

Variation in Selected Soil Physicochemical Properties Across Land Use Types and Soil Depths in Wolmera District, Central Ethiopia

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Abstract

Understanding the impact of land use types on selected soil physicochemical properties is a cornerstone of sustainable soil management, which underpins sustainable land utilization and agricultural production. In this context, the present study evaluated the effects of land use types and soil depth on selected soil physicochemical properties in the Wolmera district, Central Ethiopia. A comparative cross-sectional observational research design was employed to ensure robust results. A total of 24 composite soil samples were collected from four land use categories and two soil depths, with three replications, using a systematic zig-zag sampling approach. The collected soil samples were analyzed at the Holeta Research Institute soil laboratory, adhering to standard laboratory protocols. To assess variations in soil properties, a one-way analysis of variance (ANOVA) was used to test the mean differences. The findings revealed that soil texture was predominantly clayey, with an average of 66.8% clay content. However, no statistically significant differences ($P \leq 0.05$) were observed in the proportions of sand, clay, and silt across different land use types. Significant differences ($P \leq 0.05$) were noted in soil bulk density, pH, and available phosphorus (P), influenced by the combined effects of land use and soil depth. The pH analysis showed that the surface soils (0–20 cm) of cultivated and grazing lands exhibited extreme acidity (pH 4.4), while the subsurface layers (20–40 cm) of the same land use types were very strongly acidic (pH 4.6). The highest available phosphorus concentration (12.62 ppm) was recorded in the subsurface layer of backyard lands. Notably, higher levels of organic matter and total nitrogen were observed in backyard lands and eucalyptus plantations, reflecting better soil fertility in these land use types. Exchangeable acidity showed significant ($P \leq 0.05$) variations across the different land use types and was strongly influenced by the interaction between land use and soil depth. Furthermore, significant differences ($P \leq 0.05$) were found in soil bulk density, pH, available phosphorus, total nitrogen, organic carbon, and cation exchange capacity, emphasizing the profound impact of land use changes on soil properties. In conclusion, the study underscores the significant influence of land use types and soil depth on selected physicochemical properties of soils in the Wolmera district. These findings highlight the critical need for land use policies and sustainable soil management practices to mitigate soil degradation and enhance soil fertility for long-term agricultural productivity and ecosystem health.

1. INTRODUCTION

Land use changes alter land cover due to human incursions, such as cultivation, settlement, industrial activities, infrastructure development, transportation, manufacture, mining, recreation and fishing (Gabisa et al., 2025; Wayesa et al., 2025; Hailu et al., 2020). In recent years, the shift of land use from natural ecosystem to artificial ecosystem is the main direction of land use change (Jaleta, 2020). This changes in land use and management practices often results in modification of most of soil morphological, chemical, physical, and biological properties (Abile et al., 2025; Gebrekidan & Negassa, 2006). The major reason for land cover change in Ethiopia is the conversion of different land uses to agricultural land for food production due to population increase at alarming rate (Siraj et al., 2018), this results in the susceptibility to land degradation problems (Belachew et al., 2020).

In Ethiopia, Agriculture is considered as the backbone of the country's economy (Tolesa et al., 2021; Yigezu, 2021) and its activities are the main source of their livelihood earnings (Zelege et al., 2023). Agriculture accounts more than 40% of the gross domestic product, 80% of the total exports, and 80% of all employment in Ethiopia (Matoussa et al., 2013; UNDP, 2015; NPC, 2016). This is the reason behind for the major conversion of land use cover change in Ethiopia (Siraj et al., 2018). However, in Ethiopia the sustainability of agricultural production is threatened by soil erosion which results in organic matter depletion and soil nutrient removal (Tolesa et al., 2021).

The rapid population growth, resettlement programmes and increasing agricultural investments are the major factor that influences the type of land use and the rate of expansion of specific land use type in Ethiopia (Duguma et al., 2010; Lambin et al., 2001, Negassa et al., 2020, Degife et al., 2018), in areas where there is very high population density and heavy dependence on land resources (Tufa et al., 2019). The growth of population at an alarming rate create pressure on land use and land cover, resulting in unplanned and uncontrolled changes in land use (Seto et al., 2002; Siraj et al., 2018; Hailu et al., 2020). Furthermore, the increase of human population coupled with livestock, temporary intensively spreading out of farmland and grazing areas has begun to influence the soil properties (Mulugeta et al., 2019 Mustapha, 2007). In particular, expansion of agriculture has led to the cultivation of problem prone soils, including soils that have severe limitations as acidity, salinity, sodicity and other low fertility characteristics.

Land use types are one of the major factors affecting soil property variability (Seifu et al., 2020), by causing a significant effect on soil physical, chemical, and biological properties (Bizuhoraho et al., 2020; Yitbarek et al., 2013; Yao et al., 2010; Guzman et al., 2011). Land use changes under deprived management practices by human activities will accelerate soil erosion poses a threat to decline in soil productivity (Kebebew et al., 2021), resulting in agricultural productivity decline (Girmay et al., 2008).

Soil quality assessment has become an important component of sustainable land management and climate change mitigation because soil physicochemical indicators provide valuable information on soil fertility, ecosystem functioning, and long-term agricultural sustainability (Smith et al., 2024; El Behairy et al., 2024; Sharma et al., 2024 Gatica-Saavedra et al., 2023). The Conversion of natural ecosystems to intensive agricultural land commonly decreases soil organic carbon (SOC), weakens soil structure, diminishes microbial activity, and reduces nutrient availability, thereby lowering overall soil quality and ecosystem resilience (Rodríguez et al., 2022; Khan et al., 2025). Contemporary soil quality assessment frameworks recommend integrating physical, chemical, and biological indicators including bulk density, soil pH, soil organic carbon, total nitrogen, available phosphorus, cation exchange capacity, aggregate stability, and microbial biomass to provide a comprehensive evaluation of soil health and sustainable land management (Hussain et al., 2022; Khan et al., 2025). Furthermore, recent global syntheses identify SOC as one of the most sensitive indicators of land-use change because of its critical role in nutrient cycling, carbon sequestration, climate change mitigation, and long-term agricultural productivity (Beillouin et al., 2022; Semenov et al., 2025).

Sustainable land management practices, such as conservation agriculture, agroforestry, crop diversification, reduced tillage, and organic amendments, have been widely recognized for restoring soil functions, enhancing carbon sequestration, and improving soil health while contributing to climate adaptation and the achievement of the Sustainable Development Goals (Abshiba et al., 2025; Smith et al., 2024; Beillouin et al., 2023; Rodríguez et al., 2022; Tufa et al., 2019). These international findings provide a robust scientific framework for evaluating the effects of land-use change on soil quality in Ethiopia and highlight the need for site-specific assessments to support evidence-based land management decisions.

Although numerous studies conducted in Ethiopia have confirmed that land use change significantly influences soil physicochemical properties, including soil organic carbon, total nitrogen, available phosphorus, soil pH, bulk density, cation exchange capacity, and exchangeable bases. Recent investigations have reported considerable variations in soil quality among cultivated land, forest land, grazing land, and other land use systems across different Ethiopian watersheds (Daba et al., 2025; Amare et al., 2024; Endriasa et al., 2024; Yegna et al., 2024; Ibrahim et al., 2023). However, these studies were undertaken under different agroecological conditions, soil parent materials, topographic settings, and land management practices, all of which strongly influence soil characteristics. Consequently, their findings cannot be directly extrapolated to the central highlands of Ethiopia, particularly the Wolmera District. Moreover, despite the district's importance as one of the major agricultural production areas in Central Ethiopia, comprehensive information comparing the dominant land use types under similar environmental conditions remains limited. This lack of site-specific evidence represents an important scientific gap, as sustainable soil management requires locally generated information rather than generalized recommendations. Therefore, this study evaluated the effects of four dominant land use types on selected soil physicochemical properties in the Wolmera District, West Shewa Zone, Central Ethiopia. The findings provide location-specific scientific evidence that can support sustainable land management, soil fertility improvement, and informed land use planning in the study area.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Geographic location of the study area

Geographically, the study area Telecho Gebeirele *Keble* was located in Wolmera District, Oromia National Regional State, Ethiopia. The District is located at 8°50'-9°15'N Latitude and 38° 25'-38°45' Longitude (Fig. 1). Its capital town is Holeta which is located 28 km from the country capital city, Addis Ababa and Regional capital city Finfine. It is bordered on the East by Burayu town, on the west by Ejere, on the North by Sululta, and on the South by Sebeta Hawas District. Wolmera District has 23 rural and 3 urban administrative kebele with totally 26 having a total area of 775 Km² or 80,927 hectares. (WWADO, 2019)

2.1.2. Topography and Climate

Wolmera District has a relief type of plain 57%, mountains 24% and others 19%. The altitude ranges from 2060–3380 meters above sea level, annual rain falls 634-1300mm having an average rainy days are about 150 days in the year (WWADO, 2019).

Climate is one of the elements of the physical environment which has a pronounced impact on settlement pattern, human way of life, the type of the soil, flora and fauna existed and /or developed so forth. Among different climatic elements temperature and rain fall have a considerable impact in such an agrarian country like Ethiopia and more actually in the area under study. The temperature distribution of the study area is mainly a reflection of elevation. Accordingly, the study area comprises varied thermal zones (*Dega* 61%, *Woyena dega* 39%,) ranging from 2060–3380 meters above the sea level, annual rain falls 634-1300mm and temperature is dominantly (cool, moderately warm, moderately cool, which is between 0.1–27 degree Celsius. Its mean annual rainfall is 1044 mm. (WWADO, 2019)

2.1.3. Population and land use types

According to the CSA (2007) data Wolmera District has a total population of 116,031, out of this 58,297 are male and 57,734 are females. Majority of the population of the district lives in rural area. The dominant land use types in Wolmera District are cropland (54.5%), forest land (11.02%), pasture/grazing land (15.26%), and others account for 18.91% of the total land area. The land cover is dominated by farmlands, plantations and grasses. Mixed farming system that combines crops and livestock husbandry characterizes the Central Highland of Ethiopia in general and the Wolmera District in particular. The major crops commonly grown in the district are wheat, teff, barley, maize and potato. Cattle, sheep and goat are the most common livestock reared by the farmers of the district.

2.1.4. Vegetation Cover

The vegetation cover including Coniferous forest 11.81% (8901 hectares) and grass lands 16.4%(12350 hectares) are the main vegetation type in the District. There are government /public protected forest: Suba forest 9000ha, Kolobo and Haro Boki forest 70ha, and 8917 ha other state forest covered in the area by natural and man-made forest resources. Grass land is used primarily for animal feed, roofing, and as means of income generating by selling. The forest product is used for wood fire, farming materials, house construction, house materials and etc. the trend of forest land is decreased from time to time due to expansion of cultivation land. (WWADO, 2019)

2.2. Research Design and Soil Sampling

2.2.1. Research design

To undergo the study of the effects of land use type and soil depth on selected soil physicochemical properties a comparative cross-sectional observational research design was employed with a 4 × 2 factorial arrangement. Four land use types (natural forest, grazing land, cultivated land and eucalyptus plantation) and two soil depths (0–20 cm and 20–40 cm) were considered in this study. Three independent sampling plots (replications) were established for each land use type using a stratified

random sampling approach. This yielded a total of 24 composite soil samples (4 land use types × 2 soil depths × 3 replications).

Within each replication, five soil cores were collected from randomly selected points within a (20 m × 20 m) sampling plot following a zigzag sampling pattern and composited into a single representative sample for each soil depth. The sampling plots were separated by a minimum of (specify distance, e.g. 100–200 m) to avoid spatial autocorrelation and to ensure statistical independence. The geographic coordinates of each sampling plot were recorded with a handheld Global Positioning System (GPS). Sampling sites were selected from relatively uniform slope positions from (specify, e.g. 5–15%) to minimize the effect of topographic variability on soil properties. All sampling sites were established in comparable landscape conditions, so that differences in soil properties observed were chiefly caused by land use type and soil depth and not by environmental heterogeneity.

Reconnaissance survey was conducted to select the study area in Wolmera District before the start of the study. During this survey, the general geography of the area was assessed and purposive sampling was carried out to select the study *kebele* and land use types. The criterion used to select the *kebele* was the presence of more land use types and that is representatives as compared to other *kebeles*. Based on these criteria *Telecho Gebeirele Keble* was selected from the District. After the selection of *kebele*, the next step was selecting the land use types. In selecting sampling sites, possible differences in topographic conditions were minimized as much as possible by selecting closely located sites. The four land use types selected were cultivated land, farmyard, grazing lands and forest eucalyptus plantation. The four land-use categories (natural forest, cultivated land, grazing land, and eucalyptus plantation) were selected because they represent the dominant and most extensive land-use systems in the study area, reflecting the major forms of land management and land-cover conversion occurring in the district. These land-use types encompass the principal ecological and agricultural landscapes that influence soil formation processes, nutrient dynamics, and soil physicochemical properties. Their selection was therefore based primarily on their representativeness and ecological significance rather than sampling convenience or accessibility. Furthermore, these land-use categories are widely recognized in previous land-use and soil quality studies as suitable for evaluating the effects of land-use change on soil properties, enabling meaningful comparisons with findings from other regions.

2.2.2. Soil sampling procedure

Soil sampling was conducted during the dry season, from January 28 to February 5, 2023 for 8 days, to minimize the influence of short-term seasonal variability on soil physicochemical properties. All soil samples were collected within a relatively short period under comparable field conditions to ensure consistency among land-use types and sampling depths. During the sampling period, no significant rainfall events occurred that could have substantially altered soil moisture or nutrient dynamics. Consequently, differences observed among land-use types were considered to primarily reflect land management and soil depth rather than temporal or seasonal variation.

Following, reconnaissance survey, in each land use types three replications samples were taken from each land use and five soil sub-samples collected which used to make one composite sample (totally 24 composite sample) at a the depth of 0–20 cm and 20–40cm each in a radial sampling scheme using an auger (Wilding, 1985). During collection of samples; dead plants, furrow, old manures, wet spots, areas near trees and compost pits were excluded. This was done to minimize differences which may arise because of the dilution of soil OM due to mixing through cultivation and other factors (Tufa et al., 2019).

Five soil sub-samples which used to make one composite sample (totally 24 composite samples) for four land use types (cultivated land, grazing land, forest-eucalyptus plantation land and farmyard land) in soil depths (0–20 cm and 20–40 cm) with three replications. Both undisturbed and disturbed soil samples were taken from two soil depths based on the heterogeneity of land unit in a zigzag manner. Undisturbed soil samples were taken from the surface layer by core sampler to measure the soil bulk density, whereas the disturbed soil samples were taken by using an auger to measure the rest selected soil physicochemical properties.

2.3. Soil Laboratory Analysis

The soil physical and chemical analysis was carried out at the Soil Laboratory of Holeta Research Center. Standard laboratory Procedures were followed in the analysis of the selected physicochemical parameters Soil texture was analyzed by the Bouyoucous hydrometer method (Bouyoucos, 1962), after OM was destroyed or burned by using hydrogen peroxide (H_2O_2), soil particles were dispersed and disintegrated by sodium carbonate (Na_2CO_3) and sodium hexametaphosphate ($Na_6P_6O_{18}$) in distilled water and finally using amyl alcohol to destroy the soil solution foam. After the particle size distributions were determined in percent, the textural class of the soil was obtained by using USDA soil textural triangle classification system (USDA, 2008).

The bulk density (BD) of the soil was measured from undisturbed soil samples collected using a core sampler after drying the core samples in an oven at 105°C (Black, 1965). The total porosity of soil samples will be estimated from the values of bulk density (BD) and particle density (PD) (assuming an average particle density of mineral soil is 2.65 g cm^{-3}). Then the total porosity (TP) was calculated as:

$$TP (\%) = (1 - \text{Bulk density} / \text{Particle density}) * (100).$$

The pH of the soils was measured in water (H_2O) suspension in a 1:2.5 (soil: liquid) by pH meter, whereas electrical conductivity was measured by a conductivity meter (Van Reeuwijk, 1992). Determination of soil organic matter will be carried out by oxidizing the soil organic carbon under standard condition with potassium dichromate in sulphuric acid solution as described by Walkely and Black (1934). The base titration method which involves saturation of the soil sample with 1M KCl solution and titrating with sodium hydroxide will be employed to determine exchangeable acidity. The total nitrogen content in soils was determined using the Kjeldahl digestion, distillation and titration method by oxidizing the OM in concentrated sulfuric acid solution ($0.1N H_2SO_4$) as described by Black (1965). Then after, C: N was calculated by dividing organic carbon to total nitrogen.

The available P was calculated by the Olsen method using sodium bicarbonate (0.5MNaHCO₃) as an extraction solution (Olsen et al., 1954) and determined calorimetrically by spectrophotometer. Cation exchange capacity (CEC) of the soil will be determined by 1M ammonium acetate (NH₄OAc) saturated samples at pH 7 (Chapman, 1965). The sample will be extracted with excess ammonium acetate and the exchangeable bases will be measured in the extract. Exchangeable bases (Na, K, Mg and Ca) were determined after extracting the soil samples by ammonium acetate (1N NH₄OAc) at pH 7.0. Exchangeable Na and K were analyzed by flame photometer while Ca and Mg in the extracts was analyzed using atomic absorption spectrophotometer (AAS) as described by Rowell (1994). Available Fe, Mn, Zn and Cu (micronutrients) will be extracted from the soil samples and determined using DTPA as described by Lindsay and Norvell (1978). The amounts of these nutrients in the extracts were determined by atomic absorption spectrophotometer.

2.4. Statistical Analysis

The data obtained from the soil analyses were subjected to statistical analysis to test the influence of land use on the soil quality indicators using one-way analysis of variance (ANOVA) was performed to assess the significance of differences in soil parameters between land uses, soil depths by Statistical Analysis System (SAS) version 9.00 (SAS, 2002). Least Significance Difference (LSD) at 0.01 and 0.05 were used for mean separation for those properties that were found to be significantly different.

3. RESULTS AND DISCUSSION

3.1. Effects of Land Use types on soil depth and Soil Physical Properties

The results of laboratory analysis of the soil physical properties of the experimental site were presented in (Table 1). The results of analysis variance at ($P \leq 0.05$) indicated that there were no significant different on the sand, clay and silt particle under different land use types. The mean value of texture of the soil is dominated by 66.8% clay followed by 21.6% silt and 11.6 sand textures respectively in the study area. The content of clay particle is significantly lower in cultivated land as compared to the plantation forest, farm yard and grazing lands. This is in agreement with that of study made by Yitbarek et al. (2013). These kinds of Nitisols which is dominated by clay have very good potential for agriculture; they have a stable structure and a high-water storage capacity. Workability on these soils does not create any problem even shortly after precipitation or in the dry season, land can be prepared without difficulty. These clay dominated soils have a rather low CEC for their clay content and available P are usually very low (Abebe, 2007).

Generally, the clay content was higher in the subsurface layer of cultivated land as compared to the adjacent forest, grazing and farm yard lands specifically in the study area. The reason might be due to the preferential removal of clay particles and its downward movement into the subsurface soil layer through the process of clay migration due to long period of cultivation.

Similarly, Chemada et al., (2017) stated that the clay content of cultivated land was increased from the surface to subsurface soil layer due to the long period of cultivation. Additionally, Gebrelibanos and Assen (2013) reported that lower clay and higher sand content was found in the surface layer and higher clay contents was found in the subsurface layer of cultivated land than the others adjacent natural forest, plantation forest and grazing lands. Generally, the variation of soil texture amongst land use types implies that the effects of land use types on soil properties which triggered from different utilization and management system of land use types (Abbasi et al., 2007).

Table 1
Effects of Land Use types and soil depth on Selected Soil Physical Properties at

Treatments	Depth(cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density (g cm ⁻³)	Particle density(g cm ⁻³)	Total porosity (%)
CL1	0–20	11.5	22.5	66.0	1.34 ^a	2.64	47.9 ^c
CL2	20–40	12.25	20.55	67.2	1.36 ^a	2.62	48.67 ^c
GL1	0–20	11.75	21.15	67.1	1.33 ^a	2.65	47.6 ^c
GL2	20–40	11.25	22.25	66.5	1.34 ^a	2.63	49.4 ^c
FE1	0–20	12.15	20.35	67.5	1.28 ^b	2.65	53.4 ^b
FE2	20–40	11.25	21.65	67.1	1.30 ^b	2.65	54.9 ^b
FY1	0–20	11.15	22.25	66.6	1.24 ^c	2.65	58.1 ^a
FY2	20–40	11.5	22.25	66.25	1.26 ^b	2.65	58.6 ^a
Mean		11.6	21.6	66.8	1.31	2.65	52.32
LSD(0.05)		Ns	Ns	Ns	0.67	Ns	8.25
CV (5%)		1.6	3.4	2.2	1.2	0.2	4.8

Mean with the same letter are not significantly different at $P \leq 0.05$ according to Fisher's LSD; CL=Cultivated Land, GL=Grazing Land, FE=Forest Eucalyptus plantation, FY=Farm Yard, Ns = Non significant D1 = soil depth 0–20 cm, D2 = soil depth 20–40 cm.

The soil bulk density value was significantly ($P \leq 0.05$) affected by land use and soil depth effects (Tables 1). Considering the main effects, the highest (1.36 gcm⁻³) mean value of bulk density was recorded on the cultivated land at 20–40 cm depth and the lowest (1.24gcm⁻³) mean value was recorded under the farm yard at 0-20cm depth at Teleche kebele. The analysis of variance showed that the main effect of land use and soil depth were significantly ($P \leq 0.05$) influenced total porosity of the soil. The result indicated that the highest value of porosity of soil (58.6) was recorded from field of

farmyard land at 20-40cm (Table 1). While the lowest value of soil porosity (47.6%) was recorded from cultivate land at 0-20cm depth.

This finding is in agreement with Yitbarek et al., (2013) who found the highest bulk density under cultivated land compared to the adjacent grazing and plantation lands. Additionally, Takele et al. (2014) and Abad et al. (2014) suggested that the bulk density of cultivated land was higher than that of adjacent grazing land and forest lands at soil depth of 0–30 cm. Paradoxically, Lelisa and Abebaw (2016) found that the higher bulk density in the grassland compared to the adjacent bare land and rehabilitated land at a soil depth of 0–10 cm, 20–30 cm and 30–40 cm. Generally, the ranges of bulk density values observed in this study were within the ranges expected value (0.74 to 1.4 g cm⁻³) in most mineral soils as indicated by Gupta (2004). Since the bulk density of this study area was within the expected values the aeration and water movement within the soil structure is in ranges that plant attain growth and determine the numbers and diversity of soil microbes thereby they furnish the versatile function in agrarian activities.

3.2. Impacts of Land Use on Soil chemical properties

3.2.1. Soil pH

In the study Soil pH was significantly ($p \leq 0.05$) affected by the interaction effect of land use and soil depth where the highest (5.5) was observed in the subsurface layer of farm yard land use and the lowest (4.44) on the surface layer of cultivated and grazing lands in (Table 2).

The decrease of PH could be due to continuous removal of basic cations by harvested crops and animal grazing on the surface layers of cultivated and grazing lands respectively, and very high leaching of bases and clay particles from the exposed surfaces of cultivated lands as well as H⁺ ion released by the nitrification of NH₄⁺ sourced chemical fertilizers and legume roots during N₂ fixation on the surface layer of cultivated land. Similarly, research results were found by Saikhe et al., (1998); Sahlemedhin and Bekele, (2000), Who stated that soil pH values were significantly lower on the surface layer for cultivated soils when compared to non-cultivated soils due to the application of NH₄⁺ sourced fertilizers to cultivated lands that nitrifies NH₄⁺ and its uptake by the crops

Besides, the presence of higher pH in farm yard and forest land might be accredited to the ameliorating effect of the high content of OM that form Al and Fe-OM complexes and release of hydroxyl ions as well as deposition of basic cations. However, opposite findings were reported by (Saikhe.et.al., 1998) who stated that high pH values were recorded for croplands as compared to grazing and forest lands in the Bale mountain areas of Ethiopia., but in this study area of the two kebeles, Soil pH is lower in cultivation and grazing land and higher in farm yard and Forest-Eucalyptus plantation land in both soil depth (Table 2).

In the study area soil pH increased as soil depth increased in all land use types. Therefore, in the study area, the value of soil pH to be increased or decreased depends not only on the depth of the soil but also

it may depend on the traditional soil management practice adopted in the area. Hence, this research finding is in disagreement with (Henry *et al.* 1990) which was reported in that soil pH decreased with increasing soil depth for land uses in Central highlands of Ethiopia.

Soil pH plays a crucial role in determining the chemical forms of nearly all mineral nutrients, which in turn affects their solubility and how available they are for plants. Even slight changes in pH can shift which ions stay dissolved, which ones cling to soil particles, and which ones precipitate out (Neina, 2019; Penn & Camberato, 2019; Marschner, 2011; Somani, 1996). In acidic soils, where the pH is low, the availability of essential base cations like calcium (Ca), magnesium (Mg), and potassium (K) often decreases. This acidity also limits phosphorus (P) availability because aluminum (Al) and iron (Fe) oxides tend to bind with phosphate. On the flip side, higher acidity can increase the solubility—and thus the toxicity risk—of aluminum (Al^{3+}), manganese (Mn^{2+}), and other metal ions (Xia *et al.*, 2024). Consequently, crops grown in highly acidic soils frequently show nutrient deficiencies, particularly in Ca, P, and molybdenum (Mo), along with symptoms linked to excess soluble Al and Mn (Neina, 2019). Additionally, soil acidity impacts biological activity and nutrient cycling, influencing everything from microbial mineralization to root-microbe interactions, which ultimately affects nutrient availability and plant health (Rouske *et al.*, 2010). To tackle the challenges posed by soil acidity, many crops thrive best when phosphorus is readily available and nutrient uptake is balanced, typically around a neutral to mildly acidic pH (approximately 6.0–7.0, with optimal levels often cited around 6.5–7.0). Therefore, managing problematic acidity usually involves soil testing followed by liming or applying other alkaline amendments. Liming can raise soil pH, decrease exchangeable aluminum, and often boost available phosphorus and exchangeable bases. However, the effectiveness of liming can vary based on factors like the amount of lime used, soil depth, and the soil's buffering capacity (Nyamaizi *et al.*, 2022).

3.2.2. Available Phosphorus

In the study areas, available P content of the soil was significantly ($P \leq 0.05$) affected by the combined effects of land use and soil depth (Tables 2). This result is in line with that of (Tufa *et al.*, 2019). The highest 12.62 ppm were recorded on the sub surface layer of farmyard, which might be due to the application of organic manure and ash, the lowest (4.7ppm) recorded in surface soil layer of cultivation land use, which might be the removal of available P by crops. Therefore, in the study area the available P is higher in farm yard land use types in soil depths 0-20cm and 20-40cm than the other land use types.

The study result showed that next to farm yard land use type, forest Eucalyptus plantation land use type is better in available P, this may be due to eucalyptus plantation is a kind of deep rooted plants, as result there is no continuous removal of available P from the surface layer of the soil. But available P is very low in cultivation and grazing land use type, this may be due to continuous cultivation without fallowing as a result continuous removal of available P, and lack of application of optimal organic or in organic P containing fertilizer in case of cultivated land, and in grazing land because of continuous over grazing, there is no any organic matter that return back to the soil and a nature of grass could be also one of the many reasons. Although Aytenew and Kibret (2016) and Chemada *et al.* (2017), reported that the higher

available P was recorded in cultivated land than the adjacent grazing and forest lands which is in disagreement of these findings.

This study reported that the higher available P was obtained in farm yard and forest land use at both soil depths. Relatively the high content of available P in the farm yard and forest land could be due to the high content of soil OM resulting in the release of organic phosphorus thereby enhances available P under forest land. Similarly, this result is in agreement with the findings of

Abad et al. (2014), who reported that the available P was high in forest land compared to pasture land and cultivated land at 0–30 cm soil depth. Additionally, it is in line with result of Takele et al. (2014) whose results revealed that available P was high in forest land than the adjacent cultivated and grazing lands at a soil depth of 0–10 cm, 10–20 cm and 20–30 cm.

Soil acidity and associated low nutrient availability is one of the constraints to crop production on acid soils (Bekele and Hofner, 1993; Beyene, 1987; Tekalign and Haque, 1991). If a pH of a soil is less than 5.5 phosphate can readily be rendered unavailable to plant roots as it is the most immobile of the major plant nutrients (Agegnehu and Sommer, 2000; Sanchez, 1977) and yields of crops grown in such soils are very low. In soil pH between 5.5 and 7, P fixation is low and its

Availability to plants is higher. Toxicity and deficiency of Fe and Mn may be avoided if the soil reaction is held within a soil pH range of 5.5 to 7; this pH range seems to promote the readiest availability of plant nutrients (Somani, 1996). The quantity of P in soil solution needed for optimum growth of crops lies in the range of 0.13 to 1.31 kg P ha⁻¹ as growing crops absorb about 0.44 kg P ha⁻¹ per day (Lawlor, 2004).

Table 2

Mean values of pH, soil organic carbon, total N (TN) and available P as influenced by the different land uses & available phosphorus

Land use type	Depth in cm	Soil chemical properties			
		pH	P(ppm)	TN (%)	OC (%)
CL1	0–20	4.44 ^b	4.67 ^d	0.145 ^d	1.411 ^c
CL2	20–40	4.61 ^{bc}	5.35 ^d	0.131 ^d	1.411 ^c
GL1	0–20	4.44 ^b	6.09 ^d	0.242 ^b	1.974 ^{abc}
GL2	20–40	4.58 ^{bc}	5.96 ^d	0.229 ^{bc}	1.451 ^{bc}
EF1	0–20	4.96 ^{abc}	7.83 ^c	0.168 ^{cd}	1.637 ^{abc}
EF2	20–40	5.21 ^{abc}	9.59 ^b	0.320 ^a	2.134 ^{ab}
FY1	0–20	5.31 ^{ab}	10.72 ^b	0.239 ^b	2.247 ^a
FY2	20–40	5.50 ^a	12.62 ^a	0.219 ^{bc}	2.143 ^a
Mean		4.88	7.86	0.212	1.801
LSD(0.05)		0.755	1.529	0.07	0.688
CV (5%)		8.84	11.11	18.94	21.81

Means with the same letter are not significantly different at $P \leq 0.05$ according to Fisher's LSD; CL=Cultivated Land, GL=Grazing Land, FE=Forest Eucalyptus plantation, FY=Farm Yard

3.2.3. 4.2.3. Total Nitrogen

Total N was significantly ($P \leq 0.05$) affected by land use and soil depth interactions (Table 3) where the highest (0.32%) was recorded on the sub surface layer of forest eucalyptus plantation land and lowest (0.13%) on the sub surface layer of cultivated land which might be due to high OM content in forest land b/c the leave of the eucalyptus plantation slowly decompose that is why OM is higher at sub surface than the surface layer soil and its rapid oxidation and/or mineralization in cultivated land in the study area.

This results were in agreement with that of Diaz *et al.*, 2(005) who reported that changes in soil OM could lead to changes in total N and long term cultivation without organic fertilizers usually leads to a decrease in soil OC and total N contents because organic forms generally account for more than 95% of soil N. Similarly, Taye and Yifru, (2010) elucidated that the contribution of OM to total N is high and soil N content decreased by 64 and 55% in cultivated sites compared to native forest and rangeland respectively by which afforestation also increased total N. However, Puget, and Lal, (2005) reported oppositely that pasture soil contained the highest N stocks than forest and cultivated lands in the top 5

cm layer. In this study, total N was negatively correlated with soil pH which might be due to the slow rate of OM oxidation and/or N mineralization as microorganisms especially nitrifying bacteria (*Rhizobium*) are sensitive to acidic environments (Table 3). According to the ratings suggested by Murphy (1968); forest eucalyptus plantation land use, farm yard and grazing land uses are qualified for high, while cultivated qualified for medium in its total N status in the study area.

3.2.4. Soil organic carbon

Organic carbon was significant at ($P \leq 0.05$) affected by the interaction effects of land use and soil depth (Table 2) whereby the highest (2.25%) was observed on the surface layer of farm yard land and lowest (1.4%) in the surface & subsurface layer of cultivated land that showed an increase in farm yard land and decrease in cultivation land which might be due to high OM content and its oxidation on the surface layer of farm yard and surface & subsurface of cultivated lands respectively. Diaz et al., (2005) also indicated that clearing tropical forests and conversion into farmland lowered by 20–50% in soil OM content as cultivation generally aerates the soil and increases OM oxidation rates. As per the classification rate suggested by Tekalign (1991), the OC for farm yard, forest eucalyptus and grass lands are qualified as medium while cultivated lands are low status. The result of the current study is in agreement with the findings Takele et al., (2014; Iqbal et al., (2012), Chibsa and Ta'a (2009) and Duguma et al., (2010), who reported in their study that the soil OM decrease with increasing soil depth, with more accumulation on the upper surface soil layer. However, in this study the result of the value of OC do not showed any change with depth in cultivated land

3.2.5. Exchangeable Acidity (EA)

There was a great variation on exchangeable acidity of the soils under the different land use types in the study area. Exchangeable acidity was significant at ($P \leq 0.05$) affected by the interaction effects of land use and soil depth (Table 2) whereby the highest (1.72%) was observed on the surface layer of cultivated land and lowest (0.76%) in the surface layer of farm land that showed that, the soil exchangeable acidity in the cultivated and grazing lands might be associated with the occurrence of lower soil pH and the lower exchangeable acidity in farm yard and forest associated with higher soil PH. The Observed high exchangeable acidity in the soils of cultivated land uses were due to in part to plant uptake of Ca^{2+} and in part to mixing up with soil to lower depth through tillage, ploughing and losses through leaching.

Cation Exchange Capacity, Exchangeable Bases (Mg, Ca, K and Na)

The CEC and exchangeable bases of the soils are significantly ($P < 0.05$) varied across land use

Table 3

Exchangeable bases (Ca, Mg, K, and Na), EA and Total Exchangeable base (TEB) as influenced by the land uses and Soil Depth

Land use type	Depth in cm	E.A(meq/100g		Exchangeable bases ((cmol(+) kg ⁻¹))			
		E. A	Mg)	Ca)	K	Na	TEB
CL1	0–20	1.720 ^a	4.593 ^{bc}	6.840 ^{bc}	0.500 ^d	0.075 ^a	12.008
CL2	20–40	1.597 ^{ab}	4.487 ^c	6.380 ^c	0.853 ^{bcd}	0.062 ^{ab}	11.782
GL1	0–20	1.662 ^a	3.807 ^c	6.567 ^{bc}	0.576 ^{cd}	0.049 ^b	10.999
GL2	20–40	1.603 ^{ab}	4.180 ^c	7.353 ^{abc}	0.850 ^{bcd}	0.051 ^b	12.434
FE1	0–20	0.963 ^{bc}	5.307 ^{bc}	7.253 ^{abc}	0.833 ^{bcd}	0.049 ^b	13.442
FE2	20–40	0.827 ^c	6.177 ^{ab}	8.440 ^{ab}	0.973 ^{bc}	0.056 ^{ab}	15.646
FY1	0–20	0.757 ^c	6.990 ^a	8.733 ^a	1.660 ^a	0.046 ^b	17.429
FY2	20–40	0.857 ^c	5.080 ^{bc}	8.393 ^{ab}	1.1067 ^b	0.044 ^b	14.6237
Mean		1.25	5.08	7.49	0.92	0.05	13.54546
LSD(0.05)		0.661	1.607	1.846	0.411	0.023	
CV (5%)		30.22	18.06	14.06	25.58	24.51	
Means with the same letter are not significantly different at $P \leq 0.05$ according to Fisher's LSD; CL=Cultivated Land, GL=Grazing Land, FE=Forest Eucalyptus plantation, FY=Farm Yard							

TEB= Total exchangeable base.

Exchangeable Mg was also highly significantly ($P \leq 0.05$) affected by the interaction effect of land use and soil depth where the highest (6.9 cmol(+) kg⁻¹) was observed in the subsurface layer of farm yard land use type and lowest (3.8 cmol(+) kg⁻¹) on the sub surface layer of grazing land. This study is in agreement of what Banafshe *et al.*, (2011) reported that the lowest exchangeable Mg was obtained in cultivated land which could be due to the high intensity of cultivation and abundant crop harvest with little or no use of inputs. The value of exchangeable Mg in the study area was significant ($p \leq 0.05$).

Exchangeable Ca was significant ($P \leq 0.05$) affected by the interaction effects of land use and soil depth (Table 3). The highest exchangeable Ca (8.7 cmol(+) kg⁻¹) was observed on the surface layer farm yard land where as lowest (6.4cmol(+) kg⁻¹) on the sub surface layer of cultivated land. Tesema *et al.*, 2026 and Gebeyaw, (2007) reported that cultivation led to reduction and leaching of exchangeable cations, especially in acidic tropical soils.

Exchangeable K was significantly ($P \leq 0.05$) affected by land use and soil depth interactions (Table 3) whereby the highest ($1.7 \text{ cmol}(+) \text{ kg}^{-1}$) was recorded on the surface layer of farm yard land use type while the lowest ($0.5 \text{ cmol}(+) \text{ kg}^{-1}$) in the surface layer of cultivated land. The higher exchangeable K on the surface layer of farm yard and forest land could be due to the availability of Organic matter and surface biomass through litter falling and little or no surface soil disturbance by rain drops, surface runoff and other severe erosion agents. The derivative of this phenomenon is the reasonable for lower exchangeable K in case of surface layer of Cultivated and grazing land in which higher leaching and soil disturbance was severe and exacerbate soil erosion. Similarly, this result is in agreement with the work of Yitbarek et al., (2013) and Duguma *et al.*, (2014) whose findings was reported that the exchangeable K of soil is higher in the forest land than cultivated and grazing lands.

Exchangeable Na was significantly ($P \leq 0.05$) affected by land use and soil depth interactions (Tables 3). The highest exchangeable Na ($0.07 \text{ cmol}(+) \text{ kg}^{-1}$) was recorded on the surface layer of cultivated land and lowest ($0.04 \text{ cmol}(+) \text{ kg}^{-1}$) on the sub surface layer of farm yard land in the study area.

Exchangeable Ca and Mg were by far higher than K and Na in all land uses of the study area since divalent cations were higher in macro-aggregate fractions than the monovalent once which was similar to Tekalign (1991) who reported that deforestation, leaching, limited recycling of dung and crop residues, declining fallow periods and soil erosion have contributed to depletion of basic cations and reduction in CEC in cultivated land as compared to the adjacent forest land.

4. CONCLUSION AND RECOMMENDATION

The properties of a given soil are influenced by land use types, which, in turn, determine the availability of essential nutrients within the soils. This study highlights that both land use types and soil depth significantly impacted selected physicochemical properties of soils. Specifically, the findings revealed substantial variations in these properties attributable to the effects of land use types in the study area. However, soil texture did not exhibit a significant difference ($P \leq 0.05$) across different land use types. On average, the texture of the soil was classified as clay, covering approximately 66.8% of the study area. Soil bulk density, on the other hand, was significantly influenced ($P \leq 0.05$) by both land use types and soil depth, with the highest mean bulk density observed in cultivated lands at a soil depth of 20–40 cm.

The chemical properties of the soil also demonstrated significant variation ($P \leq 0.05$) concerning land use types and soil depth. Notably, the available phosphorus (P) content varied due to the interaction effects of land use and soil depth. Among the land use types, farmyard land exhibited the highest levels of available phosphorus, followed by forest eucalyptus plantations. Exchangeable acidity, total nitrogen (N), and organic carbon (O C) were also significantly affected ($P \leq 0.05$) by the interplay between land use types and soil depth, with the highest values recorded in forest eucalyptus plantation soils and the lowest in cultivated lands.

The study underscores that soil acidity and the depletion of organic matter are critical challenges to sustainable crop production in the study area. These findings highlight the potential risks associated

with variations in soil physicochemical properties between different land use types, which pose significant threats to sustainable agricultural productivity and effective land management systems in the region.

To address these challenges, sustainable soil management practices and the maintenance of soil quality must be prioritized. Reducing land cover conversion and adopting appropriate soil management strategies are essential to sustain agricultural production while maintaining soil fertility. Effective land use management strategies, including targeted interventions to mitigate soil acidity, are imperative for enhancing soil health and ensuring long-term agricultural sustainability in the study area. These efforts must be supported by policies and practices that promote the integration of sustainable land management principles into local agricultural systems.

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The authors declare no conflict of interest related to this papers.

Consent for publication

The authors have agreed to submit and approved the manuscript for submission.

Author contributions

K.A. collected data and wrote the 1st draft Manuscript, P.D. Language edition ,Writing – review & editing. and writing and S.M. Writing – review & editing.

Data availability

All data generated or analyzed during this study are included in this manuscript

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Ethics approval and consent to participate

NA

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Figures

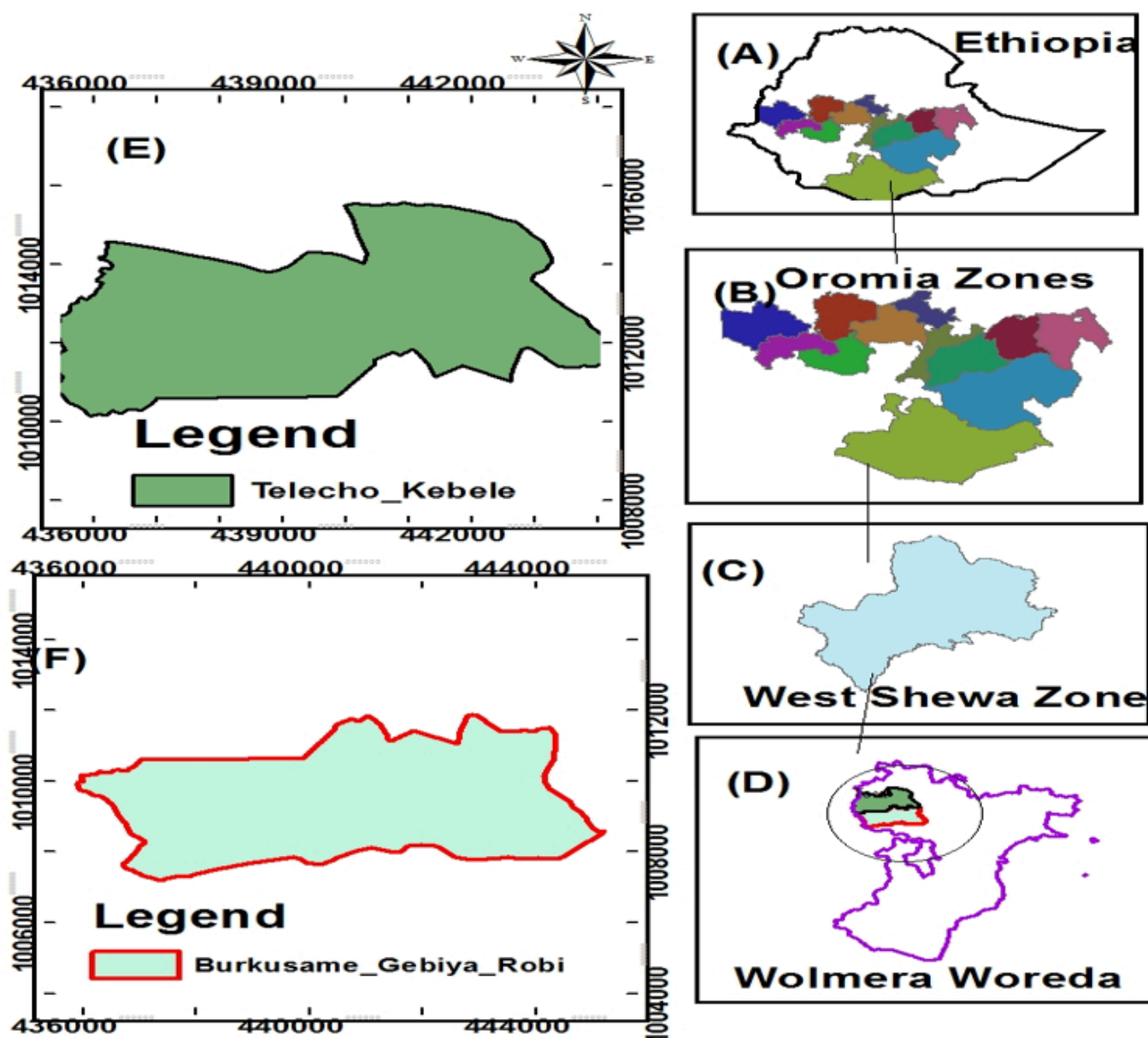


Figure 1

Map of the study area.

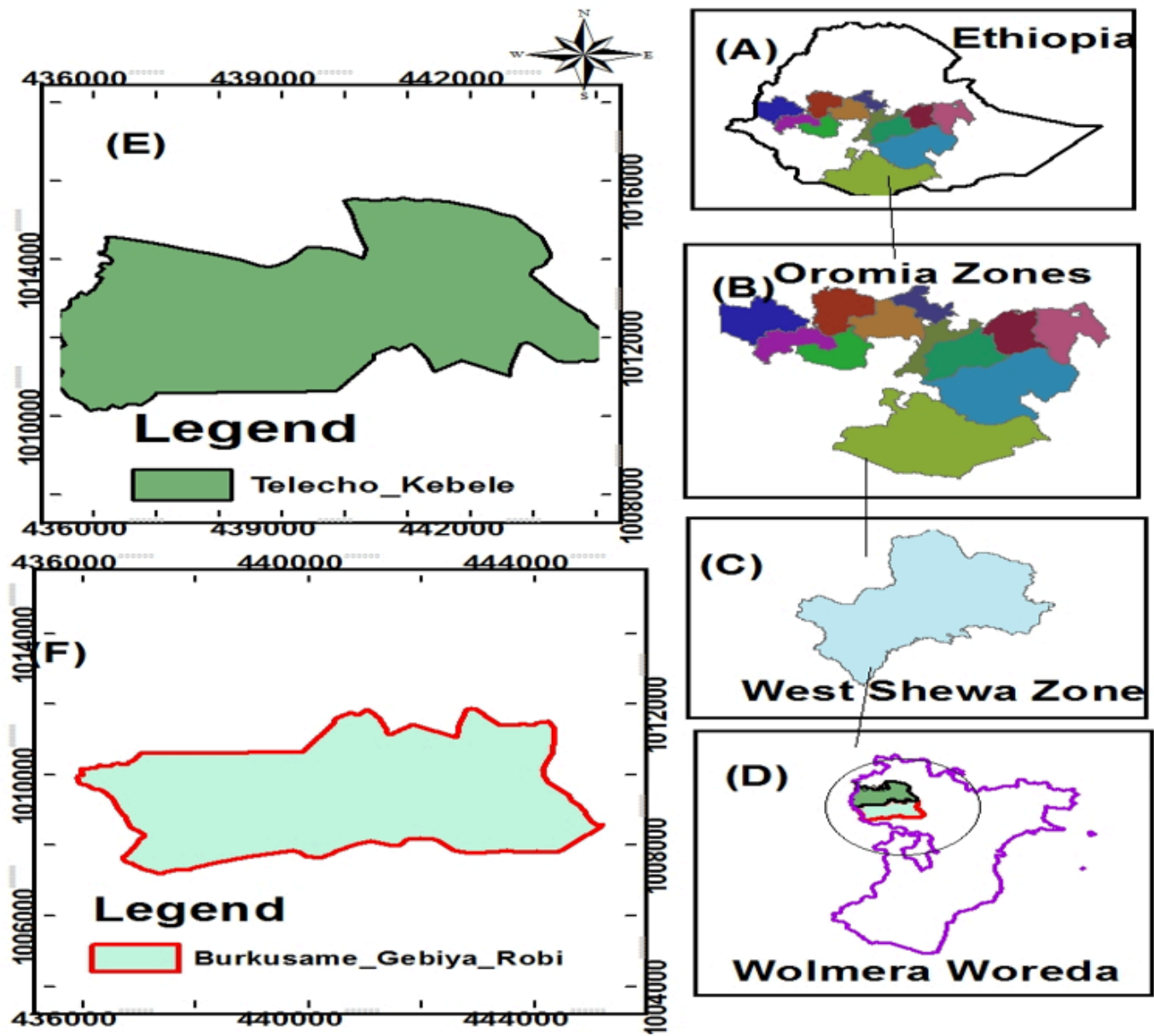


Figure 1

Map of the study area.

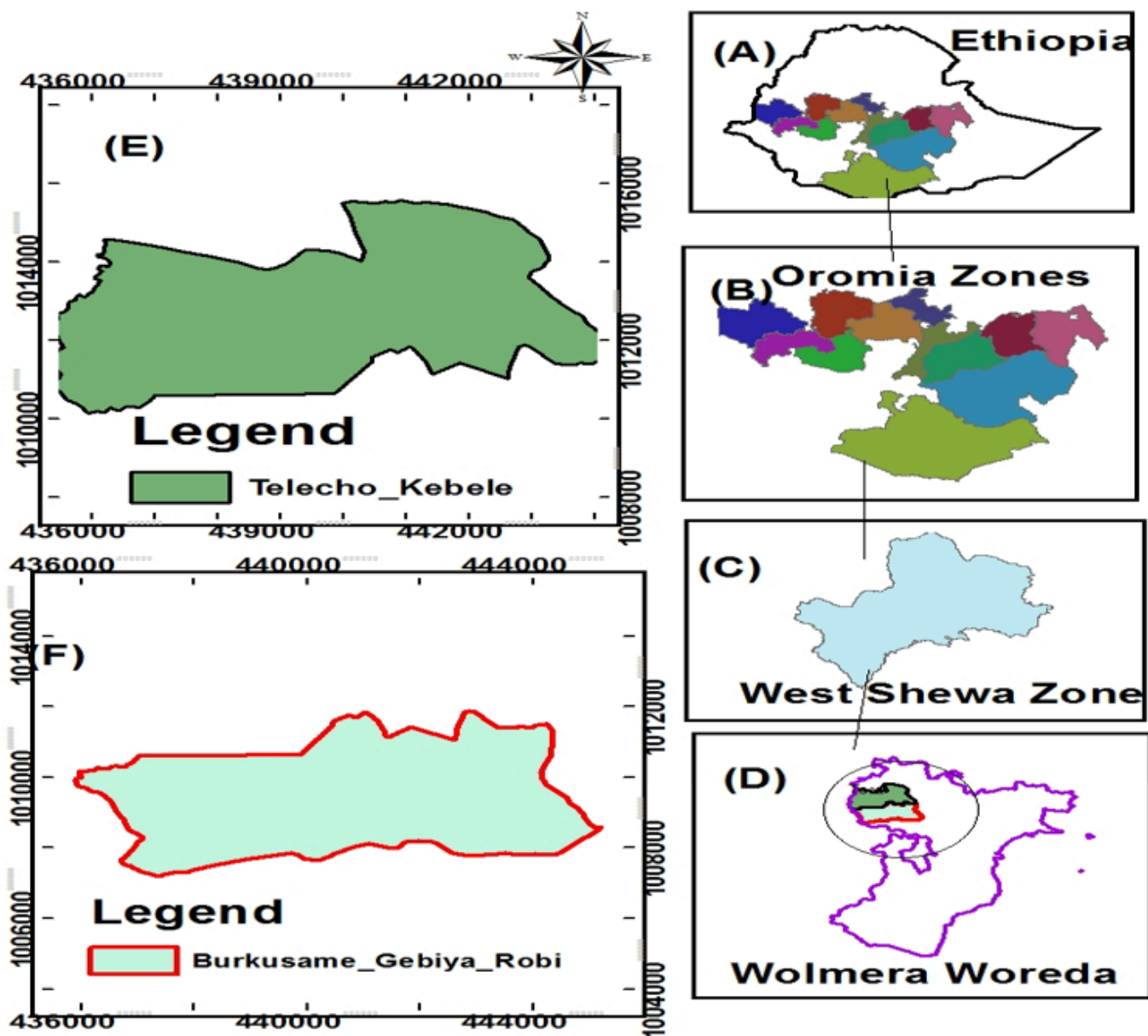


Figure 1

Map of the study area.

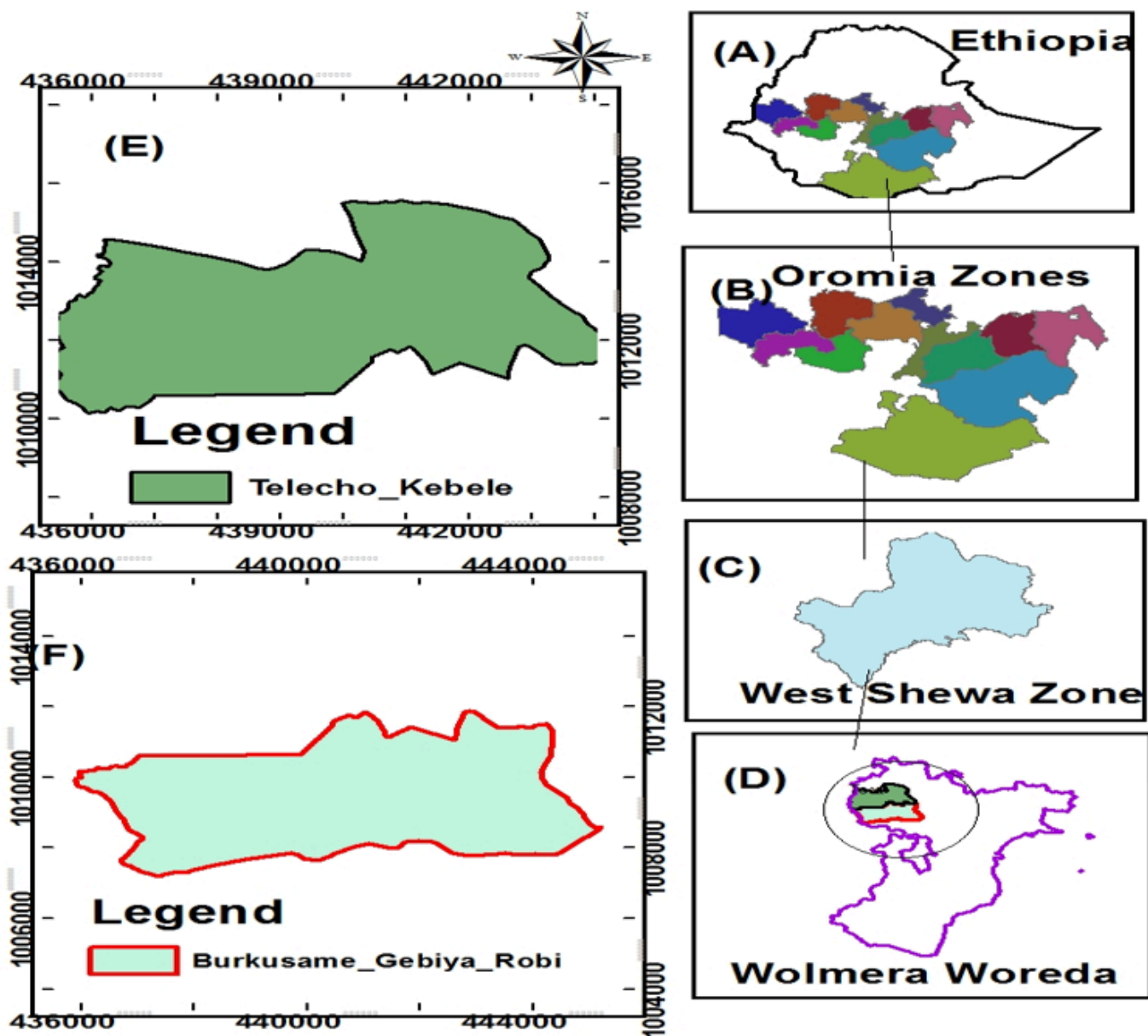


Figure 1

Map of the study area.

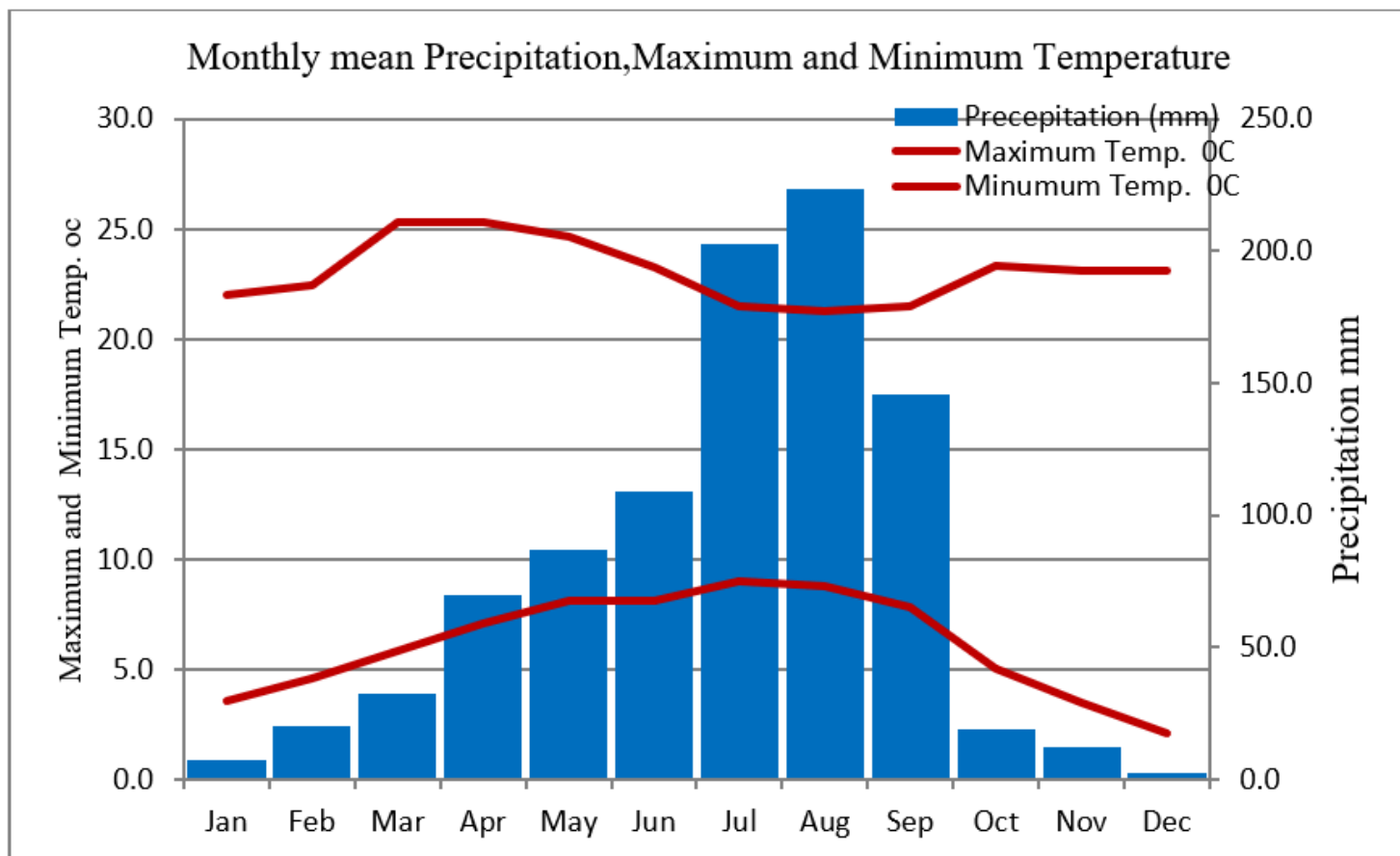


Figure 2

Mean monthly rainfall and mean maximum and minimum temperatures of the study area

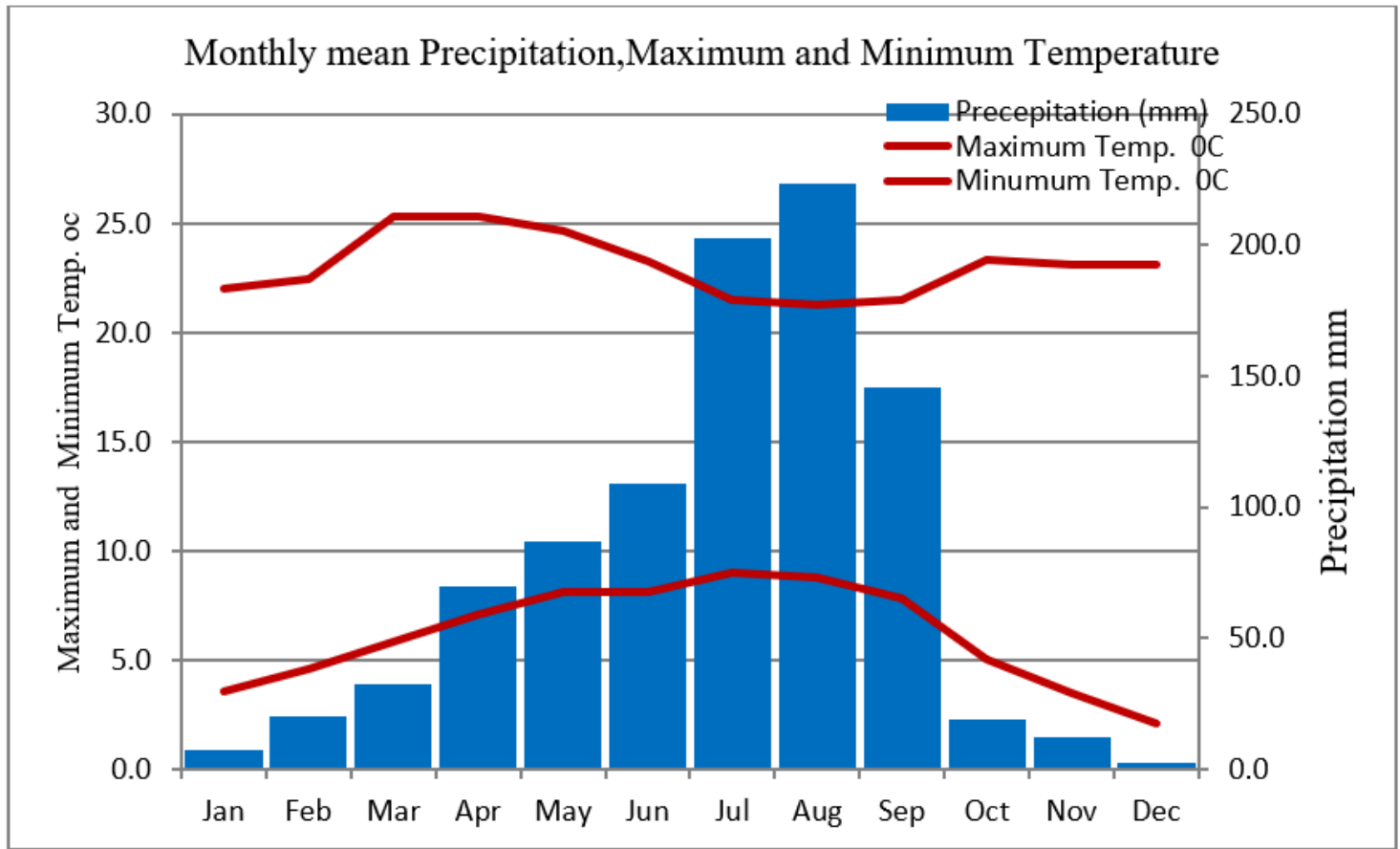


Figure 2

Mean monthly rainfall and mean maximum and minimum temperatures of the study area

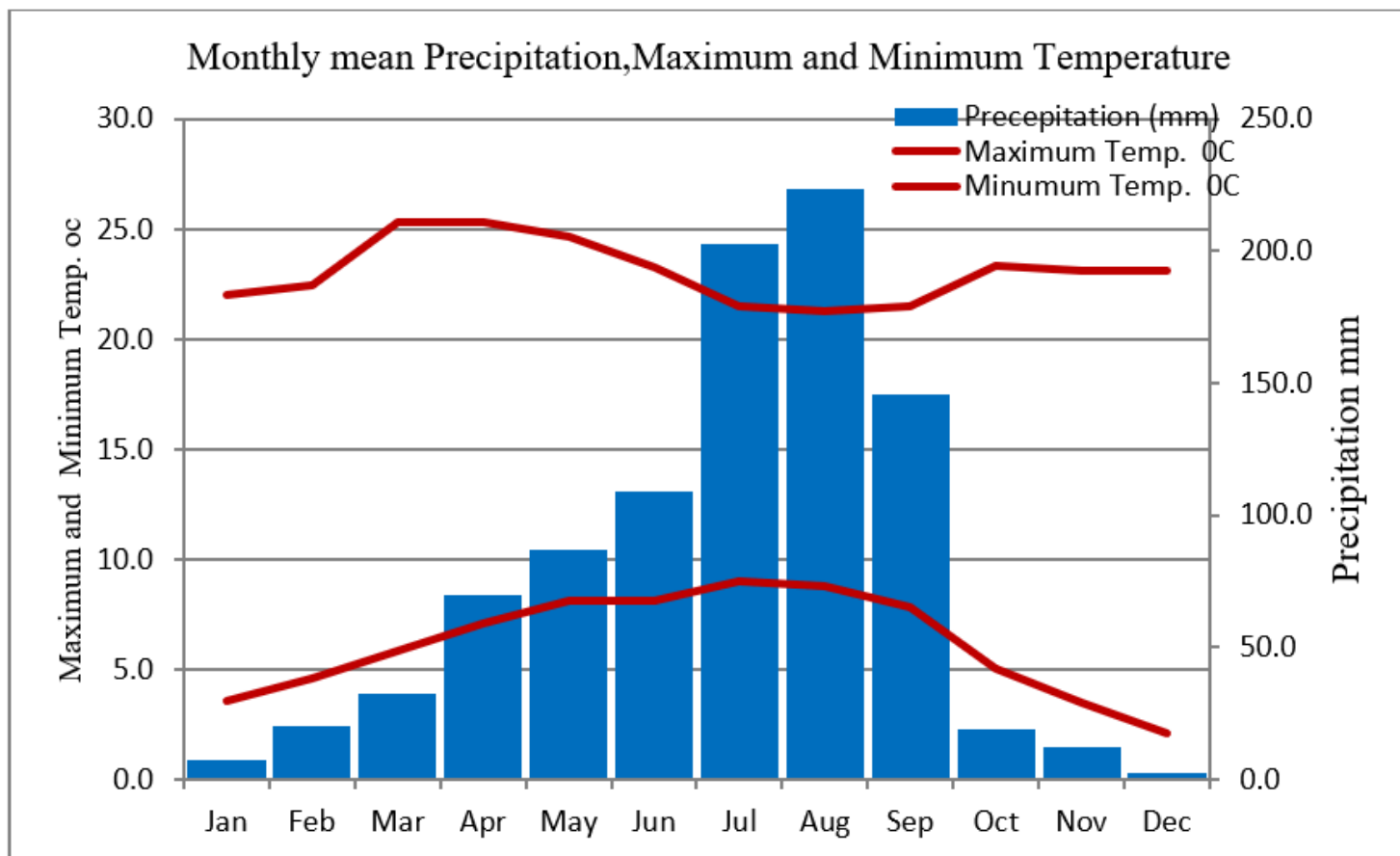


Figure 2

Mean monthly rainfall and mean maximum and minimum temperatures of the study area

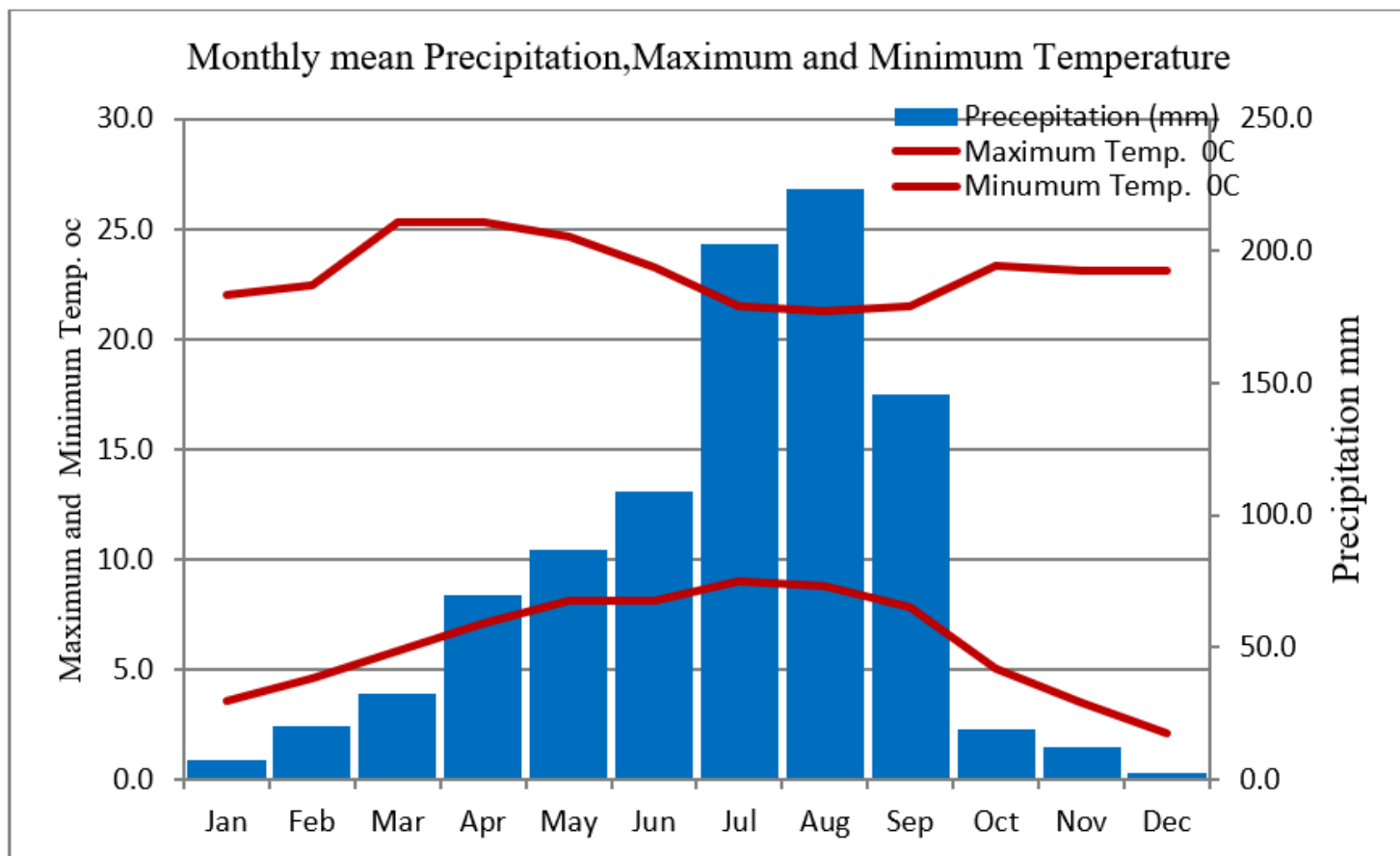


Figure 2

Mean monthly rainfall and mean maximum and minimum temperatures of the study area

Supplementary Files

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