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The impact of land use practice on the spatial variability of soil physicochemical Properties at Wondo Genet, Southern Ethiopia

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Abstract

The present research deals with changes that occurred in physical, chemical, and microbiological soil qualities due to different land-use practices. Soil samples were taken from three nearby soil plots with varying land uses, including natural forest, plantation forest, and agricultural land at both 0–30 and 30-60 cm soil depth and at each land-use category, fifteen samples were taken for each land use type. Total nitrogen, soil organic carbon, and microbial biomass were determined by the micro-Kjeldahl method, and fumigation extraction method, respectively. Using kriging interpolation techniques in a GIS framework, geostatistical analysis was done to depict the spatial variability of soil parameters. The result shows that among all land use patterns the highest bulk density was recorded from agricultural land /Khate farm (0.96±0.018%) followed by plantation forest /Cupressus (0.93±0.012%) and NF (0.81±0.03%). Soil organic carbon was found to be higher in Natural forest (4.25±0.28%) followed in decreasing order by plantation forest/Podocarpus (2.77±0.49%) and agricultural land/Coffee (2.92±0.16%). Soil Total nitrogen was higher in Natural forest (0.37±0.024 μg/g) in the soil's uppermost layer and significant with PF and agricultural land. Microbial biomass carbon was higher in Natural forest (939.84±46.0μg/g) and plantation forest /Grevillea (712.8±48.4μg/g) and agricultural land /Enset (570.2± 38.8μg/g). Similarly, microbial biomass N was higher in Natural forest (81.0.4±3.9μg/g) and significant with plantation forest /Gravellea (60.08±4.2μg/g) and agricultural land /Enset (40.96± 3.3μg/g). The result of the present study indicates that the microbial biomass and physicochemical properties of soil are highly correlated with the type of vegetation and soil depths.

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1. Introduction

To fulfill the world's expanding food demand, particularly in emerging nations, the necessity to enhance agricultural productivity should be gradually improved. The expansion of agricultural land should also be systematically managed and integrated with the existing natural resources conservation systems [1][2][3]Globally, land-use change and inappropriate resource exploitation result in a 0.6 percent annual loss of forest cover [1][4][5][6].

The key mechanisms involved in nutrient transformation and cycling, soil organic maintenance, and macro aggregation for optimum water and aeration are all controlled by the soil microbial biomass[7][8]. It is a significant nutrient labile pool in the soil, accounting for 1–5% of organic carbon and more than 5% of total nitrogen[9][10]. The quantity of microorganisms present in the soil affects the nutritional status and transformation of the soil[2]. These microorganisms are important for the breakdown of plant and animal residues and the release of nutrients[11], and their activities are very susceptible to management measures including irrigation, fertilizer application, and conventional tillage [12][13][14]. As a result, the amount of soil microorganisms is a key determinant of soil health [15][16]. Forest cover with native and nonnative species influences soil's physical and chemical qualities, as well as the ecology and economics[17][18]. The transformation of forestland to agricultural land to meet the global economy impacts not only climate change but also the dynamics of soil organic matter, biodiversity, and change in ecosystem services in general [19]. Specifically, it also strongly impacts soil functions[20][21][22][23], particularly microorganism activity, nitrogen, soil organic carbon, and other soil physical properties [24]. Massive collection of wood and non-timber forest resources, overgrazing[25], and land-use pattern changes are important factors of land degradation, which modify soil quality and vegetative cover and disruptions or even inhibits natural forest regeneration[26][27].

During the last two decades, conversion of land use, for example, from natural to cultivated ecosystems, is a common process throughout the world[28][29][14], particularly in the tropics. Several scholars focused on tropical ecosystems due to increasing anthropogenic disturbances, decreasing C budgets[18][30], and the land-use change affecting the forest ecosystem in these regions. Moreover, dry and rainy seasons are two extreme conditions in tropical ecosystems which have a major influence on productivity, nutrient cycling and microbial biomass, and physicochemical properties of soil [23]. Hardwood forests area has been converted to farmland at an alarming rate in recent decades due to increased demand for firewood, timber, pasture, food, and residential dwelling [31].

In recent decades, ecologists have focused their attention on soil SOC, microbial features, and microbial activity due to the effect of the land-use shift from natural forest to agricultural land and plantation[32][33]. Total soil quality, including physicochemical and microbiological performance, has been recognized as a driver of soil organic matter[23][34]. To put it another way, the physicochemical qualities of the soil are inextricably tied to soil organic matter [35]. The soil microbial properties respond more readily to soil disturbance in any ecosystem compared to soil chemical or physical properties[36][37]. Therefore, any change in microbial properties can be used as a sensitive index for soil disturbance. Several studies have shown that land-use change has a significant impact on the soil microbial community, particularly in temperate regions.

Transformation of natural forests into other land-use types is common in tropical countries like Ethiopia, and it causes not only climate change, biodiversity loss, and changes in ecosystem services, but also affects soil physicochemical and biological properties[26][37]. The study area was also recognized as one of the most forested areas in the country. The region once inhabited by natural ecosystems has been converted to new land uses, such as plantation forests and agricultural fields, due to a requirement for economic gain (mostly cash crops). Plantations are frequently formed following forest clear-cutting to supply demand for lumber, whereas agricultural areas are largely utilized to cultivate cash crops and food staples.

The application of appropriate management approaches for sustained agricultural production necessitates timely and reliable soil information; however, the source of spatial knowledge on soil microbiological and physicochemical parameters at the smallholder farming level is severely restricted [38]. Geospatial technologies have tremendous promise in soil data collection and analysis and have opened up new avenues for enhancing soil information by providing an expedited, repeated, spatio-temporal perspective. GIS and remote sensing are useful methods for assessing large amounts of geographical problems and can enable spatial analysis; hence, there is indeed a tremendous opportunity to enhance the accuracy of soil surveys via the use of GIS and remote sensing technologies.

Therefore the main objective of the present study is to assess the effect of land-use change and analyze and map the spatial variations in soil microbial and physicochemical properties at different land-use practices in Rift Valley, Ethiopia. To achieve these objectives, the present study has evaluated changes in the physicochemical and microbial properties due to the transformation of natural forests into plantation forests, agricultural land, and other land-use types.

2. Methods and Materials

2.1. Description of the study area

The research was carried out in the Wendo Genet watershed, Wondo Genet, Ethiopia. Wondo Genet has situated 263 km from the capital Addis Ababa, 38 km from the regional capital Hawassa and 13 km from the nearby town of Shashemene, West Arsi zone in Oromia Regional State. It is located between $7^0$02'-$7^0$07'N latitude and $38^0$37' and 38^0 42' E longitude

(Figure 1). The area falls within an altitudinal range of 1600 and 2500 m.a.s.l. The area comprises a series of hills that are the southwestern spur of the Bale Mountains. The agro-climatic zone of the district is traditionally categorized under Woyna-Dega (mid-highland). The area receives a bimodal rainfall pattern (short rains between February and April, and long rains between June and September) with a total annual rainfall ranging between 700 and 1400mm [39]. Based on the vegetation cover, the research area was divided into three principal sites these include agricultural land, natural, and plantation forest.

According to [40] the main parent materials are volcanic deposits of ignimbrite, ash, lava, and tuff. The geological bedrock of the area consists of mainly acidic rocks, sometimes interbedded with lavas of basaltic composition, probably of tertarian origin [41]. The soil of the study area is identified to be Mollic Andosol. Andosol is characterized by having soil bulk density of less than 0.9 kg dm-3, more clay and an Alox, high phosphate retention of 70 percent or more; and volcanic glass content in the fine earth fraction of less than 10 percent; and thickness of at least 30 cm[42][43]. The soil pH of the study area varies between 5.6 and 6.5.

Natural Forest land

This is an area of land that is made up of bigger trees that are generally taller than 3 meters and have a canopy cover of more than 30% [44]. This land-use category accounts for 405 hectares (14.3 percent) of the total watershed area (Figure 1). The physical, chemical, and microbiological qualities of soil can be influenced by the kind of land and plants.

Plantation forest

An area of the land consisting of planted trees mostly*Euqlyputus, Podocarpus, Cupressus, and Gravillea*. This land-use category accounts for 405 hectares (14.3 percent) of the overall catchment areas (Figure 1). The land and forest restoration taking place in this land cover type may have an impact on the physicochemical and microbiological soil properties.

Agricultural Land

An area of land designed for producing irrigated cash crops such as khat, enset, coffee, and sugarcane, as well as other crops, with river water. In addition, irrigated maize, onion, tomato, potato, carrot, and other crops are grown by the local community. Farmland accounts for 174 hectares (6.2 percent) of the overall study area (Figure 1). The use of chemical fertilizers regularly and intense land cultivation may influence the physical, chemical, and microbiological elements of the soil.

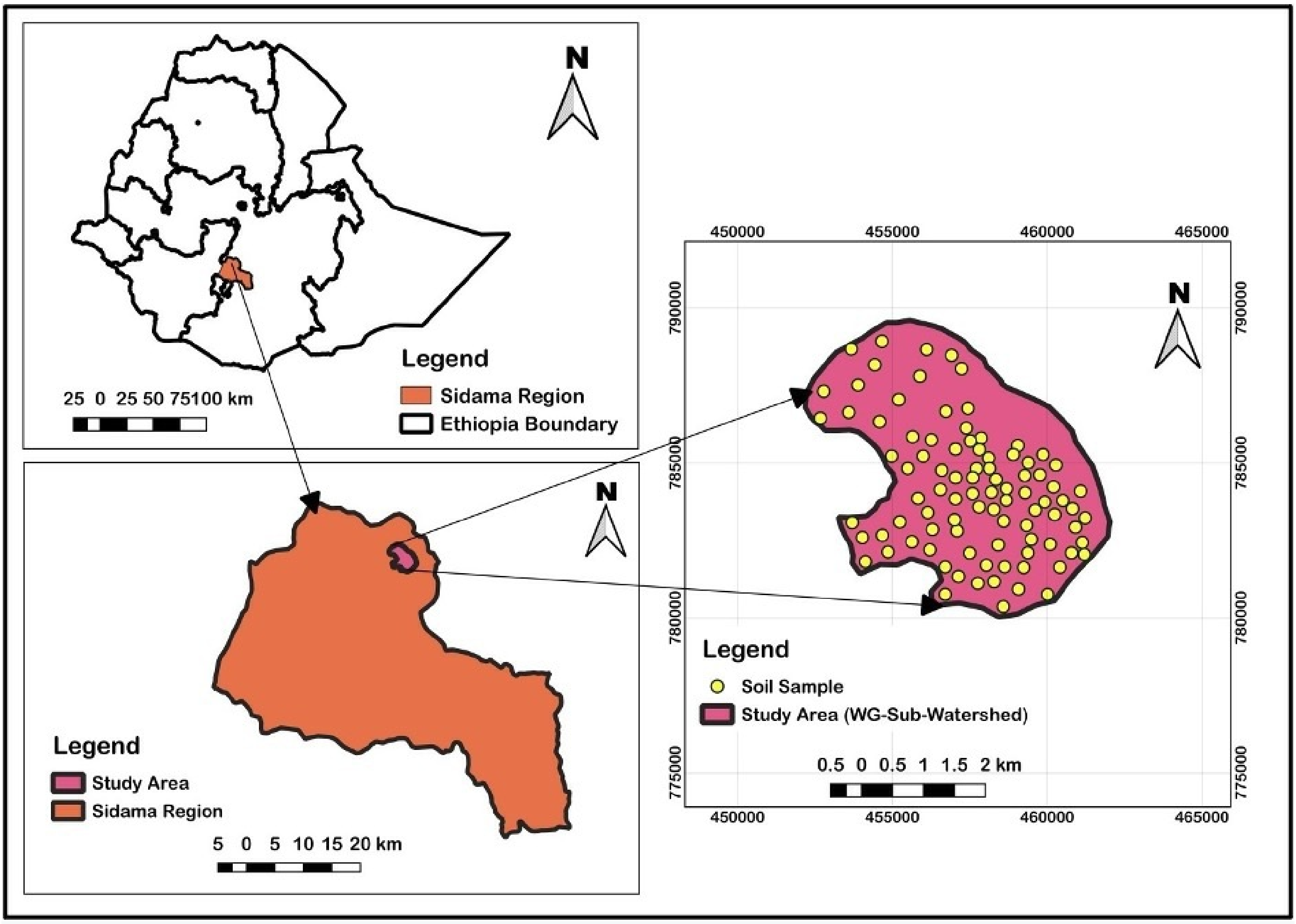

Figure 1. *Map of Wondo Genet sub-watershed with sampling locations*

2.2. Soil Sampling Techniques

Soil samples were taken from the three major land-use types (Natural forest, Plantation forest, and Agricultural land) from 60cm depth for investigating the effects of changes in land use on the Physico-chemical and biological characteristics of the soil. The forest has been separated into six sub-sites of 100m x 100m for each, at each sub-site four soil samples were taken and combined to form a single composite sample for each study site. For plantation forest and agricultural land, the study site was subdivided into different sub-sites based on vegetation cover. *Grevillea, Cupprusses, Eucalyptus, and Podocarpus* were considered plantation forests whereas khat plantation, enset plantation, coffee plantation, and sugarcane plantation were considered farmland. The soil samples were taken to the laboratory for further analysis and air-dried for physicochemical examination[38][45]. For sample collection and analysis, the same approach was used for planted forests and agricultural land. Soil samples were taken from two different depths: the top 0-30cm and the bottom 30-60cm.

2.3. Soil analysis

Standard procedures for measuring soil physical and chemical parameters (pH, organic C, moisture content, Porosity, and Bulk density) were used, as proposed by[46][47]. Microbial biomass C was estimated by the chloroform fumigation extraction method using purified CHCl3 treatment[48][49]. Using a Gerhardt digester and distillation unit, the N content in microbial biomass was measured using the micro Kjeldahl method [50]. Microbial biomass C (ug dry soil) and N are calculated by the following formulas:

$$Microbial\ Biomass\ C = \frac{NF - F}{B} * 3168$$

and

$$Microbial\ Biomass\ N = (Fu - NFu) * 207.407$$

Soil Aggregates: Kemper and Chepil's dry technique was used to estimate soil aggregates (1965). A dried sample of soil (100 g) was piled on a set of seven sieves and sieved on a horizontal shaker (92 rpm) for three minutes, separating three dry aggregate size classes: 1000 mm (macro-aggregate), 212-500 mm (meso-aggregate), and 53-150 mm (micro-aggregate) (micro-aggregate).

2.3.1. Spatial distribution of soil chemical properties analysis

Both descriptive statistical analyses (such as minimum, maximum, mean, coefficient of variation (CV), standard deviation, etc.) and geo-statistical techniques were used to describe the physicochemical soil properties and analyze the spatial distribution of soil properties across different land use types of Wondo Genet watershed. Geostatistics techniques (especially Kriging) have been widely used to estimate and map the distribution of different soil properties across different landscapes using the grid soil data obtained from the HUSD database. Kriging is a precise geostatistical approach [51] that is frequently utilized in various areas [52]. Ordinary kriging is a good spatial model that predicts the geostatistical analysis of environmental variables [53], such as soil parameters[54][55] over the different land use types in the QGIS 3.8 environment. Using ordinary kriging methods several raster layers for different soil parameters were generated using the grid soil data obtained from the HUSD database. Finally, the generated raster layers of each soil parameter were further reclassified in spatial analyst tools of the QGIS 3.8 software using different soil parameter rating methods for clear analysis of the parameters[51][52][56].

3. Results and Discussion

3.1. Soil Physical and chemical properties

Bulk Density, Porosity, pH, and Aggregates

The major physical characteristics of soils are provided in three distinct land-use categories (farmland, plantation, and natural forest) (Table 2). The study revealed that the greater bulk density was recorded in agricultural land followed by plantation forest and Natural forest. Among land use categories and soil depth, soil porosity exhibited the opposite tendency as bulk density. The natural forest has the highest porosity (0.685 percent), followed by plantation forest (0.66 percent) and agricultural land (0.66 percent) (0.64). Soil physicochemical characteristics and microbial biomass vary significantly at $p<0.05$ across all land use categories. Because of variations in terrain, temperature, weathering processes, plant cover, and microbiological activity[57][58], as well as various other biotic and abiotic variables, the physicochemical characteristics of forest soils fluctuate through time and place[2][9]. As a result, soil qualities vary over short distances depending on parent rocks, plant cover, and land usage. Trees, in combination with cultural practices, can change soil conditions by affecting micro-climate and detritus production [9], redistributing nutrients [51], promoting N2 fixation [40], and soil arthropod communities[29][35]. Many soil parameters change as land use patterns and treatment systems change[16][25][35].

With the value of bulk density and porosity, the analysis of variance indicated no significant differences between land use categories and soil depth at $p<0.05$. Cash crops, on the other hand, were found to have a greater bulk density than forest soil and plantation woods. This was most likely related to reducing carbon stocks and improving the soil as a result of repeated planting and harvesting activities [19]. Bulk density was likewise lower in soils with significant organic matter concentration, according to [34]. The great porosity of the forest soil allowed for optimal oxygen diffusion and water penetration. This demonstrates high structural quality, which is beneficial to the biological community's effective development [58].

Mean soil pH ranged from 5.64 to 6.78 in the surface layer (0-30cm) and from 5.9 to 6.86 in the subsurface layer (30-60cm) (Figure 2). The highest soil pH was recorded in sugarcane whereas the lowest pH was recorded in Cupressus plantation. Cupressus land-use type soils were somewhat acidic compared to other land-use types.

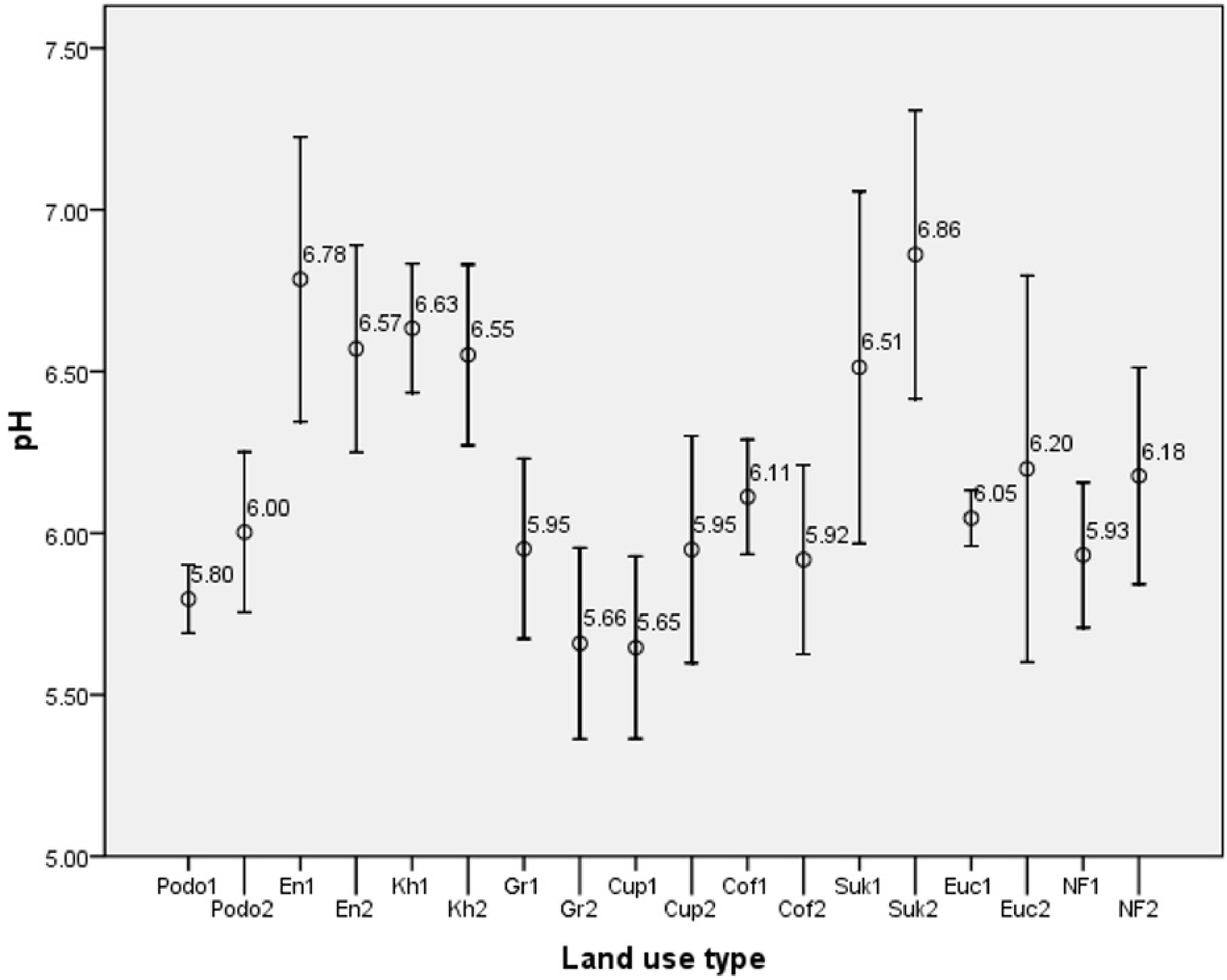

Figure 2. *Impacts of land-use types on soil pH*

NB: Podo1- Podocarpus 0-30cm; Podo2- Podocarpus 30-60cm; En1-Enset 0-30cm; En2-Enset 30-60cm; Kh1-Khate 0-30cm; Kh2-Khate 30-60cm; Gr1-Gravillea 0-30cm; Gr2- Gravillea 30-60cm; Cup1-Cupressus 0-30cm; Cup2-Cupressus 30-60cm;

Co1-Coffee 0-30cm; Co2-Coffee 30-60; Suk1-Sugarcane 0-30cm; Suk2-Sugarcane 30-60cm; Euc1-Eucalyptus 0-30cm; Euc2- Eucalyptus 30-60cm; Nf1-Natural forest 0-30cm; Nf2-Natural forest 30-60cm.

Soil aggregate is a naturally formed collection of soil particles that determines the creation of organometal complexes in the soil[58][59]. Across all land-use categories, macroaggregates made up 53.9-67.6 percent of the soil, followed by meso-aggregates (29.3-41.9 percent) and micro-aggregates (4.4-12.2 percent) (Table 1). Macro-aggregates were significantly higher in the Khate plantation (67.6%) whereas the least was recorded in the eucalyptus plantation (48.1%) in the upper layer of the soil. In the eucalyptus plantation and natural forest, respectively, meso and micro-aggregates were greater (41.9%) and (12.1%). Khate plantation had the most macro aggregate (67.6%), but the least meso (25.7%) and micro aggregates (25.7%) among the plantation land use categories (6.6%). Eucalyptus plantations were found to have the lowest macro-aggregates (48.1%) and the greatest meso (36.39%) and micro-aggregates (36.39%). The soil aggregates in the natural forest accounted for 53%, 33%, and 12% of Macro, Meso, and micro soil aggregates in the upper layers of the soil, respectively. This was lower than Cupressus, Podocarpus, coffee, Khate, Sugarcane, and Enset farm but higher than Eucalyptus and Gravillea. This might be attributable to the fact that in a planted forest, there is no tillage, there is less interference, and there is more organic matter intake (litters and root biomass) that binds soil aggregates together, leading to better soil structure development. Natural forests, on the other hand, had lower aggregates owing to soil disturbance and a higher micro percentage, which were attributed to continuous SOM distribution and quick oxidation, respectively [60].

Table 1. Percentage distribution of different dry aggregate soil size classes in different land-use types

Soil depth (cm)	Natural forest	Plantation forest				Agricultural Land			
		EuC	Cupr	Gr	Podo	Coffee	Khat	Sugarcane	Enset
Macro aggregates (%)									
0-30	53.9 ± 4.6^{1a}	48.1 ± 6.1^{1a}	59.3 ± 8.6^{1a}	48 ± 4.3^{1a}	62.6 ± 8.3^{1a}	62.7 ± 7.6^{1a}	67.6 ± 4.4^{1a}	66.9 ± 6.1^{1a}	62.2 ± 8.7^{1a}
30-60	48.2 ± 8.9^{1a}	61.7 ± 11.4^{1abc}	70.1 ± 8.1^{1bc}	51.9 ± 7.1^{1ac}	70 ± 8.7^{1bc}	55.1 ± 8.8^{1ac}	79.2 ± 2.9^{1b}	81.5 ± 2.3^{1b}	63 ± 8.9^{1bc}
Meso									
0-30	33.9 ± 1.8^{1ac}	41.9 ± 2.3^{1a}	30.8 ± 5.8^{1ac}	39.7 ± 1.5^{1ac}	29.3 ± 5.5^{1ac}	25.3 ± 2.1^{1c}	25.7 ± 5.7^{1c}	28.6 ± 5.1^{1ac}	29.9 ± 4.2^{1ac}
30-60	37.5 ± 7.2^{1a}	29.6 ± 7.3^{1ab}	19 ± 4.8^{1b}	35.6 ± 7.2^{1a}	24.4 ± 9.9^{1ab}	32.5 ± 7.8^{1a}	16.1 ± 1.8^{1bc}	12 ± 4.7^{2b}	28.1 ± 6.2^{1ac}
Micro									
0-30	12.1 ± 4.1^{1a}	9.9 ± 4.5^{1a}	9.8 ± 2.9^{1a}	12.2 ± 5.2^{1a}	7.99 ± 2.9^{1a}	11.9 ± 6.1^{1a}	6.6 ± 2.8^{1a}	4.4 ± 1.4^{1a}	7.8 ± 4.9^{1a}
30-60	14.2 ± 4.1^{1a}	8.6 ± 4.4^{1a}	10.8 ± 5.8^{1a}	12.4 ± 3.8^{1a}	5.58 ± 1.2^{1a}	12.3 ± 5.1^{1a}	4.6 ± 1.24^{1a}	6.4 ± 2.5^{1a}	8.8 ± 3.15^{1a}

Values are mean ± SE. Values with distinct superscripts in each column and row are substantially different from each other at $P< 0.05$. ("Letter" indicates the land use types; "Number" indicates the soil depths for each aggregate size). Note: Co-Coffee; Kh-Khat; Suk-Sugarcane; En-Enset; NF-Natural Forest; EuC-eucalyptus; Cupr-cupressus; Gr-Gravellea; Podo-podocarpus; MBC- Microbial biomass carbon; SC-soil organic carbon; BD-Bulk density; Mc- moisture content; Por-porosity

Soil organic carbon and total nitrogen

As indicated in Table 2, soil organic carbon and total nitrogen distinctly vary depending on the land use types and soil depth. The value of soil organic carbon varied greatly across all land-use patterns and soil depths, ranging from 1.1 to 4.25 percent. Natural forests had the highest levels of organic carbon, followed by plantation forests and farmed land. The mean values of organic carbon (OC) in the natural forest was (4.25%) at topsoil, followed by Coffee (2.92%), Podocarpus (2.77%), Gravillea (2.73%), Enset (2.56%), Cupressus (2.50%), Eucalyptus (2.25%) and Sugarcane (1.56%). Similar studies have been made in different countries in the world, for instance, the forest had more OC than Jatropha plantation/reforested area and lowest in the agroecosystem, according to[60] and [61], whereas others observed better soil OC concentration in the natural forest than tilled farmlands[62]. Similarly, [63] found that agroforestry yielded the most soil OC, followed by cropland, grassland, and fallow land. Because of the regular buildup of plant biomass and limited intervention in the natural forest, the conversion of natural forest to plantation forest, as well as cash agriculture, resulted in a considerable fall in soil OC[64]. Furthermore, greater root biomass contributes to the preservation and stability of SOC in aggregates by increasing the return of residues[25][52]. Moreover, the presence of diverse leaf litter in the forest floor contributes to the replenishment of SOM as well as providing better habitats and food for soil organisms, which enhance soil organic carbon accumulation.

As in the case of OC, soil tN significantly varied among the land use practices and soil depth. The highest contents of soil tN were recorded in the top layer of the soil of the natural forest (Table 1). The order of the concentration of tN along the land use types in the upper layer was NF (0.37%); Gr (0.24%); Podo (0.24%); Coffee (0.25%); Enset (0.22%); Cupr (0.22%); Euc (0.19%); Khate (0.16%); sugarcane(0.13%) at $p < 0.05$. Several studies have confirmed that agricultural practices reduce the amount of tN in the soil[33][61]. Also, [57]

demonstrated that, under comparable site conditions, natural lands often preserved more soil organic carbon than croplands due to larger residual inputs and lower turnover.

Furthermore, the soil OC and tN losses from agricultural land can be due to its removal by crops[26]; and continuous tillage practice (accelerates organic matter oxidation by destroying soil aggregates and exposing newer sites to microbial attack) [44]. The amount of tN obtained from coffee and Enset farm is comparable with plantation forest but not significant. This is probably due to the inputs from broadleaf litter and less intense agricultural activity as compared to Khat and Sugarcane farms [47].

Table 2. Soil Physicochemical properties under three major land-use categories (farmland plantation and natural forest)

Soil depth (cm)	Natural forest	Plantation forest				Agricultural Land			
		EuC	**Cupr**	**Gr**	**Podo**	**Coffee**	**Khate**	**Sugarcane**	**Enset**
Bulk Density (g/cm3)									
0-30	0.81±0.03^{a}	0.89±0.056^{abcd}	0.93±0.012^{abcd}	0.78±0.016^{a}	0.83±0.032^{ab}	0.83±0.061^{a}	0.96±0.018^{bcd}	0.89±0.064^{abcd}	0.92±0.035^{abcd}
30-60	0.84±0.028^{ab}	0.86±0.013^{abcd}	0.98±0.013^{cd}	0.87±0.027^{abcd}	0.93±0.085^{abcd}	0.91±0.076^{abcd}	0.99±0.05^{cd}	0.99±0.046^{cd}	0.95±0.042^{bcd}
Porosity (%)									
0-30	0.69±0.011^{a}	0.66±0.021^{abcd}	0.65±0.004^{abcd}	0.71±0.006^{a}	0.68±0.012^{ab}	0.68±0.022^{a}	0.63±0.009^{bcd}	0.66±0.024^{abcd}	0.66±0.018^{abcd}
30-60	0.68±0.01^{ab}	0.67±0.004^{abcd}	0.63±0.005^{cd}	0.67±0.01^{abcd}	0.64±0.03^{abcd}	0.65±0.028^{abcd}	0.62±0.026^{cd}	0.63±0.017^{cd}	0.64±0.022^{bcd}
SOC (%)									
0-30	4.25±0.28^{a}	2.25±0.1^{bc}	2.5±0.03^{bc}	2.73±0.36^{b}	2.77±0.49^{ab}	2.92±0.16^{ab}	1.8±0.35^{bc}	1.56±0.022^{bc}	2.56±0.625^{bc}
30-60	1.17±0.13^{c}	1.41±0.31^{bc}	1.52±0.25^{bc}	1.48±0.047^{bc}	1.47±0.25^{bc}	1.68±0.25^{bc}	1.1±0.52^{bc}	1.22±0.35^{bc}	1.55±0.311^{bc}
STN (%)									
0-30	0.37±0.024^{a}	0.19±0.01^{bc}	0.22±0.0016^{bc}	0.24±0.038^{b}	0.24±0.042^{bc}	0.25±0.014^{ab}	0.16±0.03^{bc}	0.13±0.01^{bc}	0.22±0.053^{bc}
30-60	0.1±0.011^{c}	0.12±0.027^{bc}	0.13±0.012^{bc}	0.13±0.01^{bc}	0.13±0.022^{bc}	0.14±0.02^{bc}	0.09±0.045^{bc}	0.1±0.03^{bc}	0.13±0.032^{bc}

Values are mean ± SE. Values with distinct superscripts in each row are substantially different from each other at P 0.05.

Note: Co-Coffee; Kh-Khat; Suk-Sugarcane; En-Enset; NF-Natural Forest; EuC-eucalyptus; Cupr-Cupressus; Gr-Gravellea;

Podo-podocarpus; MBC- Microbial biomass carbon; SC-soil organic carbon; BD-Bulk density; Mc- moisture content; Por- porosity

Note: The superscript letter indicates significance among the land use types in each row.

When compared to natural forests, plantation forests had lower OC and tN, but were greater than agricultural land/cash croplands (Table 2). The conversion of natural forest into agricultural land for coffee, khat, sugarcane, and enset agriculture resulted in considerable reductions in SOC content, with lower values of 31.29%, 57.6%, 63.2%, and 39.7%, respectively. In comparison to agricultural land, the rise in soil OC and tN in plantation forests was likely attributable to the addition of nutrient-rich leaf litter to the soil, as well as the recycling of these nutrients[31][65]. Natural forest conversion to EuC, Cupr, Gr, and Podo soils resulted in considerable reductions in SOC content, with lower values of 47%, 41%, 37.5%, and 34.8%, respectively. Podocarpus plantation (2.77±0.49%, 0.24±0.042%) in the top layer soil had the greatest organic carbon and tN, whereas Eucalyptus plantation (2.25±0.1%, 0.19±0.01) in the upper layer soil had the lowest organic carbon and tN. The larger amount of soil organic carbon and nitrogen might be due to a higher intake of leaf litter in the podocarpus soil, as well as fewer disturbances[36][66]. In comparison to natural forests and other plantations, studies on nutrient cycling found that the poor quality of Cupressus and Eucalyptus litter, which decomposes slowly and limits organic matter intake, eventually leads to a fall in SOC[33][40].

3.2. Soil Microbial Biomass Carbon and Nitrogen

Microbial Biomass Carbon

For all depths, the level of soil microbial biomass carbon (MBC) varied substantially between land-use types, ranging from 94.7ug/g to 939.84ug/g (Table 3). Mean soil MBC ranged from 131.1 to 939.8 ug/g in the surface layer and from 11.3 to 81 ug/g in the subsurface layer. Soil MBC was highest (939.84ug/g) in the natural forest in the upper layer, followed in decreasing order by Grevellea plantation, Podocarpus plantation, Cupressus, Enset farm, Sugarcane farm, Eucalyptus farm, and Khat farm. In the lower layer, the highest MBC was found in the natural forest whereas the least was recorded from the Cupressus plantation. Likewise, the mean microbial biomass nitrogen (MBN) values under the natural forest, plantation forest, and agricultural land in both depths were (16.37,8.11ug/g; 13.64, 6.97 ug/g; 11.10, 5.3 ug/g), respectively. It was observed that soil MBN tends to decrease with soil depth in all land-use types. The MBN content was observed to be higher at upper soil depth and lower at lower soil depth in all the land use patterns (Table 3). The order of the level of MBN among the land use types is NF>Gr>Enset>Podo>Euc>Coffee>khat>Sugarcane>Cup ($p < 0.05$).

This finding is similar to findings from earlier research, which found that the MBC and MBN differed considerably across the forest, pasture, and agricultural area[66][67]. The transformation of natural forests into plantation forests and farmland reduced soil organic carbon (SOC) and total nitrogen (tN), lowering microbial biomass concentration [68]. Increased availability of resources such as soil organic matter, more diversified organic matter input, and related processes are thought to be the cause of the greatest MBC and MBN in the natural forest. Previous researchers have shown that mixed forests produce a higher-quality litter, have a faster rate of litter decomposition, and have more soil nutrient mineralization than monocultures[7][54].

High levels of root debris and exudates supported high microbial activity[69]. Because most microbes are heterotrophic, their dispersion and biological activity are typically dependent on organic matter, the findings of the research revealed a tight relationship between MBC and SOC or tN.n[38][70]. In general, the quantity and quality of C inputs have a direct relationship with the amount of soil microbial biomass.

Large microbial biomass may suggest increased quantity in the organic pool and, depending on soil management, might constitute either a sink or a source of plant-available nutrients. The greater C and N levels in soil microbial biomass may be attributable to the microorganisms' increased ability for nutrient immobilization from decaying cover species residues. Microorganisms utilize the organic wastes left on the soil as a source of energy and nutrients. Various land covers contain different chemical elements that can impact microbial characteristics in a variety of ways and to varying degrees. The greater microbial biomass in natural forests also suggests that maintaining native vegetation provides the ideal circumstances (macro porosity, litter dry mass, and K and P levels), which helps the soil microbiota thrive and establish[52][71]. The availability of microbial biomass and its activity might lead to improved soil aggregate formation and stability, improved plant litter decomposition, increased nutrient cycling and transformation, slow-release organic nutrient storage, and disease control, among other things[49][72].

Among plantation forests, the highest amount of microbial biomass C and N was obtained from Gravellea whereas the least was from Cupressus. Among agricultural land, the highest microbial biomass carbon and nitrogen were obtained from the Enset farm. This is most likely due to an increase in the supply of resources such as soil organic matter, more diversified soil organic input, and related processes that sustain microbial activity. Furthermore, the opening of the canopy cover in agricultural land, particularly khat and sugarcane, increases the intervention of physical elements including intensity of light, wind velocity, and moisture content. Incident light intensity and wind velocity rise when the canopy opens, lowering moisture content and stimulating organic matter mineralization.

Table 3. Soil Microbial Biomass under three major land-use types; Natural forest, Plantation forest, and Farm forest

Soil depth (cm)	**NF**	**Plantation forest**				**Agricultural Land**			
		EuC	**Cupr**	**Gr**	**Podo**	**Co**	**Kh**	**Suk**	**En**
MBC (µg/g)									
0-30	939.8± 46.0^{a}	422.4±27.9^{bg}	131.1±21.1^{f}	712.8±48.4^{h}	538.6±48.3^{dg}	387.8±22.5^{bg}	372.2± 37.4^{b}	240.3±25.2^{bc}	570.2±38.8^{d}
30-60	475.2± 9.2^{g}	242.9±41.2^{c}	94.7±7.28^{f}	211.2±10.5^{cf}	211.8±31.6^{cf}	278.6±37.1^{ce}	293± 26.9^{ce}	145.7±36.4^{cf}	332.6±12.9^{be}
MBN(µg/g)									
0-30	81.0±3.9^{a}	36.4±2.4^{bg}	11.3±1.08^{f}	60.08±4.2^{h}	46.42±4.2^{dg}	33.43±1.9^{bg}	32.09±3.2^{b}	20.72±2.2^{bc}	40.96±3.3^{d}
30-60	40.9±0.8^{g}	20.9±3.5^{c}	8.16±0.62^{f}	18.21±0.9^{cf}	19.12±2.7^{cf}	24.01±3.2^{ce}	25.26±2.3^{ce}	12.56±3.1^{cf}	28.67±1.1^{be}

Values are mean ± SE. Values with distinct superscripts in each row are substantially different from each other at P 0.05. Note: Co-Coffee; Kh-Khat; Suk-Sugarcane; En-Enset; NF-Natural Forest; EuC-eucalyptus; Cupr-Cupressus; Gr-Gravellea; Podo-podocarpus; MBC- Microbial biomass carbon; SC-soil organic carbon; BD-Bulk density; Mc- moisture content; Por-porosity

3.3. Soil Chemical Properties

Table 4 below shows the variation of soil chemical properties along with different land use types and soil depth. All thesoil chemical property data (pH, N, P, K, CEC, OC, SAR, and ESP) were obtained from the girded soil database of HUSD. The values of both soil depth and soil chemical properties for each land use type (NF, PF, and AL) are representing the mean values. Detecting and analyzing soil chemical properties at individual tree species (like other Tables 1-3) level is very difficult, due to the generalization and lower resolution of the girded soil data. Thus, the soil chemical properties values were analyzed and detected at three land use types (natural forest, plantation forest, and agricultural land). Accordingly, as indicated in Table 4, the soil chemical properties are varied at each land use type.
The present soil property study shows that the pH value of NF, PF, and AL were recorded at 5.523, 5.645, and 6.510 respectively. While, in the range of soil depth from 0 to 30 cm, the pH value is 5.566 and from 30 to 60 cm the soil value is 6.420 (Table 4), this indicates the variation of pH value in both soil depths. Soil can be said to be slightly acidic in the three-dimensional practice[19][73]. To show the local distribution of pH at depths of 0 - 30 cm and 30 - 60 cm, the pH values of soil samples of various depths were sorted and assembled using a kriging interpolation technique. It is evident in Table 4 that most soils are slightly acidic in a layer of 0-30 cm area. Although the soil is slightly acidic, the pH distribution within the subsoil layer (30-60 cm) is between 5.23 and 6.510 overall.

This study shows that substantial variations were registered in the overall amount of soil nitrogen between the three land-use activities ($p<0.05$) and at depth. The largest NF content however amounted to 0.370% with 0.346% of natural forest PF supplemented by 0.287% of agricultural land (AL) (Table 4). This means that all three land-use practices have very little nitrogen content in their soils[26][72]. Figures 3 a & b showed the interpolation result of total nitrogen and pH values across the study area, the result revealed that there are spatial heterogeneities in the distribution and variability of pH and total nitrogen at different land-use practices.

Table 4: Soil chemical properties variation along land use types and soil depth

	pH (H_20)	*N* (%)	P (cmol+/kg)	K (Cmol/kg)	CEC(cmol(+)/kg)	OC g/kg	SAR	ESP%
Land use								
NF	5.523	0.370	3.68	0.232	4.31	6.37	0.043	0.63
PF	5.645	0.346	2.74	0.162	3.87	5.42	0.035	1.67
AL	6.510	0.287	2.96	0.142	5.02	5.03	0.035	1.47
LSD	0.341	0.054*	1.125	0.017	2.202	0.280	0.005*	0.289
Depth								
0–30 cm	5.566	0.304	2.85	0.056	4.46	8.61	0.086	1.182
30–60 cm	6.420	0.182	3.28	0.103	4.52	4.50	0.052	1.601
LSD	0.162	0.015***	0.780	0.013*	1.560	0.758***	0.006	0.203

***Significant at 0.01% probability,*Significant at 0.05% probability

pH: pH value; N: nitrogen value in %; K: potassium; P: Phosphorus; CEC: cation exchange capacity; OC: organic carbon; SAR: sodium adsorption ratio; and ESP: Exchangeable Sodium Percentage; and NB: NF- Natural forest; PP- plantation forest; AL- agricultural land

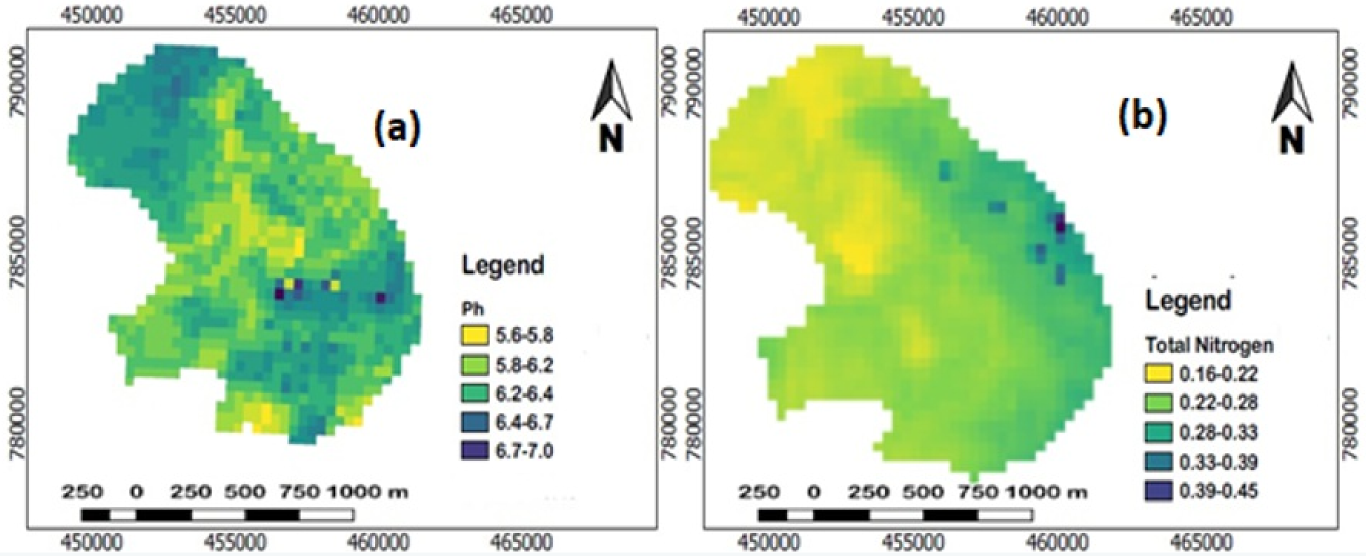

Figure 3. *Spatial Distribution of Ph- value (a) and Total Nitrogen (b) in the study area*

Changes in the phosphorus content in the sample area between the three practices were observed, but there were no major differences. Correspondingly, there was no considerable variation in the concentration of potassium in the sample area, but there are significant differences in depth ($p<0.05$) of potassium values for the three land-use systems. While there was no substantial variation between the depths, the spatial variability of phosphorus values in the three land-use systems was interpolated to determine the spatial variability and distributed around the sample region as shown in Figure 4.

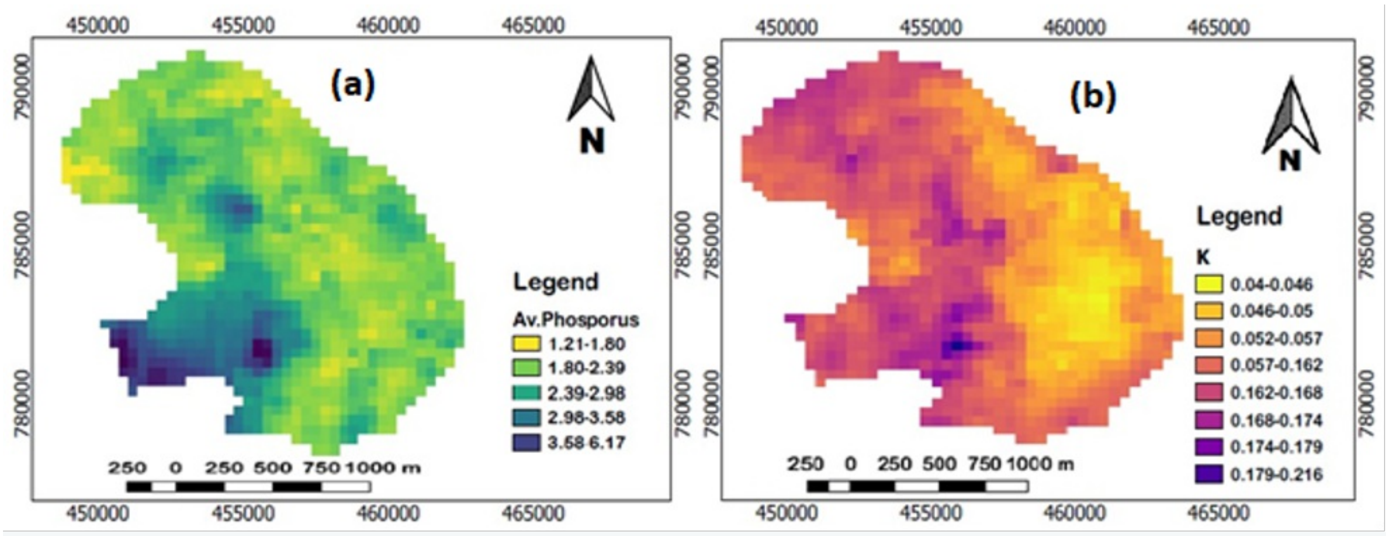

Figure 4. *Spatial Distribution of Phosphorus (a) and Potassium (b) in the study area.*

The natural carbon concentrations of the sample study area varied from 6.31 to 8.34 g/kg while the natural forest has a maximum value of 8.34 g/kg. The soil laboratory analysis result showed that there are no significant variations among the three land-use systems at a higher level although there are statistically significant variations in-depth (p 005). As indicated in **Table 4** the spatial variability and distribution of soil organic carbon and CEC values are lower throughout the study area. The value of CEC for all land-use systems ranged from 2.4 to 4.8 Cmol/kg due to the low flexible foundations of the soil, but the CEC value must have greater than 10 cmol/kg of soil to be satisfactory [74].

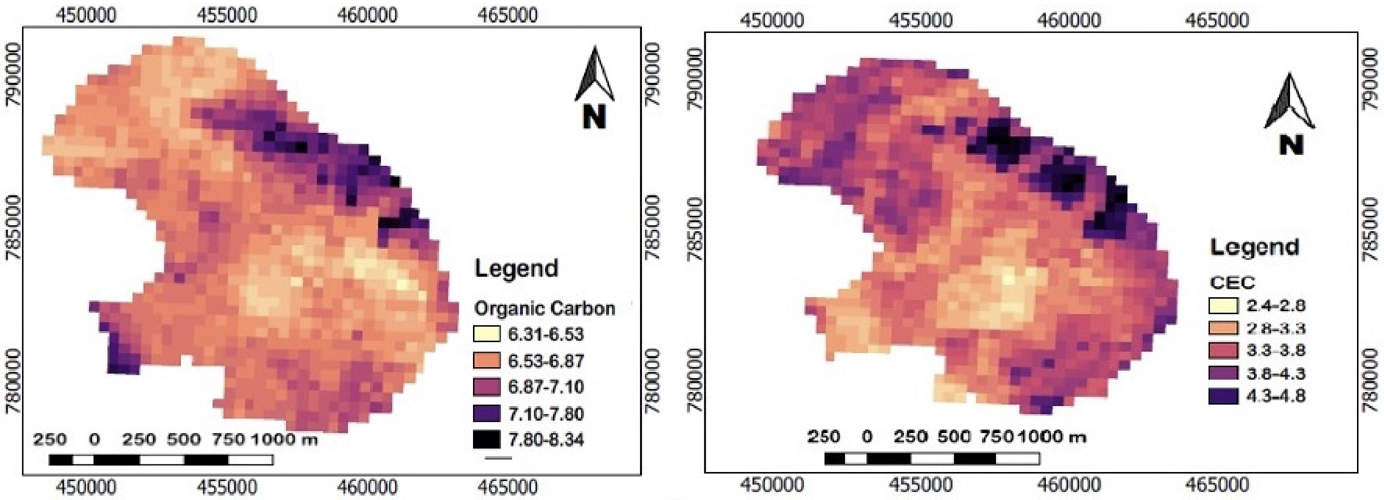

Figure 5. Spatial Distribution of Soil Organic Carbon (a) and CEC (b) in the study area

There was no also statistically significant variation between the three land-use systems and the soil depths since both values were below the acceptable sum. The soil samples analysis for sodium adsorption ratio (SAR) revealed substantial variations between land-use systems and depth ($p<0.01$). Results showed that most soils have low SAR values in all the land-use systems as well as at all the soil depths (Table 4). Similarly, the Exchangeable Sodium Percentage (ESP %) of all soils in the three land-use systems was low, with all values lower than 2 percent. The soil sample SAR values and ESP values were plotted and spatially analyzed to demonstrate the distribution across the study areas (Figure 6(a) and (b)).

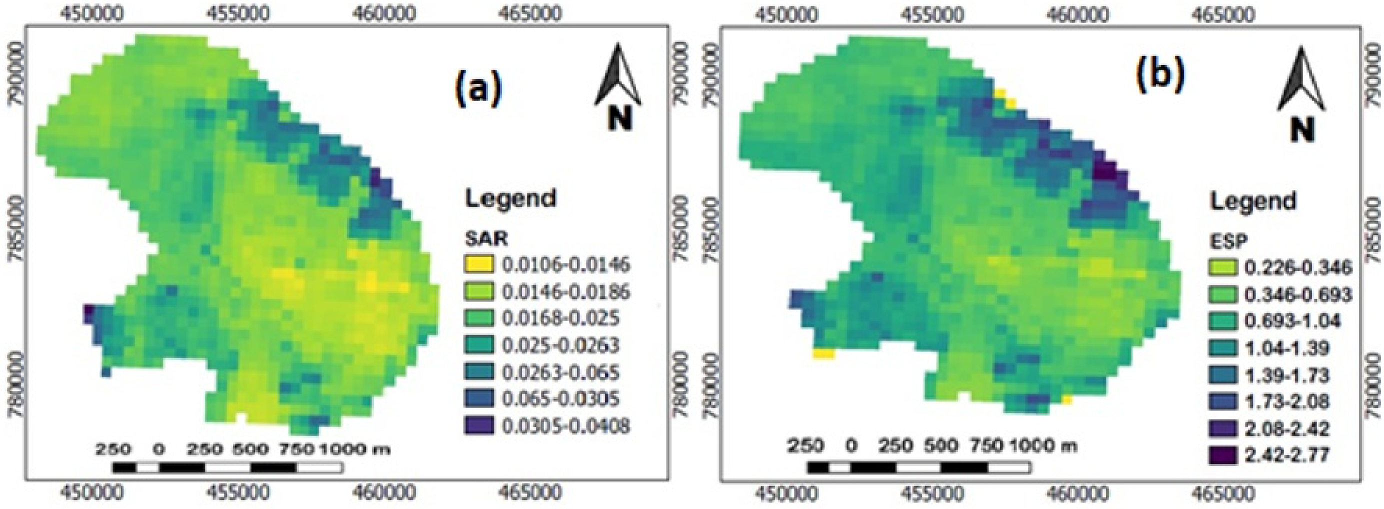

Figure 6. Spatial Distribution of Sodium Adsorption Ratio (SAR) (a) and ESP (b) in the study area

3.4. Geostatistical analysis

Tables 5 and 6 show how the spatial structure of soil properties is determined by semi-variograms and the most appropriate model describing these soil structures in the sample field. The best fit is presented for each parameter in this model at both depths (0-30cm and 30-60cm). At first depth (0-30cm), the Gaussian model was more suitable for most parameters, but the exponential model was more suitable for SAR and OC; and the circular model was also more suitable for the CEC. Although the Gaussian model included most of the parameters in the second depth (30-60cm), descriptive and circular models were better suited to OC, CEC, pH, and SAR, respectively (Table 6).

Table 5. Model parameters for soil variables at 0-30 cm depth under four land-use types

Variables	Nugget (Co)	Sill (C1)	Range (A)	Spatial ratio % (Nugget/Sill)	Spatial class	Model
PH(-H+])	0.362	0.859	0.0025	42.14	Moderate	Gaussian
TN (%)	0.0005	0.0041	0.0013	12.20	Strong	Gaussian
P (cmol+/kg)	1.986	4.023	0.0058	49.37	Moderate	Gaussian
K(cmol+/kg)	0.507	2.256	0.0015	22.47	Strong	Gaussian
CEC(cmol(+)/kg)	2.4679	5.252	0.0724	46.99	Moderate	Spherical
OC (%)	0.2462	5.9286	0.0003	4.15	Strong	Exponential
SAR	5.4356	14.015	0.0042	38.78	Moderate	Exponential
ESP (%)	0.1872	0.4048	0.0029	46.25	Moderate	Gaussian

Note: pH: pH value, TN: total nitrogen value in %, K: potassium, P: Phosphorus, CEC: cation exchange capacity, OC:

organic carbon, SAR: sodium adsorption ratio, and ESP: Exchangeable Sodium Percentage.

Table 6: Model parameters for soil variables at 30-60 cm depth under four land-use types Model parameters for soil variables at 30-60 cm depth under four land-use types

Variables	Nugget	Sill	Range	Spatial ratio (%)	Spatial class	Model
pH (–log [H+])	1.2045	3.8632	0.0028	31.18	Moderate	Spherical
***T.N* (%)**	0.0021	0.0098	0.0012	21.43	Strong	Gaussian
P (cmol+/kg)	0.5711	2.856	0.0046	20.00	Strong	Gaussian
K (Cmol+/kg)	2.0016	4.0105	0.0021	49.91	Moderate	Gaussian
CEC (Cmol+/ kg)	1.0106	3.1157	0.0628	32.44	Moderate	Exponential
OC (%)	0.4004	3.1253	0.0010	12.81	Strong	Exponential
SAR	10.9	16.9001	0.0025	64.50	Moderate	Spherical
ESP (%)	1.0093	2.2545	0.0037	44.77	Moderate	Gaussian

Note: pH: pH value, TN: total nitrogen value in %, K: potassium, P: Phosphorus, CEC: cation exchange capacity, OC: organic carbon, SAR: sodium adsorption ratio, and ESP: Exchangeable Sodium Percentage.

As can be seen in Tables 5 and 6, the effect of the nugget, herring, and control spectrum on each parameter varied between parameters. The degree of automatic correlation between sample points was found to be equal to the local dependence rate, expressed in percentages. Studies conducted by [51][75] and [76]

location-dependent variants are classified as highly dependent on location if the ratio is less than 25, moderately dependent if the ratio is between 25 -75 percent, and highly dependent on location if the ratio is greater than 75 percent. As a result, at first depth (0-30cm), T. N (percentage), K (cmol / kg), and OC (percentage) were highly dependent on location, while PH, P, CEC, SAR, and ESP were moderately dependent. In the second depth, the model shows that T.N, P, and OC were the major location-dependent variables, while PH, ESP, K, SAR, and CEC are also the local variables in the middle of this model.

Conclusions

Investigating the effect of changes in land use and mapping the diversity of landforms is an important prerequisite for land management. The present study shows that the physicochemical properties of soil in the study area were significantly affected by land-use change and various land-use systems over time. Total nitrogen, microbial biomass, bulk density, soil organic carbon, & porosity are higher in natural forests, but plantation forests and agricultural land show a decreasing trend. In addition, the Gravillea plantation site and Enset farm have shown the highest amount of biomass carbon and nitrogen emissions from plantation forests & farmlands. In contrast, farmland was larger in bulk density than other land uses, while natural forests had lesser bulk density, but had a positive correlation with soil organic carbon, nitrogen, and porosity.

The geospatial map of selected areas showed that the farmland of the present study site was described by low rhizobia and soil OC/tn, but not much potassium & phosphorus. This means that soil characteristics are more susceptible to variations in land management and land utilization processes. Besides, there is a loss of essential nutrients that can lead to decreased productivity of agricultural land in this study area. Thus, we concluded that the best practices for soil management that improve soil organic carbon, nitrogen and rhizobia and reduce soil pH in agricultural land must be prioritized.

Data Availability Statement

1. Datasets are available in our institution (Hawassa University, Wondo Genet College of forestry and Natural resources) repository that assigns persistent identifiers to datasets.
2. Datasets derived from public resources and made available with the article.
    - Data analyzed in this study were a re-analysis of existing data, which are openly available at locations cited in the reference section.
3. Data sharing not applicable (e.g., for review articles or theory-based articles).
    - “No datasets were generated or analyzed during the current study.”
4. Datasets are restricted and not publicly available.
    - There is no restriction on supporting data publicly availability
5. No valid data repositories exist.
    - The dataset on which this paper is based is too large to be retained or publicly archived with available resources. Documentation and methods used to support this study are available from Hawassa University, Wondo Genet College of forestry and Natural resources.

Conflict of interests

The authors have not declared any conflict of interest.

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