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Assessing the Effects of Land-Use and Land Cover Change and Topography on Soil Fertility in Melka Wakena Catchment of Sub-Upper Wabe-Shebelle Watershed, South Eastern Ethiopia

Hussein Hayicho*, Mersha Alemu, Haji Kedir

Department of Geography and Environmental Studies, Madda Walabu University, Bale Robe, Ethiopia
Email: *hussienhayicho2000@gmail.com

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Abstract

This study was conducted in Melka Wakena catchment; south eastern Ethiopia to assess land use/cover change (LULCC) and topographic elevation effect on selected soil quality/fertility parameters. 144 soil samples collected from 0 - 30 cm depth under three land cover types across three elevation gradients were analysed for selected soil quality/fertility parameters. Data were statistically analyzed using analysis of variance (ANOVA) and mean comparisons were made using Least Significant Difference (LSD). The soil properties examined generally showed significant variations with respect to land-use/land cover changes and elevation. Soil particles, soil organic carbon, total N, pH, available phosphorus, potassium and calcium content significantly decreased as forestland is converted into cropland/grassland. Heaviest soil deterioration was recorded in soils under cropland and followed by grassland soils. The conversion of natural forest to different land uses without proper soil conservation and management practices resulted in the overall decline of soil fertility quality. Thus, integrated land resource management approach is indispensable for sustaining agricultural productivity and the environmental health of the Melka Waken a catchment.

Keywords

Land Use/Cover, Resource Management, Soil Quality, Spatial Variation, Topographic Elevation, Soil Quality Parameters

1. Introduction

Soil is a vital natural resource that has several functions in the biosphere and has several values to the society and environment. For instance, it regulates solute flow, filters, buffers, immobilizes, and detoxifies organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition; stores and cycles nutrients and other elements within the earth's biosphere; and provides support of socioeconomic structures and protection for archaeological treasures associated with human habitation [1] [2] [3]. These soil functions are performed on different levels and are determined by inherent soil characteristics (e.g. texture, organic matter and nutrient contents, pH, cation exchange capacity, bulk density, porosity and others) and external environmental (climate, terrain/topography, hydrological, biological) and anthropogenic (soil-use and management) factors [4] [5].

Nevertheless, such proper function of soil and its fertility status bay large is adversely affected by human induced soil degradation resulted from land use changes, mainly conversion of natural forest to agricultural and grazing lands are known to result in changes in soil chemical, physical and biological properties [6]. Land use and land cover change are associated with large negative impacts on ecosystems observed at local, regional and global scales. High rates of water, soil and air pollution are the consequences of observed LULCC. Biodiversity is reduced when land is changed from a relatively undisturbed state to more intensive uses like farming, livestock grazing, selective tree harvesting, etc. [7] Land use change due to deforestation in the tropics was the major contributor to CO_2 emissions in the 1990s, which averaged between 0.5 and 2.7 Giga tone of carbon (GtC) per year [8]. These changes alter ecosystem services and affect the ability of biological systems to support human needs, and also determine, in part, the vulnerability of places and people to climatic, economic and socio-political perturbations [9]. Land degradation, which includes degradation of vegetation cover, soil degradation and nutrient depletion, is a major ecological problem in Ethiopia [9].

Soil degradation is defined as a process that causes deterioration of soil productivity and low soil utility as a result of natural or anthropogenic factors [7] [8] [9] [10] [11] [12]. It is caused by wrong land management practices of human interferences in the natural ecosystems [9] [10] [11] [13] [14] [15]. As a result of globally, it has been estimated that nearly 2 billion hectares of land are affected by human-induced soil degradation [12] [16]. The [13] [17] estimated that over 85% of the land in Ethiopia is moderate to very severely degraded, and about 75% is affected by desertification.

Soil is subject to a series of human-induced degradation processes, which namely are displacement of soil material, and internal soil deterioration [15] [18]. Loss of organic matter and soil biodiversity and consequently reducing soil fertility are often driven by unsustainable agricultural practices such as overgrazing of pasturelands, over intensive annual cropping, deep ploughing on fragile soils, cultivation of erosion-facilitating crops, continuous use of heavy machinery destroying soil structure through compaction, unsustainable irrigation systems contributing to the salinisation and erosion of cultivated lands [15] [16]

[19] [20]. Land degradation has multiple and complex impacts on the global environment through a range of direct and indirect processes affecting a wide array of ecosystem functions and services [17] [21]. The principal environmental impacts of land degradation include a rapid loss of habitat and biodiversity, modifications of water flows, and sedimentation of reservoirs and coastal zones [18] [22]. Moreover, the processes of soil degradation have major implications on the global carbon cycle, reduction in soil buffering capacity, water and air quality, biodiversity, food production, food and feed safety and human health. Degradation processes, such as soil erosion, salinization, crusting, and loss of soil fertility, affect the biological productivity of the land with subsequent impacts on the biodiversity of vegetation cover and/or its density [23]. Socio-economic factors, including poverty, land fragmentation, low standards of living and earning, a low level of education, and health condition, were cited as drivers contributing to an increased risk of degradation during the last few decades [24].

Biophysical factors, including geomorphologic features, rainfall variation and climate changes, and soil properties, also contribute significantly to land degradation [25]. Topography modifies microclimate and hydrological conditions of landscapes, which in turn influence pedogenic processes and soil properties by affecting the types and rates of geomorphic processes. Topography influences runoff, drainage, soil temperature, soil erosion and consequently soil formation. Decrease in soil temperature with elevation reduces litter decay, soil organic matter decomposition rates [19] [26] and N-mineralization rates [20] [27], consequently affecting soil quality and distribution. Elevation (altitude) influences soil organic matter (SOM) by controlling temperature conditions, soil water balance and geologic deposition processes. Researchers [21] [22] [23] [28] [29] [30] reported variations in soil properties in relation to variation in topographic elevation. Variation in soil properties due to topography contributes to soil physical, biological and chemical quality variations at different elevation categories. These variations influence the soil's capacity to sustain plants and other organisms and the productivity in natural or managed ecosystems.

Biophysical and human induced land degradation has become a serious environmental and socio-economic problem in this study catchment. This land degradation was reflected through observed soil erosion and soil nutrient loss, flooding, sedimentation of dams and river, and other associated issues such as water pollution and declining water storage capacity of the dam in the catchment of Melka-Wakena dam. Understanding the effects of land use/land cover change and topographic variation on soil quality/fertility helps to design sustainable land resource management practice in this study area. Therefore, the aim of this study was: 1) assess the effects of land use/land cover change and topography on soil fertility/quality; 2) assess local farmers' perception on soil degradation.

2. Materials and Methods

2.1. Description of Study Areas

The study catchment is located between 6˚40'00" and 7˚25'00" north latitude and

38˚38'00" - 39˚45'00" east longitudes, in West Arsi zone, Oromia regional state, Ethiopia (Figure 1). The total area of the catchment is 4280 km^2.

The mean annual temperature of the study catchment is found between 2˚C - 15˚C in the higher altitude areas and 16˚C - 24˚C in the lower plateau areas. The study catchment is classified into two agro-climatic regions: The warm temperate/baddadaree/and cool temperate/badda/covering 24% and 76% of the total the area, respectively. The mean annual rainfall of the study area ranges from 1200 mm to 2940 mm. Geological survey shows that the relief of the study catchment is characterized by plain, hilly, valley and gorges, highest peaks and dissected plateaus. The mean elevation of the watershed is 2911 m with maximum of 4322 m (Kaka mountains peaks) and minimum elevation is 2143 m above sea level which is found near the Melka-Wakena dam sub-station. The catchment is naturally endowed with many rivers and streams as well as with one artificial lake.

The study area is characterized by a wide range of soil types. The dominant soils in the study catchment are Vertisols, Chernozems, Cambisols, Luvisols, Nitosols. The nature and distribution of the vegetation of these districts range from wooded grassland to Afro-Alpine. Alpine, Afro and sub Afro-Alpine vegetation are found in the area above 3100 m sea level of the area. Abundant low bush taught grasses and lichens are common species on the top of the mountain where temperature is very low. Below the Afro-Alpine and sub Afro-Alpine broad leafed forests which are dominated by Juniperus, Podocarpus, *Hagena abyssinica* tree species as well as shrub and bush which highly dominated by Asta/Erica species are found parts of Adaba and Dodola districts. The diverse climate and topographic phenomenon have provided a wide range of natural

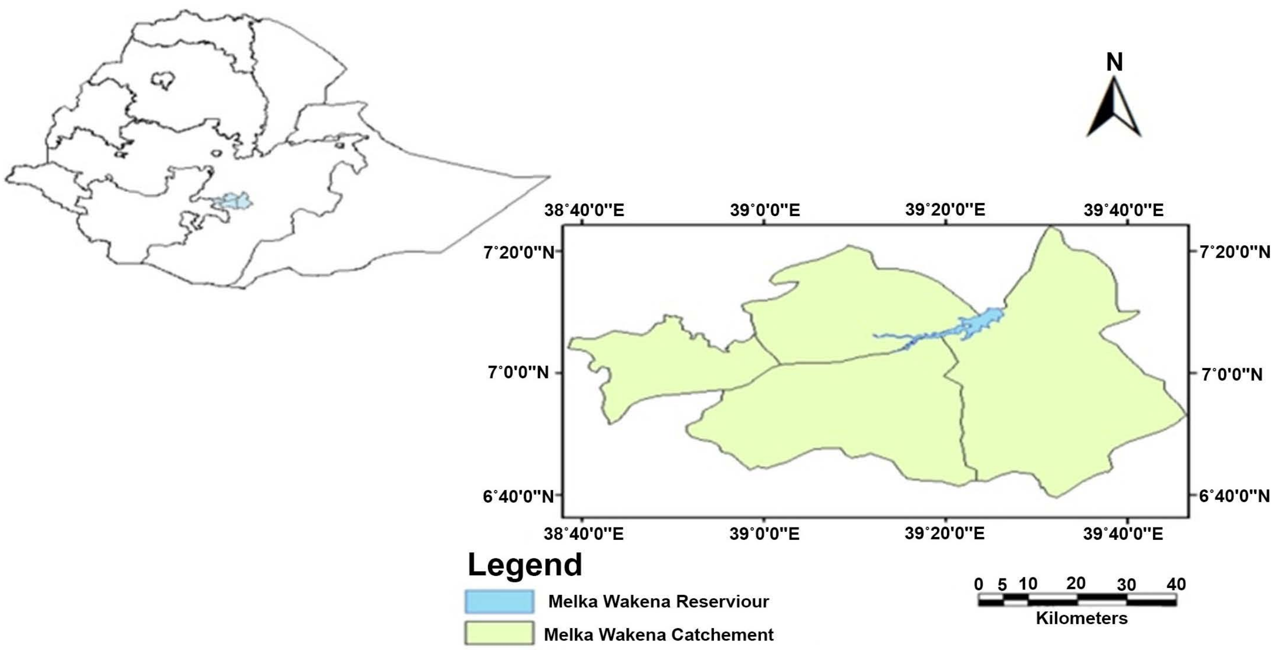

Figure 1. Map study area.

environments, which form favorable habitat for a wide variety of fauna in study catchment. The local inhabitants rely on the forest to supply most of their needs, mainly fuel wood, pasture, timber, wild fruits and medicinal herbs [24] [31].

Agriculture is the main livelihood base and economy of the study catchment. Like other parts of the Ethiopian highlands, the major farming system is mixed cereal-livestock. The cool and the sub-tropical climatic condition of the study catchment make the districts suitable for the production of major cereals crops such as Teff, Wheat, Barley and Maize. Rearing animals serve for a variety of purposes including food, draught power, transport, manure and skin. Modern livestock extension package of dairy and beef farms development was not well introduced and well adapted in the area, particularly in the rural areas. There is a gradual declining of pastureland and consequently declining the quantity and quality of livestock due to the expansion of farmland at the expense of grazing land.

The ever-increasing price of agricultural inputs (chemical fertilizer, improved seeds, insecticides and herbicides), expansion of weeds; soil erosion due to improper farming practices, and waterlogging were major agricultural problems that attributed to low agricultural production and productivity in study catchment. Besides, lack of long term credit, road inaccessibility to urban centers for selling their produces and scarcity of grazing land were other factors affecting agricultural development and the livelihoods of the local community in general [24] [31].

2.2. Soil Sampling Procedures

The study was designed to evaluate soil fertility status under different land use cover types and soil variability across landscape in study catchment. Purposive stratified sampling was used to cluster sampling sites into strata of three elevation categories, three land use cover types and five transect walks to come up with random proportional sampling points.

For this effective, soil sampling sites were selected by stratifying the entire study catchment into three elevation categories based on dominant LULC types, dominant crops grown and differences in altitude and as well as using mosaic topographic map of the study catchment. With these considerations, the catchment was classified into three elevation categories from which three major land use/land cover types were identified. The elevation categories that were purposively identified include plain (2143 - 2462 masl), middle (2463 - 2948 masl) and upper (2949 - 4215 masl). Besides, the major land use/land cover types identified based on their area coverage and dominance were cropland (CL), grassland (GL) and forest land (FL). The study catchment covers about 4100 km^2. Purposely, this large area of the catchment was further divided into five transects to make easy soil sample collection or reduce sampling errors.

Field soil samplings were undertaken from land use types and elevation categories along the identified transects in January to February 2016. To assess the effects of LULC change and topography on soil quality/fertility and to evaluate the overall soil fertility status of the study catchment a total of 144 disturbed soil samples were collected in the catchment, Accordingly, for each LC type and in each elevation range, 20 replications from CL and 14 replications each from WL and 3 GL (8 × 3 × 3 + 5 × 3 × 3 + 3 × 3 × 3 = 144) were taken randomly from the surface soil 0 - 30 cm depth, respectively. The sample was taken from 10 m × 10 m plot located within the same physiographic landforms. The samples at each elevation range and under different land use/land cover categories were then bulked/homogenized into a single composite sample representing the sample plot at each of the three elevation categories and land cover classes.

The soil was then air dried, grounded and passed through a 2 mm sieve for soil laboratory analysis. Soil samples were analyzed for their physical and biochemical properties. In this paper, average values of the replicates of analysis of soil parameters are reported. As conditions of native soil can serve as reference criteria for assessing soil quality/fertility changes [25] [32], the WL cover category was used as a benchmark to compare the mean difference due to the impact of LC on selected soil quality/fertility indicators.

2.3. Laboratory Analysis

Collected soil samples were analyzed for their physio-chemical properties at various soil analytical service laboratories (Sinana research center, Wondo Genet College of forestry and Ziway soil laboratory center).The composite soil samples were air-dried and ground to pass through a 2 mm sieve. Particle size distribution was determined by the Bouyoucous hydrometer method [26] [33] and textural classes were made following the United States Department of Agriculture (USDA) systems of textural classification. Soil pH was measured on a 1:2.5 soil-water ratio suspension [27] [34]. Organic carbon was estimated using Walkley-Black method [28] [35] and content of organic matter was obtained by multiplying content of organic carbon by a factor of 1.724. Total nitrogen was analyzed using the Kjeldahl distillation method [26] [33]. The available phosphorus was determined by the means of the Olsen method [29] [36]. Exchangeable bases total N content, cation exchange capacity (CEC), exchangeable cations (Ca, Mg, K) were determined by means Atomic Absorption Spectrophotometer (AAS).

2.4. Soil Degradation Index

Soil degradation index (DI) was computed on assumptions that the status of soil properties under the CL, GL were once similar to less disturbed natural FL. Accordingly, differences between mean values of soil properties under CL, GL and FL were compared with mean values of soil properties under native WL and expressed as a percentage of the mean value of individual properties. In considering the values of important soil parameters for plant growth, SOC, N, P, K) were selected for soil degradation assessment. Laboratory results were subjected to descriptive statistics using deterioration index. The mean value of FL soil property minus the mean value of CL soil property was divided by the mean value of forest soil property, multiplied by 100. Deterioration index with negative (−) values indicates an appreciation in soil property while positive (+) value shows depreciation in soil property under CL.

Equation (1) computed percentage changes in the soil properties of cultivated land or grassland compared to forestland ($Ch_{Cl,Gl}$).

$$Ch_{Gl,Gl} = Lu_{Cl,\ or\ Gl} - Lu_{Fl} \times 100$$

$$Lu_{Fl}$$

where $Ch_{Cl,Gl}$ is the percentage changes in soil property of cultivated or grasslands compared to forestland and Lu_{Cl}, Lu_{Gl} and Lu_{Fl} are mean values of soil property under consideration of cultivated, grass and forestland respectively.

2.5. Household Survey

As environmental degradation impacts the daily life of farmers, an understanding of their perceptions on the matter is important for sustainable land management. Three hundred twenty-four (324) households selected using systematic sampling techniques were surveyed, and qualitative and quantitative data were collected from key informant interviews and structured and semi-structured questionnaires. The information collected was enriched by observations during field visits.

Statistical analysis Statistical analyses were performed to test the influence of land use and landscape position on soil nutrients using one-way ANOVA, and mean comparisons were made using the least significant difference (LSD) method with $p < 0.05$. The independent variables used in this study were land use types, landscape positions and slope aspects. A Pearson correlation coefficient matrix analysis was also employed to determine the nature of the relationship between the soil variables, LUC types and elevation. Multiple comparisons were also computed between groups and within the groups using Turkey's HSD post hoc method. All data were analyzed using excel window and the Statistical Package for Social Science (SPSS—A statistical software program, version 20, 2017).

3. Results

3.1. Effect of LC Types and Topographic Position on Soil Physical Quality Parameters of the Catchment

The soil in the catchment is characterized by a texture of clay ranging from 33% to 45% and silt varying from 28% to 36% (Table 1). This shows its weakly resistant to erosion. The mean percentage of sand and silt were significantly higher under cropland in the upper elevation areas (32% and 41%) when compared to the lower elevation (24% and 27%). Conversely, higher (49%) clay fraction content was observed in the lower elevation than in the middle elevation (39%) and in the upper elevation (26%). Hence, soil particle size distribution was affected by elevation ($p < 0.05$) and land cover types ($p < 0.01$, $p < 0.00$) (Table 3).

On other hand, silt fraction increased with an increase in elevation, 27, 28 and 41 (lower, middle and upper) respectively. The reason probably that the surface downward elevation increment of clay size fraction is associated with selective

Table 1. Mean value of soil physic-chemical properties as influenced by the effects of land use/cover types.

Soil parameters	Land use/cover change			Elevation categories		
	crop	grass	forest	lower	middle	upper
Clay (%)	44.75 (1.64)^{a}	41.85 (2.68)^{b}	33.46 (3.82)^{ab}	49.97 (0.62)^{a}	38.94 (1.97)^{b}	25.33 (2.20)^{c}
Silt (%)	28.26 (1.56)^{b}	35.96 (0.71)^{a}	29.85 (1.61)^{a}	27.07 (0.79)^{b}	28.12 (0.84)^{b}	41.10 (1.03)^{a}
Sand (%)	26.98 (1.82)^{bc}	30.56 (1.73)^{b}	28.26.14 (2.53)^{b}	24.82 (0.71)^{b}	30.25 (2.11)^{a}	32.00 (2.47)^{a}
OC (%)	3.72 (0.04)^{b}	4.09 (0.06)^{bc}	7.82 (0.03)^{a}	3.38 (0.02)^{a}	4.72 (0.05)$^{)a}$	7.25 (1.33)^{b}
TN (%)	0.29 (1.09)^{b}	0.37 (1.18)^{a}	0.31 (2.24)^{a}	0.27 (1.20)^{a}	0.32 (0.74)^{a}	0.44 (2.16) ^{a}
Av.P (%)	8.58 (1.00)^{b}	5.56 (0.49)^{b}	7.08 (1.20)^{a}	11.94 (1.00)^{a}	6.59 (0.86)^{a}	8.49 (1.34)^{a}

*Mean values within rows of each soil property followed by the same letter(s) are not significantly different at $p < 0.05$ and values within brackets represent mean of standard error.

removal of the finer and lighter materials from the higher to lower elevation categories as the topography generally slopes/declines in that direction. This is because clay requires a relatively lower velocity in the water to be transported than the silt and sand particles [30] [37]. Thus, the upper elevation zone contained more sand and silt particles while the lower elevation zone was dominated by clay particles (**Table 1**). Similar results were reported by [31] [32] [38] [30]. This high clay fraction in cropland in lower elevation may be because of cultivation, aided by warm temperature, promotes further weathering processes [33] [39] that may lead to further disintegration of soil particles and secondary minerals into clay particle size. Clay shows negative correlation decreasing with the increase in altitude at the rate of correlation coefficient of −0.398 at $p < 0.001$ significance (**Table 4**). Silt and sand in other hand, had significant positive correlation and variation with altitude at $p < 0.001$ and $p < 0.001$ significance respectively (**Table 4**).

On the other hand, the distribution of soil texture was not significantly affected by LULC types (**Table 1**). However, relatively the sand content of soils of forestland was higher than on soils of cultivated land and grassland (**Table 3**). Similar results were also reported in other south-eastern parts of Ethiopia [33] [39] and in northeast Wellega [34] [40]. The clay fraction on cultivated land and grazing land increased compared to forestland, but the change is greater in cultivated land than grazing land. The lower content of sand and higher content of clay fractions in the cultivated land may be attributed to the process of plowing, clearing, and the leveling of farming fields [34] [40]. Because the clay particles are very small in size, silt, and sand fractions could be removed by runoff from the cultivated land. Moreover, the higher clay content of the cropland could be attributed to the mixing of the surface soil with the sub-surface soil as a consequence of the plowing.

As indicated in **Table 5** multiple comparison results also showed very significant ($p < 0.001$) difference in clay content between cropland and forest land, and significant ($p < 0.004$) differences in sand concentration between cropland and forest land cover types and differences in silt content between cropland and forestland ($p < 0.05$). Although the spatial variation of particle size is largely the result of the interaction effect of natural factors [35] [41], it was evident that the various management practices such as deforestation and farming practices contributed to such variations in the study of the catchment area. Soil texture classes show clear difference with the difference in altitude.

Generally, the increasing trends of sand and silt proportion towards the higher elevation may affect the amount of water and nutrient availability to plant growth, and at the same time water logging and aeration problem due to high clay fraction deposition at low-lying areas may reduce soil quality and subsequently affect soil productivity [36] [42].

Organic matter in the soil exerts considerable influences on physical-chemical constituents and biological processes; and enhance on soil structure, water holding capacity, cation exchange capacity, and ability to form complexes with ions and as a nutrient source and store in soil pool [37] [43]. However, human-induced conversion of natural landscapes into cultivated and grazing systems cause an abrupt decline in soil organic matter and reduces the nutrient content of soil through reduced litter production, increase erosion rates and decomposition of organic matter by oxidation [38] [44]. Human-induced LULC changes significantly ($p < 0.05$) (**Table 1**) affected the distribution of soil organic carbon in study catchment. Accordingly, the content of SOC was the highest in forestlands and the lowest in cultivated land. Similarly, the highest SOC stock under forest and lowest under cropland was reported by [30] [45]. This decrease in SOC contents in cultivated land may be attributed to high accelerated rates of erosion and decomposition processes in cultivated lands than forestland and grazing lands [39] [46]. SOM also increases soil water-holding capacity and CEC and enhances soil aggregation and the structure of soils of forestland. Multiple comparison results showed that the OC content of the soil differed significantly ($p < 0.05$) between crop, forestland and grassland. The low SOC content in cropland indicates a reduction in the nutrient supply, water holding capacity, structural stability and CEC of the soil (Amir *et al.*, 2010) [40] [47].

Similarly, there was statistically significant difference ($p < 0.01$) in SOC content between different elevation ranges. In this regard, it was found that SOC showed an increasing trend with elevation in all identified land use/land cover type (**Table 1**). Positive correlation values between SOC and altitude have been also reported in other studies [48] [49] [41] [42]. The reason for this that cool temperatures, as well as high precipitation and subsequent increase in the area of plant cover and low mineralization rate with an increase in elevation lead to higher values of soil OC content [43] [50]. Therefore, temperature and soil moisture directly influence the activity of soil decomposers and are the most important factors affecting the rate of organic matter decomposition [44] [51]. In contrast, the high rate of SOC decomposition/mineralization enhanced by relative higher temperatures and tillage in the lower elevation may contribute to lower SOC accumulation.

However, the interaction between land use types and elevation variation does not show any significant difference between them. This statistical insignificant variation of OC among them might be due to their interaction with multiple variables.

With reference to the forestland value of the SOC, cropland and grassland showed a degradation of 48% and 41% respectively. As SOC influences many of the soils physical and chemical properties, its decline by 48% after conversion of forestland to cropland can serve as a good indicator of soil quality/fertility degradation in the study catchment. Such a decline in SOC/SOM may result negative effects on crop productivity; emission of CO_2 that may contribute to climate change. Therefore, improving its level is a prerequisite to ensuring soil quality; and future agricultural productivity and sustainability [45] [43].

It is therefore essential to improve and sustain SOC content to ensure sustainable management of land and future agricultural productivity and sustainability.

Next to N, phosphorus is essential for plant growth and grain development. The mean differences between soil-available P of forestland and grazing lands, on the one hand, and cultivated and grazing lands, on the other hand, are statistically significant ($p < 0.05$) (**Table 1**) but the mean difference between forestland and cultivated lands is not statistically significant. In the study catchment the available P content was significantly influenced by differences in elevation ($p < 0.05$). This implies the variation of available P distribution across the elevation. However, this variation of available P contents under different land use types was inconsistent in each elevation range. Accordingly, the highest mean available P contents were found in lower/plain of grassland and cropland than middle and upper elevation categories, respectively (**Table 1**).

The finding of this study was in line with the observation made by [46] [52]. In the other hand, the higher phosphorus content in grass might be the result of less effect of overgrazing, leaching and erosion in lower plain. In contrast, the available phosphorous content in the soil is higher in forest land than the cropland and grassland in upper elevation. This relatively higher available P content in forest land soils might be attributed to the presence of high organic matter content resulting from decomposed litter falls and plant residuals contributing to organically derive available P. As indicated above, the low and high pH values in the cultivated and forestland soils might have contributed to the low and high available P contents respectively [47] [48]. There was no significant difference in available P content among adjacent land use types. The finding in this study is in line with the observation made by [46], also in Ethiopia.

Nitrogen is the most important nutrient element for crop growth, which normally produces the greatest yield response in crop plants [48] [53]. Thus, understanding the behavior of Nitrogen in soil is essential for maximizing crop productivity and profitability [49] [54]. The concentration of total N in the soil was significantly ($p < 0.01$) influenced by the elevation variations and interaction effects of LULC changes and elevation ($p < 0.05$) (**Table 1**). However, with respect to the effects of land use change, no significant differences was observed, with the mean value of total N concentration of 0.29 in cropland soil and 0.37% and 0.31% in the adjacent forestland and grassland soils, respectively, of the catchment.

Despite insignificant variation among land use types, there was the highest total N content in forestland. This was in line with other study reported the highest mean value of total N in soils of forestland and lowest in cultivated land in west-eastern [34] [40]. The change in total N is higher in cultivated land than in grazing land and forestland (**Table 1**). Relatively, low total N concentration in cropland was found probably as the result of rapid mineralization of organic substrates [50] [55], insufficient organic input application [51] [56], as well as its degradation due to continuous cultivation and poor management practices. In the other hand, the high total N content under forestland could be due to nutrient recycling since the amount extracted gets returned to the soil through the decomposition of leaf litter.

Total nitrogen was significantly differed with elevation ($p < 0.05$) (**Table 1**). In this respect, low and relatively high total N in the lower and upper cropland and low and relatively high was obtained at lower and upper grassland categories of the elevation, respectively. Likewise low and relatively high total N content was recorded under forest land. As soil organic matter is the main source of total N, its distribution and concentration in soils reflected similar trends and patterns to organic matter concentration among elevations and land use/cover types [36] [42].

Regarding its relationship with other variables, soil total N had strong correlation with SOC ($r = 0.391$, $p < 0.001$); elevation ($r = 0.391$, $p < 0.001$); land use/land cover types ($r = 0.287$, $p < 0.01$) and Mg ($r = 0.269$, $p < 0.001$) (**Table 5**).

All studied exchangeable bases/cations showed significant differences among LUC types and elevation gradients of the study catchment (**Table 2**). Exchangeable calcium content was the dominant basic cations in all LUC types and elevations followed by exchangeable magnesium. The soil mean exchangeable Ca content differed significantly between elevation categories ($p < 0.05$). for instance, the Mean difference of exchangeable Ca content in the lower, middle and upper crop land was 22, 19 and 16 $cmol^+/kg$ soil respectively (**Table 2**). Such decrease in exchangeable Ca content of the soil with elevation might be attributed to the effects of erosion, leaching and run off as topography is one factor of soil erosion.

On the other hand, although there was no statistically significant mean difference between land use types, the highest mean value in forestland [34] (28) and the lowest in grassland (16) and cropland (17) $cmol^+/kg$ soil respectively was recorded. This implies a low exchangeable Ca content in grass and croplands compared to forest land LULC types. The conversion of forest land cover to grass and croplands caused the degradation of exchangeable Ca by 43%. This can be attributed to the removal of the Ca element as the result of overgrazing, erosion and removal of crop residues from cropland. A similar nutrient degradation

Table 2. Mean value of soil biochemical properties as influenced by the effects of land use/cover types.

Soil parameters	Land use/cover change			Elevation categories		
	crop	grass	forest	lower	middle	upper
pH (H_2O)	5.82 (0.13)^b	6.08 (0.09)^b	6.54 (0.31)^a	6.38 (0.09)^a	6.05 (0.12)^a	5.98 (0.29)^a
Ca ($Cmol^+/kg^2$ soil)	16.98 (2.05)^b	16.41 (0.89)^b	28.71 (2.54)^a	16.22 (0.88)^b	19.68 (1.62)^a	22.77 (1.84)^b
Mg ($Cmol^+/kg^2$ soil)	6.41 (0.72)^a	7.95 (0.57)^a	8.00 (0.32)^a	6.88 (0.49)^a	6.93 (0.17)^a	13.22 (0.35)^b
K ($Cmol^+/kg^2$ soil)	0.15 (0.12)^b	0.15 (0.14)^b	0.19 (0.30)^a	0.17 (0.08)^a	0.16 (0.11)^b	0.16 (0.32)^a

*Mean values within rows of each soil property followed by the same letter(s) are not significantly different at p < 0.05 and values within brackets represent mean of standard error. *values in the brackets represent plus or minus (±).

pattern due to overgrazing has been reported in other parts of Ethiopia [43] [57]. Generally, according to the [52] [58] rating, the average status of exchangeable Ca content was low to medium for the studied LUC and elevation in the study catchment.

Exchangeable Mg mean values showed significant differences across elevations ($p < 0.01$) and LULC ($p < 0.01$) due to the interactive effect of LULC and elevation ($p < 0.01$) (**Table 3**). The content of exchangeable Mg varied between forest land and cropland as well as along elevation ranges (**Table 2**). Low concentration was observed in lower elevations as compared to the middle and upper zones. There was also significance difference in exchange Mg concentration among LULC types. Lower values (6%) were observed in disturbed areas (grassland and cropland areas) more than in undisturbed natural ecosystems (8%) and this was probably due to the removal of magnesium by erosion and crop residual harvesting.

Compared to the soils of forestland, the overall pattern of exchangeable Ca, and Mg concentrations in cropland showed declining trends, but with varying rates (**Table 2**).

Exchangeable K was highly influenced by the interaction effects of both LULC types and elevation ($p < 001$) (**Table 2**). Soils under cropland and grassland had lower exchangeable K than forest land cover type. Lower K content was also observed under intensive cultivated soils [48] [59]. The land use/land cover change from forestland to cropland and/or grassland and continuous harvesting without return of crop residues or fertilizers may lead to a decline of exchangeable K over time [53] [60]. As the result of such factors exchangeable K content was low. It was varied between cropland (0.15) and forest land (0.19) $cmol^+/kg$ soil and such a range fall in the lowest level for K [52] [58] (Landon, 1991; [54] [61]. Thus, low contents of exchangeable K observed in the study catchment area may affect plant growth, soil quality and productivity.

Soil pH has been considered in soil health/quality tests to assess impacts of land use change and agricultural practices [55] [56] [62] [63]. Soil pH and base saturation are important soil properties that influence nutrient availability and crop growth [57] [64]. Soil pH value of the study catchment was ranged from 5.82 to 6.54 with a mean value of 6.18. The lowest pH value was being found in

Table 3. Interaction effects of land use/cover types and elevation on selected soil physical and chemical properties.

Parameters	Land use types		Elevation		Land use types X elevation	
	F	P	F	P	F	P
Clay (%)	0.633	0.532	11.258	0***	0.380	0.768
Silt (%)	0.910	0.405	7.686	0**	0.265	0.851
Sand	0.065	0.938	2.777	0*	0.231	0.874
PH(H_2O)	1.928	0.149	6.444	0**	0.418	0.740
Ca ($Cmol^+/kg^2$)	2.486	0.087	4.172	0*	1.056	0.370
Mg ($Cmol^+/kg^2$)	5.566	0**	4.890	0**	4.691	0**
K ($Cmol^+/kg^2$)	1.096	0.337	0.062	.940	4.260	0**
P (mg/kg)	0.201	0.818	2.928	0*	0.558	0.643
OC (%)	4.179	0*	11.749	0***	0.233	0.874
TN (%)	0.911	0.405	7.235	0.0**	2.884	0.0*

cropland and grassland and the highest value in the adjacent forestland. However, this does not show a significant variation of soil pH distribution understudied land use types. A similar result was reported in the Tsegede area in the northern highlands of Ethiopia [36] [42]. Thus, soils in the cultivated land were more acidic than those of the grazing land and forestland. Such lower pH values in crop and grasslands can be attributed to the removal of basic cations by plants due to continuous cultivation with little nutrient return to the soil, and erosion and overgrazing on grasslands.

Moreover, the acidifying effects of acid-forming nitrogen fertilizer, poor nutrient cycling, and the mining of basic cations through harvested crops, soil erosion, and acid rain may be attributed to lower pH values in cropland [34] [40]. In contrast, the higher pH value in forest land may be related to little removal of base-forming minerals by erosion and the release of elements from wood litters through decomposition [30] [37]. Statistically significant differences ($p < 0.01$) were observed in soil pH values across the elevation ranges. This shows a declining trend of soil pH value with increasing in elevation in all land use types. Continuous cultivation practices, excessive precipitation, steepness of the topography and application of inorganic fertilizer could be attributed to reduction of soil pH value at the middle and upper elevation zone [58] [65].

It is also suggested that the low soil pH values in higher altitudes (**Table 2**) is due to the washing out of solutes from these parts [59] [66] to lower elevation categories. Moreover, Soil pH is mostly related to the nature of the parent material, climate, organic matter and topographic situation [60] [67]. The topographic situation of the study catchment was therefore responsible for such soil pH value variation. Other hands, multiple comparison analysis shows a significant variation in soil pH between forest land and cropland ($p < 0.01$) and between forest land and grassland ($p < 0.01$) across topographic position, respectively (**Table 5**). This implies that there is higher soil pH under forest land and grass land at middle and higher elevation than in the lower elevation.

With regard to relationship with other variables or parameters the values of soil pH were significantly and positively correlated with calcium($r = 599$, $p < 0.01$) and potassium ($r = 401$, $p < 0.01$) (**Table 4**). This is because plant nutrient availability is strongly tied to the activity of soil pH in the soil solution. In contrast, it was negatively and significantly ($p < 0.01$) associated with elevation (**Table 3**).

Although lowest soil pH value is observed (5.1) in some area under cropland, in general the average soil pH status of the study catchment falls within the range of moderately acidic (5.82) to slightly acidic (6.54) [61] [68]. Most crops grow best when the soil pH is between 6.0 and 8.2. The moderate to slightly acidity of the soil may affect the process of other nutrient transformations, solubility, or plant availability of many plant essential nutrients [62] (Barua and Haque, 2013). Therefore, soil management strategies need to apply to improve such soil acidity.

Accordingly, differences between mean values of soil properties under CL, GL and FL were compared with mean values of soil properties under native WL and expressed as a percentage of the mean value of individual properties. For this purpose the most important soil parameters for plant growth (SOC, N, P, K) were selected for soil degradation assessment. Soil deterioration indices reflect differences in soil quality of different land use patterns, while changes in soil quality reflect management practices. The calculated deterioration indices of selected soil quality parameters at the surface layer (0 - 30 cm) showed a negative trend in all LC types from their values under WL cover. Soil parameters under CL showed the most negative cumulative effect (−389.87 percent) followed by GL (−387.29 percent) which indicate deterioration in soil quality from deforestation (**Table 6**). Results confirmed assumptions that LC change (from natural FL to CL) to different land uses without proper soil conservation and management practices result in declining soil quality. Mulugeta *et al.* (2004) [63] and Eyayu *et al.* (2009) [64] reported that soil quality declines with natural forest conversion to other LC types. Sustainable soil management practices minimize nutrient loss and maintain soil quality, ensuring the sustainability of agricultural activities and food security within the study catchment.

3.2. Local Community Perception of Soil Fertility Status

Sustainable land management practice depends on perceptions of land users such as farmers. Their perception and responses to environmental issues are reflected in their land use and management practices. In addition to the soil laboratory and soil data analysis of soil fertility, local community perception of their farm plot fertility was also evaluated. The majority of the respondents from lower, middle and upper streams perceived that the fertility of their farm plot was low (**Table 6**). The most commonly (99.95 & 96% o) cited cause of poor soil fertility in all three elevation categories was water logging. The absence of fallowing

Table 4. Pearson correlation matrix for selected soil parameters, land use/land covers types and elevation of the study catchment.

	LU	ELV	OC	OM	Av.P	pH	Sand	Clay	Silt	TN	Ca	Mg	K
LU	1.0												
ELV	0.1	1.0											
OC	0.1	0.4	1.0										
OM	0.1	0.4	1.0	1.0									
Av.P	−0.1	0.2*	0.0	0.0	1.0								
pH	0.2	0.2**	−0.1	−0.1	0.1	1.0							
Sand	0.1	0.2**	0.1	0.1	−0.1	0.0	1.0						
Clay	−0.1	0.4**	0.3**	0.3**	−0.2*	0.1	−0.8	1.0					
Silt	0.1	0.3**	0.3**	0.3**	−0.2	0.0	0.1*	0.5	1.0				
TN	−0.1	0.3**	0.4	0.4	0.0	0.0	0.0	−0.2	0.2	1.0			
Ca	−0.1	0.1*	0.3**	0.3**	0.3	0.6**	0.2	0.3**	−0.1	0.1	1.0		
Mg	0.1	0.1	0.2**	0.2**	−0.1	0.1	−0.1	0.0	0.1	0.3	0.1	1.0	
K	−0.1	−0.1	0.2	0.2	0.1	.1**	0.0	0.0	0.0	0.1	0.4**	0.1	1.0

Table 5. Results of LSD post hoc multiple comparisons of soil property under three elevation categories and four LULC types of the study catchment.

Soil Parameters	Land Use Types	
	Significant Contrast of Value of Soil Property	P
Clay	Crop and Forest	0.000**
	Forest and Grass	0.007**
Silt	Crop and Forest	0.004**
	Forest and Grass	0,027*
Sand	Crop and Forest	0.042*
pH	Crop and Forest	0.000***
	Crop and Grass	0.003**
Ca	Crop and Forest	0.000***
	Forest and GRASS	0.000***
Mg		
K	Crop and Wood	0.002**
	Grass and Forest	0.000***
Av. P		
OC	Crop and Forest	0.000***
TN	Crop and Forest	0.017*
	Crop and Wood	0.001**

***Contrast is significant at the 0.001 level, **Contrast is significant at the 0.01 level and, *Contrast is significant at the 0.05.

Table 6. Soil degradation index for selected soil nutrients.

Land use type	Selected Soil nutrients				Total
	OC	TN	AV.P	K	
Wood land	0	0	0	0	
Crop land	−96.28	−99.71	−91.42	−99.88	−389.87
Grass land	−95.91	−99.63	−94.40	−99.88	−387.29

Source: extracted from.

was the second most cited cause of poor soil fertility (70%), which was mainly attributed to fast growing human population in the area.

On the other hand, farmers in the mid-land identified that the inadequate application of fertilizer and waterlogging were the major causes of poor soil fertility problems in the area. In general speaking, according to the sample household heads, the major causes for this poor farm plot fertility were soil erosion, inadequate application of fertilizer, absence of fallowing system, and waterlogging (**Table 7**). Soil erosion is the prominent culprit for soil fertility in all three sites with significant differences at $p < 0.001$ (**Table 7**).

The study reported that about 97%, 100% and 98% of sample household heads from lower, middle and upper streams perceived the prevailing of soil erosion in their locality (**Table 8**). With respected to the level of severity of erosion about 91% 71%, and 68% of respondents from upper middle and lower stream respectively reported that there was high rate of soil erosion (**Table 8**). The highest rate of soil erosion at upper stream of the study area may attribute to the number of factors such as the nature of topography, rainfall, soil, land cover and types of land management practices of their area. As a result of these contributing factors the formation of several sheets, rills and gullies were observed in several places in the study catchment. As far as the trends and intensity of soil erosion are concerned over the 20 years in their area, the majority of respondents at different altitude reported the increase of soil erosion. From this result one can conclude that soil and water conservation practice was either not well adopted by farmer or formerly built structures are being destroyed.

Farmers associated the removal of upper layers of soil with soil erosion and declining soil fertility quality. Local perception of soil degradation concurred with the results of soil laboratory analysis. Respondents interviewed indicated that soil erosion and associated soil fertility decline resulted in lowered agricultural production, and thus more land was placed under cultivation to ensure agricultural viability, leading to more land degradation. The researchers' observations of gullies in upper and middle elevation sections of the Melka Wakena confirmed the farmer responses. Efforts to combat soil erosion and improve soil fertility management practices to minimize effects of soil degradation need to be supported by adequate technical and material support to ensure sustainable land management practices that would improve local livelihoods and environmental health.

Table 7. Respondents evaluation of their farm plot fertility.

Perception of soil fertility		Respondents perception in percent at different sites			X^2	p
		Lower altitude	Middle altitude	Upper altitude		
Evaluation of farm plot fertility	Low	77	64	73	5.281	0.260
	Medium	23	34	27		
	High	0	0	0		
Perceived causes of poor soil fertility						
Soil erosion	Yes	58	66	71	23.999	0.000
	No	42	33	29		
Inadequate application of fertilizer	Yes	69	79	20	4.498	0.105
	No	31	21	80		
Absence of fallowing	Yes	61	54	70	4.888	0.087
	No	39	45	30		
Water logging	Yes	99	95	96	3.060	0.216
	No	1	5	4		

Table 8. Respondents perception of soil erosion in their locality.

Perception of soil erosion	Response	Percent of respondents			X^2	p
		Low land	Mid-altitude	High land		
Awareness of soil erosion as problem (N = 117)	Yes	97	100	98	12.567	0.050
	No	3	0	2		
If yes: how serious is the problem? (N = 114)	Low	26	2	3	94.964	0.000
	Medium	6	23	6		
	High	68	71	91		
Observed change in the intensity of soil erosion over the last 20 years	Increase	58	90	74	40.626	0.000
	No change	5	0	9		
	Decrease	37	10	27		
Do you believe erosion can be controlled?	Yes	100	98	95	3.809	0.149
	No	0	2	5		
Status of soil erosion protection structures	Totally removed	29	12	3	29.908	0.000
	Partially removed	69	84	92		
	Well maintained	2	4	5		

4. Conclusion

Most studied soil quality/fertility parameters showed changes associated with LC type and across elevations within different circumstances of change. LC change from natural ecosystems (WL) to CL and GL influenced the distribution and content of soil particles, pH, calcium, potassium, total nitrogen and phosphorus across the catchment. Calculated deterioration indices of soil quality parameters (SOC, total N, P, K) at the surface layer (0 - 30 cm) showed negative in LC types from their values under WL cover. Soil parameter under CL showed the most negative cumulative effect (−388.82 percent) followed by GL (−387.29 percent), indicating deterioration in soil quality due to deforestation. The conversion of natural forest (native WL) to different land uses without proper soil conservation and management practices resulted in the overall decline of soil quality. Soil analysis confirmed declining trends of soil fertility quality, which farmers confirmed, was attributed to soil erosion, overcultivation, low fertilizer input and monoculture cropping system practiced by many farmers. Soil quality degradation is of concern for local communities, as it prevents food production increase and sustainable use of land resources. Therefore, practicing appropriate land resource management in order to promote sustainable agricultural development and environmental health in the study catchment is important. Further research on soil (quality) and integrated land resources in order to introduce land use planning for sustainable land resource management practices in the Melka Wakena catchment are required.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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