SOIL & CROP SCIENCES | RESEARCH ARTICLE

The role of sustainable soil management practices in improving smallholder farmers’ livelihoods in the Gosho watershed, Northwest Ethiopia

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Abstract: Although significant conservation techniques had been established over the preceding forty years, there was little quantifiable evidence regarding the roles of soil management practices on livelihoods in the highlands of Ethiopia. In the Gosho watershed in northwest Ethiopia, the study aimed to investigate how the joint use of indigenous and introduced soil management practices impacted the development of smallholders’ livelihoods. A systematic sampling technique was used to choose 141 household heads from which primary and quantitative data were gathered. The data were collected through conducting face-to-face interviews with each sampled respondent. The data were analyzed using an independent sample t-test and multiple linear regression models. Comparing adopter farm households to non-adopter farm households, the adopters’ natural, physical, human, financial, and social asset indices were larger by 0.28, 0.43, 0.64, 0.54, and 0.15, respectively. Compared to non-adopter farm households, adopter farm households had a 0.41 higher overall livelihood index. Additionally, using both introduced and indigenous structural, vegetative, and agronomic conservation practices on a single plot was the most significant underlying factor for improvements in smallholder farmers’ livelihood assets when compared to using either introduced or indigenous practices alone. Hence, there needs to be a scale-up of the combined use of traditional and introduced structural, vegetative, and agronomic soil management practices on each farmland to sustain smallholder livelihood.

Subjects: Agriculture & Environmental Sciences; Environmental Management; Environment & Society; Conservation - Environment Studies; Environmental Change & Pollution

Keywords: Combined-Use; Indigenous and Introduced Soil Management Practices; Livelihood Development; Farm Household; Gosho Watershed

1. Introduction
The productivity of land resources and human livelihoods are seriously threatened by land degradation on a worldwide scale (Nachtergaele et al., 2013). About 30% of the world’s land area is considered to be degraded (Nkonya et al., 2016). According to Nkonya et al. (2016), land degradation and the use of land degrading management practices on cropland and grazing land cost the global economy roughly 300 billion USD, with Sub-Saharan Africa bearing the biggest portion of the total cost (22%). Although the majority of the region’s rural poor rely largely on its natural resources for their livelihood, Sub-Saharan Africa has witnessed serious land degradation brought
on by changes in land use and cover (Nkonya et al., 2016). Loss of soil, water, vegetation cover, biodiversity, and nutrient depletion are all signs of land degradation (Mkomwa et al., 2017). The most significant sign of land deterioration is soil degradation. In particular, Sub-Saharan Africa is anticipated to see the biggest increases in soil erosion rates as a result of farmland expansion at the expense of plant cover (Borrelli et al., 2013).

In the highlands of Ethiopia, where a mixed farming system of subsistence crops and livestock provides the majority of smallholder farmers’ means of subsistence, soil degradation is a serious issue. The most significant signs of soil degradation in Ethiopia’s highlands are vegetation removal, nitrogen depletion, and water-induced soil erosion (Ewunetu et al., 2021). A common theory for the proximate cause of soil degradation is improper land use and management. The most significant inappropriate management practice is the continued use of conventional farming methods based on intensive tillage, crop residue clearance or in-situ burning, and continuous cropping. Other significant practices under the unsuitable land use and management system include the spread of cropland toward steep slope areas, the use of animal manure and crop straw as fuel for energy consumption, and free grazing. Major soil quality indicators like soil organic carbon and nitrogen drastically decrease when natural forests are converted to farmland (Delelegn et al., 2017). The underlying causes have an indirect impact on the immediate causes. Soil deterioration may be caused by a lack of a strong institutional framework, poverty, and unstable land tenure.

In Ethiopia’s northwest highlands, the accelerated rate of soil loss is a major issue. The average soil loss rate in the upper Blue Nile basin ranges from 28.68 t ha$^{-1}$ yr$^{-1}$ to 57.98 t ha$^{-1}$ yr$^{-1}$ (Elnashar et al., 2021; Endalama et al., 2021). In the Lake Tana Sub-basin, the average projected soil loss was about 37.89 t ha$^{-1}$ yr$^{-1}$ (Balabathina et al., 2020). The accelerated rate of soil loss is one of the key elements affecting the improvement of rural farm households’ livelihoods and the sustainability of agricultural output in Ethiopia (Amsalu & Mengaw, 2014; Adugna et al., 2015; Molla & Sisheber, 2017a; Tesfaye & Tibebe, 2018; Atoma et al., 2020). It results in declining agricultural yield that in turn affects food and livelihood security, and contributes to worsening poverty (Adimassu et al., 2020; Gashu & Muchie, 2018). Because poor households cannot afford to invest in sustainable land management methods, poverty and livelihood insecurity are thought to have a role in soil deterioration. Additionally, it is asserted that because poor farmers’ livelihoods rely so largely on soil resources, they may have a strong motivation to spend their funds on the long-term preservation of soil resources.

Over the past forty years, significant soil conservation investments have been made in place to avert the many components of soil degradation at the watershed level (Gebregziabher et al., 2016). However, the conservation initiatives in the Ethiopian highlands were not properly integrated with the entire land-use systems or backed by scientific evidence (Chot et al., 2019; Hunegnaw et al., 2017). The failure of continued maintenance of the structure has been attributed to insufficient technical compatibility of the practices to farmers’ agricultural systems and rigorous enforcement of farmers with limited technical help during practice time (Gedefaw et al., 2018; Mekuriaw et al., 2018). New terracing had less of an effect on agricultural output and household income in sub-humid areas (Mekuriaw et al., 2018). To resolve this, it is vital to promote the combined use of traditional and introduced soil management practices. Consideration of the benefits and drawbacks of indigenous conservation techniques is a crucial component for the successful implementation of any improved practices that preferentially increase the benefits to be gained from the indigenous ones. To popularize sustainable soil practices and ensure their long-term viability, it is crucial to develop them using both modern knowledge and traditional technological expertise (Yifru et al., 2022). To increase agricultural productivity in the farming systems of Ethiopia, the combined use of vegetation stabilization, erosion control, crop residue recycling, and compost application should be encouraged (Bekele & Negesse, 2019).

The adoption of sustainable soil management practices was influenced by ownership status of farmland, technical fitness of terracing, perception of soil erosion and fertility status, extension
contact, productive labor size, and size of farmland and livestock (Debie, 2021; Ewunetu et al., 2021). There need to integrate structural, biological, and agronomic land management practices for averting diverse aspects of soil degradation and addressing livelihood development (Ewunetu et al., 2021). Soil loss controlling effect of vegetation stabilized terracing should supplement by composting, legume-cereal crop rotation, and other agronomic soil conservation practices (Debie, 2021). This could be more efficient for sustaining high agricultural yield and livelihood assets development with low input costs (Debie, 2022; Gedefaw et al., 2018; Tanto & Laekemariam, 2019).

The combination of vegetative-stabilized terracing and agronomic practices could result in the highest agricultural productivity when compared to terracing alone (W Abera et al., 2020). However, there had been studies on soil, crop production, and household income benefits of introduced soil conservation practices (Abebe & Bekele, 2014; Adimassu et al., 2018, 2017; Belayneh et al., 2019; Chot et al., 2019; Hailu, 2017; Siraw et al., 2018; Welemariam et al., 2018). These variables alone did not give a strong impression about the impacts of introduced soil conservation practices on livelihood assets development. Varied components of livelihood assets were not addressed in the studies. Besides, this study considered the role of sustainable land management implying that combined use of indigenous and introduced soil management practices on livelihood development, whereas the previous research focused on only introduced terracing practices like soil bund and stone bund. Introduced terracing has to be supplemented with traditional and other introduced agronomic, vegetative, and structural soil management practices to bring livelihood assets development and ecosystem services values (Debie, 2022; Sinore et al., 2018). Hence, the livelihoods of smallholder farmers are more likely to improve with the use of sustainable soil management practices. The aim of the study was to evaluate the impact of combining indigenous and introduced structural, vegetative, and agronomic soil management practices on the improvement of rural farm households’ livelihood in the Gosho watershed, Northwest Ethiopia.

2. Materials and methods

2.1. Description of the study watershed
Gosho watershed is located between 10° 36’ 30”–10° 38’ 30” N Latitude and 37° 29’ 30”–37° 31’ 0” E Longitude (Figure 1). The total area of the Gosho watershed is 590 hectares. The Elevation ranges from 2,261 to 2,485 meters above mean sea level. The watershed is found in the tepid-moist agro-ecological zone, and the local climate is dominantly humid sub-tropic, where high annual rainfall and moderate temperature are recorded (Mekonnen & Tolera, 2019). The average rainfall is 1500 mm/yr. The mono-modal rainfall occurs in the summer season (from June to September). More than three-fourths percent of the total rainfall occurs in the summer season (locally known as Kiremt) with peaks in July and August (Belachew et al., 2020). The driest months are December, January, and February (locally known as the Bega season). The average temperature is 15°C. The majority of the watershed is characterized by a steep slope, with the smallest stream having a first-order stream pattern and the main Gosho river having a fourth-order stream pattern (Figure 1). The Eutric Nitosol (covers 385.9 ha or 65.4%) and Vertisols (covers 204.1 ha or 34.6%) are the major soil types distributed in the watershed (Mekonnen & Tolera, 2019). Cultivated land, forest land, grazing land, settlement, and shrublands are the major land use/cover types. When compared to other land use/cover, cultivated land contains the largest proportion. Diverse tree or shrub species are grown in farmlands, churches, and homesteads of the watershed.

The livelihoods of farm households depend on the crop-livestock mixed farming system. Rain-fed crop production with intensive cultivation is commonly practiced. The major crops, such as Teff (Eragrostis abyssinica), Maize (Zea mays), and Wheat (Triticum aestivum) are grown. After that Barley (Hordeum vulgare), and legume crops such as horse beans (Vicia faba) and pea (Pisum sativum) are produced. Livestock husbandry plays a significant role in the livelihoods of farm households. It is a source of food, cash, power, fuel, and crop production fertilizer. The common types of livestock include cattle, sheep, poultry, and donkey. Growing indigenous trees and planting...
exotic plants is a supplementary source of cash income, fuel energy, home construction, farmland fencing, and other activities. For instance, the growing indigenous trees are including Bisana (Croton macrostachyus), Yeabesha Girar (Acacia Abyssinia), Weyra (Olea Europea), Yeabesha Tid (Dombeya torrida), Yeferenji Tid (Cupressus Lusitanica), and Gesho (Rahmu spinoides). The Exotic species, such as Nech-Bahir-Zaf (Eucalyptus globules), decurrens (Acacia decurrens), and Sesbania (Sesbania sesban) are grown in the watershed (Mekonnen & Tolera, 2019).

2.2. Sampling design

The total list of 458 household heads holding farmland in the Gosho watershed was collected from kebeles (small administration unit) development agents (DAs) offices. From the total lists, 141 sample farm households were determined (Kothari, 2004).

\[
 n = \frac{z^2 \cdot p \cdot q \cdot N}{e^2(N-1) + z^2p \cdot q} 
\]  

(1)

Where,

\( N \) = Total farm households in the Gosho watershed (458),

\( n \) = Total sample size in the Gosho watershed,

\( e \) = the estimation allowable error was \((0.03) = 3\%\)

\( z \) = Standard variant at 95% confidence level = 1.96,

\( p \) = Sample proportion \((0.05) = 5\%\)
\[ q = 1 - \rho, \]
\[ n = \frac{1.96^2 \times 0.05 \times 0.95 + 458}{0.03^2 \times (458 - 1) + 1.96^2 \times 0.05 \times 0.95} = \frac{83.574008}{0.4113 + 0.182476} = \frac{83.574008}{0.593776} = 140.74 \approx 141 \]

The farm households that adopted the introduced soil management practices (280) and households that did not adopt them (178) were identified. Hence, adopters and non-adopters were selected proportionally using the following proportional sampling method.

\[ n_1 = \frac{N_1}{N} \times n \tag{2} \]
\[ n_2 = \frac{N_2}{N} \times n \tag{3} \]

\[ n_1 = \text{Sample size for adopter farm households}, \]
\[ N_1 = \text{Total farm households of adopter farm households (280),} \]
\[ n_2 = \text{Sample size for non-adopter farm households}, \]
\[ N_2 = \text{Total farm households for non-adopter farm households (178),} \]
\[ N = \text{Total farm households in the Gosho watershed (458),} \]
\[ n = \text{Total sample size in the Gosho watershed (141),} \]
\[ n_1 = \frac{280}{458} + 141 = 86.2 \approx 86 \text{ (The sample size for adopter farm households)} \]
\[ n_2 = \frac{178}{458} + 141 = 54.79 \approx 55 \text{ (The sample size for non--adopter farm households).} \]

The determined sample size of 86 adopters and 55 non-adopters was selected using the systematic sampling method. After arranging a list of adopters and non-adopters alphabetically, the first farm household was selected randomly from the first three farm households, where
\[ K = N_1/n_1 = 280/86 = 3.25 \approx 3^{rd} \text{ adopter}, \]
\[ K = N_2/n_2 = 178/55 = 3.23 \approx 3^{rd} \text{ non-adopter.} \]

2.3. Variable specification and measurement
Farmers’ decisions to use a combination of structural, vegetative, and agronomic soil management practices on a particular plot are assumed to be influenced by socioeconomic factors like sex, age, education level, the number of families overall, and dependence ratio. The soil management index was an independent factor. Adopters and non-adopters were the response groups of the dependent variable, and the statistical differences between these groups were examined using both continuous and categorical independent variables. Adoption of at least three newly introduced soil management techniques, such as one structural, one vegetative, and one agronomic, was thought to be the primary criterion for sampling groups in the context of the Gosho watershed (adopter and non-adopter). Farmers were referred to as adopters when they embraced and modified newly offered management practices. Adoption is implementing and upholding the newly introduced soil management practices without making any changes. By utilizing alternative indigenous soil management techniques, adoption means embracing and maintaining new methods with some modification. Otherwise, farmers who demolished the built-in structural practices from cropping fields without replacing them with indigenous practices and didn’t employ the introduced vegetative and agronomic soil management methods in the specific agricultural system were considered non-adopters. Adopter farm homes are labeled 1 and 0 otherwise.
|   | Socioeconomic characteristics | Definition and measurement of variables |
|---|-------------------------------|------------------------------------------|
| 1 | Age                           | From 15 to 65 = 1 and greater than 65 = 0 |
| 2 | sex                           | Gender of household head: 1 if male, 0 otherwise |
| 3 | Education                     | primary education and above = 2; Read and write = 1; and cannot read and write = 0 |
| 4 | Family size                   | Family size: in number |
| 5 | Dependency ratio              | in ratio value |

| II | Types of soil conservation practices | Value categories for index measurement |
|----|-------------------------------------|----------------------------------------|
| A  | Structural soil conservation practices                      | Yes = 1 and No = 0 |
| 1  | Soil bund (introduced)                        | Yes = 1 and No = 0 |
| 2  | Stone bund (introduced)                        | Yes = 1 and No = 0 |
| 3  | Fanya juu bund (introduced)                    | Yes = 1 and No = 0 |
| 4  | Check dam (introduced)                         | Yes = 1 and No = 0 |
| 5  | Drainage ditches (indigenous)                  | Yes = 1 and No = 0 |
| 6  | Cut off drain (indigenous)                     | Yes = 1 and No = 0 |
| B  | Vegetative soil conservation practices                      | Yes = 1 and No = 0 |
| 1  | Grass/shrubs/strip (introduced)                | Yes = 1 and No = 0 |
| 2  | Re-vegetation (indigenous)                     | Yes = 1 and No = 0 |
| 3  | Area enclosure (introduced/ indigenous)        | Yes = 1 and No = 0 |
| 4  | Agroforestry (introduced)                      | Yes = 1 and No = 0 |
| 5  | Exotic tree plantation (introduced)            | Yes = 1 and No = 0 |
| C  | Agronomic soil conservation practices                      | Yes = 1 and No = 0 |
| 1  | Compost (introduced)                           | Yes = 1 and No = 0 |
| 2  | Legume-cereal crop rotation (indigenous)       | Yes = 1 and No = 0 |
| 3  | Inter-cropping (indigenous)                    | Yes = 1 and No = 0 |
| 4  | Crop residue incorporation in the soil (indigenous) | Yes = 1 and No = 0 |
| 5  | Green manure (introduced)                      | Yes = 1 and No = 0 |
| 6  | Liming (introduced)                            | Yes = 1 and No = 0 |
| D  | Combination of at least one structural, one vegetative, and one agronomic introduced or/and indigenous soil conservation practices at the particular plot | Yes = 1 and No = 0 |

Source: Identified by field observation combined with data adopted from Woreda agricultural office (2021).
2.4. Methods and procedures of data collection

There were two phases of data collection procedures. In the first phase, field observations, informal discussions with ten farmers, and key informant interviews with the watershed committee and development agents were held. This phase of the pilot survey was important to obtain background information about a farming system, practices, adoption, and benefits of soil conservation practices. Based on the pilot information and empirical literature (Abera, 2021; Chen et al., 2013; Chot et al., 2019; Gashu & Muchie, 2018; Ingxay et al., 2015; Merritt et al., 2016; Siraw et al., 2018; Tefera et al., 2017; Zerihun, 2021), structured questionnaires were developed for socioeconomic characteristics, soil conservation practices, and livelihood assets for the second phase of the household survey. A total of 141 household heads participated in the study. The data-gathering survey was carried out by two enumerators. Based on their educational background, knowledge of the location, and prior data collection experience, the data collectors were chosen. The enumerators received training from the researchers on how to conduct questionnaires correctly and get accurate data. Face-to-face interviews are conducted with each sampled respondent by the enumerators under the careful supervision of the researchers. When possible, respondents were contacted for interviews at their homes, on farms, and in churches and gathering places.
2.5. Method of data analysis

Descriptive statistics were used to present the socioeconomic and demographic data from the study. Using categorical independent variables, such as age, sex, and education, the Chi-square test was performed to examine the statistical difference between two responses. The family size and dependency ratio were utilized to evaluate if there were statistically significant differences between the means of the two responder groups using an independent t-test.

All capital assets employed by farm households for their means of subsistence were measured using an index. Before calculating the household livelihood index, all indicators were standardized using a straightforward linear scaling procedure. The researcher created indicators with the same 0–1 range using the linear standardization (min-max normalization) method using the formula below (Donohue & Biggs, 2015; Ingxay et al., 2015).

\[ X_i = \frac{R_i - V_{\text{min}}}{V_{\text{max}} - V_{\text{min}}} \]  

(4)

Where: \( X_i \) = computed value, \( R_i \) = row value to be normalized, \( V_{\text{min}} \) = minimum value of the variable, and \( V_{\text{max}} \) = maximum value of the variable.

After standardizing each indicator, the value of each type of livelihood capital and the overall livelihood capital value were calculated by using an integrated measurement equation by Chen et al. (2013):

\[ C = \sum_{n=0}^{n} \frac{I_n}{T_n} \]  

(5)

Where \( C \) is the criteria score for each asset \( (0 \leq C \leq 1) \); \( n \) denotes \( n^{th} \) indicators of criteria \( (n = 1, 2, 3 \ldots n) \); \( I \) denotes indicators; \( T \) denotes the total number of indicators; then the overall livelihood asset was calculated using the following integrated measurement equation of (Chen et al., 2013).

\[ LA = \frac{PC + NC + HC + FC + SC}{5} \]  

(6)

### Table 3. Socioeconomic characteristics of the respondents

| Variables               | Categories             | Non-adopter % | Adopter % | Total (100%) | Chi square (χ²) |
|-------------------------|------------------------|---------------|-----------|--------------|----------------|
| Age group               | 15–65                  | 24.8          | 58.9      | 83.7         | 26.56**        |
|                         | >65                    | 14.2          | 2.1       | 16.3         |                |
| Sex                     | Female-headed          | 12.1          | 1.4       | 13.5         | 23.51**        |
|                         | Male-headed            | 27            | 59.6      | 86.5         |                |
| Education Level         | Cannot read and write  | 18.5          | 3.6       | 21.9         | 78.89**        |
|                         | Read and write         | 17            | 5.7       | 22.7         |                |
|                         | primary education and above | 3.5 | 51.7 | 55.2 | | |

| Variables               | Mean | Mean | Mean diff | Independent test (t) |
|-------------------------|------|------|-----------|----------------------|
| Total family size       | 6.36 | 5.17 | 1.189     | 3.86*                |
| Dependency ratio        | 1.11 | 0.232| 0.876     | 11.025*              |

Source: Survey, 2021.

Note: ** represents significant at \( p < 0.01 \). Dependency ratio refers to the number of dependents (children < 15 years plus old people > 65) per economically active (between 15 to 65 years) member of the family.
Where, LA = livelihood asset; PC = physical capital; NC = natural capital; HC denotes human capital; FC denotes financial capital, and SC = social capital.

The difference in livelihood development between soil conservation practices adopters and non-adopters was demonstrated using the independent sample t-test. The relative explanatory power of introduced, indigenous, and mixed uses of structural, vegetative, and agronomic soil conservation practices was examined using multiple linear regression models. Below is a description of the formula for a multiple linear regression model:

\[ Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots \ldots + \beta_n X_n + \epsilon \]  \hspace{1cm} (7)

Where,

- \( Y \) = the dependent variable, or livelihood assets
- \( \beta_0 \) = the intercept/constant, the predicted value of y when the \( X_1, X_2 \ldots \ldots \ldots X_n \) is 0,
- \( \beta_1, \beta_2, \beta_3 \ldots \beta_n \) = the regression coefficient—how much we expect y to change as \( X_1, X_2, X_3 \ldots \) increases,
- \( X_1, X_2, X_3 \ldots X_n \) = the independent variable (the variable we expect is influencing y),
- \( \epsilon \) = the error of the estimate, or how much variation there is in our estimate of the regression coefficient (Kothari, 2004). Finally, substituting the variables into the model results,

\[ Y \text{(HLI)} = \beta_0 + \beta_1 \text{(introdSCP)} + \beta_2 \text{(indigSCP)} + \beta_3 \text{(CombinSCP)} + \epsilon \]  \hspace{1cm} (8)

Where HLI = household livelihood index, introdSCP = introduced soil conservation practices, indigSCP = indigenous soil conservation practices, and CombinSCP = Combination of soil conservation practices. Multicollinearity was checked before conducting the regression analysis. The correlation matrix was used to examine the predictor variables for multicollinearity. The presence of multicollinearity is indicated by an absolute Pearson correlation coefficient of >0.7 between two or more predictors (Young, 2017).

3. Results and discussions

3.1. Socioeconomic characteristics of the respondents

The socioeconomic characteristics of the respondents, including sex, age, educational attainment, family size, and dependency ratio, are shown in Table 3. About 59.6% of the respondents were from male-headed households, and this difference was statistically significant (\( \chi^2 = 23.51 \) & \( P < 0.01 \)), indicating that male-headed farm households embraced the new soil conservation techniques at a higher rate than female-headed households. This is because agricultural households led by men have more access to information regarding the technical know-how and advantages of newly implemented conservation methods (Abera et al., 2021; Kokoye et al., 2016).
Of the total adopters, 58.9% of the respondents fell into the productive age category and showed a significant difference at $\chi^2 = 26.56$ and $P < 0.01$. The outcome shows that the household head in the productive age group was more likely than the elder household head to implement newly introduced soil conservation methods. Due to their greater labor potential than elderly homes, productive age households were more likely involved in composting and terracing maintenance (Chot et al., 2019; Debie, 2021; Wolka & Negash, 2014).

The majority of adoptive farmers (51.7%) had primary education or higher, and there was a statistically significant difference at $\chi^2 = 78.89$ & $P < 0.01$. This suggests that a higher degree of education is significantly linked to the likelihood that newly proposed soil conservation methods will be adopted. Having a degree gives you the chance to interact with professionals, agricultural specialists, and other organizations that run soil conservation projects (Chot et al., 2019).
addition, the key factor influencing the diversification of livelihood strategies was education level (Abera et al., 2021). The determination of a fruitful family size at the home level might be influenced by education level. Adopter homes had a slightly smaller average family size, and the difference was statistically significant ($t = 3.86$ & $P < 0.01$) compared to non-adopters. The dependency ratio of adopting households was substantially different at $t = 11.025$ & $P < 0.01$ and decreased by 0.876. Families with more adults of working age were more likely to adopt and fund labor-intensive conservation practices, such as introducing terracing and composting (Chot et al., 2019).

### 3.2. Types of soil conservation practices in the Gosho watershed

Both adopters and non-adopters of introduced soil conservation practices frequently use structural, vegetative, and agronomic indigenous soil conservation practices. For instance, cutoff drains

### Table 4. Impacts of soil conservation practices on livelihood development of smallholder farmers

| Capital indicators | Mean index | Independent t-test |
|--------------------|------------|-------------------|
| Adopters | Non-adopter | Mdf. | t |
| Average farm size | 0.46 | 0.58 | −0.12 | −4.969 b |
| Livestock owned | 0.60 | 0.20 | 0.4 | 18.321 a |
| Perennial crops growing | 1.00 | 0.31 | 0.69 | 10.987 a |
| Average crop production | 0.74 | 0.17 | 0.57 | 28.823 a |
| Potable water distance | 0.05 | 0.19 | −0.14 | −14.239 b |
| Natural capital | 0.57 | 0.29 | 0.28 | 18.332 a |
| Fertilizer use | 1.00 | 0.98 | 0.07 | 2.058 |
| Access to irrigation | 0.38 | 0.04 | 0.34 | 5.930 b |
| Improved seed use | 1.00 | 0.27 | 0.73 | 12.000 b |
| Index of soil conservation practices | 0.84 | 0.25 | 0.59 | 55.447 a |
| Physical capital | 0.80 | 0.37 | 0.43 | 16.311 a |
| Visit other model watersheds | 0.22 | 0.00 | 0.22 | 4.910 b |
| Develop technical skills from WDT | 1.00 | 0.15 | 0.85 | 17.812 a |
| Human capital | 0.74 | 0.10 | 0.64 | 18.228 a |
| Annual income | 0.70 | 0.16 | 0.54 | 30.033 a |
| Financial capital | 0.70 | 0.16 | 0.54 | 30.033 a |
| Participation in labor sharing | 1.00 | 0.95 | 0.05 | 4.294 |
| Member of social institutions | 1.00 | 0.98 | 0.02 | 1.000 |
| Develop social networks with KS | 1.00 | 0.84 | 0.16 | 3.250 a |
| Social capital | 1.00 | 0.85 | 0.15 | 4.884 a |
| Households livelihood index | 0.76 | 0.35 | 0.41 | 30.569 a |

Source: Own Survey, 2021.

Note: WDT = watershed development training, KS = key stockholders, Mdf. = mean difference, a and b represent statistically significant at $P < 0.001$ and $P < 0.05$. TLU = Tropical livestock unit. Multiple responses were considered for percentage value results.
and drainage ditches are two regularly utilized methods for preventing structural soil loss in the neighborhood. Agronomic soil conservation techniques that are frequently used in the region include intercropping, leguminous-cereal crop rotation, and crop residue incorporation in the soil. Additionally, it is common practice to enclose privately held fallow croplands and grazing fields, as well as to apply green manure by burying weeds during the Belg (from March to May) and Meher (September to November) seasons of plowing. Adopters’ farm households in the watershed have adopted new vegetative, structural, and agronomic soil conservation methods. For instance, the research site employs structural techniques for erosion management such as soil bunds, stone bunds, and Fanya juu (Figure 2). To keep soil, water, and nutrient loss at manageable levels and enable the cultivated fields to sustain crop yields, erosion control methods need to be supplemented with agronomic practices (Debie et al., 2019).

The newly proposed agronomic soil conservation practices include composting and liming. Utilizing compost can be a cost-effective, ecologically friendly method of increasing crop production and soil fertility (Debie, 2021; Gulyas & Fuleky, 2013). Making lime from pulverized limestone rock, which naturally includes calcium carbonate and magnesium carbonate, is a method of amending soil. It is used in croplands when soil acidity is a problem. Lime works to raise the soil’s pH, making it more alkaline and less acidic (Dinkecha & Tsegaye, 2017).

Some of the newly adopted vegetative soil conservation measures in the watershed include the cultivation of elephantiasis grass or Sesbania sesban grass, agroforestry, and acacia decurrens plantations. Runoff could be reduced and sediments carried by runoff could be captured by a grass/shrub/strip. Farm plot terracing is stabilized by grass or shrub strips, which also supply fodder for livestock feeding (Atnafe et al., 2015). Agroforestry systems include fully established woody perennials (trees, shrubs, etc.) along with non-woody plants (crops, pastures), as well as changes in location, a rotation, or both (Singh et al., 2019). In addition to annual crops, farm households also planted a variety of permanent crops, including Gesho (Rahmnu spinaoides) and other trees (see, Figure 3a,b & c). Agroforestry provides farmers with food, cash, fuel-wood, and fodder. A plantation of eucalyptus globules and acacia decurrens could stabilize terracing and help smallholder farmers’ livelihoods (Atnafe et al., 2015).

In the watershed, soil conservation practices that combine native and introduced structural, vegetative, and agronomic practices on a particular plot are also used (Figure 3a-d). Combining soil conservation techniques on a single piece of land can significantly improve land productivity, runoff reduction, soil erosion control, feed availability for livestock, and farm household livelihoods (Atnafe et al., 2015; Chot et al., 2019).

3.3. Roles of soil management practices on livelihood capitals development
Table 4 disclosed that soil conservation practices determine the development of livelihood assets, such as natural, physical, human, financial, and social.

4. Natural capitals
More natural capital growth was explained by livestock husbandry, perennial crop cultivation, and increased crop yield. When compared to non-adopter farm households, adopter farm households’ livestock husbandry increased by 3.61 TLU and significantly varied at $t = 18.321$ and $P < 0.001$. Livestock productivity had grown as a result of the improvements in fodder production brought about by the adoption of soil conservation techniques (Gebregziabher et al., 2016; Meaza et al., 2016; Siraw et al., 2018). Rotational grazing, cut-and-carry grazing, and controlled grazing are three practices that can help recover damaged pasture land and increase animal productivity (Almaw et al., 2019). Harvesting fodder for animals and fuelwood for cooking might reduce crop production; however, it can be made up for by planting high-value grasses and trees on unused bund/terrace segments (Adimassu et al., 2017). Planting Ficus thonningii trees helped to significantly reduce the essential animal feed shortage during the dry season (Asmare & Mekuriaw, 2019). Cow gains in terms of income, poverty, and food security would increase as livestock diet
Table 5. Farmhouse responses to the usage of chemical fertilizers

| Types of chemical fertilizers | Adopter (N = 86) | Non-adopter (N = 55) | Mean difference | t     |
|-------------------------------|------------------|----------------------|-----------------|-------|
| UREA in kg/hectare used       | 166.28           | 247.27               | −80.994         | −7.072*|
| DAP in kg/hectare used        | 155.93           | 161.45               | −5.524          | −0.698 |
| The total amount of fertilizer used | 322.21       | 408.73               | −86.518         | −4.864*|

Source: Own Survey, 2021. Where diff = difference * indicates a statistically significant difference at p < 0.05.

quality improved (Shikuku et al., 2017). Methane output per unit of milk and meat can be decreased with increased livestock feed intensification through agroforestry and perennial crop development, which can also increase meat and milk yield (Thornton & Herrero, 2010).

According to the survey’s findings, all adopter farm households and 30.9% of non-adopter farm households have planted perennial crops such as sesbania sesban, elephantiasis grass, and Gesho (Rahmnu spinoides) for socio-ecological reasons. There was a statistically significant difference between farm households that did not adopt and those that did at t = 10.987 and P < 0.001 between the planting of perennial crops on terracing as a source of additional revenue for farm households. Compared to the control watershed, farmers in the protected watershed had grown considerable amounts of perennial crops (Assan & Beyene, 2013; Siraw et al., 2018). Growing perennial crops and implementing agroforestry techniques have helped farm households improve their standard of living and sustain their way of life (Zerihun, 2021). The stabilization and repair of the badlands are positively impacted by the planting of quickly growing trees and perennial crops on active gully systems next to farmland, which also significantly reduces sediment export (Borji et al., 2018). In addition to providing fuel, building materials, timber, fodder, and fruits for self-consumption and monetary benefit, planting trees on farms permits the sequestration of carbon, recycling of nutrients through reaching deep soil layers, and reduction of soil erosion (Mkomwa et al., 2017).

When compared to non-adopter farm households, the average annual crop production of adopter farm households increased by 1540 Kg and statistically differed at t = 28.823 & P = 0.000. The outcome is consistent with earlier research on Ethiopia’s findings (Assan & Beyene, 2013; Belayneh et al., 2019; Chot et al., 2019; Gebregziabher et al., 2016; Hadush, 2015; Mena et al., 2018; Siraw et al., 2018). The livelihood of households and food security were significantly improved through crop diversification and intensification (Mengistu et al., 2021). Additionally, adopter households’ average travel time to potable water sites fell by 0.14 hours and were substantially different from non-adopter households at t = −14.239 & P < 0.05. Farmers were able to reach groundwater within a few meters of the surface and use a water pump to acquire drinking water thanks to the joint use of vegetative and structural conservation methods in the homestead and the surrounding area. At t = 18.332 &P < 0.001, adopter farm households’ natural capital index was generally greater than non-adopter farm households’. This suggests that soil conservation techniques helped to increase household natural capital. In agreement with this, Siraw et al. (2018) found that a conserved watershed in northwest Ethiopia had a higher natural capital value than the controlled watershed.

5. Physical capitals

Table 4 shows that the physical capital was responsible for explaining the usage of fertilizer, access to irrigation, enhanced seed use, and the index of soil conservation methods. On both irrigated and rain-fed croplands, farmers utilize chemical fertilizers. Farm households with access to irrigation made up about 38.4% of adopters and 3.6% of non-adopters. With a difference of 0.34 and a statistically significant difference of t = 5.93 and P < 0.001, the index of adopters’
access to irrigation rose. Adopting farm households employ motor pumps to irrigate plots and have proximity to groundwater on their conserved land. Increased household income, daily calorie consumption, and the development of livelihoods are all influenced by having access to conventional irrigation for the production of grain crops, vegetables, and fruits (Assan & Beyene, 2013; Etana et al., 2021; Jambo et al., 2021). Farmers employed modified seeds to increase crop productivity in rain-fed and irrigated croplands. Improved seeds were used in farmlands by 27.3% of non-adopter farm families and 100% of adopter farm households in the crop year 2020–2021. Comparing adopter households to non-adopters, the indicator of enhanced seed consumption increased by 0.73, and the difference was statistically significant at $t = 12$ & $P = 0.022$. The sustainability of smallholder farmers’ livelihoods was greatly enhanced by using better seeds and diversifying their crops (Etana et al., 2021). It is necessary to combine the use of chemical fertilizers and better seeds with structural, vegetative, and agronomic soil conservation practices in specific farmland.

The average soil conservation practices indices for the adopter and non-adopter farm households in the study watershed were 0.84 and 0.25, respectively. Comparing adopter farm households to non-adopter farm households, the index of soil conservation practices was higher by 0.59 and significantly different at $t = 55.45$ & $P < 0.001$. Adopter households’ physical capital index improved by 0.43, and the difference between adopters and non-adopters was statistically significant ($t = 16.31$, $P = 0.001$). Practicing sustainable land management provided a considerable contribution to the livelihood improvement of smallholder farmers (Etana et al., 2021). To ensure the security of the livelihood of the expanding population, it is essential to maximize the productivity of existing agricultural land through sustainable management practices (Pretty et al., 2018).

To boost the productivity of croplands, almost all responders have utilized chemical fertilizers like UREA and DAP. When compared to non-adopter farm homes, the average amount of fertilizers (UREA and DAP) utilized by adopter farm households decreased by 86.52 Kg (Table 5). According to the findings, farm households that did not adopt utilized more chemical fertilizers. Due to soil erosion and soil fertility depletion, a considerable amount of chemical fertilizer was applied in the control watershed, which was likely the reason for the poor soil fertility (Chot et al., 2019; Siraw et al., 2018).
### Table 7. Results of multiple linear regression models

| Factors                                      | B    | SE  | t    |
|----------------------------------------------|------|-----|------|
| (Constant)                                   | .234 | .013| 18.710* |
| Indigenous soil conservation practices       | .181 | .049| 3.694* |
| Introduced soil conservation practices       | .192 | .048| 4.025* |
| Combination of soil conservation practices   | .29  | .026| 11.356* |

**Model Summary**

| Model | R   | R Square | Adjusted R Square | Std. Error of the Estimate |
|-------|-----|----------|-------------------|----------------------------|
| 1     | .962* | .925     | .923              | .05818                     |

a. Predictors: (Constant), introduced soil conservation practices index, Indigenous soil conservation practices index, and combined use of indigenous and introduced soil conservation practices index.
b. Dependent Variable: Household Livelihood index.

c. Predictors: (Constant), introduced soil conservation practices index, Indigenous soil conservation practices index, and combined use of indigenous and introduced soil conservation practices index.

d. Dependent Variable: Household Livelihood index.

Source:—Own Survey, 2021. **Note:** *, B, SE, and stand for statistically significant at P < 0.001, beta coefficient, standard error, and independent t-test in that order.
6. Human capitals
Visits to other model watersheds and the acquisition of technical skills through watershed development training are two variables utilized in this study to assess the human capital of farm households. For farm households to build and maintain adopted soil conservation techniques on their farmlands, sharing experiences through visiting other model watershed areas is vital. Farmers should become more aware of the various socio-ecological advantages of soil conservation techniques. Through a program run by the Woreda Agricultural Office and the Water and Land Resource Research Center, only 22.1% of adopter farm households chosen based on their success in soil conservation practices had the opportunity to visit the Arjenie model watersheds. At $t = 4.910 & P = 0.043$, the difference between adopters and non-adopters in the frequency of visits to the model watershed was statistically significant. All adopter farmers had additionally taken part in several watershed development training courses. Adopters gained technical knowledge about how to apply several newly introduced soil conservation methods from the workshop. At $t = 17.812$ and $P = 0.000$, the difference in technical skill development from watershed development training was statistically significant. Crop seeds, fodder trees, and technical skill training in their production and use all made a substantial contribution to raising the productivity of the crop-livestock mixed agricultural system (Asmare & Mekuriaw, 2019). The most significant factor influencing the livelihood security of smallholder farmers was a capacity development effort on farmers’ skills and technology through proper training and informal education (Mengistu et al., 2021). Farmers’ deficiencies in designing site-specific management practices should be filled by extension personnel through efficient capacity development training (Debie et al., 2019). When compared to non-adopter families, adopter farm households’ overall human capital index increased by 0.64 and showed a difference at the $t = 18.23$ and $P < 0.01$ significant levels. In northwest Ethiopia, there was a statistically significant difference in human capital between the conserved and the control watershed (Siraw et al., 2018).

7. Financial capitals
The indicators utilized to assess the financial capital of farm households were annual income and savings (Table 4).

When compared to non-adopter families, adopter farm households’ average annual income and saving income indices were 0.54 higher and statistically different at $t = 30.033 & P < 0.01$. As a result of combining several soil conservation methods, adopter farm households were shown to have increased annual revenue from various sources. Compared to non-adopter families, adopter farm households had an average saving income of more than 5,909 Birr. In the Ethiopian highlands, watershed development interventions have improved household income (Gebregziabher et al., 2016; Kassa & Beyene, 2014; Siraw et al., 2018; Yaebiyo et al., 2015) and annual saving (Assan & Beyene, 2013; Kassa & Beyene, 2014; Siraw et al., 2018).

The growth in annual revenue and the amount saved had been significantly impacted at a $P < 0.01$ level by the increase in selling income from crop productivity, livestock management, and perennial crops (Table 6). The outcome demonstrated that agricultural sales were the main source of income. Crop sales, according to Chot et al. (2019), were the main source of income and savings at the household level. The average yearly household income had increased by 23,031.28 Birr thanks to the use of better agriculture and livestock technologies (Wordafa et al., 2021). For smallholder farmers in Ethiopia’s highlands, increasing crop productivity through diversification and intensification led to longer-lasting livelihoods (Etana et al., 2021). Farm households that adopted the program had a higher overall financial capital index than those that did not; this difference was significant ($t = 30.033 & P < 0.001$; Table 4). In numerous watersheds of the Ethiopian highlands, soil conservation techniques have increased financial capital (Assan & Beyene, 2013; Kassa & Beyene, 2014; Yaebiyo et al., 2015). The diversification of livelihoods through agriculture, non-farm, and off-farm occupations was significantly impacted by the growth in annual income and the amount saved (Abera et al., 2021).
8. Social capitals

The indicators utilized to explain the social capital of farm households included the growth of social networks, labor-sharing involvement, and membership in social institutions (Table 4). Farm households that used social networks differed from those that did not at a significant level ($t = 3.250 \& P = 0.000$). As a result, social networks with various stakeholders, including farmers, kebele development agents, woreda agricultural specialists, watershed committees, kebele administrative agents, and agents from non-governmental organizations, were developed. The capacity to use and routinely sustain labor-intensive land management techniques for increased livestock husbandry, crop production, and plantation operations is determined by greater social networks (Mengistu & Assefa, 2019; Tefera et al., 2017).

The social capital index’s findings, which were statistically significant at $t = 4.884 \& P = 0.000$, show that adopter farm households had higher social capital than non-adopter farm households. Interventions in diverse watersheds to save soil and water have raised households’ social capital (Assan & Beyene, 2013). According to the aggregated livelihood outcome, the natural, financial, human, physical, and social capital indices of the adopter and non-adopter farm households, respectively, were 0.57, 0.70, 0.74, 0.80, and 1.00 (Table 4). Human, financial, natural, physical, and social capital indices for adopter farmers were higher by 0.64, 0.54, 0.28, 0.43, and 0.15, respectively, and statistically different from non-adopter farmers at $P < 0.001$.

Figure 4 demonstrates that the major and secondary most significant developments, respectively, were growth in human and financial capital. The most crucial elements in enhancing the lives of smallholder farmers were raising knowledge of the advantages of newly introduced practical technologies and offering effective training about technical skills of adaptive conservation technologies. Additionally, increased agricultural, livestock, and tree yields boost household total income and savings, which in turn stimulates the household level to diversify and deepen off-farm, non-farm, and on-farm income activities. The adopter and non-adopter farm households’ overall livelihood indices were 0.76 and 0.35, respectively. Compared to non-adopter farm households, adoptive farm households’ livelihood index increased by 0.41 and the difference between the two households was statistically significant ($t = 30.57 & P = 0.001$). In several regions of Ethiopia, introduced soil conservation intervention increases agricultural households’ capital for subsistence (Assan & Beyene, 2013; Chot et al., 2019; Gebregziabher et al., 2016; Kassa & Beyene, 2014; Meaza et al., 2016; Meshesha & Birhanu, 2015; Siraw et al., 2018).

8.1. Soil management practices in determining livelihood development

The two approaches used to assess multicollinearity among variables are tolerance (TOL) and variance inflation factor (VIF). An independent variable’s multicollinearity is often indicated by a VIF rate of more than 10 and a tolerance close to zero. The data had no multicollinearity issues, according to the variance inflation factor (VIF) and tolerance (TOL) results. R2 statistics are used to quantify the model’s goodness of fit and explain the predictor variable. This describes the percentage of variation in the dependents that the explanatory variables account for. According to a model summary result in Table 7, the independent variables were able to predict 92.5 % of the variance in household livelihood. Household livelihood = 0.234 + 0.181* (indigenous soil conservation practice) + 0.290* (introduced soil conservation practices) + 0.192* was the regression equation used to predict household livelihood from the independent variables (combination of soil conservation practices).

The findings showed that with all other factors held constant, a one-unit increment in both indigenous and introduced soil conservation techniques resulted in a factor increase in the household’s livelihoods of 0.181 and 0.192, respectively, at a significant level of $P < 0.001$ (Table 7). Furthermore, if all other factors remained the same, a unit increment in the combined application of introduced and indigenous soil conservation practices would boost the adopter farm households’ livelihoods by a factor of 0.29 at $P < 0.001$. This suggests that the key determining factor for the growth of smallholder farmers’ livelihoods in the study watershed was the joint employment of structural, vegetative, and agronomic introduced and indigenous soil conservation practices. Combining indigenous, cutting-edge,
vegetative stabilization, and agronomic traits effective conservation methods have considerably improved livelihoods (Adimassu et al., 2017; Alemu & Melesse, 2019; Debie et al., 2019).

9. Conclusion
In order to prevent various forms of soil deterioration and take care of livelihood development, it is crucial to combine both indigenous and newly introduced structural, biological, and agronomic land management practices. Despite the fact that significant conservation practices had been developed during the preceding forty years, there was little quantifiable evidence addressing the impacts of sustainable soil management practices on livelihoods in the highlands of Ethiopia. The study sought to determine how the blending of introduced and indigenous soil management methods affects the growth of smallholder’s livelihoods in the Gosho watershed in northwest Ethiopia. The livelihood assets of rural farming households were evaluated using 16 carefully chosen capital asset indicators.

The results disclose that adopter farm households performed better than non-adopter farm households in the following areas: livestock husbandry, perennial crop growing, crop production, potable water distance, access to irrigation, the improved seed used, index of soil conservation practices, visit other model watersheds, develop technical skills from watershed development training, annual income, annual saving, and social network development. The adopting farmers’ indices of natural, physical, human, financial, and social capital were higher by 0.28, 0.43, 0.64, 0.55, and 0.15, respectively, and the differences were statistically significant at P < 0.001. For adopter farm households and non-adopter farm households, the total household livelihood index was 0.35 and 0.76, respectively.

The joint adoption of structural, vegetative, and agronomic introduced and indigenous soil conservation measures was the determinant factor in the improvement of smallholder farmers’ livelihoods. Therefore, for sustained agricultural productivity and livelihood development, the strategy should increase the combination of these conservation practices on particular farmland.

Acknowledgment
The authors are grateful to household respondents for their valuable contribution to the study.

Funding
The authors received no direct funding for this research.

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Disclosure statement
No potential conflict of interest was reported by the author(s).

Ethics approval and consent to participate
The study design was fully explained to the respondents for gaining consent. Data generated from a participant were kept confidential and all informants are acknowledged.

Citation information
Cite this article as: The role of sustainable soil management practices in improving smallholder farmers’ livelihoods in the Gosho watershed, Northwest Ethiopia, Ermias Debie, Tadesse Yaye & Mesfin Anteneh, Cogent Food & Agriculture (2022), 8: 2097608.

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