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Research Article

Impact of Elevation Change on the Physicochemical Properties of Forest Soil in South Omo Zone, Southern Ethiopia

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The assessment of the distribution of soil physicochemical properties provides basic information for our understanding of the soils to grow crops and sustain forests and grasslands. The changes in soil physicochemical properties along elevational gradients were studied in a less accessible Sida Forest, southern Ethiopia. Hence, the present study was conducted to assess the distribution of soil physicochemical properties along the elevational gradients and to evaluate the fertility status of the soil. Data on soil physicochemical properties were collected from five points (four from each corner and one from the center) of the main plot. A pit of 20 cm × 20 cm was dug at a depth of 0–30 cm and a kilogram of composite soil samples was brought to the Wolkite Soil Testing Laboratory for physicochemical analysis. The results revealed that the physicochemical properties of the collected soil samples show a significant correlation with elevation changes. Sand had a significantly negative correlation and variation with elevation; it decreases as elevation increases with the rate of correlation ($r = -0.44^{**}$, $P \leq 0.001$). However, silt had a nonsignificantly positive ($r = 0.20$, $P < 0.079$) correlation to the elevation, while clay had a significantly positive correlation to elevation, and it increases as elevation increases with the rate of correlation coefficient ($r = 0.40^{**}$, $P \leq 0.001$). Soil OC, OM, TN, CEC, and exchangeable Mg^{2+} had significant positive correlation to the elevation; they increase as elevation increases with the rate of correlation coefficient ($r = 0.42^{**}$, $P \leq 0.001$), ($r = 0.41^{**}$, $P \leq 0.001$), ($r = 0.44^{**}$, $P \leq 0.001$), ($r = 0.34^{**}$, $P < 0.002$), and ($r = 0.27^{*}$, $P < 0.014$), respectively. While BD, pH, EC, Av. P, exchangeable Ca^{2+}, and exchangeable K^{+} had a nonsignificant negative correlation to the elevation, they decrease as elevation increases with the rate of correlation ($r = -0.70^{**}$, $P < 0.134$), ($r = -0.20$, $P < 0.075$), ($r = -0.05$, $P < 0.683$), ($r = -0.04$, $P < 0.701$), ($r = -0.04$, $P < 0.693$), and ($r = -0.053$, $P < 0.693$), respectively. This study attempted to provide information on the impact of elevation on soil's physicochemical properties. Given that, the soil's physicochemical properties exhibit variation with elevation changes.

1. Introduction

Soil is a collection of natural bodies representing one of the most active and complex natural systems that support plants and have properties due to the integrated effect of climate and biological activities upon parent materials [1, 2]. Soil can influence plant community composition and physiological activities directly, and it is one of the key indexes in the functional recovery and maintenance of ecosystems. It is an essential component of nearly every ecosystem in sustaining the existence of many forms of life on earth, provides a medium for plant growth, supplies the organisms with most of their nutritional requirements, and regulates the environment [1, 3]. In addition, food, fodder, and fuel are provided for meeting basic human and animal needs [4]. In forest ecosystems, soil determines species composition, timber productivity, wildlife habitat, species richness, and diversity, maintaining water quality and long-term site productivity [5]. The ability of soil to support plant growth depends on its physicochemical and biological properties.

Soil is a heterogeneous unit and shows great variability in its physical and chemical properties. Soil properties varied significantly among soil types and across locations showing differences in parent materials, climate, and land use [6].

Knowledge of variation of soil properties is very essential as this determines the productivity and usage of the area. Soil characterization provides information for our understanding of the soils we depend on to grow crops and sustain forests and grasslands [7]. Forest stands are covered with different tree species and differ in litter quality and root exudates. These differences ultimately create variations in soil properties and may influence the soil microbial community [8]. Soil microbes regulate the decomposition rate, organic matter content, and physicochemical properties of forest soil [8, 9]. All soils have different properties, and working with them requires an understanding of these properties [10], and the assessment of soil quality requires a combination of physical, chemical, and biological factors. The physical and chemical characteristics of soil influence root distribution and the ability to extract water and nutrients [11]. The physical property of soil plays an important role in soil fertility because the amount and sizes of the soil particles determine the porosity and bulk density, which account for nutrient retention or leaching of nutrients [12]. The knowledge of the physicochemical properties of soil helps in managing resources while working with a particular soil [2]. Before implementing forest conservation or afforestation, it is essential to assess the soil factors, such as soil type, soil depth, soil texture, soil structure, pH, and soil nutrient dynamics of each vegetation type [11, 13]. Different factors significantly influence the physicochemical properties of the soil. Climatic variations such as increasing rainfall and decreasing temperature along the elevation gradient are the most important factors that have significant effects on soil properties [14, 15]. The other most critical forms of soil degradation are depletion of soil quality and soil erosion by water, loss of soil organic matter and reduction in soil biological activity, and increased toxicity due to acidification and salinization. As reported by Ambade et al. [16], Ambade et al. [17], Peng et al. [18], and Gereslassie et al. [19], the physicochemical qualities of the soil are affected by soil contamination by polycyclic aromatic hydrocarbons (PAHs). The primary sources of PAH emissions are fossil fuel and coal combustion, vehicle emission, and biomass/wood burning [20–24]. As reported by Ambade et al. [21] and Ambade et al. [22], the concentrations of this pollutant (PAHs) were reduced during the lockdown, due to the COVID-19 pandemic, because all activities (industry work, transport work, construction work, traffic movement, etc.) were closed. Kumar et al. [25] and Ambade et al. [26], indicated that the concentration of PAHs was higher in the winter season than in the summer season, and the health risk issue is higher in the winter season than in the summer season [27]. Various studies addressed the impact of elevation on soil physicochemical properties [3, 14, 15, 28–33], but there are limited data from forest ecosystems.

Soil, land, water, and forests are the basics of Ethiopia's economic development, food security, and livelihood sustenance. The diverse topography, climatic conditions, and geology of the country contributed to the diverse soil resources [33]. This soil resource in Ethiopia is considered an asset, but its management is considered a challenge. Soil degradation in Ethiopia is associated with the past use of fire to clear vegetation, charcoal production, and overcultivation/overgrazing, which causes billions of tons of soil removal every year [34–37]. In addition to this, slope steepness, deforestation, and unwise utilization of land are the factors in the loss of soil [38, 39]. Food insecurity and rural poverty in the African smallholder farming system are due to soil nutrient depletion [37]. Most previous studies carried out on the Ethiopia soils focused on potential agriculture areas, for master plan preparation and small-scale soil map preparation [40]. Thus, the soil in Ethiopia needs high attention on soil-specific management, which in turn requires a major investigation across the country. Knowledge of the geographical distribution of the soils and their physicochemical properties is necessary for policymakers to improve forestland management and increase the well-being of the population. Information on soil characteristics and their management requirements is mostly obtained through soil surveys and soil fertility evaluation can be carried out using field and laboratory diagnostic techniques [41]. To understand the relationships between soils and vegetation in forest ecosystems, it is necessary to identify and determine the factors that characterize their relationships. Thus, consistent monitoring of soil quality and the up-to-date status of soil properties is a very important tool for the management of forest ecosystems on a sustainable basis [42, 43]. The Sida natural forest is a less accessible and virgin forest, which comprises four vegetation types in Ethiopia: the Acacia-Commiphora woodland and bushland, Combretum-Terminalia woodland and wooded grassland, dry evergreen Afromontane forest and grassland complex, and the Riverine vegetation which is located on a steep slope. The local communities depend on this natural forest for medicine, wild food, fuel wood, timber, water, honey and livestock fodder, and other biodiversity-related benefits. However, there are no studies were done so far on the soil physicochemical properties that control the distribution and productivity of plant species in Sida forest. Thus, this study attempted to provide information on the impact of elevation on soil's physicochemical properties along the Sida forest's elevation gradients. The soil's physicochemical properties exhibit variation with elevational changes. These results can be helpful to scientists and forest managers to understand the interactive relationships between elevation, vegetation, and soil properties in forest ecosystems to implement protection plans, increase plant biodiversity, and restore forests.

2. Materials and Methods

2.1. Descriptions of the Study Site. This study was conducted in Benna-Tsemay district, south Omo zone, southern Ethiopia (Figure 1). The Benna-Tsemay district is located about 739 km away from the capital city of Ethiopia, Addis Ababa. The study district is located at 5°03′–5°34′ N and 36°33′–37°03′ E with altitudes ranging from 500 to 2400 m.a.s.l. The majority of the communities in the Benna-Tsemay district belong to Benna and Tsemay ethnic groups. Pastoralism and agropastoralism are the two main livelihood options in the study area. The livelihoods of these pastoralist

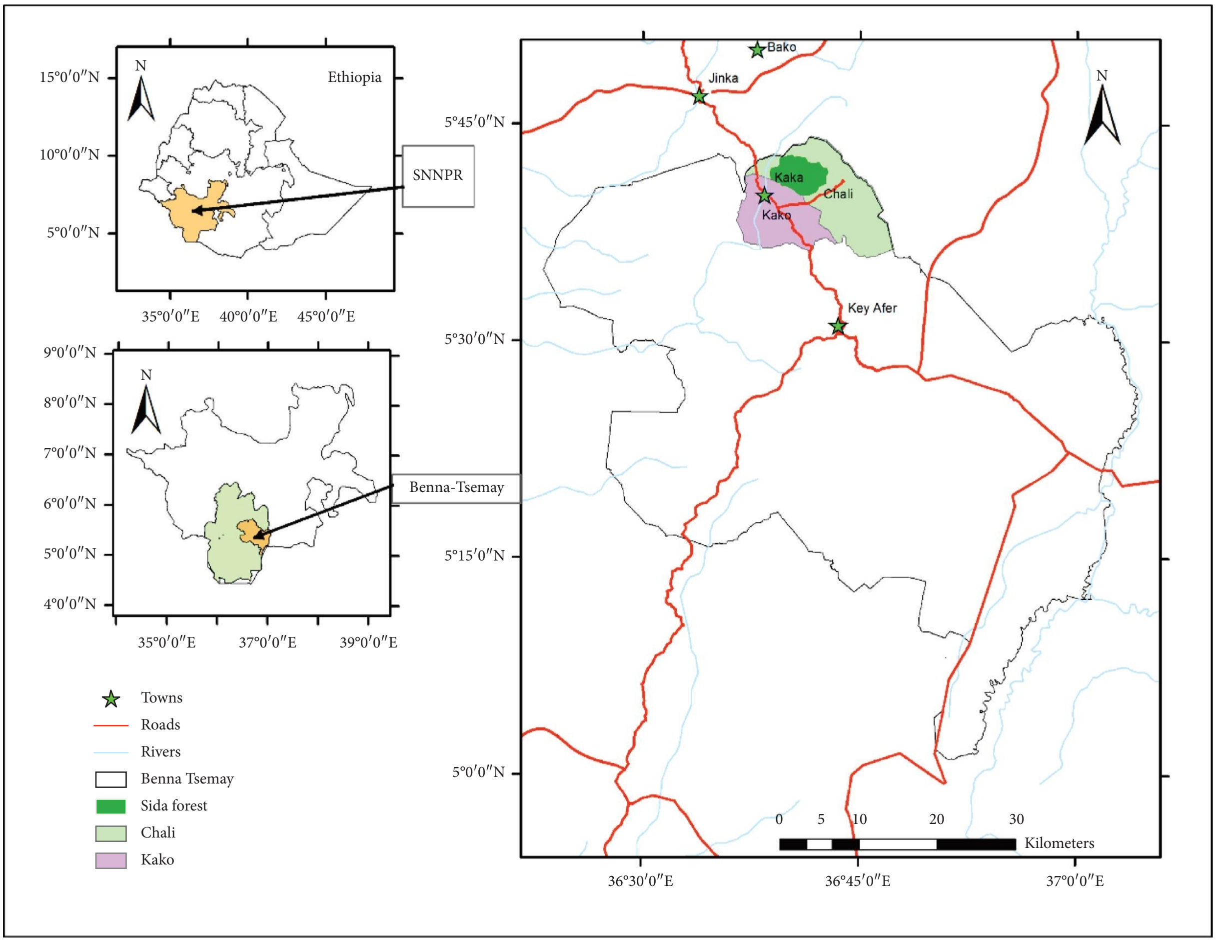

FIGURE 1: Map of Ethiopia showing the location of the study area, Benna-Tsemay districts in south Omo zone, southern Ethiopia.

communities are mainly the rearing of livestock, goats, and sheep and the use of their products and the agropastoralists are dependent on both livestock products and crop cultivation. The greater proportion of the study area is characterized by arid and semiarid climatic conditions. The major vegetation type of the study area belongs to Acacia-Commiphora woodland and Combretum-Terminalia woodland and wooded grassland [44].

The rainfall pattern of the study area is bimodal. The average annual precipitation of the district was 933 mm and the average annual temperature was 20.7°C. The dry season occurred from the beginning of December to the end of February. The long rainy period occurs from the end of March to the beginning of June and the short rainy season occurs between October and November. The average monthly maximum temperature of the warmest month is 30.2°C and the average monthly minimum temperature of the coldest month is 12.3°C (Figure 2).

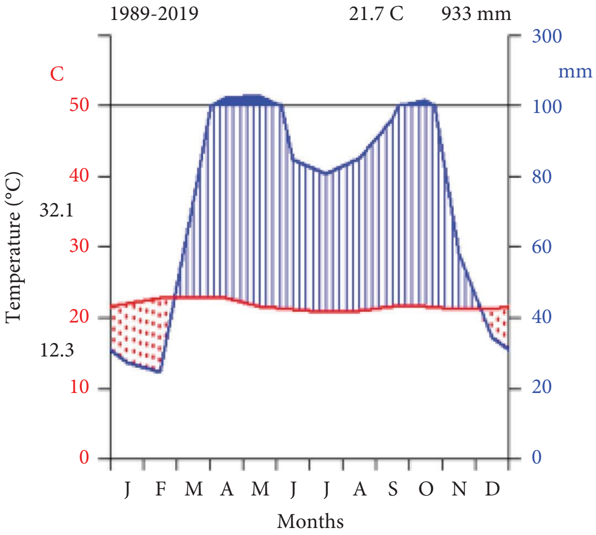

FIGURE 2: The climate diagram of the study district shows rainfall distribution and temperature variation from 1989 to 2019.

2.2. Soil Sample Collection and Preparation for Physicochemical Analysis

2.2.1. Soil Sample Collection. A total of eighty-two composite soil samples were collected from Sida natural forest having different elevation ranges (1500 to 2400 m.a.s.l.). Plots of 20 m × 20 m were laid systematically due to large size plots, to minimize biased sampling, and locations of the sample plots were recorded by GPS (global positioning system) coordinated at the center. Then, soil samples were collected from five places, four from each corner and one from the center of the main plot. At a depth of 0–30 cm, a 20 cm × 20 cm pit was dug, and various soil samples were collected. Then, the samples were mixed well to form a composite, and about a kilogram of samples was brought to Wolkite Soil Testing Laboratory using sterile polythene bags from each plot.

2.2.2. Soil Laboratory Analysis. The laboratory analyses (physical and chemical properties) were carried out following standard procedures. Accordingly, soil samples were air dried in a properly ventilated room on a plastic tray, and ground in a Wiley mill, to pass through a 2 mm sieve for all the soil parameters except for TN and OC passed through a 0.5 mm sieve to remove the coarser materials (root particles, rocks, and large organic materials). Then, the air-dried, ground, and sieved samples were labeled and stored in semiopen plastic bags to maintain a low air exchange until the physicochemical analysis. The laboratory analysis was carried out for both physical (particle size distribution) and chemical properties (pH-H_2O, electrical conductivity (EC), organic carbon (OC), organic matter (OM), total nitrogen (N), available phosphorus (P), cation exchange capacity (CEC), and exchangeable cations (Ca^{2+}, Mg^{2+}, and K^+)) of the soil.

For the analysis of soil texture classes, the Bouyoucos hydrometer method was used as suggested by Bouyoucos [45] and Kalra and Maynard [46], after destroying OM using hydrogen peroxide (H_2O_2). Soil color (dry) was determined using the Munsell soil color chart [47]. Bulk density (BD) was determined using the core-sample method as described by Blake and Hartge [48]. The soils from core samples were oven-dried at 105°C for 24 hours and the bulk density was calculated by dividing the masses of the oven-dry soils (g) by the respective volumes (cm^3) of the soil.

BD = $M2 - M1/V$, where BD is the dry soil bulk density (gm/cm^3), $M1$ is the weight of core (g), $M2$ is the weight of core + oven-dried soil (g), and V is the volume of the core (cm^3).

The soil pH (pH-H_2O) was determined in a 1 : 2.5 soil-to-water ratio using a pH meter as described by Webster [49]. The electrical conductivity (EC) of soils was determined in a soil: water ratio of 1 : 2.5 extract with the aid conductivity meter as described by Okalebo et al. [50]. The soil organic carbon (SOC) content was determined using the wet oxidation method with potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid medium [51], and the percent soil organic matter was obtained by multiplying the percent SOC by Van Bemmelen factor (1.724). Total nitrogen (TN) was determined following the Kjeldahl distillation method as described by Bremner [52]. The carbon-to-nitrogen ratio (C : N) was calculated from the ratio of soil organic carbon to total nitrogen. Available phosphorus was determined calorimetrically using a spectrophotometer after the extraction of the soil samples with 0.5 M sodium bicarbonate ($NaHCO_3$) at pH 8.5 following the Olsen method [53]. Cation exchange capacity (CEC) was determined titrimetric by repeated saturation using 1 M ammonium acetate (NH_4OAC) followed by washing, distilling, and titrating [54]. The exchangeable base cations were also extracted by saturating the soil sample using neutral 1 M NH_4OAC. Exchangeable Ca and Mg were determined from the extract using an atomic absorption spectrophotometer (AAS), while exchangeable K was determined from the same extract using a flame photometer (FP) [54].

2.3. Quality Control. Quality control is a method to minimize errors and raise accuracy and precision in all aspects of laboratory work. In this study, all the chemicals and reagents meet the purity standards set by the American Chemical Society (ACS), which is a high-quality chemical for laboratory use. All laboratory equipment (instruments) meets the standards for soil chemical and physical laboratory analysis. The equipment has been calibrated periodically, tested before use, maintained properly, and verified depending on their proposed use. The data were generated under statistical control by trained staff in the laboratory and each laboratory activity was done using standard procedures, following proper laboratory management. During soil testing standard operating procedures (SOPs), standardized methods, and standard solutions at specific (optimum) temperatures and pH ranges were used. Before taking the soil samples to the laboratories, the samples were checked for homogeneity, placed on a plastic tray, dried, and ground using mortar and pestle to pass through a 2 mm sieve. The duplicated samples were analyzed within one to five days after they are received at the laboratory and the soil test results were released immediately after sample analysis, and the remaining soil samples were stored for reference.

2.4. Statistical Analysis. The elevation of the study area varied from 1500 to 2410 meters above sea level and was classified into three different elevation classes. The three elevation classes are lower (1505–1800 m), middle (1800–2100 m), and higher (2100–2410 m). A global positioning system (GPS) was used to identify the site's elevation, longitude, and latitude. The data obtained from the laboratory analysis result were statistically analyzed and summarized as mean ± SE (standard error) in descriptive statistics. The analyses were conducted using the computer program IBM SPSS statistical software (version 26.0) package for Windows. Statistical differences between soil parameters and the three elevational ranges were tested using a one-way analysis of variance (ANOVA). Pearson correlation coefficient was carried out to assess the relationship between soil parameters and elevation ranges. A P value less than 0.05 ($P < 0.05$) was considered statistically significant.

3. Results and Discussion

3.1. Physicochemical Properties of the Soils

3.1.1. Soil Colours. All soil colours were determined under wet conditions and hue 7.5 YR was used for soil colour determination. The lower and middle elevations have colours ranging from 7.5 YR 4/2 (greyish brown) to 7.5 YR 2/2-3/1 (brownish black), while at higher elevations the soil colours were ranging from 7.5 YR 4/1–6/1 (brownish grey) to 7.5 YR 3/3-3/4 (dark brown). The majority (56.10%) of the soil in the study area was brownish black followed by brownish grey (31.71%) (Table 1). The colour of the soil is usually a reflection of the amount of organic matter present in the soil hence darker soils with brown/black colour indicate the presence of high amounts of organic matter as compared to those with greyish brown coloured soils.

3.1.2. Soil Texture (Sand, Silt, and Clay Proportions (%)).

In this study, the physical properties were determined from the particle size distribution. Particle size distribution was determined based on the relative proportion of sand, silt, and clay within the soil sample. The particle size distribution of the soil showed clear differences in that sand content was higher in all plots. The sand content ranged from 32% to 80%, the highest percentage (80%) was obtained at the lower elevation, while the least percentage (32%) was recorded at the higher elevation. The silt content of the soil sample ranged from 6% to 30%, the highest percentage (30%) was recorded at the higher elevation, while the least percentage (6%) was obtained from the lower and middle elevations. The clay content of the soil sample ranged from 2% to 43%; the highest percentage (43%) was recorded from the higher elevation, while the least percentage (2%) was recorded from the middle elevation.

The analysis of variance showed that there is no significant ($P < 0.05$) difference in the percentage of sand, silt, and clay concerning elevation. The correlation analysis revealed that there is a statistically significant negative correlation between sand and elevation ($r = -0.44^{**}$, $P \leq 0.001$); however, a nonsignificant positive ($r = 0.20$, $P < 0.079$) correlation exist between silt and elevation. While, the content of clay showed a statistically significant positive ($r = 0.40^{**}$, $P \leq 0.001$) correlation with elevation. Considering the three elevation gradients, the highest (69.17 ± 1.07) mean value of sand was recorded at the lower elevation and the least (60.38 ± 2.31) sand value was recorded at the higher elevation, indicating that the concentration of sand decreased along the elevational gradient. The highest (21.10 ± 1.95) mean value of clay was recorded at the higher elevation and the least (14.76 ± 0.94) value of clay was recorded at the lower elevation, showing that the clay concentration increased along the elevational gradient.

From the soil textural triangle, the texture class distribution of the soil varied from sandy loam to clay. The majority of the textural classes of the soils are sandy loam 48 (58.54%) followed by sandy clay loam 27 (32.93%) and clay loam 3 (3.66%), as indicated in Figure 3. The differences in textural class might be due to the difference in parent material, vegetation type, and pedogenic processes in the study area. The result indicated that sandy loam is the dominant texture class in the upper (0–30 cm) layer of the soil of the study area.

Table 1: Soil colour types of the study area.

Soil colours (hue 7.5 YR)	Lower	Middle	Higher	Total	%
Brownish grey (4/1–6/1)	9	10	7	26	31.71
Brownish black (2/2–3/2)	15	10	21	46	56.10
Greyish brown (4/2–6/2)	5	2	0	7	8.54
Dark brown (3/3-3/4)	0	2	1	3	3.66

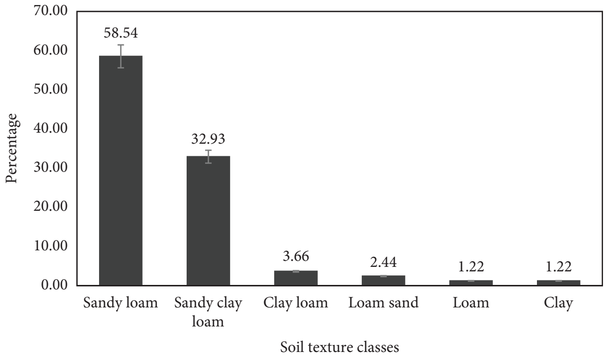

Figure 3: Soil textural class size distribution in the study area.

3.1.3. Bulk Density (BD) (gm/cm^3).

The bulk density value of the soils varied from 0.13 gm/cm^3 at the higher elevation to 0.54 gm/cm^3 at the lower elevation. The highest BD value was recorded at the lower elevation, while the least BD value was recorded at the higher elevation. The correlation analysis result revealed that BD showed a nonsignificant negative ($r = -0.70^{**}$, $P < 0.134$) correlation with elevation. The results of the analysis of variance indicated that there is no significant ($P < 0.05$) difference in BD along with an increase in elevation. The highest (0.46 ± 0.02) mean value of BD was recorded at the lower elevation, while the least BD was recorded at the middle (0.21 ± 0.01) and higher (00.15 ± 0.01) elevation, indicating a decreasing trend in BD along with an increase in elevation (Table 2).

3.2. Chemical Properties of the Soil

3.2.1. PH of the Soil.

The pH (1 : 2.5-H_2O) values throughout all the plots of the soils varied from 4.6 to 7.1 in the lower elevation (Table 3). The pH values had shown a tendency to decrease with an increase in elevation. The analysis of variance showed that there is no significant ($P < 0.05$) difference in pH value along with an increase in elevation. The Pearson correlation analysis revealed that soil pH was found to be nonsignificantly negative ($r = -0.20$, $P < 0.075$) correlation with elevation; however, there were slight numerical variations in the soil pH along with an increase in elevation. The lowest (5.98 ± 0.09) mean value of pH was recorded at the higher elevation, whereas the highest (6.13 ± 0.10) mean value was recorded at the lower elevation. This trend indicated that acidity increased along with an increase in elevation.

Table 2: The physical properties of the soil across the three elevation classes show the mean (mean ± SE), correlation coefficient (r), and significant level of the soil texture and bulk density.

Soil parameters	Elevation			Correlation coefficient (r)	Sig. (2 tailed)	$P < 0.05$
	Lower	Middle	Higher			
Sand	69.17 ± 1.07	67.29 ± 1.58	60.38 ± 2.31	-0.444^{**}	0.001	0.206
Silt	16.34 ± 0.85	16.67 ± 1.10	18.52 ± 1.00	0.195	0.079	0.808
Clay	14.76 ± 0.94	16.04 ± 1.29	21.10 ± 1.95	0.395^{**}	0.001	0.217
BD	0.46 ± 0.02	0.21 ± 0.01	0.15 ± 0.01	-0.697^{**}	0.001	0.134

**Significant at 0.01 level (2-tailed); *significant at 0.05 level (2-tailed).

Table 3: The chemical properties (pH, electrical conductivity, organic carbon, total nitrogen, C : N ratio, and available phosphorus (Av. P)) of the soil across the three elevation ranges.

Soil parameters	Elevation			Correlation coefficient (r)	Sig. (2 tailed)	$P < 0.05$
	Lower	Middle	Top			
pH	6.13 ± 0.10	6.02 ± 0.09	5.98 ± 0.09	−0.198	0.075	0.845
EC	158.24 ± 16.25	107.21 ± 13.20	145.06 ± 20.45	−0.046	0.683	0.241
OC	3.41 ± 0.42	2.75 ± 0.30	5.55 ± 0.71	0.416^{**}	0.001	0.036
OM	5.81 ± 0.71	4.68 ± 0.51	9.46 ± 1.25	0.411^{**}	0.001	0.037
TN	0.29 ± 0.04	0.23 ± 0.03	0.49 ± 0.06	0.436^{**}	0.001	0.030
C/N	11.82 ± 0.10	11.79 ± 0.06	11.78 ± 0.41	−0.048	0.671	0.001
Av. P	10.71 ± 1.05	12.10 ± 2.100	9.98 ± 1.68	−0.043	0.701	0.297

**Significant at 0.01 level (2-tailed); *significant at 0.05 level (2-tailed).

3.2.2. *Electrical Conductivity (Milisimese/Centimeter ($mScm^{-1}$)) of the Soil.*

The electric conductivity (EC) of the soil is used to estimate the soluble salts of aqueous soil extract. In this study, the EC of the soils ranged from $14\,\mathrm{mScm}^{-1}$ at the lower elevation to $630\,\mathrm{mScm}^{-1}$ at the higher elevation. The ANOVA result showed a nonsignificant ($P < 0.05$) difference in EC value along with an increase in elevation. The correlation analysis revealed that EC content was found to be nonsignificant negatively ($r = -0.05$, $P < 0.683$) correlated with elevation. EC did not show any significant variation along elevation gradients, even though relatively higher mean values were recorded at the lower (158.24 ± 16.2) and higher (145.06 ± 20.45) elevations than at the middle (107.21 ± 13.20) elevation (Table 3). There was no regular variation of EC along with elevational gradients except for a slight decrease at the middle elevation. The reason for the highest EC recorded in higher and lower elevations might be that it contains the highest amount of basic cations.

3.2.3. *Organic Carbon, Organic Matter, Total N, C/N Ratio, and Available Phosphorus.*

The organic carbon (OC) content of the soil differs among the three elevation ranges, showing an increasing trend with increasing elevation. The SOC of the study area varied from 0.78% in the lower elevation to 1.24% in the higher elevation. The correlation analysis result revealed that SOC showed a significant positive ($r = 0.42^{**}$, $P \leq 0.001$) correlation with elevation. The analysis of variance also showed that there is a significant ($P < 0.05$) difference in SOC along with an increase in elevation. Indicating that elevation had a significant impact on soil organic carbon, as elevation increase SOC also increase. Considering the three elevation classes, the highest (5.55 ± 0.7) mean value of SOC was recorded at the higher elevation, while the least (3.41 ± 0.42 and 2.75 ± 0.30) mean values were recorded at the lower and middle elevations respectively (Table 3). The amount of organic carbon contained in a particular soil is a function of the balance between the rate of deposition of plant residues in the soil and the rate of mineralization of the residue carbon by soil microbes [55].

The organic matter (OM) content varied from 1.31% at the lower elevation to 25.1% at the higher elevation indicating an increase along with the elevation gradient. The correlation analysis revealed that SOM showed a significant positive ($r = 0.41^{**}$, $P \leq 0.001$) correlation with elevation. The ANOVA result also showed that there is a significant ($P < 0.05$) difference in the content of SOM along with an increase in elevation. The highest (9.46 ± 1.25) mean value of SOM was recorded at the higher elevation, while the least (5.81 ± 0.71 and 4.68 ± 0.51) mean value of SOM was recorded at the lower and middle elevations, respectively (Table 3).

The total nitrogen (TN) content of the soils ranged from 0.06% at the lower elevation to 1.25% at the higher elevation. The correlation analysis result showed a significant positive ($r = 0.44^{**}$, $P \leq 0.001$) correlation of TN with elevation. In addition, the ANOVA result revealed that there is a significant ($P < 0.05$) difference in TN content with an increase in elevation, indicating that the total nitrogen content increased along with an increase in elevation. Based on the effect of elevation on soil TN across the different elevational ranges, the highest (0.49 ± 0.06) mean value of TN was recorded from the higher elevation, while the least was recorded from the lower (0.29 ± 0.04) and middle (0.23 ± 0.03) elevation (Table 3). The distribution pattern of TN with an elevational gradient was similar to that of OC and OM, showing an increasing trend along the elevation gradients.

Carbon to Nitrogen Ratio (C/N). The carbon to nitrogen ratio varied from 3.06 to 19.38 at the higher elevation. The correlation analysis revealed that the C/N ratio was found to be nonsignificant negatively ($r = -0.05$, $P < 0.671$) correlated with elevation. However, the ANOVA result showed that there is a significant ($P < 0.05$) difference in the C/N ratio with an increase in elevation. The highest (11.82 ± 0.10) mean value of the C/N ratio was recorded at the lower elevation, followed by the middle (11.79 ± 0.06) and higher (11.78 ± 0.41) elevation (Table 3), indicating a decrease in the C/N ratio along with an increase in elevation.

Available Phosphorus (Av. P). The available phosphorus values varied from 1.43 mg/kg at the middle elevation to 3.88 mg/kg at the lower elevation. The correlation analysis revealed that Av. P was found to be nonsignificant negatively ($r = -0.04$, $P < 0.701$) correlated with elevation. The ANOVA result also revealed that there is no significant ($P < 0.05$) difference in Av. P content along with an increase in elevation. However, there was a minor numerical variation in available phosphorus content along with an increase in elevation. Accordingly, the maximum (12.10 ± 2.10) mean value of Av. P was recorded at the middle elevation, followed by the lower (10.71 ± 1.05) and higher (9.98 ± 1.68) elevations (Table 3). The Av. P values had shown a general tendency to decrease with an increase in elevation.

3.2.4. Cation Exchange Capacity (CEC) (Milli Equivalent/100 g Soil (meq/100 g)). Cation exchange capacity is the capacity of the soil to hold cation nutrients and exchange cations. CEC content of the soil of the study area varied from 1.4 meq/100 g soil at the lower elevation to 49 meq/100 g soil at the higher elevation. The correlation analysis result revealed a significant positive ($r = 0.34^{**}$, $P < 0.002$) correlation between CEC and elevation. However, the ANOVA result indicated that there is no significant ($P < 0.05$) difference in CEC with an increasing elevation. However, there is a slight numerical variation among CEC content along with an elevational gradient. Accordingly, the highest (23.55 ± 2.06) mean value of CEC was recorded at the higher elevation, followed by the lower (17.96 ± 1.60) and middle (16.67 ± 1.14) elevation (Table 4). These showed that CEC content was changed in response to a change in elevation, an increase in elevation leads to an increase in CEC.

3.2.5. Exchangeable Base Cations (Milli Equivalent/100 g Soil (meq/100 g)). The exchangeable calcium (Ca^{2+}) contents of the soil varied from 0 meq/100 g of soil to 38 meq/100 g of soil at the lower elevation. The correlation analysis revealed that Ca^{2+} showed a nonsignificant negative ($r = -0.04$, $P < 0.693$) correlation with elevation. The ANOVA result also showed that there is no significant ($P < 0.05$) difference in Ca^{2+} concentration along with an increase in elevation. However, there is a slight numerical variation in exchangeable Ca^{2+} content along with the elevational gradients. The least mean value (7.67 ± 0.81) of Ca^{2+} was recorded at the middle elevation, whereas the maximum mean value was recorded at the lower (10.86 ± 1.45) and higher (9.76 ± 0.88) elevations (Table 4).

The exchangeable magnesium (Mg^{2+}) content of the soil varied from 0 meq/100 g of soil to 16 meq/100 g of soil at the higher elevation. The correlation analysis revealed that exchangeable Mg^{2+} showed a significant positive ($r = 0.27^{*}$, $P < 0.014$) correlation with elevation. However, the ANOVA result exhibited that there is no significant ($P < 0.05$) difference in Mg^{2+} content along with an increase in elevation. There was no regular variation of exchangeable Mg^{2+} content with an increase in elevation, the highest (8.52 ± 0.77) mean value of Mg^{2+} was recorded at the higher elevation, followed by the lower (6.55 ± 0.67) and middle (5.92 ± 0.71) elevation (Table 4).

The exchangeable potassium (K^{+}) content of the soil varied from 0.04 meq/100 g of soil to 2.3 meq/100 g of soil at the lower elevation. The correlation analysis revealed that exchangeable K^{+} was a nonsignificantly negative ($r = -0.053$, $P < 0.693$) correlation with elevation. The ANOVA result also showed that there is no significant ($P < 0.05$) difference in exchangeable K^{+} content along with an increase in elevation. However, there was a slight numerical variation in K^{+} along with an increase in elevation. The exchangeable K^{+} values had shown a tendency to decrease with an increase in elevation. Relatively, a higher (0.49 ± 0.09) mean value was recorded at the lower elevation, and the least mean value was recorded at the highest (0.47 ± 0.06) and middle (0.42 ± 0.097) elevation (Table 4). There was no regular variation of K^{+} along with the elevational gradients.

4. Discussion

4.1. The Physical Properties of the Soil

4.1.1. Soil Colours. The colours of the soil varied from greyish-brown to brownish-black. There was not much variation in soil colour along with an increase in elevation. The colours of the soil are usually a reflection of the amount of organic matter present in the soil hence darker soils with brown/black colours indicate the presence of high amounts of organic matter as compared to those with greyish-red coloured soils. The variations in soil colour might be due to variations in organic matter and soil texture [56]. On the other hand, a study report by Walia and Rao [57] indicated that soil colours look to be the function of chemical and mineralogical composition as well as textural makeup of the soils and are conditioned by topographic position and moisture regime. According to Mangalassery et al. [58], the variations in soil colours might be due to the differences in content and hydration of iron oxide and variation in mineral suites coupled with other dominant pedological features.

4.1.2. Soil Texture (Sand, Silt, and Clay Proportions (%)). The results of the study revealed that sand has the highest percentage (80%) followed by clay (43%) and silt (30%), indicating the dominance of sand-forming minerals in parent materials. The variations in soil texture may be due to differences in parent material, physiography, in situ weathering, and translocation of clay [59, 60]. The size class distribution directly influences the porosity and sand is the most porous that cannot retain water; however, clay has

Table 4: Cation exchange capacity (CEC) and exchangeable cations across the three elevation classes.

Soil parameters	Elevation Lower	Elevation Middle	Elevation Higher	Correlation coefficient (r)	Sig. (2 tailed)	$P < 0.05$
CEC	17.96 ± 1.60	16.67 ± 1.14	23.55 ± 2.06	0.337**	0.002	0.471
Ca^{2+}	10.86 ± 1.45	7.67 ± 0.81	9.76 ± 0.88	−0.044	0.693	0.387
Mg^{2+}	6.55 ± 0.67	5.92 ± 0.71	8.52 ± 0.77	0.271*	0.014	0.755
K^+	0.49 ± 0.09	0.42 ± 0.097	0.47 ± 0.06	−0.053	0.635	0.607

**Significant at 0.01 level (2-tailed); *significant at 0.05 level (2-tailed).

a good water retention capacity, which is an important factor in soil fertility and makes it more stable than other soil particles. Thus, clay particle is referred to as the nutrient storehouse and hold nutrient cations for nutrient exchange in the soil for plant uptake. In this study, there is no significant variation in silt content along the elevation gradient. However, sand content decreases along with an increase in elevation, whereas clay content increased with an increase in elevation. Yang et al. [61] and Charan et al. [62] indicated that climate, parent material, vegetation type, and pedogenic processes influence the textural class of the soil along with elevation changes. Hence, the soils of the study area have more proportion of coarse-grained soil particles, which indicates the slow process of soil formation.

The textural class of the soils varied from sandy loam to clay. About 58.54% of the sample tested soil texture classes were sandy loam. A study report by Defera et al. [63] showed that sandy loam is a dominant soil texture class in forest land. The differences in textural classes along an elevation gradient in the study area might be due to the difference in parent material, vegetation type, and pedogenic processes. According to Sireesha and Naidu [60], the variation in soil texture classes might be due to the differences in topography, in situ weathering, and translocation of clay by eluviation and age of soils. This texture class (sandy loam) has a very rapid infiltration rate and permeability (>120 mm/h) [64]. A study report by Charan et al. [62] indicates a similar result for soil texture classes.

Bulk density (BD) has a strong effect on porosity at field capacity and soil strength. In this study, BD has a significant correlation and variation with elevation, indicating that the value of BD decreased along with an increase in elevation, ranging from 0.13 gm/cm^3 to 0.542 gm/cm^3. Following the BD rating suggested by Hazelton and Murphy [64], the BD of the soils was within the range of very low (<1.0) in all elevations. Indicating bulk density was higher at a lower elevation than at the middle and higher elevation. This is associated with the high content of soil organic carbon, organic matter, and clay content at the higher elevation. The values of soil OC, OM, and clay were inversely proportional to BD, indicating that they increase as BD decreases and vice versa. A similar study reported by Saeed et al. [28] revealed that bulk density was higher at a lower elevation as compared to at a higher elevation. The possible reason for the low BD at the higher elevation was associated with high organic carbon, organic matter, and higher clay content [65, 66]. According to the study reported by Shiferaw et al. [67], the low BD at a higher elevation resulted from fewer disturbances, higher litterfall, and organic matter accumulation, while the highest BD value recorded at the lower elevations was due to high sand content and compaction of soil by grazing [37, 66, 68, 69]. Organic matter increased soil porosity and lowered bulk density [37, 70]. Thus, as BD increases the pore space of the soil decrease, and the soil particle compact together hampering the air and water circulation between soil pore spaces. However, in the study area, the value of BD was lower, indicating that the soil has better conditions for plant root growth and provides good aeration for microorganisms and good water retention capacity of the soil is an important factor in soil fertility.

4.2. The chemical properties of soil

4.2.1. Soil pH and Electrical Conductivity. In this study, the results showed a decreasing trend of soil pH along with an increased elevation. The pH values varied from 4.6 to 7.1. According to the pH rating suggested by Hazelton and Murphy [64], the pH of the soils was within the range of very strongly acid (4.5–5.0) to neutral (6.6–7.3). Evaluation of pH along elevational classes showed a tendency to decrease with an increase in elevation, indicating acidity increases with an increase in elevation. A similar study reported by Yimer et al. [71] indicated that the negative relationships of pH with elevation could be because increasing elevation increases rainfall and thus causes increased leaching and a reduction in soluble base cations leading to higher H^+ activity and registered as decreased pH levels. The difference in soil pH along with an increase in elevation is associated with changes in species richness and composition [72] and leaching of base cations due to more precipitation [73, 74]. Other similar studies also reported that soil pH decreased significantly along with an increase in elevation [75–77].

(1) Electrical Conductivity (EC). Salinity levels are usually determined by measuring the electric conductivity of soil/water suspensions. In this study, the EC value of the soils ranged from 14 $mScm^{-1}$ to 630 $mScm^{-1}$. Following the soil EC rating suggested by Seifu et al. [37], the EC content of the soils in the study area was within the range of moderately saline (8–16) to strongly saline (>16). The result indicated that there is no significant ($P < 0.683$) difference in salt accumulation along with increasing elevation. However, there is higher EC in the higher elevation followed by lower and middle elevations. The highest clay content in higher elevations holding nutrient cations for nutrient exchange in the soil for plant uptake contributes to higher EC. In agreement with this, Charan et al. [62] reported that the higher EC content of the soil in the higher elevation is linked

with higher clay content that contains a higher accumulation of base-forming cations, while the higher EC value in the lower elevation might be due to the highest amount of basic cations (base-forming cations) such as Ca^{2+}, Mg^{+2}, and K^{+}. In this regard, Charan et al. [62], described that lower elevations have more salt accumulation due to the highest amount of basic cations. In contrast to this, the lower EC value in the middle elevation might be due to the lowest amount of basic cations, which is removed by washing away basic cations by erosion and leaching. This result is in agreement with the result reported by Seyoum [78] who stated that the lowest EC of middle elevation could be associated with the loss of exchangeable bases by erosion and leaching.

4.2.2. Organic Carbon, Organic Matter, Total N, C/N Ratio, and Available Phosphorus. The soil organic carbon content showed a wide variation along the elevational gradient, varying from 0.78% to 1.24%. Following the soil OC rating suggested by Hazelton and Murphy [64], the SOC content of the soils in the study area was within the range of low (0.60–1.00) to moderate (1.00–1.80). The distribution of organic carbon exhibited that the content was lower at lower elevations and increased with an increase in elevation. The variation in organic carbon content is directly dependent on carbon input through plant residue decomposition and the amount of litter accumulated on the soil surface under different tree species. The reduction in organic carbon content could be related to the levels of disturbances, livestock grazing, vegetation cover change, increase in soil erosion rate, removal of woody species, and dominance of invasive species [14, 79]. Different vegetation and tree species with different characteristics have different litter decomposition processes leading to differences in organic carbon and nitrogen in the soil. This variation can be attributed to a different rate of organic matter decomposition, the activity of soil microorganisms, litter volume, root system, soil texture, and environmental factors such as temperature and species composition along the elevational gradient [55, 73, 79, 80].

Soil texture class influences SOC storage, the high SOC at the higher elevation is associated with an increase in clay and silt content than at the lower elevation. Similar results were reported in other studies by Charan et al. [62], Bhattacharyya et al. [81], and Saiz et al. [82] indicated that increasing clay and silt content suppresses microbial activity, reduces carbon leaching, and stimulates plant production via increasing water holding capacity and thus increases carbon inputs to the soil thus leads to an accumulation of SOC. Sandy soils had the lowest SOC stocks regardless of climate because of the low nutrient and water retention capacity as well as the poor structural characteristic of these soils [82].

The greater SOC content in the higher elevation was linked to less solar radiation, higher soil moisture, and lower temperature [83–86], which inhibited soil respiration and promoted the mineralization of organic matter. Higher amounts of precipitation lead to higher plant biomass production and OC inputs. Soil moisture positively mediated litter decomposition and litter biomass influences SOC and STN [87, 88]. Moreover, this increase of organic carbon at a higher elevation is associated with a shorter period of plant growth [14]. These results agree with previously reported studies where SOC was higher in colder and wetter areas as compared to hotter and drier areas [62, 64, 79, 89]. On the other hand, Bangroo et al. [90] indicated that soil in the shady area has high SOC than in sunny areas, due to higher soil moisture and lower temperature, and Xiang et al. [91] stated that SOC stocks were higher under the middle and high canopy density than those under low canopy density. According to Durán Zuazo et al. [92], the lower density of vegetation cover at the lower elevation could lead to a decrease in soil organic matter, increased runoff, erosion, and decreased organic carbon content. A significant increase in soil organic carbon with increasing elevation was also shown in other studies [14, 30, 85, 91, 93]. However, there is no clear pattern in the distribution of soil organic carbon along an elevational gradient. Studies by Segnini [94] and Kumar [95] indicated that organic carbon content decreased with increasing elevation due to a change in the rate of organic matter decomposition.

Soil organic matter (SOM) is the most reactive and powerful factor in the formation of soil and its fertility. Soil organic matter provides energy for biological processes, improves soil structural stability, influences water retention capacity, alters thermal properties, and contributes to the cation exchange capacity [10, 55, 96]. In this study, the SOM content increased with an increase in elevation, ranging from 1.31% to 25.1%. According to Hazelton and Murphy [64], the OM content of the soils in the study area was within the range of low (1.00–1.70) to very high (>5.15). The highest soil OM content was recorded at the higher elevation and the least was recorded at the lower and middle elevations. The high OM content at higher elevations is associated with soil texture [62] and clay soils contain more OM than sandy soils [89]. Poorly drained soils accumulate higher SOM than well-drained soils, due to poor aeration causing a decline in soil oxygen concentrations. Many soil microorganisms involved in decomposition are aerobic and will not function well under anaerobic conditions. In this study, the high OM content was associated with more clay content at the higher elevation [89]. The higher amount of precipitation in higher elevations naturally produced greater plant biomass that was quickly decomposed due to favorable temperature and moisture conditions, while dry and hot conditions in lower elevations suppressed the production of plant biomass and limited the accumulation of SOM [55]. In agreement with this a study result reported by Bhattacharyya et al. [81], Gupta and Germida [97], Walker et al. [98], and Karbozova-Saljnikov et al. [99] revealed that lack of water in the dry area, higher precipitation, and lower temperatures of higher elevation especially in winter when it falls below a threshold suppress microbial and enzymatic activities resulted in retarded mineralization of plant residues and limit the decomposition of SOM resulting in accumulation of OM.

Total nitrogen (TN) measures the total amount of nitrogen present in the soil, much of which is held in organic matter and is not immediately available to plants. The total nitrogen content of the study area ranged from 0.06% to 1.25%. According to the TN rating suggested by Hazelton and Murphy [64], the TN content of the soils of the study area was within the range of low (0.05–0.15) to very high (>0.5). In this study, the total nitrogen content is higher at high elevations than at middle and lower elevations, showing a significant increase with an increase in elevation. These results agree with previously reported studies by Han et al. [32] and Shedayi et al. [85] revealed that there is a significant increase in total nitrogen content with an increase in elevation. The higher nitrogen contents are attributed to the large supply of plant residue and the low temperature at a higher elevation. These results agree with the report by Saljnikov et al. [55] where TN was significantly higher in colder and wetter as compared to hotter and drier climates. While the reduction in soil TN content in the lower and middle elevations could be related to the level of disturbances, such as overgrazing, logging, firewood collection, and deforestation. In agreement with this, the studies reported by Tolessa and Senbeta [79], Demessie et al. [100], Peng et al. [101], and Gurmessa et al. [102] revealed that disturbances reduce the content of TN in the soil. On the other hand, Chinevu et al. [12] reported that reduction in aeration, higher compaction of soil, and conversion of nitrate to gaseous nitrogen by anaerobic soil microorganisms cause nitrogen losses. According to Gebreselassie et al. [103], the low TN content recorded might be due to the rapid mineralization of SOC and reduced input of plant residues. The increase in temperature will accelerate the decomposition of nitrogen in soil organic matter, which will affect soil availability of nitrogen. Similar studies by Han et al. [32] and Manning et al. [104] revealed that climate warming enhances the mineralization of soil organic matter, which contains most of the soil nitrogen.

The carbon-to-nitrogen ratio of the soil decreases along with an increase in elevation. The C/N ratio ranged from 3.06% to 19.38%. According to the C/N ratio rating suggested by Hazelton and Murphy [64], the C/N ratio of the soils in the study area was within the range of very low (<10) to medium (5–25). The carbon-to-nitrogen ratio measures the relative nitrogen content of organic materials. It can be measured for soil carbon or organic materials. The carbon-to-nitrogen ratio (C/N) is commonly used as an indicator of organic matter quality.

The Available Phosphorus (Av. P). The available phosphorus concentrations ranged from 1.43 mg/kg to 3.88 mg/kg. According to Hazelton and Murphy [64], the Av. P of the study area was within the range of very low (<5). In agreement with these Yimer et al. [71], reported that the lower levels of available phosphorus are due to increased phosphorus fixation, and more than half of the phosphorus content is stored in the tree biomass, hence the quantity and quality of litterfall are important factors on phosphorus content. There are variations in the Av. P content among the three elevation ranges, indicating a decrease in Av. P content with an increase in elevation. The higher Av. P content in the lower elevation than the middle and higher elevation is associated with an increase of organic carbon at a higher elevation. Lemenih and Itanna [27] revealed that an increase in organic carbon content at higher elevations could have resulted in low available phosphorus. A similar result reported by Pourbabaei et al. [14] indicated that variations of phosphorus at different elevations with differences in the nutrient content could be related to geological changes and the density of tree species.

4.2.3. Cation Exchange Capacity (CEC) and Exchangeable Cations (Ca^{2+}, Mg^{2+}, and K^+).

The cation exchange capacity (CEC) refers to the exchange of positively charged ions at the surface of negatively charged colloids. The higher the CEC, the more capable the soil can retain mineral elements [76]. The CEC status in the soil of the study area ranged from 1.4 meq/100 g of soil to 49 meq/100 g of soil. According to the CEC rating suggested by Hazelton and Murphy [64], the CEC of the soils was within the range of very low (<6) in the lower elevation to very high (>40) in the higher elevation, indicating an increase in CEC with an increase in elevation. According to Chinevu et al. [12], the higher the clay content of the soil, the higher the cation exchange capacity and the higher the fertility of the soil. The concentration of CEC is determined by the amounts of clay and humus present in the soil [12, 70]. Clay and humus substances are essential cation reservoirs of the soil; therefore, the high clay content with high content of organic matter in the higher elevation of the study area is associated with the high CEC, and the low CEC in the lower elevation is due to high sand soils with little organic matter. This result is in agreement with the findings of Brady and Weil [2], Chinevu et al. [12], and Ping et al. [70].

Exchangeable Base Cations. The decreases and losses of base cations from forest soils are primarily linked with downward leaching [105, 106], increased soil acidity, increased soil OM mobilization, soil compaction, and decreased cation exchange capacity associated with greater losses of base cations [107, 108].

Exchangeable potassium (K^+) contents were varied from 0.04 meq/100 g of soil to 2.3 meq/100 g of soil. According to the K^+ rating suggested by Hazelton and Murphy [64], the K^+ of the soils in the study area was within the range of very low (0–0.2) to very high (>2). The K^+ values show a tendency to decrease with an increase in elevation. Similar studies reported by Poubabaei et al. [14] and Sapkota [109] revealed that potassium decrease with an increase in elevation. The reduction in K^+ content with an increase in elevation is associated with its high leaching. Potassium does not combine with organic compounds of the soil and the increased base saturation (calcium and magnesium) along with elevation leads to easy leaching of K^+ from the soil [110]. A study reported by Tsui et al. [73] revealed that less leaching of soil at lower elevations can be a source of accumulation of soluble ions, including potassium.

Exchangeable calcium (Ca^{2+}) contents were varied from 0 meq/100 g of soil to 38 meq/100 g of soil. Following Hazelton and Murphy [64], the Ca^{2+} of the soils was within

Table 5: Pearson's correlation coefficient (r) for selected soil physicochemical parameters and elevation.

	Correlations															
	Elevation	pH	EC	OC	OM	TN	C/N	Av. P	CEC	Ca^{2+}	Mg^{2+}	K^+	BD	Sand	Clay	Silt
Elv.	1															
pH	0.198	1														
EC	−0.046	0.201	1													
OC	0.416^{**}	0.002	0.168	1												
OM	0.411^{**}	−0.001	0.154	1.000^{**}	1											
TN	0.436^{**}	−0.014	0.156	0.978^{**}	0.978^{**}	1										
C/N	−0.048	0.078	0.349^{**}	−0.041	−0.06	−0.21	1									
Av. P	−0.043	0.043	−0.02	-0.313^{**}	0.311^{**}	0.316^{**}	0.017	1								
CEC	0.337^{**}	0.004	0.238^{*}	0.711^{**}	0.708^{**}	0.706^{**}	0.021	0.295^{**}	1							
Ca^{2+}	−0.044	0.412^{**}	0.345^{**}	0.531^{**}	0.528^{**}	0.519^{**}	−0.092	−0.18	0.638^{**}	1						
Mg^{2+}	0.271^{*}	−0.093	0.236^{*}	0.391^{**}	0.389^{**}	0.386^{**}	0.078	-0.241^{*}	0.537^{**}	0.168	1					
K^+	−0.063	0.389^{**}	0.379^{**}	−0.051	−0.06	−0.07	0.241^{*}	0.274^{*}	−0.04	0.041	−0.1	1				
BD	-0.697^{**}	0.002	0.119	−0.119	−0.11	−0.13	−0.019	−0.03	−0.14	0.142	−0.1	−0.064	1			
Sand	0.444^{**}	0.17	0.015	-0.597^{**}	0.597^{**}	0.627^{**}	0.145	0.280^{*}	0.610^{**}	−0.187	-0.278^{*}	−0.031	0.219^{*}	1		
Clay	0.395^{**}	−0.06	−0.05	0.683^{**}	0.684^{**}	0.684^{**}	−0.075	0.375^{**}	0.607^{**}	0.257^{*}	0.280^{*}	−0.124	0.185	-0.851^{**}	1	
Silt	0.195	−0.2	0.056	0.061	0.06	0.118	−0.157	0.051	0.215	−0.024	0.09	0.251^{*}	0.096	-0.560^{**}	0.05	1

Elv. = elevation, EC = electric conductivity; OC = organic carbon; OM = organic matter; TN = total nitrogen; C/N = carbon to nitrogen ratio; Av. P = available phosphorus; CEC = cation exchange capacity; K^+ = exchangeable potassium; Ca^{2+} = exchangeable calcium; Mg^{2+} = exchangeable magnesium; BD = bulk density; **significant at $P < 0.01$; *significant at $P < 0.05$ between soil properties and elevation.

Table 6: Pearson's correlation coefficient (r) for soil physicochemical parameters and elevation.

		Correlations															
		Elevation	pH	EC	OC	OM	TN	C/N	Av. P	CEC	Ca^{2+}	Mg^{2+}	K^+	BD	Sand	Clay	Silt
Elv.	Pearson correlation	1	−0.198	−0.046	0.416**	0.411**	0.436**	−0.048	−0.043	0.337**	−0.044	0.271*	−0.063	−0.697**	−0.444**	0.395**	0.195
	Sig. (2-tailed)		0.075	0.683	0.001	0.001	0.001	0.671	0.701	0.002	0.693	0.014	0.574	0.001	0.001	0.001	0.079
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
pH	Pearson correlation	−0.198	1	0.201	0.002	−0.001	−0.014	0.078	0.043	0.004	0.412**	−0.093	0.389**	0.002	0.170	−0.060	−0.200
	Sig. (2-tailed)	0.075		0.070	0.983	0.993	0.898	0.488	0.701	0.972	0.001	0.406	0.001	0.988	0.128	0.594	0.072
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
EC	Pearson correlation	−0.046	0.201	1	0.168	0.154	0.156	0.349**	−0.024	0.238*	0.345**	0.236*	0.379**	0.119	0.015	−0.052	0.056
	Sig. (2-tailed)	0.683	0.070		0.132	0.167	0.161	0.001	0.834	0.031	0.002	0.033	0.001	0.289	0.892	0.644	0.620
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
OC	Pearson correlation	0.416**	0.002	0.168	1	1.000**	0.978**	−0.041	−0.313**	0.711**	0.531**	0.391**	−0.051	−0.119	−0.597**	0.683**	0.061
	Sig. (2-tailed)	0.001	0.983	0.132		0.001	0.001	0.714	0.004	0.001	0.001	0.001	0.649	0.287	0.001	0.001	0.586
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
OM	Pearson correlation	0.411**	−0.001	0.154	1.000**	1	0.978**	−0.056	−0.311**	0.708**	0.528**	0.389**	−0.055	−0.114	−0.597**	0.684**	0.060
	Sig. (2-tailed)	0.001	0.993	0.167	0.001		0.001	0.618	0.004	0.001	0.001	0.001	0.625	0.309	0.001	0.001	0.592
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
TN	Pearson correlation	0.436**	−0.014	0.156	0.978**	0.978**	1	−0.214	−0.316**	0.706**	0.519**	0.386**	−0.065	−0.130	−0.627**	0.684**	0.118
	Sig. (2-tailed)	0.001	0.898	0.161	0.001	0.001		0.054	0.004	0.001	0.001	0.001	0.564	0.245	0.001	0.001	0.292
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
C/N	Pearson correlation	−0.048	0.078	0.349**	−0.041	−0.056	−0.214	1	0.017	−0.021	−0.092	0.078	0.241*	−0.019	0.145	−0.075	−0.157
	Sig. (2-tailed)	0.671	0.488	0.001	0.714	0.618	0.054		0.882	0.849	0.411	0.484	0.029	0.865	0.195	0.502	0.159
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
Av. P	Pearson correlation	−0.043	0.043	−0.024	−0.313**	−0.311**	−0.316**	0.017	1	−0.295**	−0.182	−0.241*	0.274*	−0.026	0.280*	−0.375**	0.051
	Sig. (2-tailed)	0.701	0.701	0.834	0.004	0.004	0.004	0.882		0.007	0.102	0.029	0.013	0.816	0.011	0.001	0.647
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
CEC	Pearson correlation	0.337**	0.004	0.238**	0.711**	0.708**	0.706**	−0.021	−0.295**	1	0.638**	0.537**	−0.039	−0.135	−0.610**	0.607**	0.215
	Sig. (2-tailed)	0.002	0.972	0.031	0.001	0.001	0.001	0.849	0.007		0.001	0.001	0.726	0.227	0.001	0.001	0.052
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
Ca^{2+}	Pearson correlation	−0.044	0.412**	0.345**	0.531**	0.528**	0.519**	−0.092	−0.182	0.638**	1	0.168	−0.041	0.142	−0.187	0.257*	−0.024
	Sig. (2-tailed)	0.693	0.001	0.002	0.001	0.001	0.001	0.411	0.102	0.001		0.130	0.711	0.203	0.092	0.020	0.830
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
Mg^{2+}	Pearson correlation	0.271*	−0.093	0.236*	0.391**	0.389**	0.386**	0.078	−0.241*	0.537**	0.168	1	−0.103	−0.095	−0.278*	0.280*	0.090
	Sig. (2-tailed)	0.014	0.406	0.033	0.001	0.001	0.001	0.484	0.029	0.001	0.130		0.358	0.393	0.011	0.011	0.422
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
K^+	Pearson correlation	−0.063	0.389**	0.379**	−0.051	−0.055	−0.065	0.241**	0.274**	−0.039	−0.041	−0.103	1	−0.064	−0.031	−0.124	0.251**
	Sig. (2-tailed)	0.574	0.001	0.001	0.649	0.625	0.564	0.029	0.013	0.726	0.711	0.358		0.566	0.780	0.267	0.023
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
BD	Pearson correlation	−0.697**	0.002	0.119	−0.119	−0.114	−0.130	−0.019	−0.026	−0.135	0.142	−0.095	−0.064	1	0.219**	−0.185	−0.096
	Sig. (2-tailed)	0.001	0.988	0.289	0.287	0.309	0.245	0.865	0.816	0.227	0.203	0.393	0.566		0.048	0.097	0.390
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
Sand	Pearson correlation	−0.444**	0.170	0.015	−0.597**	−0.597**	−0.627**	0.145	0.280*	−0.610**	−0.187	−0.278*	−0.031	0.219*	1	−0.851**	−0.560**
	Sig. (2-tailed)	0.001	0.128	0.892	0.001	0.001	0.001	0.195	0.011	0.001	0.092	0.011	0.780	0.048		0.001	0.001
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
Clay	Pearson correlation	0.395**	−0.060	−0.052	0.683**	0.684**	0.684**	−0.075	−0.375**	0.607**	0.257*	0.280*	−0.124	−0.185	−0.851**	1	0.051
	Sig. (2-tailed)	0.001	0.594	0.644	0.001	0.001	0.001	0.502	0.001	0.001	0.020	0.011	0.267	0.097	0.001		0.647
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
Silt	Pearson correlation	0.195	−0.200	0.056	0.061	0.060	0.118	−0.157	0.051	0.215	−0.024	0.090	0.251*	−0.096	−0.560**	0.051	1
	Sig. (2-tailed)	0.079	0.072	0.620	0.586	0.592	0.292	0.159	0.647	0.052	0.830	0.422	0.023	0.390	0.001	0.647	
	N	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82

**Correlation is significant at the 0.01 level (2-tailed); *correlation is significant at the 0.05 level (2-tailed).

the range of very low (0–2) to very high (>20). There were variations among the Ca^{2+} content along with the elevational gradient. The higher Ca^{2+} content was recorded in the lower elevation and the least was recorded in the higher and middle elevations. Similar studies by Wang et al. [75] and Sapkota [109] indicated that the content of exchangeable Ca^{2+} decreased with an increase in elevation.

Exchangeable magnesium (Mg^{2+}) contents varied from 0 meq/100 g of soil to 16 meq/100 g of soil at the higher elevation. According to Hazelton and Murphy [59], the Mg^{2+} content of the soils was within the range of very low (0–0.3) to very high (>8). It is found that exchangeable magnesium contents of soils showed a significant difference with elevation. A similar study reported by Sapkota [109] revealed that Mg^{2+} showed a significant difference with elevation. The concentration of exchangeable Mg^{2+} showed a significant increase along with an increase in elevation.

4.3. Pearson's Correlation Analysis for Selected Soil Physicochemical Parameters with Elevation. A diverse range of correlations was recorded among different soil variables with elevation. The result of Pearson's correlation revealed that different soil variables were significantly correlated with elevation and with each other. Elevation was positively correlated with soil OC, OM, TN, CEC, exchangeable Mg^{2+}, clay, and silt. However, pH, EC, C/N ratio, Av. P, exchangeable Ca^{2+}, exchangeable K^+, BD, and sand were negatively correlated with elevation. The pH had a positive and nonsignificant correlation with the EC ($r = 0.201$, $P < 0.070$), OC ($r = 0.002$, $P < 0.983$), C/N ($r = 0.078$, $P < 0.488$), Av. P ($r = 0.043$, $P < 0.701$), CEC ($r = 0.004$, $P < 0.972$), BD ($r = 0.002$, $P < 0.988$), and ($r = 0.170$, $P < 0.128$). While exchangeable Ca^{2+} and K^+ had a positive and highly significant relationship ($r = 0.412^{**}$, $P \leq 0.001$) ($r = 0.389^{**}$, $P \leq 0.001$) with pH, respectively. However, OM ($r = -0.001$, $P < 0.993$), TN ($r = -0.014$, $P < 0.898$), exchangeable Mg^{2+} ($r = -0.093$, $P < 0.406$), clay ($r = -0.060$, $P < 0.594$) and silt ($r = -0.200$, $P < 0.072$) had negative and nonsignificant correlation with pH. Organic carbon had a positive significant correlation with OM ($r = 1.000^{**}$, $P \leq 0.001$), TN ($r = 0.978^{**}$, $P \leq 0.001$), CEC ($r = 0.711^{**}$, $P \leq 0.001$), exchangeable Ca^{2+} ($r = 0.531^{**}$, $P \leq 0.001$), exchangeable Mg^{2+} ($r = 0.391^{**}$, $P \leq 0.001$), and clay ($r = 0.683^{**}$, $P \leq 0.001$), while positive and nonsignificant correlation with pH ($r = 0.002$, $P < 0.983$), EC ($r = 0.168$, $P < 0.132$), and silt ($r = 0.061$, $P < 0.586$). However organic carbon had a negative significant correlation with Av. P ($r = -0.313^{**}$, $P < 0.004$) and sand ($r = -0.597^{**}$, $P < 0.001$) but a negative nonsignificant correlation with C/N ($r = -0.041$, $P < 0.714$), exchangeable K^+ ($r = -0.051$, $P < 0.649$), and BD ($r = -0.119$, $P < 0.287$) (Table 5).

The significant relationship of soil physicochemical parameters with elevation can be seen in Table 5 and for their *P* value refer Table 6.

5. Conclusions

The soil's physicochemical properties exhibit variations in relation to changes in elevation. In this study, the effect of elevation variation on the physicochemical properties/qualities of the soil was analyzed and the results revealed that the elevation changes had a significant impact on the physicochemical properties of the soil. The highest percentage of sand was recorded at the lower elevation, while the highest percentage of clay and silt was recorded at the higher elevation. The evaluation of soil properties indicated that the values of some soil physicochemical properties were increased with increasing elevation. The concentration of soil organic carbon, organic matter, total nitrogen, and cation exchange capacity increases along with an increase in elevation. This is due to the different rates of organic matter decomposition, the activity of soil microorganisms, litter volume, root system, soil texture, and environmental factors such as temperature and plant species composition. While the highest bulk density, pH, and electric conductivity values were recorded at the lower elevation, indicating a decrease with an increase in elevation. This is due to high sand content and livestock trampling causing an increased bulk density, and an increased rainfall in higher elevations causes leaching of base cations and decreased pH levels. However, there was no regular variation in the content of available phosphorus and exchangeable bases (Ca^{2+}, Mg^{2+}, and K^+) along the elevational gradients. The result of Pearson's correlation revealed that the different soil variables were significantly correlated with each other and with elevation. Elevation was positively correlated with soil OC, OM, TN, CEC, exchangeable Mg^{2+}, clay, and silt, while pH, EC, C/N ratio, Av. P, exchangeable Ca^{2+}, exchangeable K^+, BD, and sand were negatively correlated with elevation. Finally, this study provides information on the impact of elevation on soil's physicochemical properties along the elevation gradients. However, the variation in soil physicochemical properties of the Sida Forest is not only related to elevation change but also related to other factors including changes in vegetation, soil erosion, grazing, and other factors.

Data Availability

The data presented in this study are available on request from the corresponding author.

Disclosure

The funding sponsor (Addis Ababa University) had no role in the design of the study, data collection, analyses, interpretation of the data, in the writing of the manuscript, and in the decision to publish the results.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

MB designed the study, carried out the data collection, designed the experiments, performed the experiments, analyzed and interpreted the data, and wrote the manuscript.

ZW, ZA, and EL revised the manuscript critically and made considerable input for its enrichment to the present form. All authors read and approve the manuscript to reach its final form and agreed on its submission.

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