterways.

Independent variables

Drawing on earlier research, we hypothesized that smallholder farmers' choice of portfolios of SLM practices are influenced by a combination of socio-economic, biophysical, institutional, and perceptual factors. In this regard, we also hypothesized that farmers' choice of SLM practices is

likely to vary significantly across elevation gradients. Farmers located in high elevation areas can easily perceive the negative effects of soil erosion [23] and will be more likely to implement a range of SLM practices [33]. Choice of SLM practices is also likely to vary across other factors. For example, male-headed households are more likely to use SLM practices [41] such as agronomic [23, 24] and agroforestry practices [52] because of their better access to and control over resources. Older farmers are less likely to use many SLM practices because of their shorter planning horizon and reduced levels of physical fitness and energy [28]. In addition, household size influences labor supply, and larger households are more likely to use diverse land management measures [53]. This is true because such households can more easily employ labor-intensive SLM practices [24] such as physical practices [30] and manure application [23]. Household endowments (number of plots, land size, livestock, and annual income) also play positive roles in the implementation of SLM practices by smallholder farmers through compensating for the opportunity costs incurred through the use of SLM practices and avoiding resource competition [54].

Farmers' membership in agricultural cooperatives facilitates the rapid spread of SLM practices [29]. This type of local institution aggregates local social networks for smallholder farmers and can enhance their awareness and knowledge about SLM practices. In addition, farmers' exposure to varying sources of extension information allows them to overcome any initial ambiguity they may feel about the practices and to access timely information, thereby facilitating greater diffusion and adoption of SLM practices [21].

Farmers' perception of LD severity is also an important factor in determining their adoption of various SLM practices, whereby those who perceive more severe LD are more likely to implement different SLM practices to address the problem, and those who perceive less severe LD are less likely to do so [21]. It is often assumed that secure land tenure and lower perceived economic risks incentivize smallholder farmers to undertake more SLM measures on their farmlands [55]. Moreover, farmers who have prior awareness of changes in climatic conditions and their link with LD view their application of various SLM practices as coping and adaptation strategies [36].

The explanatory variables and summary statistics are presented in Table 1.

311 **Table 1.** Description and summary statistics of selected explanatory variables.

Variable definition/description	Explanatory variable	Measurement	Mean	SD
Study location (agro-ecological zones representing mid-, high-, and lowlands)	Aba Gerima	Categorical, 1 if Aba Gerima;	0.33	0.47
	Guder	2 if Guder;	0.33	0.47
	Dibatie	3 if Dibatie	0.33	0.47
Slope of farmland (flat, moderate, steep)	Flat	Categorical, 1 if flat;	0.18	0.38
	Moderate	2 if moderate;	0.77	0.42
	Steep	3 if steep	0.05	0.23
Sex of the household head	Sex	Binomial, 1 if male	0.84	0.37
Age of the household head	Age	Metric, in years	48.30	12.90
Number of individuals in household	Household size	Metric, numbers	5.60	2.40
Number of farmland plots operated by household	Number of plot	Metric, numbers	3.24	1.51
Land size operated by household	Landholding	Metric, in ha	2.01	1.95
Livestock size owned by household	Livestock size	Metric, in TLU ^a	4.70	3.20
Total income obtained by household	Farm income	Metric, in US\$	511.74	516.72
Household is a member of rural cooperatives	Cooperatives	Binomial, 1 if yes	0.54	0.50
Household access to agricultural information sources	Information access	Index value	0.96	0.36
Farmer reports farmland LD has decreased (slightly, moderately, considerably)	Slight decline LD	Categorical; 1 if slight;	0.47	0.50
	Moderate decline LD	2 if moderate;	0.42	0.49
	High decline LD	3 if high	0.11	0.317
Farmer reports farmland LD has increased (slightly, moderately, considerably)	Slight increase LD	Categorical; 1 if slight;	0.59	0.49
	Moderate increase LD	2 if moderate;	0.38	0.49
	High increase LD	3 if high	0.03	0.18
Farmer perception of economic risks of land-use policy (low, medium, high)	Low economic risks	Categorical; 1 if low;	0.34	0.47
	Medium economic risks	2 if medium;	0.45	0.50
	High economic risks	3 if high	0.21	0.41
Farmer perception of land tenure security (low, medium, high)	Low tenure security	Categorical; 1 if low;	0.17	0.38
	Medium tenure security	2 if medium;	0.63	0.48
	High tenure security	3 if high	0.20	0.40
Farmer reports climate change exacerbates LD	Climate change cause	Index value	0.43	0.33

312 Note: SD = standard deviation; ^a Tropical livestock unit

3. Results

3.1. Sample household characteristics

The main summary statistics of respondents are shown in Table 1. About 84% of sample households were male-headed, and each household had an average of 5.6 members. The mean landholding size and livestock number were 2.01 ha and 4.7 tropical livestock units, respectively. More than 90% of the farmers had been exposed to various extension information sources. About 34% and 21% of the farmers perceived low and high economic risks of land-use policy, respectively, and 17% and 25% had low and high levels of perceived tenure security. About 43% of the farmers responded that they thought climate change contributed to LD.

3.2. Extent of use of portfolios of sustainable land management practices

After FA, the SLM practices implemented by the smallholder farmers were extracted within five PFC portfolios that had eigenvalues of ≥ 1 (using Kaiser's criterion) (Table 2).

The descriptive analysis shows that the status of use of portfolios of SLM practices was low (39%); moreover, only 24% of them were persistently practiced. More specifically, the proportion of farmers who always practiced agronomic, horticulture, agroforestry, soil conservation, and runoff control practices were 40%, 20%, 11%, 18%, and 33%, respectively. Likewise, the proportion of farmers who sometimes used these practices were 11%, 8%, 7%, 10%, and 14%, respectively (Figure 2 and AT E).

We also generated an index after FA to gauge the extent of use of SLM practices based on their degrees of scored coefficients for each watershed (Table 3). Agronomic practices had the highest use index (0.5603); however, the use index was considerably higher in the Dibatie and Aba Gerima watersheds. Farmers' in the Guder watershed practiced relatively more agroforestry (48.02%), whereas the agroforestry proportion was only 4.31% in the Dibatie watershed. Aba Gerima watershed had the highest use index (0.5821) of soil conservation practices. One-way ANOVA tests indicated significant variation in the use of the SLM portfolios among the watersheds ($P < 0.01$).

339 **Table 2.** Extracted principal factor components (PFCs) of existing sustainable land management (SLM) practices.

Retained factors (PFCs)	SLM practices	Bartlett test of sphericity (<i>P</i> value)	KMO	Rotated factor loading score	Scoring coefficient	Factor rotation correlation matrix
Agronomic practices	Improved crop variety	0.000	0.834	0.7465	0.23438	1.0000
	Crop rotation			0.7311	0.22974	
	Agronomic knowledge			0.7192	0.20236	
	Basic crop calendar			0.8194	0.33620	
	Contour cultivation			0.5760	0.13230	
Horticulture practices	Horticulture	0.000	0.638	0.6627	0.30091	1.0000
	Compost			0.5813	0.23124	
	Irrigation			0.7654	0.46735	
Agroforestry practices	Agroforestry	0.000	0.740	0.6726	0.32133	1.0000
	Forestry/nursery			0.6137	0.26209	
	Trench/half-moon terrace			0.6972	0.35259	
	Cut and carry system			0.4321	0.15235	
Soil conservation practices	Stone bund	0.000	0.666	0.5811	0.29108	1.0000
	Soil bund			0.6155	0.32467	
	Stone-faced soil bund			0.6543	0.37104	
Runoff control practices	Check dam	0.000	0.618	0.4978	0.19780	1.0000
	Cutoff drains			0.7389	0.45150	
	Water way			0.6723	0.34134	

340 Note: A KMO (Kaiser-Meyer-Olkin) measure of sample adequacy of ≥ 0.5 is considered to be acceptable. The Bartlett test of sphericity
341 is significant at the 0.01 level. The SLM practices' with factor loading score of ≥ 0.4 were extracted, and the correlation matrix is ≥ 0.85 .

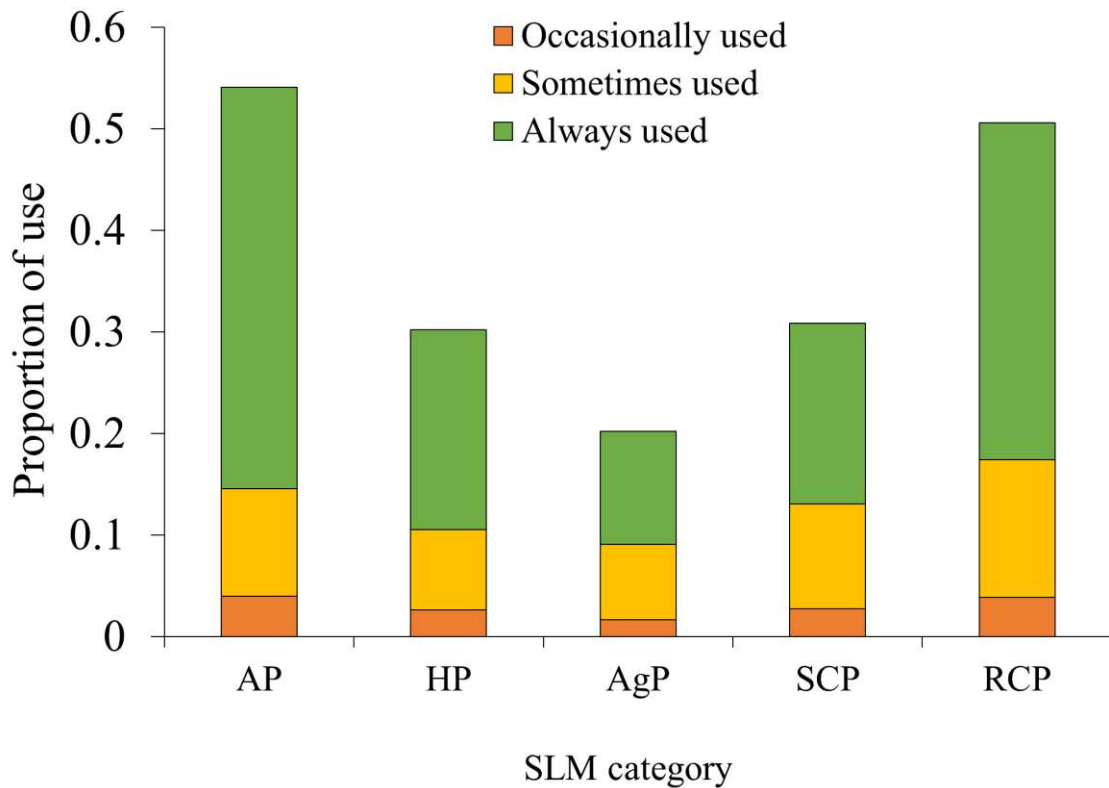


Figure 2. Extent of use of portfolios of sustainable land management practices (AP, agronomic practices; HP, horticulture practices; AgP, agroforestry practices; SCP, soil conservation practices; RCP, runoff control practices).

Table 3. Extent of use of portfolios of sustainable land management practices across the three watersheds

Watershed	<i>N</i>	Agronomic practices	Horticulture practices	Agroforestry practices	Soil conservation practices	Runoff control practices
Aba Gerima	100	0.6157	0.3058	0.0643	0.5821	0.3606
Guder	100	0.4392	0.4717	0.4802	0.1802	0.6431
Dibatie	100	0.6261	0.1053	0.0431	0.3532	0.6282
Mean	300	0.5603	0.2942	0.1959	0.3718	0.5441
ANOVA (<i>F</i> -value)		6.84***	28.33***	132.30***	35.52***	18.61***

*** $P < 0.01$

3.3.Determinants of smallholder farmers' choice of portfolios of SLM practices

Table 4 shows the SUR model results of the determinants of farmers' choice of portfolios of SLM practices. We tested the null hypothesis that the error terms of the regression equations for the five PFCs of SLM practices were not correlated. The Breusch-Pagan (BP) test (χ^2 [10] = 152.016, P = 0.0000) rejected the null hypothesis of independence at the 1% level of significance, implying the appropriateness of the SUR model. The χ^2 statistic measures overall goodness of fit of the estimated SUR model and it shows that the model significantly explained the heterogeneity in farmers' choice of portfolios of SLM practices.

Agroforestry ($P < 0.01$) and runoff control ($P < 0.05$) practices were more likely to be utilized by smallholder farmers in the highland (Guder) watershed than those in the midland (Aba Gerima) watershed, but agronomic ($P < 0.01$) and soil conservation ($P < 0.01$) practices were less likely to be utilized. In the lowland (Dibatie) watershed, only runoff control practices ($P < 0.01$) were more likely to be used, but horticulture ($P < 0.01$), agroforestry ($P < 0.05$), and soil conservation ($P < 0.01$) practices were less so. Smallholder farmers were less likely to apply agroforestry practices ($P < 0.1$) on moderately sloped farmlands than on flat farmlands, while they more likely used soil conservation ($P < 0.1$) and runoff control ($P < 0.05$) practices. Similarly, they were more likely to use soil conservation practices ($P < 0.1$) on steeply sloped farmlands.

Male-headed households were more likely to use agronomic practices ($P < 0.01$). Households headed by older farmers were less likely to implement soil conservation practices ($P < 0.1$), whereas those with more farm plots and livestock were more likely to implement them ($P < 0.05$). Larger households were more likely to implement horticulture practices ($P < 0.05$). Likewise, farmers with greater land endowments were more likely to adopt agroforestry ($P < 0.05$) and soil conservation ($P < 0.1$) practices. Farmers who were members of rural cooperatives were more likely to use horticulture ($P < 0.05$) and soil conservation ($P < 0.01$) practices. Moreover, farmers' who accessed diversified extension information were more likely to use agronomic ($P < 0.01$), horticulture ($P < 0.01$), and agroforestry ($P < 0.05$) practices, but less likely to implement soil conservation ($P < 0.05$) practices.

376 **Table 4.** Seemingly unrelated regression model results of the determinants of farmers' choice of portfolios of sustainable land
377 management practices.

4. Explanatory variable	Agronomic practices		Horticulture practices		Agroforestry practices		Soil conservation practices		Runoff control practices	
	β	SE	β	SE	β	SE	β	SE	β	SE
Guder	-0.300***	0.067	0.039	0.059	0.323***	0.037	-0.322***	0.059	0.291***	0.068
Dibatie	-0.086	0.085	-0.208***	0.074	-0.119**	0.047	-0.235***	0.075	0.288***	0.085
Moderate	0.007	0.059	-0.059	0.051	-0.058*	0.032	0.101*	0.052	0.128**	0.059
Steep	-0.007	0.104	0.003	0.090	-0.014	0.057	0.175*	0.091	0.120	0.104
Sex	0.186***	0.064	-0.079	0.056	-0.004	0.035	0.053	0.056	0.094	0.064
Age	0.001	0.002	0.002	0.001	0.001	0.001	-0.002*	0.001	0.000	0.002
Household size	0.001	0.010	0.018**	0.009	0.004	0.006	-0.001	0.009	0.004	0.010
Number of plots	0.003	0.015	0.012	0.013	-0.009	0.008	0.026**	0.013	0.000	0.015
log(Landholding)	-0.002	0.042	0.004	0.037	0.046**	0.023	0.066*	0.037	0.011	0.042
Livestock size	0.008	0.009	-0.002	0.008	0.007	0.005	0.018**	0.008	0.005	0.009
log(Farm income)	-0.004	0.008	0.004	0.007	-0.001	0.005	-0.005	0.007	-0.001	0.009
Cooperatives	0.076	0.050	0.085**	0.043	0.005	0.026	0.113***	0.044	0.044	0.050
Information access	0.306***	0.075	0.193***	0.066	0.152**	0.041	-0.158**	0.066	0.095	0.075
Slight decline LD	-0.031	0.046	-0.068*	0.040	-0.041	0.025	0.087**	0.040	0.046	0.046
High decline LD	0.273***	0.074	0.202***	0.064	0.026	0.041	0.191***	0.065	0.193***	0.074
Slight increase LD	-0.012	0.046	0.008	0.040	0.007	0.025	-0.081**	0.041	-0.010	0.046
High increase LD	-0.450***	0.120	-0.272***	0.105	-0.090	0.066	-0.010	0.105	-0.144	0.120
Low economic risks	0.008	0.051	0.130***	0.044	-0.043	0.028	0.003	0.045	-0.049	0.051
High economic risks	0.072	0.062	0.049	0.054	-0.015	0.034	-0.144***	0.055	-0.126**	0.062
Low tenure security	-0.065	0.062	-0.061	0.054	-0.072**	0.034	0.092*	0.055	-0.087	0.062
High tenure security	-0.228***	0.059	-0.059	0.052	-0.041	0.033	0.043	0.052	-0.047	0.059
Climate change cause	0.083	0.071	0.218***	0.062	0.073*	0.039	0.175***	0.062	0.187***	0.071
Constant	0.153	0.146	-0.133	0.128	-0.048	0.081	0.403***	0.128	-0.063	0.147
R^2	0.3406		0.4012		0.6102		0.3943		0.2666	
χ^2	143.10***		185.57***		433.70***		180.32***		100.67***	
N	300									
Breusch-Pagan test of independence: $\chi^2(10) = 152.016$; $P = 0.0000$										

378 Note: The variables are defined in Table 1. * $P < 0.1$; ** $P < 0.05$; *** $P < 0.01$. SE: standard error.

Farmers who reported that LD had slightly decreased were less likely to engage in horticulture practices ($P < 0.1$), but they were more likely to use soil conservation practices ($P < 0.05$). Likewise, farmers who reported that LD considerably declined were more likely to apply all types of SLM practices ($P < 0.01$) except agroforestry. Farmers who reported that LD slightly increased were less likely to practice soil conservation ($P < 0.05$), whereas those who reported that LD had considerably increased were less likely to use agronomic ($P < 0.01$) and horticulture ($P < 0.01$) practices. Farmers who perceived low economic risks were more likely to engage in horticulture practices ($P < 0.01$), while those who perceived high economic risks were less likely to apply soil conservation ($P < 0.01$) and runoff control ($P < 0.05$) practices. Farmers who perceived that land tenure was less secure were less likely to implement agroforestry ($P < 0.05$), but they were more likely to use soil conservation ($P < 0.1$) practices. Conversely, those who perceived that the tenure system was more secure were less likely to implement agronomic practices ($P < 0.01$). Finally, farmers who perceived changes in climate conditions were more likely to use all types of SLM practices except for agronomic practices.

4. Discussion

Despite continuous LD dynamics and efforts to promote SLM in Ethiopia, smallholder farmers' investment in SLM remains low in spite of increasing LD [21]. The extent of SLM practices applied by smallholder farmers varied across the study sites. Comparatively, agronomic practices were applied more in the Aba Gerima and Dibatie watersheds than in the Guder watershed. Soil conservation practices, which are usually constructed in cropland areas, were more likely to be practiced by farmers in the Aba Gerima watershed. Both agronomic and soil conservation practices are implemented in cropland areas, so a plausible explanation for the differences in implementation by farmers in the respective watersheds could be the greater coverage of cultivated lands in those areas [56]. In contrast, farmers in the Guder watershed used more agroforestry practices than those in Dibatie owing to the expansion of cash crop cultivation in that watershed (e.g., *A. decurrens* and highland fruits) [57].

When it comes to sustainable behaviors such as the adoption of SLM practices, it is important to know what influences smallholder farmers' choices. Our findings reveal that farmers' decisions to implement SLM practices in their farmlands are determined by several factors. Noteworthy among these determinants is the landscape position. Farmers located in medium and higher elevation areas

(Aba Gerima and Guder watersheds, respectively) were more likely to experience more erosion and rapid surface runoff on their farmlands as compared with farmers in lower elevation areas (the Dibatie watershed), which is concurrent with the findings of Nigussie, Tsunekawa (58). This kind of first-hand experience may allow the farmers to better understand the importance of investing in land management and become more likely to implement soil conservation practices [23]. Farmers in medium elevation areas were less likely to implement agroforestry practices, which is probably associated with their choice to use a greater proportion of their farmlands for crop cultivation to meet their own food demand.

As anticipated, younger farmers who are generally healthier were more likely to apply soil conservation practices, most likely because of their greater physical fitness to implement such labor-intensive activities as compared with older farmers. Additionally, because of their longer planning horizon, younger farmers are more likely to foresee and positively assess the long-term productivity gains from using these practices [28]. Similarly, the positive effect of household size on the application of horticulture practices can be associated with the availability of the labor needed to undertake the labor-intensive activities associated with horticulture, such as land preparation, application of organic fertilizers, irrigation, and management of day-to-day farm operations, which is in agreement with the findings of Miheretu and Yimer (25). Smallholder farmers with relatively higher labor capacities may be able to invest more in horticultural practices in a quest to improve yield and return on investment.

Based on the household head's gender differentials, we find that male heads were more likely to make use of agronomic management practices than their female counterparts, implying that they had access to the resources necessary to implement agronomic practices, in agreement with the findings of Nigussie, Tsunekawa (28). This result is not surprising since females are more likely to own fewer resources compared to males. For instance, in this study, male-headed households were endowed with a larger average household size, greater land holdings, and more livestock (tropical livestock units) than their female counterparts (42.8%, 43.8%, and 66.7% higher, respectively). Likewise, single male-headed households were more endowed than their single female counterparts (14.3%, 15.4%, and 40%, respectively). This result is also in line with that of Holden, Shiferaw (59). In general, in a traditional society such as in our case, male-headed households have better access to resources to purchase productivity-enhancing external farm

inputs (e.g., chemical fertilizer, improved seed) and to tend crops following improved agronomic and management practices. However, there is a need for further study on gender issues and their relationships with farmers' application of agricultural innovations as shaped by the interplay of gender norms, gendered access to and control over resources, and decision-making in lieu of taking the present result as conclusive.

Membership in rural cooperatives was positively associated with implementation of horticulture and soil conservation practices. This is a plausible result in that membership in a farmers' group often can enhance farmers' awareness and knowledge through group interactions and network cooperation. Moreover, application of soil conservation practices creates positive externalities that extend beyond the farm of an individual farmer [28]; hence, it may explain why such practices are more effective in a cooperative setting. Likewise, farmers' access to extension information significantly increased the likelihood of application of agronomic, horticultural, and agroforestry practices, but it hurt soil conservation practices. The former result suggests that farmers' access to extension information helps them to overcome any initial doubts related to the application of these practices, in agreement with the findings of Nyanga, Kessler (60). The latter result is also in agreement with Amsalu and De Graaff (61), who found that ongoing agricultural extension does not induce farmers to apply physical SLM technologies, suggesting a need to find other knowledge transfer mechanisms and capacitate local agricultural experts with new extension communication methods and approaches. These findings further underscore the need for agricultural policy to promote membership in farmers' groups and expand knowledge-sharing platforms.

Operators of larger farms and those with more livestock (proxies for the relative wealth of farmers) were more likely to implement soil conservation practices. A plausible reason could be that their larger land and livestock holdings may enable farmers to absorb short-term opportunity costs incurred from the application of soil conservation practices (e.g., the land needed for the treatment competes with land for crops) to reap benefits that will arise at some point in the future [28]. It may also be the case that their access to greater resources enable them to afford the upfront and ongoing labor requirements to construct and maintain the soil conservation measures [62]. Land size also had a positive effect on the application of agroforestry practices, implying that farmers with larger farms were more likely to apply agroforestry practices, in agreement with Nigussie, Tsunekawa (28), who noted that farmers with larger landholdings invest more in cash-oriented

agroforestry technology. Booms in agroforestry-based cash cropping have been observed, such as with chat in Aba Gerima and *A. decurrens* in Guder. As the amount of land allocated to agroforestry increases, farmers with larger farms can also benefit from land-use efficiency (e.g., intercropping teff and *A. decurrens*) or economies of scale to lower the opportunity costs of implementing soil conservation measures [28].

Farmers who perceived a slight decline in LD were less likely to engage in horticulture practices, but they were more likely to use soil conservation practices. The former result may hold true because of their low awareness of the possibilities of sustaining the productivity of staple crops by using improved organic fertilization and irrigation management. These farmers may instead be inclined to cultivate cash crops to support their livelihood. The latter result is probably related to the positive role played by government-led SLM activities to promote these practices. However, farmers who perceived that LD is considerably declining preferred all types of SLM practices, except for agroforestry practices. Farmers who perceived an improvement in LD conditions, which is usually reflected through improved crop yields, may apply more SLM practices to reap gains that could be obtained from additional investment. This is true because marginal productivity losses resulting from LD from relatively less degraded farmlands are higher than those from considerably degraded farmlands. Thus, applying SLM practices on relatively less degraded farmlands is expected to yield higher returns in the short term [63]. Surprisingly, farmers who perceived that LD is increasing were less likely to use soil conservation, agronomic, and horticulture practices. This is consistent with the findings of Adimassu, Kessler (64), who found that farmers' perception of soil erosion was negatively and significantly associated with their investment in SLM practices. Smallholder farmers might not experience the negative effects of LD on their farmlands in the short run and refrain from implementing these SLM practices [63]. Similarly, it could be related to the increased cost of agricultural inputs (e.g., high-yield seed varieties, fertilizer, and labor) associated with using these practices [64], which may in turn decrease profitability. In contrast, Nigussie, Tsunekawa (28) noted the positive influence of farmers' perception of soil erosion on implementing SLM practices.

Farmers who perceived a lower uncertainty on likely economic benefits of land-use policy were more likely to engage in horticulture practices; in contrast, farmers who perceived higher uncertainty were less likely to implement soil conservation and runoff control practices. A

plausible reason for the former result could be that, as per capita landholding size becomes smaller because of a lack of access to additional land (absence of land redistribution for a long time), farmers may be more inclined to cultivate high-value crops (e.g., vegetables and fruits) to enhance land productivity by using irrigation and compost [65]. The latter result may indicate that, aside from not having enough land access, when farmers are more uncertain as to when the benefits might be realized, they may feel insecure about implementing long-term productivity-enhancing SLM practices such as soil conservation and runoff control practices, which is consistent with information from key informants and the findings of Nigussie, Tsunekawa (21). Moreover, lower perceived tenure security was less likely to induce farmers to apply agroforestry practices, whereas farmers who perceived a higher level of tenure security were less likely to implement agronomic practices. The former result indicates that farmers could be less interested in implementing agroforestry practices with an inefficient land tenure arrangement because these practices may not provide economic benefits in the short term and incur higher post-establishment opportunity costs [66]. Similar studies have revealed that the absence of tenure security can lead to a fragile land-use system and be a main contributor to inefficiency in farmers' utilization of SLM practices to effectively adapt to the effects of LD [32].

Climate-induced risks present an important threat to the subsistence agriculture system through increasing agricultural production risks and changing smallholder farmers' incentives to invest in mitigating those risks [36]. In this context, our results indicated that the farmers who indicated they understood the risk posed by climate change and its link with LD were more likely to use all of the SLM practices, except agronomic practices. Smallholder farmers' awareness of climate change could enable them to afford some of the investment costs associated with the implementation of SLM practices, which, in turn, could strengthen the local responses in adapting to and mitigating against the effects of climate change, and hence LD [67].

5. Conclusions

In Ethiopia, LD is increasing with devastating consequences on smallholder farmers' livelihood options, and conditions are even worse in the severely degraded UBNB. The government and international organizations have been widely promoting SLM practices, but they have had trouble achieving their objectives. We aimed to assess the extent of use of portfolios of SLMs by smallholder farmers and analyze the factors that determine their implementation. Although

smallholder farmers did use combinations of SLM practices, less than 25% were found to always practice them. In addition, there was significant variation in the use index across elevation gradients. In smallholder farm settings, it is also important to consider underlying household characteristics such as sex and age of household head, household size, access to land, and watershed conditions in designing and deploying SLM practices.

The mixed results related to access to extension information might imply that the existing information exchange system is not strong enough to induce farmers to implement a multitude of SLM practices (e.g., soil conservation practices). As a result, farmers need to be well aware of the problems their farmlands are facing to encourage them to take up measures against it. The relationship between farmers' perceptions about the land-use policy's impact on the economic benefits of SLM practices and their likelihood of implementing soil conservation and runoff control practices implies that the extension system considers less to economic productivity when trying to encourage the use of SLM practices. Thus, there is a need for introducing economic incentives to supplement farmers' ongoing conservation efforts because implementing most of the SLM practices may not—at least in the short term—fully incentivize farmers to invest in various SLM practices. One possibility is to promote income-generating activities aimed at compensating farmers for the opportunity costs incurred by SLM practices and subsidizing improved agricultural inputs (e.g., seed and fertilizer) to motivate farmers to implement diverse SLM practices. Finally, the negative relationship between farmers' perceptions of tenure security and the use of SLM practices implies a need to reassess the impacts of land tenure and its governance and their respective link with SLM implementation by farmers.

Although this paper presents interesting findings on the extent of uptake of portfolios of SLM practices among smallholder farmers and the factors that drive their adoption based on our analyses of cross-sectional data, there is a need to study panel data to monitor the dynamics of adoption behavior over time. Therefore, future research should focus on this aspect to understand the sustainability of SLM practices in a smallholder farm setting.

555 **Acknowledgment**

556 The Science and Technology Research Partnership for Sustainable Development (Grant Number
557 JPMJSA1601) and the Japan Science and Technology Agency/Japan International Cooperation
558 Agency supported this research. We acknowledge the contributions of field research assistants Mr.
559 Anteneh Wubet and Mr. Niguss Taddesse for organizing the local community and for their
560 continued support during data collection. We also thank the data enumerators and respondents for
561 their kind cooperation in collecting data and providing information, respectively.

562 **Funding**

563 The Science and Technology Research Partnership for Sustainable Development (Grant Number
564 JPMJSA1601) and the Japan Science and Technology Agency/Japan International Cooperation
565 Agency supported this work.

566 **Declaration of Competing Interest**

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

569 **Availability of Data**

570 The datasets generated and/or analyzed during the current study are available from the
571 corresponding author upon reasonable request.

572 **Clinical Trial Number**

573 Not applicable.

574 **Consent to Participate Declaration**

575 The study obtained informed consent from all participants.

576 **Consent to Publish Declaration**

577 Not applicable.

578 **Ethics Approval and Accordance Declaration**

579 This research was approved by the College of Agriculture and Environmental Sciences Research
580 Review and Ethics Committee and was conducted in accordance with Bahir Dar University's
581 Senate Legislation.

References

1. Haregeweyn N, Tsunekawa A, Tsubo M, Fenta AA, Ebabu K, Vanmaercke M, et al. Progress and challenges in sustainable land management initiatives: a global review. *Science of the Total Environment*. 2023;858:160027. doi: <https://doi.org/10.1016/j.scitotenv.2022.160027>.
2. Stocking MA. Land Degradation. In: Smelser NJ, Baltes PB, editors. *International Encyclopedia of the Social and Behavioral Sciences*. Oxford: Pergamon; 2001. p. 8242-7.
3. Nkonya E, Johnson T, Kwon HY, Kato E. Economics of land degradation in Sub-Saharan Africa. *Economics of land degradation and improvement—a global assessment for sustainable development*: Springer, Cham; 2016. p. 215-59.
4. Borrelli P, Robinson DA, Fleischer LR, Lugato E, Ballabio C, Alewell C, et al. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*. 2017;8(1):1-13.
5. Fenta AA, Tsunekawa A, Haregeweyn N, Poesen J, Tsubo M, Borrelli P, et al. Land susceptibility to water and wind erosion risks in the East Africa region. *Science of the Total Environment*. 2020;703:135016.
6. Fenta AA, Tsunekawa A, Haregeweyn N, Tsubo M, Yasuda H, Kawai T, et al. Agroecology-based soil erosion assessment for better conservation planning in Ethiopian river basins. *Environmental Research*. 2021;195:110786. doi: <https://doi.org/10.1016/j.envres.2021.110786>.
7. Humi K, Zeleke G, Kassie M, Tegegne B, Kassawmar T, Teferi E, et al. Economics of land degradation (ELD) Ethiopia case study. *Soil degradation and sustainable land management in the rainfed agricultural areas of Ethiopia: an assessment of the economic implications Report for the Economics of Land Degradation Initiative* 2015. p. 94.
8. Haregeweyn N, Tsunekawa A, Poesen J, Tsubo M, Meshesha DT, Fenta AA, et al. Comprehensive assessment of soil erosion risk for better land use planning in river basins: case study of the Upper Blue Nile River. *Science of the Total Environment*. 2017;574:95-108.
9. Daniel D. *Soil and water conservation manual: guideline for Ethiopia*. Soil and Water Conservation Team, Natural Resources Management and Regulatory Department, Ministry of Agriculture, Addis Ababa 2001.
10. Yesuf M, Mekonnen A, Kassie M, Pender J. *The cost of land degradation in Ethiopia: a review of past studies*. World Bank, Washington DC. 2007.

- 613 11. Adegbo T, Simane B, Woldie GA. Sustainability, institutional arrangement and challenges
614 of community based climate smart practices in northwest Ethiopia. *Agriculture and Food Security*.
615 2018;7(1):56.
- 616 12. Herrick J, Abrahamse T, Abhilash P, Ali S, Alvarez-Torres P, Barau A, et al. Land
617 restoration for achieving the sustainable development goals: an international resource panel think
618 piece: United Nations Environment Programme; 2019.
- 619 13. Stern PC, Young OR, Druckman DE. Global environmental change: understanding the
620 human dimensions: National Academy Press; 1992.
- 621 14. Vlek P, Khamzina A, Tamene L. Land degradation and the Sustainable Development
622 Goals: threats and potential remedies. International Center for Tropical Agriculture (CIAT),
623 Nairobi, Kenya: CIAT; 2017. p. 67.
- 624 15. Jónsson JÖG, Davíðsdóttir B. Classification and valuation of soil ecosystem services.
625 *Agricultural Systems*. 2016;145:24-38.
- 626 16. UNDP. Combating land degradation: securing a sustainable future.
627 [https://www.undp.org/content/undp/en/home/librarypage/environment-](https://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_land_management/combating-land-degradation---securing-a-sustainable-future.html)
628 [energy/sustainable_land_management/combating-land-degradation---securing-a-sustainable-](https://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_land_management/combating-land-degradation---securing-a-sustainable-future.html)
629 [future.html](https://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_land_management/combating-land-degradation---securing-a-sustainable-future.html). 2019.
- 630 17. Mitiku H, Herweg K, Stillhardt B. Sustainable land management—a new approach to soil
631 and water conservation in Ethiopia, Land Resource Management and Environmental Protection
632 Department, Mekelle University, Mekelle, Ethiopia. Center for Development and Environment
633 (CDE), University of Bern and Swiss National Center of Competence in Research (NCCR) North-
634 South, Bern, Switzerland. 2006.
- 635 18. Haregeweyn N, Tsunekawa A, Nyssen J, Poesen J, Tsubo M, Tsegaye Meshesha D, et al.
636 Soil erosion and conservation in Ethiopia: a review. *Progress in Physical Geography*.
637 2015;39(6):750-74.
- 638 19. Haregeweyn N, Berhe A, Tsunekawa A, Tsubo M, Meshesha DT. Integrated watershed
639 management as an effective approach to curb land degradation: a case study of the Enabered
640 watershed in northern Ethiopia. *Environmental Management*. 2012;50(6):1219-33.
- 641 20. Taye G, Poesen J, Wesemael BV, Vanmaercke M, Teka D, Deckers J, et al. Effects of land
642 use, slope gradient, and soil and water conservation structures on runoff and soil loss in semi-arid
643 northern Ethiopia. *Physical Geography*. 2013;34(3):236-59.

21. Nigussie Z, Tsunekawa A, Haregeweyn N, Adgo E, Cochrane L, Floquet A, et al. Applying Ostrom's institutional analysis and development framework to soil and water conservation activities in north-western Ethiopia. *Land Use Policy*. 2018;71:1-10.
22. Abera W, Tamene L, Tibebe D, Adimassu Z, Kassa H, Hailu H, et al. Characterizing and evaluating the impacts of national land restoration initiatives on ecosystem services in Ethiopia. *Land Degradation and Development*. 2020;31(1):37-52.
23. Kassie M, Teklewold H, Jaleta M, Marenja P, Erenstein O. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*. 2015;42:400-11.
24. Kassie M, Zikhali P, Manjur K, Edwards S. Adoption of sustainable agriculture practices: evidence from a semi-arid region of Ethiopia. *Natural Resources Forum*. 2009;33(3):189-98.
25. Miheretu BA, Yimer AA. Determinants of farmers' adoption of land management practices in Gelana sub-watershed of northern highlands of Ethiopia. *Ecological Processes*. 2017;6(1):19.
26. Teshome A, de Graaff J, Ritsema C, Kassie M. Farmers' perceptions about the influence of land quality, land fragmentation and tenure systems on sustainable land management in the north western Ethiopian highlands. *Land Degradation and Development*. 2016;27(4):884-98.
27. Sileshi M, Kadigi R, Mutabazi K, Sieber S. Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia. *International Soil and Water Conservation Research*. 2019;7(4):354-61. doi: <https://doi.org/10.1016/j.iswcr.2019.08.002>.
28. Nigussie Z, Tsunekawa A, Haregeweyn N, Adgo E, Nohmi M, Tsubo M, et al. Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia. *Land Use Policy*. 2017;67:57-64.
29. Mangole CD, Maina CM, Mulungu K, Tschopp M, Harari N, Suresh R, et al. Adoption of sustainable land and water management practices and their impact on crop productivity among smallholder farmers in sub-Saharan Africa. *Land Use Policy*. 2025;153:107533. doi: <https://doi.org/10.1016/j.landusepol.2025.107533>.
30. Getachew Z, Destaw F, Asfaw A. Factors influencing adoption of sustainable land management practices among rural households in Godere district, southwest Ethiopia. *Discover Sustainability*. 2026. doi: 10.1007/s43621-026-03913-3.

31. Belay A, Recha JW, Woldeamanuel T, Morton JF. Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the central Rift Valley of Ethiopia. *Agriculture and Food Security*. 2017;6(1):24.
32. Wubneh M. Policies and praxis of land acquisition, use, and development in Ethiopia. *Land Use Policy*. 2018;73:170-83.
33. Babalola D, Olayemi J. Determinants of farmers' preference for sustainable land management practices for maize and cassava production in Ogun State, Nigeria. *Journal of Land and Rural Studies*. 2014;2(2):233-47.
34. Temesgen G, Amare B, Silassie H. Land degradation in Ethiopia: causes, impacts and rehabilitation techniques. *Journal of Environment and Earth Science*. 2014;4(9):98-104.
35. Gebrehaweria G, Dereje AA, Girmay G, Giordano M, Langan S. An assessment of integrated watershed management in Ethiopia. *IWMI Working Paper*. 2016.
36. Martey E, Kuwornu JK. Perceptions of climate variability and soil fertility management choices among smallholder farmers in northern Ghana. *Ecological Economics*. 2021;180. doi: <https://doi.org/10.1016/j.ecolecon.2020.106870>.
37. Alemu GT. Profitability of sustainable land management practices in the Upper Blue Nile Basin, Ethiopia. *SN Social Sciences (Accepted Pending Revision)*. 2026.
38. Alemu GT. Impacts of selected land management practices on agricultural productivity in the Upper Blue Nile Basin, Ethiopia. *Discover Sustainability (Accepted Pending Revision)*. 2026.
39. Jack V. Factor analysis in international relations. interpretation, problem areas and application: University of Florida Press; 1971.
40. Beavers AS, Lounsbury JW, Richards JK, Huck SW. Practical considerations for using exploratory factor analysis in educational research. *Practical Assessment, Research, and Evaluation*. 2013;18(1):6.
41. Paudel GS, Thapa GB. Impact of social, institutional and ecological factors on land management practices in mountain watersheds of Nepal. *Applied Geography*. 2004;24(1):35-55.
42. Yahya W, Adebayo S, Jolayemi E, Oyejola B, Sanni O. Effects of non-orthogonality on the efficiency of seemingly unrelated regression (SUR) models. *InterStat Journal*. 2008:1-29.
43. Zellner A. An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American Statistical Association*. 1962;57(298):348-68.
44. Greene WH. *Econometric analysis*: Pearson Education India; 2003.

45. Cameron AC, Trivedi PK. Microeconometrics: methods and applications: Cambridge University Press; 2005.
46. Breusch TS, Pagan AR. The Lagrange multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies*. 1980;47(1):239-53.
47. Teka MA. Exploring the scaling-up of sustainable land management in the Central highlands of Ethiopia. Wageningen, Netherlands: Wageningen University; 2019.
48. World overview of conservation approaches and technologies [Internet]. 2015. Available from: https://qcat.wocat.net/en/wocat/technologies/view/technologies_1201/
49. GIZ. Lessons and experiences in sustainable land management. Gesellschaft für Internationale Zusammenarbeit (GIZ). Addis Ababa, Ethiopia. 2015.
50. Djordjević-Milošević S, Milovanović J. Agroforestry: Multiplying Benefits from Forest Lands. In: Leal Filho W, Azul AM, Brandli L, Özuyar PG, Wall T, editors. *Zero Hunger*. Cham: Springer International Publishing; 2019. p. 1-11.
51. GIZ. GIZ Ethiopia: Lessons and Experiences in Sustainable Land Management. Addis Ababa, Ethiopia. pp. 236. 2015.
52. Nkomoki W, Bavorová M, Banout J. Adoption of sustainable agricultural practices and food security threats: effects of land tenure in Zambia. *Land Use Policy*. 2018;78:532-8.
53. Shiferaw B, Holden ST. Resource degradation and adoption of land conservation technologies in the Ethiopian highlands: a case study in Andit Tid, North Shewa. *Agricultural Economics*. 1998;18(3):233-47.
54. Tey YS, Brindal M. Factors influencing the adoption of precision agricultural technologies: a review for policy implications. *Precision Agriculture*. 2012;13(6):713-30.
55. Alemu GT, Tsunekawa A, Haregeweyn N, Nigussie Z, Tsubo M, Elias A, et al. Smallholder farmers' willingness to pay for sustainable land management practices in the Upper Blue Nile Basin, Ethiopia. *Environment, Development and Sustainability*. 2020;23(4):5640-65. doi: <https://doi.org/10.1007/s10668-020-00835-6>.
56. Berihun ML, Tsunekawa A, Haregeweyn N, Meshesha DT, Adgo E, Tsubo M, et al. Exploring land use/land cover changes, drivers and their implications in contrasting agro-ecological environments of Ethiopia. *Land Use Policy*. 2019:104052.
57. Nigussie Z, Tsunekawa A, Haregeweyn N, Adgo E, Tsubo M, Ayalew Z, et al. Economic and financial sustainability of an *Acacia decurrens*-based Taungya system for farmers in the Upper

735 Blue Nile Basin, Ethiopia. Land Use Policy. 2020;90:104331. doi:
 736 <https://doi.org/10.1016/j.landusepol.2019.104331>.

737 58. Nigussie Z, Tsunekawa A, Haregeweyn N, Adgo E, Nohmi M, Tsubo M, et al. Farmers'
 738 perception about soil erosion in Ethiopia. Land Degradation and Development. 2017;28(2):401-
 739 11.

740 59. Holden S, Shiferaw B, Pender J. Market imperfections and land productivity in the
 741 Ethiopian highlands. Journal of Agricultural Economics. 2001;52(3):53-70.

742 60. Nyanga A, Kessler A, Tenge A. Key socio-economic factors influencing sustainable land
 743 management investments in the west Usambara highlands, Tanzania. Land Use Policy.
 744 2016;51:260-6.

745 61. Amsalu A, De Graaff J. Determinants of adoption and continued use of stone terraces for
 746 soil and water conservation in an Ethiopian highland watershed. Ecological Economics.
 747 2007;61(2-3):294-302.

748 62. Darkwah KA, Kwawu JD, Agyire-Tettey F, Sarpong DB. Assessment of the determinants
 749 that influence the adoption of sustainable soil and water conservation practices in Techiman
 750 Municipality of Ghana. International Soil and Water Conservation Research. 2019;7(3):248-57.
 751 doi: <https://doi.org/10.1016/j.iswcr.2019.04.003>.

752 63. Graaff Jd. Soil conservation and sustainable land use: an economic approach. Amsterdam:
 753 Royal Tropical Institute; 1993.

754 64. Adimassu Z, Kessler A, Yirga C, Stroosnijder L. Farmers' perceptions of land degradation
 755 and their investments in land management: a case study in the central Rift Valley of Ethiopia.
 756 Environmental Management. 2013;51(5):989-98.

757 65. Alemu GT, Berhanie Ayele Z, Abelieneh Berhanu A. Effects of land fragmentation on
 758 productivity in northwestern Ethiopia. Advances in Agriculture. 2017;2017. doi:
 759 <https://doi.org/10.1155/2017/4509605>.

760 66. Persha L, Stickler MM, Huntington H, editors. Does Stronger Land Tenure Security
 761 Incentivize Smallholder Climate-Smart Agriculture? Understanding Drivers of Agricultural
 762 Investment in Zambia's Eastern Province. Annual World Bank Conference on Land and Poverty;
 763 2015.

764 67. Branca G, Lipper L, McCarthy N, Jolejole MC. Food security, climate change, and
765 sustainable land management. a review. *Agronomy for Sustainable Development*. 2013;33(4):635-
766 50.

Appendix Tables

A. Outcome indicators of media type

Type	Extracted factor's rotated loading score
Development agent	0.421
Farmers' field day	0.571
Development group	0.479
Public meeting	0.527
Political cell	0.589
Watershed association	0.585
Irrigation association	0.518
Explained variance (%)	100.01

B. Outcome indicators of land degradation

Indicator	Extracted factor's rotated loading score	
	Decreasing indicators	Increasing indicators
Increasing crop production	0.679	
Increasing crop productivity	0.643	
Increment of livestock feed resource	0.714	
Increasing livestock productivity	0.779	
Increasing annual household income	0.742	
Increasing land quality	0.771	
Increased stony land coverage		0.770
Dominancy of poor soil structure		0.813
Occurrence of frequent flooding		0.613
Explained variance (%)	65.45	37.45

774 C. Outcome indicators of land-use policy's economic risks and tenure security

Indicator	Extracted factor's rotated loading score	
	Economic risks	Tenure security
Increasing crop productivity	0.790	
Increasing livestock productivity	0.799	
Increasing the sustainability of SLM activities	0.839	
Increasing the sustainability of agroforestry works	0.767	
Increasing agricultural incomes	0.786	
Increasing the status of household food security	0.651	
Developing sense of land ownership		0.511
Efficient land-use allocation		0.486
Efficiency of land transfer		0.587
Efficiency of avoiding/solving land disputes		0.474
Efficiency of compensation for expropriated land		0.676
Efficiency of land rent amount		0.644
Efficiency of avoiding land fragmentation		0.614
Assuring the equity of landholding size		0.739
Assuring the equality of access to land for all		0.694
Explained variance (%)	50.91	41.86

775

776 D. Outcome indicators of climate change causes

Indicator	Extracted factor's rotated loading score
Soil degradation	0.452
Declining of forest coverage	0.509
Extreme free grazing	0.562
Environmental pollution	0.538
Intensive use of agricultural chemicals	0.430
Explained variance (%)	111.49

777

778 E. Extent of use of sustainable land management practices

Category	SLM practice	Use status (<i>N</i> = 300)		Use extent (<i>N</i> = 300)		
		No (%)	Yes (%)	Occasionally (%)	Sometimes (%)	Always (%)
Soil conservation practices	Stone bund	210 (70)	90 (30)	10 (3.3)	30 (10)	50 (16.7)
	Soil bund	156 (52)	144 (48)	10 (3.3)	41 (13.7)	93 (31)
	Stone-faced soil bund	196 (65.3)	104 (34.7)	5 (1.7)	22 (7.3)	77 (25.7)
Runoff control practices	Check dam	219 (73)	81 (27)	11 (3.7)	39 (13)	31 (10.3)
	Cutoff drain	126 (42)	174 (58)	11 (3.7)	40 (13.3)	123 (41)
	Water way	99 (33)	201 (67)	13 (4.3)	43 (14.3)	145 (48.3)
Agronomic practices	Improved crop variety	153 (51)	147 (49)	10 (3.3)	39 (13)	98 (32.7)
	Crop rotation	131 (43.7)	169 (56.3)	6 (2)	34 (11.3)	129 (43)
	Agronomic knowledge	152 (50.7)	148 (49.3)	13 (4.3)	27 (9)	108 (36)
	Basic crop calendar	146 (48.7)	154 (51.3)	20 (6.7)	31 (10.3)	103 (34.3)
Agroforestry practices	Contour cultivation	106 (35.3)	194 (64.7)	11 (3.7)	28 (9.3)	155 (51.7)
	Agroforestry	255 (85)	45 (15)	0(0)	4 (1.3)	41 (13.7)
	Forestry/nursery	219 (73)	81 (27)	2 (0.7)	25 (8.3)	54 (18)
	Cut and carry system	211 (70.3)	89 (29.7)	7 (2.3)	42 (14)	40 (13.3)
	Trench/half-moon terrace	269 (89.7)	31 (10.3)	12 (4)	18 (6)	1 (0.3)
Horticulture practices	Horticulture/vegetables	234 (78)	66 (22)	9 (3)	19 (6.3)	38 (12.7)
	Irrigation	212 (70.7)	88 (29.3)	4 (1.3)	20 (6.7)	64 (21.3)
	Compost	182 (60.7)	118 (39.3)	11 (3.7)	32 (10.7)	75 (25)

779

780 F. Multicollinearity test: Variance Inflation Factor (VIF)

Explanatory variables	VIF	1/VIF
Guder	2.54	0.394349
Dibatie	4.02	0.248499
Moderate	1.56	0.641919
Steep	1.36	0.732620
Sex	1.40	0.716604
Age	1.20	0.833732
Household size	1.57	0.636367
Number of plots	1.24	0.804872
log(Landholding)	2.78	0.359479
Livestock size	1.98	0.505494
log(Farm income)	1.36	0.733967
Cooperatives	1.55	0.646229
Information access	1.83	0.546147
Slight decline LD	1.32	0.755950
High decline LD	1.37	0.729823
Slight increase LD	1.30	0.770709
High increase LD	1.16	0.858793
Low economic risks	1.46	0.683167
High economic risks	1.59	0.627868
Low tenure security	1.37	0.731749
High tenure security	1.40	0.713474
Climate change cause	1.37	0.728932
Mean VIF	1.67	

781