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Research article

Effects of land-use-cover-changes on selected soil physicochemical properties along slope position, Coka watershed, Southern Ethiopia

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ABSTRACT

Land-use changes along slope position can have a major positive or negative impact on soil environment and agricultural productivity. Relevant information to understand the negative effect of land-use change and slope variability on soil property is a vital element to monitor, plan and make the decision to improve productivity and restore the environment. The aim was to examine the effects of land-use-cover-changes along slope position on the selected soil physicochemical properties in the Coka watershed. Soil samples were gathered from 5 nearby land uses, namely forestland, grassland, bushland, cultivated land, and bare-land, and 3 slope positions (upper, middle, and lower slope) at 0–30 cm soil-depth, analyzed in Hawassa University Soil testing laboratory. The results show that the highest field capacity, available water-holding, porosity, silt, nitrogen, pH-value, cation exchange capacity, sodium, magnesium, and calcium were in forestlands and lower-slope. The highest water-permanent-wilting-point, organic-carbon, soil-organic-matter, and potassium were in bushland; bulk density was in bare land while the highest clay and available-phosphorus were revealed in cultivated land and lower slope. Most soil properties showed a positive correlation with each other except bulk density which has a negative correlation with all soil properties. Generally, cultivated land and bare land have the least concentration in most soil properties which indicates of increasing degradation rate in the area. Thus, soil-organic-matter and other yield-limiting nutrients should be improved in cultivated land to maximize productivity by using an integrated implementation of soil fertility management through cover crops and rotation, compost, manures, and minimum tillage; and amending soil pH-value by liming.

1. Introduction

Spatial heterogeneity in soil properties is closely associated with the land-use-cover (LULC) changes and their management practices [1]. Soil properties play a central role in sustaining soil quality, environmental quality, and crop production in general [2]. Soil physic-chemical properties have been remarkably impacted by changing aspects of LULC modifications. Transformations of forestland to cultivated land affect soil nutrient availability and organic matter which could hamper the addition of litter [3], rise erosion rates [4], lead to deterioration in soil value, and loss of biodiversity [1], and speed up soil degradation [5]. Zhang et al. [6]

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have revealed that conversation of forestlands to other land-use systems enhanced soil deterioration, in China. As stated by Ref. [7], pH, total N, av.P, SOM, CEC, and cations contents in soil diminished significantly with the change of forestland to plantations in China. Cultivated soils have lower water retaining capacity and porosity but higher bulk-density than forestland and grassland [8,9]. Similarly, LULC fluctuations considerably influenced the soil silt, sand, and clay portions in Cameroon [10,11]. Thus, the humiliation of topsoil productivity and fertility because of the transformation from a natural ecosystem to farmland in a different location in the world. Land resources have been used to encounter the social, material, spiritual, and cultural wants of human beings.

In Ethiopia, many empirical studies have shown that environmental factors and fast population growth lead to the alteration of forestland and grassland into cultivated land. For instance, the transfiguration of grassland and forestland into cultivated land occurred due to human-induced and environmental driving factors [12]. Anthropogenic LULC changes have contributed to soil loss by deteriorating the physicochemical properties of soil and making the ecosystem more susceptible to land degradation [13]. The soil degradation could be initiated by both off-site and on-site land-use variations in which cultivated land faced the highest average annual soil erosion rate (42 $Mtha^{-1}$) than grassland (5 $Mtha^{-1}$); an estimated economic loss of USD 1 billion/year, Ethiopia. Different empirical studies confirmed these in Ethiopia in various parts (for instance, Refs. [12,14]. Defending soil worsening is essential to keep having services from the soils [15]. According to Ref. [16], LULC change was seriously influenced by slope class which is among the driving forces to influence soil properties. Similarly [16,17], argued that more forests on steep slopes were observed due to the inaccessibility of the area for anthropological activities which is dissimilar to the gentle and moderate slopes.

Sound effects of land-use changes and slope positions on selected soil properties have become an increasing focus of research topics due to their significance in affecting the value of ecosystem services. For instance Ref. [18], said that increasing in BD and a reduction in exchangeable cations, CEC contents, SOM, and total N following the transformation of woodlands to farmland and grassland in Ethiopia. The pH value and the content of SOM declined in crop-land than in forestland in northwestern Ethiopia [18]. Soil exchangeable bases, cation exchangeable capacity, and soil micronutrients were varied by land-use-cover changes [9]. [19] argued that upper slopes showed more soil acidity than other slope classes which is related to soil properties.

Coka watershed community faced food insecurity due to low agricultural productivity for last long periods [20], the occurrence of climate alteration and unwise use of natural resources [21], and continuous population growth [22]. The present study area, the Coaka

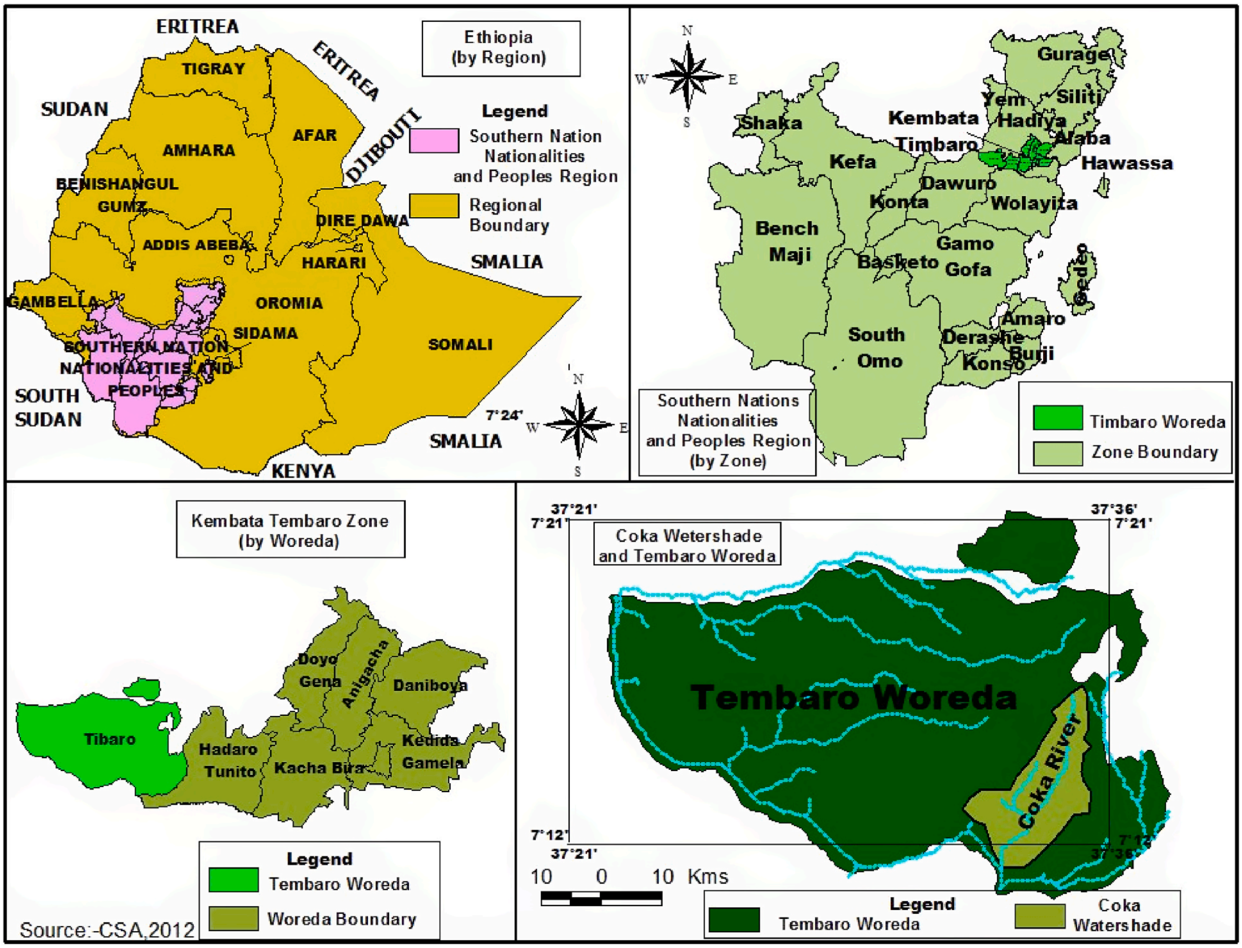

Fig. 1. Location map of the Coka watershed, Southern Ethiopia.

watershed, has no well-organized information and data about LULC dynamics and topographic attributes and their impact, soil properties as linked to LULC change and topographic attributes and their contribution to soil physicochemical properties, environmental degradation (soil erosion) and socioeconomic influences. Therefore, this study focused on the environmental problems prevailing in the study watershed with emphasis on LULC dynamics and topographic attributes on soil characteristics and its cause, nature, consequence, and management practices implemented to reverse the problem. The Coka watershed is facing severe land degradation e.g. soil quality deterioration, deforestation, the occurrence of drought, and chronic and transitory food insecurity. This is expected to be linked to inappropriate misunderstanding of the need for efficient LULC change management practices, and lack of knowledge about LULC change impact.

Therefore, this gap put forward the need for empirical investigation on the effects of LULC changes and topographic factors on soil properties and consequent degradation at the watershed level. To this end, very limited work was done on the effects of LULC changes along slope classes on dynamics of soil properties which have implications for land degradation, crop production, food security, and land management strategies in the area. Therefore, the objective of this study was to provide new insights into the quantitative relationships among effects of LULC change on selected soil physicochemical properties along slope position and the influence on their ecosystem services.

2. Materials and methods

2.1. Study area description

Geographically location of Coka watershed is between 7°12′10″N - 7°18′20″N and 37°31′0″E – 37°34′25″E about 195 km from Hawassa city and, 330 km south west of Addis Ababa. Its' total area is about 3731 ha and its' altitude ranges from 771 to 2524 m.a.s.l. (Fig., 1). The district slope gradient ranges between gently (2%) to very steep (>60%) (Figs. 1–3).

The area's rainfall variability observed between 1988 and 2021 mean annual rainfall is 1330.25 mm and its' min and max temperature is 9.9 °C and 30.0 °C, respectively [23]. Bimodal rainfall seasonal rotation major (*Kiremt*) and small (*belg*) occur in the site. February to April faces short rainfalls while between June to September appears the main rainy period which implements for agricultural activities and causes erosion.

The drainage of the study watershed into the Coka stream, forming a tributary of the Omo River that flows into L. Turkana, south of Ethiopia bordering Kenya. Moderate to deeper soils are found on the moderate to gentler slopes and shallower soils are found on steeper slopes in the Coka watershed. The communities are engaged in the mixed agricultural system that involves crop cultivation and livestock rearing is common. Moreover, the site comprises cultivated lands, forestland, bushland, grassland, and bare-lands.

The total population of the study watershed showed growth from 12493 in 1994 to 22,194 in 2021 [24]. This reveals that it increased by 56.3% during the 1994–2021 period. Suggesting, the presence of a dramatic increment of the population over the 30 years in need of food, construction material, fuel, and income in the study watershed.

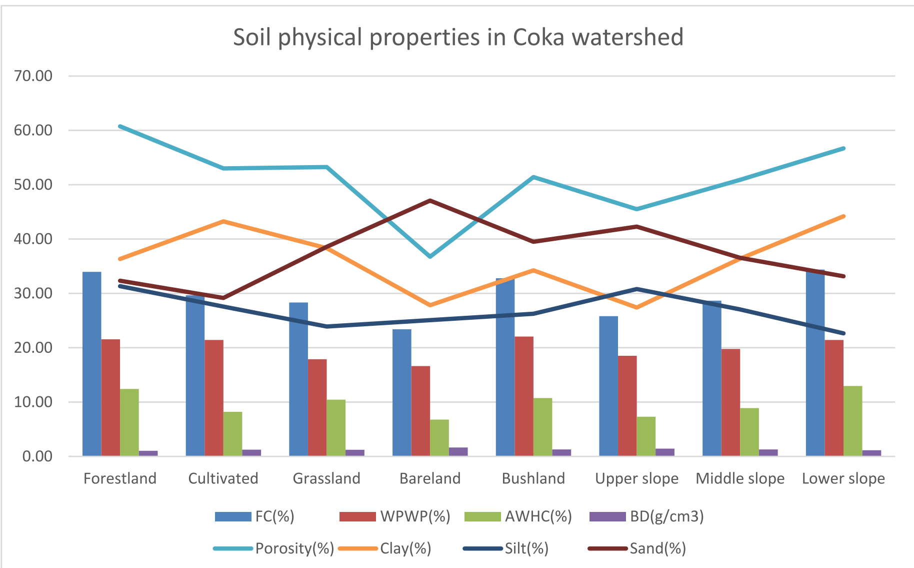

Fig. 2. Effect of LULC change along slope-position on soil physical properties.

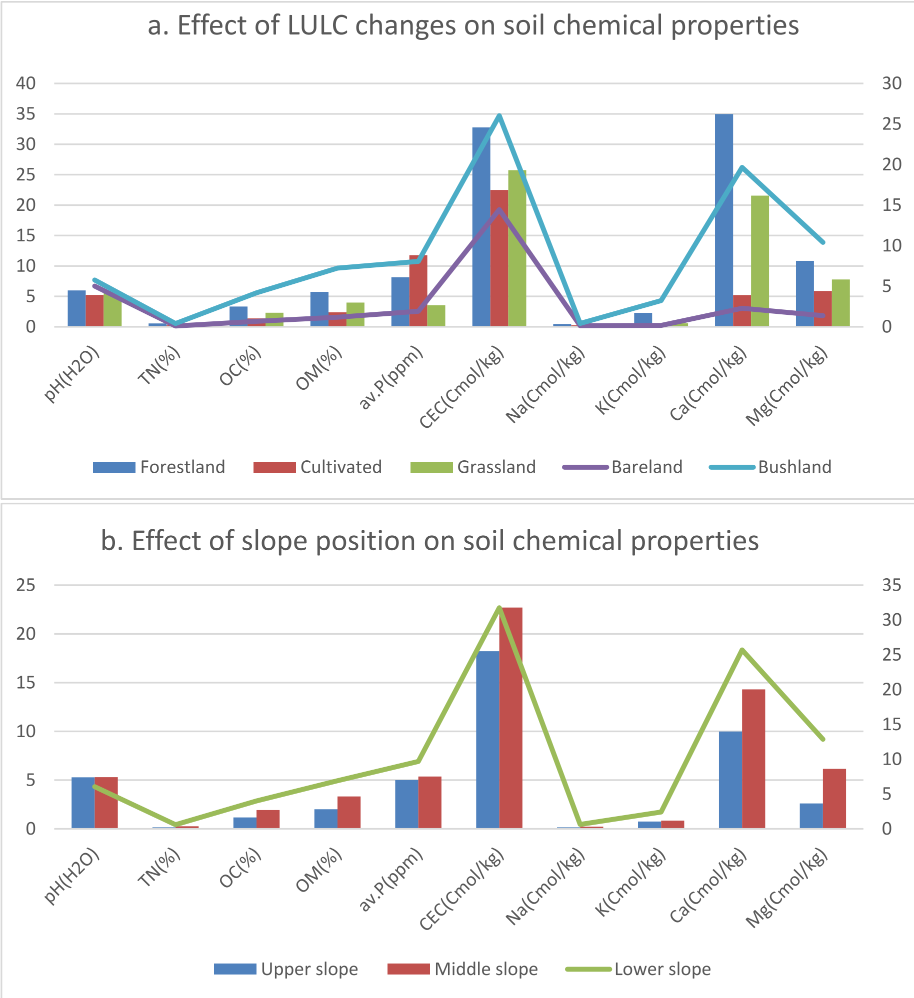

Fig. 3. Effect of LULC change and slope position on soil chemical properties.

2.2. Soil sampling procedures and laboratory analysis

2.2.1. Soil sampling procedures

An investigation survey occurred to classify soil representative sampling plots subsequently corresponding transects were laid along contour lines. Separate composite samples were gathered to evaluate the effect of recognized and dominant land-use-cover types and differences in topographic characteristics on soil selective properties. The topographic attributes were categorized into 3 landscape (slope) positions, upper-slope (>30%), middle-slope (10–30%) and lower-slope (0–10%). The upper-slope position represents the upper and lower interfluves which receive no overland or little flow but could donate overflow to the down-slope position. The middle slope encompasses shoulder, lower, and upper linear which gets overland flow from the upper slope and gives runoff to the lower slope. The lower slope symbolizes the base of the hill slope. Representative samples of soil were assembled from all landscape sites. Representative soil sampling was conducted immediately after the harvesting period, which was taken from major recognized LULC types and slope classes. The representative samples were randomly extracted 60 soil samples (disturbed) and 60 soil samples (undisturbed) for required soil analysis from the surface soil (0–30 cm depth) using an augur for disturbed soil and a core sampler of known volume for undisturbed soil. The disturbed samples were mixed in a tray and homogenized into single composite samples for laboratory analysis. They were air-dried, grounded, and passed through a 2 mm sieve for laboratory analysis. Samples were analyzed for their soil physical and chemical properties.

2.2.2. Soil test analysis

Total samples of soil were collected (4 soil samples replicates x 3 topographic attributes x 5 LULC types) to examine their properties. Standard soil analysis procedures were followed on both undisturbed and disturbed soil samples. Soil-bulk-density (BD) was measured in undisturbed samples taken with a known volume of core ring samplers. Soil water retaining at field capacity (FC) (−0.33 bar) and permanent-wilting-point (PWP) (−15 bars) were tested by using the pressure plate method from undisturbed samples. The available water-holding capacity (WHC) was estimated by deducting PWP from FC [25]. Total porosity was obtained from the values of BD divided by an assumed particle density (PD) of 2.65 g/cm^3 and multiplying the result by 100. Hence, Total porosity % = (1-BD/PD) *100. Particles-size-distributions were calculated by the Bouyoucous hydrometer method [26], and textural classes were made following the USDA system of textural classification. Soil pH values were measured in 1:2.5 soil–water ratio suspensions. Organic carbon (OC) contents of soil were estimated using the [27] wet digestion method. Contents of OM (organic matter) were calculated by multiplying the content of OC by a factor of 1.724. Total nitrogen (TN) was analyzed using the micro-Kjeldahl digestion, distillation, and titration procedure as stated by Ref. [28]. Available phosphorus (av.P) was estimated by following Olsen's phosphorus testing method [29]. Exchangeable-bases (Ca, Mg, K and Na) and cation-exchange capacity (CEC) were analyzed by ammonium acetate method at pH 7 [30], where potassium (K) and sodium (Na) in their extracts were detected by flame photometry, and exchangeable calcium (Ca) and magnesium (Mg) were read by an atomic-absorption spectrophotometer (AAS).

2.2.3. Statistical analysis

The data was entered into IBM statistical package for social sciences (SPSS) software version 26 windows. One-way ANOVA was used to assess the statistical significance of the effect LULC type and slope classes on selected soil physicochemical properties by LSD post hoc multiple comparisons test at the 0.05 level. The main and interaction effects were done by using the multivariate tests at the 0.05 level.

3. Result and discussion

3.1. Effects of land-use changes and slope-positions on selected physical properties

According to the multivariate test results (Table 1), land-use-cover (LULC) systems and slope classes were revealed statistically significant ($P < 0.01$) main effects on soil physical properties as well as the interaction effect. Using the multivariate tests, the main effects of land use and slope positions were statistically significant ($P < 0.001$), demonstrating the selected physical properties of soil were varied significantly by land uses and slope positions. The multivariate interactional effect of slope-position and LULC system was statistically significant ($P = 0.00$) (Table 1).

According to the ANOVA test and mean analysis (Fig. 2, Table 2), physical properties of soil were observed statistically significant mean difference ($P < 0.05$) in LULC types and slope-position. The highest significant mean difference for FC in forest and lower-slope (mean = 33.98, 34.40%), PWP in bushland and lower-slope (22.06, 21.44%), AWHC in forestlands and lower-slope (12.43, 12.96%), BD in bare-land and upper-slope (1.65, 1.43 g/cm^3), porosity in forest-land and lower-slope (60.75, 56.70%), clay in cultivated-land and lower-slope (43.25, 44.20%), silt in forest and upper-slope (31.33, 30.80%) and sand in bare-land and upper-slope (47.08, 42.30%), silt/clay ratio in bare-land and upper-position were analyzed, respectively. According to bivariate correlation analysis result, FC, PWP, WHC, porosity and clay particles are positively and significantly correlated ($r = 0.79^{**}, 0.86^{**}, 0.81^{**}$ and 0.64^{**}) and silt, sand and BD are negatively correlated ($r = -0.81, -0.18$ and -0.65), respectively. Statistically significant ($P < 0.05$) changes were evaluated for the effects of the LULC-types and slope classes on the selected soil quality. The capacity of water retaining was increased in the following trend: bare-land < cultivated-land < grassland < bushland < forestland. The decreasing trend of clay observed from cultivated-land to bare-land (cultivated-land > grassland > forestland > bushland > bare-land). The BD was showed increasing trend from forestland to bare-land (forest < grassland = cultivated-land < bushland < bare-land) and lower-slope to upper-slope (lower < middle < upper-slope). On average, BD showed the presence of workable soil, less compacted, good crop portability, and water movement except in bare land. The result of porosity showed that the soil of the study area was good for aeration and water retaining capacity. The mean soil physical properties in the area showed that soils in all LULC-types and slope classes have been in a good range for agricultural productivity. According to Ref. [31], WHC and total porosity were rated from medium to high in all land-use systems and slope classes in the Coka watershed. This finding agreed with the investigation of [9] reported that soil BD, soil porosity, and WHC were affected by land-use-cover changes.

3.2. Effects of land-use changes and slope-position on soil chemical properties

As analyzed by multivariate test, both main effects and interaction effects of LULC type and slope-positions were divulged statistically significant ($P < 0.001$) on selected chemical properties of soil in the Coka watershed. As mean and ANOVA analysis Fig. 3a and b and Table 3, soil pH under forestland (5.98) and lower-slope (6.05) had significantly ($P < 0.05$) higher than bushland > grassland > cultivated > bare-land and middle-slope > upper-slope. According to the rating of [32], soil pH values of the study area ranged from strongly acidic (<5.5) to moderately acidic (5.6–6.5). This indicates that it might be due to applied inorganic fertilizers, precipitation variability, farming practice, accelerated erosion, microbial oxidation, cation depletion, and steepness of the land. The

Table 1
Multivariate test analysis of main and interaction of LULC types and slope-position.

Effect	Tests	Value	F	Hypothesis df	Error df	Sig.
LULC Type	Wilks' Lambda	0.00	13.33	40.00	138.36	0.00
Slope position	Wilks' Lambda	0.02	25.493b	20.00	72.00	0.00
LULC Type * Slope position	Wilks' Lambda	0.01	2.78	80.00	236.90	0.00

Table 2
ANOVA analysis of LULC types and slope position on selected soil physical properties.

LULC Type	FC (%)	PWP (%)	WHC (%)	BD(g/cm3)	P (%)	Clay (%)	Silt (%)	Silt/Clay	Sand (%)
Forestland	33.98	21.55	12.43	1.05	60.75	36.33	31.33	0.86	32.33
Cultivated	29.65	21.44	8.21	1.24	53.00	43.25	27.58	0.64	29.17
Grassland	28.33	17.88	10.45	1.24	53.25	38.33	23.92	0.62	38.58
Bare-land	23.40	16.63	6.78	1.65	36.75	27.83	25.08	0.90	47.08
Bushland	32.79	22.06	10.73	1.28	51.42	34.25	26.25	0.77	39.50
F	10.85	14.09	5.67	29.28	29.84	4.72	4.66	4.68	14.15
Sig.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Slope position									
Upper slope	25.82	18.52	7.30	1.43	45.50	27.40	30.80	1.12	42.30
Middle slope	28.68	19.78	8.90	1.30	50.90	36.40	27.05	0.74	36.55
Lower slope	34.40	21.44	12.96	1.15	56.70	44.20	22.65	0.51	33.15
F	19.33	4.91	20.47	8.64	8.65	25.36	21.39	23.37	6.57
Sig.	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

**FC-field capacity, PWP-water permanent wilting point, WHC-available water holding capacity, BD-bulk density, P-porosity.

Table 3
Effect of LULC types and slope position on selected soil chemical properties.

LULC Type	pH (H_2O)	TN (%)	OC (%)	OM (%)	av.P (ppm)	CEC (Cmol/kg)	Na (Cmol/kg)	K (Cmol/kg)	Ca (Cmol/kg)	Mg (Cmol/kg)
Forestland	5.98	0.57	3.33	5.74	8.14	32.78	0.47	2.28	34.97	10.85
Cultivated	5.25	0.25	1.38	2.38	11.78	22.50	0.26	0.40	5.21	5.90
Grassland	5.73	0.37	2.31	3.98	3.54	25.75	0.39	0.59	21.56	7.79
Bare land	5.02	0.10	0.68	1.18	1.91	14.45	0.15	0.18	2.29	1.38
Bushland	5.78	0.41	4.20	7.23	8.07	26.03	0.41	3.24	19.65	10.41
F	7.20	6.33	10.6	10.6	17.90	10.53	2.86	9.86	27.12	7.12
Sig.	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Slope position										
Upper slope	5.29	0.15	1.17	2.01	5.00	18.22	0.15	0.75	9.98	2.61
Middle slope	5.30	0.26	1.93	3.33	5.37	22.71	0.22	0.84	14.31	6.15
Lower slope	6.05	0.60	4.00	6.90	9.68	31.76	0.63	2.41	25.70	12.86
F	14.68	24.3	17.5	17.6	7.27	17.52	36.71	5.66	7.28	29.40
Sig.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00

finding is confirmed by Refs. [11,33] pH-value in cultivated-land and/or bare-land might have been lowered as a result of the removal of basic cation in Ethiopia.

Soils under forestland (0.57%) and lower-slope (0.60%) position contained more TN than bare-land < cultivated-land < grassland < bushland and upper-slope < middle-slope (Fig. 3a and b; Table 3). According to Ref. [32] rating, TN is categorized as very low in bare land and very high in forest lands. Depletions of TN in cultivated-land and bare-land were estimated to be 56% and 83% in comparison to forestland and also under lower-slope was increased by 57% and 75% compared to middle-slope and upper-slope positions, respectively. This considerable increase of TN in forests and low-slope could be attributed due to the addition of plant residues and removal of nutrient-rich topsoil from upper and middle-slopes to lower-slope by soil erosion, which is agreed with the study conducted by Refs. [3,34].

The result showed significant ($P < 0.01$) mean difference on soil OC content and organic matter ranged from (0.68%, 1.18%) under bare-land to (4.20%, 7.23%) under bushland and (1.17%, 2.01%) under upper-slope to (4.00%, 6.90%) under lower-slope, respectively. The concentration of SOM under bushland showed increment by 67% and 84% concerning cultivated-land and bare-land and under lower slope increased by 52% and 71% compared to middle-slope and upper-slope, respectively. The trend for SOM showed the following order: bushland > forestland > grassland > cultivated-land > bare-land and lower-slope > middle-slope > upper-slope. According to Ref. [32] rating, SOM is categorized as very low in bare-land, low under cultivated land, optimum in grassland and forestland, and high in bushland. The addition of vegetation residues under bushland and washing of topsoil from the upper and middle slope to the lower slope could be attributed to the increased SOM in bushland and lower slope. The low SOM and OC in cultivated and bare-land and upper-slope might be because of continuous cultivation, limited use of organic residue, and accelerated erosion. The same result was found by Ref. [11], SOM was varied by land-use-cover changes.

Cultivated-land (11.78 ppm) and lower-slope (9.68 ppm) had statistically significantly ($P < 0.001$) higher available phosphorus as compared to the remaining LULC types and slope positions. The content of av.P under cultivated land was increased by 84% in comparison with bare land and which in lower-slope was higher by 48% than in the upper slope. According to Ref. [32] rating, av.P was categorized as very low which is below a critical level. The decreasing trend for content of av.P in the order: cultivate-land > forestland > bushland > grassland > bare-land and lower > middle > upper-slope. The av.P content in cultivated land and lower slope seemed to be considerably higher than the rest land-use-types and slope-position which might be due to applied diammonium phosphate (DAP) fertilizer in the cultivated land and removal of topsoil from upper and middle-slope and also deposited in the lower-slope. According to Ref. [35] reported that Cultivated-land contained the highest av. P than other LULC classes.

The analysis divulges that higher CEC, Na, Ca, and Mg under forestland (32.78, 0.47, 34.97, 10.85 Cmol/kg) and lower-slope (31.76, 0.63, 25.70, 12.86 Cmol/kg) were observed, respectively (Fig. 3a and b; Table 3). The CEC and exchangeable bases (Na, Ca, and Mg) showed statistically significant ($P < 0.01$) differences among land-use-cover changes and slope classes in the order: bare-land < cultivated-land < grassland < bushland and upper-slope < middle-slope. This finding corresponded with the finding conducted by Ref. [9]. Potassium (K) was observed more amount in bushland (3.24 Cmol/kg) and lower-slope (2.41 Cmol/kg) than in the remaining LULC-types and slope positions. Generally, forestland had significantly ($P < 0.01$) higher selected soil chemical properties than other LULC-types except for cultivated land for available phosphorus and bushland for potassium. From the above analysis, exchangeable cations in sum-up showed an increasing trend in the order Na < K < Mg < Ca.

An analysis of the bivariate two-tailed test, pH with TN, OC, OM, av.P, CEC, Mg, Ca, K, and Na revealed a strong positive correlation. The lower slope showed statistically significantly ($P < 0.01$) more content of selected soil chemical properties than upper slope and middle-slope positions (Fig. 3a and b, Table 3). Based on the rating of [31], CEC, K, Ca, and Mg was categorized under medium to high in all slope classes and land-use types except Na was low in all land uses and slope classes, K and Ca were low in bare land. The contents of exchangeable bases imply that the presence of variation among land-use changes and slope classes could be due to land use types, slope position, cultivation intensity, and parent-material and particle size distribution. As reported by Ref. [9], exchangeable bases varied among land-use types due to different reasons. The exchangeable Na content implies that it could not cause alkalinity or sodicity problems for crop production due to its below critical level (1 Cmol(+) Kg^{-1}) as rated by Ref. [36]. K, Mg and Ca contents was higher than critical level of 0.2 Cmol (+) Kg^{-1}, 0.5 Cmol (+) Kg^{-1} and 0.2 Cmol (+) Kg^{-1}recommended for crop productivity by Ref. [36]. This divulges that soil K, Mg, and Ca content is sufficient without external input application in the form of fertilizer. According to Ref. [37], the critical level of soil exchangeable bases (K, Ca and Mg) should be ranged for optimum crop production from 0.28 to 0.51, 1.25–2.5, and 0.25–0.5 cmol (+) kg^{-1}, respectively. The ratio of K/Mg and Ca/Mg in the Coka watershed was 0.18 and 2.31, hence it is within the acceptable range for crop production, respectively.

4. Conclusion

Land-use-cover (LULC) types and/or slope position could be the cause for the unevenness of soil physicochemical properties from place to place in the Coka watershed. The soil of the present study area had good status of physical properties for crop production and portability and also to enhance water holding capacities such as FC, PWP, WHC, BD, porosity, and textural classes in all LULC changes along slope positions. The soil pH values have ranged from moderately acidic to strongly acidic in all land-use systems with slope positions. Available phosphorus was low in all LULC changes and slope positions. The soil chemical properties in the study area had sufficient OM, OC, TN, and exchangeable cations (Mg, Ca, K and Na) for good crop production in forestland, bushland, and grassland with the lower-slope position. Though, TN, OC, and OM are low in bare lands and cultivated lands with upper-slope and middle-slope.

Thus, the management of soil quality should give attention to maintaining and improving the level of soil OC, OM, TN, av.P, and pH values to maximize soil productivity. This could be by farmers practicing crop rotation, applying inorganic fertilizers and manures, minimizing crop residue removal, and using amendments to optimize soil acidity. Therefore, farmers should practice combining the use of inorganic and organic fertilizer applications in an integrated soil fertility management approach to maximize crop productivity and to solve the food insecurity problem in the present study area.

Author contribution statement

Tadele Buraka: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Eyasu Elias: Alemu Lelago: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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