Effects of Land Use Land Cover and Slope Gradients on Soil Fertility at Kori Sub-Watershed, East Wollega, Ethiopia

Begna Tesema Bekana  
Addis Ababa university  
https://orcid.org/0000-0002-7483-6498

Tolera Megersa Gudeta (begna2018@gmail.com)  
Wollega University

Fedhasa Benti Chalachisa  
Wollega University

Research

Keywords: Land-use land cover, slope gradients, soil properties, Sub-watershed

Posted Date: January 13th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1191827/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.  Read Full License
Abstract

Background

The complex nature of the relationship and interaction between LULC and slope gradients resulted in the decline of soil fertility parameters, which aggravate the reduction of sustainable productivity in Ethiopia in general and the study area in particular. This study was aimed to determine the effects of land use land cover and slope gradients on the physicochemical properties of soil in study area A total of 27 composite soil samples were collected from 0-20cm depth under three dominant adjacent LULC across three slope with three replications. The collected soil samples were analyzed for selected soil physicochemical properties. Two-way ANOVA was used to test the mean differences of the soil fertility parameters.

Result

The mean values of soil physicochemical parameters showed that, SOC, TN, AvP, CEC, exchangeable bases (Ca2+ Mg2+, K+, and Na+), PBS, and percentage of clay contents of cultivated land and steep slope gradient (15-30%) were low and significantly different at (P≤0.05) than forest and grad grassland of the same slope gradient.. The gentle slope (3-8%) gradients of the forest lands had the lowest BD and high TP as compared to the others.

Conclusion

The overall soil fertility status of the steep slope gradient (15-30%) of cultivated lands is lower than others and cultivating the steep slope is the cause for productivity loss in the study sub-watershed. Therefore, proper land-use planning and the use of integrated soil fertility management strategy give better production and keep the soil fertility status to a better level.

Background

The fertility status of Ethiopian soils has declined and challenged to crop production. This is due to, continuous cropping, reduced manure application, removal of crop residues, and animal dung for fuelwood and erosion together with low essential fertility of the soils (Tilahun et al., 2007).

Land-use can influence soil chemical, physical, and biological properties because of different anthropogenic activities, specifically tillage, livestock trampling, harvesting, planting, application of fertilizer (Getahun et al., 2014). In non-cultivated land, the type of vegetative cover is a factor influencing the soil organic carbon content (Liu et al., 2010; Okebalama et al., 2017). A study by Alemayehu and Shelleme (2013) found higher soil organic carbon (SOC), and total nitrogen (TN) under grassland as compared to cultivated land-use types. Similarly, according to (Yihenew and Getachew, 2013), land-uses like cultivated and grazing land-use types had more harmful effects on soil electric conductivity (EC), pH, SOC, TN, and on the overall activities of soil macro faunal in the soil. The slope position also determines or influences the physicochemical and biological properties of the soil (Salako et al., 2006). Slope accelerates soil disturbance through erosion and affects the soil properties considerably (Afshar et al., 2010).

To evaluate the quality of natural resources and their potential for sustainable use, detailed information on soil properties are required (Teshome et al., 2016). Most of the studies conducted in Ethiopia, so far on soil fertility studies have been carried out at the national and regional level which lack detailed soil fertility status at a watershed level generally, and the major gap observed particularly in the current study area Kori sub-watershed.

Therefore, the study aimed to determine the combined effects of land use land cover and slope gradients on the physicochemical properties of soil and generate data for management options in the study area.

Materials And Methods

Study area description

The study was conducted at Kori sub watershed in Guto Gida District, East Wollega Zone, Oromia Region, Ethiopia. It is located at about 12km West of Nekente town and lies between 37°01’09.33” to 37°05’04.41” E longitudes and 9°14’54.05” to 9°20’04.09” N latitudes. The total area of the study sub-watershed covers 2051 ha (Fig.1).

The rainfall of the area is unimodal, with short rains from March to April and the main rainy season extended from June to September. Thirty (30) years of recorded rainfall data of the study sub-watershed was obtained from National Meteorology Agency. According to these data, the mean annual rainfall (1989 to 2019 years) is 1095mm. The mean annual temperature in the study sub-watershed is 19°C with 11 and 27.13°C mean annual minimum and maximum temperatures, respectively (NMA, 2019). The elevation of the area ranges from 1850-2506m above sea level. It exhibits distinct variation and contains flat (0-3% slope) surrounded by steep to very steep (>30%) land features (Table 1).

According to Guto Gida District Agricultural Office report, almost all Annual crops comprise grains and horticultural crops. The forests are mostly found in between the peripheries of a river up to the middle slope of riverside hills following the streams. The dominant vegetation in the forest is Cordia Africana (locally called Waddeessaa), Prunes Africana (locally called Hoomii), Acacia Abyssinia (locally called Laaftoo), Croton macrostachious (locally called Bakkanisaa), Ficus Vasta (locally called Kiltu), Anunu, Bedessa, Coffee and others which were identified during the field observation.

Based on the data obtained from CSA (2007), the total population of the sub-watershed is 4585 According Guto Gida District Livestock Development Office report, the livestock population data in the study sub-watershed include: number of Cattle 5051, Sheep and Goat 4428, Mules 33, Horses 71, and Donkeys 821 are there, from which cattle population is the dominant livestock population of the area.
Methods

Soil sampling design and sample size determination

Soil-sampling sites were selected by stratifying the study sub-watershed on the dominant LULC and difference in slope gradient. From each slope gradients and LULC, a plot with 25mx25m size was marked as a sample plot following a method applied by The soil samples were then taken by using a zigzag sampling technique from the surface 0-20cm depth.

Twenty-seven (27) composite soil samples, from 3 slope gradients, 3 LULC, and 3 replications were collected to determine selected physicochemical properties of soil and analyzed in Nekemte Soil Research Center. In the same way, twenty-seven (27) undisturbed soil samples were taken from the surface 0-20cm depth through a 100cm³ volume steel core sampler. All sampling coordinate points were taken by using the Global Positioning System (GPS) to locate the study area (Fig. 2).

A preliminary field survey was carried out to have a general view of LULC and slope gradients in the sub-watershed. Throughout the visual observation of the study area, its geographic coordination (latitudes and longitudes) and elevation were recorded by the global positioning system (GPS). Finally, the study area, Kori sub-watershed was stratified into three major LULC and slope gradients.

Soil Laboratory Analysis

The disturbed soil samples were air dried, thoroughly mixed, homogenized into a single composite sample and pass through 0.5 and 2mm sieve for SOM and other physicochemical analysis respectively. Soil texture was estimated using Hydrometer method (Day, 1965) after destroying organic matter by adding hydrogen peroxide (H2O2) and separating the soil through adding sodium hexametaphosphate (NaPo3)6. The BD of undisturbed soil samples were determined by using metal sampler). The mass of solids and the water content of the core were determined, by weighing the core, drying it to constant weight in an oven at 105°C for 24 hours and calculated as oven dried mass per core volume.

The TP was calculated using BD and particle density (Pd) as described in Hao et al. (2008) by the following formula.

\[ TP = \left(1 - \frac{BD}{Pd}\right) \times 100 \]

where, TP - total porosity, BD - bulk density (g/cm³), and Pd - particle density (the assumed Pd is 2.65 g/cm³).

The pH and EC of soil samples were measured from a soil suspension solution prepared with 1:2.5 soils water ratios. SOM, SOC and TN content were determined following the Walkey and Black titration (1934) procedure. AvP of soil samples was determined following the (Olsen et al., 1945). The CEC and exchangeable bases (Ca2+, Mg2+, K+ and Na+) were determined after extracting the soil samples by ammonium acetate (1N NH4OAc) at pH 7.0. Exchangeable Ca2+ and Mg2+ in the extracts were analyzed using titration method while Na+ and K+ were analyzed by flame photometer (Chapman, 1965). The CEC was estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965). The PBS was calculated by dividing the sum of the base forming cations (Ca2+, Mg2+, K+ and Na+) by the CEC of the soil and multiplied by 100. Similarly, ESP was calculated by dividing exchangeable Na+ to CEC of the soil and multiplying by 100.

Data Analysis

The physicochemical properties of the soil generated from soil laboratory test were subjected to two-way analysis of variance (ANOVA) at p ≤ 0.05 & 0.01 to find out the influence of LULC and slope gradients variation on soil fertility parameters and their interaction effects using the general linear model (GLM) procedure using SPSS version 24 and XLSTAT 2015 software. The least significant difference (LSD) (p ≤ 0.05 & 0.01) test was used to separate statistically significant means of soil parameters. The Pearson correlation coefficient analysis was applied to determine the relationship between some soil physicochemical variables.

Results And Discussion

Effect of LULC and slope gradient on soil physical properties

Soil texture

The analysis of variance (ANOVA) results showed that the particle size distribution of the soil in the study sub-watershed was significantly affected by LULC and slope gradient (P≤0.01). Accordingly, the highest percentage of sand content (62.78%) was observed under the cultivated land and the lowest (44.89%) in the forest land. The percentage of the silt fractions was 23.25, 27.67, and 31.33% for cultivated, grazing, and forest lands, respectively (Table 3).

The combined effect result (Table 4) at all LULC also showed that the percentage of the clay increased as slope gradient decreases while the percentage of the sand decreased down the slope gradients.

Soil bulk density and total porosity
The result showed that soil bulk density (BD) was significantly affected by LULC and slope gradient (P ≤ 0.01). As specified table 4, the mean value of BD was lowest (0.81 g cm⁻³) under the forest and highest (1.30 g cm⁻³) in grazing land. The BD of soil is also affected by the texture of the soil. Sandy soils have higher BD when OM content and total pore space are less than clay or silt soils that can limit root penetration. On the other hand, the mean values of lowest (0.73 g cm⁻³) and highest (1.29 g cm⁻³) soil BD were recorded from the gentle slope (3-8%) and moderately steep (15-30%) slope gradient of the forest and grazing lands of the study sub-watershed, respectively (Table 4).

The TP analyses result showed that the soil TP in all LULC and slope gradients were increased as the BD decreased and vice versa (Tables 3 and 4). The mean percentage values of TP were (51.29), (59.47) and (69.4) for grazing, cultivated, and forest lands, respectively (Table 3). The mean percentage values of the TP of forest land is higher than both cultivated and grazing land and statistically, forest land had a significant difference (P ≤ 0.01) than cultivated and grazing land. The mean percentage values from the slope and LULC interaction showed a decrease in TP from the gentle slope (3-8%) to moderately steep slope (15-30%) gradients for all LULC (Table 4).

Effect of LULC and slope gradients on selected soil chemical Properties

Soil reaction (pH) and electrical conductivity (EC)

The mean value of soil pH did not show a significant difference between all LULC and slope gradients. Relatively the lowest (5.34) and highest (5.57) mean value of soil pH was observed under cultivated and forest lands respectively (Table 5).

Likewise, the lowest pH value (5.27) was observed in soils of moderately steep (15-30%) slope gradient of the cultivated land, whereas the highest pH (5.69) was observed on gentle (3-8%) slope gradient of the forest land (Table 6).

Soil organic carbon, total nitrogen, and available phosphorous

The analysis of variance results showed that soil organic carbon (SOC) contents were significantly affected by LULC and the interaction of LULC with slope gradients (P ≤ 0.05) (Table 6). Contents of SOC in the study area ranged between 2.53% and 3.72%. Relatively, SOC content in forest land was significantly higher (3.72%) as compared to the SOC content in cultivated land (2.53%) (Fig. 3).

The interaction of cultivated land with all slope gradients produced a lower soil SOC than other LULC. The highest mean value of SOC was recorded from the interaction of forest land with 3-8% slope (4.22%) gradient and had a significant difference at (P ≤ 0.05) than other lands of the same slope gradient, that is, cultivated land (2.86%) and grazing land (3.17%). The lowest mean value of SOC (2.61%) was recorded from cultivated land at the slope gradient of 15-30% (Table 6).

The SOC in the moderately steep slope (15-30%) was significantly different (P ≤ 0.01) as compared to the undulating slope (8-15%) and gentle slope (3-8%) gradients of each LULC. The total nitrogen (TN) content of soils of the study sub-watershed was significantly affected by both LULC and slope gradients (P ≤ 0.01). The mean value of TN was highest (0.32%) in soils of the forest land while the lowest (0.22%) in the cultivated land of the study sub-watershed (Fig. 3).

The result of the multiple comparisons showed that there is a significant variation in TN among all LULC in all slope gradients of the study sub-watershed (P ≤ 0.01). With the interaction of LULC by slope gradients, the highest (0.36%) mean value of TN was observed at the gentle slope (3-8%) gradients of the forest land. On the other hand, the lowest (0.23%) interaction mean value of TN was observed in the moderately steep slope (15-30%) gradients of the cultivated land (Table 6).

According to the analysis of variance, results showed that the available phosphorus (AvP) of the study sub-watershed was significantly affected by LULC and the interaction of LULC with slope gradients (P ≤ 0.01) (Table 6 and Fig. 3). The mean values of AvP in the study sub-watershed were 4.16, 4.58, and 7.96 ppm for grazing, cultivated, and forest lands respectively (Fig. 3).

Concerning the interaction effect of LULC with slope gradients, the highest (8.70 ppm) and the lowest (3.04 ppm) of AvP contents were recorded under the gentle slope (3-8%) and moderately steep slope (15-30%) gradients of the forest and grazing lands, respectively (Table 6).

The summary of the SOC, TN, and AvP contents as affected by LULC in the study sub-watershed was indicated below (Fig. 3).

Exchangeable basic cations, CEC and PBS

The analysis of variance results showed that the mean values of basic cations on the exchange site of soils of all LULC and slope gradients of the study sub-watershed were in the order of Ca²⁺ > Mg²⁺ > K⁺ > Na⁺ (Table 5 and 7). The finding also showed that the lowest and highest values of exchangeable bases were observed for moderately steep (15-30%) and gentle (3-8%) slope gradients at all LULC, respectively (Table 7).

When comparing the interaction effects of slope gradients by LULC, exchangeable Ca²⁺, Mg²⁺, Na⁺, and K⁺ in the moderately steep slope (15-30%) showed significant difference (P<0.05) compared with undulating (8-15%) and gentle slope (3-8%) gradients with values in the order gentle slope (3-8%) > undulating slope (8-15%) > moderately steep slope (15-30%) slope gradients at each LULC (Table 7).
The cation exchangeable capacity (CEC) mean values of the soils in the study sub-watershed were significantly affected by LULC and the interaction of LULC by slope gradients (P ≤ 0.05). The result of the mean values of CEC is ranged from 22.28 to 27.29 Cmol (+) /kg in the study sub-watershed. Relatively, the mean CEC values are higher for forest (27.29 Cmol (+) /kg) and lower in cultivated (22.28 Cmol (+) /kg) land (Table 5).

In another way, the lowest and highest CEC values were recorded for moderately steep slope (17.43 cmol (+) kg-1) and gentle slope (31.61 cmol (+) kg-1) gradients of cultivated land and forest lands of the study sub-watershed respectively (Fig. 4). Similar to the exchangeable basic cations the percent base saturation (PBS) of the study area was significantly affected by LULC and slope gradients (P ≤ 0.05) (Tables 5 and 7).

Discussion

The cultivated land had significantly lowest (13.97%) clay content compared to the forest (23.78%) and grazing (17.10 %) land uses (Table 3), because most of the cultivated lands in the study sub-watershed lack soil erosion control practices. This finding is in agreement with that of Teshome et al. (2013) who reported that the reason for low clay content on cultivated lands might be due to selective removal of clay from the surface by erosion.

At all LULC the percentage of the sand decreased down the slope gradients. This might be due to the removal of the clay particles by erosion is greater on the moderately steep (15-30%) slope gradient of mainly under the cultivated land while deposition of these particles occurs higher on the gentle (3-8%) slope gradients of the forest land (Table 4). This finding is in line with Mohammed et al. (2005), who reported that finer soil materials are deposited at the lower slope gradients, where they are coming from the upper sites.

The higher BD values (Table 3) in grazing land and cultivated land as compared to forest land might be due to the result over grazing and continuous cultivation and low OM input. The findings of the present study are in line with the findings of Nega (2006) and Solomon et al. (2002).

The variation of soil BD between the slope gradients and LULC might be recognized to the variation of soil particle size distribution and disturbance of soil particles with erosion. This result was also in line with the works of Yihenew and Getachew (2013).

The highest soil means percentage values of TP under cultivated and forest land might be due to lower animal trampling. This means that soils having higher SOM had lower BD which indicates higher total porosity. The result of Pearson’s correlation coefficient (r=0.62) indicated TP is positively and significantly correlated (P ≤ 0.01) with SOC (Table 8). The results were in agreement with that of Achalu et al. (2012).

The observed comparatively higher pH value in forest land soils could be related with higher SOM content. In agreement with this, Abreha et al. (2012) reported that the high pH of soils from the forest land might be due to the high accumulation of organic matter at the surface. In contrast, the lower pH in soils of the cultivated land might be due to the removal of basic cations by surface runoff and deep percolation in cultivated land because of less plant cover in cultivated land as compared to other land uses.

Person’s correlation matrix also showed that CEC, Ca2+, K+, Mg2+, and pH have had a positive relationship with each other (Table 8). This, in line with Brady and Weil (2002) who stated as, in acid soils, Al3+ becomes soluble and increases soil acidity while in alkaline soils; exchangeable basic cations tend to occupy the exchange site of the soils by replacing exchangeable H1+ and Al3+.

Generally, the similar low pH in all LULC and slope gradients of the study sub-watershed might be related to the high rainfall in western Ethiopia that causing the leaching of basic Cations (K+, Mg2+, and Ca2+) and replaced by acidic cations like Al3+, Fe3+, Cu2+, Mn2+. In line with this finding, Nega and Heluf (2013) reported that loss of base-forming cations through leaching and runoff produced from accelerated erosion reduces soil pH and thus increases soil acidity. Based on Foth and Ellis (1997) pH, between 4.6 and 5.5 is classified as strongly acidic. Accordingly, the pH of the study sub-watershed falls under strongly acidic soil.

The consistently low electrical conductivity (EC) value under different LULC and slope gradients (Tables 5 and 6) might be due to the low exchangeable Na+ content observed in the study sub-watershed. The result from Pearson’s correlation matrix revealed that EC is positively and significantly correlated with exchangeable Na+ (r=0.75**) (Table 8). According to FAO (2006) and Landon (1991) rating, EC values of the study sub-watershed were considered to be very low (0-2ds/cm) for all LULC and slope gradients which show the study sub-watershed as non-saline soil.

The higher SOC observed in the forest land of the study sub-watershed might be due to the addition of more plant residues on the surface of forest soils and their reduced rate of disturbance as compared to the other land-use types. In contrast, the decline in SOC contents in the cultivated land might be due to intensive cultivation and soil erosion. This result is in agreement with the finding of Eylachew (2001) and Yihenew (2002) who reported that most cultivated soils of Ethiopia are poor in organic matter contents due to the low amount of organic materials applied to the soil, intensive cultivation and high erosion problems.

The SOC in the moderately steep slope (15-30%) was significantly different (P ≤ 0.01) as compared to the undulating slope (8-15%) and gentle slope (3-8%) gradients of each LULC, which might be due to the higher soil erosion problem and a comparatively high percentage of sand in the steeper slope while...
the finer soil materials are deposited at the lower slope gradients of the land use types. This result is similar to Bovine et al. (2000) that indicated SOC shows significant variation in LULC and slope gradients. According to Tekalign (1991) general guidelines on the interpretation of soil SOC test results, the study sub-watershed is considered as moderate SOC content.

The higher TN in forest land could be due to an addition of a comparatively higher plant residue and slight rate of decomposition and low soil erosion impact. However, the lower TN in cultivated land might be linked to the rapid mineralization of the organic substrates following intensive cultivation. In addition, as the area receives high rainfall, the nitrogen leaching problem can be another reason for the decline of TN in soils of cultivated land. The results of the present study agree with the findings of Solomon et al. (2002); and Yihenew and Getachew (2013).

On the other hand, intensive and continuous cultivation and lower activity of N-fixing bacteria due to strong acidity pH < 5.34 might have resulted in a decrease of TN in soils of cultivated land as compared to natural forest land. The results were following the findings of Wakene and Heluf (2004) who stated that intensive and continuous cultivation forced oxidation of SOC and thus resulted in a decrease of TN. The TN contents in the soil taken from the gentle slope (3-8%) gradients of each LULC were comparatively higher because it is not susceptible to soil erosion thereby leading to accumulation of nitrogen in soil. On the other hand, the moderately steep slope (15-30%) gradients are highly susceptible to runoff and erosion that caused the removal of nitrogen and SOC from the area (Table 6). The result of Pearson correlation analysis has also shown the contents of TN in the study sub-watershed had a strong positive and significant correlation with SOC (r = 1.00**) as shown in (Table 8). As per the rating of TN indicated by Tekalign and Landon (1991), the study watershed qualifies for the moderate status of TN.

Relatively the high content of AvP in the forest land might be due to the high content of SOM resulting in the release of organic phosphorus thus increases AvP under forest land. Similarly, this result is in agreement with the findings of Abad et al. (2014) who reported that the AvP was high in forest land compared to the adjacent grazing and cultivated land at 0-30 cm soil depth.

The low AvP status in the cultivated and grazing land of the study sub-watershed might be linked with the low pH and high exchangeable acidity. In agreement with this, the Pearson correlation analysis has shown a positive correlation (r = 0.41*) of AvP with soil pH. Similarly, there exists a positive correlation between AvP and SOC (r = 0.61**) (Table 8). The low contents of AvP in the soil agree with the results reported by Murphy (1968), and Dawit et al. (2002) that the AvP under most soils of Ethiopia decline by the impacts of fixation, abundant crop harvest, and erosion. According to the rating of AvP stated by Barber 1984, the study sub-watershed qualifies for the low status of AvP.

In general, the variation of AvP content between the slope gradients of each LULC might also be the variation of SOC. This shows that SOC could contribute to the presence of more AvP in the soil. In agreement with this, Fisseha et al. (2014) found low AvP in soils having a low content of organic matter.

Similarly, exchangeable cations were higher under forest land than cultivated and grazing land and had a significant difference at (p< 0.05) between them (Table 5). This is because of the presence of different woody species and perennial plants in forest land which can add SOM and reduce the rate of soil erosion. This result is in agreement with the work of Yitbarek et al. (2013). The variation of exchangeable basic cations from upper to lower slope gradients under each LULC might also be due to their loss through runoff and erosion in the high slope gradients and accumulation in areas having lower slope gradient. In general, as per the ratings of FAO (2006), all exchangeable cations (Mg2+, Ca2+, and K+) of the study sub-watershed were found to be moderate except exchangeable Na+ which was low.

The CEC values in the cultivated land decreased mostly due to the decrease in SOC content. In agreement with this, Pearson correlation analysis has shown a strong positive correlation (r = 0.64**) of CEC with SOC (Table 8). This result is in agreement with the findings of Yitbarek et al. (2013) who suggested that the CEC of soil was higher in forest land compared to that of the adjacent grazing and cultivated lands.

The highest CEC value in the gentle slope (3-8%) of the forest land is linked to the availability of a high concentration of SOC and clay content. This is an indication that SOC and clay are major sites for exchangeable cations. This is in agreement with the finding of Teshome et al. (2016), Western Ethiopia.

The Pearson correlation result also revealed that CEC was positively and significantly correlated with clay (r = 0.61**) and SOC (r = 0.64**), while it was inversely and significantly correlated with sand (r = -0.83**) (Table 8). Based on the rating established by Landon (1991), the CEC of the study area is considered as a medium under both LULC and slope gradients.

The variances in PBS and exchangeable sodium percentage (ESP) in both LULC and slope gradients are mainly associated with differences in CEC. This indicates that high exchangeable bases and high CEC may give low PBS and ESP, while the higher exchangeable bases and lower CEC may give higher PBS and ESP. The result of Pearson correlation also showed that the PBS of the studied soils increased with increase in clay content (r = 0.56**), CEC (r = 0.61**) and basic cations mainly Ca (r = 0.87**) and Mg (r = 0.89**) (Table 8).

**Conclusion**
The result revealed that the effects of LULC types with slope gradients influenced significantly the soil fertility status in the study area. The findings indicated that, the steepest slope gradients of cultivated land had the lower as compared to the same slope gradient of forest and grazing land, this is due to a continuous cultivation of the steep land for long. Therefore, it is recommended to avoid the cultivation of steep slope for crop growing. Implementing appropriate soil and water conservation techniques should be undertaken by local communities particularly on the moderate to steep slope gradients of the cultivated lands. This study result should be complemented by further research with plant tissue analysis that grow in the study sub-watershed, and the nutrient ratings should also be done by considering the local situations of the study area.

Abbreviations

ANOVA: Analysis of Variance; DEM: Digital Elevation Model; FAO: Food and Agricultural Organization; GLM: General Linear Model; GPS: Global Positioning System; LSD: Least Significance Difference; LULC: Land Use Land Cover; NMSA: National Metrology and Satellite Agency; SPSS: Statistical Package for Social Science.

Declarations

Acknowledgments

The Author would like to acknowledge the supreme GOD for helping all and main advisor Tolera Megersa (PhD) and Co-advisor Fedhasa Benti (PhD) for their assistance from the very beginning to the end of the study. The Author also express his heartfelt and sincere gratitude to his beloved wife Workitu Fida for she gave him moral support, strength and encouragement in completing the thesis on time

Author’s Contributions

BT has contributed in the acquisition of the data, data collection, data coding and entry, data analysis, interpretation of the result. TM and FB provide comments, suggestions and editing the manuscript. All authors read and approved the final manuscript.

Funding

This Research was funded by Government

Availability of data and material

The data used in this paper is with the authors and can be available upon demand.

Ethics approval and consent to participate

Not applicable

Competing interests

The authors declare that they have no competing interests.

Funding

This Research was funded by Bureau of Oromia Public Service and Human resources

Availability of data and material

The data used in this paper is with the authors and can be available upon demand.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

References

Abad, J.R., Hassan, K., and Alamdarlou, E.H. (2014). Assessment the effects of land use changes on soil physicochemical properties in Jafarabad of Golestan province, Iran. Bulletin of Environment, Pharmacology and Life Sciences 3: 296-300.
Abreha, K., Heluf, G., Tekalign, M., and Kindie, T. (2012). Impact of altitude and land use type on some physicochemical properties of acidic soils in Tsegede highlands, Northern Ethiopia. *Open Journal of Soil Science*, 2: 223-233.

Achalu, C., Heluf, G., Kibebe, K., and Abi, T. (2012). Status of selected physicochemical properties of soils under different land use systems of Western Oromia, Ethiopia. *Journal of Biodiversity and Environmental Sciences*, 2(3): 57-71.

Afshar, F.A., Ayoubi, S., Jalalain, A. (2010). Soil redistribution rate and its relationship with soil organic carbon and total nitrogen using 137Cs technique in a cultivated complex hillslope in western Iran. *Journal of Environmental Sciences*, Radi.101, 606–614.

Alemayehu, K., Helemele, B. (2013). Effects of different land use systems on selected soil properties in South Ethiopia. 4 (5), 100–107.

Barber, S.A., (1984). Liming material and practices. pp.173-205, In: Fred Adams(ed.). *Agronomy 12*. ASA, SSSA, Madison, WI, USA.

Bovine, P., Schaffer, K., and Stuny, W. (2002). Quantifying the relationship between soil organic carbon and soil physical properties using shrinkage modeling. *Eur Journal of Soil Science* 60(4):265–275.

Chapman, H.D. (1965). Cation exchange capacity. In: Black, C.A., Ensminger, L.E., Clark, F.E. (eds.). *Methods of soil analysis* (pp. 891–901).

Chapman, H.D., David, J., Richard, C., Bishop, W., and Roger T. (2009). Natural resource damages associated with aesthetic and ecosystem injuries to Oklahoma’s Illinois River System and Tenkiller Lake.

CSA (Central Statistical Authority) (2007) Summary and statistical report of population and Housing census of Ethiopia. Central Statistical Agency, Addis Ababa

Dawit, S. Fritzschke, F., Tekalign, M. Lehmann. J. Zech, W. (2002). Phosphorus forms and dynamics as influenced by land use changes in the sub-humid Ethiopian highlands. *Geoderma* 105: 21-48.

Day, P.R. (1965). Particle size analysis. In: Black CA (ed.) *Methods of soil analysis. Part 1: Physical and mineralogical methods*, vol. 9.Am. Soc. Agro. Inc., Madison, WI. 545–

Duiker, S.W. and R.

Eylachew, Z. (2001). Study on physicochemical and mineralogical characteristics of some Vertisols of Ethiopia. pp. 87-102. Wondimagne Chekol and Engda Mersha (Eds.). *In: Proceeding of the 5th Conference of the Ethiopian Society of Soil Science (ESSS), March 30-31, 2000. Addis Ababa, Ethiopia.*

FAO (2006). Plant nutrition for food security: A guide for integrated nutrient management.

FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome.

Fisseha, H., Heluf, G., Kibebe, K., Birru Y. (2014). Study of phosphorus adsorption and its relationship with soil properties analyzed with Langmuir and Freundlich models. *Agriculture, Forestry and Fisheries*. 3(1):40-51.

Foth, H.D. and Ellis, B.G. (1997). Soil fertility (2nd ed.). Lewis CRC Press LLC., USA. 290p.

Getahun, H., Mulugeta, L., Fisseha, I., Feyera, S. (2014). Impacts of land uses changes on soil fertility, carbon and nitrogen stock under smallholder farmers in central highlands of Ethiopia: Implication for sustainable agricultural landscape management around Butajira area. *N. Y. Science Journal*. 2014, 7(2).

Hao, X., Ball, B.C., Culley, J.L., and Parkin, G.W. (2008). Soil density and porosity. In: M.R.

Carter and E.G. Gregorich (Eds.) *Soil Sampling and Methods of Analysis, Canadian society of soil science, Taylor and Francis Group*, LLC., U.S.A. 743-760.

Landon, J.R. (1991). Tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Broker, Longman.

Liu, X.L. He, Y.Q., Schroder, J.K., Zhou, J., Zhang, Z.Y. (2010). Impact of land use and soil fertility on distributions of soil aggregate fractions and some nutrients. *Pedosphere* 20(5):666–673.

Mohammed, A., Leroux, PA., and Barker, L. (2005). Soil of Jelo micro-catchment in the central highlands of Eastern Ethiopia: Morphological and physiochemical properties. *Ethiopian Journal of Natural Resource*, 7, 55-81.

Murphy, H.F. (1968). A report on fertility status and other data on some soils of Ethiopia.

Collage of Agriculture HSIU. Experimental station bulletin No. 44, Collage of Agriculture: 551p.
NMA (2019). Monthly Rainfall with Maximum and Minimum Temperature Data, Addis Ababa, Ethiopia.

Nega, E. and Heluf, G. (2013). Effect of land use changes and soil depth on soil organic matter, total nitrogen and available phosphorus contents of soils in Senbat watershed, Western Ethiopia. Asian Research Publishing Network Journal of Agricultural and Biological science, 8(3): 206-212.

Nega, E. (2006). Land use changes and their effects on soil physicochemical properties in Senbat Sub-Watershed, Western Ethiopia. MSc Thesis, Alemaya University, Alemaya. 89p.

Okebalama, C.B., Igwe, C.A., Okolo, C.C. (2017). Soil organic carbon levels in soils of contrasting land uses in southeastern Nigeria. Tropical and Subtropical Agroecosystem 20:493-504.

Olsen, S.R., Cole, C.V., Watanable, F.S., and Dean, L.A. (1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA Circular. 939: 1-19.

Salako, F.K., Tian, G., Kirchhoff, G., Akinbola, G.E. (2006). Soil particles in agricultural landscapes of a derived savanna in southwestern Nigeria and implications for selected soil properties. Geoderma 137: 90–105.

Solomon, D., Fritzschke, F., Tekalign, M., Lehmann, J., and Zech, W. (2002). Soil organic matter dynamics in the sub-humid Ethiopian highlands: Evidence from natural 13C abundance and particle-size fractionation. Soil Sci. Soc. Amr. J. 66: 969-978.

Teshome, Y., Sheleme, B., Kibebe, K. (2016). Characterization and classification of soils of Abobo area, Western Ethiopia. Applied and Environ. Soil Science. 1-16.

Teshome, Y., Heluf, G., Kibebe, K., Sheleme, B. (2013). Impacts of land use on selected physicochemical properties of soils of Abobo Area, Western Ethiopia. Agriculture, Forestry and Fisheries, 2(5): 177-183.

Tilahun, A., Endrias, G., and Takele, B. (2007). Reversing the degradation of arable land in Ethiopian highlands, Managing Africa’s soil. No. 23, IIED-London.

Walkley, A. and Black, C.A. (1934). An examination of the digestion method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37:29–38.

Yihenew, G. (2002). Selected physicochemical characteristics of soils Adet Research Center and its testing sites in North-Western Ethiopia. Ethiopian Journal of Natural Resources. 4(2): 199-215.

Yihenew, G. and Getachew, A. (2013). Effects of different land use systems on selected physicochemical properties of soils in Northwestern Ethiopia. Journal of Agric. Sci. 5 (4), 112–12.

Yitbarek, T., Gebrekidan, H., Kibret, K., Beyene, S. (2013). Impacts of land use on selected physicochemical properties of soils of Abobo Area, Western Ethiopia

Tables

Table 1. Slope categories of the study sub-watershed

| Slope Gradients(%) | Area Coverage (ha) | (% of total) |
|--------------------|--------------------|--------------|
| Flat (0-3)         | 374.1              | 18           |
| Gentle (3-8)       | 619.3              | 30           |
| Undulating (8-15)  | 590.1              | 29           |
| Moderately Steep (15-30) | 382.6       | 19           |
| Steep to Very Steep (>30) | 85.5          | 4            |

Table 2. Major LULC of the study sub-watershed
### Table 3. The mean values of selected soil physical properties under different LULC type

| LULC   | Soil physical parameters | BD (gm/cm³) | TP (%) | Sand (%) | Silt (%) | Clay (%) | STC   |
|--------|--------------------------|-------------|--------|----------|----------|----------|-------|
| CL     |                          | 1.06b       | 59.47b | 62.78c   | 23.22a   | 13.44a   | Sandy Loam |
| GL     |                          | 1.30c       | 51.29a | 55.22b   | 27.67b   | 17.10c   | Sandy Loam |
| FL     |                          | 0.81a       | 69.42c | 44.89a   | 31.33c   | 23.78c   | Loam   |
| P-value|                          | 0.00**      | 0.00** | 0.00**   | 0.00**   | 0.00**   |        |
| LSD(0.05)|                        | 0.10        | 4.40   | 5.00     | 1.80     | 3.11     |        |

Data in the same column followed by different letter are significantly different from each other at probability level of α = 0.01. **Indicates significant at α = 0.01 level, BD-Bulk Density, TP-Total Porosity, STC-Soil Textural Class, LSD-Least Significant Difference, CL-Cultivated Land, GL-Grazing Land, FL-Forest Land

### Table 4. The mean values of selected soil physical properties at combined LULC and slope gradients of the study area

| Soil physical parameters | LULC   | Slope gradients (%) | P-value | LSD (0.05) |
|--------------------------|--------|---------------------|---------|------------|
| BD (gm/cm³)              | CL     | 0.99bc              | 1.05bc  | 1.13cd     | 0.00**    | 0.19     |
|                          | GL     | 1.24de              | 1.29de  | 1.34e      |           |          |
|                          | FL     | 0.73a               | 0.80a   | 0.87ab     |           |          |
| %TP                      | CL     | 62.62cd             | 58.70bc | 57.09bc    |           | 7.63     |
|                          | GL     | 53.16ab             | 51.31ab | 49.38a     |           |          |
|                          | FL     | 72.05e              | 69.68de | 66.52d     |           |          |
| % Sand                   | CL     | 61.00cd             | 62.00cd | 65.33d     |           | 8.67     |
|                          | GL     | 54.67bc             | 55.33c  | 55.67c     |           |          |
|                          | FL     | 42.33a              | 46.33ab | 46.00ab    |           |          |
| % Silt                   | CL     | 24.33ab             | 24.00a  | 21.33a     |           | 3.17     |
|                          | GL     | 28.00cd             | 27.33bc | 27.67c     |           |          |
|                          | FL     | 32.00e              | 31.33e  | 31.00de    |           |          |
| % Clay                   | CL     | 15.00ab             | 14.00ab | 11.33a     |           | 5.48     |
|                          | GL     | 17.33bc             | 17.33bc | 16.67ab    |           |          |
|                          | FL     | 25.67d              | 22.67cd | 23.00d     |           |          |

Data in the same rows and columns followed by the different letter are significantly different from each other at probability level of α = 0.01 **. Indicates significant at the 0.01 level, BD-Bulk Density, TP-Total Porosity, LSD-Least Significant Difference, CL-Cultivated Land, GL-Grazing Land, FL-Forest Land

### Table 5. The mean values of selected soil chemical properties under different LULC of the study area

| Soil chemical properties | LULC   | % N   | % P   | % K   | % Al  | % Ca  | % Mg  | % Fe  | % Mn  |
|--------------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
|                          | CL     | 1.50  | 0.05  | 1.20  | 0.10  | 1.20  | 0.10  | 0.10  | 0.05  |
|                          | GL     | 1.50  | 0.05  | 1.20  | 0.10  | 1.20  | 0.10  | 0.10  | 0.05  |
|                          | FL     | 1.50  | 0.05  | 1.20  | 0.10  | 1.20  | 0.10  | 0.10  | 0.05  |
Table 6. The mean values of pH, EC, AvP, SOC, and TN at combined LULC and slope gradients of the study area

| Soil chemical parameters | LULC       | Slope gradients (%) | P-value | LSD (0.05) |
|--------------------------|------------|---------------------|---------|------------|
|                          | CL         | GL                  | FL      |            |
| pH (H₂O)                 | 5.34b      | 5.51b               | 5.57b   | 0.18ns     | 0.73       |
| pH CaCl₂                 | 4.74a      | 4.73a               | 5.01a   | 0.09ns     | 0.29       |
| pH (KCl)                 | 4.04a      | 4.14a               | 4.31a   | 0.48ns     | 0.28       |
| EC (ds/cm)               | 0.04a      | 0.02a               | 0.09b   | 0.00**     | 0.03       |
| Ca²⁺ (cmol(+)/Kg)        | 8.65a      | 7.17a               | 12.26b  | 0.01**     | 2.81       |
| Mg²⁺ (cmol(+)/Kg)        | 3.46a      | 2.39a               | 6.15b   | 0.00**     | 1.72       |
| K⁺ (cmol(+)/Kg)          | 0.46a      | 0.44a               | 0.56b   | 0.03*      | 0.08       |
| Na⁺ (cmol(+)/Kg)         | 0.28a      | 0.27a               | 0.33b   | 0.02*      | 0.03       |
| CEC (cmol(+)/Kg)         | 22.28a     | 21.22a              | 27.29b  | 0.04*      | 4.25       |
| % PBS                    | 56.16a     | 48.64a              | 69.18b  | 0.02*      | 9.58       |
| % ESP                    | 1.26a      | 1.31a               | 1.22a   | 0.63ns     | 0.22       |

Data in the same row and column of each variable followed by the same letter are not significantly different from each other at probability level of a = 0.05. ** and *-indicate a significant level at a =0.01 and 0.05, respectively. ns- non-significant, LULC-Land Use Land Cover, CL-Cultivated Land, GL-Grazing Land, FL-Forest Land. LSD-Least Significant Difference, pH-Power of Hydrogen, EC-Electrical Conductivity, Ca- Calcium, Mg-Magnesium, K-Potassium, Na-Sodium, CEC-Cation Exchangeable Capacity, PBS-Percentage Base, ESP-Exchangeable sodium percentage.

Table 7. The mean values of basic cations, CEC, PBS, and ESP from the combination of LULC and slope gradients of the study area

| Soil chemical parameters | LULC       | Slope gradients (%) | P-value | LSD (0.05) |
|--------------------------|------------|---------------------|---------|------------|
|                          | CL         | GL                  | FL      |            |
| pH (H₂O)                 | 5.42abc    | 5.33bc              | 5.27ac  | 0.176ns    | 0.30       |
| pH CaCl₂                 | 5.62ab     | 5.46abc             | 5.45abc |            |            |
| pH (KCl)                 | 5.69a      | 5.51abc             | 5.49abc |            |            |
| EC (ds/cm)               | 0.08abc    | 0.02d               | 0.02cd  | 0.02*      | 0.05       |
| AvP (ppm)                | 5.59c      | 4.61de              | 3.53g   | 0.00**     | 0.75       |
| % SOC                    | 2.86bcd    | 2.61cd              | 2.12d   | 0.01**     | 0.87       |
| % TN                     | 0.25bc     | 0.23bc              | 0.18c   | 0.01**     | 0.07       |

Data in the same row and column of each variable followed by the same letter are not significantly different from each other at probability level of a = 0.05. ** and *-indicate significant level at a =0.01 and 0.05, respectively. ns- non-significant, LSD-Least Significant Difference, pH-Power of Hydrogen, EC-Electrical Conductivity, AvP-Available Phosphorous, OC-Organic Carbon, TN-Total Nitrogen, LULC-Land Use Land Cover, CL-Cultivated Land, GL-Grazing Land, FL-Forest Land.
### Soil chemical parameters

| Parameter          | LULC | Slope gradients (%) | P-value | LSD (0.05) |
|--------------------|------|---------------------|---------|------------|
| Ca²⁺ (cmol(+)/Kg)  |      |                     |         |            |
| CL                 | 11.64<sup>ab</sup> | 7.20<sup>bc</sup> | 7.13<sup>bc</sup> | 0.01** | 4.88        |
| GL                 | 8.31<sup>bc</sup>  | 7.86<sup>bc</sup> | 5.34<sup>c</sup>  |         |              |
| FL                 | 15.93<sup>a</sup>  | 10.97<sup>ab</sup> | 9.88<sup>bc</sup> |         |              |
| Mg²⁺ (cmol(+)/Kg)  |      |                     |         |            |
| CL                 | 5.56<sup>bc</sup>  | 2.51<sup>d</sup>  | 2.32<sup>d</sup>  | 0.01** | 2.99        |
| GL                 | 2.84<sup>cd</sup>  | 2.42<sup>d</sup>  | 1.89<sup>d</sup>  |         |              |
| FL                 | 8.79<sup>a</sup>   | 6.41<sup>ab</sup> | 3.25<sup>cd</sup> |         |              |
| K⁺ (cmol(+)/Kg)    |      |                     |         |            |
| CL                 | 0.52<sup>bc</sup>  | 0.42<sup>bc</sup> | 0.44<sup>bc</sup> | 0.03*  | 0.15        |
| GL                 | 0.52<sup>bc</sup>  | 0.43<sup>bc</sup> | 0.36<sup>c</sup>  |         |              |
| FL                 | 0.65<sup>a</sup>   | 0.53<sup>bc</sup> | 0.51<sup>ab</sup> |         |              |
| Na⁺ (cmol(+)/Kg)   |      |                     |         |            |
| CL                 | 0.29<sup>bc</sup>  | 0.28<sup>bc</sup> | 0.26<sup>c</sup>  | 0.02*  | 0.06        |
| GL                 | 0.29<sup>bc</sup>  | 0.25<sup>c</sup>  | 0.25<sup>c</sup>  |         |              |
| FL                 | 0.37<sup>a</sup>   | 0.33<sup>ab</sup> | 0.28<sup>bc</sup> |         |              |
| % PBS              |      |                     |         |            |
| CL                 | 70.99<sup>ab</sup> | 48.86<sup>c</sup> | 48.63<sup>c</sup> | 0.02** | 16.59       |
| GL                 | 47.66<sup>c</sup>  | 52.35<sup>c</sup> | 45.92<sup>c</sup> |         |              |
| FL                 | 80.90<sup>a</sup>  | 70.94<sup>ab</sup> | 55.69<sup>bc</sup> |         |              |
| % ESP              |      |                     |         |            |
| CL                 | 1.22<sup>a</sup>   | 1.30<sup>a</sup>  | 1.26<sup>a</sup>  | 0.63<sup>ns</sup> | 0.39        |
| GL                 | 1.18<sup>a</sup>   | 1.21<sup>a</sup>  | 1.53<sup>a</sup>  |         |              |
| FL                 | 1.19<sup>a</sup>   | 1.32<sup>a</sup>  | 1.15<sup>a</sup>  |         |              |

Data in the same row and column followed by the same letter are not significantly different from each other at Probability level of $\alpha = 0.05$. ** and * -Indicate significant at $\alpha = 0.01$ and 0.05 level, respectively. **-non-significant. LSD -Least Significant Difference, Ca-Calcium, Mg-Magnesium, K-Potassium, Na-Sodium, PBS-Percentage Base Saturation, ESP-Exchangeable Sodium Percentage.

### Table 8. Pearson's correlation matrix for selected soil physicochemical properties of the study area

|          | BD    | TP    | Sand  | Silt  | Clay  | pH    | EC    | AvP   | OC    | TN    | Ca²⁺  | Mg²⁺  | K⁺    | Na⁺   | CEC   |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| BD       | 1     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| TP       | -0.99** | 1     |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Sand     | 0.60** | -0.62** | 1     |       |       |       |       |       |       |       |       |       |       |       |       |
| Silt     | -0.47  | 0.49** | -0.97** | 1     |       |       |       |       |       |       |       |       |       |       |       |
| Clay     | -0.69** | 0.70** | -0.97** | 1     |       |       |       |       |       |       |       |       |       |       |       |
| pH       | -0.31  | 0.34  | -0.53** | 0.54** | 0.53** | 1     |       |       |       |       |       |       |       |       |       |
| EC       | -0.86** | 0.87** | -0.98** | 0.59** | 0.74** | 0.39** | 1     |       |       |       |       |       |       |       |       |
| AvP      | -0.82** | 0.82** | -0.73** | 0.69** | 0.75** | 0.41** | 0.76** | 1     |       |       |       |       |       |       |       |
| OC       | -0.62** | 0.62** | -0.83** | 0.83** | 0.84** | 0.61** | 0.65** | 0.67** | 1     |       |       |       |       |       |       |
| TN       | -0.61** | 0.62** | -0.82** | 0.82** | 0.84** | 0.62** | 0.65** | 0.67** | 1     | 1.00** |       |       |       |       |       |
| Ca²⁺     | -0.72** | 0.73** | -0.57** | 0.49** | 0.64** | 0.38** | 0.89** | 0.65** | 0.62** | 0.62** | 1     |       |       |       |       |
| Mg²⁺     | -0.75** | 0.74** | -0.98** | 0.48** | 0.62** | 0.35** | 0.89** | 0.86** | 0.61** | 0.61** | 0.80** | 1     |       |       |       |
| K⁺       | -0.65** | 0.65** | -0.56** | 0.45** | 0.64** | 0.32** | 0.80** | 0.63** | 0.64** | 0.64** | 0.89** | 0.83** | 0.98** | 0.78** | 1     |
| Na⁺      | -0.69** | 0.69** | -0.55** | 0.51** | 0.60** | 0.45** | 0.75** | 0.62** | 0.72** | 0.72** | 0.76** | 0.82** | 0.76** | 1     |       |
| CEC      | -0.66** | 0.65** | -0.54** | 0.48** | 0.61** | 0.32** | 0.79** | 0.63** | 0.64** | 0.64** | 0.89** | 0.83** | 0.98** | 0.78** | 1     |
| PBS      | -0.71** | 0.72** | -0.49** | 0.43** | 0.56** | 0.39** | 0.86** | 0.66** | 0.52** | 0.52** | 0.87** | 0.89** | 0.63** | 0.67** | 0.61** | 1     |
| ESP      | 0.20   | -0.20 | 0.01   | -0.08 | 0.15  | 0.14  | -0.29 | -0.27 | -0.15 | -0.14 | -0.42 | -0.26 | -0.59** | -0.02 | -0.82** | -0.10 | 1     |

Note ** and * indicate correlation is significant at $\alpha = 0.01$ and 0.05 level, respectively. BD-Bulk Density, TP-Total Porosity, pH-Power of Hydrogen, EC-Electrical Conductivity, AvP-Available Phosphorous, OC-Organic Carbon, TN-Total Nitrogen, Ca-Calcium, Mg-Magnesium, K-Potassium, Na-Sodium, CEC-Cation Exchangeable Capacity, PBS-Percentage Base Saturation, ESP-Exchangeable Sodium Percentage.
Figures

Figure 1
Location map of the study area

Figure 2
Soil sampling location map of the study sub-watershed

Data collection methods
Figure 3

Effects of LULC on SOC, TN, and AvP of the study sub-watershed

Note: Bars followed by the same letter are not significantly different from each other at probability level of $a = 0.05$ according to Tukey test. FL-Forest Land, GL-Grazing Land, and CL-Cultivated Land.

Figure 4
Interaction of slope by LULC mean values of CEC in the study area

Note: Bars followed by the same letter are not significantly different from each other at probability level of $a = 0.05$ according to Tukey test. FL-Forest Land, GL-Grazing Land, and CL-Cultivated Land