Original Research Article

Impact of Land Use and Land Cover Changes on Soil Physio-Chemical Properties in Southern Tigray, Northern Ethiopia

ABSTRACT

Soil quality declines due to the conversion of natural vegetation into farmland and grazing areas. The response of soil properties to land use and land cover changes (LULC) exhibits both spatial and temporal variations. This study aimed to assess the effects of LULC changes on the physico-chemical properties of soil in the Wojicwatershed. Soil samples were collected from natural forests, bushland, shrubland, and cultivated lands across three landforms of the watershed (upper, middle, and lower) to evaluate the physical and chemical properties of the soil associated with different LULC types. The LULC categories were compared using mean values and critical thresholds for selected physicochemical soil properties. Soil analysis was conducted using R software, employing one-way analysis of variance (ANOVA). A normality test was performed before the post hoc analysis, and Tukey's honest significance difference (HSD) test was utilized for mean separation among the LULC types. Additionally, a normalized difference vegetation index (NDVI) was calculated for the years 1997 and 2017. A simple linear regression model was developed to estimate soil physico-chemical properties over the past 20 years, using laboratory soil parameters and the NDVI for 2017. The pH values showed a slight decrease in cultivated land (from 5.7 to 5.4), bushland (from 7 to 6.6), and shrubland (from 6.5 to 6.2) over the study period. The analysis indicated a declining trend in physico-chemical properties, attributed to changes in vegetation cover and management practices. Consequently, the government needs to enforce policies and regulations that promote effective land resource management and utilization, with particular emphasis on the proper management and conservation of forests, bushlands, and shrublands, as well as measures to prevent increased land resettlement.

Keywords**:** Land Use Change, Land Cover Change, Soil Physio-Chemical Properties,Wojicwatershed,Soil samples, Soil analysis

1. INTRODUCTION

Diriba (2020) highlights that agriculture is a cornerstone of Ethiopia's economy, contributing over 34.1% to the GDP and employing around 80% of the population. It also generates 80% of foreign earnings and provides essential raw materials and investment capital. The rapid population growth in both rural and urban areas, as noted by Bewket and Stroosnijde (2003) and Alemu et al. (2010), presents significant challenges for resource management to meet the rising food demands. This demographic shift is driving changes in land use and land cover, primarily converting forests and grazing lands into cultivated areas (Zeleke and Hurni, 2001).

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According to the Central Statistical Agency (CSA, 2014) and Diriba (2020), about 96% of farmland used for crop production is held by farmers with average landholdings of less than one hectare, contributing over 95% of the country's agricultural output. This heavy reliance on agriculture underscores the urgent need for sustainable management of natural resources, particularly soil (Lemenih, 2004).

Research by Tekle and Hedlund (2000), Belay (2002), and Kebede and Raju (2011) has shown that reducing natural vegetation and converting it to cultivated and grazing lands leads to soil quality degradation. Deforestation and the conversion of forest land to agriculture have negatively impacted the physical and chemical properties of soil in Ethiopia (Bewket and Stroosnijde, 2003). Alemu (2015) emphasized that land use practices significantly influence the distribution and availability of soil nutrients by altering soil properties and affecting biological processes in the root zone.

Studies across various regions of Ethiopia have revealed variations in soil quality indicators linked to different land uses and covers. For instance, total nitrogen (TN) and soil organic matter (SOM) levels in central Ethiopia have declined due to long-term cultivation and deforestation (Lemenih, 2004). In Northeast Wollega, TN levels were highest in forested soils and lowest in cultivated areas (Adugna and Abegaz, 2016). Abegaze et al. (2006) reported that soil bulk density (BD), porosity, infiltration, water storage, and runoff were negatively impacted by the conversion of natural forests to cultivated and grazing lands. Additionally, Lemenih (2004) found that prolonged cultivation increased BD and reduced pore space in the top 20 cm of the plow layer in the Central Rift Valley.

Elevation also plays a significant role in soil properties throughout Ethiopia (Abegaze et al., 2006; Asmamaw and Mohammed, 2013). Abate et al. (2013) identified notable effects of altitude on soil pH, BD, and silt content. For example, in the Jedeb watershed, midland areas exhibited higher soil pH and BD compared to upland regions (Teferi et al., 2016). Overall, soil physical and chemical properties are profoundly influenced by land use and land cover changes, as well as agroecological zoning, which are further affected by elevation (Bewket and Stroosnijde, 2003). These factors ultimately impact the soil's ability to support plant life and other organisms, thereby influencing the productivity of both natural and managed ecosystems (Lemenih, 2004).

Numerous studies have assessed the effects of land use changes on soil properties (Raji and Ogunwole, 2006; Tieszen L.L., 2000; Schlesinger W.H., 1999; and Martin A.N.A., 2010). However, the physico-chemical properties of soil due to land use and land cover changes have been only slightly assessed. Additionally, there is a lack of baseline data to predict the status of soil properties in past years.Moreover, developing models is crucial for predicting the temporal effects of land use and land cover changes on soil physico-chemical properties. Currently, there are no established models to estimate these changes or dynamics. Therefore, this research aims to estimate selected soil physico-chemical properties over the past two decades by developing prediction models for each soil parameter. The findings will assist researchers, planners, and academicians in their future research, teaching, and planning efforts. Additionally, it will support development partners in their planning and implementation processes.

2. MATERIALS AND METHODS

2.1. Study area description

2.1.1. Location

The Raya Azebo district is situated in the southern zone of Tigray, between latitudes 12°46’27" to 12°51’8" N and longitudes 39°34’6" to 39°55’19" E, at altitudes ranging from 912 to 3118 meters above sea level (m.a.s.l). Covering approximately 176,210 hectares, the district encompasses about 60% of the Raya Valley, which is part of the Ethiopian Rift Valley system (CASCAPE, 2014). It is located 649 km north of Addis Ababa and about 134 km south of Mekelle, the capital city of the Tigray Region.

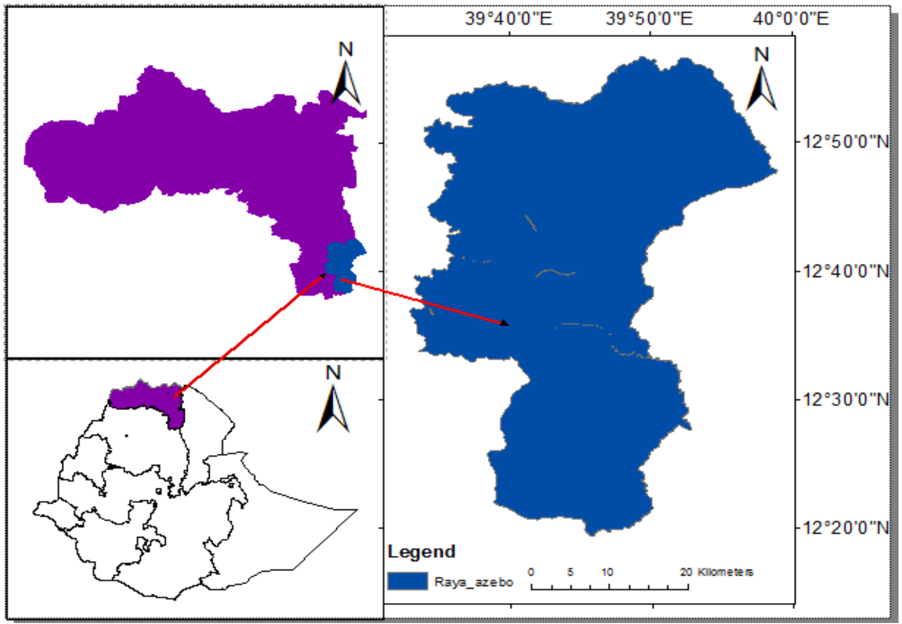

Figure 1 Map of the study district

A large part of this district, is in the mid-highland zone (80% of the area), with the lowland (500-1500masl) and highland (2300-3200 m.a.s.l) areas covering 18.6% and 1.4% of the district, respectively. Rainfall is bimodal, but potential evaporate-transpiration is high and exceeds rainfall amount in most of the years (Weldeamlak et al. 2015). According to the metrological data of Tigray regional state, the study district's mean annual rainfall is 690 mm, and the mean monthly temperature varies from 12 to 28.8oC (Figure 2).

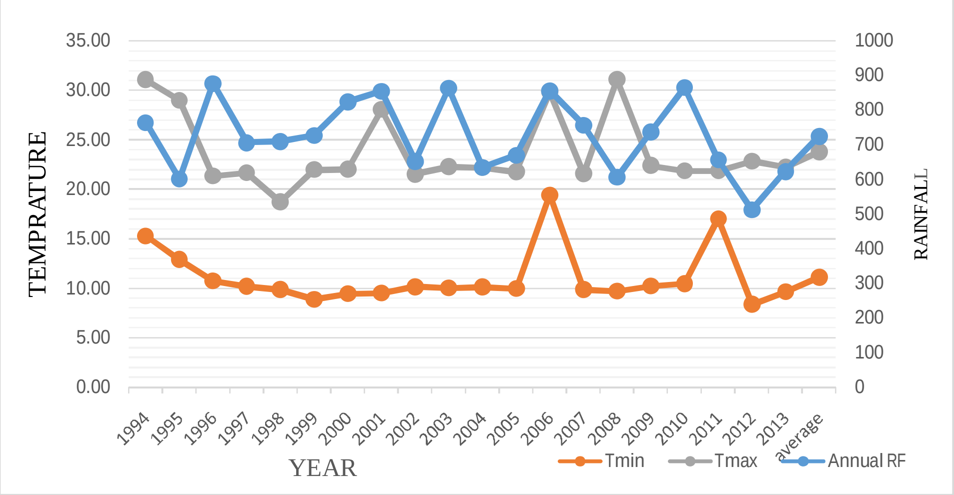

Figure 2 Metro logical data of the study watershed

As illustrated in the figure above, the mean annual rainfall in 2011 was lower compared to other years. Figure 3 shows that the study district experiences two rainy seasons: the Kiremt (summer) and Belg seasons. Bimodal crop production and small-scale irrigation activities are common in the district (New locClime, 2005). Crop production typically occurs during the Belg season (February, March, and April) and the Kiremt season (July, August, and September).

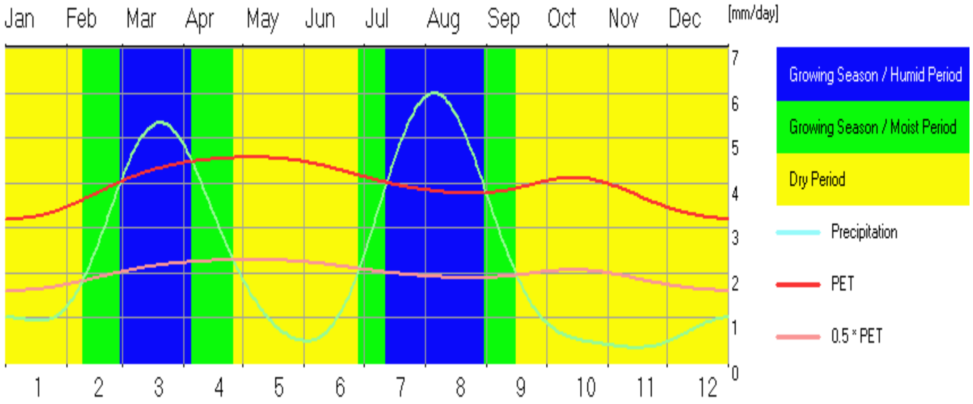

Figure 3 Growing period, of the study district (New locClime, 2005)

2.1.2. Land use and farming system

The study district features various land use types, including shrubs, bushland, forest land, grazing land, and cultivated land, with cultivated land covering approximately 24.6% of the area (Table 1). The dominant land use type is forest land, accounting for about 36% of the district.

The primary tree species in the district include Acacia saligna, Acacia tortilis (Forssk.) Hayne, Azadirachta indica, Eucalyptus camaldulensis, Balanites aegyptiaca (L.) Del., Grevillea robusta, and Melia azedarach. Dominant shrub species are Carissa edulis, Catha edulis, Dodonaea angustifolia L., and Grewia ferruginea.

Table 1 Land use type of the district

Land use	Area (ha)	(%)
Cultivated land	43279	24.6
Forest land	64074.7	36.4
Shrub land	32144.2	18.2
Grazing land	5616.4	3.2
Homestead	28605.5	16.2
Bare land	612.5	0.3
Roads and rocks	1876.75	1.1
Total	176210	100

Source BoARD, 2017

Mixed crop-livestock farming, involving cattle, sheep, goats, and camels, is the predominant farming system in the district (CASCAP, 2014). The district cultivates a variety of crops, including cereals, fruits, vegetables, pulses, and oil crops. Major crops grown are sorghum bicolor, Eragrostis tef, and Zea mays.

Beekeeping has also become increasingly important for household livelihoods in the district. According to the Agricultural Office report (2017), there are 520 hives managed by 300 people. The average landholding per household in the district is 0.75 hectares, with an average household size of 4.2 members (Weldeamlak et al., 2015).

2.1.3. Soil type

The major soil types in the district include Lithosols (15%), Chromic Vertisols (39%), CalcaricCambisols (1%), EutricRegosols (18%), VerticCambisols (13%), and EutricCambisols (14%), with Chromic Vertisols being the most dominant (FAO, 2001) (Figure 4).

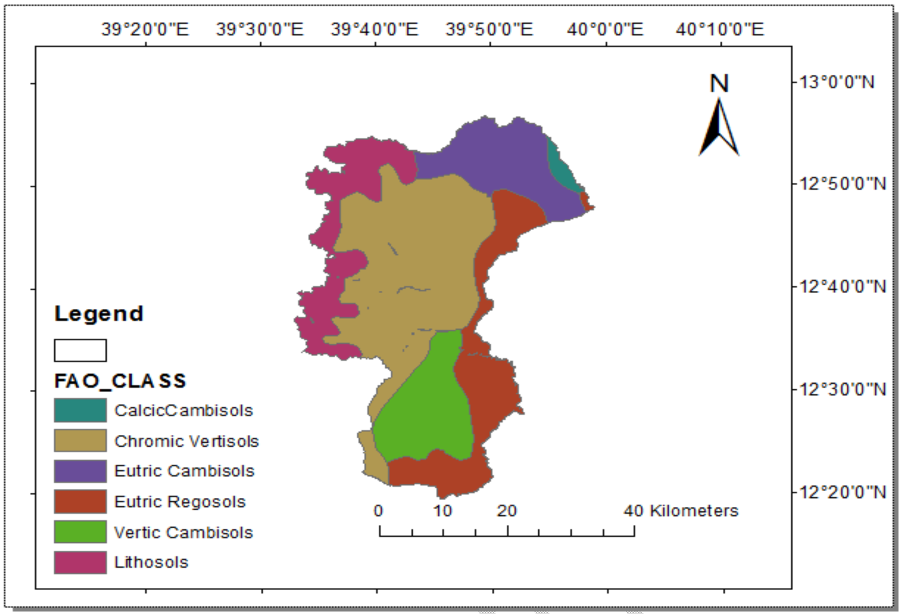

Figure 4 Soil map of the study district (soil map of the regional state of Tigray)

2.1.4. Geology

According to the geological map of the Tigray regional state, the study district is characterized by several formations: Antalo formation (1.6%), Quaternary deposits (26.7%), Hashenge formation (65.6%), Ambaradom formation (0.9%), Alaje formation (2.7%), and Aiba formation (2.4%) (Figure 5).

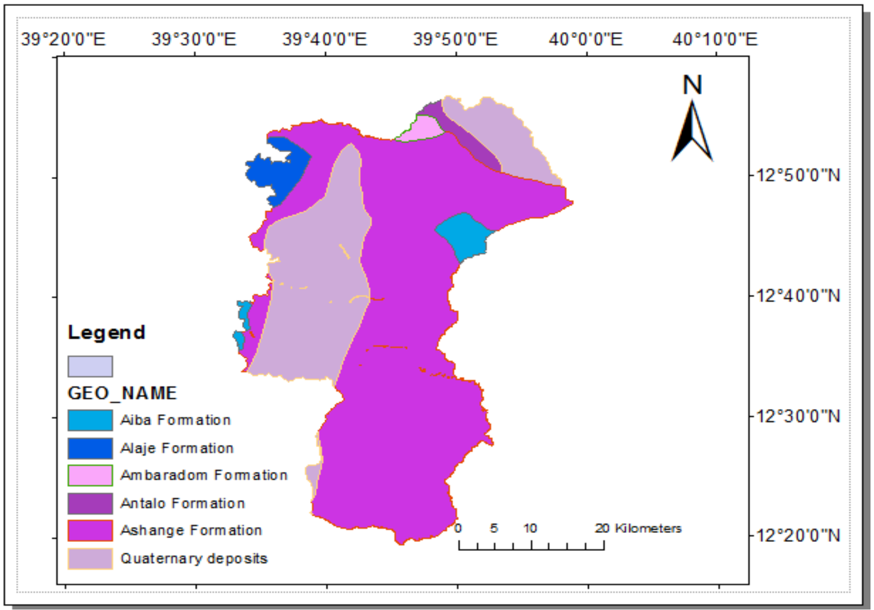

Figure 5 Geological map Raya Azebo district (Geological map of the regional state of Tigray)

2.1.5. Population size of the study District

According to the BOARD (2017), the study district is home to 158,498 individuals, comprising 78,207 females and 80,291 males. The population primarily relies on farming and trade activities for their livelihood (Weldeamlak et al., 2015).

2.1.6. The study Watershed

The study was conducted at Wojic Watershed in the Raya Azebo district, southern Tigray (Northern Ethiopia) (Figure 4). This area is located approximately 5 km west of Moheni town, the district capital. It spans between longitudes 39°16'30" to 39°37'30" E and latitudes 12°40'30" to 12°49'30" N, with altitudes ranging from 1828 to 3450 meters above sea level (Figure 6).

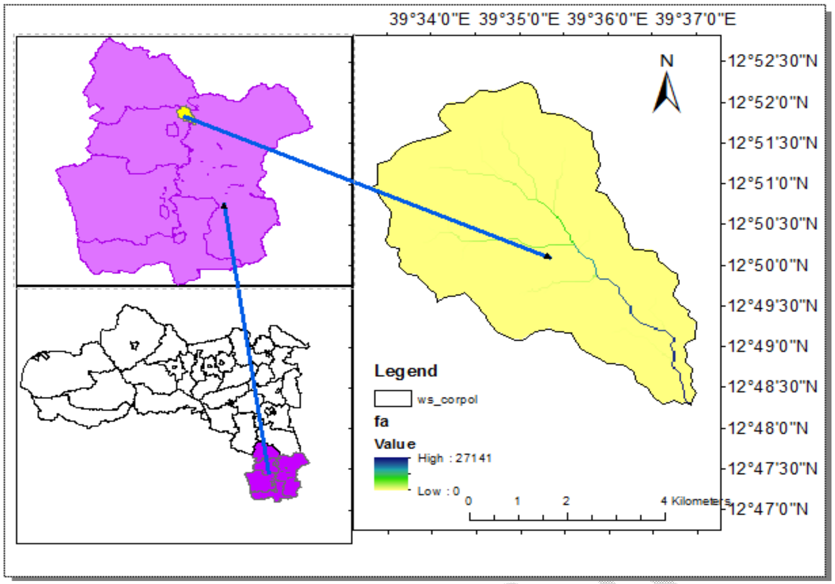

Figure 6 Map of the study watershed

The study watershed spans three districts: Emba Alaje (11.5%), Enda Mohoni (10.9%), and Raya Azebo (77.6%). According to the geological map from the regional government of Tigray, the watershed is classified under the Alaje formation, with consistent geological characteristics throughout (Figure 5).Based on FAO (2006), the land slope of the watershed is categorized into seven types: flat (<3%), gentle sloping (3-8%), rolling or sloping (8-15%), hilly (15-30%), mountainous (30-40%), steep mountainous (40-60%), and very steep mountainous (>60%). Thus, the slopes in the study watershed range from flat to very steep mountainous (Figure 7).

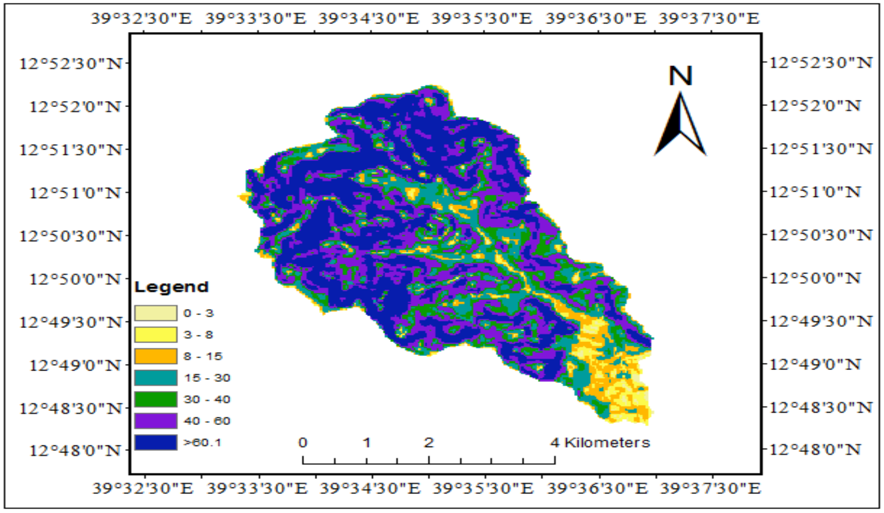

Figure 7 Slope classification of the study watershed

Field crops grown in the lower part of the watershed include Sorghum bicolor, *Eragrostis*tef, and *Zea mays L.* In the upper watershed, the major crops cultivated are *Hordeum vulgare* (barley), *Triticum aestivum* (wheat), *Vicia faba, Pisum sativum* (field pea), and *Lens culinaris* (lentil) (BoARD, 2017).

The watershed supports approximately 356 households, comprising 213 males and 143 females. The total number of individual beneficiaries in this watershed is 1,513, with 711 males and 802 females (BoARD, 2017).

Study methods

2.1.7. Site Selection

ThThe study watershed was selected in consultation with district watershed experts and through field surveys, based on pre-established criteria. These criteria included the presence of diverse land uses, various slope classes/landforms, different agro-ecologies, and watersheds that are at least two decades old. As shown in the photo below, the left side represents the lower part of the watershed, while the right side represents the upper part (Figure 8).

Figure 8Photo showing the study Watershed in part (photo: Abadi, 2017)

According to FAO (2006), the watershed is divided into three landforms: the upper part, middle part, and lower part. It encompasses four different land use types.

2.1.8. Data Collection and Analysis

2.1.8.1. Soil sampling and preparation

Before commencing the study, a general visual field survey of the watershed was conducted in 2017 to gain an overview of its variations. The field observations identified four major land uses: cultivated land, forest, bushland, and shrubland (Figure 9). These land uses are present across all landforms of the watershed, including the upper, middle, and lower regions (Figure 10).

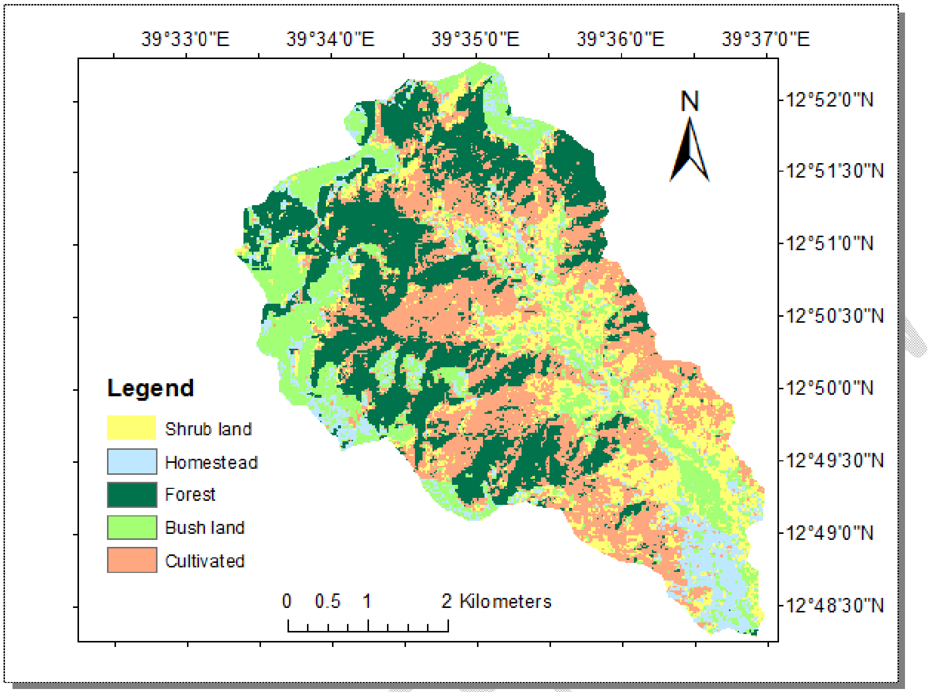

Figure 9Land use map of the study watershed

Soil samples were collected from each land cover type and slope position at a depth of 20 cm, which represents the topsoil and mobile nutrients.

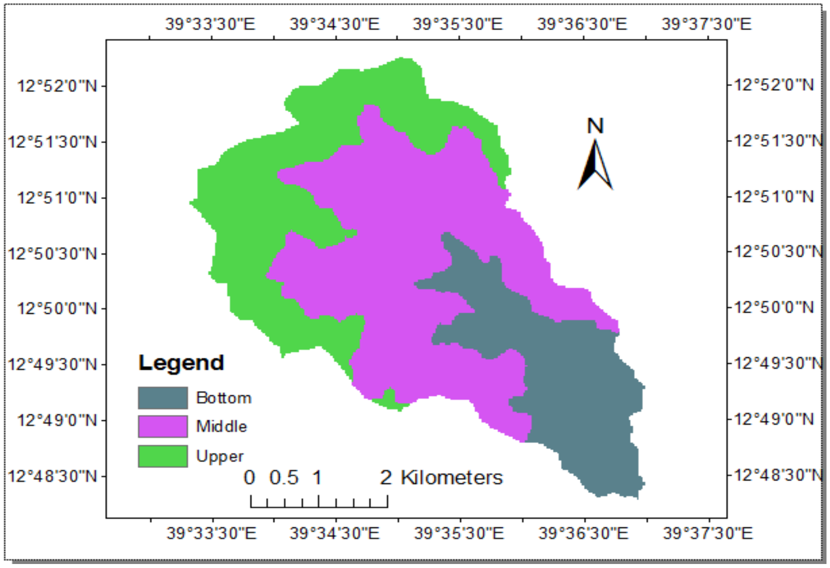

Figure 10 Landform map of the study Watershed

To achieve this, a landform map (comprising three categories: upper slope/plateau, sloping/middle slope, and lower slope/foot slope) was overlaid with a land use and land cover type map to create a land unit map.p.

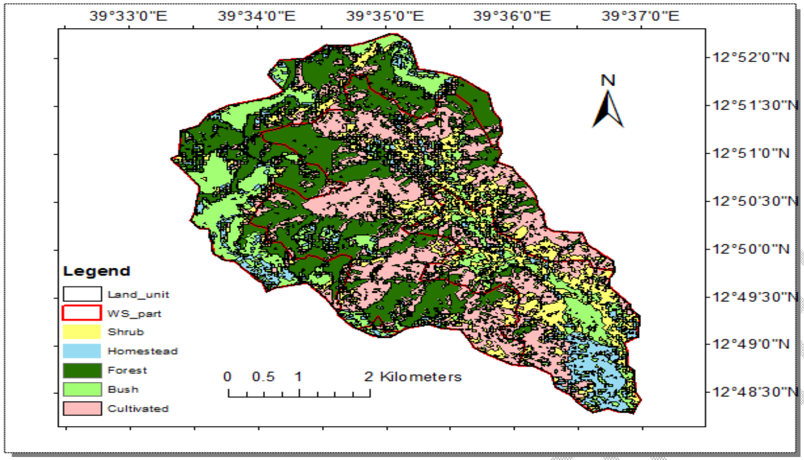

Figure 11Land unit map of the study Watershed

Based on Tefera M. (2001), disturbed and undisturbed soil samples were collected using the transect method from each land use type in December 2017, after the crop harvest. Two soil samples were taken from each land use type and slope position: one for physico-chemical property analysis and the other (undisturbed) for bulk density measurement. The landform classification was done using a digital elevation model (DEM) with a resolution of 30m by 30m, categorizing the area into three landforms: upper, middle, and lower slopes (Figure 11).

In total, twenty-four soil samples (12 disturbed and 12 undisturbed) were collected. The samples were air-dried, thoroughly mixed, and passed through a 2mm sieve. The disturbed soil samples were then taken to the laboratory for analysis of selected physico-chemical properties, including total nitrogen, organic carbon, available phosphorus, electrical conductivity (EC), cation exchange capacity (CEC), organic matter (OM), available sulfur (av. S), and pH.

2.1.8.2. Soil Laboratory Analysis

The physicochemical analyses of the composite soil samples were conducted at the Mekelle Soil Laboratory Center, following standard laboratory procedures. Soil texture was determined using the hydrometer method (Black et al., 1965). Bulk density was analyzed using the gravimetric method as described by Sahlemedhin and Taye (2000) and then calculated using Equation 1 proposed by Pearson et al. (2005).

$$\text{Bd} = \frac{ODW(gm)}{CV - (\mathbf{RF(gm)/PD(gm/cm^3)})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 1}$$

Where:-

- Bd is bulk density,
- ODW is oven-dry weight
- CV is the volume of the core sampler
- RF is the weight of fragment materials
- PD is 2.65 gm/cm^3

2.1.8.3. Analysis of soil chemical properties

The selected soil chemical properties include soil pH, electrical conductivity (EC), total nitrogen (TN), soil organic carbon (OC), cation exchange capacity (CEC), organic matter (OM), and available phosphorus. These properties were analyzed using the methods outlined in Table 2.

Table 2Selected soil physicochemical properties analyzed.

Soil parameters to be analyzed	Method of analysis	Reference
Bulk density	Gravimetric method	Sahlemedhin and Taye (2000)
Soil pH	pH-meter	McKeague (1978); McLean (1982)
Electrical conductivity	EC-meter	Richards (1954)
CEC	Ammonium acetate	Jackson (1967)
Organic carbon	Walkley and Black	Walkley and Black (1934)
Total nitrogen	Kjeldahl method	Bremner and Mulvaney (1982)
Available phosphorus	Olsen method	Olsen et. al (1954)
Soil texture	Hydrometric	Black et.al (1965)

2.1.8.4. Statistical analysis

To understand the relationship between the four land use types, descriptive statistics were performed. The land use and land cover types were compared using mean values and critical thresholds for selected physico-chemical soil properties. Soil analysis was conducted using R software version 3.3.1. A one-way analysis of variance (ANOVA) was employed to determine if the soil physico-chemical properties and soil carbon stock varied among the different LULC types. A normality test was conducted before the post hoc analysis, and Tukey's honest significance difference (HSD) test was used for mean separation of the soil physico-chemical properties among the LULC types (at ($P < 0.05$)).

2.1.8.5. Modeling land use and land cover change impacts on soil properties

A linear regression model was developed using the NDVI map and individual soil property maps of the study area for 2017. NDVI maps for 2017 and 1998 were created from Landsat images (ETM+ and TM, respectively) following Equation 7. Additionally, individual soil property maps for six soil parameters were developed for the watershed for 2017.

$$\text{NDVI} = \frac{\textbf{Float(band four−band three)}}{\textbf{float(band three+band four)}} \ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{Equation 2}$$

The resulting soil property and NDVI maps for the year 2017 were overlaid to create a regression model (equation 8)

$$Y2017 = aX2017 + (b) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{Equation 3}$$

Where Y = individual soil property for 2017, X = NDVI for 2017

The developed regression model for each soil property was validated using soil property and NDVI maps derived from soil samples and NDVI maps created for validation in 2017. Finally, the soil property data for 1998 were obtained by applying the NDVI data for 1998 to Equation 3. Soil property maps were then developed to assess changes in soil properties due to land use changes, using ArcGIS software.

3. RESULT AND RECOMMENDATION

3.1. Impact of land use land cover on selected soil properties

3.1.1. Impact of land use land cover on soil physical properties

Soils under shrubland and cultivated land exhibited the highest bulk density compared to other land use types, although this difference was not statistically significant (Table 3). The mean percentage of sand in bushland was higher than in other land uses, while the percentage of sand in shrubland was lower. However, these differences were not significant ($P > 0.05$). The mean sand content ranged from 56% in shrubland to 73.3% in bushland (Table 3). Cultivated land recorded the highest bulk density among the land use types. This finding aligns with Buytaert et al. (2002) and Zhang (2005), who reported that soil bulk density is influenced by soil management practices, particularly cultivation. High bulk densities in cultivated topsoils are primarily due to (1) rapid loss of organic matter through turnover and oxidation, and (2) soil compaction from heavy machinery.

Soils in shrubland and cultivated land had the highest mean silt percentages, at 32% and 30% respectively, showing a significant difference ($P < 0.05$). Other land use types did not show significant differences. Forest and bushland soils had lower mean silt percentages, at 28.7% and 11.3% respectively. Bushland had the highest clay content compared to other land use types, but the differences in mean clay content among the land uses were not significant ($P > 0.05$).

Table 3 Soil physical properties of WojicWatershed in different LULC

Soil physical property	Forest land	Cultivated	Bushland	Shrub land	P_value
	Mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd	
Bd (g/cm^3)	0.9942 ± 0.14^a	1.162 ± 0.086^a	1.25 ± 0.181^a	1.119 ± 0.181^a	0.296
Sand (%)	62±3.46a	60±13.9a	73.3±4.2a	56±11.1a	0.205
Silt (%)	28.7 ± 4.2^{ab}	30 ± 10.6^{ab}	11.3 ± 5^b	32 ± 9.2^a	0.038
Clay (%)	9.3 ± 1.2^a	10 ± 4^a	15 ± 7.6^a	12 ± 2^a	0.401
Textural class	SL	SL	SL	SL	

Note: SL = Sandy Loam

3.1.2. Impact of land use land cover on soil chemical properties.

Soil pH was significantly affected by land use ($p < 0.05$). The lowest mean pH value (5.4) was recorded under cultivated land, while the highest mean value (7.4) was found in forest land. The mean pH values for bushland and shrubland were 6.587 and 6.213, respectively (Table 4). The variation in pH values across land uses can be attributed to the increased activity of Al^{3+} and H^+ ions in the soil solution, which lowers soil pH and increases acidity. The measurement of pH in KCl solution indicated high potential acidity (Anon, 1993).

Various studies in Ethiopia (Woldeamlak and Stroosnijder, 2003; Papiernik et al., 2007; Habtamu et al., 2009) have also noted a significant reduction in soil pH in soils cultivated for several years. Excessive soil disturbance due to cultivation accelerates organic matter turnover and decomposition, releasing both organic (H_2CO_3) and inorganic acids (H_2SO_4, HNO_3), which reduce soil pH (Brady and Weil, 2002).

The restoration of base cations in forest land, as indicated by their significant increase, also contributes to the rise in soil pH. According to Nega and Heluf (2013), the lower mean pH value in cultivated land indicates more acidic soil compared to forest land, which aligns with this study. Conversely, Kizilkaya and Dengiz (2010) reported higher mean pH values in cultivated land than in forest land, likely because farmers in their study applied little or no fertilizers to the cultivated land, naturally enhancing soil pH.

A map of the soil pH for the analyzed soil was developed (Figure 12).

Table 4 Soil chemical properties of the study Watershed across LULC

Soil chemical properties	Forest land Mean ±sd	Cultivated Mean ±sd	Bushland Mean ±sd	Shrub land Mean ±sd	P_value
pH	7.423 ± 0.34^{a}	5.447 ± 0.07^{c}	6.587 ± 0.25^{b}	6.213 ± 0.44^{b}	0.0003^{***}
EC	0.39 ± 0.03^{a}	0.07 ± 0.032^{c}	0.19 ± 0.02^{b}	0.08 ± 0.01^{c}	0.0001^{***}
OC	3.3 ± 0.386^{a}	1.552 ± 0.37^{b}	2.32 ± 0.17^{ab}	$1.85\pm0.2S^{b}$	0.001^{***}
OM	6.78 ± 0.52^{a}	1.751 ± 0.33^{d}	4.74 ± 0.22^{b}	3.19 ± 0.4^{c}	0.0001^{***}
CEC	54.35 ± 0.98^{a}	26.66 ± 6.63^{b}	39.92 ± 4.73^{ab}	33.52 ± 7.51^{b}	0.002^{**}
TN	0.659 ± 0.231^{a}	0.17 ± 0.064^{b}	0.481 ± 0.22^{ab}	0.314 ± 0.102^{b}	0.036^{**}
Av.P	34.31 ± 4.99^{b}	81.92 ± 20.28^{a}	46.55 ± 13.72^{ab}	52.39 ± 16.6^{ab}	0.025^{**}
SCS	65.33 ± 9.48^{a}	36.4 ± 10.48^{b}	57.78 ± 6.55^{ab}	40.84 ± 1.35^{b}	0.006^{**}
Av.S	6.143 ± 0.35^{b}	9.25 ± 1^{a}	6.567 ± 0.45^{b}	7.7 ± 0.617^{ab}	0.002^{**}

Note:*PH = soil reaction, EC= electrical conductivity, OC= organic carbon, OM= organic matter, CEC= cation exchange capacity, TN= total nitrogen, Av.P= available phosphorous and Av.S= available sulfur*

According to Tekalign (1991), the soil pH classification (pH-H_2O values) rates cultivated land as moderately alkaline. The forest land use system is classified as slightly acidic. Similarly, shrubland is rated as slightly acidic, while bushland is rated as moderately alkaline.

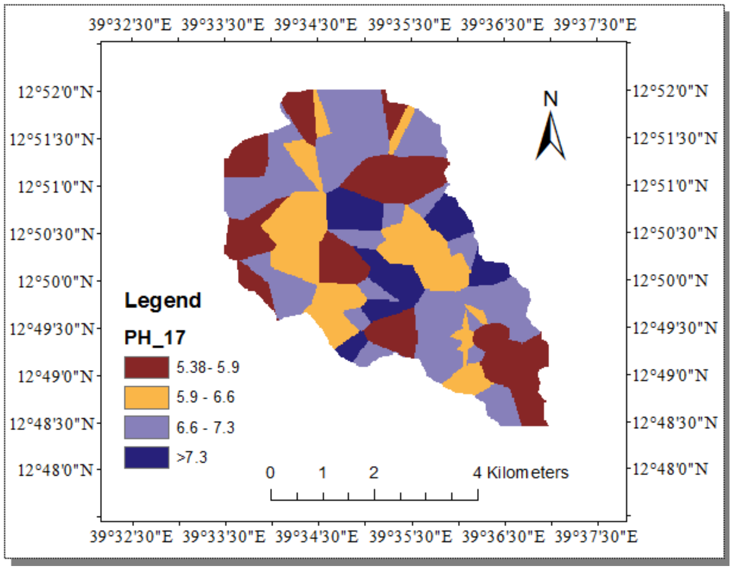

Figure 12 Map of soil pH of the study watershed.

Soil electrical conductivity was significantly influenced by land use ($p < 0.05$). Lower values were recorded in soils under cultivated land (0.068) and shrubland (0.084). In contrast, the highest mean values were observed in forest land (0.39) and bushland (0.185). A map of the soil electrical conductivity for the analyzed soil was developed (Figure 13).

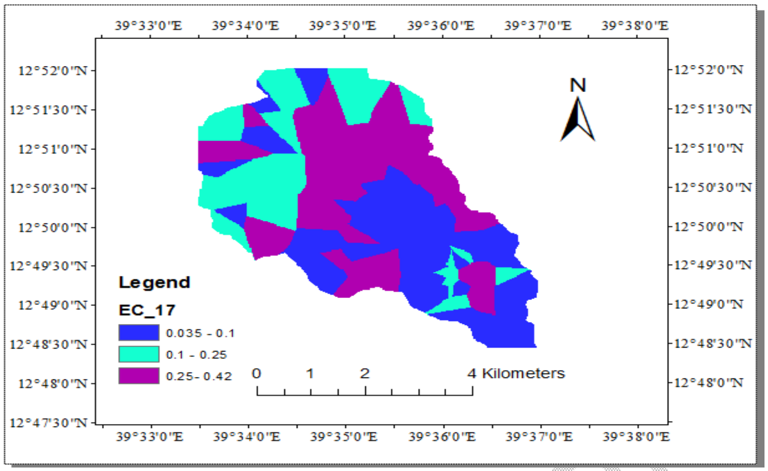

Figure 13 Map of soil electrical conductivity of the study watershed

The high exchangeable sodium (Na) content might be linked to the loss of cation bases (Ca^{2+} and Mg^{2+}) due to intensive cultivation. According to the U.S. Salinity Laboratory Staff (1954) classification, soil with electrical conductivity (EC) values greater than 4 dS/m at 25°C qualifies as saline or saline-sodic soil. This classification is based on the EC value, with 4 dS/m being the threshold for categorizing soil as saline based on its pH value.

Brady and Weil (2002) highlighted that organic matter significantly influences soil chemical and physical properties, plant nutrition, soil fertility, and biological activities. Organic matter content is highly affected by land use and land cover types. In this study, the mean organic matter content increased from cultivated land to forestland, showing a highly significant difference ($p<0.05$) among different land uses and covers. The mean organic matter content for forestland and cultivated land was 6.78% and 1.751%, respectively. For bush and shrub land, the mean values were 4.742% and 3.194%, respectively.

Kizilkaya and Dengiz (2010) reported that cultivated soils generally have lower organic matter content compared to native ecosystems. This is because increased soil aeration in cultivated lands enhances the decomposition of organic matter. A map of the soil organic matter for the analyzed soil was developed (Figure 14).

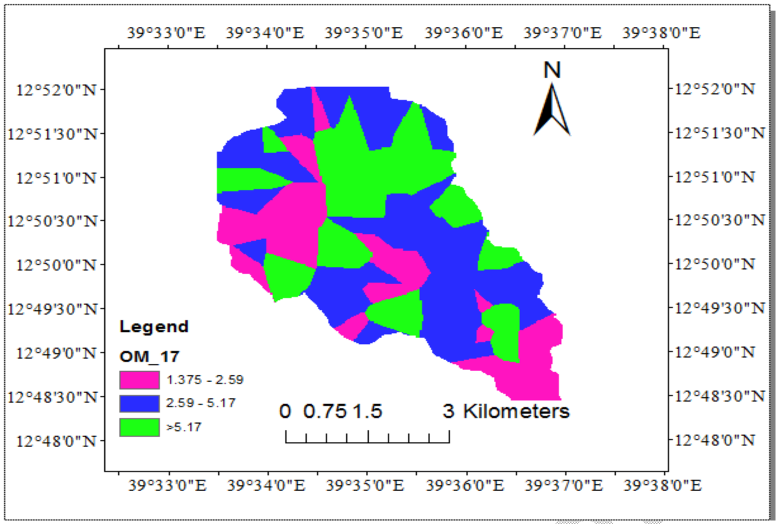

Figure 14 Map of organic matter of the study watershed

The difference in organic matter content is due to continuous cultivation practices that facilitate soil organic matter oxidation. The roots of trees and fungal hyphae in forest soils likely contribute to the higher total organic matter content (Urioste et al., 2006). These results align with findings by Negassa (2001) and Malo et al. (2005), who reported lower organic carbon in cultivated soils compared to forest land.

In the study watershed, organic matter content in cultivated land decreased slightly compared to other land use types (shrubland, bushland, forest land) by 1.5%, 3%, and 5%, respectively (Table 4). Soil analysis showed that as the mean organic matter content increased, the total nitrogen content also increased, indicating a direct relationship between them. Taye et al. (2003) reported that a high proportion of organic matter, which includes decomposed materials, significantly increases the contents of total nitrogen and organic matter. According to the critical levels given by Brhanu (1980), the mean organic matter content in forests was rated high, while bushland and shrubland were rated moderate, and cultivated land was rated low (Appendix Table 5).

Land use and land cover affect the total nitrogen content of the soil. There was a significant difference ($p<0.05$) in total nitrogen among forest, cultivated, and shrubland uses, but no significant difference among cultivated, bush, and shrubland uses. The mean total nitrogen values for forest, cultivated, bush, and shrubland were 0.66%, 0.17%, 0.48%, and 0.314%, respectively (Table 4). Yimer et al. (2007) reported similar findings, with the total nitrogen mean value being higher in forest land than in cultivated land. A map of the soil total nitrogen for the analyzed soil was developed (Figure 15).

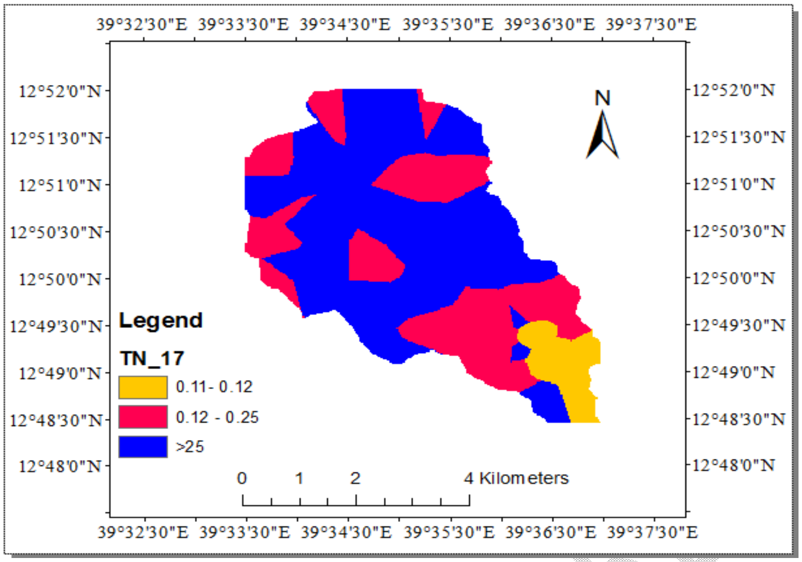

Figure 15 Map of total nitrogen of the study watershed

The significant loss of total nitrogen (N) in continuously cultivated fields can be attributed to the mineralization of soil organic matter due to continuous cultivation. This process disrupts soil aggregates and increases aeration, which enhances the oxidation of organic matter (Solomon et al., 2002). Additionally, reduced plant residues in cereal-based cropping systems contribute to the decrease in soil organic matter (OM) and soil nitrogen in cultivated soils. According to Havlin et al. (1999), the study watershed's land use is rated high for forest, bush, and shrub lands, while cultivated land is rated at a medium level.

The mean available soil phosphorus in the study watershed ranges from 34.31 mg/kg in forest land to 81.92 mg/kg in cultivated land. Bush and shrub land show mean values of 46.55 mg/kg and 52.39 mg/kg, respectively (Table 4). There is a significant difference ($p<0.05$) in available phosphorus between cultivated and forest land, but no significant difference ($p>0.005$) among forest, bushland, and shrub land. The maximum available phosphorus (81.92 mg/kg) was found in cultivated land, where the pH was near neutral (6.65), while the minimum (34.31 mg/kg) was recorded in forest land. This result is similar to Engdawork's (2002) findings, which recorded 87.02 mg/kg of available phosphorus in the surface soil (0-18 cm) of Phaeozems in the Werkarya area, South Wello. The phosphorus content in the soil is influenced by the moderately alkaline pH, which prevents phosphorus fixation, making it more available.

The cation exchange capacity (CEC) of the study area varies with land use and land cover types, with the highest value (54.3 Cmol/kg soil) under forest land and the lowest (26.66 Cmol/kg) under cultivated land (Table 4). There is a significant difference ($p<0.005$) in CEC among forest, cultivated, and shrubland, but no significant difference ($p>0.005$) between forest and bushland. These results are consistent with Wasihun's (2015) findings, which reported lower CEC values in cultivated land compared to forest land, with a recorded value of 22.5 Cmol/kg. The observed differences in soil CEC among the four land uses in the study watershed are due to the strong association of CEC with soil organic matter and soil texture. A map of the soil CEC in the watershed was also developed (Figure 16).

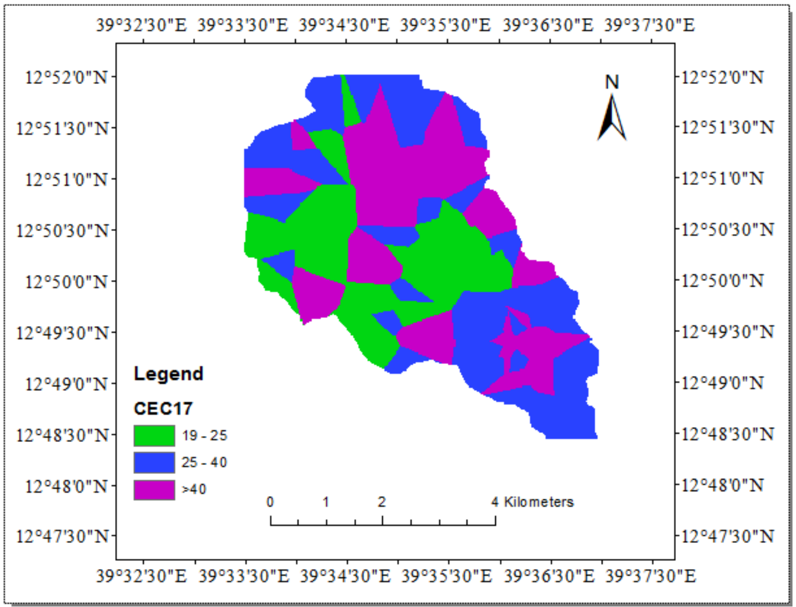

Figure 16Map of soil cation exchange capacity (CEC)

Generally, soil CEC depends on the amount and type of colloidal substances (clay and organic matter), as both provide negatively charged surfaces that play a crucial role in the exchange process. Cultivated land recorded low CEC values, consistent with the low organic matter mean values found in these areas. The reduced organic matter content decreases the soil CEC in cultivated land (Nega and Heluf, 2009). Similar findings on the depletion of organic matter have been reported by Alemayehu (2007) and Fentaw and Abdu (2011).

Soil sulfur availability in the study watershed varied from 6.143 ppm in forest land to 9.25 ppm in cultivated land. Bushland and shrubland showed sulfur levels of 6.567 ppm and 7.7 ppm, respectively (Table 4). There is a significant difference in sulfur availability between cultivated, forest, and bushland. However, there is no significant difference between shrubland and cultivated land, or between forest and bushland.

4. CONCLUSION AND RECOMMENDATION

The study examined the impact of land use and land cover (LULC) changes on soil physical and chemical properties in the Wojic watershed. Soil pH was significantly influenced by land use, with the lowest pH found in cultivated land and the highest in forest land. Soil electrical conductivity (EC) also varied by land use, with the lowest values in cultivated land and the highest in forest land. Soil organic matter, total nitrogen, and phosphorus showed significant variation across different land use and cover types. The highest mean value of soil organic matter was recorded in forest land, while the lowest was in cultivated land. The highest available soil phosphorus was found in cultivated land. Soil cation exchange capacity (CEC) was highest in forest land and lowest in cultivated land. Available soil sulfur ranged from 6.1 ppm in forest land to 9.3 ppm in cultivated land, with bushland and shrubland showing intermediate values of 6.567 ppm and 7.7 ppm, respectively. The highest mean value of available sulfur was recorded in cultivated land, while the lowest was in forest land.

The estimated soil pH was significantly affected by land use, with the highest mean values recorded in forest (7.4) and bush (7.0) lands, and the lowest in cultivated and shrub lands. Soil electrical conductivity was also significantly influenced by land use, with the highest mean value in forest land and the lowest in cultivated land. The highest mean value of soil organic carbon was recorded in forest land, while the lowest was in cultivated land. The estimated mean values of organic carbon, cation exchange capacity, and total nitrogen were highest in forest land and lowest in cultivated land.

Based on the study, the following recommendations are made:

- The developed regression equation needs further validation for similar environments, as physicochemical properties and soil carbon stock can be affected by climatic conditions, weathering history, and species composition and density.
- Further studies are required to assess the long-term effects of LULC changes on other chemical and physical soil properties, as well as on the groundwater table in the watershed.

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