

Biophysical factors determining the adoption of soil and water conservation measures in smallholder farming systems

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Abstract

Ethiopia's highlands are severely affected by moderate to severe soil erosion due to high population density, intense rainfall, and rugged, long-cultivated topography. The landscape, including steep hills, valleys, and dissected plains, contributes to soil acidity and environmental degradation. Settlement expansion, inappropriate land use, land-use changes, and construction activities further exacerbate land degradation, often resulting in sheet and rill erosion during the rainy season. Despite local governments promoting soil and water conservation (SWC) programs, implementation remains inconsistent, and adoption among farm households is limited. This study investigates household perceptions toward SWC adoption and identifies critical factors influencing the implementation of measures such as soil bunds, stone bunds, and fanya juu structures. Data were analyzed using descriptive statistics and multinomial logistic regression. Results revealed clear differences in perceptions: adopters exhibited medium to high recognition of benefits in soil fertility, erosion control, and productivity, whereas non-adopters showed low perception, indicating limited awareness and skepticism. Multinomial logistic regression identified that male-headed households, larger family size, greater farm size, livestock ownership, secure land tenure, education, and extension service contact significantly increased the likelihood of adoption. Conversely, a greater distance from home reduced adoption. The study recommends strengthening awareness programs, securing land tenure, and adapting SWC technologies to local biophysical conditions to improve adoption rates and promote sustainable land management in Southern Ethiopia.

Keywords: Adoption, Farmer Participation, Multinomial logistic regression, Southern Ethiopia, SWC measures

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1. Introduction

Soil degradation poses a significant threat to agricultural productivity, contributing substantially to food insecurity and poverty in developing countries (Kumar et al., 2019). Land degradation has diminished the productive capacity of agricultural land, with one-third of the world's farmland becoming degraded and posing a significant challenge to both current and future food security (Inyang, 2019). The magnitude of the issue is more pronounced in rural regions of developing nations, and the effects are more severe. This can be primarily attributed to the over-exploitation of natural resources, even in more environmentally sensitive areas such as protected forests (Djuwansyah, 2018; Silesh et al., 2019). Ethiopia's population predominantly resides in the highlands, where continuous cultivation has rendered the region highly susceptible to land degradation through soil erosion, a significant environmental challenge. This issue is exacerbated by natural occurrences and anthropogenic drivers, including land cover degradation, cultivation on steep slopes, intensified agricultural activities, rapid population growth, and unsustainable farming practices. Furthermore, reports have indicated a drastic decline in Ethiopia's forest cover, plummeting from 35% in the early 20th century to a mere 2.4% by 1992 (Ahmad et al., 2023a; Takele et al., 2023; Bedada et al., 2020; Debebe et al., 2025). Soil erosion leads to diminished agricultural productivity and declining food availability per capita. Recent studies suggest that soil loss in the Ethiopian highlands is even greater than earlier estimates. For instance, Girmay et al. (2021) and others estimate that Ethiopia loses around 1.5 billion tons of fertile soil per year due to water erosion. Mean soil erosion rates in many highland agricultural areas are reported between 40 and 80 tonnes per hectare per year, with more severely degraded slopes showing values of 200–300 t/ha/yr under poor land cover (Endrias et al. 2024). A watershed study in the Tana Basin (Northwestern Ethiopia) found a mean soil loss of about 18.65 t/ha/year, though individual field-scale losses in croplands reach up to 300 t/ha/year (Meshesha et al., 2024). The Ethiopian Government, in collaboration with local communities and donors, has invested in

soil and water conservation (SWC) measures throughout the country to address soil erosion issues. The program's initial efforts began in the mid-1970s (Debebe et al., 2025; Kato et al., 2011). The program was initially launched in the mid-1970s with the primary aims of mitigating erosion, replenishing soil fertility, rehabilitating degraded lands, and intensifying agricultural productivity. While the program achieved some successes in particular regions, it encountered various challenges related to farmer adoption and long-term viability (Shimeles, 2012; Mekuria et al., 2007). While the activities of the 1970s primarily focused on social security measures in drought-affected areas, they did not adequately address sustainable resource management and livelihood security. Similarly, addressing conflict and resource scarcity can be a critical step in ensuring sustainable resource management. However, previous approaches have often struggled to harmonize the competing needs for resource allocation, sustainable interventions, and livelihood sustenance (Haregeweyn et al., 2015; Mekuriawu et al., 2018). Additionally, during this period, farmers received grains and edible oils as compensation for their participation in the SWC work under the 'Food for Work' program, which followed a top-down approach with minimal involvement of the target farmers. This approach may have contributed to the observed negative nutrient balances in the region (Silesh et al., 2018; Wei et al., 2020). In response to the persistent and severe challenges posed by soil erosion, declining soil fertility, and consequent reductions in agricultural productivity, the government and development partners have formulated new strategies to promote effective technologies aimed at the sustainable intensification of rural livelihoods. Since the Ethiopian People's Revolutionary Democratic Front came to power in 1991, community-based SWC initiatives designed to enhance crop productivity and ensure food security have been central components of the country's sustainable livelihood framework (Silesh et al., 2019; Haregeweyn et al., 2015). Despite ongoing government efforts to implement various conservation measures, including bench terracing, soil bunds, stone bunds, and farm forestry in targeted intervention zones, water-

induced soil erosion remains a critical problem. Soil loss rates have accelerated, and adoption as well as sustained use of these measures by local farmers remains limited. This unfavorable trend in land degradation has further aggravated food insecurity among both rural and urban populations in Ethiopia, despite significant governmental interventions aimed at land restoration (Silesh et al., 2019; Moges and Bhat, 2020; EfD, 2010; Asnake et al., 2018; Birhan and Tekalign, 2022). Existing studies on SWC adoption in Ethiopia have largely concentrated on the northern, northwestern, and eastern regions, which experience relatively low rainfall. However, research examining the determinants of adoption in the southern highlands, a region with distinct environmental and socio-economic conditions, remains scarce. Research on soil and water conservation (SWC) adoption in the southern Ethiopian highlands remains relatively scarce compared to other regions, such as the northern and central highlands. The few existing studies primarily focus on biophysical impacts like soil erosion reduction and vegetation recovery, but provide limited examination of socio-economic and institutional determinants of adoption specific to this area (Debebe et al., 2025). Additionally, some studies employ descriptive methods or single conservation measures, limiting a comprehensive understanding of the multiplicity of factors impacting varied adoption patterns. Moreover, there are discrepancies in findings from the southern highlands that warrant further investigation. For instance, adoption rates and influencing factors reported vary significantly due to differences in methodology, sampled populations, and conservation practices studied. Some prior research lacks rigorous statistical modeling to quantify the relative impacts of variables or to distinguish adoption behaviors across different conservation measures. This research gap underscores the necessity for more comprehensive investigations to better understand the complex factors influencing the uptake of SWC practices in this part of the country (Debebe et al., 2025; Wordofa et al., 2020; Haregeweyn et al., 2017; Lemani, 20117). In Ethiopia, the average annual soil loss is estimated at 12 tons per hectare per year (Silesh

et al., 2019). However, on steep slopes with limited vegetation cover, soil loss can exceed 300 tons per hectare annually, equivalent to approximately 250 millimeters per year. Recent studies in the Wolaita areas reveal that annual soil loss has increased significantly, rising from 30.95 t ha⁻¹ yr⁻¹ in 1990 to 43.85 t ha⁻¹ yr⁻¹ in 2020 across 254 km². In response, scholars emphasize the urgent need for governments and farmers to adopt effective soil management practices. These include watershed management, the construction of physical structures such as soil/stone bunds, check dams, and trenches, as well as the implementation of agronomic measures to mitigate soil loss (Badada et al., 2020; Girmay et al., 2021). Moreover, the area (Damota area) in Ethiopia's highlands is plagued by moderate to severe soil erosion, characterized by high population density, high rainfall erosivity, and rugged topography that has been extensively cultivated for an extended period. The area's landscape, comprising rugged mountains, steep-sloped hills, valleys, and dissected plains, results in high soil acidity and environmental degradation. Factors such as settlement expansion, inappropriate land utilization, land-use changes, and building construction are well-known drivers of land degradation, leading to observable sheet and rill erosion during rainy seasons. Despite the local government's ongoing efforts to promote SWC programs, the implementation has been inconsistent, and the adoption rate is not widespread among all farm households. However, limited documentation exists on the determining factors influencing the adoption of SWC measures among farmers with diverse socioeconomic backgrounds. This study aims to explore and identify the biophysical, socioeconomic, and policy-institutional factors that hinder or facilitate farmers' decisions to implement SWC measures, particularly soil bunds, stone bunds, and (fanya juus: the structures reduce runoff velocity, minimize soil loss, and improve water infiltration). The embankments are often stabilized with grass or fodder plants, thus serving multiple ecological and agricultural functions. The findings from this study are vital in recommending the most suitable adoption strategies for local farmers and providing relevant insights for policymakers,

planners, and development actors to foster sustainable environmental management. At the household level, it could inform the selection of the best SWC strategies and address the adoption challenges for improved environmental stewardship.

2. Literature Review

2.1. Soil and water conservation in Ethiopia

Soil and water conservation (SWC) is a vital element of sustainable agricultural development in Ethiopia, where land degradation from soil erosion poses a significant threat to crop productivity and rural livelihoods. These challenges pose major risks to agricultural productivity and rural livelihoods. To mitigate these challenges, various physical and agronomic SWC measures such as soil bunds, stone bunds, check dams, terraces, and traditional practices like fanya juu have been widely promoted and implemented across diverse agro-ecological zones. These interventions aim to reduce soil loss, enhance water retention, and improve soil fertility. Soil and water conservation is critical for sustaining agricultural productivity and combating land degradation in Ethiopia, where diverse agro-ecological zones pose unique challenges. Despite extensive government and donor-supported interventions since the 1970s, adoption of conservation practices varies widely across regions, partly due to socio-economic and institutional factors. Previous research has largely focused on northern and central highland areas, leaving a gap in understanding adoption dynamics in the southern highlands. This study seeks to fill this knowledge gap by investigating the factors that influence smallholder farmers' use of soil bunds, stone bunds, and traditional fanya juu structures in the Damota area of the Wolaita Zone (Silesh et al., 2019).

2.2. Challenges to SWC in Ethiopia

Ethiopia's varied topography and diverse agro-ecological zones present distinct challenges for SWC. The highlands, covering approximately 45% of the country's land area, are especially vulnerable to soil erosion due to their steep slopes and intense rainfall patterns. In contrast, the lowlands face significant water conservation challenges under arid and semi-arid climatic

conditions. Rapid population growth and increased demand for cultivable land have driven agricultural expansion into marginal areas, thereby intensifying soil degradation. Extensive deforestation, primarily for fuelwood and agricultural expansion, has removed critical vegetative cover, accelerated erosion processes, and diminished soil fertility (Birhan and Tekalign, 2022). Moreover, overgrazing in communal pastures has further contributed to land degradation. These environmental challenges are compounded by the limited financial resources and technical expertise of smallholder farmers, which hinder their ability to adopt and sustain effective SWC practices.

2.3. Soil and water conservation: traditional practices

Ethiopia possesses a longstanding tradition of indigenous SWC practices, developed over centuries to mitigate local environmental challenges. In the highlands, traditional terracing techniques are employed to reduce surface runoff and enhance water infiltration. In semi-arid regions, stone bunds and soil bunds are widely used to control erosion and conserve soil moisture. The fanya juu method, which involves constructing earthen embankments, is another indigenous practice that effectively reduces runoff and improves water retention. In addition, agroforestry systems that combine trees and shrubs with crops and livestock are widely implemented. These systems contribute not only to soil fertility enhancement and erosion prevention but also offer supplementary benefits such as fuelwood, fodder, and shade. Despite their proven effectiveness, these traditional practices often face limitations in scalability, restricting their capacity to address widespread land degradation comprehensively (Debebe et al., 2025).

2.4. Modern approaches to soil and water conservation (SWC)

Over the past decades, the Ethiopian government, together with international development partners, has promoted modern SWC techniques to complement traditional practices. These include: Terracing: Modern bench terracing has been widely implemented to reduce soil erosion and

increase arable land. This technique has been particularly successful in highland regions. Check Dams: Constructed across gullies, check dams reduce water velocity, trap sediments, and promote groundwater recharge (Silesh et al., 2019). Area Closures: Degraded lands are designated as protected areas, allowing natural vegetation to regenerate. Area closures have proven effective in restoring soil fertility and biodiversity. Water Harvesting: Techniques such as pond construction, rainwater harvesting, and underground cisterns are used to enhance water availability for agriculture and domestic use. Integrated Watershed Management: This integrated strategy focuses on the coordinated management of soil, water, and vegetation within a watershed to promote sustainable land use (Meshesha et al., 2024).

2.5. Impact of SWC interventions

The implementation of SWC measures has yielded significant environmental, social, and economic benefits in Ethiopia. In areas where terracing and bund construction have been adopted, soil erosion has been reduced by up to 68%. Improved soil fertility and moisture retention have led to higher crop yields, enhancing food security and household incomes. Environmental benefits include increased vegetation cover, improved biodiversity, and enhanced groundwater recharge. These outcomes have contributed to greater resilience against climate variability and reduced vulnerability to droughts and floods. On the socioeconomic front, community-based SWC programs have created employment opportunities and strengthened social cohesion through collective action (Asnake et al., 2018).

2.6. Challenges in scaling up SWC

Despite the successes, several challenges hinder the widespread adoption and sustainability of SWC measures in Ethiopia. Limited financial resources, inadequate technical expertise, and weak institutional frameworks constrain the implementation of SWC programs (Debebe et al., 2025). Furthermore, some farmers hesitate to adopt modern techniques because of limited awareness or doubts regarding their long-term effectiveness. Gender disparities and unequal

participation in decision-making processes further limit the effectiveness of SWC initiatives. Women, who play a critical role in agriculture, often face barriers to accessing resources and participating in training programs. Overcoming these challenges necessitates targeted interventions, including capacity-building programs, incentive mechanisms, and inclusive policy frameworks.

2.7. Significance of the study area

Conceptually, this study combines farmers' perceptions of soil erosion with socio-economic and institutional factors to explain adoption decisions, an approach that has received limited attention in previous research. Methodologically, unlike many studies that use binary logistic regression, our research employs a multinomial logistic regression model to differentiate between multiple categories of adoption (e.g., full adopters, partial adopters, and non-adopters). This allows for a more nuanced understanding of adoption behavior and highlights heterogeneity among farming households. These contributions strengthen the distinctiveness of the study and extend the existing body of literature on SWC adoption.

3. Materials and Methods

3.1. Profile of the study area and practices of SWC

The study area encompasses the Boloso Sore, Damot Gale, and Soddo Zuriya districts in the Damota region of Southern Ethiopia, situated between 6°42'–7°10' N latitude and 37°37'–37°59' E longitude, approximately 395 km south of the capital. Covering around 97,600 hectares, the districts feature rugged and undulating terrain formed by tectonic and volcanic activity. The upper zones exhibit highly dissected mountainous landscapes with steep slopes, whereas the lower areas display gently undulating topography. Agroecologically, the region falls within the Dega and Woina Dega zones, with elevations ranging from 1,480 to 2,855 meters above sea level (Masha et al., 2021). According to Ethiopian Meteorological Institute records for the period 2000–2019, the area experiences a predominantly humid climate, with

mean monthly air temperatures varying between 14°C and 20°C. Annual precipitation averages around 1,200 mm, occurring in a bimodal distribution. The principal rainy season, locally referred to as Kiremt, spans from June to September, while a shorter secondary rainy season occurs between February and March. Croplands constitute the dominant land use, followed by shrub-woodlands, grasslands, forested areas, bare lands, and settlements. The primary livelihood system is mixed crop-livestock farming, with major crops including barley, wheat, maize, teff, beans, potatoes, and chickpeas. Livestock production consists of cattle, sheep, goats, horses, mules, donkeys, and poultry. Mixed farming serves as the principal economic activity, supplemented by off-farm and non-farm income-generating activities for households with limited landholdings. Situated within the Ethiopian highlands, the region is characterized by high population density and intensive cultivation, confronting challenges such as land fragmentation, land cover degradation, and overgrazing. Population densities vary from approximately 167 individuals per km² in the midlands to as high as 746 individuals per km² in the highlands (Teshome, 2019; CSA, 2007).

3.2. Implementation of SWC practices in the study area

The Wolaita Zone is characterized by a rugged topography with highlands, midlands, and lowlands. The Damota area, in particular, is known for its steep slopes, making it highly susceptible to soil erosion and land degradation. The region experiences significant challenges due to overpopulation, unsustainable agricultural practices, and deforestation, which have intensified soil erosion and reduced agricultural productivity over the years. Soil and water conservation measures have thus become vital for addressing these challenges and ensuring sustainable land use in the area. Traditional SWC practices have been a part of the Wolaita

community's agricultural heritage for centuries. Farmers in this region have long employed indigenous methods such as soil bunds, stone bunds, and cutoff drains to control erosion and retain soil fertility. Additionally, they have utilized agroforestry practices, such as planting indigenous trees like *Cordia africana* and *Erythrina abyssinica*, to stabilize soils and improve water retention. These practices, rooted in local knowledge, have proven to be effective in minimizing soil loss and maintaining agricultural productivity under challenging conditions (Masha et al., 2021).

In recent decades, external interventions by the Ethiopian government, NGOs, and international development partners have introduced modern SWC techniques to complement traditional practices. These include the construction of terraces, check dams, and the implementation of area closures to allow natural vegetation regeneration. Programs such as the Sustainable Land Management Program (SLMP) have played a critical role in promoting these interventions in the Damota area. Additionally, community-based watershed management approaches have been adopted, emphasizing the collective effort of local farmers to rehabilitate degraded lands. The combination of traditional and modern SWC measures has shown promising results in mitigating land degradation in the Damota region. Improved land productivity and water availability have been observed in areas where these measures have been effectively implemented. However, challenges remain, including limited financial resources, inadequate technical knowledge, and resistance to change among some community members. Addressing these challenges through capacity development, incentive mechanisms, and participatory planning is essential to ensure the long-term sustainability of SWC initiatives in the Wolaita area around Mount Damota (Figure 1).



Figure 1. Practices of SWC measures in the study area

3.3. Research methodology

This study employed a community-based cross-sectional design to examine the demographic, socio-economic, and institutional characteristics of rural households. Utilizing a survey-driven methodology, it adopted a predominantly quantitative mixed-methods approach, supplemented with qualitative components, to explore the factors that facilitate or constrain farmers' adoption of SWC practices. To optimize data collection, both adopter and non-adopter households were systematically identified and included in the survey. Gaining insights into the determinants of conservation measure adoption was essential, as the findings provide robust and actionable evidence within the limitations.

3.4. Collection tools and imputation technique

To achieve the objectives, data were collected from both primary and secondary sources. The target population consisted of smallholder farmers of varying age groups, youth, adults, and the elderly from both genders, residing in the district of Southern Ethiopia. Data collection took place from November to March 2019 using questionnaires (open-ended and closed-ended questions). Trained enumerators, proficient in the local language, facilitated this process. Specifically, three enumerators with Bachelor's and Master's degree holders were selected to administer the questionnaires. Before initiating data collection, the enumerators received comprehensive training and orientation on the questionnaire content and methods for eliciting accurate and reliable responses. Participants were

drawn from diverse demographic and socio-economic backgrounds, including members of various religious groups, model farmers, political leaders, local experts, and elders. This helps maintain sample size while minimizing bias (Teshome, 2019). Moreover, outliers were carefully examined to determine their validity; valid outliers were retained to reflect true variability in the data, while erroneous entries were excluded (Tsegaye, 2012). To gain in-depth insights into the adoption of conservation practices, focus group discussions (FGDs) were organized. Three FGDs were conducted, each involving nine participants, to ensure sufficient knowledge and experiences were captured. In addition, twelve key informants were interviewed using a structured format, comprising six local leaders, three development agents (DAs), and three model farmers. These interviews provided valuable insights into the factors influencing the adoption of conservation practices. In addition, on-site field observations were carried out to evaluate the existing condition of SWC measures within the study area.

3.5. Sample size and sampling techniques

To identify the sampled district, kebeles, and households, a multi-stage sampling procedure was employed (CSA, 2015), which is particularly effective for studies involving large and diverse populations. This approach progressively narrows the focus from larger times to smaller ones, ensuring representativeness and methodological rigor. In the first stage, the study area was divided into districts. From these, one district was purposively selected based on

specific criteria: the level of farmers' involvement in SWC (SWC) practices, population size, and accessibility. The criterion of SWC involvement was assessed using district agricultural office reports, extension agents' records, and preliminary field visits, which documented the extent of conservation activities, the number of households participating, and the coverage of conservation structures. In the second stage, three kebeles, Wandara-Gale, Dalbo-Wogene, and Gurumo-Koisha, were purposively chosen. These kebeles were selected to represent the different agroecological zones (highland, midland, and lowland) within the district and to reflect variations in farmers' participation levels in SWC practices. This ensured that the study captured diversity in both environmental conditions and conservation engagement. In the third stage, households were stratified into two categories: adopters and non-adopters of SWC practices. From the total of 25,086 households in the district, a proportional random sampling technique was applied within each kebele to select the final study participants. This step minimized potential bias introduced by purposive selection at earlier stages and guaranteed equal participation opportunities for all eligible households. By systematically narrowing down the sample in stages, this method ensured a fair and balanced representation of the study population while maintaining the rigor and reliability of the research design (Tesfaye and Seifu, 2015). In the final phase, a simple random sampling technique was employed to select sample households from each stratum, ensuring that every household had an equal probability of inclusion. The sample size for each group was determined using Kothari's formula, widely applied in research for calculating sample sizes based on population parameters and desired confidence levels. This method facilitated the selection of a statistically representative sample (Kothari, 2004). Assuming an estimated proportion of respondents (p) of 0.5, a 95% confidence level ($z=1.96$), and a margin of error (e) of 0.05, the required sample size was calculated as $N_0=384$ using the infinite population formula. In this study, the sample size for each household group was determined using

Kothari's (2004) formula for sample size calculation:

$$N = \frac{(Z^2 * P * 1 - P)}{(e^2)} \quad (1)$$

Table 1. Distribution of Sampled Household Heads

Kebeles	Total HHS	Samples		Total samples
		Adopters	Non-adopters	
Wandara-Gale	9,476	89	68	157
Dalbo-Wogene	8,147	65	55	120
Gurumo-Koisha	7,463	55	46	101

Where, Z =standard normal deviate at the desired confidence level (1.96 for 95% confidence), p =estimated proportion of the population exhibiting the characteristic of interest (here assumed 0.5 for maximum variability), e =acceptable margin of error (0.05). This formula assumes a simple random sample, a normally distributed population proportion, and independence of observations. For populations that are not large, a finite population correction was applied to adjust the sample size:

$$n_{adj} = \frac{n}{1 + n - 1} \quad (2)$$

Where N is the total population in each stratum. Using this method, a total of 378 sample households (209 users and 169 non-users) were selected proportionally from three purposively selected kebeles: Wandara-Gale, Dalbo Wogene, and Gununo Koisha. The three factors (adopters vs. non-adopters and the three kebeles) were chosen to capture both adoption status and geographic representation. Adopters and non-adopters were included to understand differential impacts, and the kebeles were selected purposively based on their significant participation in the intervention program, accessibility, and representation of the study area's demographic characteristics.

Subsequently, the finite population correction formula was applied to adjust the sample size according to the actual study population. A total of 378 sample households (209 adopters and 169 non-adopters) were selected by using proportional simple random sampling methods from three purposively selected kebeles (Wandara Gale, Dalbo Wogene, and Gurumo Koisha). The size of households was 157 in

Wandara Gale, 120 in Dalbo Wogene, and 101 in Gurumo Koisha (Table 1).

3.6. Data analysis

After completing field data collection, responses from the closed-ended questionnaires were coded and entered into SPSS version 20 for analysis. Quantitative data were analyzed using descriptive statistics such as means, standard deviations, and percentages. Meanwhile, qualitative information obtained from focus group discussions, key informant interviews, and field observations was examined through narrative interpretation to capture deeper contextual insights. A multinomial logistic regression model was used to identify the factors influencing the adoption of soil bunds, stone bunds, and fanya juu structures, enabling the determination of variables that significantly affect farmers' decisions to implement these SWC practices.

3.6.1. Ethical considerations

In carrying out this study, careful attention was given to ethical considerations to uphold research integrity and safeguard participants' rights. Prior to data collection, informed consent was obtained from all participants, ensuring they were adequately informed about the study's objectives, procedures, and their right to voluntarily withdraw at any stage without facing any adverse consequences. The questionnaires were designed to respect participants' privacy and confidentiality; personal identifiers were removed, and data were anonymized to protect individual identities. Additionally, the training provided to enumerators emphasized the importance of ethical conduct, including respectful engagement with participants and sensitivity to cultural norms within the diverse demographic groups represented in the study. Special attention was given to vulnerable populations, including youth and elderly farmers, ensuring that their voices were heard and respected throughout the research process. The study also adhered to ethical guidelines set forth by relevant institutional review boards, which included a thorough review of the research design to mitigate any potential risks to participants.

3.7. Variables

3.7.1 Dependent variable

Within the conservation framework, adoption is defined as the implementation of soil and water management practices on farmers' plots (Takele et al., 2023). In this study, farmers who had not applied any such practices were classified as non-adopters ($Y=0$). Conversely, those who adopted soil bunds were coded as $Y=1$, stone bunds as $Y=2$, and fanya juu structures as $Y=3$. These three conservation measures were identified as the predominant practices during preliminary field assessments.

3.7.2 Independent variables

The factors influencing the adoption decisions of farm households encompass demographic, socio-economic, institutional, and plot-related characteristics (Takele et al., 2023). In this context, the hypothesized independent variables were expected to either positively or negatively influence the likelihood of adopting soil and water conservation (SWC) measures.

4. Result

4.1. Characteristics of the households

The results showed that 55.28% of the sampled households had adopted at least one SWC measure on their farmland (Table 2). On the other hand, about 55.28% (95% CI: 49.75%–60.81%), indicating moderate uptake among the sampled households. This adoption rate is comparable to previous studies in the Wolaita Zone, which reported adoption rates ranging from 50% to 60%, suggesting consistency in household-level adoption patterns across similar contexts. The demographic profile of the sample revealed that 78.83% of the households were headed by males, while 21.17% were female-headed. This finding aligns with previous research (Green, 2000; Chinwe, 2015), which highlights the limited capacity of women in many countries to engage in work outside the home. The average age of the farmers was 50.5 years, with the youngest being 30 years and the oldest 67 years. Household size varied from 2 to 13 members, with an average family size of 8 and a standard deviation of 3.25. The average number of years of formal education was 5.10 years, with 39.94% of respondents able to read and write, 34.12% having completed

education beyond primary school, and 25.94% being illiterate. Additionally, around 62% of the respondents reported that their farm plots were

located on steeper slopes, which they perceive as prone to chronic soil erosion.

Table 2. Distributions of dummy household characteristics

Households' characteristics	Frequency	%
Adoption of SWC measures		
1) Yes	209	55.28%
2) No	169	44.72%
Sex of households		
1) Male	298	78.83%
2) Female	80	21.17%
Educational level attainment		
1) Above primary level	129	34.12%
2) Write and read	151	39.94%
3) Illiterate	98	25.94%
Do you have any access to credits?		
1) Yes	101	28.30%
2) No	271	71.70%
Slope of your farming lands?		
1) Steep	233	61.70%
2) Gentle	145	38.30%
Land tenure security right		
1) Secured	159	42.00%
2) Not secured	219	58%

Table 2 presents descriptive statistics for various variables used in your study. Age averages 50.05 years with an SD of 7.86, ranging between 30 and 67 years. Education has a mean of 5.10 years or levels, with considerable variation (SD 3.45) and a maximum value reported as 12+. Farming experience averages 14 years, ranging from 1 to 45, with very low variation (SD 0.49).

Family size averages 8 members (SD 3.25), spanning from 2 to 13 persons. Farm size has a mean of 0.5 units (which may be hectares or other), with SD 0.32, and ranges from 1 to 4 units. The number of livestock averages 4.47 heads, with a wide dispersion (SD 3.72) from none to 17.

Distance of farm lands averages 1 unit (possibly kilometers or a scale), with a small SD of 0.13, ranging between 0.25 and 2. Land ownership averages 1.64 (possible categorical coding between 1 and 2). Land slopes vary with a mean of 0.64, ranging from 0 to 1. Extension contacts average 2, spanning from 0 to 4 contacts. Non-farm activities have a mean of 0.43, indicating that 43% of the sample engage in such activities, coded as 1 or 0. Overall, the table provides a quantitative result of the sample characteristics and variability, which informs interpretation of later modeling results (Zeweld et al., 2017; Legess, 2010).

Table 3. Descriptive statistics of continuous variables

Variables	Descriptive Statistics			
	Mean	SD	Maximum	Minimum
Age	50.05	7.86	67	30.00
Education	5.10	3.45	12	0.00
Farming experiences	14.00	0.49	45	1.00
Family size	8.00	3.25	13	2.00
Farm size	0.50	0.32	4	1.00
Number of livestock	4.47	3.72	17	0.00
Distance of farm lands	1.00	0.13	2	0.25
Land ownership	1.64	0.47	2	1.00
Land slopes	0.64	0.47	1	0.00
Extension contacts/week	2.00	0.49	4	0.00
Non-farm activities in number	0.43	0.49	1	0.00

5. Discussions

5.1. The Major causes of soil erosion and farmers' perception

The Damota region has faced increasing soil erosion. Various factors have contributed to the expansion of this issue. One primary driver is population pressure, as respondents indicated that a rapidly growing population has led to the conversion of marginal land to agricultural use and the expansion of rural settlements, ultimately resulting in land degradation manifested through deforestation, overgrazing, and overexploitation (Table 5). This is consistent with the study of Belayneh et al. (2019), who confirmed the problem of soil erosion, which is associated with high population growth coupled with the cultivation of marginal land. Erosive rainfall is the second driving force, in which a considerable number of respondents (24.33%) reported erosive

rainfall, which is attributed to the erodibility of the soil of the districts (Table 5).

The same study of (Gashaw, 2017) elaborated erosive rainfall that is the essential driving force for natural runoff generation and the detachment of soil particles, and runoff production. The rugged landscape also made its own contribution to fostering erosion. In this regard, about 18.78% of respondents indicated that the dissected nature of the topography of Damota leads to the slope steepness and slope length for the increase in soil erosion in the area. This is consistent with the study of (Gashaw, 2017), who indicated the impact of topographic variables, particularly slope length and steepness, which increases the rate of soil erosion by accelerating the speed and runoff accumulation.

Table 5. Causes of soil erosion in the study area

Causes of soil erosion	Freq.	%
Conversion of marginal land to agriculture	111	29.36
Occurrences of erosive rainfall	92	24.33
Dissected nature of topography	71	18.78
Poor agricultural system	54	14.28
Other causes	50	13.25

On the other hand, SWC (SWC) measures are promoted as an essential part of agricultural land management, not only for controlling soil erosion but also for rehabilitating degraded lands and increasing agricultural productivity Masha et al., (2021). Although SWC measures have substantially contributed to reducing soil erosion, a major threat to the region's land resources, approximately 45% of households in the district have not implemented any form of SWC practices on their farmland (Table 2). One of the focus group discussion (FGD) respondents articulated the challenges faced by many households in adopting soil and water conservation (SWC) practices, stating;

"While we understand the importance of conservation measures to protect our land, many of us lack the resources and knowledge to implement them effectively. For instance, some farmers are hesitant to invest in terraces or other structures because they worry about the costs and whether they will see immediate benefits. Additionally, there is a fear that without proper training, these practices might not be effective or

could even lead to more problems." Findings from key informant interviews revealed that, although the average rate of soil erosion has decreased over the past decade as a result of SWC measures, erosion remains a pressing challenge, continuing to diminish crop yields and contribute to sediment loss. This highlights the persistent extent of land degradation in the study area, primarily driven by the low adoption of SWC measures by smallholder farmers (Wordofa et al., 2020).

5.2. Farmers' perception towards SWC measures in the study area

The results shown in Table 5 regarding farmers' perceptions of SWC in the study area indicate noticeable differences between adopters and non-adopters of conservation measures. Among the adopters, 27.51% demonstrated a high level of awareness and a positive attitude toward the importance of SWC practices. This suggests that households that have already implemented SWC measures are more likely to recognize their benefits in improving soil fertility, reducing

erosion, and sustaining agricultural productivity. Similarly, 22.75% of adopter households fall within the medium perception category, indicating that while they acknowledge the relevance of SWC, their understanding and appreciation may not be as strong as those with high perception. Only a small fraction (7.67%) of adopters was categorized under low perception, highlighting that very few adopters remain unconvinced of the value of these practices. This trend reflects a positive relationship between adoption and perception, where experience with conservation practices strengthens farmers' awareness of their environmental and economic benefits.

On the other hand, non-adopter households displayed a markedly different pattern. Only 7.93% of non-adopters expressed a high level of perception toward SWC, which is significantly lower compared to their adopter counterparts. A moderate proportion of non-adopters (13.22%) fell under the medium perception category, while the majority (20.81%) exhibited a low perception. This indicates that non-adopters generally have weaker awareness or less favorable attitudes toward conservation technologies. The dominance of low perception among non-adopters may stem from several factors, including lack of exposure to extension services, inadequate awareness of the long-term benefits of SWC, or skepticism about the labor and land requirements associated with the practices. Such findings are consistent with earlier studies in the Ethiopian highlands and other Sub-Saharan African contexts, where farmers' adoption of conservation measures was strongly influenced by their perception of soil erosion as a problem and their awareness of the effectiveness of the technologies (Takele et al., 2023).

The comparative results between adopters and non-adopters in this study also corroborate the observation of Legess (2010), who found that farmers with direct experience in implementing SWC structures developed stronger perceptions about their necessity, while non-adopters often underestimated land degradation risks. Furthermore, the pattern suggests that perception is not only an outcome but also a driver of adoption decisions. Farmers who perceive land degradation as severe and SWC as effective are

more motivated to adopt, whereas those with low perception remain resistant. This dynamic relationship between perception and adoption underscores the importance of targeted awareness creation and capacity-building initiatives. Extension efforts, farmer field schools, and demonstration plots have been shown to enhance farmers' understanding and shift perceptions in favor of sustainable land management (Legess, 2010).

Overall, the findings highlight a dual challenge: while adopters have generally developed favorable perceptions of SWC, a significant portion of non-adopters remains unconvinced. Bridging this perception gap is crucial, as it directly influences adoption decisions and, by extension, the sustainability of land use. Enhancing perception through participatory approaches, knowledge-sharing platforms, and integrating local knowledge into conservation programs will be vital to increasing the uptake of SWC measures and mitigating the pressing issue of soil erosion in the study area.

Table 5. Farmers' perception of SWC

No	Perception rate		Freq.	%
1	High	Adopters	104	27.51
		Non adopters	30	7.93
2	Medium	Adopters	86	22.75
		Non adopters	50	13.22
3	Low	Adopters	29	7.67
		Non adopters	79	20.81

5.3. Factors determining farmers' adoption of SWC measures

As presented in Table 6, this study analyzed the adoption of three principal SWC measures: Soil bunds, stone bunds, and fanya juu structures were considered in the analysis. A multinomial logistic regression model was used to evaluate a dependent variable with multiple categories, with non-adopters designated as the reference group. Prior to interpreting the determinant factors, model adequacy and variable selection were assessed using Deviance goodness-of-fit statistics, and multicollinearity diagnostics were performed. Out of 14 tested variables, 11 were found to be statistically significant at $p < 0.05$. The likelihood ratio test demonstrated that the fitted model with explanatory variables provided a significantly better fit than the intercept-only

model, indicating a strong association between the odds of adopting conservation practices and the predictor variables. Although not all individual coefficients were statistically significant, the pseudo- R^2 values and highly significant chi-square statistics confirmed the model's strong explanatory capacity.

Both the likelihood ratio test statistics and the Pearson chi-square analysis further validated the appropriateness of the model fit. The parameter estimates from the multinomial logistic regression model revealed the direction and magnitude of the effects of the independent variables on adoption decisions, while the odds ratios (Exp (Coef)) show how many times the odds change (increase >1 , decrease <1) for that increment when other factors are constant. Hence, the estimated coefficients and odds ratios are presented in Table 6. Overall, the adoption of soil bunds, stone bunds, and fanya juu structures was significantly influenced by multiple determining factors, which are discussed in the subsequent sections.

5.3.1. Demographic characteristics

The results showed that the gender of the household head significantly influenced the adoption of soil bunds and fanya juu practices. Households headed by women were less likely to adopt these SWC measures than those headed by men. This lower likelihood may be due to female household heads often not engaging directly in land cultivation unless they employ male labor and tending to participate more in non-farm activities rather than focusing on agricultural production and conservation. Engagement in non-farm activities can influence adoption negatively because households relying more on such activities may prioritize income generation outside agriculture, thereby allocating fewer resources, both time and labor, to conservation practices. However, in certain contexts, non-farm income may also enhance the adoption of conservation by providing households with additional financial capacity to hire labor or purchase inputs. In the current study, the evidence suggests that non-farm engagement constrained direct adoption of SWC. These findings align with previous studies (Ahmad et al., 2023a; Lemani, 2017; Aklilu et al., 2006;

Tenge et al., 2004), which found that male-headed households are generally more likely to adopt modern agricultural technologies. Regarding age, the study showed a negative, though statistically insignificant, relationship between the household head's age and the adoption of soil bunds, stone bunds, and fanya juu structures.

The negative relationship implies that older household heads are less likely to adopt conservation practices than younger ones, corroborating some previous findings (Shiferaw et al., 2014). However, this contrasts with other studies (Berihanu et al., 2016; Damtew et al., 2015), which have shown that younger farmers often demonstrate lower levels of commitment to adopting SWC measures compared to older farmers.

5.3.2. Socio-economic factors

The findings indicated a positive relationship between household size and the adoption of soil bunds, stone bunds, and fanya juu structures. This association was statistically significant for stone bunds at the 5% level and for fanya juu at the 1% level. Larger households benefit from a greater labor supply, which facilitates the implementation of labor-intensive conservation practices. Controlling for other factors, the analysis showed that each additional family member increased the likelihood of adopting soil bunds by a factor of 1.10, stone bunds by 1.44, and fanya juu by 2.15. These findings are consistent with previous studies (Lemani, 2017; Berihanu et al., 2016; Damtew et al., 2015), which similarly identified a positive association between household size and conservation practice adoption. Regarding farm size, the study identified a positive and highly significant effect on the adoption of all three conservation measures at the 1% level. This suggests that farmers with larger landholdings have greater incentives and capacity to implement conservation practices due to the potential for expanded production. Specifically, other things being constant, a one-time increase in farm size corresponded to increased odds of adoption by factors of 6.32 for soil bunds, 12.66 for stone bunds, and 9.53 for fanya juu. This result aligns with findings by Tadesse and Belay (2004),

highlighting that larger landholders often possess more financial resources to invest in conservation.

Similarly, livestock ownership was found to significantly increase the adoption of soil bunds, stone bunds, and fanya juu structures, with statistical significance at the 5% and 1% levels. Increased livestock holdings contribute to higher household income, thereby improving the feasibility of investing in conservation measures. The results demonstrated that each additional livestock raised the odds of adopting soil bunds by 1.57 times, stone bunds by 1.27 times, and fanya juu by 1.57 times, supporting conclusions by Kassa (2014) that livestock ownership promotes the adoption of physical SWC practices.

5.3.3. Institutional

The study revealed a positive and statistically significant relationship between education level and the adoption of soil bunds and fanya juu measures at the 10% significance level. Educated farmers are more likely to adopt these practices due to a better understanding of soil erosion impacts. Controlling for other factors, each additional year of education increased the likelihood of using soil bunds by 1.32 times, stone bunds by 1.21 times, and fanya juu by 1.51 times. These findings corroborate earlier research (Lemani, 2017; Erki, 2016), which highlights that higher educational attainment improves farmers' awareness of erosion risks and motivates investments in conservation. Concerning land tenure security, the study found a positive and significant effect on the use of soil bunds, stone bunds, and fanya juu at the 5% level. Secure land tenure was shown to encourage farmers to invest in soil conservation practices, with the probability of use increasing by factors of 2.28, 1.42, and 2.06, respectively, when other variables were held constant. This result aligns with previous findings (Belay and Bewket, 2013), which emphasize the critical role of tenure security in conservation adoption. Furthermore, interaction with extension workers positively and significantly influenced the use of soil bunds at the 10% level. Households with access to extension services were more likely to adopt soil bunds, stone bunds, and fanya juu structures, with

adoption likelihoods increased by factors of 7.64, 2.30, and 0.66, respectively, compared to households without such support. This supports earlier studies (Ahmad et al., 2023a; Dantew et al., 2015; Erki, 2016; Mohammed et al., 2018) that underscore the importance of extension services in promoting conservation, although it contrasts with (Berihanu et al., 2016), which reported a negative effect of extension contact on the adoption of SWC practices.

Empirical studies report mixed or context-dependent effects of non-farm activities on conservation adoption. Some research suggests that engaging in off-farm activities may provide additional income that could facilitate the adoption of labor- and capital-intensive SWC practices by reducing liquidity constraints and expanding resource availability. However, other studies indicate that participation in non-farm work might limit the available labor and time farmers can devote to their own land, potentially reducing the likelihood of adopting conservation measures (Erki, 2016; Kassie et al., 2013). Specifically, in settings where labor availability on the farm is crucial for constructing and maintaining SWC structures, non-farm employment may compete for this scarce resource, leading to negative or no effects on adoption. Additionally, farmers involved in non-farm activities might prioritize immediate income gains over long-term conservation investments (Wainaina et al., 2016; Wagayehu, 2003).

5.3.4. Factors related to farm land

The study revealed that gentler farmland slopes had a negative but statistically insignificant effect on the adoption of soil bunds, stone bunds, and fanya juu structures. This suggests that farmers with gently sloping fields are less concerned about soil erosion risks. These results align with previous studies (Kassie et al., 2013), which indicate that farmers on steeper slopes are more likely to implement soil conservation measures due to their heightened awareness of erosion hazards. The distance of farmland from the home was negatively and significantly related to the adoption of conservation measures at the 1% level. The greater the distance of a farm plot from the homestead, the less likely farmers are to adopt soil bunds, stone bunds, and fanya juu structures.

The results showed that for each increase in distance, the adoption of conservation measures decreased by 0.009, 0.021, and 0.036 times, compared to the reference category. This is consistent with studies suggesting that closer proximity of farmland to the home enables better supervision and attention, increasing the likelihood of adopting conservation practices (Senait, 2005; Borku et al., 2024a).

Household farming experience was positively and significantly related to the adoption of soil

bunds at the 10% level. Experienced farmers were more likely to adopt soil bunds than less experienced farmers. Specifically, for each additional year of farming experience, the likelihood of using soil bunds, stone bunds, and fanya juus increased by 8.97, 3.05, and 3.75 times, respectively. This supports previous findings (Shiferaw and Holden, 2008; Fikadu et al., 2013; Borku et al., 2024b) that experienced farmers are better able to recognize soil erosion risks and are more likely to invest in conservation practices.

Table 6. Factors determining the adoption of the SWC Measures model result

Independent Variables	Soil bunds		Stone bunds		Fanya juus	
	Coeff.	OR	Coeff.	OR	Coeff.	OR
Sex	-2.88**	0.056(1.03)	-0.665	0.514(0.89)	-2.201*	0.111(1.15)
Age	-0.08	0.091(0.05)	-0.044	0.095(0.58)	0.058	1.06(0.06)
Education	0.28**	1.32(0.12)	0.196	1.217(0.11)	0.413**	1.511(0.14)
Family size	0.1	1.10(0.15)	0.366*	1.44(0.16)	0.77***	2.159(0.20)
Farm size	1.84***	6.32(0.05)	2.55***	12.86(0.49)	2.254***	9.530(0.58)
Perception of erosion	1.28	3.62(0.85)	0.199	1.220(0.82)	0.38	1.462(0.87)
Extension Services	2.02**	7.64(0.84)	0.835	2.30(0.79)	-0.411	0.663(0.93)
Credits Access	0.073	1.075(0.90)	0.617	1.85(0.85)	-2.94**	0.052(0.94)
Farming experiences	2.19**	8.97(0.81)	1.117	3.055(0.75)	1.323	3.755(0.86)
Land slopes	-0.057	0.945(0.74)	-0.115	0.892(0.72)	-0.793	0.453(0.84)
Non-farm activities	-1.36	0.256(0.81)	0.57	1.76(0.77)	1.658*	5.249(0.86)
Distance of farm land	-4.72***	0.009(0.76)	-3.866***	0.021(0.74)	-3.328***	0.036(0.75)
Land tenure security	0.826*	2.28(0.82)	0.351	1.421(0.79)	0.727	2.069(0.87)
Number of live. (TLU)	0.45***	1.57(0.1)	0.246*	1.279(0.10)	0.451***	1.570(0.11)

Non-adopters were taken as a base case, Coeff=Coefficients, SE=Standard Error; Number of observations=378, Wald chi-square 657.056, - 2 Log likelihood 296.247; The significance levels of *** for 1%, ** for 10%, and * for 5%.

In general, despite these contextual specificities, our study makes several contributions to the broader body of knowledge on SWC adoption. First, it fills a research gap by focusing on the southern Ethiopian highlands, a less studied area compared to the northern and central regions, thus broadening geographic understanding of conservation adoption factors. The use of multinomial logistic regression to distinguish adoption among different conservation measures adds methodological rigor and nuance (Borku et al., 2024c). Moreover, findings on the influence of socio-economic, institutional, and biophysical factors correspond with and complement existing literature from other Ethiopian and sub-Saharan contexts, reinforcing the role of education, land tenure security, farm size, and extension access in

conservation use. These shared determinants suggest underlying patterns that may be relevant for designing regionally adapted but broadly informed policy and intervention strategies.

6. Limitations

The study's limitation lies in its cross-sectional design, which captures data at a single point in time. While this approach allows for examining patterns of association between variables, it does not account for the dynamic nature of rural livelihoods over time. Rural livelihoods are influenced by a range of physical, economic, social, and cultural factors, all of which may evolve. Therefore, the study may not fully reflect the changes in these livelihood elements that occur in response to various influences over time.

A key recommendation for future research is to incorporate a longitudinal survey to observe significant changes over time. This type of design would enable researchers to track the progression of variables, potentially allowing for the establishment of causal relationships between the factors that influence rural livelihoods. By collecting data at multiple points, longitudinal studies can offer deeper insights into the dynamic processes that shape rural livelihoods and can better capture the temporal shifts in the adoption of conservation measures or other livelihood strategies.

7. Conclusion

This study underscores the serious challenge of land degradation in the Damota area, which threatens agricultural productivity and exacerbates food insecurity and poverty. The study was conducted in a specific context characterized by unique environmental and socio-economic conditions, such as rugged topography, high population density, steep slopes susceptible to soil erosion, and mixed crop-livestock smallholder farming systems. These factors influence the adoption of SWC measures in ways that may differ from other parts of the Ethiopian highlands or regions in sub-Saharan Africa. While the findings provide detailed insights into determinants specific to this area, caution should be exercised when generalizing results to broader contexts, given the heterogeneity of agro-ecological zones and socio-economic conditions across regions. About 29.36% of respondents attributed land degradation to unsustainable practices, with adopter households perceiving soil erosion as severe and increasing, while non-adopters viewed it as less critical. The Multinomial Logit analysis revealed that several socioeconomic and institutional factors significantly influence the adoption of SWC practices, including soil bunds, stone bunds, and fanya juus. Age and perception of soil erosion, however, did not significantly affect adoption decisions, suggesting that other structural and contextual factors may be more influential. The findings highlight the need for targeted interventions that enhance awareness, strengthen extension services, improve access to resources, and tailor conservation strategies to

local contexts. These insights can inform similar efforts in other Ethiopian regions facing land degradation challenges.

8. Recommendation and Future Research Direction

To enhance understandings of generalizability, future research should incorporate longitudinal and multi-site studies across different ecological and socio-economic zones in Ethiopia and sub-Saharan Africa. Such approaches would capture dynamic and contextual factors shaping adoption over time and across varied settings, facilitating the development of scalable and adaptable conservation interventions. Practically, our findings serve as a useful reference for policymakers and practitioners aiming to tailor SWC programs to similar smallholder farming communities facing land degradation challenges, highlighting the need for participatory, locally relevant solutions backed by institutional support. Based on the existing findings, the following recommendation is required.

Strengthen Community Awareness and Education: Implement targeted awareness campaigns and educational programs to bridge the perception gap between users and non-users households. These initiatives should focus on the tangible benefits of SWC measures, emphasizing their role in mitigating soil erosion and enhancing agricultural productivity.

Promote Sustainable Land-Use Practices: Develop policies and programs to discourage the conversion of marginal lands to agriculture and settlements. Encourage sustainable practices such as agroforestry, crop rotation, and controlled grazing to reduce deforestation, overgrazing, and over-exploitation, thereby addressing the root causes of land degradation.

Enhance Institutional Support and Incentives: Strengthen institutional frameworks to provide consistent and accessible extension services. Offer financial incentives such as subsidies or credit facilities to motivate households to adopt soil bunds, stone bunds, and fanya juus. These supports will address socioeconomic barriers and promote the widespread adoption of conservation measures.

Integrate Population Management and Land Planning Strategies: Address population growth

and settlement expansion by integrating family planning programs and implementing land-use planning strategies. Establish zoning policies to regulate agricultural and settlement activities, protecting vulnerable areas from unsustainable exploitation and ensuring the long-term sustainability of natural resources.

Author Contributions:

Mamush Masha: Developed the study framework, gathered the necessary data, and performed the data analysis.

Abraham Woru Borku: Reviewed the manuscript, identified an appropriate journal, and prepared it for publication.

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