The Effect of Soil and Water Conservation Structures on the Soil Biophysical and Chemical Properties in the Gidabo Sub-basin, Ethiopian Rift Valley

Getahun Hassen, Amare Bantider, Abiyot Legesse, and Malesu Maimbo

Abstract—Soil erosion is one of the global challenges noticed as a cause for unsustainable socio-economic and environmental conditions. Over the last half-century, various soil and water conservation (SWC) practices were introduced in Ethiopia, but the conservation work could not be fully achieved in many areas. Therefore, this study aimed to explore the effect and constraints of physical SWC on selected soil biophysical and chemical properties of the Ethiopian rift valley. The primary and secondary data sources were used to answer the intended objectives. The statistical analysis of variance showed that the soil texture of the study area was affected by the type of conservation technologies than agroecology and slope characteristics. However, soil bulk density was not significantly affected at all. The study also showed that the soil biophysical and chemical properties were significantly affected by the variation of agroecology and SWC technologies. The overall result of the study depicted that about 40% of the conservation work failed to maintain soil fertility because the farmers have constraints to adopt and adapt the SWC work. The constraints include small land size, shortage of fuel wood, dependency on food aid, less productivity of the soil, youth migration, and long lasted effect of conservation works. These constraints were seen as causes for inferior agricultural product, food insecurity, famine, migration and frequent drought of the area. The study concluded that the SWC work of the area should focus on variation of agroecology, SWC technologies, and local constraints. Also, the policy of natural resource conservation should consider local constraints to implement the national SWC guideline.

Index Terms—Community, food security, soil nutrients, soil and water conservation.

I. INTRODUCTION

Natural resource degradation is one of the significant challenges that the world is facing today and is feared to risk future life all over the globe [1]. Though natural resource degradation processes do occur without interference by man, accelerated land degradation is most commonly caused as a result of human action in the environment [2]. Soil erosion is one of the causes of natural resource degradation and the socio-economic and environmental threat to agriculture's sustainability and productive capacity [3]. In developing countries, soil erosion is a severe problem because of their direct dependence on the soil resource [4]. Research results confirmed that soil erosion and nutrient depletion had been the main challenges in Ethiopia that adversely affect crop productivity and reduces agricultural production [5].

The poor performance of the agricultural sector, food-deficit, unsustainable subsistence agriculture, famine, starvation, frequent drought and desertifications is common in Ethiopia that has been credited mainly to soil erosion [6]. Global effort on natural resource conservation work started before 5000 years [7]. However, special emphasis was given to watershed-based soil and water conservation (SWC) following the UN conference of 1972 to 2003 [8]. In Ethiopia, the traditional natural resource conservation has been applied since the Aksumite Kingdom from 400 BC to 800 AD [9]. Institutional based and large scale SWC work was begun in the 1970s [10]. Though research reports in Ethiopia showed inconsistent results on the effectiveness of SWC, the report by [5], [11] and [12] showed that in most areas of Ethiopia, the SWC was found relatively at a low level of success. Therefore, this research work aimed:

1) To investigate the effectiveness of SWC works in improving soil fertility at different agroecology.
2) To evaluate the effectiveness of SWC in improving soil fertility at different conservation technologies.
3) To assess the effectiveness of SWC work in improving soil fertility at different slope category.
4) To identify the constraints of SWC.
5) To contribute to the debate on the effect of soil and water conservation work.

II. MATERIALS AND METHODS

A. Study Area Description

Gidabo river sub-basin is situated in the southeastern Rift valley region of Ethiopia. The area is specified in the limits of 6°11'N to 6°34’N latitude and 38°12’E to 38°32’E Longitude. The southeastern rift valley region of Ethiopia is part of the Great East African Rift Valley. The administrative boundary of the Gidabo river sub-basin is in the Southern Nations Nationalities and Peoples and the Oromia Regional States of Ethiopia (see Fig. 1).

The highest altitude of the river sub-basin is about 3029 m a.s.l in the south, and the lowest point is 1205 m a.s.l in the west part of the sub-basin. The Gidab river sub-basin covers

Manuscript received June 13, 2021; revised August 18, 2021.
Getahun Hassen is with the Department of Natural Resources Management, Dilla University, Ethiopia (e-mail: getahunhassen5@gmail.com).
Amare Bantider is with the Water and Land Resource Centre of Addis Ababa University, Ethiopia. He is also with the Center for Food Security Studies, Addis Ababa University, Ethiopia (e-mail: amare.bantider@gmail.com).
Abiyot Legesse is with the Department of Geography and Environmental Studies, Dilla University, Ethiopia (e-mail: abiyottura@gmail.com).
Malesu Maimbo is with the Water Management Unit at the World Agroforestry Centre (ICRAF) based in Nairobi, Kenya (e-mail: M.MALESU@cgiar.org).

doi: 10.18178/ijesd.2021.12.12.1362
about an area of 102,738 ha. Although the main economic activity of the river basin is forest-based agriculture (agroforestry), mixed farming (livestock production and cultivation of crops) is the principal occupation of the people in the highland and lowland area of the river basin. According to [13] the climate of the Gidabo river sub-basin ranges from humid to sub-humid in the highlands of the escarpment to semi-arid in the lowland, which is characterized by warm and wet summer and dry, cold and windy winter (see Fig. 2).

Fig. 1. Location map of Gidabo river sub-basin.

Fig. 2. Rainfall graphs for different station. Source: Ethiopian meteorological station (2020)

B. Research Method and Tools of Data Collection

This research was conducted using field observation, field works, interview, group discussion, and lab work. The study site selection was carried out through a bio-sequential approach. Bio-sequential refers to the research site selection based on the variation of agroecology, landscapes, and land management [14].

C. Key Informant Interview (KII)

Participants for the interview were purposefully selected from seven kebeles (the lower administrative divisions) found at different agroecology/altitudinal belts. The KII aimed to obtain crucial qualitative information about their knowledge and perception of SWC work on soil fertility and constraints of the SWC technologies.

D. Focus Group (FG)

Focus group discussants of the study area were purposefully selected from the sampled seven Kebeles with a maximum of five to six participants. The FG was intended to understand the stakeholders ’ perception of soil erosion, land management (soil fertility), and attitude on soil fertility management strategies.

E. Field Observation and Measurement

During field observations, a transect walk was carried out to collect data about different agroecology/altitudinal belt, slope category, SWC technology, age of conservation structures, and physical impact of conservation work and soil sample.

1) Soil sampling technique

Judgment/targeted sampling was used to select the plot site based on the similarity of agroecology, land management, age of conservation structures and slope gradient. Then zigzag sampling was used to select soil sample from the identified plot site. A total of about 36 composite soil samples were collected and coded for laboratory analysis. This refers to 3 altitudinal belt x 3 conservation structures x 3 replicates x 1 soil depth (20cm) = 27 for treated land. The same procedure was carried out for non-treated land of 3 agroecologies x 3 replications x 1 soil depth = 9, which is 27+9 =36.

2) Data analysis

The data analysis was made to test the significant difference between physical and bio-chemical soil fertility indicators at the three agroecology (altitudinal belt), conserved and non-conserved land and at different slope gradient. The variation was tested using an analysis of variance (ANOVA). Also, the household survey was analyzed and presented using descriptive statistics, such as frequency, tables, and percentages.

III. RESULT AND DISCUSSION

A. Impact of SWC Structures, Agroecology/Altitudinal Belt and Slope Characteristics on the Soil Physical Characteristics

1) Soil texture

The ANOVA result showed no significant difference in soil texture across different land management practices except the sandy soil in the highland and silt soil in the lowland. The statistical result also showed no significant difference of sand, silt and clay was observed along different agroecology (midland, lowland and highland) and slope character (upper, middle and bottom). Nevertheless, a significant difference between silt and clay was observed along with different soil management practices. For instance, the greater mean value of silt soil was recorded in conserved land and clay in non-conserved plots of the study area (Table I and II).

The high concentration of silt soil in the conserved land is attributed to the comparative effect of SWC, which increased the deposition of fine soil particles. The high clay content in the non-conserved land might be related to the remaining
resistant clay soil in the eroded land. This result agrees with the report by [15] and [16]; soils of the non-conserved land had the highest per cent of clay compared to the soils of the conserved one.

2) Soil bulk density (SBD)

The overall mean value of SBD at $p \leq 0.05$ has no significant difference across slope gradient, agroecology/altitudinal belt and soil management practices. The ANOVA result showed that variation of SWC structures, agroecology and slope characteristics have no significant impact on the soil bulk density of the study area (see Table I, II and III). Consistently, studies have reported that the soil bulk density was not statistically significant along with the slope variation [17] and across different soil management practices [15].

Though there is no significant difference, the soil bulk density is relatively higher in the non-conserved landscape than conserved (Table I, II and III). The result was supported by [16] that reported non-conserved micro-watershed significantly exhibited the highest mean value of bulk density than the treated land with SWC structures. The high bulk density of the non-conserved land might be associated with the high soil density. This observation could be caused by soil compaction and fine soil organic matter by erosion. However, in the land treated with SWC structures, microbial development has a higher probability of reducing the compaction and density of soil. According to [18], soil bulk density higher than $1.6 \text{ g/cm}^3$ tends to restrict root growth. Therefore, the mean value of soil bulk density of the conservation structures of the study area that ranges between $1.45$ to $0.65 \text{ g/cm}^3$ does not tend to restrict plant root growth and ideal for plant growth.

| TABLE I: MEAN SD OF SOIL TEXTURE AND BULK DENSITY ALONG DIFFERENT LAND MANAGEMENT OF ALL ALTITUDINAL BELTS |
| Altitudinal belt | Land mgt. | Sand | Clay | Silt | BD |
| Highland (> 2,300 m) | SB | 45.33 ± 1.15 | 24.0 ± 2 | 34.66 ± 1.15 | .66 ± .068 |
| | FN | 58 ± 2 | 32.0 ± 2 | 30 ± 4 | 1.08 ± .56 |
| | CD | 49.66 ± 4.72 | 21.33 ± 8.32 | 26 ± 2 | .65 ± .13 |
| | CN | 53 ± 6.08 | 21.0 ± 2.64 | 26.66 ± 5.5 | 1.24 ± .51 |
| | F | 7.787 | 3.735 | 3.647 | .775 |
| Sig | .009 ** | .060 ns | .064 ns | .230 ns |
| Mid land (1500 -2300 m) | SB | 33.3 ± 6.42 | 4.33 ± 4.16 | 23.33 ± 3.05 | 1.28 ± .03 |
| | FN | 39.33 ± 11.01 | 40.66 ± 11.7 | 20 ± 3.46 | 1.12 ± .02 |
| | CD | 34.66 ± 8.08 | 40.66 ± 14.04 | 24.66 ± 6.42 | 1.38 ± .44 |
| | CN | 50 ± 7.21 | 29 ± 6.55 | 18.66 ± 2.08 | 1.45 ± .07 |
| | F | 2.451 | 1.245 | 1.406 | 1.212 |
| Sig | .138 ns | .356 ns | .310 ns | .366 ns |
| Low land (5000 -1500 m) | SB | 34.66 ± 13.01 | 52 ± 13.09 | 13.33 ± 2.30 | 1.22 ± .05 |
| | FN | 53 ± 3.91 | 42.66 ± 11.54 | 12 ± 5.29 | 1.22 ± .04 |
| | CD | 45.33 ± 3.05 | 32.66 ± 1.15 | 22 ± 4 | 1.12 ± .12 |
| | CN | 53 ± 6.08 | 30.00 ± 1.73 | 11 ± 4.35 | 1.30 ± .09 |
| | F | 2.691 | 3.316 | 4.454 | 2.332 |
| Sig | .117 ns | .078 ns | .040 * | .151 ns |

SB (Level soil bund), FN (Level Fanya Juu), CD (Cut off drain), CN (None Conserved)

| TABLE II: THE TWO-WAY ANOVA ANALYSIS OF SOIL PHYSICAL POSTHOC MULTIPLE COMPARISONS |
| Soil variable | Source | SS | DF | MS | F | Sig |
| Sand soil (%) | Slope | 150.056 | 2 | 75.028 | .791 | .463 |
| | Ago ecology/altitudinal belt | .222 | 2 | .111 | .001 | .999 |
| | SWC structure | 196.528 | 3 | 65.509 | .691 | .565 |
| | Error | 2656.167 | 28 | 94.863 | |
| Total | 71211.000 | 36 | |
| Silt soil (%) | Slope | 44.056 | 2 | 22.028 | .569 | .572 |
| | Ago ecology/altitudinal belt | 12.056 | 2 | 6.028 | .156 | .857 |
| | SWC structure | 980.528 | 3 | 326.843 | 8.445 | .000* |
| | Error | 1083.667 | 28 | 38.702 | |
| Total | 19325.000 | 36 | |
| Clay soil (%) | Slope | 203.722 | 2 | 101.861 | 1.022 | .373 |
| | Ago ecology/altitudinal belt | 22.222 | 2 | 11.111 | .112 | .895 |
| | SWC structure | 1827.778 | 3 | 609.259 | 6.115 | .002* |
| | Error | 2789.833 | 28 | 99.637 | |
| Total | 46732.000 | 36 | |
| BD (g/cm^3) | Slope | 648 | 2 | 320 | .203 | .111 |
| | Ago ecology/altitudinal belt | 5.102 | 28 | .182 | |
| | Total | 47.775 | 36 | |

B. The Impact of Different Agroecology (Altitudinal Belt), SWC Technologies, and Slope Characteristics on the Soil Biochemical Properties

1) Soil organic carbon (SOC)

The statistical analysis showed significant variation of SOC across different agroecology (midland, lowland and highland) and soil managements (FN, CD, SB and NC) than
differences of slope gradient (upper, middle and bottom). This result refers to the distribution of SOC significantly affected by agroecology with different climatic characteristics and land management (Table IV). For instance, in the midland, the mean SOC has a greater value in the land treated with SWC structures than non-treated. In contrast, in the highland and lowland agroecology, the mean value of SOC has no significant difference between treated and non-treated land.

According to Table VI, the statistical result showed that irregular distribution of SOC was observed between treated and non-treated land of the highland and lowland altitudinal belt. The result depicted that certain conservation structures are not successful in improving the SOC, which might be related to constraints limiting the effectiveness of the conservation structures (see section 3.7). The effectiveness of any SWC could be determined by the type of land management, slope characteristics, climate, cropping system, soil types and access to resources [19], [20]. According to [21], soil organic carbon is highly determined by the level of land management practices. In this regard, the higher value of SOC on treated land of the midland altitudinal belt implies that agroecological conditions of the area have positively contributed to improving the SOC in the treated land.

2) Total nitrogen (TN)

The combined effect of TN in Table IV indicated that significant difference was observed across various agroecology and SWC structures and no difference on the slope gradient. For instance, the relatively greater value of TN was recorded in the soil treated with SWC structures of the highland and lowland area (Table VI). However, in the midland irregular distribution of TN was observed among different soil management practices. For instance, the mean value of TN in the FN and CD structures was lower than the land not treated with SWC. Nevertheless, the mean value of TN in soil treated with SB structures is greater than in non-treated land.

The high mean value of TN in the soil treated with SWC structures of the highland and lowland area agree with the report by [15] and [22] that showed the mean total nitrogen of the soil was greater in conserved land than non-conserved. The lower mean value of TN in the FN and CD structures than non-conserved land depicted that the conservation work was failed or not succeed in improving the soil’s total nitrogen content.

It might be due to failure to select the right conservation technology and or poor design/layout of the structures to keep soil erosion. According to the report by [17], appropriate conservation structures for ecological and socio-economic conditions are necessary for effective conservation work.

3) Soil pH

The soil pH value is the negative hydrogen ion concentration of soil that determines the availability of soil bacteria, nutrient leaching, nutrient availability, toxic elements, and soil structure. According to Table IV, the two ways analysis of variance at p ≤ 0.05 showed a significant difference of soil pH across different agroecology and soil management practices than along different slope category. The result depicted that variation of agroecology, and different soil management has a significant impact on the distribution of soil pH of the study area. For instance, in the highland, midland and lowland agroecology, the highest mean value of soil pH was observed in the treated land than non-treated.

The result on the distribution of soil pH indicated the positive impact of conservation work. This result might be related to the SWC work that retains the basic cations and fine fraction, raising the soil pH. A report by [23] showed that a soil pH was significantly higher in the soil with management practice than soils with no management practices. Contrary to the distribution of soil pH along different slope categories, it has not shown significant change; it shows the most negligible impacts of slope gradient in the soil pH concentration of the soil (Table IV). The soil pH result on slope gradient agrees with the report by [8] that showed the spatial distribution of soil pH was not statistically significant across different slope classes in the Geshy Sub catchment of

---

**TABLE III: MEAN AND STANDARD DEVIATION OF SOIL TEXTURE AND BD IN RELATION TO THE DIFFERENCE IN SOIL MANAGEMENT AND SLOPE CATEGORY**

| Land management | Soil variable | Slope category | F  | sig |
|-----------------|--------------|----------------|----|-----|
| Level soil band | Sand         | Upper          | 38.66 ± 6.42 | 1.386 | .007 |
|                 |              | Middle         | 30.66 ± 11.71| .921  | .39 |
|                 |              | Bottom         | 1.961    | .221  | ns  |
|                 | Clay         | Upper          | 40.00 ± 15.09| .614  | .572 | ns  |
|                 |              | Middle         | 46.66 ± 20.03| .108  | .899 | ns  |
|                 |              | Bottom         | 1.081    | .953  | ns  |
| Level Fanya Juu| Sand         | Upper          | 41.33 ± 4.16 | .353  | .046 | *   |
|                 |              | Middle         | 33.33 ± 4.61 | .344  | .084 | ns  |
|                 |              | Bottom         | 1.087    | .953  | ns  |
| Cut off drain   | Sand         | Upper          | 43.33 ± 6.42 | .327  | .577 | ns  |
|                 |              | Middle         | 38.66 ± 13.61| 1.444  | .080 | ns  |
|                 |              | Bottom         | 1.226    | .538  | ns  |
| Controlled      | Sand         | Upper          | 43.33 ± 6.42 | .327  | .577 | ns  |
|                 |              | Middle         | 38.66 ± 13.61| 1.444  | .080 | ns  |
|                 |              | Bottom         | 1.226    | .538  | ns  |

---

**TABLE IV: STATISTICAL ANALYSIS OF VARIOUS SOIL TEXTURE AND BD IN RELATION TO THE DIFFERENCE IN SOIL MANAGEMENT AND SLOPE CATEGORY**

| Soil variable | Bulk density | Clay | Silt | Sand |
|---------------|--------------|------|------|------|
| Level soil band| 1.50 ± .30 | 1.97  | 25.33 ± 4.93 | 53.66 ± 4.04 |
|               | 1.05 ± .32 | 1.05  | 19.33 ± 9.01  | 48 ± 6.55  |
| Level Fanya Juu| 1.05 ± .32 | 1.05  | 23.33 ± 9.01  | 48 ± 6.55  |
|               | 1.05 ± .24 | 1.03  | 25.33 ± 8.08  | 6.295    |
| Cut off drain  | 1.05 ± .24 | 1.03  | 25.33 ± 8.08  | 6.295    |
| Controlled     | 1.05 ± .24 | 1.03  | 25.33 ± 8.08  | 6.295    |
Gojeb River.

4) **Electrical conductivity (EC)**

The ANOVA result revealed a significant difference in soil EC across various agroecology and conservation structures. For instance, about 90% of the highland and midland agroecology’s conserved soil has a higher mean value of soil EC than non-conserved land (Table VI). The higher mean value of soil EC in the conserved land might be related to household wastes, livestock manure, dung ash and other decomposable materials used on the conservation structures, which collectively enhance soil EC over a long time. A similar result was reported by [24] in the study area. The local farmers mostly throw wastes, residue, dung, wood, and other decomposable materials in the farmland that gradually increase soil EC.

Though the least value of the soil EC in the lowland was found in the non-treated land, statistically, the difference is not significant among various soil management practices. The ANOVA result of Table V showed that the overall average value of soil EC has no significant difference along slope variation. The result implies that variation of the slope has no significant impact on the distribution of soil EC. The result was in agreement with [24], who reported the soil EC did not show significant difference among slope category in the Deko watershed.

5) **Cation exchange capacity (CEC)**

The analysis of variance at $p < 0.05$ showed a significant difference of soil CEC across various agroecology and soil management practices but none across different slope classes (Table V). For instance, the mean value of CEC is greater in conserved land compared with non-conserved land. A study report by [23] and [25] showed that the mean value of CEC content in soils under un-conserved farm plots was lower than the value recorded in conserved farm plots. The result indicated that the SWC technologies significantly affected the soil CEC in the study area. The higher soil CEC indicates soil fertility improvement because it shows the soil’s ability to supply essential plant nutrients, such as calcium and magnesium.

6) **Available phosphorus (Av.P)**

The available phosphorus was significantly different in the study area at $p \leq 0.05$ along different agroecology and soil conservation structures but not significantly different across slope classes (Table V). For instance, in all agroecology or altitudinal belts, the soil’s available phosphorus (AP) was greater in conserved land than non-conserved plots. The result in the Table VI revealed that the SWC structures have significantly contributed to the improvement of phosphorous in the soil than non-conserved soil. These result agree with the finding by [7] and [26] reported that the physical SWC measures caused a higher amount of available phosphorous on conserved land. The high concentration of AP in the treated land could be attributed to the application of chemical fertilizers (urea, CO, NH2), diammmonium phosphate (DAP), and organic fertilizers (e.g., compost, manure, and household wastes) in the cultivation land.

7) **Available potassium (Av.K)**

The ANOVA result showed a significant difference of available potassium (AK) across different agroecology and SWC structures but not significantly different across the slope gradient (Table V). Though the irregular distribution of AK was recorded within different soil management practices of the midland and lowland agroecology, in the highland area, a greater value of AK was recorded in conserved land. The value of (AK) in the highland area was in line with the report by [27], in which higher soil potassium was observed on the treated land than non-treated.

| Soil variable | Source | SS     | DF | MS      | F      | Sig    |
|--------------|--------|--------|----|---------|--------|--------|
| OC           | Slope  | 2,512  | 2  | 1,256   | 2,326  | .116   |
|              | Agro ecology/ altitudinal belt | 116.341 | 2  | 58.170  | 107.747 | .000*  |
|              | SWC structure  | 5.727  | 3  | 1,909   | 3,536  | .027*  |
|              | Error    | 15.117 | 28 | .540    |        |        |
|              | Total    | 416.302 | 36 |         |        |        |
| pH           | Slope  | .372   | 2  | .186    | 1.617  | .217   |
|              | Agro ecology/ altitudinal belt  | 8.006  | 2  | 4,003   | 34.758 | .000*  |
|              | SWC structure  | 6.295  | 3  | 2,098   | 18.218 | .000*  |
|              | Error    | 3.225  | 28 | .115    |        |        |
|              | Total    | 1129.899 | 36 |         |        |        |
| TN           | Slope  | .022   | 2  | .011    | .945   | .401   |
|              | Agro ecology/ altitudinal belt | 1.527  | 2  | .764    | 65.731 | .000*  |
|              | SWC structure  | .081   | 3  | .027    | 2.324  | .080*  |
|              | Error    | 3.25   | 28 | .012    |        |        |
|              | Total    | 9.306  | 36 |         |        |        |

Slope (bottom, middle and upper slope of the plot); agroecology/altitudinal belt (500 to 1500, 1500 to 2200, and above 2200); SWC structures, soil bund, Fanya Jiu, and cut off drain.

The high concentration of AK in the treated land of highland agroecology might be related to reducing soil loss in the treated land that was contributed to the improvement of soil nutrients. Whereas the varying concentrations of AK in the midland and lowland agroecology across different soil management work imply, particular SWC work was unsuccessful in enhancing soil fertility. For instance, the SWC work such as cutoff drain in the midland and lowland area’s sampled plot had less impact on improving the soil AK. This observation might be related to the constraints on...
selecting conservation structures, design/layout, and maintenance of the structures that failed to reduce soil loss (Section 3.7).

### Table V: Two Way ANOVA Analysis of Soil Chemical Properties Posthoc Multiple Comparisons

| Soil variable | Source                      | SS    | DF  | MS    | F     | Sig  |
|---------------|-----------------------------|-------|-----|-------|-------|------|
| CEC (meq/100gm) | Slope                       | 17.349| 2   | 8.675 | 1.997 | .155 |
|                | Ageo ecology/altitudinal belt | 2385.032| 2   | 1192.516| 274.462 | .000* |
|                | SWC structure                | 39.725| 3   | 13.242| 3.048 | .045*|
|                | Error                        | 121.658| 28  | 4.345 |       |      |
|                | Total                        | 6997.076| 36  |       |       |      |
| EC (µs/cm)     | Slope                       | 5734.694| 2   | 2867.347| 2.273 | .122 |
|                | Ageo ecology/altitudinal belt | 21394.071| 2   | 10697.035| 8.481 | .001*|
|                | SWC structure                | 26659.140| 3   | 8886.380| 7.046 | .001*|
|                | Error                        | 35315.764| 28  | 1261.277|       |      |
|                | Total                        | 180026.020| 36  |       |       |      |
| Av.K (mg/l)    | Slope                       | 5129.389| 2   | 2564.694| .120 | .887 |
|                | Ageo ecology/altitudinal belt | 318819.757| 2   | 159409.879| 7.479 | .002*|
|                | SWC structure                | 171542.857| 3   | 57180.952| 2.683 | .009 |
|                | Error                        | 596788.963| 28  | 21313.892|       |      |
|                | Total                        | 2092214.300| 36  |       |       |      |
| Av.P (mg/l)    | Slope                       | 5.116| 2   | 2.558 | 5.159 | .098 |
|                | Ageo ecology/altitudinal belt | 49.567| 2   | 24.783 | 49.986| .000*|
|                | SWC structure                | 11.809| 3   | 3.936 | 7.939 | .001*|
|                | Error                        | 13.883| 28  | .496  |       |      |
|                | Total                        | 1051.319| 36  |       |       |      |

### Table VI: Mean Difference of Soil Biochemical Properties along Different Agroecology and Land Management

| Agro ecology | Land mgt | N | % OC | CEC (meq) | % TN | PH | EC | AK | AP |
|--------------|----------|---|------|----------|------|----|----|----|----|
| Highland (> 2,300 m) | SB       | 3 | 5.71 ± .015 | 24.56 ± 1.75 | .82 ± 02 | 5.93 ± .09 | 27.86 ± 5.48 | 130.7 ± 108.6 | 7.39 ± .76 |
|                | FN       | 3 | 4.60 ± .87 | 20.71 ± 1.65 | .71 ± 05 | 5.48 ± .11 | 28.66 ± 1.53 | 223.8 ± 72.4 | 6.51 ± .31 |
|                | CD       | 3 | 5.70 ± 14  | 19.78 ± 1.62 | .77 ± 03 | 4.88 ± .18 | 42.96 ± 7.22 | 82.8 ± 23.88 | 7.19 ± .17 |
|                | CN       | 3 | 4.83 ± 1.16 | 19.72 ± 2.24 | .59 ± 21 | 4.41 ± .19 | 21.53 ± 1.62 | 72.83 ± 46.43 | 6.18 ± .30 |
|                | F        |   | 1.884 ± 6.71 | 2.345 | 24.960 | 11.272 | 5.724 | 4.760 |
| Sig           |          |   | .211 ns | .036* | .149ns | .000 ** | .003** | .081* | .035* |
| Mid land (1500 to 2300 m) | SB       | 3 | 3.51 ± 39 | 8.61 ± 2.01 | .47 ± 05 | 5.55 ± 38 | 21.5 ± 91 | 118 ± 194.9 | 4.32 ± .48 |
|                | FN       | 3 | 2.09 ± 87 | 6.38 ± 3.81 | .38 ± 08 | 6.10 ± 38 | 181.8 ± 68.98 | 114 ± 83.5 | 5.32 ± .93 |
|                | CD       | 3 | 1.63 ± 39 | 5.40 ± .42 | .34 ± 04 | 6.10 ± 17 | 82.13 ± 22.15 | 76.26 ± 15.40 | 4.02 ± .52 |
|                | CN       | 3 | 1.38 ± 38 | 4.46 ± 1.62 | .40 ± 15 | 4.94 ± 57 | 52.86 ± 30.6 | 175.513 ± 131.2 | 3.98 ± 1.16 |
|                | F        |   | 8.766 ± 5.028 | 5.028 | 9.25 | 5.685 | 9.337 | 1.120 | 5.767 |
| Sig           |          |   | .007** | .030* | .472 ns | .022* | .005** | .136ns | .24ns |
| Low land (5000 -1500 m) | SB       | 3 | 4.6 ± 39 | 1.90 ± 08 | .17 ± 05 | 6.23 ± 10 | 26.5 ± 10.73 | 144 ± 27.56 | 3.92 ± .50 |
|                | FN       | 3 | .93 ± 34 | 1.66 ± 1.30 | .20 ± 08 | 6.78 ± 46 | 73.5 ± 50.05 | 230.33 ± 83.75 | 5.25 ± .94 |
|                | CD       | 3 | 1.87 ± 54 | 5.46 ± 2.08 | .38 ± 06 | 5.76 ± 06 | 24.86 ± 2.66 | 76.26 ± 15.40 | 4.12 ± .44 |
|                | CN       | 3 | .49 ± 48 | 1.19 ± 1.78 | .15 ± 07 | 5.48 ± 51 | 18.86 ± 4.11 | 242.36 ± 93.35 | 3.06 ± .02 |
|                | F        |   | 6.396 ± .016 | 9.695 | 8.049 | 2.860 | 9.471 | 7.122 |
| Sig           |          |   | .5463ns | .024* | .013* | .008** | .104ns | .014* | .012* |

SB (Level soil bund), FN (Level fanya juu), CD (Cut off drain), CN (None Conserved)

### C. Perception of Farmers on Soil Erosion

In the study area, about 90% of the farmers perceive that soil erosion problem is increasing in their farmlands that are related to deforestation (land degradation), shortage of land, steep slope cultivation, inadequate land cover, climate variability, inaccessibility of resources such as fertilizers, seeds and pesticides and land management problems. These are the causes for the decline of crop and livestock production of the area throughout the year. The link between soil erosion and decline in soil fertility levels appeared evident to the respondents. The declining soil fertility was the driving force to expand their farmlands to forestlands and marginal areas, characterized by rugged topography. According to [28], expanding cultivation land to the marginal lands, forest land, and grazing land are the major causes of the increasing vulnerability of agricultural land to soil erosion in Ethiopia. Because of this, large numbers of farmers of the study area are dependent on food aid; others are shifting their livelihood from farming to daily labor in the urban areas.

### D. Farmers Attitude on Soil Fertility versus Soil Fertility Management Strategies

Farmers have the knowledge to identify soil fertility that developed through experience. According to the land users, soil color and depth, crop productivity, gully erosion, and runoff (blue color of the water) are the best indicators of soil fertility. Mainly soil color is highly influential in soil fertility; about 84% of farmers of the study area have perceived that reddish brown soil is an indicator of poor fertility, and darker (black) soils are fertile soils.

They also perceive that low depth soil has lesser soil fertility than deep soil. This result agrees with the study report by [29] in southern Ethiopia. In the study area, the farmers have been applying different soil fertility strategies.
management strategies, such as land rotation, crop rotation, applying residuals (dung), horizontal plough, mulching, and planting indigenous trees (agroforestry) that are the long-last ed approaches, which are referred to as the traditional strategies.

Besides these, from the time when 2002/3 watershed based SWC technologies such as terracing, stone bund soil bund, check dam, micro basin, and cut of drain have been practiced in different areas. Parallel to the SWC works, the farmers use organic fertilizers for homestead products and mineral fertilizers for annual grain crops grown on distant fields and less fertile soils, which are essential for soil fertility management.

E. Impact of Farmers’ Perception on Land Management (Soil Fertility)

Among several socio-cultural factors that influence land management, farmers’ perception is the most important in deciding on resource conservation work. If the land users failed to perceive land management or SWC enhance agricultural productivity, they would feel reluctant to take action against soil erosion [30]. During household survey and interview, the farmers were asked about their perception of the importance of SWC. Of the total household survey, more than 85% were perceived that both traditional and introduced SWC works are important to improve agricultural productivity.

Based on the interview and household survey result, most respondents perceive that SWC has a significant impact on successful land management practices. However, more than half of interviewed farmers have not adopted SWC practices in their farmland. Others gradually started to abandon certain SWC practices, such as fallowing, terracing, crop residues, and others introduced conservation measures related to the study area’s current challenge (constraints).

F. Constraints to Adopt and Adapt the Soil and Water Conservation Practices

The primary constraints of farmers to adopt/adapt SWC work are small land size, shortage of fuel wood, dependency on food aid, less productivity of the soil, the high price of chemical fertilizers, youth migration, and long lasted effect of conservation works. For instance, shortage of land had not allowed the farmers to fallow their land or apply physical SWC structures according to the standard because they perceived it consumes the land. On the other hand, the shortage of fuel wood and fodder forced the farmers to reduce the application of crop residuals on their farm land that has a higher probability of improving soil fertility. The other challenge of the farmers adopting SWC practices was the high price of chemical fertilizers and seeds. The farmers said that the implementation of SWC work without the application of chemical fertilizers was meaningless. This result agrees with the study report by [31] in the Gidabo watershed of southeastern Ethiopia.

Nevertheless, the price of chemical fertilizer is not affordable to many farmers. Therefore, most of them abandoned the adoption of SWC and are looking for non-cultivated land from marginal area to feed their family, adversely affecting the farmers’ role in land management, agricultural production, and sustainable socio-economic and environmental system of the area. In general, the identified constraints were seen as severe problems for farmers to adopt and apply the standard dimension of SWC structures and land management, which minimized the full effect of the conservation work on soil fertility.

IV. Conclusion and Recommendations

The ANOVA result at $p \leq 0.05$ showed no significant difference in soil texture along different agroecology and slope gradient. However, a significant difference in silt and clay texture was observed along various soil management practices. For instance, the greater mean value of silt soil was recorded in conserved land and clay in non-conserved land. The high concentration of silt soil in the conserved land is attributed to the comparative effect of SWC, which increased the deposition of fine soil particles. The high clay content in the non-conserved land might be related to the resistant clay soil in the eroded land. Though no significant difference in soil bulk density was observed relatively higher mean value of SBD was recorded in non-conserved land. This observation might be associated with the high soil density that could be caused by compaction of the soil and removal of soil organic matter by soil erosion.

The land treated with SWC structures has the opportunity to develop microorganism that reduces the compaction and density of the soil. Regarding the soil biochemical properties, the distribution of most soil fertility indicators was significantly affected by agroecology/altitudinal belt and SWC management than slope characteristics because the agroecological variation of the area has a different climate, land cover, land management, population density and livelihoods of the community.

The bio-chemical distribution of the soil in the study area depicted that the SWC work is not entirely attributed to improving soil fertility because the conservation work was exacerbated soil loss in some condition. For instance, some plots of grass cover removed for conservation work, but the conservation work was not adequately implemented. Contrary the removal of grassland increases the vulnerability of the soil to erosion. Therefore the overall result of the SWC work indicated that about 40% of soil conservation activities was failed to maintain soil fertility. The identified constraints of SWC practices are small land size, lack of labor force, less agricultural product, lack of interest among youth for agricultural work, the prolonged effect of SWC and lack of access to chemical fertilizer. Though the farmers have a positive interest in the conservation work, the constraints were enforced the farmers to be reluctant to adopt/adapt the standard SWC work, which minimized the effort to enhance soil fertility. This attitude will cause unsustainable socio-economic and environmental development in the study area. The study concluded that the SWC work of the area should focus on variation of agroecology, SWC technologies, and local constraints that are important for sustainable ecosystem services. In addition, policymakers should set option for the constraints that hinder the implementation of nationally designed SWC practices.
CONFLICT OF INTEREST

The authors declare no conflict of interest

AUTHORS CONTRIBUTIONS

GH contributed to the design of the work data acquisition, analysis, interpretation, and write-up of the manuscript. AB designed the work, supervised, and substantively revised the work. AT designed the work, supervised, and substantively revised the work. MM designed the work, supervised, and substantively revised the work.

ACKNOWLEDGEMENT

The authors are thankful to the German Academic Exchange Service (DAAD) joint programme and World Agroforestry Center (CRAF) In-Country/In-Region Scholarships and Dilla University for the financial support for the research work.

REFERENCES

[1] A. Gemaechu, “Estimation of soil loss using revised universal soil loss equation and determinants of soil loss in TiroAleta and Dedo districts of Jimma zone,” Trends Agric Econ., Oromiya National Regional State, Ethiopia, vol. 9, no. 1–3, pp. 1–12, 2016.

[2] P. Blaikie, The Political Economy of Soil Erosion in Developing Countries, Routledge, 2016.

[3] G. Gebreabherea, D. A. Aberra, G. Gebresamuel, M. Giordano, and S. Langan, “An assessment of integrated watershed management in Ethiopia,” International Water Management Institute (IWMI), vol. 170, 2016.

[4] A. Bantider et al., “Soil and water conservation and sustainable development,” Clean Water and Sanitation, Switzerland: Springer, p. 13, Encyclopedia of the UN Sustainable Development Goals, 2021.

[5] Z. Nigussie et al., “Farmers’ perception about soil erosion in Ethiopia,” Land Degradation and Development, vol. 28, pp. 401–411, 2017.

[6] T. Molla and B. Sinheber, “Estimating soil erosion risk and evaluating erosion control measures for soil and water conservation planning at Koga watershed in the highlands of Ethiopia,” Solid Earth, vol. 8, pp. 13–25, 2017.

[7] M. Dagnachew, A. Muges, and A. Kassa, “Effects of land uses on soil quality indicators: The case of Geshy sub-catchment, Goejeb River Catchment, Ethiopia,” Applied and Environmental Soil Science, 2019.

[8] H. Hurni et al., Soil and Water Conservation in Ethiopia: Guidelines for Development Agents, Bern, Switzerland: Centre for Development and Environment (CDE), University of Bern, with Bern Open Publishing (BOP), 2016.

[9] N. Haregeweyn et al., “Soil erosion and conservation in Ethiopia: A review,” Prop Physiol. Geogr., vol. 39, no. 6, pp. 750-774, 2015.

[10] N. Haregeweyn et al., “Integrated watershed management as an effective approach to curb land degradation: A case study of Enabled watershed, northern Ethiopia,” Environ Manag., vol. 50, no. 6, pp. 1219–1233, 2012.

[11] S. Dargbouth et al., “Watershed management approaches, policies, and operations: lessons for scaling up,” 2008.

[12] A. Tesfaye, W. Negatu, R. Brouwer, and P. Zaag, “Understanding soil conservation decision of farmers in the Gede watershed, Ethiopia,” Land Degradation and Development, vol. 25, pp. 71–79, 2014.

[13] A. Mechal, T. Wagner, and S. Birk, “Recharge variability and sensitivity to climate: the example of Gidabo river basin, Main Ethiopian Rift,” Journal of Hydrology: Regional Studies, vol. 4, pp. 644-660, 2015.

[14] G. Worku, A. Bantider, and H. Temesgen, “Effects of land use/land cover change on some soil physical and chemical,” 2014.

[15] M. Belayneh, T. Yirgu, and D. Tesgaye, “Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed,” Ecological Processes, Upper Blue Nile Basin, Ethiopia, vol. 8, no. 1, p. 36, 2019.

[16] A. Asfaw and Z. Gush, Debremarkos University School of Graduate Studies, 2011.

[17] S. Namarembe, J. M. Neyoka, and J. M. Gathenywa, “A guide for selecting the right soil and water conservation practices for smallholder farming in Africa,” ICRAF Technical Manual No.24, Nairobi, Kenya: World Agroforestry Centre (ICRAF), 2015.

[18] R. H. McKenzie, A. B. Middleton, L. Hall, J. DeMulder, and E. Bremer, “Fertilizer response of barley grain in the south and central Alberta,” Canadian Journal of Soil Science, vol. 84, no. 4, pp. 513-523, 2004.

[19] E. Elia, “Selected chemical properties of agricultural soils in the Ethiopian highlands: A rapid assessment,” South African Journal of Plant and Soil, vol. 36, no. 2, pp. 153-156, 2019.

[20] T. Gashaw, T. Tulu, and M. Argaw, “Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia,” Environmental Systems Research, vol. 6, no. 1, p. 1, 2018.

[21] M. R. Motsara and R. N. Roy, “Guide to laboratory establishment for plant nutrient analysis,” Rome: Food and Agriculture Organization of the United Nations, 2008.

[22] Y. Ademe, T. Kebede, A. Mullatu, and T. Shafi, “Evaluation of the effectiveness of soil and water conservation practices on improving selected soil properties in Wonago district, Southern Ethiopia,” Journal of Soil Science and Environmental Management, vol. 8, no. 3, pp. 70–79, 2017.

[23] D. B. Gadana, P. D. Sharma, and D. T. Selfeko, “Effect of soil management practices and slope on soil fertility of cultivated lands in Mawula watershed, Loma district, Southern Ethiopia,” Advances in Agriculture, 2020.

[24] T. Negasa, H. Ketema, A. Legesse, M. Sisay, and H. Temesgen, “Variation in soil properties under different land-use types managed by smallholder farmers along the topso sequence in southern Ethiopia,” Geoderma, 2017.

[25] M. Mohammed, G. Takele, and K. Kibret, “Effects of physical soil and water conservation structures and slope gradients onsoil physicochemical properties in West Oromia, Ethiopia,” Int. J. Soil Sci., vol. 15, pp. 1-7, 2020.

[26] T. Tanto and F. Laekemariam, “Impacts of soil and water conservation practices on soil property and wheat productivity in Southern Ethiopia,” Environmental Systems Research, vol. 8, no. 1, pp. 1-9, 2019.

[27] B. Assnake and E. Elias, “Effect of soil and water conservation (SWC) measures on soil nutrient and moisture status, a case of two selected watersheds,” Journal of Agricultural Extension and Rural Development, vol. 11, no. 4, pp. 85-93, 2019.

[28] Z. Adimassu, K. Mekonnen, C. Yirga, and A. Kessler, “Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia,” Land Degrad Develop, vol. 25, no. 6, pp. 554–564, 2014.

[29] F. Laekemariam, K. Kibret, and T. Mamo, “Farmers’ soil knowledge, fertility management logic and its linkage with scientifically analyzed soil properties in southern Ethiopia,” Agriculture & food security, vol. 6, no. 1, p. 57, 2017.

[30] B. Tegene, “Farmers’ perceptions of erosion hazards and attitudes towards soil conservation in Gumuno, Wolaita, Southern Ethiopia,” Ethiopian Journal of Development Research, vol. 14, no. 2, pp. 31-58, 1992.

[31] G. Hassen, A. Bantider, A. Legesse, and M. Maimbo, “Assessment of design and constraints of physical soil and water conservation structures in respect to the standard in the case of Gidabo sub-basin, Ethiopia,” Cogent Food & Agriculture, vol. 7, no. 1, p. 1855818, 2021.

Copyright © 2021 by the authors. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (CC BY 4.0).

Getahun Hassen is a PhD candidate in the Department of Natural Resources Management at Dilla University, Ethiopia. He has more than six years of teaching experience in different government and non-government organizations. Getahun also worked as a Dilla University Research and Dissemination Support center coordinator until his current PhD study. Professionally he has five publications (research and review work) internationally peer-reviewed journals. Besides, he has more than ten certificates of participation in academic and social training at national and international forums. His research interest is physical geography and natural resource conservation.
Amare Bantider (PhD) is an associate professor of geography land resource management. He is a senior researcher in the Water and Land Resource Centre of Addis Ababa University and lectures at the Center for Food Security Studies, College of Development Studies, Addis Ababa University. Overall, he has more than 30 years of professional experience, of which 23 years are in higher learning institutions as a researcher, instructor and in several academic leadership positions. He obtained his first and second degrees from the Department of Geography and Environmental Studies at Addis Ababa University (Ethiopia) in 1987 and 1996. He obtained his PhD degree from Bern University, Switzerland, in 2007. He authored and co-authored papers and book chapters and published in peer-reviewed journals and books on thematic areas of land use and land cover changes, watershed management, climate change adaptations, soil and water conservation, resource governance and related fields.

Abiyot Legesse (PhD) is an associate professor of geography & land resource management. He served in several professional, academic and administrative positions. Notable ones include being Editor-in-chief of Journal of Environment and development, Vice president for Academic Affairs, Dilla University, Dean of School of Graduate Studies, Dilla University, vice-director for teacher development, Dilla University and others. He has 16 publications in international peer-reviewed journals. His research interest is Geographic information system (GIS) and remote sensing for Hazard mapping and environmental modeling, spatiotemporal analysis for physical geography and natural resource conservation.

Maimbo Mahanga Malesuis is an agricultural engineering expert with 32 years of experience in managing programmes and projects and facilitating sustainable small holder agricultural research and development in land management, conservation agriculture, soil and water conservation, small and large-scale irrigation and water harvesting and management. His contribution is mainly in bettering small-scale farmers' livelihoods and engineering and science through over 80 peer-reviewed publications. Eng. Malesu is head of the Water Management Unit at the World Agroforestry Centre (ICRAF) based in Nairobi, Kenya. In addition, he is the Leader of the Transformative Partnership Platform – TPP on Forests and Water in the merged CIFOR-ICRAF. He is a registered member of the American Society of Agricultural and Biological Engineers (ASABE).