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Original Research

Effects of Soil and Water Conservation on Selected Soil Physicochemical Properties in Debatie District, Northwestern Ethiopia

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Abstract

Ethiopia's soil resources are primarily depleted by erosion, which reduces agricultural production. Conservation of soil and water reduces soil loss and nutrient loss. This research examined how SWC techniques affect soil physicochemical properties. At 0–20 cm depth, soil samples were taken from top and bottom slopes of grazing, preserved, and uncaring fields. Specific soil fertility indicators were assessed using standard laboratory procedures. In accordance with GLM, SAS version 9.2's one-way ANOVA was used to analyze data. The study examined if SWC procedures altered soil physicochemical parameters. In both treated and untreated crops, physical SWC methods measured the mean values of accessible phosphorus (1.96, 4.18 mg kg1), total nitrogen (0.11%, 0.17%), soil pH (5.56, 5.93), and soil organic matter (2.26, 3.59%). Physical SWC showed that treated farmland had higher mean values than untreated farmland. The SWC method showed a statistically significant difference in bulk density between treated and untreated crops. Many soil physicochemical characteristics and agricultural productivity improved with engineered soil and water conservation. Thus, effective guidance, application, and use are essential for soil production and agricultural sustainability.

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INTRODUCTION

In the Ethiopian highlands, land degradation—which manifests as soil erosion and fertility loss—poses a serious threat to crop productivity, food security, and the preservation of natural resources. The primary causes of the severe issues, which eventually lead to a decline in agricultural output, are the fast population growth as well as the inappropriate use and management of land resources. A number of issues that lead to land degradation in the nation include uneven and erosive rainfall patterns, slope topography, deforestation, improper land use, fragmentation of land, overgrazing, and insufficient management techniques (Belayneh, 2019).

Negative effects also extend to the natural water storage capacity of catchment regions, constructed reservoirs, and dams, the ecological balance, the quality of surface water, and the aesthetic value of the landscape (Negese et al., 2021; Hamid et al., 2020). Soil erosion is a major issue in Ethiopia, as it is in many other countries worldwide. Due to soil erosion caused by water, Ethiopia's rural households' ability to preserve their current way of life is seriously threatened (Wordofa et al., 2020; Mekuriaw et al., 2018; Bewket et al., 2002). Reduced soil fertility leading to low yields poses a severe danger to Ethiopian agriculture. It is not well known how soil parameters are affected by soil and water conservation (SWC) measures, either separately, in combination, or in conjunction with older practices (Adesodun et al., 2007). The primary goal of this study was to determine how soil and water conservation measures affected specific key soil physicochemical parameters at protected and unconserved areas in Debate District, Northwest Ethiopia.

MATERIALS AND METHODS

Geographical Environment of the Study Area

The study was carried out in Northwest Ethiopia, in the Debatie area of the Metekele Zone of the Benishangul Gumuz Regional Regions. The district is situated along the main road heading westward in Ethiopia, approximately 557 and 78 kilometres from Addis Ababa and Gelegel Beles, the capital of the zone, respectively. The administrative study area is defined by the Mandura district in the north, the Amhara region in the east, the Kemash Zone in the south, and the Gumuz Zone in the west and east, respectively. Geographically, the research region is located between latitude 35°58′56″ and longitude 36°26′05″E and between longitude 10°06′38″ and 10°54′29″N. The altitude range in which soil samples were collected was 892–250 metres above sea level (Figure 1).

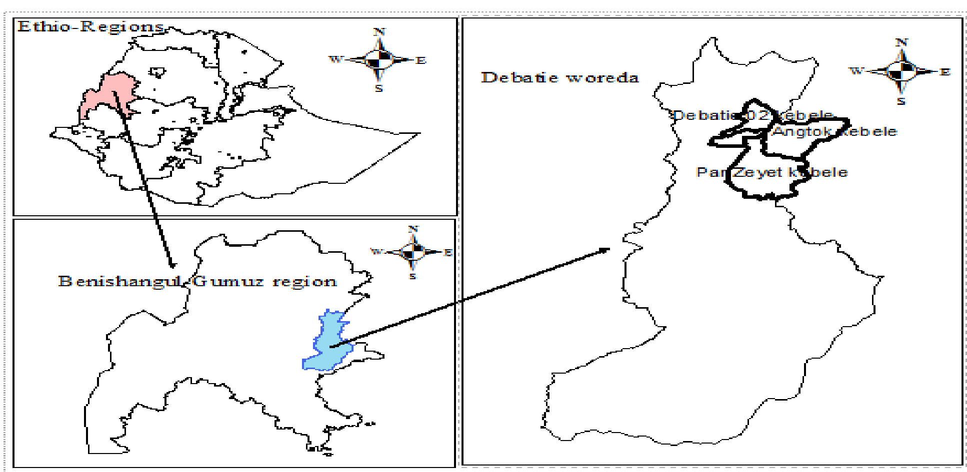

Figure 1. *Map of the Study Area*

The research area's geography is nearly flat in the lowlands and gently undulating, particularly in the highlands. There are 22.5% steep, 11.5% flat, 4.5% gorge, 5.6% hill, and 5.2% other features in the research area. The region has a unimodal rainfall pattern, according to long-term meteorological data (1990 to 2017). The mean annual rainfall was recorded at 1054 mm. The rainy season runs from April to October, with June, July, and

August seeing the most rain. The month of June through September receives over 80% of the average yearly rainfall. With mean minimum, mean maximum, and average air temperatures of 11.6°C, 33.6°C, and 22.6°C, respectively, it has a warm, humid climate. The study region is divided into two agroecological zones according to temperature, rainfall, height, and vegetation cover: lowland (Gammoojjii) at 20% and midland (Badda Daree) at 80%. The high-altitude zone takes up the most space, with the mid- and low-altitude climatic zones following behind. The range of crops and animal resources in the studied area attests to its generally good agricultural potential. The district's total area is estimated to be 338,289 hectares, of which 23% are farmland, 46% are forest land, 13% are grazing lands, 14% are cultivable farmlands, 3% are useless land, and 1% are settlements.

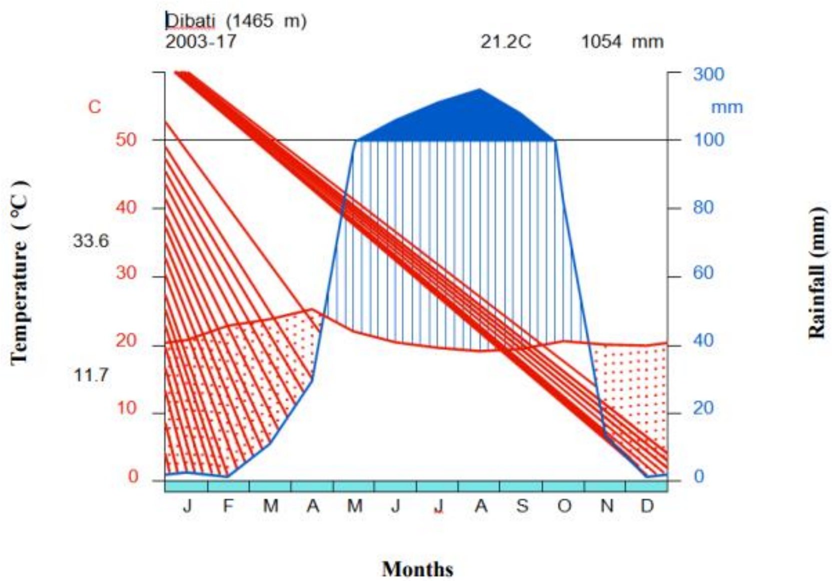

Figure 2. *Mean monthly rainfall, maximum and minimum temperatures*

Red soil (Biyyoo Diimaa) accounts for 5% of the study area; black cotton soil/vertisols (Biyyoo Kooticha) accounts for 5%; black soil (Biyyoo Gurraacha) accounts for 15%; and brown soil (Biyyoo Magaala) accounts for 25%. Reddish-brown Nitosols make up the majority of the soil in the region. Clay and loam soils make up the majority of the soil texture class in the research area (Table 2). The research region is rich in a variety of flora types, from small, old, dense natural forests in pocket areas at the points of both upstream and downstream sides to patches of sparse shrub-grass complex scattered throughout. The primary vegetation species of the study area are Eucalyptus camalduleses (Bargamoo diimaa), Grewia ferruginea (Dhooqonuu), Calpurnia aurea (Ceeka), Ficusvaita (Qilxuu), and Croton mycrostachyus (Bakkaniisa). Other dominant tree species in the area are Acacia abysinica (Laaftoo), Vernonia amygadalina (Eebicha), Ocimum sauva (Hancabbii), Grewia ferruginea (Dhooqonuu), and Olea Africana (Ejersa). In the research region, Eucalyptus camalduleses (Bargamoo diimaa) are commonly encountered. The research region has a drainage system that runs from north to south. Major rivers including the Gibe (laga gibe), Sama (laga saama), Jima (laga Jimaa), Qela (laga Qallaa), Mara (laga Maraa), Leku (laga Lakkuu), and Habuko (laga Habukkoo) flow through the study region. There are 197 villages in Kebeles 29 and 29 kebeles in the district. Based on their lengthier conservation age—more than nine years—and the condition of their soil and water conservation practices, three Kebeles were particularly selected for each location—lowland, midland, and highland. Official figures from 2007 indicate that there are 66,654 people living in the district, 33,452 of them are men and 33,202 of whom are women. 7,399 people—or 11.1% of the total population—live in cities. The district has 133,584 total residents, comprising 65,293 males and 68,291 women, with 22,880 households.

The region is known for its mixed farming system, with cattle, sheep, goats, equines, and poultry being the main livestock grown there. In order of significance, the area's main annual and perennial crops are: maize (Zea mays L.), sorghum (Sorghum bicolor), teff (Eragrostis tef), wheat (Tiriticum vulgare), barley (Hordeum vulgare), nigger seed (Guizotia abyssinica), beans (Vicia faba) and peas (Pisumsativum), hot pepper (Capsicum frutescense L.), haricot bean (Phaseolus vulgar L.), sweat potato (Ipomoea batatas Lam), mango (Mangifera indica L.), banana (Mussa spp.), and sugar cane (Saccharum officinarum L.). Small-scale irrigation from rivers, springs, and drainage for temperate and sub-temperate fruit and cash crop production (vegetables like onion (Allium cepa), garlic (Allium sativum), potato (Solanum tuberosum), cabbage (Brassica oleracea), tomato, and various types of spices) are among the other diverse livelihoods observed in the study area. The two main crops farmed in the region are maize and pepper.

Soil sampling

To obtain a wide picture of the changes in the research area during the course of 2017, a general visual field survey of the area was initially carried out. Three primary land use categories were distinguished: farmed, unconserved, and grazing. The three land use types—cultivated, grazed, and unconserved—that were selected for this study can all be located in the same sub-catchment, not far from one another. Samples of soil were gathered from each land unit for laboratory analysis. From each of the eighteen composite soil samples, three replications were obtained at a depth of 0 to 20 cm. The soil samples were air dried, well mixed, and passed through a 2 mm screen; on the other hand, the samples meant to be used for calculating the levels of accessible phosphorus, total nitrogen, and organic carbon were crushed so they could pass through a 0.5 mm size sieve.

Soil Analysis

The soil samples were allowed to air dry at room temperature before being crushed, mixed with mortar, and sieved using a 2 mm screen size. To determine the total nitrogen, the soil sample was further sieved using a 0.5 mm sieve. Samples were then analysed to look for particular soil physicochemical traits. The soil laboratory analysis was carried out by the Pawi Agricultural Soil Research and Fertility

Improvement Centre. A specified amount of soil was dried in a 1050°C oven for a full day in order to determine the bulk density of the soil using the core sampler method. The volume of the sampling core was then divided by the mass of the oven-dried soil to estimate the quantity. The ratios of soil particle size were calculated using the hydrometer method (Sakar & Haldar, 2005). Subsequently, the equilateral triangle developed by the United States Department of Agriculture (USDA) (Osman, 2012) was utilised to ascertain soil texture and textural classification.

Throughout the night, the soil samples were dried in an oven set to 105°C. The samples were taken out of the oven and their weights were measured 24 hours later. According to Van Reeuwijk (2002), soil response, or pH of the soil, was measured using a pH metre and a 1:2.50 soil-to-water ratio.Soil organic carbon (SOC%) was calculated using the Walkley and Black technique (Schnitzer, 1982). To get soil organic matter (SOM%), which is the percentage of carbon, it was multiplied by 1.724. The Kjeldahl methods as modified by Sakar and Haldar (2005) were applied to determine the total nitrogen (TN%). Baize (2000) states that the amount of readily available phosphorus (P) was determined using Bray 2. Tugizimana (2015) states that this procedure comprises extracting the substance using a solution of 0.025N hydrochloric acid and 0.03N ammonium fluoride. (Sakar and Haldar, 2005) used the ammonium acetate method to calculate CEC.

Analysis of Statistical Data

An analysis of variance was performed on the soil samples using the general linear model (GLM) approach in the statistical analysis system (SAS) statistical software version 9.0.2004. The ANOVA method was employed to investigate treatment differences. The least significant difference (LSD) approach was used to ascertain whether there was a difference of P 0.05 between the treatment means. For separation, Tukey's honest significance difference (HSD) test was used after an analysis of variance showed statistically significant differences (p 0.05). Using the CV to characterise the degree of variability for each soil parameter within and among land uses, the relationship between key aspects of soil characteristics within practices was also indicated.

RESULTS AND DISCUSSION

Soil Textural Fractions and Bulk density

The results showed that soil textural components are significantly ($p < 0.05$) impacted by conservation (Table 1). All soils, with the exception of clay loam, had clayey textural classes and were dominated by clay fractions. There was a noticeable difference in the amount of sand and silt in the soils of grazing field and neighbouring preserved land. Data investigation showed that texturing is unaffected by SWC management. According to Tesfaye and Fanuel (2019), there was no statistically significant difference in texture between the SWC management approaches and Lemma et al. (2021). Given that soil texture is an inherent property that is difficult to alter, this may be the case. According to Jiru et al. (2022) the outcome indicates that notable changes or impacts on soil texture resulting from SWCs may only be achieved after a considerable duration and the implementation of conservation measures.

Table 1 demonstrates that the soils on preserved area have a proportionately larger percentage of sand than those on non-conserved land. The protected Mine chit by Mengistu et al. (2016) had a greater mean clay concentration than the non-conserved Zikire sub-watershed. Reasons for the much lower concentration in non-conserved plots could include increased soil erosion, loss of fine materials, loss of clay content, and loss of organic matter. This protected zone, however, had the lowest mean sand content (39.3%) due to conservation efforts to better assemble organic matter and clay components. The amount of clay present in the mixture Clay concentrations were less than 50% in both saved and non-preserved areas, with a slight (2%) increase in conserved areas relative to non-conserved. The findings suggest that this may have been directly impacted by the temporary conservation measures that were put in place in the research area. There was no statistically significant difference between the amount of clay on preserved land and non-conserved areas, according to the one-way ANOVA of LSD at the P 0.05 level.

In contrast, the area that was saved had 19.3% more silt than the region that was not. Consequently, compared to farmed area without soil bunds, forests and fallow land had a much higher mean silt proportion (Bezabih et al., 2016). Conversely, Table 1's non-conserved area has the lowest percentage of silt content (15%). In general, sandy clay was the predominant soil textural class in the research area, indicating that soil and water conservation methods do not change the textural class of the soil in the end. In certain parts of the research region, the soil has a texture closer to that of sandy clay. Table 1 illustrates a kind of soil texture for both conserved and unconserved areas.

Table 1

Effects of SWC on selected physical properties of the soils of the Debatie district.

Slope class	Soil texture			Texture class		
	Clay (%)	Sand (%)	Silt (%)		BD(g/cm^3)	SMC(%)
	Conserved					
C1	52	20	28	Clay	0.85^a	6.04^a
C2	32	52	16	Sand Clay	0.54^a	5.58^a
C3	40	46	14	Sandy clay	0.42^a	5.43^a
Mean	41.3^a	39.3^a	19.3^a			
	Non-Conserved					
C1	46	38	16	Clay	1.14^b	3.94^b
C2	32	39	13	Sandy clay	1.11^b	3.654^b
C3	40	44	16	Sandy clay	1.00^b	3.43^b
Mean	39.3^a	40.3^a	15^a		1.69	4.67
LDS(0.05)	0.67	0.61	0.173		7.91	8.14
Significant at(0.05)	Ns	Ns	Ns		**	**

The study's findings showed that conservation measures decreased the bulk density (BD) of soil (gcm^3). It decreased from 1.46 gcm3 in non-conserved cropland to 0.85 gcm3 on conserved land (Table 1). The decreased mean BD value under integrated measures may be attributable to the subsequent effects of reduced crop residue and soil loss through erosive processes, as well as the addition of organic matter from plants. Similar findings were reported by (Zuazo et al. 2009; Pimentel et al. 2000; Lal et al. 1998). At effective soil depths of 0–20 cm, the bulk density of the protected land in the study region was lower than that of the unconserved land. This is because conservation efforts in the area have produced an above-average amount of organic matter (Sitaula, 2004). Because of soil compaction brought on by topsoil erosion and plant residues, the non-conserved area has a higher bulk density value. Conservation efforts decreased bulk density (BD) (gcm-3), according to the data. Table 1 shows the typical values of soil bulk density and moisture in protected and unconserved areas.

The soil moisture content (SMC)

A significant difference in soil moisture content was found between non-conserved and conserved land at levels of (p0.05) according to the data analysis. Comparing agricultural plots with SWC practices to those without, the Soil MC was greater in the former. This could be explained by the fact that the SWC measures showed much more organic matter, lower runoff velocity, and higher infiltration than the non-conserved farm plots, which had a faster runoff flow down the slope. The enhancement of soil structure brought about by soilOM affects the stocking of the soil's water stores; soil SMC was highest (6.04%) on conserved land and lowest (3.94%) on non-conserved land. Improved water penetration during rainy seasons as a result of soil and water conservation efforts may have contributed to the exceptionally high moisture levels that were found in the preserved field (Stroosnijder et al., 2004).

The study's findings also showed that employing soil and water conservation techniques considerably increased the moisture content of the soil. In water-limited areas, soil moisture content has a major influence on agricultural output; it was higher on land that had been conserved than on land that had not. This could be explained by the significantly larger concentration of organic matter—which increases infiltration and slows runoff—than in unconserved areas.

Effects of SWC on selected chemical properties of the soils of the Debatie district

Soil pH

The chemical properties of the soil's acidity or alkalinity are measured by the soil reaction (pH). According to the investigation, the soil's pH ranged from 5.56 to 5.93 based on the conservation measures used. The lowest and maximum pH values from non-conserved land and integrated SWC practices, respectively, were recorded for a period of six years (Table 2). The findings demonstrated that the application of physical SWC techniques had raised soil pH over time. The loss of soil organic matter and exchangeable bases brought on by runoff and erosion raised the pH of the soil. This demonstrates that the soil's pH was elevated by the SWC's effect. The pH of the treated farmland was higher than that of the untreated agriculture, indicating an improvement in the acidity of the soil.

The findings are in line with the findings of (Getahun, 2014), who found that the pH values of non-conserved farms were lower than those of conserved farms. Significant soil erosion, nitrogen loss, a relatively low base saturation percentage, and a decrease in soil organic matter content were all factors in this discrepancy.

Organic Matter in Soil (SOM %) and Total Nitrogen (TN %)

Table 2 shows the average values of the chemical characteristics of the soil for both conserved and unconserved areas. The investigation's findings showed that SWC practices had an impact on SOM concentration. Organic matter in the soil was positively impacted by physical structure. According to the study's findings (Table 2), the mean SOM difference value was calculated to be (3.59%) in areas with conserved soil bunds and (2.26%) in those without. By decreasing runoff velocity, soil and water conservation practices increase the amount of organic matter in the soil. If not, the earth would be swept down the hill by erosion. This demonstrates the beneficial effects of SWC methods on enhancing the crops' nutritional condition. Furthermore, the results showed that conserved sites had higher quantities of soil organic matter than equivalent non-conserved sites on slopes with similar gradients. This could be the result of different plant biomasses decomposing in protected land soil. This has been reported in Mekuria et al. (2007) and Million (2003).

The analysis's findings demonstrate the positive impact of SWC techniques on the concentration of total nitrogen. Physical conservation methods subsequently changed the overall nitrogen accumulation on agriculture (Table 2). Under the specified physical conditions, the mean TN difference value between preserved and unconserved farms was 16.15 (Table 2). It demonstrated the beneficial effects of SWC practice on the studied area's soil TN. However, in this analysis, preserved practices had a considerably higher mean value of TN than non-conserved land. Because of this, the protected area might have had a higher organic matter content than the unprotected ones. The low average total nitrogen contents of both preserved and non-conserved land may be attributed to the challenges associated with managing legume crops, which fix atmospheric nitrogen through the nodules in their roots.

Table 2

Effects of SWC on selected chemical properties of the soils of the Debatie district.

Land use type	Variables(Soil chemical properties)				
	PH	SOM	TN (%)	Av.P(ppm)	CEC(meq/100g)
Conserved Land	5.93[a]	3.59[a]	0.17[a]	4.18[a]	32.79[a]
Non-Conserved Land	5.56[b]	2.26[b]	0.11[a]	1.46[b]	20.82[b]
Table.2 continues..					
CV (%)	5.11	11.42	16.15	15.67	4.30
LSD(0.05)	0.29	1.27	0.06	0.72	1.15
Significance at(p<0.05)	**	**	Ns	**	**

Means within a column followed by the same letter are not significantly different at (p ≤ 0.05); LSD = least significant difference; CV = coefficient of variation.

Table 2 illustrates that, on average, non-preserved land has a nitrogen content of 0.11% in its soils, which is somewhat lower than the nitrogen level of conserved land (0.17%). The non-conserved land in the research area had low total nitrogen values. This may be the result of the absence of biological soil conservation techniques or other soil-improving soil management procedures. This could be due to soil erosion taking organic matter from steeper or higher slopes, or it could be because leguminous plants—which fix nitrogen from the atmosphere through their root nodules—are not included in soil conservation techniques.

Available Phosphorus and Cation Exchange Capacity

SWC methods affected the phosphorus availability. Physical techniques that preserved soil and water made it better (Table 2). Numerous studies have documented differences in the phosphorus availability between agriculture practices that are conserved and those that are not. Physical SWC techniques yielded a mean available phosphorus value of 2.82 on conserved and unconserved land (Table 2). The amount of accessible phosphorus varies statistically significantly (p 0.05) between land that has been protected and land that has not. The highest average P value from preserved land was 4.18 ppm, with a range of 4.18 ppm to 1.46 ppm. This could be because soil organic matter is higher on preserved land with SWC structures than on unconserved land. The data analysis's findings showed that preserved land had more accessible phosphorus than non-conserved land. Because of the strong interactions between soil particles and erosion, phosphorus is easily transferred, increasing the amount of useable P in the soil collection zone of terraces.

Even though there were very little differences between CEC values, the study's findings showed that the mean CEC was not statistically significant in relation to treatments or slope gradients (Table 2). Between treatments and between slope gradients, the mean CEC (cmol/kg) varied from 34.05 to 35.03 and from 33.33 to 34.23. The average CEC value increased between conserved and non-conserved land from 20.82 to 32.79. In comparison to soils rated a (Landon20), the soils in the study area had a higher CEC. Due to the application of soil chemical characteristics, the organic colloid retained in the soil has a significant impact on the CEC. Overall, the findings show that soil and water conservation practices have a positive effect on soil CEC.

Correlation between selected soil chemical and physical properties

When compared to clay, silt concentrations were positively non-significant at (p0.05), according to the Pearson correlation matrix. Accordingly, PH had a negative insignificant effect ($p>0.05$) on both the sand and the BD components. The soil in the research region had silt and clay contents, although the difference was not statistically significant ($p>0.05$). The findings for accessible phosphorus (0.714**), CEC (0.806**), and clay% in relation to organic matter (0.79**) were all likewise uninteresting ($p>0.05$). Clay content has a major effect on CEC, soil organic matter, and plant nutrition. CEC and accessible phosphorus had comparable values of 0.806 and 0.714, respectively. Clay content has a major effect on CEC, soil organic matter, and plant nutrition. Consequently, compared to soils with less clay, soils with a high concentration of clay have higher quantities of soil organic matter, soil CEC, and plant nutrients. Soinne (2021) provided evidence in support of this hypothesis, demonstrating that the majority of soil attributes were significantly and favourably correlated with clay concentration. Conversely, the levels of clay and sand were shown to have a significantly negative connection (-0.806**). According to Table 3, this study demonstrates that when clay concentration increases, the amount of sand decreases. Olorunfem and this research were in agreement.

Table 3

Correlations coefficients among soil physicochemical properties under different land-use types

	Soil texture and soil physicochemical Properties											
	Alt	Depth	Sand	Silt	Clay	BD	SM C	Av.P	PH	SOM	TN	CEC
Altitude	1											
Depth	--	1										
Sand	-.486*	.309	1									
Silt	.392	-.107	---	1								
Clay	.412	-.411	-816**	.363	1							
BD	-.144	.59**	.614**	.312	-.72**	1						
SM	-.011	.415	.376	-.208	-.42	.781**	1					
Av.p	.197	-.56*	-.59**	.280	.71**	-.830	-.300	1				
PH	-.639	.47	.63**	-.460	-.58*	---	.342	---	1			
SOM	.035	-.64**	-.532*	.105	.79**	-.63**	-.404	.59**	-.396	1		
TN	.354	.134	-.265	.042	.42	-.382	-.209	.391	-.367	.431	1	
CEC	.071	-.533	-.64**	.205	.81**	-.72**	-.452	.67**	-.459	.89**	.44	1

** and * = correlation is significant at ($p \leq 0.01$) and ($p \leq 0.05$) level, respectively

CONCLUSIONS

This paper aims to evaluate the impact of soil and water conservation on the soil physicochemical parameters in the studied area. Despite making a significant economic contribution, the agricultural industry is threatened by soil erosion and negatively impacted by the decline in soil productivity. As previously said, land degradation and soil erosion have an impact on the soil's ability to produce and its ability to function properly by decreasing the physical, chemical, and biological qualities of the soil, which results in yield losses. The study's findings did, however, imply that structural soil and water conservation measures had a positive impact on runoff and soil losses. This lowers the loss of related nutrients and soil organic carbon, which enhances the soil's physicochemical characteristics and benefits agricultural land. improves the soil as a result. Therefore, improved crop yields and soil productivity are found in preserved areas as opposed to unconserved areas. To summarize, structural soil and water conservation interventions had a significant impact on the development of soil physicochemical properties in the research region, which was able to increase soil productive capacity and crop production. Consequently, good guidance, monitoring, the use of agroforestry, and maintenance are required for agricultural sustainability and soil development.

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DECLARATION

There are no competing interests in this paper.

DATA AVAILABILITY

The data of the findings are available from the corresponding author.

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