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Research Article

Impact of Soil and Water Conservation Measures and Slope Position on Selected Soil Attributes at a Watershed Scale

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The Ethiopian highlands are affected by soil erosion resulting in the deterioration of soil properties. To reverse this, different soil and water conservation (SWC) measures were spatially practiced; however, the effect of SWC and slope gradient on soil properties is not well studied in the area. Hence, this study was conducted to evaluate the effects of SWC and slope gradient on selected soil physicochemical properties in Dawnt watershed, northwestern Ethiopia. The treatments were a combination of four different SWC measures on three slope gradients replicated at three sites. Disturbed and undisturbed soil samples were collected from 0–20 cm soil depth, and physicochemical properties were determined following standard laboratory procedures. The laboratory results depict that sand, bulk density, moisture, particle density, porosity, pH, organic carbon (OC), cation exchange capacity (CEC), total nitrogen, and available phosphorus were significantly ($P < 0.05$) affected by SWC measures and slope gradient. High OC (2.44%), CEC (45 cmol (+) kg^{-1}), and moisture (19.55%) were obtained from stone-faced soil bund stabilized with grass (SFSBG) and higher available phosphorus (7.83 ppm) from soil bund (SB), while lower bulk density (1.13 gm/cm^3) was obtained from SFSBG. Additionally, higher clay (41.67%) and moisture (19.81%), and lower bulk density (1.14 $g{\cdot}cm^{-3}$) were obtained from the lower slope. Higher pH (6.75) and OC (2.89%) were recorded at the lower slope under SFSBG and lower pH and OC (6.03 and 1.02%) at the upper slope with nonconserved. Soil chemical properties, except available potassium, were increased down the slope. The interactions of slope position and SWC measures affect soil texture, pH, organic carbon, and available phosphorus but not affect soil bulk density, moisture content, particle density, total porosity, cation exchange capacity, total nitrogen, and available potassium. In general, the soil properties were improved through integrating conservation practices with multipurpose grass species across the study watershed. Therefore, it is possible to infer that SFSBG measures improve the observed physicochemical soil properties, which urge for the maintenance and the development of SWC measures in the study watershed as well as nearby highlands with similar topographic conditions and agroclimatic characteristics.

1. Introduction

Humans derive more than 99.7% of their food from the land and less than 0.3% from the ocean and aquatic ecosystem [1]. Thus, preserving cropland and maintaining soil fertility and productivity should be of the highest significance to human prosperity [2]. About 10 million hectares of cropland are lost each year due to soil erosion, which leads to a reduction in crop yield and food production worldwide [3]. According to Lal [1], two-thirds of the world's population is malnourished as a result of cropland productivity reduction. Similarly, Pimentel and Burgess [3] reported that soil was being degraded 10 to 40 times faster from the agricultural lands than the rate of soil formation. The major causes of land degradation in Ethiopia are rapid population increase, deforestation, low vegetative cover, and unbalanced crop and livestock production [4]. Generally, natural resource degradation is the main environmental problem in the country [5].

The majority of farmers in Ethiopia are subsistence-oriented, cultivating sloppy lands that are susceptible to soil erosion [6]. Crop production is inhibited not only by low input utilization and technology levels but also by land fragmentation and soil erosion [7]. The pressure of intense human activity and improper farming and management practices pose serious threats to the sustainability and suitability of the soil for crop production [8]. Ethiopia is considered one of the least developed countries where agriculture has always played a central role in the country's economy. The Ethiopian highlands have been experiencing declining soil fertility and severe soil erosion due to intensive farming on steep and fragile lands [9]. Bobe [10] reported that soil loss in the Ethiopian highlands was estimated to reach up to 300 t $ha^{-1}yr^{-1}$ with an average of about 70 t $ha^{-1}yr^{-1}$.

Soil erosion in the northwestern Amhara region, Ethiopia, has been a subject of anxiety, resulting in a major environmental threat to the sustainability of agricultural land [11]. Gondar highland is one of the most soil erosion vulnerable parts of Ethiopia, as the area has a high erosive force of rainfall, intense land use, and high population pressure [12]. Hence, this study attempts to understand the effects of different SWC and slope classes on the physicochemical properties of the soil.

In Ethiopia, erosion by water is the most serious land degradation problem [13]. Crops need favorable soil physical and chemical properties for optimum production; however, due to the removal of soil macro- and micronutrients by erosion, productivity is decreasing. The government as well as nongovernment organizations designed different strategies, and out of the strategies construction of stone/soil bunds is the one that is promising to enable the community to avert the impacts of rainfall-driven soil erosion in the area. Stone/soil bunds are elevated physical soil and water conservation structures that are constructed along contours on erosion vulnerable land uses [14]. Stone/soil bunds reduce the volume and speed of overland flow, and reduce sheet erosion and gully head developments while increasing the retention service [15]. Soil erosion and sedimentation problems in the Ethiopian highlands urge the implementation of SWC measures that are crucial to reduce soil erosion and thereby decrease the rate of land degradation and filling up of reservoirs [14–16]. In the study watershed, almost all soil management activities were done similarly along the slope, although each specific area needs particular soil management practices.

The Ethiopian government responded with large-scale rehabilitation measures and the establishment of various soil and water conservation (SWC) interventions across the country to counteract the ongoing soil depletion [11, 17]. Similarly, the local administration of the study area introduced and implemented different SWC measures through the mass mobilization of the local community and the elderly were the most responsible persons that actively participated in implementing SWC structures and tried to rehabilitate the area from soil degradation. However, in the watershed, the significant contributions of SWC measures in improving the soil properties since the introduction period were not known. Meanwhile, scientifically quantifying the impacts of SWC measures and slope gradient on the soil property status and availing the findings for the community and policymakers are timely and crucial and help the decision-makers to understand whether the present practices are enhancing the soil fertility status or not. Considering the above issues into account, this research aimed at evaluating the effects of SWC measures and slope gradient on the selected soil physicochemical properties in the study watershed. Regarding its limitations, this work only addressed the impacts of the introduced SWC measures using minimal soil attributes only in the cultivated lands of the watershed. Thus, it has a limitation to address the cost-benefit analysis of the selected SWC structures, such as the costs required, the on and off-site effects, and their effects on crop yield.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted on farmers' cropland in Dawnt watershed, Shor-Sar-Wuha kebele, Gondar Zuria District. The district is located in the Central Gondar administrative zone of the Amhara National Regional State. The watershed is geographically located within 12°17′18.4″ to 12°18′7.3″N and 37° 36′ 48.6″ to 37°36′35.9″E (Figure 1). The watershed covers a total area of 444.3 ha with a total population of 9,045. The annual mean minimum and maximum temperatures of the watershed were 21°C and 28°C, respectively. The annual rainfall ranges from 950 to 1,035 mm, while the altitude ranges from 1962 to 2185 meters above sea level. In general, the watershed has 5% cool and 95% cool semihumid agroecology, while the topographic conditions of the area are composed of 0.34% of the watershed flat to gentle (0–3%), 5.26% of the watershed moderate (3–12%), 8.17% of the watershed steep (12–20%), 27.91% of the watershed very steep (20–35%), and 58.32% of the watershed extreme (>35%). The three major soil colors widely distributed in the watershed include 5% red (Nitisols), 85% brown (Cambisols), and 10% black (Vertisol) with the soil depth of the watershed ranging from 20 to 100 cm. Typically, the fertilizer types applied in the Ethiopian agricultural system are only urea (NH_2CONH_2), NPSK, and di-ammonium phosphate (DAP) ($(NH_4)_2$ HPO_4), which contain just nitrogen, phosphorus, sulfur, and sometimes potash; however, they may not probably satisfy the nutritional requirements of crops grown in the study watershed. The major crops grown in the agricultural land include sorghum, teff (*Eragrostis Teff*), faba bean, wheat, chickpea, linseed, maize, and barley.

2.2. Land-Use Patterns and Major Agricultural Activities. Although the land-use patterns of the 444.3 ha watershed are highly dynamic, about 146.7 ha are cultivated, 60.02 ha are used for grazing, 56.49 ha are used for plantation forest, and 130.41 ha are reforested by trees and shrubs, 36.16 ha are used for settlements, and 14.52 ha are bare land. The watershed is characterized by subsistence mixed farming of rainfed agriculture and livestock.

2.3. Experimental Design and Sampling Techniques. The study consisted of a factorial combination of four levels of SWC (nonconserved (C), stone-faced soil bund (SFSB),

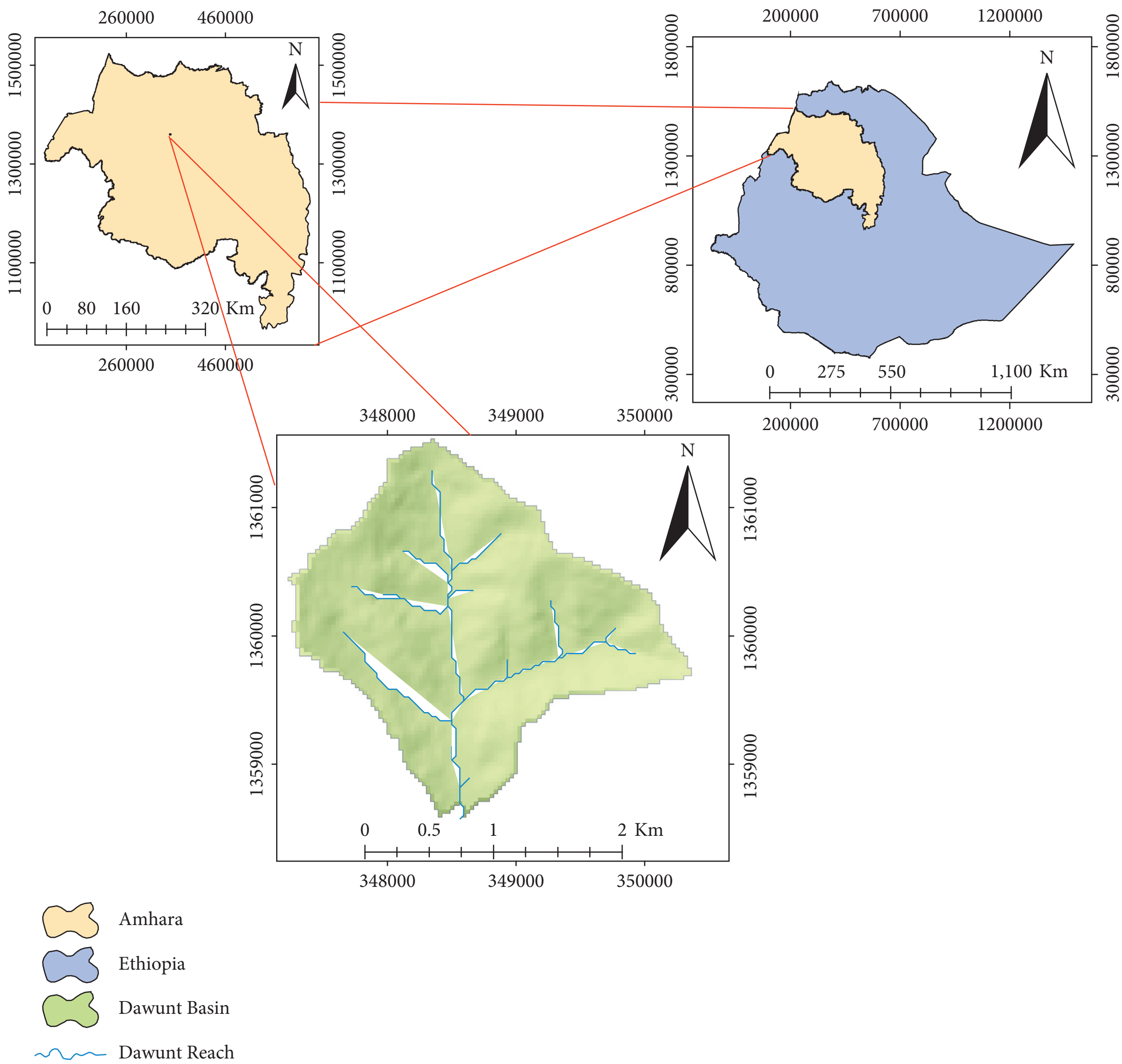

FIGURE 1: Location of Dawnt watershed in the northwestern Amhara region, Ethiopia.

stone-faced soil bund stabilized with kidan grass (SFSBG), and soil bund (SB)) and three slope gradients [upper slope (30–60%)), middle slope (15–30%)), and lower slope (10–15%)] with a total of 12 treatments replicated three times resulting in 36 composite soil samples. Three subplots (3 m by 3 m) separated by 5-m intervals within each treatment were established on the cultivated land after harvesting. The soil conservation measures in the study watershed were implemented fully with the participation of farmers in 2012 on the cultivated lands of Cambisols. Meanwhile, soil samples from the four corners and at the center of each subplot were collected in 2019 and thoroughly mixed to make a composite sample, and about 2 kg from each subplot were collected from the surface soil horizon (0–20 cm) for chemical and physical analyses. Soil samples from four levels of SWC under three slope steepness classes—(30–60%), (15–30%), and (10–15%)—were collected using a bucket auger, and the undisturbed soil samples were collected from each plot using core cylinder equipment. Generally, the approach used is a more or less standard approach to be used for soil and water conservation and slope gradient study. Nevertheless, the topic (physical soil and water conservation measures stabilized with grass and slope position) is important, and the collected dataset in Dawnt watershed, Gondar Zuria District, is valuable and had regional significance.

2.4. Sample Preparation and Laboratory Analysis. The cleaned and air-dried soil samples were ground and then passed through a 2-mm sieve for the determination of the soil parameters, while soil total nitrogen and organic carbon were determined from samples sieved with 0.5 mm to avoid coarser materials [18]. The soil texture was analyzed by the Bouyoucous hydrometer method [19]. Soil bulk density (BD) was determined from oven-dried undisturbed cores sample as a mass per volume of oven-dried soil [20]. Soil moisture was determined by the gravimetric method [21]. Soil particle density (PD) is the ratio of the mass (oven-dry weight) of the soil particles to the particle volume (solid no pore space) and is calculated through the following equation [22]:

$$\text{soil PD}\left(\frac{\text{gm}}{\text{cm}^3}\right) = \frac{\text{mass of oven dried soil}}{\text{volume of soil particles or solids}} \times 100. \tag{1}$$

Total porosity (TP) is a measure of the void space in soil, represented as the volume of voids divided by the total volume of soil, and TP (%) of a soil occupied by the pore space is calculated as follows [23]:

$$\text{total porosity (\%)} = \left(1 - \frac{BD}{PD}\right) \times 100. \tag{2}$$

The soil pH was determined by the potentiometric method at a 1 : 2.5 soil-to-water ratio [24]. Soil organic carbon was analyzed by using the Walkley and Black titration method [25]. The soil total nitrogen was determined by the Kjeldahl method [26]. Soil available phosphorus was determined by the Olson method [27]. Available potassium was determined using the ammonium acetate solution method and measured by a flame photometer [28]. Soil CEC was determined by the ammonium acetate saturation method at pH 7.0 [29]. For the determination of CEC, the soil samples were leached with 1N ammonium acetate solution and washed with ethanol (97%) to remove excess salt followed by leaching with sodium chloride to displace the adsorbed ($NH^+{}_4$). The amount of ammonia was then measured by distillation and taken as the CEC of the soil [30].

2.5. Statistical Analysis. The data were subjected to the analysis of variance (ANOVA) in Statistical Analysis Software (SAS). Statistically significant different treatment means were separated using the least significant difference (LSD) technique at $P \leq 5\%$ significance level.

3. Results and Discussion

3.1. Effects of SWC on Selected Soil Attributes

3.1.1. Soil Texture. The textural analysis result showed that two different soil textural classes were observed within the Dawnt watershed and these are clay loam and clay. The resulting soil clay and silt contents were not significantly ($P > 0.05$) affected by soil and water conservation measures (Table 1). Similarly, Mohawesh et al. [31] described that the variation in clay and silt contents as a result of bunds seemed to be insignificant; however, it takes a very long time to stabilize the clay and silt contents after the construction of bunds.

Sand content was significantly ($P < 0.01$) affected by soil and water conservation measures, and higher sand contents (30.0% and 28.89%) were recorded at stone-faced soil bund and nonconserved, respectively. The lowest sand content (24.22%) was measured on stone-faced soil bund stabilized with kidan grass. Numerically, higher silt and significantly lower sand contents were observed in the stone-faced soil bund stabilized with kidan grass, and this might be due to the fact that kidan grass has conserved the soil particles from erosion by reducing runoff and improving the soil organic matter through decomposition (Table 1). Mekonen and Tesfahunegn [32] and Tesfahunegn et al. [33] also stated that the sand content had been significantly affected by SWC measures.

3.1.2. Bulk Density, Moisture Content, Particle Density, and Total Porosity. Soil and water conservation measures significantly ($P < 0.01$) affected soil bulk density, moisture content, particle density, and total porosity (Table 1). The highest bulk density (1.48 g·cm^{-3}) was obtained from nonconserved land followed by stone-faced soil bund (1.24 g·cm^{-3}). Meanwhile, the lowest (1.13 g·cm^{-3}) was obtained from stone-faced soil bund stabilized with kidan grass. The highest moisture content (19.55%) was recorded under stone-faced soil bund stabilized with kidan grass and the lowest (11.01%) on nonconserved land. Similarly, the highest particle density (2.43 g·cm^{-3}) at stone-faced soil bund stabilized with kidan grass and the lowest (1.89 g·cm^{-3}) on the nonconserved land. The highest total porosity (TP) (51.93%) was recorded under stone-faced soil bund stabilized with kidan grass, and the lowest (20.89%) TP was recorded under nonconserved land (Table 1).

The result is in agreement with Muhammad et al. [34] who reported that SWC practices can intercept rainwater and enhance the soil moisture contents. Similarly, Husen et al. [35] and Sinore et al. [36] argued the improvement of soil bulk and particle density with vetiver grass conservation measures. This might be due to the reduction in physical soil loss by the conservation measures and the reduction in slope length and steepness [37]. Besides, different researchers [38–40] also reported significantly lower bulk density and higher total porosity in the conserved land probably because conservation measures improve OM (Table 1), which ultimately reduced runoff speed and enhanced infiltration.

Moreover, soil bulk density and moisture content were significantly different between stone-faced soil bund stabilized with kidan grass and stone-faced soil bund as well as stone-faced soil bund stabilized with kidan grass and nonconserved land. The soil particle density of nonconserved land has been significantly different from the other conservation measures. Total porosity showed a significant difference between stone-faced soil bund stabilized with kidan grass and other conservation measures. This might be a result of the decomposition of dead leaves, stems, and roots of kidan grass, which ultimately improves the TP. Similarly, Tadesse et al. [41] stated that integrating bunds with forage species was a better option to improve soil properties through the decomposition of dead forage parts than bunds alone.

3.1.3. Soil pH, Organic Carbon, and Cation Exchange Capacity. The analysis of variance showed that soil pH, organic carbon, and cation exchange capacity were

Table 1: Effects of SWC measures on selected soil physicochemical properties in the study watershed.

Conservation measures	Parameters												
	Clay (%)	Silt (%)	Sand (%)	BD ($g \cdot cm^{-3}$)	MC (%)	PD ($g \cdot cm^{-3}$)	TP (%)	pH (H_2O)	OC (%)	CEC (cmol(+) kg^{-1})	TN (%)	Ava.P (ppm)	Ava.K (cmol(+) kg^{-1})
C	38.44	32.67	28.89a	1.48a	11.01a	1.89a	20.89a	6.20c	1.36c	37.01c	0.13b	3.03c	0.42b
SFSB	35.56	34.44	30.00a	1.24b	14.48b	2.30b	44.66b	6.42ab	2.06b	43.67b	0.16a	4.76b	0.42b
SFSBG	38.22	37.56	24.22b	1.13c	19.55c	2.43b	51.93c	6.46a	2.44a	45.00a	0.17a	5.75b	0.60a
SB	40.89	33.56	25.56b	1.16c	17.70c	2.35b	46.49b	6.37b	2.42a	43.87b	0.17a	7.83a	0.56a
LSD (0.05)	Ns	Ns	2.87	0.04	2.62	0.15	4.59	0.06	0.30	1.09	0.02	1.20	0.10
CV (%)	9.95	10.75	10.82	12.97	17.10	16.71	11.46	8.60	14.61	12.64	12.00	22.92	19.59

BD = Bulk density, MC = moisture content, PD = particle density, TP = total porosity, CEC = cation exchange capacity, total nitrogen, Ava.P = available phosphors, Ava.K = available potassium, OC = organic carbon, C = nonconserved, SFSB = stone-faced soil bund, SFSBG = stone-faced soil bund stabilized with kidan grass, SB = soil bund, LSD = list significant difference, and CV = coefficient of variation.

significantly ($P < 0.01$) affected by SWC measures (Table 1). The highest soil pH (6.46), organic carbon (2.44%), and cation exchange capacity (45.00 cmol (+) kg^{-1}) were obtained from a stone-faced soil bund stabilized with kidan grass, while the lowest pH (6.20), organic carbon (1.36%), and cation exchange capacity (37.01 cmol (+) kg^{-1}) were obtained from the nonconserved land.

In fact, soil pH is influenced by the leaching of exchangeable bases, acid rain, decomposition of organic matter, application of commercial fertilizer, SWC measures, and other farming practices [42]. Similarly, the variation in soil pH in the study watershed could probably be due to the effect of SWC measures. Besides, Sinore et al. [36] reported that soil pH, organic carbon (OC), and cation exchange capacity were significantly improved with the use of SWC practices supported by elephant grass and Sesbania. They also stated that the high pH under elephant grass and Sesbania was attributed to the presence of high organic matter, clay fraction, and better cation exchange capacity in the conserved land.

Significantly higher organic carbon and CEC were obtained from SFSBG, while the lowest were from the nonconserved plot (Table 1). The higher organic carbon content in the SFSBG might be attributed to the organic matter content retained from the organic residues washed down from the upper slope as well as biomass return from the biological measures (kidan grass). This confirmed that supporting physical conservation with biological measures can improve soil properties. In line with this result, Hishe et al. [43] reported significant differences in the organic carbon content between conserved and nonconserved landscapes. Similarly, the highest CEC was obtained from SFSBG, and this could be due to the accumulation of clay and soil OM, which come from the upper slope by erosion.

3.1.4. Total Nitrogen, Available Phosphorus, and Available Potassium. The analysis of variance reflecting soil total nitrogen, available phosphorus, and available potassium showed a highly significant ($P < 0.01$) variation as a result of SWC measures. The highest soil total nitrogen (0.17%) was recorded under stone-faced soil bund stabilized with kidan grass and soil bund, and similarly, the highest available potassium (0.60 cmol (+) kg^{-1}) was recorded under stone-faced soil bund stabilized with kidan grass, while the highest available phosphorus (7.83 ppm) was recorded under soil bund. The lowest total nitrogen (0.13%) and available phosphorus (3.03 ppm) was recorded under nonconserved land; similarly, the lowest available potassium (0.42 cmol (+) kg^{-1}) was observed under nonconserved and stone-faced soil bund (Table 1).

In line with this study, Sinore et al. [36] reported higher soil total nitrogen and available phosphorus under Sesbania due to a higher biomass return into the soil from the Sesbania plant, and its ability to fix atmospheric nitrogen. Alemayehu and Fisseha [44] also pointed out that total nitrogen and available phosphorus reflected a significant difference and this difference among conserved and nonconserved treatments could be due to the biophysical conservation measures. Moreover, Rashid et al. [45] and Teressa [46] confirmed that total nitrogen, available phosphorus, and available potassium were significantly varied due to conservation measures. This could be attributed to the availability of higher soil moisture and the reduction in rainfall-driven erosion and the effect of organic matter as most N forms are part of the soil OM [47].

3.2. Effect of Slope Gradient on Selected Soil Properties

3.2.1. Soil Texture. The results of soil clay and sand particles showed a significant ($P < 0.01$) change due to slope gradient. The clay content observed at the lower slope classes was significantly different from the upper and middle slope classes (Table 2). Sand particles at all slope classes showed a significant variation (Table 2). The results also showed that the highest clay (41.67%) and sand (30.00%) contents were recorded at lower and upper slope classes, respectively. The variation might be due to the selective transportation process during water erosion where fine particles have been carried away on the lower slope. In agreement with this finding, Khan et al. [48], Yossif and Ebied [49], Nnabude et al. [50], Hishe et al. [43], Musa and Gisilanbe [51], and Yasin and Yulnafatmawita [52] stated that clay and sand contents were significantly different at different slope classes.

On the other hand, a silt particle was not significantly ($P > 0.05$) affected by the slope gradient (Table 2). Different researchers [8, 53, 54] also confirmed that sand and clay

Table 2: Effects of slope gradient on selected soil physicochemical properties in the study watershed.

Slope classes	Parameters												
	Clay (%)	Silt (%)	Sand (%)	BD ($g{\cdot}cm^{-3}$)	MC (%)	PD ($g{\cdot}cm^{-3}$)	TP (%)	pH (H_2O)	OC (%)	CEC (cmol (+) kg^{-1})	TN (%)	Ava.P (ppm)	Ava.K (cmol(+) kg^{-1})
Upper (30–60%)	35.50b	33.50	31.00a	1.40a	10.52a	1.94a	26.68a	6.10a	1.83a	35.17a	0.14a	2.80a	0.53
Middle (15–30%)	37.67b	35.67	26.67b	1.22b	16.73b	2.25b	44.44b	6.35b	1.86a	43.10b	0.15a	5.23b	0.52
Lower (10–15%)	41.67a	34.50	23.83c	1.14c	19.81c	2.54c	51.85c	6.65c	2.53b	48.90c	0.18b	8.01c	0.45
LSD (0.05)	3.22	Ns	2.49	0.03	2.27	0.13	3.98	0.05	0.26	0.95	0.02	1.04	Ns
CV (%)	9.95	10.75	10.82	12.97	17.10	16.71	11.46	8.60	14.61	12.64	12.00	22.92	19.59

BD = Bulk density, MC = moisture content, PD = particle density, TP = total porosity, CEC = cation exchange capacity, TN = total nitrogen, Ava.P = available phosphorus, Ava.K = available potassium, OC = organic carbon, LSD = least significant difference, and CV = coefficient of variation.

contents, but not silt content significantly differed among slope positions.

3.2.2. Soil Bulk Density, Moisture Content, Particle Density, and Total Porosity. Slope gradient significantly ($P < 0.01$) affected soil bulk density, moisture content, particle density, and total porosity (Table 2). The highest bulk density (1.40 $g{\cdot}cm^{-3}$), the medium (1.22 $g{\cdot}cm^{-3}$), and the lowest (1.14 $g{\cdot}cm^{-3}$) were recorded at the lower, middle, and upper slopes gradients, respectively, while the highest soil moisture content, particle density, and total porosity (19.81%, 2.54 $g{\cdot}cm^{-3}$, and 51.85%), the medium (16.73%, 2.25 $g{\cdot}cm^{-3}$, and 44.44%), and the lowest (10.52%, 1.94 $g{\cdot}cm^{-3}$, and 26.68%) were obtained at lower, middle, and upper slope classes, respectively (Table 2). The mean separation also showed that soil bulk density, moisture content, particle density, and total porosity were significantly different in each slope class.

This finding agreed with Aytenew [55] who stated that the effects of slope gradient on soil bulk density and total porosity were significant. These variations among the slope gradient might be attributed to the selective removal of fine soil particles and organic matter from the upper slope and deposited at the lower slope, which ultimately reduced soil bulk density and improved porosity. The result is also supported by Hailu et al. [24] and Khan et al. [48] who found soil bulk density, moisture content, and particle density were significantly affected by slope position. Similarly, Mekonen and Tesfahunegn [32] reported that soil moisture content, total porosity, and particle density were significantly affected by slope gradient due to the removal of fine soil particles and organic matter contents from the upper slope and deposited in the lower slope positions.

3.2.3. Soil pH, Organic Carbon, and Cation Exchange Capacity. With respect to slope gradient, soil pH, organic carbon, and cation exchange capacity were significantly ($P < 0.01$) affected (Table 2). The highest soil pH, organic carbon, and cation exchange capacity (6.65, 2.53%, and 48.90 cmol (+) kg^{-1}, respectively) were observed in the lower slope followed by the middle slope (6.35, 1.86%, and 43.10 cmol (+) kg^{-1}, respectively), and the lowest mean soil pH, organic carbon, and cation exchange capacity (6.10, 1.83% and 35.17 cmol (+) kg^{-1}, respectively) were noted at upper slope class, which indicates a decrease with an increasing slope position (Table 2). The result showed that the slope position had a significant influence on soil pH, OC, and cation exchange capacity, which might be due to the removal of exchangeable bases from the higher slope gradient and their accumulation on moderate and gentle slopes.

Typically, soil with a large amount of clay and organic matter has a larger cation exchange capacity than sandy soil with low organic matter [54, 56]. Hence, soil encompassing high clay content at the lower slope has a high pH and cation exchange capacity [57]. According to Yossif and Ebied [49], Addis et al. [58], Beyene [59], and Liu et al. [8], the slope gradient had significant effects on soil pH, organic carbon, cation exchange capacity, and total nitrogen. This is due to the fact that the steeper the slope, the higher the runoff, and the greater the relocation of soil material downslope through rainfall-driven erosion.

3.2.4. Soil Total Nitrogen, Available Phosphorus, and Available Potassium. Slope gradient significantly ($P < 0.01$) affected soil total nitrogen and available phosphorus content but not available potassium (Table 2). A similar study conducted by Asadi et al. [60] showed that available potassium is not significantly different across slope positions. Even though the available potassium did not show a statistically significant difference due to the slope gradient, the mean value increased down the slope. The highest total nitrogen, available phosphorus, and available potassium (0.18%, 8.01 ppm, and 0.45 cmol (+) kg^{-1}, respectively) were observed in the lower slope followed by the middle slope (0.15%, 5.23 ppm, and 0.52 cmol (+) kg^{-1}, respectively), and the lowest nitrogen, available phosphorus, and available potassium (0.14%, 2.80 ppm, and 0.45 cmol (+) kg^{-1}, respectively) were recorded at the upper slope classes. The mean separation also showed that total nitrogen at lower slope was significantly different from the middle and upper slope classes; meanwhile, the available phosphorus was significantly different in each slope class.

This finding agreed with Akbari et al. [61], Gebrelibanos and Assen [53], and Musa and Gisilanbe [51] who stated that

Table 3: Effects of SWC measures and slope gradient on selected soil physicochemical properties in the study watershed.

Slope classes	Conservation measures	Parameters: Clay (%)	Silt (%)	Sand (%)	BD($g{\cdot}cm^{-3}$)	MC (%)	PD($g{\cdot}cm^{-3}$)	TP (%)	pH (H_2O)	OC (%)	CEC(cmol (+) kg^{-1})	TN (%)	Ava.P (ppm)	Ava.K(cmol (+) kg^{-1})
Upper (30–60%)	C	34.00c	30.00de	36.00a	1.63	5.62	1.74	5.90	6.03e	1.02e	29.65	0.12	1.50e	0.33
	SFSB	43.33b	31.33cde	25.33de	1.39	9.29	1.98	29.48	6.12de	1.90c	36.20	0.14	2.48de	0.38
	SFSBG	37.33bc	36.67abc	26.00cde	1.28	14.23	2.10	38.84	6.17d	1.91c	37.73	0.14	3.21cde	0.53
	SB	35.33c	33.33bcde	31.33ab	1.31	12.93	1.94	32.51	6.08de	2.48ab	37.09	0.14	4.01 cd	0.58
Middle (15–30%)	C	37.33bc	32.00bcde	30.67abc	1.48	11.63	1.92	22.91	6.15d	1.35de	36.90	0.12	3.84 cd	0.43
	SFSB	34.00c	38.00ab	28.00bcd	1.21	16.30	2.30	47.61	6.43b	1.53 cd	44.17	0.15	4.41 cd	0.44
	SFSBG	37.33bc	36.00abcd	26.67bcde	1.07	19.71	2.44	55.22	6.48b	2.53ab	46.54	0.17	4.75c	0.59
	SB	35.33c	41.33a	23.33def	1.12	19.28	2.35	52.02	6.33c	2.02bc	44.78	0.17	7.90b	0.61
Lower (10–15%)	C	42.00b	35.33abcd	22.67ef	1.33	15.78	2.02	33.85	6.43b	1.71 cd	44.48	0.13	3.76 cd	0.49
	SFSB	34.67c	34.67bcd	30.67abc	1.13	17.86	2.63	56.90	6.70a	2.75a	50.65	0.19	7.38b	0.44
	SFSBG	34.67c	38.00ab	27.33bcde	1.05	24.72	2.75	61.72	6.75a	2.89a	50.72	0.19	9.30b	0.69
	SB	53.33a	28.00e	18.67f	1.06	20.88	2.76	54.94	6.70a	2.75a	49.74	0.19	11.59a	0.48
LSD (0.05)	6.91	6.29	4.98	4.98	Ns	Ns	Ns	Ns	0.09	0.51	Ns	Ns	2.07	Ns
CV (%)	9.95	10.75	10.82	10.82	12.97	17.10	16.71	11.46	8.60	14.61	12.64	19.59	22.92	19.59

BD = Bulk density, MC = moisture content, PD = particle density, TP = total porosity, CEC = cation exchange capacity, TN = total nitrogen, Ava.P = available phosphorus, Ava.K = available potassium, OC = organic carbon, C = nonconserved, SFSB = stone-faced soil bund, SFSBG = stone-faced soil bund stabilized with kidan grass, SB = soil bund, LSD = least significant difference, and CV = coefficient of variation.

slope positions significantly affect soil total nitrogen and available phosphorus. This might be due to the reduction in the soil organic matter content by the action of soil erosion from the upper slope gradient.

3.3. Effects of SWC Measures and Slope Gradient on Selected Soil Attributes

3.3.1. Soil Texture. The laboratory analysis result showed that clay and silt contents were highly significant ($P < 0.01$), and the sand content was significantly ($P < 0.05$) affected by the interactions of SWC measures and slope position. The highest clay content (53.33%) was obtained from the lower slope position under soil bund, while the lowest (34.00%) was obtained from nonconserved and stone-faced soil bund under upper and middle slope classes (Table 3). The higher silt content (41.33%) was measured at the middle slope class under soil bund, and the lower (28.00%) was recorded at the lower slope under soil bund, whereas the highest sand content (36.00%) was obtained from the upper slope position under nonconserved fields and the lowest (18.67%) was from the lower slope position under soil bund (Table 3). The mean separation also showed that silt and sand contents in each slope class and clay content at upper and lower slope positions had shown significant variations. This could be attributed to the selective removal of fine topsoil fractions by erosion from the upper slope class of the watershed towards the lower slope class as suggested by Kehali et al. [62].

3.3.2. Soil Bulk Density, Moisture Content, Particle Density, and Total Porosity. The analysis of variance revealed that soil bulk density, moisture content, particle density, and total porosity were not significantly ($P > 0.05$) affected by the interactions of slope position and conservation measures (Table 3). A similar result was reported by Mengistu et al. [63] who documented that soil bulk density, moisture content, and total porosity did not show significant variation due to the interaction of SWC measures and slope position.

3.3.3. Soil pH, Organic Carbon, and Cation Exchange Capacity. Soil pH and organic carbon were significantly ($P < 0.05$) affected by SWC measures and slope gradient interaction (Table 3). The highest soil pH and organic carbon (6.75 and 2.89%) and the lowest (6.03 and 1.02%) were recorded at the lower slope under stone-faced soil bund stabilized with Kidan grass and upper slope without conservation measures, respectively. This is due to the fact that conservation structures might be trapped fine clay particles and decrease the loss of basic cations through leaching. Similarly, Gebrelibanos and Assen [53] confirmed that the interaction of SWC measures and slope position significantly affect soil organic carbon distribution.

In study watershed, soil cation exchange capacity was not significantly ($P > 0.05$) affected by the interaction of SWC and slope gradient (Table 3). On the contrary, Gadana et al. [64] documented that soil cation exchange capacity was significantly influenced by slope gradient variation and SWC measures.

3.3.4. Soil Total Nitrogen, Available Phosphorus, and Available Potassium. Soil total nitrogen and available potassium did not show a significant ($P > 0.05$) variation with respect to SWC measures and slope gradient interaction (Table 3). The application of artificial fertilizers (urea and potash) may be the reason for the prevailing no significant variation in the soil. This result is in agreement with the findings of Mengistu et al. [63] and Teressa [46] who reported that the amount of total nitrogen and available potassium were not significantly varied as a result of slope class and SWC measured interaction. However, numerically the highest total nitrogen (0.19%) was observed at the lower slope under conserved land, while the lowest (0.12%) was recorded in the middle and upper slope under nonconserved land. Numerically, the highest available potassium (0.69 cmol (+) kg^{-1}) was measured at the lower slope under stone-faced soil bund stabilized by Kidan grass, and the lowest (0.33 cmol (+) kg^{-1}) was observed at the upper slope under nonconserved land.

Meanwhile, soil available phosphorus had shown a significant ($P < 0.05$) variation as a result of the interaction effects of SWC and slope gradient (Table 3). The highest available phosphorus (11.59 ppm) was obtained from the lower slope class under soil bund, and the lowest (1.50 ppm) was measured at the upper slope classes under nonconserved land (Table 3). This might be due to the downward movement of fine soil particles and OM by erosion from the upper slope and accumulation at the lower slope position with SWC measures. This result is in agreement with the findings of Bekele et al. [65] who stated that the amount of available phosphorus was significantly varied as a result of SWC measures.

4. Conclusions

Soil and water conservation measures affect the selected soil physicochemical properties in the study watershed. Most of the observed soil physicochemical properties were significantly higher in stone-faced soil bund stabilized with kidan grass, followed by soil bund and stone-faced soil bund, while lower soil attributes were observed in the nonconserved agricultural land. Similarly, the slope gradient affected most of the measured soil physicochemical properties. The majority of soil properties were significantly higher in the lower slope followed by the middle, while significantly lower soil properties were recorded at the upper slope class. The interactions of slope gradient and SWC measures affected soil texture, but pH, organic carbon, and available phosphorus did not affect soil bulk density, moisture content, particle density, total porosity, cation exchange capacity, total nitrogen, and available potassium. In general, this study concludes that the stone-faced soil bund stabilized with grass can significantly improve the majority of observed soil properties in the watershed. However, in cases where applying the stone-face soil bund stabilized with grass is not possible, the soil bund is useful to improve the majority of observed soil properties considerably. Therefore, in the study watershed and other similar agro-ecologies of the Ethiopian highlands, farmers should use SWC measures to avert the rainfall-driven soil nutrient loss. In addition, to maintain sustainable agricultural production in the watershed, there should be proper soil and water conservation measures through capacitating local institutions with the participation of the community to formulate by-laws that improve the farmer's willingness and knowledge to construct SWC measures in the area. The study suggests further research about the cost-benefit analysis of the selected SWC practices, such as the costs required, the on- and off-site effects, and their effects on crop yield.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] R. Lal, "Soil carbon sequestration to mitigate climate change," *Geoderma*, vol. 123, no. 1-2, pp. 1–22, 2004.

[2] F. W. Kagambèga, S. Traoré, A. T. A. M. Lykke, and J. I. Boussim, "Effects of soil and water conservation techniques on soil properties under degraded lands in Burkina Faso," *Journal of Agriculture and Environmental Sciences (JAES)*, vol. 6, pp. 78–87, 2017.

[3] D. Pimentel and M. Burgess, "Soil erosion threatens food production," *Agriculture*, vol. 3, no. 3, pp. 443–463, 2013.

[4] G. Taddese, "Land degradation: a challenge to Ethiopia," *Environmental Management*, vol. 27, no. 6, pp. 815–824, 2001.

[5] H. K. Addis, A. Abera, and L. Abebaw, "Economic benefits of soil and water conservation measures at the sub-catchment scale in the northern Highlands of Ethiopia," *Progress in Physical Geography: Earth and Environment*, vol. 44, no. 2, pp. 251–266, 2020.

[6] G. Taye, J. Poesen, B. V. Wesemael et al., "Effects of land use, slope gradient, and soil and water conservation structures on runoff and soil loss in semi-arid Northern Ethiopia," *Physical Geography*, vol. 34, pp. 236–259, 2013.

[7] Y. Kassa, F. Beyene, J. Haji, and B. Legesse, "Impact of integrated soil and water conservation program on crop production and income in West Hareghe Zone, Ethiopia," *International Journal of Environmental Monitoring and Analysis*, vol. 1, no. 4, pp. 111–120, 2013.

[8] R. Liu, Y. Pan, H. Bao et al., "Variations in soil physico-chemical properties along slope position gradient in secondary vegetation of the hilly region, guilin, southwest China," *Sustainability*, vol. 12, no. 4, Article ID 1303, 2020.

[9] M. Tadesse and K. Belay, "Factors influencing adoption of soil conservation measures in southern Ethiopia: the case of Gununo area," *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, vol. 105, pp. 49–62, 2004.

[10] B. W. Bobe, *Evaluation of Soil Erosion in the Harerge Region of Ethiopia Using Soil Loss Models, Rainfall Simulation and Field Trials*, University of Pretoria, Hatfield, South Africa, 2005.

[11] H. K. Addis, S. Strohmeier, F. Ziadat, N. D. Melaku, and A. Klik, "Modeling streamflow and sediment using SWAT in Ethiopian Highlands," *International Journal of Agricultural and Biological Engineering*, vol. 9, pp. 51–66, 2016.

[12] H. K. Addis, B. Adugna, M. Gebretsadik, and B. Ayalew, "Gully morphology and rehabilitation measures in different agroecological environments of northwestern Ethiopia," *Applied and Environmental Soil Science*, vol. 2015, Article ID 789479, 8 pages, 2015.

[13] L. Tamene and P. L. G. Vlek, "Soil erosion studies in northern Ethiopia," in *Land Use and Soil Resources*Springer, Berlin, Germany, 2008.

[14] H. Lemma, A. Frankl, A. Griensven, J. Poesen, E. Adgo, and J. Nyssen, "Identifying erosion hotspots in lake tana basin from a multisite soil and water assessment tool validation: opportunity for land managers," *Land Degradation & Development*, vol. 30, no. 12, pp. 1449–1467, 2019.

[15] T. Gashaw, Y. T. Dile, A. W. Worqlul et al., "Evaluating the effectiveness of best management practices on soil erosion reduction using the SWAT Model: for the case of Gumara watershed, Abbay (Upper Blue Nile) Basin," *Environmental Management*, vol. 68, no. 2, pp. 240–261, 2021.

[16] H. Briak, R. Mrabet, R. Moussadek, and K. Aboumaria, "Use of a calibrated SWAT model to evaluate the effects of agricultural BMPs on sediments of the Kalaya river basin (North of Morocco)," *International Soil and Water Conservation Research*, vol. 7, no. 2, pp. 176–183, 2019.

[17] K. Herweg and E. Ludi, "The performance of selected soil and water conservation measures-case studies from Ethiopia and Eritrea," *Catena*, vol. 36, no. 1-2, pp. 99–114, 1999.

[18] W. Sebnie, E. Adgo, and H. Kendie, "Characterization and classification of soils of zamra irrigation scheme, northeastern Ethiopia," *Air, Soil and Water Research*, vol. 14, Article ID 11786221211026577, 2021.

[19] J. L. Jensen, P. Schjønning, C. W. Watts, B. T. Christensen, and L. J. Munkholm, "Soil texture analysis revisited: removal of organic matter matters more than ever," *PLoS One*, vol. 12, no. 5, Article ID e0178039, 2017.

[20] J. A. Osunbitan, D. J. Oyedele, and K. O. Adekalu, "Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria," *Soil and Tillage Research*, vol. 82, no. 1, pp. 57–64, 2005.

[21] A. Shukla, H. Panchal, M. Mishra et al., "Soil moisture estimation using gravimetric technique and FDR probe technique: a comparative analysis," *American International Journal of Research in Formal, Applied Natural*, vol. 8, pp. 89–92, 2014.

[22] A. L. Flint and L. E. Flint, "2.2 particle density," *Methods of soil analysis: Part IV physical methods*, vol. 5, pp. 229–240, 2002.

[23] T. Keller and I. Håkansson, "Estimation of reference bulk density from soil particle size distribution and soil organic matter content," *Geoderma*, vol. 154, no. 3-4, pp. 398–406, 2010.

[24] W. Hailu, A. Moges, and F. Yimer, "The effects of "fanya juu" soil conservation structure on selected soil physical &

chemical properties: the case of goromti watershed, western Ethiopia," *Resources and Environment*, vol. 2, no. 4, pp. 132–140, 2012.

[25] F. Gelman, R. Binstock, and L. Halicz, "Application of the Walkley-Black titration for the organic carbon quantification in organic rich sedimentary rocks," *Fuel*, vol. 96, pp. 608–610, 2012.

[26] J. Dieckow, J. Mielniczuk, H. Knicker, C. Bayer, D. P. Dick, and I. Kögel-Knabner, "Comparison of carbon and nitrogen determination methods for samples of a paleudult subjected to no-till cropping systems," *Scientia Agricola*, vol. 64, no. 5, pp. 532–540, 2007.

[27] M. Iatrou, A. Papadopoulos, F. Papadopoulos, O. Dichala, P. Psoma, and A. Bountla, "Determination of soil available phosphorus using the Olsen and Mehlich 3 methods for Greek soils having variable amounts of calcium carbonate," *Communications in Soil Science and Plant Analysis*, vol. 45, no. 16, pp. 2207–2214, 2014.

[28] K. Affinnih, I. Salawu, and A. Isah, "Methods of available potassium assessment in selected soils of Kwara state, Nigeria," *Agrosearch*, vol. 14, no. 1, pp. 76–87, 2014.

[29] P. Buurman, B. Van Lagen, and E. Velthorst, *Manual for soil and water analysis*, Backhuys, Leiden, Netherlands, 1996.

[30] H. D. Chapman, *Total Exchangeable Bases 1. Methods Of Soil Analysis. Part 2. Chemical And Microbiological Properties*, American Society of Agronomy, Soil Science Society of America, Madison, WI, USA, 1965.

[31] Y. Mohawesh, A. Taimeh, and F. Ziadat, "Effects of land use changes and soil conservation intervention on soil properties as indicators for land degradation under a Mediterranean climate," *Solid Earth*, vol. 6, no. 3, pp. 857–868, 2015.

[32] K. Mekonen and G. B. Tesfahunegn, "Impact assessment of soil and water conservation measures at Medego watershed in Tigray, northern Ethiopia," *Maejo International Journal of Science and Technology*, vol. 5, p. 312, 2011.

[33] G. B. Tesfahunegn, L. Tamene, and P. L. Vlek, "Catchment-scale spatial variability of soil properties and implications on site-specific soil management in northern Ethiopia," *Soil and Tillage Research*, vol. 117, pp. 124–139, 2011.

[34] R. Muhammad, K. Rahina, A. Sarosh, M. Akram, K. Rizwan, and H. Bashir, "Evaluation of loose stone terrace structures for soil moisture and fertility conservation in sloppy lands of Attock District, Pakistan," *Academia Journal of Agricultural Research*, vol. 4, pp. 25–33, 2016.

[35] D. Husen, F. Esimo, and F. Getechew, "Effects of soil bund on soil physical and chemical properties in Arsi Negelle woreda, Central Ethiopia," *African Journal of Environmental Science and Technology*, vol. 11, pp. 509–516, 2017.

[36] T. Sinore, E. Kissi, and A. Aticho, "The effects of biological soil conservation practices and community perception toward these practices in the Lemo District of Southern Ethiopia," *International Soil and Water Conservation Research*, vol. 6, no. 2, pp. 123–130, 2018.

[37] C. K. Gachene, S. O. Nyawade, and N. N. Karanja, *Soil and Water Conservation: An Overview*, College of Agriculture and Veterinary Sciences, University of Nairobi, Nairobi, Kenya, 2019.

[38] A. Challa, A. Abdelkadir, and T. Mengistu, "Effects of graded stone bunds on selected soil properties in the central highlands of Ethiopia," *International Journal of Natural Resource Ecology and Management*, vol. 1, pp. 42–50, 2016.

[39] S. Gadisa and L. Hailu, "Effect of Level Soil Bund and fayna Juu on soil physico-chemical properties, and farmers adoption towards the practice at Dale wabera district, western Ethiopia," *American Journal of Environmental Protection*, vol. 9, pp. 107–120, 2020.

[40] A. Gesesse, T. Balemi, P. Natarajan, and Y. Amha, "Effect of vetiver grass headges in maintaining soil fertility and productivity at anno agro industry farm, gobu sayo district, oromiya region, Ethiopia," *Journal of Science and Sustainable Development (JSSD)*, vol. 1, pp. 37–49, 2013.

[41] B. Tadesse, S. Mesfin, G. Tesfay, and F. Abay, "Effect of integrated soil bunds on key soil properties and soil carbon stock in semi-arid areas of northern Ethiopia," *South African Journal of Plant and Soil*, vol. 33, no. 4, pp. 297–302, 2016.

[42] T. Tanto and F. Laekemariam, "Impacts of soil and water conservation practices on soil property and wheat productivity in Southern Ethiopia," *Environmental System Research*, vol. 8, pp. 1–9, 2019.

[43] S. Hishe, J. Lyimo, and W. Bewket, "Soil and water conservation effects on soil properties in the middle Silluh Valley, northern Ethiopia," *International Soil and Water Conservation Research*, vol. 5, no. 3, pp. 231–240, 2017.

[44] T. Alemayehu and G. Fisseha, "Effects of soil and water conservation practices on selected soil physico-chemical properties in Debre-Yakob micro-watershed, Northwest Ethiopia," *Ethiopian Journal of Science and Technology*, vol. 11, no. 1, pp. 29–38, 2018.

[45] M. Rashid, S. Alvi, R. Kausar, and M. I. Akram, "The effectiveness of soil and water conservation terrace structures for improvement of crops and soil productivity in rainfed terraced system," *Pakistan Journal of Agricultural Sciences*, vol. 53, 2016.

[46] D. Teressa, "The effectiveness of stone bund to maintain soil physical and chemical properties: the case of Weday watershed, East Hararge zone, Oromia, Ethiopia," *Civil and Environmental Research*, vol. 9, pp. 9–18, 2017.

[47] A. Ganuza and G. Almendros, "Organic carbon storage in soils of the Basque country (Spain): the effect of climate vegetation type and edaphic variables," *Biology and Fertility of Soils*, vol. 37, no. 3, pp. 154–162, 2003.

[48] F. Khan, Z. Hayat, W. Ahmad et al., "Effect of slope position on physico-chemical properties of eroded soil," *Soil & Environment*, vol. 32, pp. 22–28, 2013.

[49] T. Yossif and G. M. Ebied, "Effect of slope on some soil characteristics at wadi Naghamish, North western coast of Egypt," *Alexandria Science Exchange Journal (ASEJ)*, vol. 36, pp. 429–439, 2015.

[50] P. Nnabude, I. Nweke, and K. Ekwealor, "Integrated effect of slope classes and different soil depths on soil physico-chemical properties of watershed ecosystem," *American Journal of Environment and Sustainable Development (AJEP)*, vol. 1, pp. 11–16, 2016.

[51] H. Musa and S. Gisilanbe, "Differences in physical and chemical properties of soils on yelwa-dobora toposequence in ganye local government area, adamawa state, Nigeria," *Sky Journal of Soil Science and Environmental Management (SJSSEM)*, vol. 6, pp. 011–018, 2017.

[52] S. Yasin and Y. Yulnafatmawita, "Effects of slope position on soil physico-chemical characteristics under oil palm plantation in wet tropical area, West Sumatra Indonesia," *Journal of Agricultural Sciences*, vol. 40, pp. 328–337, 2018.

[53] T. Gebrelibanos and M. Assen, "Effects of slope aspect and vegetation types on selected soil properties in a dryland Hirmi watershed and adjacent agro-ecosystem, northern highlands of Ethiopia," *African Journal of Ecology*, vol. 52, no. 3, pp. 292–299, 2014.

[54] B. A. Miheretu and A. A. Yimer, "Spatial variability of selected soil properties in relation to land use and slope position in Gelana sub-watershed, Northern highlands of Ethiopia," *Physical Geography*, vol. 39, no. 3, pp. 230–245, 2018.

[55] M. Aytenew, "Effect of slope gradient on selected soil physicochemical properties of dawja watershed in enebse sar midir district, Amhara national regional state," *American Journal of Scientific and Industrial Research*, vol. 6, pp. 74–81, 2015.

[56] E. Babur, Ö. S. Uslu, M. L. Battaglia et al., "Studying soil erosion by evaluating changes in physico-chemical properties of soils under different land-use types," *Journal of the Saudi Society of Agricultural Sciences*, vol. 20, no. 1, 2021.

[57] A. Ito and R. Wagai, "Global distribution of clay-size minerals on land surface for biogeochemical and climatological studies," *Scientific Data*, vol. 4, pp. 170103–170111, 2017.

[58] H. Addis, A. Klik, T. Oweis, and S. Strohmeier, "Linking selected soil properties to land use and hillslope - a watershed case study in the Ethiopian Highlands," *Soil and Water Research*, vol. 11, no. 3, pp. 163–171, 2016.

[59] S. Beyene, "Topographic positions and land use impacted soil properties along Humbo Larena-Ofa Sere toposequence, Southern Ethiopia," *Journal of Soil Science and Environmental Management*, vol. 8, pp. 135–147, 2017.

[60] H. Asadi, A. Raeisvandi, B. Rabiei, and H. Ghadiri, "Effect of land use and topography on soil properties and agronomic productivity on calcareous soils of a semiarid region, Iran," *Land Degradation and Development*, vol. 23, no. 5, pp. 496–504, 2012.

[61] J. Kehali, M. Tekalign, and K. Kibebew, "Characteristics of agricultural landscape features and local soil fertility management practices in Northwestern Amhara, Ethiopia," *Journal of Agronomy*, vol. 16, no. 4, pp. 180–195, 2017.

[62] A. Akbari, R. Azimi, and N. Bin, "Influence of slope aspects and depth on soil properties in a cultivated ecosystem," *Electronic Journal of Geotechnical Engineering*, vol. 19, pp. 8601–8608, 2014.

[63] D. Mengistu, W. Bewket, and R. Lal, "Conservation effects on soil quality and climate change adaptability of Ethiopian watersheds," *Land Degradation & Development*, vol. 27, no. 6, pp. 1603–1621, 2016.

[64] D. B. Gadana, P. D. Sharma, and DT Selfeko, "Effect of soil management practices and slope on soil fertility of cultivated lands in Mawula watershed, Loma district, Southern Ethiopia," *Advances in Agriculture*, vol. 2020, Article ID 8866230, 13 pages, 2020.

[65] M. Bekele, M. Lemenih, and A. Regassa, "The effects of integrated soil conservation practices on soil physico-chemical properties: the case of Menesibu District, West Ethiopia," *Journal of Natural Sciences Research*, vol. 6, pp. 35–45, 2016.