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Original Research

Assessment of Effects of Land Uses on Soil Quality Indicators: The Case of Gibe watershed, Western Ethiopia

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Abstract

This study set out to assess the effects of different land-use patterns on soil quality indicators. Agricultural, pasture, and forest land use systems were all recognized. In order to acquire soil samples, we went to three different local land uses and dug down 0-20 cm. To evaluate specific soil fertility indicators, standard laboratory methods were followed. The conversion of forest area to agricultural land resulted in significant decreases in organic matter, aggregate stability, silt contents, N, P, and K. The pH, sand content, and bulk density, on the other hand, rose significantly. Soil natural resource depletion, reduced land productivity, and exposure to leaching and erosion are all consequences of water-saving methods, intensive farming, excessive grazing, monoculture, and poor soil management, according to the study's findings. Findings indicated that most of the soils tested were clays, which exhibited slow penetration rates, somewhat acidic content, and low SOC concentrations. Thus, sustainable and integrated land management is the way to go if we want to halt the decline of soil quality. This type of management is crucial to the functioning of ecosystems that can withstand the test of time since it seeks to enhance suitable land use systems.

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INTRODUCTION

Common knowledge holds that cultivation, deforestation, and excessive grazing alter the soil's physical characteristics. The effects of these changes on the land's use and management will vary. Deforestation and forest land exploitation reduce total porosity, according to multiple studies. Clays with low SOC concentrations, moderate acidity, and slow infiltration rates make up the majority of these locations (Teshome et al., 2013). In the context of natural or controlled ecosystems, soil quality refers to a soil's ability to sustain plant and animal life, water and air quality, and human health and housing (Doran et al., 2000). The soil's fertility decreases as a result of these influences. The conversion of native vegetation to arable land in Ethiopia causes a fast depletion of soil nutrients. Soil physicochemical qualities have deteriorated as a result of prolonged and extensive cropping without effective land management (Kitila et al., 2016). In the farmed region, the levels of

SOM declined by about 76%, TN by about 61%, and CEC by about 39%, as reported by Lanzarone et al. (2015).

The shift from forested to agricultural land use has an effect on several soil parameters, including total nitrogen, exchangeable cations, CEC, pH, and organic matter (OM), as reported by Adugna and Abegaz (2016). There are major agricultural problems in the present study area, Bako, as a result of poor soil fertility, rising population pressure, and an inadequate amount of land for farming and grazing livestock. As a result, the once-natural vegetation was turned into meadows where cattle could be raised and fed. In addition, the soil's fertility is diminished because farming is done on steep slopes. Consequently, the soil has become worse and its quality has decreased. Due to population growth, continued farming, and an insufficient land management system in Ethiopia, the Gibe watershed of Bako Tibe has experienced soil degradation, massive deforestation, and significant changes in land use (Nega, 2006). There is a lack of scientific data on the effects of land use changes on soil quality indices (SQ), even though the government has invested much in sustainable land management (SLM) to fight land degradation. In order to determine the feasibility of different land use alternatives and to make necessary adjustments to land management techniques to improve SQ for SLM, it is crucial to properly evaluate and measure changes in SQ caused by changes in land use. There is a substantial relationship between the type of soil and the site-specific effect of land use changes on SQ. Consequently, it is critical to assess how different changes in land use affect SQ. Still, no studies have looked at the Gibe watershed in western Ethiopia's Bako District to see whether SQ indicators are impacted by land use changes. Therefore, this study set out to answer the question, *"How did land use in the Gibe watershed of the Bako Tibe District in western Ethiopia affect certain SQ variables?"* by looking at the data from that area.

MATERIALS AND METHODS

Description of the Study Area

Approximately 233 kilometers west of Addis Ababa (Finfine), the capital of Ethiopia, lies the Bako Tibe District, where the research was conducted. The Gibe Watershed, located in western Ethiopia between 9°00 and 9°10 N and 37°00 and 37°9 E, encompasses an area of around 64,646 km^2, located 1650 meters above sea level, it is a very tall place. In Figure 1. Plains, hills, plateaus, and valleys are some of the geographical categories that make up the district. Here are the districts that make up its borders: Jima Rare and Jima Geneti to the north, Chelliya and Ilu Galan to the east, Gobu Sayo and Gudeya Bila to the west, and Boneya-Boshe to the south, as shown in Figure 1. Bako Tibe District is home to three distinct agroecological communities: the Gammoojjii, the Badda Daree, and the Baddaa highlands. Nearly 51% of the study region consists of land. Mid- and low-altitude climates occupy the second and third largest areas, respectively, after the highest-altitude zone. Gammoojjii, or Gibe, lives in the lowlands.

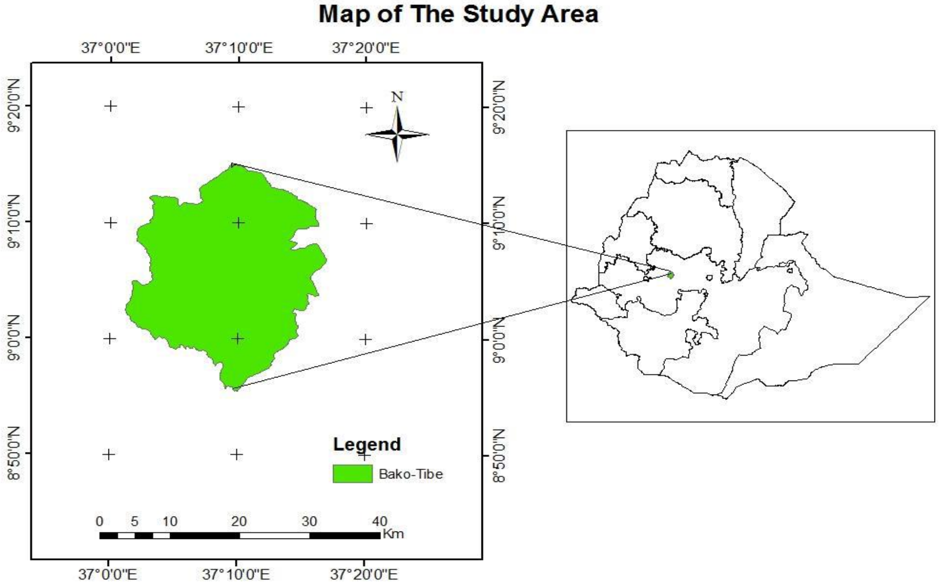

Figure 1 *Map of the study area*

February through May are the hottest months according to the data collected from the meteorological stations at the Bako Agricultural Research Centre. June through August, which falls in the heart of the main rainy season, are the coldest (Figure 2). The months of May through September see the most precipitation, while the months of November through February get the least. This pattern is known as unimodal rainfall. The average annual rainfall was 1,273 millimeters and the average lowest and maximum temperatures were 13.4, 28.49, and 20.95 degrees Celsius from 1990 to 2017 (BTDAO, 2018). At an altitude of 1670–1690 meters above sea level, the area was situated.

Because of its very good agricultural potential, the area displays a variety of land uses and cover types. Tolesa, Mammo, and Bohnett (2021) report that out of the total responsive land area, approximately 54.25 percent is cultivable, 23.9 percent is pasture, 5.12 percent is forest, and 16.65 percent is built-up upland. earthy brown. The soil type most commonly found in the region is nitisol. Soil types most often found in the United States are clay and loam (2014). In the research region, a wide variety of plant species can be found, including dense, old forests at the junctions of upstream and downstream stream banks, as well as patches and small areas of less dense forest cover. Eucalyptus camalduleses, also known as Bargamoo diimaa, are abundant in the study region.

There is a north-to-south orientation to the drainage system in the study area. Large rivers may flow through the research region. In the region under consideration, precipitation plays a crucial role in replenishing the flow. The overall population of the district is 133,584. 25,293 males and 68,291 females made up 22,880 households. A wide variety of farming techniques are common in the region under investigation. According to BTAO (2019), the two main crops grown in the region are pepper and maize.

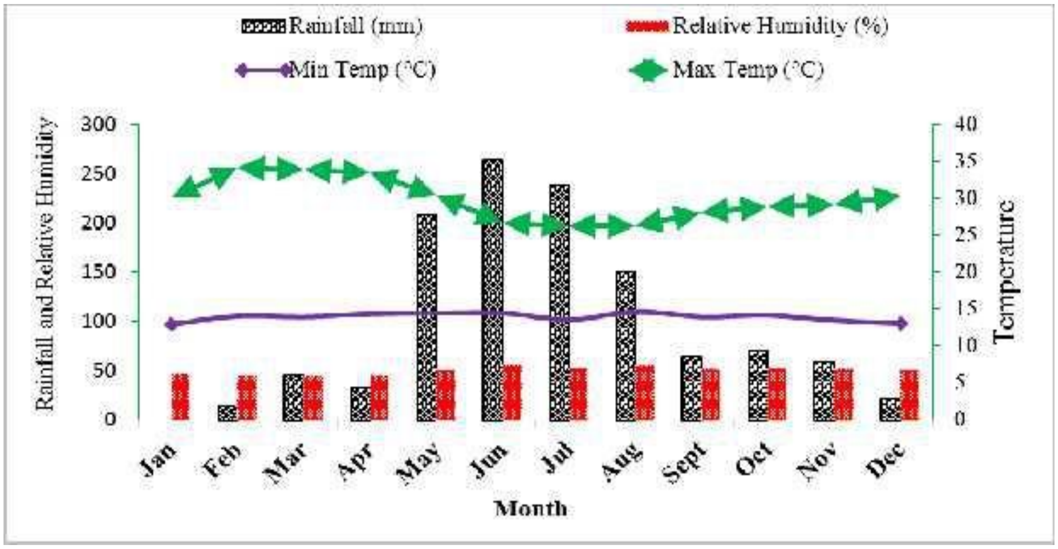

Figure 2 *The study area's annual rainfall as well as its maximum and lowest temperatures*

Figure 3 shows that the entire land area of the district is 64,646 acres. The region's land cover is as follows: 4.84% forest, 8.03% built-up or designated, 19.3% undesignated, and 54.4% arable or cultivable (BTAO, 2019). A total of 51,050 ha are utilized for agriculture, 6,647 ha are set aside for livestock, 1,448 ha are covered in trees, 1,090 ha are adorned with plants and shrubs, 4,361 ha are characterized by swamps, rocks, or mountains, and 933.63 ha are devoted to coffee plantations. A total of 28 kebeles, 4 of which are urban, make up the Bako-Tibe district. (from DURLA, 2010).

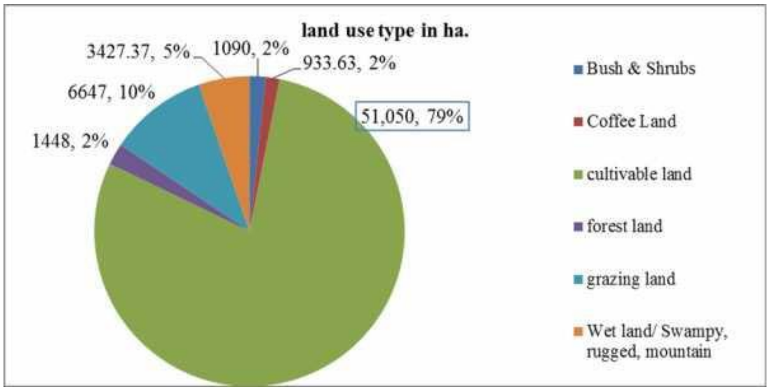

Figure 3 *Land Use Pattern of Bako Area*

Sampling Site Selection and Soil Sample Collection

From a total of three locations, three soil profiles representing forest, pasture, and cultivated land uses were selected for this study. Soil samples were collected in May 2019 at a depth of 0-20 cm using a hand auger. There had been 11 years of continuous farming on the farmed land and 6 years of grazing on the uncultivated section when the samples were taken. In order to determine which soil properties are most important, a total of 18 experimental units will be used, with 3 treatments, 3 replications, and 2 locations per unit.

Laboratory Data analysis

Mixing the disturbed composite soil samples from each land use type's representative plots, letting them air dry, and finally filtering them through a 2 mm filter allowed us to examine specific physical and chemical aspects of the soil. The soil was tested chemically and physically in the soil testing facility of the Bako Agricultural Research Center, using normal laboratory methods.

The bulk density (BD) of the soils was determined using the undisturbed core sampler samples collected from various land uses. For 24 hours following their weight at field moisture content, the samples were dried in an oven at 105°C. Soil particle size distribution was determined using the hydrometer method. According to Sarkar and Haldar (2005), for calculating soil organic matter (SOM) from SOC data, the factor 1.724 was utilized. Soil organic carbon (SOC) levels were measured using the Walkley-Black fast titration method. Using a potentiometric method, the pH of the soil in a soil-to-water mix of 1:2.5% was measured. The method of micro-Kjeldahl digestion, distillation, and titration outlined by Bremner and Mulvaney (1983) was employed to determine the total nitrogen content. The Bray-II extraction method was used to find the available P, while a flame photometer was used to measure the available K, exchangeable cations (Na+ and K+), Ca2+, and Mg2+. The Walkley-Black oxidation method was used to quantify the quantity of soil organic carbon (SOC). The following methods were used to measure different elements: the Kjeldahl digestion method for total nitrogen (TN), ammonium acetate extraction for cation exchange capacity (CEC), Bray-II extraction for available P, exchangeable cations (Na+ and K+), and available K; an atomic absorption spectrophotometer for Ca2+ and Mg2+; and a soil/water suspension of 1:5 for electrical conductivity (EC) (Kirk, 1950).

Statistical analysis

Different types of land use were considered as factors, with soil quality serving as the dependent variable. When the analysis of variance revealed statistically significant differences ($p < 0.05$), Tukey's honest significance difference (HSD) test was used to calculate the mean separation. To find out if there was a significant difference between soil quality indicators and land use categories at a significance level of ($P < 0.05$), the analysis of variance (ANOVA) and general linear model (GLM) technique were utilized in the Statistical Analysis System (SAS) version 9.4.

RESULTS AND DISCUSSION

Soil Textural Fractions

Soil physical property results are shown in Table 1. Soil sand, silt, and clay textural fractions were significantly affected by land use categories. Overall, the soil fractions of sand, silt, and clay were higher in the protected forest soil compared to the soil fractions under farmed land. Then came the broad grasslands for grazing. Table 1 shows that under grazing land the soil included the highest percentage of sand (39.00%), whereas under continuously farmed land the soil contained the lowest percentage (38.00%) and under forest land the lowest percentage (34.83%). It was found that 34.83% of the forest area and 39.00% of the pasture land contained sand at both sites. Land that was continuously cultivated had the second-highest mean silt content (47.33%), followed by grazing land (47.0%), and soil beneath forest land (48.13%). Table 1 shows that the soil concentration of clay was 14.0% in the grazing area and 16.83% in the forest. In forest land, the percentage of clay was found to be the highest at 16.83% and the lowest at 14.000%. Forest land contains the highest amount of clay (16.83%) and the lowest percentage of sand (34.83%). On the flip side, the sluggish pace of weathering processes could account for the grazing field's greatest sand percentage (39.00%) and lowest clay percentage (14.0%). There was no statistically significant change in the silt content across three land uses. In general, the silt content of the forested area was 48.33% lower than that of the farmed land, which was 47.33 percent. The top layer of soil on continuously farmed land is less silty than that on forested land.

Bulk Density (gcm^{-3}) and Total porosity (%)

Different land uses result in different bulk density values (Table 1). The overall mean soil bulk density in the research area differs significantly between land use types ($\boldsymbol{U} < 0.5$) and their interaction effects, as shown in Table 1. Soil bulk density ranges from 1.21 gcm-3 in agricultural settings to 1.32 gcm-3 in open grazing areas, depending on the land use. Similar studies found that different forms of land use were significantly associated with varying bulk densities due to differences in land management and land use histories (Mulugeta et al., 2005). The highest bulk density value observed in grazing areas can be due to the compacting of large amounts of sand and soil caused by the footfall of cattle. This could lead to unfavourable soil conditions, which would impact agricultural productivity negatively, because root growth and air circulation are restricted. Still, forest land use has the lowest bulk density value of all land uses. According to Table 1, the forest land had a bulk density of just 1.05%, while the areas used for cultivation and grazing had substantially higher densities of 1.21% and 1.32%, respectively. According to Gupta (2004), the bulk density of mineral soils typically falls within the acceptable range of 1.1 to 1.4 g cm-3. Therefore, the bulk density values of the land use classifications were within the allowed range. Aeration and water flow within the soil structure stimulate plant growth, govern the quantity and variety of soil microorganisms, and serve a flexible function in agricultural activities; this is due to the fact that the bulk densities of the soils in this research region were within projected ranges. Soil disturbance is minimal and clay content is high, which may explain why forest land has the lowest soil bulk density. This meant that the soils in the study area did not have very compact bulk density values, which meant that water and air could still pass through and roots could extend their reach. This points to the presence of loose soil conditions and, by extension, good structure across all land use categories. Soil porosity was often impacted by bulk density. Since total porosity increases with decreasing bulk density and decreases with increasing bulk density, this is the result. The results showed that the total porosity of the soils in agricultural, grazing, and forest land use categories were 52.45%, 56.52%, and 57.01, respectively (Table 1). Greater organic matter content and bulk density were associated with greater total porosity values. Soils in the Itang-Kir area of Ethiopia's Gambella Region and the Jelo sub-catchment of the Chercher highlands in western Ethiopia's Bako area had similar results in studies conducted by Mohammed (2003), Negassa, and Gebrekidan (2003). The soil in pastures gets less porous due to animal plow compaction, which is worse than the soil on farmed land. All of the land units have extremely high percentages of total porosity, according to the Roy (2006) evaluation. Based on the total porosity identified on all land units, the soils in the research region may provide good aeration for plants and microorganisms, which is an indicator of their physical fertility.

Table 1

Effects of land-use types on physical properties of the soils of the Bako Tibe district.

Treatment	Soil Particle size distribution								
	Sand (%)	Silt (%)	Clay (%)	TC	B D ($g\ cm^{-3}$)	TP (%)	FC (mm)	PWP (mm)	AWHC (mm)
Land-Use Types									
cultivated	38.00a	47.33a	14.67a	clay	1.21b	52.45^{b}	360^{f}	239^{e}	121^{d}
grazing	39.00a	47.01a	14.00a	clay	1.32a	56.52^{a}	368^{e}	250^{d}	118d^{c}
Forest	34.83a	48.35a	16.83a	clay	1.05c	57.01^{a}	398^{d}	265^{c}	133^{c}
LSD	10.29	9.33	4.29		0.08	2.55	0.65	0.84	0.90
CV(%)	22.29	15.85	22.85		5.51	2.75	1.72	3.31	3.40
P-value	0.456	0.806	0.217		0.103				
Significance	NS	NS	NS	NS	**	**	**	**	**

The main effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$. NS = not significant; CV =coefficient of variation; LSD = least significant difference.

Available water holding capacity (AWHC)

It was discovered that the type of land use and the interaction impact significantly (p 0.01) affect the available water holding capacity (AWHC). At PWP, it was found that forests had the maximum water content (265 mm), while cultivated land had the lowest (239 mm). Soil water holding capacity (AWHC) was greatest in forested land types (133 mm) and lowest in non-forested land types (118 mm). Climate changes brought about by litter may have contributed to this by lowering the bulk density (b), increasing the clay content dramatically, and decreasing the soil organic matter content. Another consequence of using low FC in farming is a decrease in the soil's ability to retain water due to decreased structural aggregation (Negassa and Gebrekidan, 2003). In the woods, the AWHC was at its peak. A higher organic matter and clay content in the soil supplied the vast surface area needed for water molecule absorption and retention (Materechera and Mkhabela, 2001). However, unlike loam-textured soils, soils rich in clay retain a lot of water at FC and PWP, limiting the quantity of water that crops may access.

Table 1 shows that the concentrations of sand, silt, and clay at FC and PWP may cause them to have different water contents. Conversely, the increased FC, PWP, and AWHC values in the farmed land use may be attributable to the higher clay content in that area. In cultivated land usage, lower moisture contents were associated with lower FC, PWP, and AWHC. The AWHC of farmed land is reduced because this has a detrimental impact on PWP and FC. Soil water holding capacity was found to be affected by differences in soil water content, which in turn affected AWHC, FC, and PWP. This can be due to changes in soil organic matter and clay levels caused by land usage.

The effect of land use type on soil chemical properties

Soil reaction (pH)

The study's findings showed that neither the site nor the treatments had any discernible effect on the soil's pH level (p 0.05). There is around a 4.16% coefficient of variation in the soil pH in the study area, which varies from 5.47 to 6.22 among treatments (Table 2). According to Table 3, the soil pH values under the forest land were 6.22 and 5.47, respectively, under the agricultural areas. This indicated that soil pH was highest in forested regions due to the accumulation of organic matter and higher quantities of exchangeable base cations.

Rainfall that is particularly heavy in the region may be the root cause of soil erosion and the leaching of exchangeable basic cations (Ca, Mg, K, and Na) from soil surfaces, leading to soils with the lowest pH values under farmed land. Intense agricultural methods, continual fertiliser treatments, and crop harvesting that removes basic cations could perhaps be to blame for the declining pH levels in the studied area. There are two main reasons why agricultural land often has the lowest soil pH value. Harvesting crops, rapid erosion runoff, and the most intense microbial oxidation—which produces organic acids and adds H+ ions to the soil solution—all contribute to a decrease in basic cations, which are then released into streams. Soil pH levels were lower in agricultural and grazing areas in northwest Ethiopia compared to forest areas, according to Eyayu et al. (2010). Our results corroborate their findings.

Another finding was that soil pH was classified as extremely acidic in areas with cultivated and grazing pastures, and somewhat acidic in areas with forest cover. Soil pH values in the study regions drop as one moves from wooded to agricultural and grazing areas in both sites. Soil acidity, high rates of leaching and erosion, limited nutrient availability, and inadequate soil management all contribute to arable land having a soil pH as low as 5.47. As a result, soil fertility declines from forested areas to agricultural and pasture areas. The results support what Negassa and Gebrekidan (2003) found: that soils in forested and grazing areas seemed more acidic than those in farmed areas. The only way to lower the soil's acidity is to save it. Soil liming is a viable option for controlling soil acidity on farmed land, according to Yao et al. (2010).

Table 2

Effects of land use types on selected chemical properties of the soils

Land use types	pH (1:2.5 H2O)	SOC %	SOM %	TN %	C:N ratio	Av.P (ppm)	CEC (cmol kg^{-1})
Cultivated	5.47b	3.16a	5.45a	0.18b	17.56a	17.43b	27.98b
Grazing	5.74b	3.27a	5.64a	0.20b	16.35a	16.42a	32.24ab
Forest	6.22a	3.40a	5.86a	0.30a	11.33b	12.58a	35.46a
LSD	0.30	0.61	0.98	0.04	1.22	1.75	7.46
CV (%)	4.16	15.10	14.40	14.80	6.28	9.13	18.88
P value	0.2027	0.8774	0.7227	0.1958	0.0052	0.0038	0.4241
Significance	**	NS	NS	**	**	**	NS

The main effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$. NS = not significant; CV =coefficient of variation; LSD = least significant difference

Soil organic carbon and organic matter

The analysis's findings demonstrated that the Table 2 shows that the amounts of organic carbon in the soil were unaffected by the treatments ($P > 0.05$). The treatments did not exhibit statistically significant variation, even if there were numerical differences. Samples of soil from farmed land (3.16% SOC), pasture land (3.27% SOC), and forested land (3.40% SOC) demonstrated quantitatively different levels of soil organic carbon (SOC). The mean SOC content was 3.16 percent on forested land and 3.4 percent on farmed land, respectively, according to the data. This results was in agreement with what Chimdi et al. (2012) found: that compared to other types of land, farming had a lower SOC content. The study area has a medium SOC concentration across all land use categories, as reported by Tesfahunegn (2016).

Total nitrogen (TN%) and carbon to nitrogen ratio (C/N)

Tabulated in Table 3 are the total nitrogen concentrations of the two sites' agricultural, pasture, and woodland fields. The total nitrogen content of the soils was significantly affected by the treatments (P 0.05), according to the data analysis. There is a 0.18 to 0.30 percentage point difference in the mean total nitrogen across the study area's two sites and treatments. Soil nitrogen content is reduced overall by farming, as seen by the generally lower total nitrogen concentrations of cultivated soils compared to forestlands. Table 2 shows that the total nitrogen coefficient of variation is 14.80%. Forest land had the greatest mean TN value (0.30), whereas cultivated land had the lowest (0.18). Leaching, heavy rainfall, erosion, and a lack of soil conservation measures may have contributed to the lower total nitrogen concentration on farmed and grazed land in the research region. Soil samples taken from agricultural, grazing, and forest areas all revealed greater average total N levels, which is consistent with previous studies (Nega, 2006; Abera and Belachew, 2011). Forest land had a medium TN% in the study area, while cultivated and grazing land had a low TN% (Landon 2014). Cultivated soils often contain far less total nitrogen than forest land, suggesting that agriculture gradually reduces soil total nitrogen levels.

Available Phosphorus (Av. P, ppm) and Cation Exchange Capacity (CEC cmol kg^{-1})

There is a noticeable disparity ($p < 0.05$) in the average P contents among various LU forms. It seems that the cultivation type of LU had a higher average P concentration (17.43 ppm) than the other types. This could be because inorganic fertilisers like urea (CO(NH2)2) and di ammonium phosphate (DAP) and organic fertilisers like compost, manure, and household waste were applied to the cultivation land. According to Table 2, the forest had the lowest average P concentrations at 12.58 ppm, whereas the cultivated land had the highest at 17.43 ppm. In a similar vein, Melaku et al. (2019) found that arable land had a substantially higher Av. P than forested and grazing areas. One possible explanation for this variation is the usage of compost, animal manure, and home garbage. Forest area may have a lower average P content due to phosphorus fixation. The average quality of all land uses was low, according to Landon (2014). Possible reasons for the deficiency of accessible P in forest regions include water-induced erosion and the low P quality of the parent materials. Soil erosion, crop harvesting, and P fixation all contribute to the low accessible P found in most Ethiopian soils. The data analysis revealed that different land use categories had a significant impact (P 0.05) on the Cation exchange capacity of the soil in the research area, as shown in Table 2. Values of 27,98, 32.24, and 35.46 cmol kg-1 for the Cation Exchange Capacity (CEC) are shown in Table 2 for the agricultural, grazing, and forest zones, respectively. Different amounts of soil organic matter may explain why CEC is higher or lower in forested and agricultural areas, respectively. As the concentration of organic matter and clay particles in the soil increased, the results showed that the soil's ability to exchange cations also increased. Results showed that CEC values were lowest (27.98) and greatest (35.46) in forested areas, respectively.

CONCLUSIONS

Most soil quality indicators in the Gibe watershed vary greatly between land uses. Different types of LU resulted in significantly different soil quality indicators, such as sand fractions, dry soil bulk density (ρb), AWHC concentrations, TP, TN, C:N ratio, and Av. P. Soil pH, organic carbon levels, and the ratio of silt to clay, as well as other LU kinds, were not significantly different. Soil AWHC, TP, SOC concentrations, and TN characteristics were all lower on the farmed land than on the adjacent pasture and woodland areas. Soils in the Gibe watershed that were tested showed low levels of organic carbon, clay fractions, and acidity.

The significantly reduced values of (ρb) in grazing areas and on the surface could be attributed to heavy animal trampling, which increases with soil depth and reduces SOC and SOM concentration. The transition from forested to agricultural and grazing land has altered water circulation in the soil system, which, together with an absence of effective land management practices, is a major contributor to the problem. It is possible that the relatively acidic nature of the soils under investigation was caused by the heavy rainfall that washed away basic Cations from the soils' upper layers.

The soil quality was jeopardized due to a multitude of factors, such as human interference, continuous animal invasion, and intensive agricultural production systems, as seen by the low levels of organic carbon and soil organic matter content, total nitrogen, and accessible phosphorus in all LU types. The decrease in TN, SOC, and SOM content in agricultural fields could be due to the burning and removal of biomass, together with insufficient replenishing. For this reason, sustainable and integrated land management—which seeks to enhance suitable land use systems and is fundamental to the long-term health of ecosystems—is the way to go if we want to put an end to soil erosion and restore soil quality.

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DECLARATION

The author declares that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

All data are included in the article.

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