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Effect of Slope Gradient on Soil Attributes of Gara Ades Forest in Western Hararghe Zone of Oromia Region, Ethiopia

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Abstract: Forests are vital ecosystems that protect watersheds, maintain biodiversity, and support indigenous ways of life. Topography, particularly slope gradient, influences soil growth and soil moisture storage, affecting plant structure and vegetation. Soil properties, such as drainage, soil erosion, and textural composition, also vary due to topography. Soil erosion in Ethiopia is a significant issue due to steep terrain, erosive rains, and human activities. This leads to soil organic carbon losses and redistribution, resulting in a 3.4% loss of land productivity. The Gara Ades woodland, home to indigenous and exotic trees, has a diverse vegetation cover and soil type. However, there is limited research on the impact of slope gradients on soil physical and chemical characteristics in this area. This study aimed to investigate the impact of slope gradient differences on soil physical and chemical attributes in the Gara Ades forest. Clinometers, tripods, ropes, and meters were used to measure slope gradients and compute slope gradient classification. Primarily, slope classes were set purposefully, with lower slope class (LSC: <10%), middle slope class (MSC: >10–20%), and upper slope class (USC: >20–<30%). Soil samples were collected from 45 experimental main quadrants using auger at a depth of 30 cm, followed by composite soil sample preparation. Results of soil texture class analysis shows that there is no significant difference in soil particles of sand and clay among slope gradient classes, but, silt soil indicated a significant difference. However, results of soil chemical content parameters shows that, the potential of Hydrogen (pH), Electrical Conductivity (EC), Organic Carbon (OC), Organic Matter (OM), Total Nitrogen (TN), Calcium (Ca), Magnesium (Mg), available Potassium (K), Sodium (Na) and Cation Exchange Capacity (CEC) have a significance difference ($p < 0.05$) among slope gradient classes; whereas, available Phosphorus (P) has no significance difference. The highest mean value of pH, EC, OC, OM, TN, Ca, Mg, K, Na, and CEC was observed in LSC followed by MSC and USC. The significant effect ($p < 0.05$) of slope gradient class difference can be summarized as LSC > MSC > USC for all soil chemical property parameters. Generally, results of this study revealed that slope gradient differences and their interaction had a significant effect on soil physicochemical properties. The disparity of slope gradient should have to be considered during further ecological studies in the study area as well as other mountainous sites to reduce deviations that occur due to slope gradient variation.

Keywords: Topography, Slope Gradient, Soil Chemical Properties, Soil Texture Properties, Soil Erosion

1. Introduction

Forests are environments that protect watersheds, maintain biodiversity, and support indigenous ways of life [45]. They are also natural capital that supports economic growth, as well as carbon sinks that reduce greenhouse gas emissions that contribute to climate change. Topography has climatic influence concerning prevailing sunshine, air currents, and water bodies. The slope gradient is the primary topographic feature that might impact soil growth [36].

More recently, research in tropical forests throughout the world has demonstrated species relationships with terrain, water, and nutrient availability on small scales [12, 46]. These discoveries have given rise to a slew of proposals to explain high diversity at local scales [27, 50]; many of these hypotheses rely on density- and frequency-dependent processes. The temperature on a large scale and the terrain on a local scale are two dependent characteristics that define the climax community's resource availability and organization [27, 50].

The primary topographic element controlling the distribution and patterns of vegetation in mountain environments is slope Titshall *et al.* [44]. Slope affects the microclimate and consequently the large-scale geographical distribution and patterns of vegetation in numerous ways [31, 5, 11]. Land topography (slope gradient) impacts soil moisture storage, which affects plant structure [6].

Soils differ in their characteristics primarily due to topography [7], which influences rainfall, drainage, soil erosion, textural composition, and other soil properties that affect plant growth [9]. Due to topography, major variations in soil type can occur over relatively little differences in distance. Environmental variables such as topography have a substantial effect on the regional variation of soil characteristics [28, 35]. Topography has a significant impact on the type and distribution of soils Gómez-Plaza *et al.* [24]. The combined impacts of slope gradient, water dynamics, and/or erosion and deposition can all have an impact on soils Van Oost *et al.* [47].

Soil erosion caused by water is a pervasive and difficult issue in Ethiopian environments. It is caused by the geomorphologic aspects of the terrain, which are characterized by steep slopes, as well as erosive rains and human influences via the abuse of natural resources Hancock *et al.* [25]. The combination of rocky topography and erosive rains increases the likelihood of soil organic carbon losses and redistribution Hancock *et al.* [25]. Water erosion causes major land degradation processes such as terrain deformation and mass displacement Nyssen *et al.* [34]. The resulting loss of soil fertility due to sheet, rill, and gully erosion has led to a 3.4% loss of land productivity [26].

Despite the steepness of the slopes, Ethiopian fields are resistant to gully erosion due to deep soils containing significant amounts of rock fragments Nyssen *et al.* [34]. The redistribution of SOC in the watershed is caused by soil erosion and deposition in different land use types owing to topography influences Hancock *et al.* [25].

Variability in soil parameters associated with slope gradient classes was studied in northern and southern Ethiopia [4, 1, 14]. Many studies have demonstrated that the amount and distribution of major nutritional components are greater on flat slopes than on steeper slopes [4, 1, 14, 16]. The location of the landscape affects flow, drainage, erosion, and soil depth, and hence soil formation and development. Soil parameters such as pH, OC, sand and clay content, and distribution are strongly connected to landscape locations [49, 32]. Physiographic variation in agricultural fields has a significant impact on soil parameters and plant productivity [13, 14]. Soil pH and exchangeable bases are increasing as the slope decreases [13]. Lower-slope land sites had greater mean values of total nitrogen (TN), organic matter (OM), and cation exchange capacity (CEC) than upper-slope land positions in Gebreselassie *et al.* [22]. Slope facilitates soil disturbance through erosion and has a significant impact on soil characteristics [3].

Gara Ades woodland has forest, bush land, shrub land, communal land, and pasture land as its vegetation cover. The Gara Ades forest is home to a variety of indigenous and exotic trees, the most prominent of which are *Juniperus procera, Podocarpus falcatus, and Cupressus Lusitanica*. [29].

The largest part of the study's area and the surrounding areas are encompassed by limestone and granite types of rock, and the soil type was mostly sandy and clay soil with some loamy soil, which is crucial for the study area's moderate organic carbon levels in the soil [29]. Even though research on the Ades forest has been done in recent years, there is an absence of information in the study region regarding the impact of slope gradient on soil physical and chemical characteristics. As a result, the purpose of this study was to discover new information about the influence of slope gradient difference on soil physical and chemical attributes of the Gara Ades forest in the Western Hararghe Zone of Oromia Region, Ethiopia.

2. Material and Methods

2.1. Description of the Study Area

Location: The study was carried out at Gara Ades forest which is located at the boundary of both Doba and Tullo districts. The study site is situated in Ethiopia's eastern highlands, in the Western Hararghe Zone of the Oromia National Regional State. The research site was 407 km east of Addis Abeba, Ethiopia, and 30 km from Hirna town. Geographically, Gara Ades forest was found at 90 14′ 60.00″N and 410 00′ 0.00″E. The Gara Ades forest's altitudinal gradients range from 2517 to 2743 m.a.s.l. The entire forest covering the area under study was predicted to be 483 hectares, with varied plant and animal species (Figure 1).

Climate: The study area's weather condition was characterized by the coldest temperature, which was dubbed 'Dega' by the locals. The rainy season in the study area typically lasts from July through September. The dry and hot season lasted from mid-December until the end of March. Based on data from the nearest station, Hirna meteorological station the mean annual rainfall ranged from 698mm to 1185mm (National Metrological Agency of Jigjiga branch). The Gara Ades forest's typical annual maximum and lowest temperatures are 27.9 and 8.2 degrees Celsius, respectively (National Metrological Agency of Jigjiga branch).

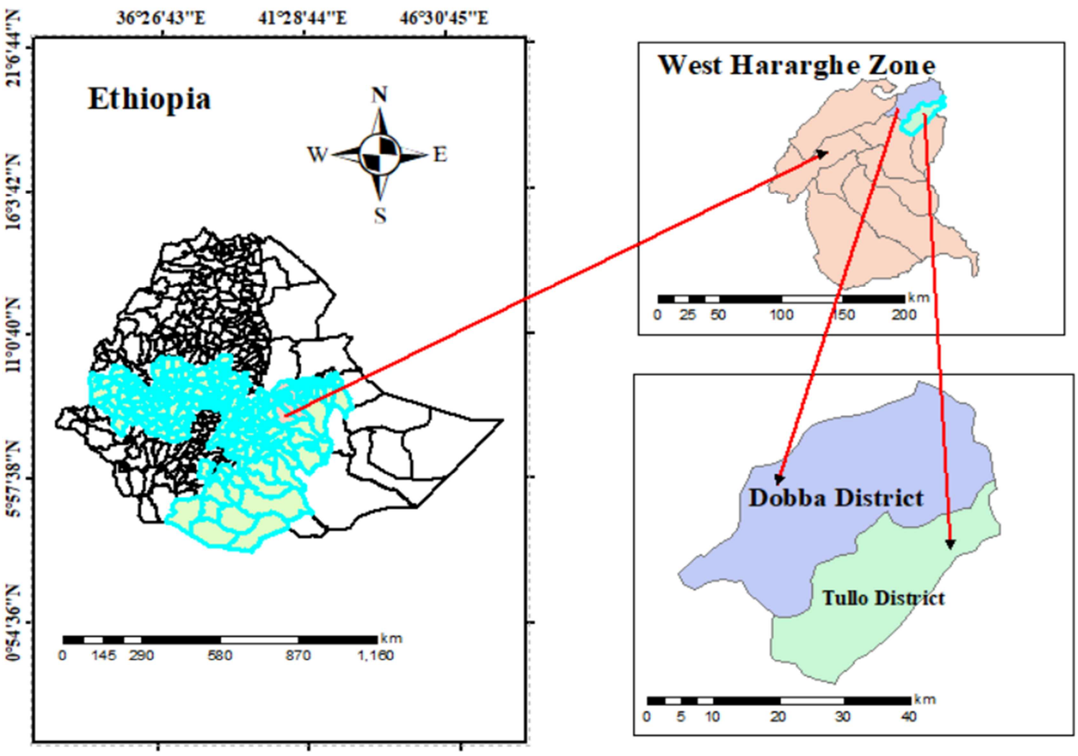

Figure 1. *Map of the study area.*

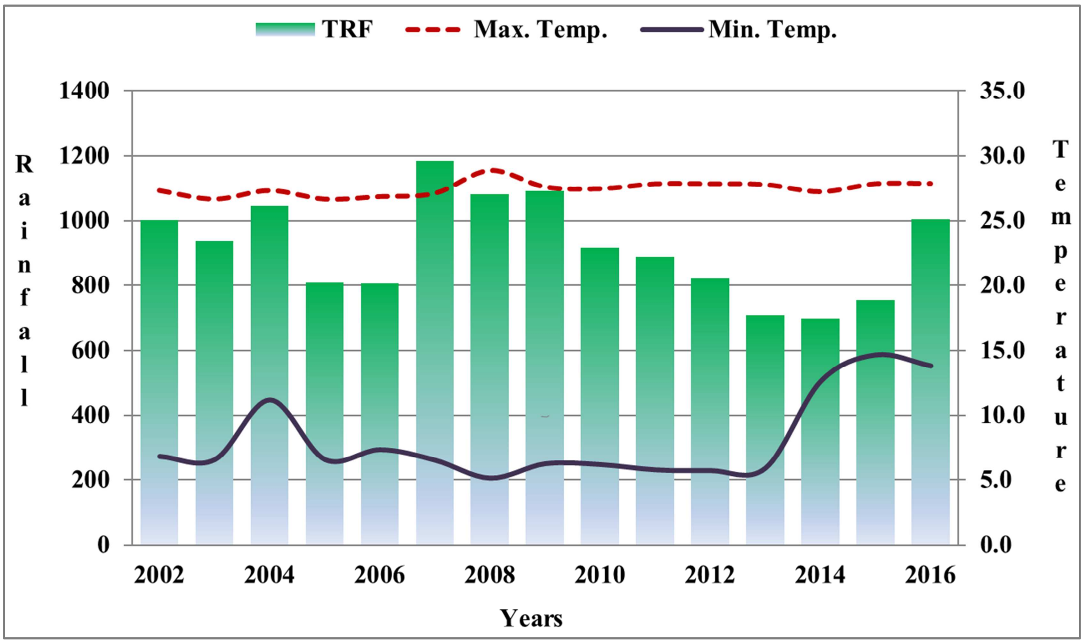

Figure 2. *Total annual precipitation, maximum and minimum temperature of Ades district. (TRF = Total Rainfall, Min.Temp. = Minimum Temperature, Max. Temp = Maximum Temperature).*

2.2. Sample Quadrant Arrangement

Experimental quadrants were drawn from Lower Slope (<10%), Middle Slope (>10 - < 20%) and Upper Slope (>20 - <30%) classes purposively [42]. A space of 200m was left at the periphery/border of the study site to avoid edge effect; adjacent/similar quadrants were left to avoid pseudo replicated quadrants. Slope gradient measurement was done using clinometers, tripod, rope and meter. Slope gradient classification on the experimental site was computed using a formula; Vertical Interval (VI) divided by Horizontal Interval (HI) multiply with 100.

$$\text{Slope} = \frac{\text{VI}}{\text{HI}} \times 100 \Longleftrightarrow \text{Slope} = \frac{\text{Rise}}{\text{Run}} \times 100$$

Source: (https://www.firstinarchitecture.co.uk/how-to-calculate-slopes-and-gradients/)

2.3. Soil Sample Collection

In order to investigate and evaluate changes in soil chemical properties along slope gradient classes a total of 225 (15 main quadrant x 5 sub-quadrant from each main quadrant x 3 slope classes) soil samples were collected from 45 experimental main quadrant at a depth of 30cm. Soil samples were collected using auger at a depth of 30cm after scraping the surface litter, grass, pebbles, and stones to take a uniform and clean surface soil. Accordingly, 45 composite soil samples (1 composite soil sample from each main 20m × 20m quadrant) were prepared from soil samples for laboratory analysis. Finally, 45 composite soil samples were weighed, labeled, and packed properly using plastic bags and transported to Bedele soil laboratory of Oromia Agricultural Research Institute (OARI) for soil texture and chemical property analysis.

2.4. Data Analysis

The soil physical and chemical parameter results were subjected to analysis of variance (ANOVA) using GenStat 18th Edition statistical software. One way analysis of variance was used to assess significant differences among soil parameters. Significant differences between and within treatment means were separated at P<0.05 using Duncan's LSD.

3. Results and Discussion

3.1. Soil Texture Minimum, Maximum, and Mean Values

The key statistical measures used to evaluate soil texture class parameters are the minimum, maximum, mean, and mean standard error (SEM) values. These measures provide valuable insights into the range and central tendency of soil textural characteristics.

Generally, the study area recorded soil textures of sand, clay, and silt with a mean value of 46.11, 23.22, and 30.67 respectively. Sand soil percentage is higher while silt and clay follow accordingly (Table 1). The standard error of mean values was 4.8, 4.5, and 3.2 for sand, clay, and silt soil textures respectively.

Table 1. *Soil texture minimum, maximum, and mean values of Gara Ades forest.*

Soil Property	Sample size	Minimum	Maximum	Mean	SEM
Sand %	45	33.00	53.00	46.11	4.8
Clay %	45	16.00	31.00	23.22	4.5
Silt %	45	21.00	37.00	30.67	3.2

3.2. Effect of Slope Gradient and Its Interaction with Soil Texture Properties

This study shows that the soil particle of sand and clay has no significant difference (P > 0.05) among slope gradient classes. However, silt soil particles recorded a significant difference (P < 0.05) among slope gradient classes (Table 2).

Table 2. *The soil property of Gara Ades forest.*

Soil Properties	Slope class			CV	LSD (5%)	Significance Level
	LSC	MSC	USC			
Sand (%)	44.05^{a}	47.15^{a}	47.05^{a}	10.4	3.53	Ns
Clay (%)	22.65^{a}	23.95^{a}	23.5^{a}	19.6	3.347	Ns
Silt (%)	33.3^{a}	28.9^{b}	29.4^{b}	10.4	2.357	**

Where: $^{a, b}$ Mean values having the same letters within a row are not significantly different, while mean values followed by different letters are significantly different at P < 0.05; LSD=Least significant difference; CV=Coefficient of variation; ns=non-significant; LSC= lower slope class; MSC=middle slope class; USC=upper slope class.

This study revealed that the soil texture of sand particles recorded a mean value of 44.05, 47.15, and 47.05 in LSC, MSC, and USC respectively. The soil texture proportion in the MSC and USC is dominated by sand particles which indicate that there is limited nutrient and water retention capability. This is similar to the findings of [38, 39] where sand particle dominates in the upper stream slope gradients. This suggests that there are fewer binding agents in the MSC and USC soils. The low water holding capacity and plant available water content in the upstream areas may contribute to increased overflow and soil content erosion risk. Soil clay particles recorded 22.65, 23.95, and 23.5 in LSC, MSC, and USC respectively. Numerically, MSC and USC have higher clay soil particle proportions than LSC.

Silt soil particles recorded a mean value of 33.3, 28.9, and 29.4 in the LSC, MSC, and USC respectively. The existence of higher silt soil property in the LSC could be due to the easy erosion of finer soil particles from steeper to flatter slope soils. Slope gradient is one of the important topographical factors affecting the drainage process; surface run-off and soil erosion thus affect the physicochemical properties of the soil [19]. The presence of higher alluvial soil particles in the LSC facilitates higher dry biomass production and higher basal cover of herbaceous species. In wooded grasslands, it is common to see grasses growing on finer-textured soils. Soil with a finer texture is usually more basic and provides a favorable source of nutrients for grasses. It is generally assumed that soil loss will increase as the slope increases, due to a corresponding increase in surface runoff rates. Therefore, the silt soil particle is affected by the difference in slope gradient classes (Table 2).

3.3. Soil Nutrient Minimum, Maximum, and Mean Values

Among the key statistical measures used to evaluate these parameters are the minimum, maximum, and mean values. These measures provide valuable insights into the range and central tendency of soil characteristics. Thus, the minimum, maximum, mean, and mean standard error values of Gara Ades forest soil parameter analysis results are indicated below (Table 3).

Table 3. *Minimum, maximum, mean, and mean standard error values of soil parameters.*

Soil Properties	Sample size	Minimum	Maximum	Mean	SEM
pH	45	6.22	7.04	6.55	0.04
EC (mmhos/Cm)	45	49.1	85.1	68.75	2.21
OC (%)	45	3.04	7.51	4.68	0.26
OM (%)	45	5.24	12.95	8.08	0.44
TN (%)	45	0.13	0.33	0.24	0.009
Av. P (mg kg^{-1})	45	1.14	3.71	1.82	0.15
Ex. Ca^{++} ppm	45	39.09	67.79	57.31	1.42
Ex. Mg^{++} ppm	45	11.28	37.64	27.86	1.35
Ex. K^{+} ppm	45	0.91	1.78	1.41	0.05
Na (Cmol (+)/kg	45	0.19	2.99	1.18	0.06
CEC (Meq/100g soil)	45	21.5	38.8	29.54	1.09

Where: pH=potential of Hydrogen; EC=Electrical Conductivity; OC=Organic Carbon; OM=Organic Matter; Av.P=Available Phosphorous; Ex.Ca=Exchangeable Calcium; Ex.Mg=Exchangeable Magnesium; Ex.K=Exchangeable Potassium; Na=Sodium; CEC=Cation Exchange Capacity; TN=Total Nitrogen; SEM=Standard Error of Mean.

The minimum mean value represents the lowest observed measurement of a specific soil parameter within a given dataset of our experiment. It indicates the lower boundary or extreme of the parameter's variability. Conversely, the maximum mean value represents the highest observed measurement and signifies the upper boundary or extreme of its range. The soil minimum/maximum value recorded was 6.22/7.04, 49.1/85.1, 3.04/7.51, 5.24/12.95, 0.13/0.33, 1.14/3.71, 39.09/67.79, 11.28/37.64, 0.91/1.78, 0.19/2.99, and 21.5/38.8 for the potential of hydrogen (pH), electrical conductivity (EC), organic carbon (OC), organic matter (OM), total nitrogen (TN), calcium (Ca), magnesium (Mg), available potassium (K), sodium (Na) and cation exchange capacity (CEC) respectively.

The mean value is calculated by summing all measurements for a particular soil parameter and dividing it by the total number of observations. This statistical measure provides an estimation of the central tendency or average value of a given soil property parameter. The mean values for pH, EC, OC, OM, TN, Ca, Mg, K, Na, and CEC were 6.55, 68.75, 4.68, 8.08, 0.24, 1.82, 57.31, 27.86, 1.41, 1.18, and 29.54 respectively.

In addition to mean values, it is also important to consider their associated standard errors. In our study, the mean standard error (Table 3) quantifies how much variability or uncertainty exists around the estimated mean value and serves as an indicator of precision or reliability in our statistical analyses of all soil parameters.

3.4. Effect of Slope Gradient and Its Interaction with Soil Chemical Properties

The study and analysis of soil chemical property parameters play a crucial role in understanding the composition and fertility of soil. These parameters provide valuable insights into the nutrient content, acidity or alkalinity levels, and overall health status of the soil. By assessing parameters such as pH, organic matter, cation exchange capacity, nutrient availability, and heavy metal concentrations, scientists and agronomists can make informed decisions regarding soil management practices, crop selection, fertilizer application, and environmental protection. So, the soil chemical nutrient analysis result of the Gara Ades forest (Table 4) provides a comprehensive understanding of soil chemical properties; which enables policymakers to optimize the productivity of the forest while ensuring sustainable agricultural practices.

Table 4. *Soil chemical nutrient analysis result of Gara Ades forest.*

Soil Properties	Slope class			CV	LSD (5%)	Significance Level
	LSC	MSC	USC			
pH	6.65^{a}	6.55^{ab}	6.46^{b}	2.4	0.12	*
EC (mmhos/Cm)	76.50^{a}	67.45^{b}	62.33^{b}	12.5	6.31	**
OC (%)	5.33^{a}	4.40^{b}	4.32^{b}	21.3	0.74	*
OM (%)	9.18^{a}	7.59^{b}	7.45^{b}	21.3	1.27	*
TN (%)	0.32^{a}	0.21^{b}	0.20^{b}	14.0	0.03	**
Av. P (mg kg^{-1})	2.10^{a}	1.71^{a}	1.64^{a}	32.9	0.44	Ns
Ex. Ca^{++} ppm	66.16^{a}	53.99^{b}	51.78^{b}	9.6	4.06	**
Ex. Mg^{++} ppm	33.36^{a}	32.72^{a}	17.43^{b}	18.8	3.86	**
Ex. K^{+} ppm	1.51^{a}	1.50^{a}	1.22^{b}	13.8	0.14	**
Na (Cmol (+)/kg	2.33^{a}	0.94^{b}	0.26^{c}	20.9	0.18	**

Soil Properties	Slope class			CV	LSD (5%)	Significance Level
	LSC	MSC	USC			
CEC (Meq/100g soil)	32.02[a]	29.90[ab]	26.71[b]	14.3	3.11	**

Where: [a, b, c] Mean values within a row with different superscripts differ significantly and Mean values followed by same letter(s) within a column do not differ at P < 0.05; * =(P < 0.01); ** =(P<0.001); ns=not significant; pH=potential of Hydrogen; EC=Electrical Conductivity; Ex. Ac.=Exchangeable Acidity; OC=Organic Carbon; OM=Organic Matter; Av. P=Available Phosphorous; Ex. Ca=Exchangeable Calcium; Ex. Mg=Exchangeable Magnesium; Ex. K=Exchangeable Potassium; Na=Sodium; CEC =Cation Exchange Capacity; TN =Total Nitrogen; SEM =Standard Error of Mean.

3.4.1. Soil pH

Soil pH was significantly affected (P < 0.05) by the difference in slope gradient. The highest pH mean value (6.65) was recorded in soils within the lower slope class than in the middle slope class (6.55) and upper slope class (6.46). The loss of basic cations due to increased runoff and erosion on steeper slopes is believed to contribute to the lower pH values observed in the soils of MSC and USC. This is similar to the study, by Qurban *et al.,* where soil pH and exchangeable bases increase as the slope decreases (37). This can be explained by the facilitated loss of base-forming cations through leaching on steeper slopes, resulting in increased soil acidity [33].

3.4.2. Soil Electrical Conductivity

Soil Electrical Conductivity (EC) is significantly influenced by slope gradient (P < 0.05). Whereas, the soil of the LSC recorded 76.5 mean EC concentration levels than MSC and USC soil which were 67.45 and 62.33 respectively. Soil Electrical conductivity has a negative correlation versus slope gradient. The migration of soil EC towards flatter slopes results in lower EC in soils of steeper grounds. This might be caused by accelerated runoff and erosion. As stated by Afshar *et al.* [3], slope gradient has a significant impact on soil properties and speeds up soil disturbance due to erosion.

3.4.3. Soil Organic Carbon, Organic Matter and Total Nitrogen

Soil organic carbon (OC) and total nitrogen (TN) are the major indexes used to estimate soil fertility and quality. Soil organic carbon (OC), Organic Matter (OM), and Total Nitrogen (TN) were significantly affected (P < 0.05) by slope gradient differences. The maximum mean percentage of OC, OM, and TN was recorded in the LSC soils (Table 4). Soil organic carbon (OC) mean value recorded for LSC, MSC, and USC was 5.33, 4.4, and 4.32 respectively. However, soil organic matter (OM) recorded a mean value of 9.18, 7.59, and 7.45 at LSC, MSC, and USC respectively.

Agreeing with a study [23] aboveground and below-ground carbon tends to decrease with slope increase. This study [23] also depicts the OC accumulation available in the soil starts to decline after attaining the climax point abundance. Soil OC serves as a source of energy and nutrients for soil biota and influences soil microbial diversity. Many biologically mediated soil processes play an important role in soil microbial abundance, and ground cover [48, 17]. This contradicts a study by Adugna *et al.* [2] where aboveground and belowground carbon tends to increase with slope gradients.

The amount of OM in the soil is the product of diverse factors over some time on the relative rates of return of organic residues to the soil and their subsequent breakdown in the soil as revealed by [43]. Since LSC has the advantage of having higher vegetation covers of its own and that of MSC and USC which might be eroded downward to lower slopes due to erosion and runoff. The LSC can accumulate higher litter biomass; leading to increased soil OM and protecting the soil from erosion Tessema *et al.* [41]. The result of the present study is also in conformity with the findings of Barthes *et al.* [10], where steep slopes increase material mobility and cause soil erosion; soils located on steep slopes are more susceptible to erosion. Furthermore, in a study reported by [15], deforestation also leads to the depletion of organic matter (OM) in the soil; where deforestation is severe in the MSC and USC as observed in the Gara Ades forest.

In our study, we discovered that the population of herbaceous and woody vegetation is higher in LSC as compared to MSC and USC. Good ground cover of herbaceous and woody vegetation might reduce the impact of soil erosion, decrease run-off, and reduce topsoil loss which leads to increased levels of soil fertility. Available litter production (grass, tree, and shrub leaf shattering) also increases plant remains added to the soil surface which contributes to the stocking of soil OC, OM, and TN percentages further than the slope gradient. This is similar to the results of Kooch *et al.* [30] where different tree species produce different types of litter in terms of nutrient and chemical composition.

Maximum mean percentage of total nitrogen (TN) was recorded in LSC soils, followed by MSC and USC soils (Table 4). Soil total nitrogen content recorded a mean value of 0.32, 0.21, and 0.2 at LSC, MSC, and USC respectively. LSC gradient is significantly different (P < 0.05) from MSC and USC; whereas, there is no significant difference (P > 0.05) observed between LSC and USC gradients. The mean percentage of total nitrogen was inversely correlated with slope gradient. This inverse correlation could be due to the downward movement of TN with runoff from the upper slope gradient and accumulation on the LSC, as well as higher rates of microbial degradation and nitrogen conversion in LSC like that of OC and OM. However, the mean total nitrogen value was higher on a lower slope gradient than on a higher slope gradient as reported by Gebreselassie *et al.* [22]. Our study also reveals that soil OC, OM, and TN properties were positively correlated and it shares similar features with this study.

3.4.4. Soil Phosphorus

The differences in slope gradient had no significant ($P > 0.05$) effect on Olson's available P (Table 4). However, numerical variances in slope gradients were discovered. The soil available Phosphorus (P) mean value recorded for LSC, MSC, and USC was 2.1, 1.71, and 1.64 respectively. Even though it is not statistically significant, the numerical difference is strongly related to the variation in organic matter content in each slope gradient class. This indicates that soil organic matter may contribute to the existence of higher accessible P in the soils of flatter slopes. In agreement with this, Fisseha *et al.* [20] discovered low accessible P in soils with low OM concentration. In the contrary, [33] determined that the accessible P content of tropical soils did not always decrease with decreasing organic matter.

3.4.5. Soil Exchangeable Base Cations

Results of this study indicate that slope gradient variations had a significant ($P < 0.05$) effect on soil exchangeable base cations. The LSC had the greatest mean levels of exchangeable base cations while the USC had the lowest mean values of base cations (Table 4). The maximum soil exchangeable Calcium concentration (66.16) was found in LSC, whereas the lowest was found in MSC and USC which were 51.78 and 53.99 respectively. This might be because of numerous exchangeable cations, such as calcium, are moving downhill. According to [8], slope steepness was a significant topographical feature influencing the drainage process; runoff and soil erosion therefore alter soil distribution and physicochemical qualities.

Similarly, soil Magnesium shows a significant difference ($P < 0.05$) where LSC recorded higher mean values as compared to MSC and USC. The soil Magnesium (Mg) mean value recorded for LSC, MSC, and USC was 33.36, 32.72, and 17.43 respectively. Nevertheless, there was no significant difference observed among LSC and MSC (Table 4). This is similar to [18], where soils below the gently sloping and inclined areas had higher exchangeable magnesium (Mg) content than the steeper slopes.

Study results also indicated that soil potassium (K) parameter analysis showed a significant difference ($P < 0.05$) among slope class gradients. Both LSC and MSC recorded a mean value of 1.5; but, USC recorded a mean value of 1.2 which is significantly different from the two slope gradient classes. This is similar to the study, by [16] where, higher mean exchangeable potassium (K) values were measured in soils on flat slopes than on steep slopes.

Soil sodium (Na) parameter analysis result also indicated that there is a significant difference observed ($P < 0.05$) among slope gradient classes (Table 4). The mean values of LSC, MSC, and USC differ significantly from each other; this shows that the slope classes have a strong influence on the available soil sodium (Na) in the study area. It is similar to [18], where soils below the gently sloping and sloping areas had higher exchangeable Na content than the steeper slopes.

Generally, the ultimate abundance of soil exchangeable basic cations was observed in the LSC due to downslope movement by runoff and erosion than higher slopes and accumulation in areas of lower slope gradients. Based on their mean values exchangeable base cations were ordered as Lower slope > Middle slope > Upper slope gradients. Many studies [4, 1, 14, 16, 18] also reported that the amount and distribution of most nutrients were higher on flatter slopes than on.

3.4.6. Soil Cation Exchange Capacity

Soil cation exchange capacity (CEC) was significantly ($P < 0.05$) affected by differences in slope gradient classes and are negatively correlated with increasing slope gradient (Table 4). A higher CEC was recorded in the LSC which was 32.02; whereas MSC and USC soils recorded 29.9 and 26.71 respectively. Soil cation exchange capacity was positively correlated with the organic matter. Soil CEC has a strong relationship with soil organic matter concentration, which is altered by various soil management practices [21]. Similarly, Teshome *et al.* [40] revealed that soil CEC values declined mostly owing to a decrease in organic matter content. This indicates that soil organic matter content was a major contributor to the presence of a high CEC. Therefore, this study suggests that soil organic matter might be the main factor affecting CEC in in the soil.

4. Conclusions

This study found that slope gradient has a substantial influence on the physicochemical properties of the soil. The findings of soil particles indicated that silt soil property was strongly impacted by slope gradient differences, even though sand and clay were not. Increased slope gradient has a detrimental impact on the chemical content of the soil in the studied location. However, the LSC and MSC had considerably greater proportions of soil chemical content, whereas the USC exhibited lower quantities. Soil chemical content analysis reveals that except for Phosphorus, EC, OM, TN, Ca, Mg, K, Na, and CEC were significantly different with distinct degrees. External factors that might impact soil variables within the research location include unlawful human and animal exertion on the forest, which poses an important issue for the conservation of both natural and established forests.

As a result of the rapidly rising human population, changing climate, and global warming, appropriate management of soil property in forests like Gara Ades is critical. The results of this study emphasized the necessity for further study regarding slope gradient and soil interactions in closed and open forest ecosystems in Ethiopia, which support grassland vegetation.

Principally, I recommend that implementing terracing techniques can significantly reduce soil erosion rates in hilly areas. Secondly, the use of cover plants was found to be effective in preventing soil erosion and improving soil health. Efforts to maintain and manage forests and grasslands should also be integrated. A study of long-term changes in soil physicochemical characteristics along different slope gradients in forest grasslands is essential to understand the ecological impact of slope gradients and to encourage sustainable soil and vegetation management. Additionally, this study highlights the importance of proper land management practices in alleviating soil erosion. Finally, it is also important to acknowledge the limitations of this study because this study was conducted in a specific geographical area on specific topographic gradients.

Conflict of Interest

The authors declared that there is no conflict of interest.

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Appendix

Figure A1. *Gara Ades forestland.*

Figure A2. *Materials and tools.*

Figure A3. *Soil sample collection.*

Figure A4. *Disturbing composite soil samples.*

Figure A5. *Segmenting disturbed soil samples.*

Figure A6. *Soil sample weighing.*

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