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ABSTRACT: Change in land-use management practices such as cultivation of steep slopes, overgrazing, and no or limited fallow periods, and slope position affects the quality of soils. As a result, assessing soil physicochemical properties and subsequent implications on soil fertility is essential for understanding the influence of agro-ecosystem revolution on agricultural soil quality and efficiency. In this research, we assessed the effect of land-use management practices on selected soil properties under varying terrain slopes and with and without soil conservation measures in a highly disturbed landscape in the northern part of Ethiopia in 2016. Based on the result, for all slope positions considered—namely, lower (1%-15%), middle (15%-30%), and upper (30%-45% and above)—with and without soil conservation, soil moisture content, porosity, silt, and clay proportions were lower in the cultivated land compared with grazing and forestland-use units. Conversely, soil bulk density and the sand fraction were higher in the cultivated land than grazing and forestland units, relatively. Observing changes in a terrain slope position, sand content of forest, grazing, and cultivated land units increased from lower to upper slope position whereas silt and clay fraction generally showed a decreasing trend from lower to an upper slope positions. In all slope positions with and without conservation practice, cation exchange capacity, exchangeable K^+, Ca^{2+}, and Mg^{2+} showed a significant increase from cultivated land to grazing and then forestland. The mean value of pH and electrical conductivity of cultivated lands with and without soil conservation were significantly low in all slope categories. Summarizing the analysis of variance for selected soil chemical properties with different slope positions, except available phosphorous, all chemical properties considered in this study are statistically significant ($P < .05$). In summary, the result confirmed that soil properties were strongly influenced by terrain slope, land use, and changes in management practice. Consequently, to conserve soil resources, policymakers need to implement appropriate land conservation strategies based on land-use structure and slope variation.

KEYWORDS: Land-use types, slope, soil properties, Kabe watershed, Ethiopia

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Introduction

Land-use management practice changes such as cultivation of steep slopes, overgrazing, and no or limited fallow periods, and lack of institutions to enact regulations or laws that enhance sustainable land management practices have remarkable effects on the dynamics of soil properties.[1-3] Land-use changes from forest cover to cultivated land may reduce input or organic residues that lead to a decline in soil fertility,[4] increased rates of soil erosion,[5] loss of soil organic matter, and nutrients.[6]

Changes in land cover density and intensification of agriculture aggravate the leaching rate of soil organic matter and nutrients,[7] and an accelerated rate of land degradation.[8] The cliché is also true, for example, integrated management of arable soil is the key to deal with most complex soil properties, thereby maintaining the land cover dynamics.[9] For example, a study conducted in the karstic regions of Romania focusing on the relationship between soil chemistry and land use while forest is converted into agricultural land indicated that land-use changes have a significant impact on soil properties and in some cases they are considered to be among the main threats to soil erosion.[8] Zajícová and Chuman[8] also highlighted that a mosaic of 6 different land uses where 60 soil samples were analyzed for cation exchange capacity (CEC), pH, accessible P, total N, base saturation, amount of Ca^{2+}, Mg^{2+}, K^+, and soil organic carbon showed very low concentrations of analyzed elements. It has also been noted that current extensive arable land use exhibited the lowest values of soil organic carbon.[8,10]

Ethiopia is part of the dynamic land-use management change where more than 90% of the country's highlands were once forested. A study conducted to assess the trend of land degradation and sustainable land management practices of Ethiopian highlands in 2010[11] indicated that the average percentage of forest cover during the year 2010 was well below 4%.[11] A research conducted in the near vicinity of the area, northwestern Ethiopia,[12] indicates that land cover change in the area and country at large was an outcome of natural and socioeconomic factors and their usage by man both in time and space. According to the findings of Nyssen et al[13] in the Ethiopian and Eritrean highlands, a dominantly mountainous country with highly erodible soils on steeply sloping land loses an estimated 1 billion tons of topsoil each year mainly as a result of water and wind erosion. Both forms of erosion can therefore appropriately define human impacts on the environment and land degradation in the Ethiopian and Eritrean highlandsregion. Soil erosion selectively detaches the fertile fractions of soils and carts them away in runoff.[14] Soil colloids are required for soil fertility, structural stability, favorable pore size distribution, and aggregation.[15]

One of the most important key factors enhancing land degradation in some regions of Ethiopia are farming on steep and breakable soils, in-adequacy of investments for soil conservation, and declining use of fallow.[10,11] In addition, unpredictable and erosive rainfall patterns, incomplete recycling of manure and crop rests to the soil, partial application of external sources of plant nutrients, deforestation, and overgrazing significantly enhances land degradation.[16,17] Thus, with appropriate management of the factors controlling erosion and degradation, it is possible to increase agricultural productivity and reduce poverty.[18] Thus, every effort should be directed to maintain the physical, biological, and socioeconomic environment for the production of food crops, livestock, wood, and other products through sustainable use of the ecosystem.

Land-use change is a general term for the variation and conversion of the earth's surface by human factors and natural events such as flooding, fire, and climate fluctuations.[19] On the contrary, land cover, in its narrowest wisdom, often assigns only the plants that are either natural or man-made on the earth's surface.[20] Knowledge of the allocation of land use and land cover is essential for preparation and management activities.[21] Land-use change is active and it provides a complete understanding of the interaction and relationship of anthropogenic activities with the surroundings.[22] Changes in land-use practices are strongly linked with direct and indirect human actions that puts long-term pressure on the environment thereby aggravating land-use transformation. Changes from farming land to residential use and degradation of land by overgrazing and deforestation are examples of the land-use transformation.[23] According to Deribew and Dalacho,[23] for example, over the course of 60 years (1957-2017), the direction and extent of land-use land cover have become more dynamic in the central highland of Ethiopia. He highlighted that there has been a 37.8% reduction in the forest cover while the agricultural land use has shown a 36.7% increase in areal coverage, which means that the average net change for forest was negative with varying rates of deforestation.

In Ethiopia, the contribution of agriculture to the national economy is strongly linked to rainfall patterns and this is reflected particularly in the Blue Nile Basin of Ethiopia where agriculture is practiced in a sloping landscape.[24,25,26,27] In these areas, land degradation is obvious and soil and water conservation (SWC) practices such as implementation of different types of terraces, contour farming, bunds, cut off drains, and vegetative strips are mainly applied. In spite of the effort to implement conservation measures, the persistent land degradation issue in the farming systems attracted the attention of many researchers and have raised to top policymakers in recent years. Some of the many studies included assessment of the effect of SWC on discharge and sediment yield[25,28] and ddeterminants for adoption of physical SWC measures.[29] In Ethiopia, a large proportion of the human population depends almost entirely on natural resources for their livelihoods that brought about an increasing competing demand for usage, development, and sustainable management of land resources. Soil properties are also affected by terrain slope and land-use distribution.[30]

Soils vary widely as a function of their position on the landscape[31-33] and agricultural management, land use, and cultivation intensity.[24,34] To account for unpredicted soil property spatial variation and relationships, Weill et al[35] recommend employing geostatistical analysis tools. Ceddia et al[36] indicated that soil physical properties are related to topography over a landscape, which could be mapped using cokriging point iteration with topography as an auxiliary variable. For example, based on a grid scheme field observation, Vauclin et al[37] used geostatistical concepts employing krige and cokrige to assess the spatial variability of available water content, sand, silt, and clay. In addition, the spatial variation of soil properties can be determined using pedo-transfer functions (PTFs).[30,38]

As a result, assessment of soil-topography relationships is an important tool used by pedologists in soil classification and mapping.[36] Soil physicochemical properties are related to topographic heterogeneity,[36] and changes in soil properties could affect soil water content, vegetation response,[37] and the rate of land-use change.[35,40] In addition, as an important indicator of topography, terrain slope has a clear effect on the rate of erosion,[36,41] thereby affecting the soil and pattern of land use. According to Opršal et al,[42] environmental factors are more influential in areas with greater topographic heterogeneity. Among which soil properties, climate, and topographic factors would be expected to affect land-use change,[43] which, in turn, will have a substantial effect on soil properties such as fertility, carbon content, and soil texture.[44-46]

The main goals of this research are to (1) explore the effect of land-use types (LUTs) and slope position on soil physiochemical properties and (2) examine the interactive effect of SWC practices, LUTs, and slope position on soil physiochemical properties. To achieve these objectives, we used the information set from static landscape datasets (soil, land use, and elevation) to collect field soil physicochemical properties at different land use and slope positions followed by laboratory procedures.

Methods of the Study

Study area description

The research is conducted in the Kabe watershed (39° 24′ 30″ to 39° 27′ 8.7″ E and 10° 47′ 14.1″ to 10° 53′ 35.8″ N) in Were Ilu

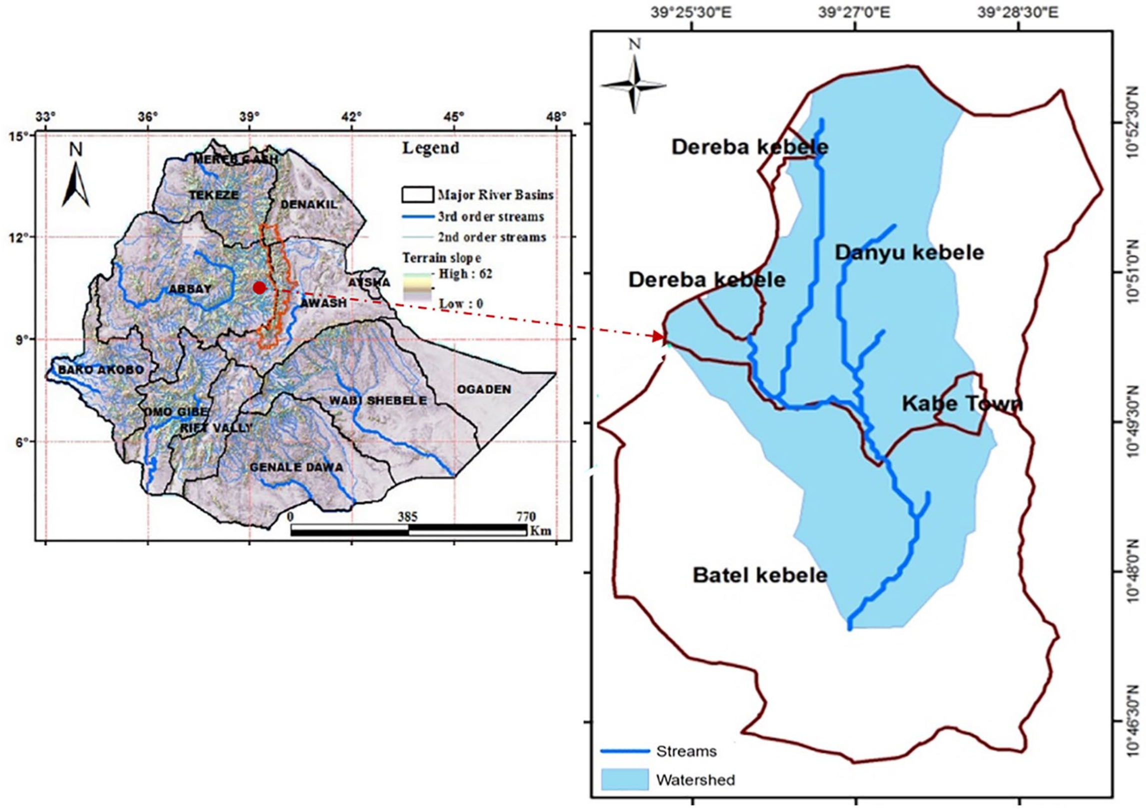

Figure 1. Location map of the study area: terrain slope, geographical setting of major river basins, and network of streams (left) and Kabe watershed (right).

district, about 470 km north of Addis Ababa (38.7578° E, 8.9806° N). The watershed (Figure 1) lies to the North of Yewol mountain and water flows from Yewol to Selgie river in its way to join Jemma river, sub-basin of the Ethiopian Blue Nile.

According to the South Wollo Zone bureau of finance and economic development report, the population size of Were Ilu is about 162 874 (2009 census) and has a 5.7% share of the zone's total population.[47] Out of the total population, nearly 95% lives in rural areas and the remaining 5% in small towns. The population density is 106.7 persons per km^2. This indicates that it is one of the highly populated areas in the country.[47]

Almost all households in Were Ilu district are dependent on subsistence crop farming. Rainfall is bimodal allowing some farmers to produce twice a year.[48] Based on Ethiopian National Meteorology Authority, Kabe Wollo station datasets, the mean annual air temperatures and rainfall of the area is 14.8°C and 1215.6 mm, respectively. In recent years, however, except some mountain-dominated areas such as Kabe watershed, plain landscapes do not receive much rainfall during spring season (except short rains between March and April exist). Most farmers in the Were Ilu district produce only once during the autumn season when rains are generally received between July and September.

Soil sampling design and land cover distribution

Delineation of dominant land-use classes and terrains slope positions defines the required number of composite soil samples per each LUT for soil physical and chemical analysis. Agricultural and grazing land units are the dominant LUTs in Kabe watershed. Agricultural lands are mainly found in agriculturally accessible areas and downhill. Grazing lands, on the contrary, are mostly situated on moderately steep terrain slopes and around the homestead area of a community. The soil in the area is plow with traditional agriculture and tillage frequency ranges from 1 to 4 times per cropping season,[49] depending on crop types usually owned and managed by individual farmers.

The spatial sampling technique involved classification of landscape in varying slope positions as lower (1%-15%), middle (15%-30%), and upper (30%-45% and above) slope positions. These slope classes are selected based on the availability of the same slope classes at different land-use units. Representative sampling fields were then selected based on vegetation and cultivation history, which was categorized as forest, grazing, and cultivated LUTs.

Following the identification of 3 different land-use classes across the watershed and classification of the terrain in 3 slope ranges, a total of 54 composite soil samples were collected at the depth 0-30 cm from each of the LUTs (ie, forest, grazing, and cultivated land) stratified into upper, middle, and lower slope positions. The samples are taken both at conserved/treated and unconserved/untreated areas considering different land-use units on May 2016. Data were collected at 3 slope positions for 3 different LUTs both at treated and untreated areas totaling to 54 samples (ie, 2 treatments × 3 LUTs × 3 slope positions × 3 replicates). At each point, soil samples were taken using a 5 cm diameter auger and core sampler for bulk density analysis. Each of the composite soil samples was collected from a 10 m × 10 m at least 100 m apart demarcated plots. A total of 18 core soil samples were collected in a randomized complete block design for laboratory analysis. To make 1 composite soil sample, 1 kg of each subsample was mixed well and about 1 kg of the mixed composite samples was properly labeled. Finally, 54 total composite soil samples were prepared and gently sieved through a 2-mm mesh to remove stones and roots, and were sealed in plastic bags for laboratory analysis.

The major geologic parent materials of the area are Cenozoic volcanic rocks particularly Tarmaber–Megezez formations (transitional and alkaline basalts).[50,51] Studies by Hailu et al[50] indicated that the major soil types in the area typified with world reference base for soil classification system[52] are haplic leptosols (eutric, ferric), leptic cambisols (orthoeutric, ferric), vertic luvisols (clayic, ferric), and stagnic vertisols (hypereutric, ferric) covering nearly 51.4%, 24%, 14.6%, and 10% of watershed total.

Soil sample preparation and laboratory analysis

Following the field procedure, composite soil samples were air-dried, mixed, and pasted via a 2-mm sieve for selected soil physicochemical properties. Eighteen undisturbed core samples from all land use and at varying slope positions (lower, middle, and upper) were used to parametrize selected soil physical properties such as soil bulk density, total porosity (TP), and soil gravimetric moisture content. During soil chemical analysis, after removing soil Organic Matter (OM) content using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexametaphosphate ($NaPO_3$), soil particle size distribution analysis was determined by the Boycouos[53] hydrometric technique. Besides, we analyzed soil total N content, pH, CEC, and exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) using the method explained in supplementary table (Table s1).

Statistical analysis

Statistical analyses were carried out using the Statistical Package for Social Science (SPSS; it is a software package used for the analysis of statistical data). The soil property data generated through laboratory analysis were then assessed using the general linear model (GLM), procedure of the statistical analysis system as a tool for statistical analysis to breakdown the mean, standard error, *F* and *P* values, and test significance of differences between each soil properties based on different independent/fixed variables. Descriptive statistics, analysis of variance (ANOVA; a statistical method in which the variation in a set of observations is divided into distinct components), and Pillai's trace test was employed for mean separation for the soil physiochemical properties that were found to be statistically significant. The effect of LUTs, SWC practices, and slope positions against soil physiochemical properties and their interactions were tested at $\alpha = .05$.

One-way ANOVA was used to analyze the mean values of different physiochemical properties of soil as dependent variables. This included soil texture (sand, silt, clay, silt/clay), bulk density,[2] soil moisture,[54] silt–clay ratio (SCR), TP, soil reaction (pH), electrical conductivity (EC), soil organic matter content,[47] total nitrogen,[11] available phosphorous (AP), CEC, exchangeable bases (Calcium [Ca], magnesium,[45] sodium [Na], potassium [K]), and percentage base saturation (PBS). The independent variables are LUT, slope position, and treated/untreated SWC areas. Percentage changes in the soil physiochemical properties of cultivated and grazing land units compared with forestland were explained as

$$CI = \left(\frac{C_{L,\ orGL} - F_L}{F_L} \right) \times 100 \quad (1)$$

where C_L represents percentage changes in the mean value of soil physiochemical properties of cultivated or grazing land compared with forestland units. C_L, G_L, and F_L are mean values of soil physicochemical properties for cultivated, grazing, and forestland use, respectively. Sample site LUTs are dominantly agricultural, grazing and forest, which can be validated with the recent planimetric surveys. Figure 2 shows watershed and stream definition (top left), elevation, and 100-m interval contour map (top right), and study aerial photo observation showing various LUTs and slope positions with (lower panel). The spatiotemporal land cover distribution for 3 snapshots, namely, 1986, 2000, and 2015 and the aerial view of the terrain topography is also shown in Figure 3.

Result and Discussion

Effect of land uses on selected soil physical properties

Table 1 summarizes the SPSS and ANOVA for the selected physical property of soil concerning land use. From the table, silt and sand are statistically significant ($P < .001$). From the ANOVA, it is also found that there is a significant difference ($P < .05$) for clay (%), SCR, BD, and TP (most soil physical

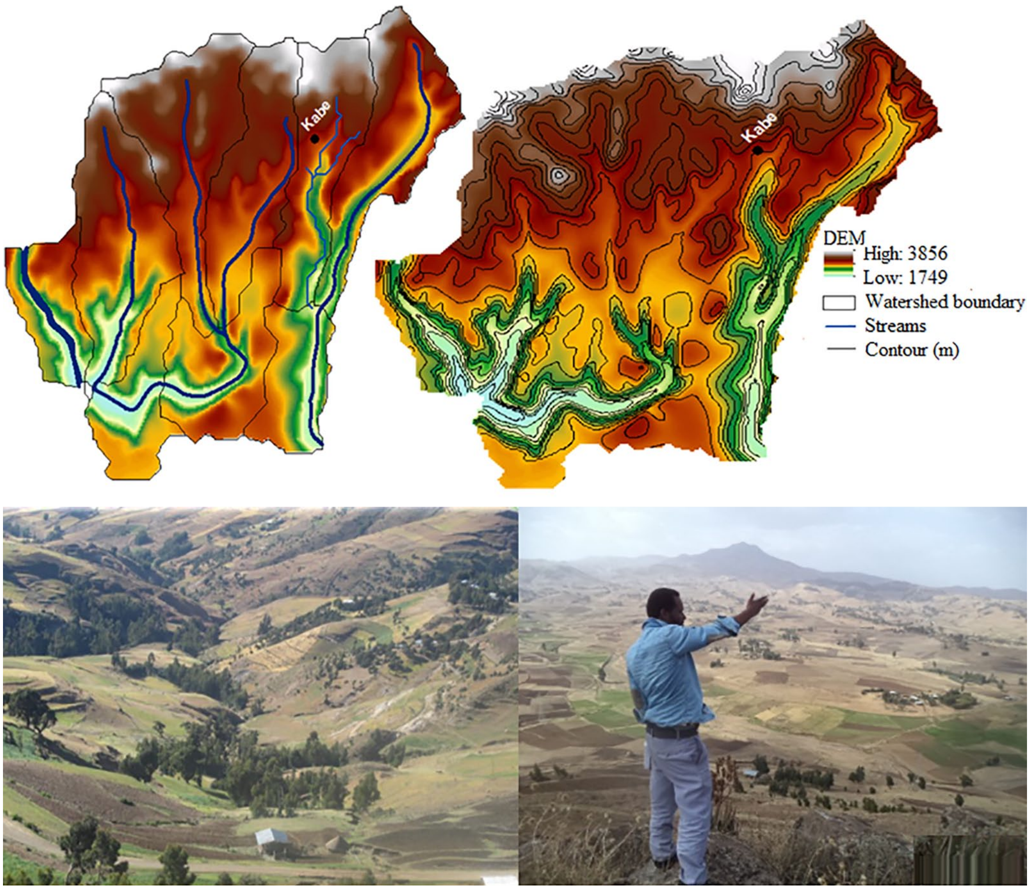

Figure 2. Watershed and stream definition (top left), terrain elevation and 100-m interval contour map (top right), and land-use distribution and study photo observation showing various LUTs and slope positions (lower right). The field researcher, Fikru Assefa, pointing to the various terrain topographies in the study area and the different land cover types. LUT indicates land-use type.

properties were direct affect by LUTs in the study area). The mean value of sand fraction (66%) was highest in cultivation areas followed by grazing (48%) and forest (30%), it means the cultivated area was eroded by soil erosion, low water holding capacity, and others. On the other hand, soil structural composition for forestland use has the highest both for silt and clay accounting 35% (it may be high water holding capacity). Soil moisture (31.33%) is nearly equally abundant both in the grazing and forestland-use units. From the table, it is also shown that TP is highest in the forestland followed by grazing land use accounting 55.16% and 51.16%, respectively.

On the contrary, it is also indicated that except soil moisture, which is not significant, all other soil physical properties considered in this study (viz, sand, silt, clay, SCR, BD, and TP) are highly significant. Soil moisture in the grazing and forestland-use units is relatively higher, which may result from the dominant composition of silt and clay typified by increased water holding capacity. Conversely, soil moisture is lowed in the cultivated areas characterized by sandy texture (66%).

Effect of LUT and conservation practice on selected soil physical properties

Soil physical properties were considerably influenced by changes in land use and the implementation of conservation practices.[28] As can be seen from Table 2, soil bulk density,[2] gravimetric soil moisture content, soil porosity, and proportion of soil texture (sand, silt, and clay) contents were significantly different under different LUTs. It is also shown that land uses with soil conservation structures have lower soil bulk density than land uses without soil conservation practice. Selassie et al[55] reported that progressive increase in soil bulk density due to continuous cultivation in the top plow layers might have resulted from a decline in the soil organic matter content and compaction from the tillage. Higher bulk density in the cultivated and grazing land units was the product of continuous shallow depth cultivation and dry season livestock trampling. Variation in soil bulk density could also result from the absence of soil conservation practices that removes soil organic matter. Soil bulk density of the forest, grazing, and cultivated land with soil conservation had lower bulk density than land uses without soil conservation. Lower grazing

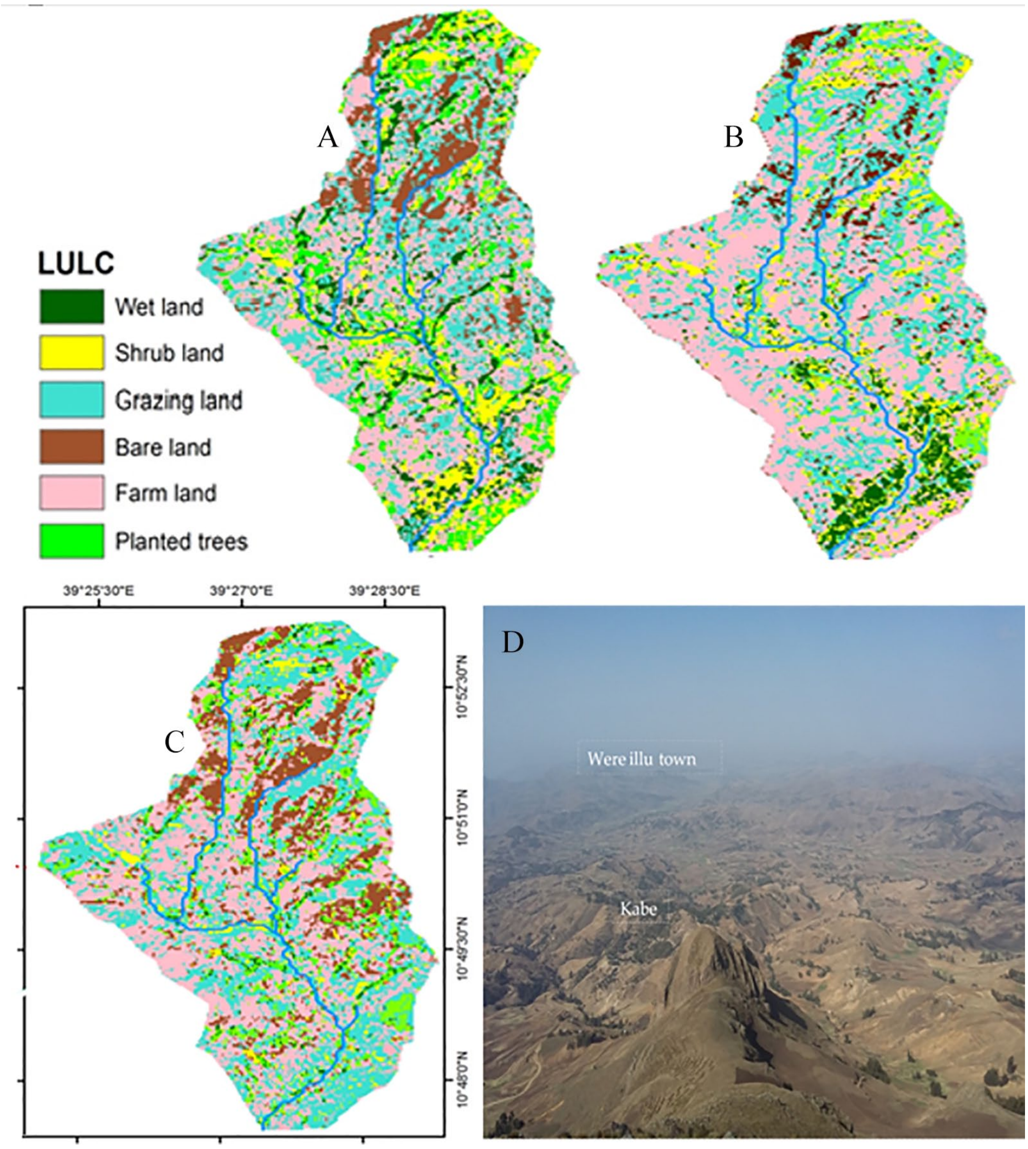

Figure 3. Study area land-use land cover maps (LULC) from 1986 (A), 2000 (B), and 2015 (C). Top view of the area (D) will show the real terrain topography environment of the study area (Photo credit: Fikru a Assefa, January 29, 2016).

Table 1. Effect of land use (Forest, Grazing, and Cultivated) on selected soil physical properties in Kabe watershed.

PROPERTIES	FOREST	GRAZING	CULTIVATED	MEAN	SE	*F*	*P*	SIGN
Sand (%)	30	48	66	48	2.14	172.428	.000	***
Silt (%)	35	30	20	28	0.903	239.70	.000	***
Clay (%)	35	20	15	23	1.442	58.39	.021	***
SCR	1.01	2.19	1.36	1.52	0.181	4.15	.012	***
BD (g/cm^3)	1.22	1.32	1.36	1.30	0.0198	4.796	.000	***
Soil moisture	31.33	31.33	22.27	28.31	0.905	18.429	.069	NS
TP (%)	55.16	51.16	49.38	51.90	1.051	2.821	.000	***

Abbreviations: BD, bulk density; NS, not significant; SCR, silt–clay ratio; TP, total porosity.

intensity in the forestland area might have also resulted in increased soil water content, which in turn increased soil organic matter.[56] For all LUT and conservation practices (Table 2), the mean sand, silt, clay, SCR, BD, SM, and TP does not show any significant variation with and without SWC measure; however, the individual mean of soil physical properties explained the

Table 2. Effect of land-use type and treatment conditions on selected soil physical properties.

PROPERTIES	FOREST	GRAZING	CULTIVATED	MEAN	SE	*F*	*P*	SIGN
Treated								
Sand (%)	31	46	65	48	0.793	67.99	.00	***
Silt (%)	34	31	20	28	0.268	110.9	.00	***
Clay (%)	37	18	16	24	0.802	24.6	.00	***
SCR	0.93	3.1	1.3	1.53	0.159	4.09	.004	***
BD	1.1	1.2	1.3	1.3	0.01	35.64	.00	***
SM	32	32	23	28	0.717	7.3	.00	***
TP	59	57	54	51	0.792	9.1	.00	***
Untreated								
Sand (%)	30	49	67	48	0.793	67.99	.00	***
Silt (%)	36	30	20	28	0.268	110.9	.00	***
Clay (%)	35	23	15	24	0.802	24.6	.00	***
SCR	1.1	1.3	1.4	1.53	0.159	4.09	.004	***
BD	1.4	1.4	1.5	1.3	0.01	35.64	.00	***
SM	31	30	22	28	0.717	7.3	.00	***
TP	52	45	44	51	0.792	9.1	.00	***

Abbreviations: BD, bulk density; SCR, silt–clay ratio; SM, soil moisture; TP, total porosity.

change. Other studies conducted in different parts of the world supports our findings.

For example, a study conducted to assess the effects of SWC measures on soil quality indicators in the Gojeb river catchment of Ethiopia[57] indicated that farmlands with SWC measures had relatively improved soil physical properties such as volumetric soil water content, and clay and silt fractions compared with farmlands without SWC measures. They also highlighted that soil chemical properties such as pH, OC, TN, C: N ratio, and AP have showed an improvement under SWC practice than without. Other studies have also shown land use–soil–slope interactions in assessing the effect of land management practices on soil physical and chemical properties in the other part of Gojeb river, Southwest Ethiopia.[29,58] According to Bezabih et al,[58] several soil physical–chemical properties showed slight variations among land uses in association with and without soil bund under different slope category. They found low gravimetric soil moisture content, soil porosity, and silt and clay proportion in the cultivated land with and without soil bund compared with areas covered by fallow and woody land with and without soil bund for all slope categories. However, sand fraction and soil bulk density were found to be highest in the cultivated land than woody and fallow land units.

In addition, a research-based evidence on the effects of SWC practices on soil physicochemical properties in the northwest highlands of Ethiopia[59] indicated that SWC practices tended to increase soil fertility and most of the soil chemical properties showed relative change with landscape positions. Guadie et al[59] highlighted that raising awareness and convincing farmers toward SWC practice is essential for future sustainable land management. Other studies conducted to assess variations in soil properties under different LUTs in southern Ethiopia[60] supported our finding and indicated that change in LUT, slope category, and management practice significantly affected soil textural fraction (silt, sand, and clay), soil pH, EC, OC, bulk density, and TN.

Effects of slope positions on selected soil physical properties

Table 3 summarizes the ANOVA for selected soil physical properties with a slope position. From the table, except clay, silt/clay, and BD, all other physical properties of soil considered in this study are not statistically significant ($P \leqslant .05$) by slope position. As can be seen from Table 3, all variables showed considerable varying records under various slopes. However, from the ANOVA, it is also found that BD and SM showed no variation in middle and lower slope positions. It is also indicated that except TP, sand and silt content, all other soil physical properties are highly significant by slop positions. Alternatively, in upper slope position, sand was higher and soil moisture is low. It means that, in all sandy soil, its water holding capacity is poor. In the lower slope of our study area, its soil moisture is high due to soil erosion push fertile soil from the upper slope

Table 3. Effects of slope positions on selected soil physical properties.

PROPERTIES	UPPER SLOPE	MIDDLE SLOPE	LOWER SLOPE	MEAN	SE	*F*	*P*	SIGN
Sand (%)	54	48	42	48	2.08	2.6	.083	NS
Silt (%)	27	28	30	28	0.90	1.03	.366	NS
Clay (%)	18	25	29	24	1.32	5.88	.005	***
BD	1.4	1.3	1.3	1.3	0.02	3.36	.042	**
SM	27	29	29	28	0.91	0.74	.483	**
TP	46	52	58	52	0.82	18.62	.000	NS

Abbreviations: BD, bulk density; SM, soil moisture; NS, not significant; TP, total porosity.

position to it and its clay contents were higher. Several author studies confirmed the effect of slope positions on soil physical properties.

For example, Rodrigo-Comino et al[61] clearly highlighted the effect of slope positions on selected soil physical properties. Their results of chemical and physical analysis in Mediterranean hillslope vineyards of Montes de Málaga, Spain, showed that, although the average values are similar, materials bigger than 2 mm were predominant along middle and upper slope positions, slope > 55%, and under the vines (56.7%). Rodrigo-Comino et al[61] noted the existence of mean variations in soil physical and chemical properties at varying slope positions. They found that although tillage practices tended to homogenize the soil properties among slope positions, it is not always the case. For example, while all studied samples have a texture silt loam with exceptions of silt along the middle and foot slopes under vines (≈80%), highest concentration of sand was located along the middle slope and under vines (≈30%).

Other studies similar to Rodrigo-Comino et al[62] conducted to understand the soil erosion process and statistics of mobilized fine soil particles at varying slope positions in the Mediterranean sloping vineyards (Montes de Málaga, Spain) strengthen this finding. According to Rodrigo-Comino et al,[62] the size and distribution of several soil physical–chemical properties showed slight variations under different slope categories, which later affected the rate of soil loss, overland flow, and runoff threshold. It was found that catchment hydrologic response showed high variability depending on the soil texture such as sand, silt, and clay composition; stoniness; and antecedent conditions of tillage. It was also indicated that the sloping vineyards were typified with bare soils associated with high soil losses and an uneven spatiotemporal distribution of hydrogeomorphological processes.

Effect of LUT and slope position on selected soil physical properties (interaction effect)

For all LUTs and slope positions (Table 4), the means of soil physical properties (viz, sand, silt, clay, SCR, BD, SM, and TP) do not show significant variation with slope position but all affect significantly. However, it is also indicated that there are changes for individual variables under different LUT. For example, for soil texture variables, sand, silt, and clay, the overall mean value in all slope positions is 48%, 28%, and 24%, respectively. Considering changes in the sand, silt, and clay percentage for cultivated land, for example, the respective values are 71%, 17%, and 13% for upper slope; 66%, 21%, and 15% for middle; and 61%, 23%, and 18% for lower slope positions. This clearly showed the decreasing nature of clay content with a decrease in slope (when we go from upper to lower slope positions). On the contrary, silt and sand contents showed a steady increase with a decrease in terrain slope (we go from lower to upper slope positions). Besides, in the cultivated land unit, SCR does not show a significant difference in upper and middle slope positions, whereas changes have been observed for SM, BD, and TP. For the same land use, soil bulk density seems unaltered in the middle and lower slope positions.

As can be indirect from TP concentration for upper, middle, and lower slope positions (46, 51, and 58, respectively), in grazing intensity and soil erosion vulnerability is higher in upper slope than middle and lower positions. The mean value of bulk density was comparatively higher in the cultivated and grazing land and appears to be smaller in forested areas. A study conducted to assess the effect of land management practices on soil physicochemical properties in a tributary of Gojeb river, Ethiopia's southwest region, indicated that an increase in bulk density with an increase in terrain slope position in the cultivated and grazing areas might be attributed to continuous cultivation and livestock trampling effects.[58] An increase in bulk density may also result from excessive dry season livestock trampling and continuous shallow depth cultivation. Bezabih et al[58] highlighted that soil bunds play a vital role in controlling the variation of soil bulk density by collecting the soil organic matter, thereby weakening the natural stability of soil aggregates and facilitating its susceptibility to erosion. They also indicated that soil condition in forestland areas was more desirable than in cultivated land-use units resulted from the percentage of vegetation.[58] Lower grazing intensity in forestland cover might have resulted in increased soil moisture which improves soil structure, and subsequently increased organic matter.

Table 4. Effect of LUT and slope position on selected soil physical properties.

LUT/SLOPE	SAND (%)	SILT (%)	CLAY (%)	SCR	BD	SM	TP
Upper slope							
Forest	41	34	28	1.2	1.3	29	48
Grazing	50	30	13	4.1	1.4	31	46
Cultivated	71	17	13	1.4	1.5	21	45
Mean	48	28	24	1.5	1.3	28	51
SE	0.252	0.194	0.406	0.138	0.018	0.651	0.781
F	473.45	137.91	78	6	2.3	7	6.4
P	.000	.000	.000	.000	.035	.000	.000
Sign	***	***	***	***	***	***	***
Middle slope							
Forest	30	35	36	0.9	1.2	36	56
Grazing	49	30	24	1.2	1.3	30	51
Cultivated	66	21	15	1.4	1.3	21	48
Mean	48	28	24	1.5	1.3	28	51
SE	0.252	0.194	0.406	0.138	0.018	0.651	0.781
F	473.45	137.91	78	6	2.3	7	6.4
P	.000	.000	.000	.000	.035	.000	.000
Sign	***	***	***	***	***	***	***
Lower or back slope							
Forest	21	37	44	0.9	1.2	29	62
Grazing	45	31	25	1.2	1.3	34	58
Cultivated	61	23	18	1.3	1.3	26	56
Mean	48	28	24	1.5	1.3	28	51
SE	0.252	0.194	0.406	0.138	0.018	0.651	0.781
F	473.45	137.91	78	6	2.3	7	6.4
P	.000	.000	.000	.000	.035	.000	.000
Sign	***	***	***	***	***	***	***

Abbreviations: BD, bulk density; LUT, land-use type; NS, not significant; SCR, silt–clay ratio; SM, soil moisture; TP, total porosity.

Alternatively, soil TP showed a decreasing trend with an increase in terrain slope for all land-use classes (Table 4) and TP was also recorded lower in the untreated land-use classes (Table 4). In this case, soil bulk density and soil TP are inversely related, an increase in soil bulk density showed a decrease in soil TP, and vice versa. As can be seen from Table 2, all land uses assisted with soil conservation practices have comparatively higher soil moisture content than land uses without conservation practices. This could be attributed to the presence of soil bunds that improves soil organic matter, which enhances soil TP thereby increasing the soil water holding capacity.

Gravimetric soil moisture content was found to be significantly different for varying land-use classes. For forestland cover both with and without any treatment (SWC) practice, significantly higher soil moisture continent was recorded (Table 2). In addition, in forestland types in the middle slope positions, significantly higher soil moisture continent was recorded. Also, for all slope positions considered, soil moisture content was lower in cultivated land than forest and grazing land in the study areas (Table 4). Generally, changes in soil moisture content showed a varying trend for land uses treated with and without soil conservation practices. Considering changes in a slope position, soil moisture content showed the unpredictable trend in either of the

Table 5. Effect of land-use types (forest, grazing, and cultivated) on soil chemical properties.

PROPERTY	FOREST	GRAZING	CULTIVATED	MEAN	SE	*F*	*P*	SIGN
pH (H_2O)	5.84	5.51	5.19	5.51	0.423	74.56	.000	***
EC	0.168	0.118	0.100	0.129	0.0048	51.00	.000	***
OC	3.05	2.48	1.86	2.46	0.074	98.34	.000	***
TN	0.267	0.216	0.161	0.215	0.0078	35.43	.000	***
AP	4	3	2	3	0.1517	46.31	.000	***
CEC	27	19	13	20	0.895	111.82	.000	***
Ca	29	27	19	25	0.986	14.40	.000	***
Mg	3	3	3	3	0.090	7.55	.001	***
Na	0.00	0.00	0.00	0.00	0.00	–	–	–
K	0.444	0.388	0.00	0.277	0.061	6.17	.004	***
BS	77.05	74.72	65.66	72.48	1.769	4.33	.018	***

Abbreviations: AP, available phosphorous; CEC, cation exchange capacity; EC, electrical conductivity OC, organic carbon; TN, total nitrogen; PBS, percent base saturation.

sloping directions, from upper to lower and vice versa for all LUTs and conservation practices (Table 4).

The mean values of sand, silt, and clay contents that define soil texture for the 3 land-use classes with soil conservation practices were significantly different in comparison with adjacently located similar LUTs without soil conservation practice. Cultivated land is characterized by a significantly higher proportion of sand content than forest and grazing land uses with and without soil conservation practices (Tables 5-7). It indicated that cultivated land in Kabe watershed was characterized more eroded and its soil fertility was very low because its water holding capacity is very low, and its clay soil contents were very low (ie, its organic matter contents were very low). In contrast, forestlands had the lowest mean value of sand fraction and the highest silt and clay contents. For all land-use classes and slope positions considered, there was a slight variation of sand, silt, and clay fraction between land uses (Table 4).

Soil texture is affected by the degree of intensity of cultivation, which could contribute to the variations in particle size distribution at the surface horizon of cultivated land units. Regarding changes in a terrain slope position, sand content of forest, grazing, and cultivated land units increased from lower to upper slope position whereas silt and clay fraction generally show a decreasing trend from lower to upper slope position (Table 4). Bezabih et al[58] reported that this could be attributed to the decrease in organic matter resulted from soil erosion, which reduces supper slope clay content.

Effect of changes on soil chemical properties

Effect of LUTs on soil chemical properties. Table 5 summarizes the SPSS, ANOVA for selected soil chemical properties with land use. From the table, all chemical properties considered in the Kabe watershed are statistically significant ($P < .001$), except PBS. The pH and EC are among the soil chemical properties that are highly affected by changes in land use and management practice. They both tend to increase with an increase in soil land cover and decrease with the intensity of agriculture. As a result, higher pH and EC values were observed in the forest and grazing lands and the values were lowered at cultivated land-use areas (Table 5). Researches[58] reason that pH value in the cultivated land might have been lowered as a result of extreme basic cation removal. Other research findings conducted in North West Ethiopia[55] stated that washing away of solutes and basic cations tended to lower soil pH value.

The mean value of pH (5.19) was lower in the cultivated land than grazing (5.51) and forest (5.84) covers, which indicates the forest and grazing land uses were moderately acidic than the cultivated lands (its soil contents are strongly acid). Except for Mg and Na, the other soil chemical properties considered in this study (ie, EC, OC, TN, AP, CEC, Ca, K, and PBS) were lowest in the cultivation areas and highest in the forest cover (ie, each mean values on cultivated < grazing < forestland-use types). On the contrary, soil structural composition for forestland use was the highest both for silt and clay accounting 35%. Soil moisture (31.33%) is nearly equally abundant both in the grazing and forestland-use units.

According to Landon,[63] pH value ranging from 5.1 to 5.5 is strongly acid, and a value range from 5.5 to 6.0 is classed as moderately acid. In this case, the cultivated land use is strongly acid compared with the other 2 land-use units. Landon[63] indicated that a value of soil organic matter less than 2% is classed as very low in organic matter content and a value range from 2% to 4% indicates low organic matter abundance. In this regard, organic matter was found highest in the forestland use compared with cultivated and grazing land. This could be attributed to the increase in organic matter in the forested areas than other land cover units considered.[58]

Table 6. Effect of SWC practices on selected soil chemical properties.

PROPERTY	TREATED	UNTREATED	MEAN	SE	*F*	*P*	SIGN
pH (H_2O)	5.46	5.56	5.51	0.042	1.374	.247	NS
EC	0.133	0.125	0.129	0.0048	0.712	.403	NS
OC	2.55	2.38	2.46	0.0749	1.260	.267	NS
TN	0.22	0.20	0.21	0.0078	0.536	.467	NS
AP	3	3	3	0.1517	3.511	.067	NS
CEC	21	19	20	0.895	1.114	.296	NS
Ca	27	23	25	0.9861	5.410	.024	**
Mg	3	3	3	0.0902	1.529	.222	NS
Na	0.00	0.000	0.000	0.000	–	–	–
K	0.29	0.25	0.27	0.0615	0.8	.767	NS
PBS	79.04	65.93	72.48	1.538	18.172	.000	***

Abbreviations: AP, available phosphorous; CEC, cation exchange capacity; EC, electrical conductivity; NS, not significant; OC, organic carbon; PBS, percentage base saturation; SWC, soil and water conservation; TN, total nitrogen.

Table 7. Effects of slope positions on selected soil chemical properties.

PROPERTIES	UPPER SLOPE	MIDDLE SLOPE	LOWER SLOPE	MEAN	SE	*F*	*P*	SIGN
pH (H_2O)	5.7	5.5	5.4	5.5	0.04	4.77	.013	***
EC	0.12	0.13	0.15	0.13	0.005	3.57	.035	***
OC	2.2	2.5	2.7	2.47	0.071	4.37	.018	**
TN	0.19	0.22	0.24	0.22	0.008	2.54	.089	NS
AP	2	3	3	3	0.143	4.52	.016	***
CEC	17	20	23	20	0.854	3.68	.032	***
Ca	26	30	19	25	0.77	17.99	.000	**
Mg	4	3	3	3	0.83	5.82	.005	***
Na	0.00	0.00	0.00	0.00	0.000	–	–	–
K	0.11	0.06	0.66	0.278	0.049	15.59	.000	***
BS	60	74	84	73	1.22	29.92	.000	***

Abbreviations: AP, available phosphorous; CEC, cation exchange capacity; EC, electrical conductivity; NS, not significant.

The causes for acidic soil development are known to be leaching of bases but this does not hold for the profile investigation; pH remained low while base saturation and contents of exchangeable bases are in the high range. According to Elias,[64] possible explanations might include acidic parent material, management practices that deplete organic matter and continuous application of acid-forming ammonium phosphate fertilizer such as di-ammonium phosphate (DAP) and UREA.

Plants require a correct balance of essential nutrients for healthy growth and performance. Most of the soil types investigated in the Ethiopian highlands are found to be deficient in several of the macro- and micro-nutrients, including N, P, K, and others.[65] On the contrary in Kabe watershed, soils' multiple nutrient deficiencies including phosphorus (P) and potassium (K) in Forest and cultivated LUT, respectively, were low (Table 5). The reasons for nutrient deficiencies are many and complex. Primary, it is the agronomical unbalance fertilizer regime that supplies only N and P in the form of DAP. This is believed to have exhausted the soil nutrient stocks as crops remove many more nutrients than just N and P. In particular, the uptake and deficiency of potassium and micro-nutrients (mainly Zn, Cu, B) can be emphasized due to continued application of N and P fertilizers alone.[66] Second, the low levels of fertilizer application result in mining soil nutrient stocks. The national average rate of application is about 29 kg/ha DAP or 17 kg/ha N–P nutrients,[64] which is very low compared with the average nutrient application of 48 kg/ha neighboring Kenya and the world average of 78 kg/ha.[67] Accordingly Alias[65] highlighted that such low and blanket application not only proved inappropriate but also irrelevant in the light of huge diversities in soil types that succeed in the country. However, these practices are slowly changing as the country transforms from the use of DAP and urea alone to site and soil specific blend fertilizer recommendations.

Effect of SWC practices on selected soil chemical properties. Table 6 summarizes the ANOVA for selected soil chemical properties about SWC practices. From the table, except PBS and calcium, all chemical properties considered in this study are not statistically significant ($P > .05$). Soil chemical properties were considerably influenced by the implementation of conservation practices. As can be seen from Table 6, all variables showed considerable varying records under various treatments. However, from the ANOVA, it is also found that AP, Mg, and Na showed no variation between treated and untreated areas. It is also indicated that excepting Ca and PBS, all other soil variables are non-significant. Soil chemical properties like EC, OC, CEC, Ca, K, and PBS are higher in treated areas than the untreated area in the study area. But, soil pH is higher in the untreated area in Kabe watershed. On the contrary, soil organic carbon (hence organic matter) in all LUTs and/or both treated and untreated areas of Kabe watershed is low (Tables 5 and 6). Low organic matter is driven by complete removal of crop residues from fields as livestock feed or burning for household energy. Animal dung is made into dung "cake" and used for household energy. This deprives the soil of an important source of organic matter and nutrients. Many forms of physical degradation such as topsoil erosion, loss of rooting depth, surface crusting, and so on are secondary features emanating from this basic cause.[64]

Effects of slope positions on selected soil chemical properties. Table 7 summarizes the ANOVA for selected soil chemical properties with different slope positions. From the table, all chemical properties except AP, considered in this study are statistically significant ($P < .05$). The ANOVAs also found significant affect at ($P < .001$) for Ca, K, and PBS. Soil chemical properties were considerably influenced by terrain slope positions. As can be seen from the table, all variables showed considerable varying records under various slopes. However, from the ANOVA, it is also found that Na showed no variation with changes in terrain slope. Besides, it is also indicated that excepting Na and AP, all other soil chemical properties are highly significant. It means that slope positions affect the chemical properties of soil in Kabe watershed. Finally, the mean values of most chemical properties except pH, Mg, Ca, and Na are higher in lower slope > middle slope > upper slope positions of the study area. We conclude that, when we go from upper to lower slope positions of the study area, the soil acidic contents are increased.

Effect of SWC and LUT on selected soil chemical properties (interaction effect). For all land-use units considered (Table 8), there is a relatively slightly higher pH value for forestland use without SWC measures than the same land use with SWC practices. This change in the value of pH could be attributed to changes in erosion response. SWC practices reduce surface runoff, thereby reducing the soil erosion rate, hence improving the availability of soil organic matter and enhancing crop growth. A relatively higher mean variation of EC was observed in forestland use with and without soil conservation practices (Table 8). On the contrary, cultivated land with and without SWC had the lowest EC in all slope positions (Tables 8 and 9). Results showed that for all the land-use classes considered with and without SWC, the mean EC values in forestland use increased from upper to lower slope position (Table 9). In reality, for hill slope—dominated catchments characterized by a significant change in slope position—soluble anions and cations move downward with surface runoff, accumulating suspended clay toward the lower slope. This, in turn, might have caused an increase in EC values down the slope.

In addition, for both land-use management practices, with and without conservation, pH and EC values showed an increase from Forest > Grazing land > cultivation land (Table 8). The mean value of pH and EC of cultivated lands with and without soil conservation were significantly lowest in all slope categories (Table 9). The lowest value of soil pH in the cultivated land might result from higher microbial oxidation that creates organic acid and reduction in basic cations. Fertilizer application in cultivation land units might reduce the pH value. Researchers[68] reason that lowering of pH value in cultivated land areas results from nitrification of NH^{4+} from chemical fertilizer, which releases. From the table, it is also indicated that all soil chemical properties were considered significant.

Soil organic carbon[46] and total nitrogen[12] are found to be significantly affected by changes in conservation practice (Table 8). For the cultivated land, the mean OC and TN values were less than the value for grazing forestland units, the change being maximum between cultivated and forestland use. This might have resulted from topsoil erosion, which is mainly resulted from anthropogenic activities that aggravate agricultural activities. Lowering of organic matter could also have resulted from soil erosion that tended to reduce soil clay content in the cultivated area. Alijani and Sarmadian[69] explained that soil carbon content could be affected by topographic features, climatic conditions, and extent of soil conservation practice. The value increased from cultivated to grazing land, the highest being forestland use both with and without soil conservation. The variation in the value of carbon content with changes in forest cover could result from improved nutrient management in the forest and grazing land-use classes. On the contrary, due to rapid mineralization and poor nutrient management, the value was lowest in the cultivated land cover. This finding was supported by another research[70] on the theme to assess the impact of land-use change on soil acidity. They found that poor organic

Table 8. Effect of SWC and LUT on selected soil chemical properties.

LUT/SLOPE	PH	EC	OC	TN	AP	CEC	CA	MG	NA	K	BS
Treated area											
Forest	5.8	0.18	3.1	0.27	4	29	31	3	0.00	0.56	81
Grazing	5.5	0.11	2.5	0.22	3	19	30	3	0.00	0.33	80
Cultivated	5.1	0.10	1.9	0.17	2	14	21	3	0.00	0.00	76
Mean	5.5	0.20	2.5	0.22	3	20	25	3	0.00	0.28	72
SE	0.021	0.003	0.033	0.005	0.086	0.375	0.763	0.079	0.000	0.057	1.4
F	34.29	23.17	44.2	13.99	23.49	50.98	8.11	4.4	–	2.7	7.6
P	.000	.000	.000	.000	.000	.000	.000	.002	–	.031	.000
Sign	***	***	***	***	***	***	***	***	–	***	***
Untreated area											
Forest	5.9	0.15	2.9	0.26	4	26	26	3	0.00	0.33	73
Grazing	5.5	0.12	2.5	0.21	2	18	25	4	0.00	0.44	69
Cultivated	5.2	0.09	1.7	0.15	1	12	17	3	0.00	0.00	56
Mean	5.5	0.20	2.5	0.22	3	20	25	3	0.00	0.28	72
SE	0.021	0.003	0.033	0.005	0.086	0.375	0.763	0.079	0.000	0.057	1.4
F	34.29	23.17	44.2	13.99	23.49	50.98	8.11	4.4	–	2.7	7.6
P	.000	.000	.000	.000	.000	.000	.000	.002	–	.031	.000
Sign	***	***	***	***	***	***	***	***	–	***	***

Abbreviations: AP, available phosphorous; CEC, cation exchange capacity; EC, electrical conductivity; LUT, land-use type; SWC, soil and water conservation.

matter and total nitrogen in the cultivated lands resulted from poor nutrient management. The presence of SWC and trees in the forestland might have reduced soil loss, which could increase soil organic carbon and total nitrogen.

Effect of LUT and slope position on selected soil chemical properties (interaction effect). The result showed that AP was significantly affected by changes in land use and slope positions (Table 9). The average mean values of AP ranged from 2 to 5 (ppm) for cultivated and forestland cover, respectively. On the contrary, grazing land has an in-between value amounting. For a similar reason with other research findings,[71] the result showed that cultivated land had significantly lower available phosphors, which might have resulted from high soil erosion, low organic and inorganic fertilizer application, and crop residue removal in the cultivated land as compared with other LUTs. Considering the 3 slope positions, the mean AP was found to be highest in the forestland. The lowest value was recorded in the cultivated land in all slope positions. For all land-use classes, high mean values of AP were observed in land use with soil conservation practice. On the contrary, for both conserved and none conserved land uses, the average value of AP decreased from lower to upper slope position (Table 9).

In this study, land-use change was found to significantly affect CEC and exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+). For all land-use classes with and without implementation of SWC practice, a linear increase in CEC was observed when we go down the slope (Table 9). In all slope positions with and without conservation practice, CEC, exchangeable K^+, Ca^{2+}, and Mg^{2+} showed a significant increase from cultivated land to grazing and then forestland. However, the 2-digit approximation of exchangeable Na^+ revealed a relatively varying trend for different slope positions. Exchangeable Na^+ showed a general increase for cultivated and forestland uses down the slope and without implementation of SWC. On the contrary, a fluctuating value was recorded for grazing land.

Conclusion and Recommendation

Many studies highlighted variations in soil physicochemical properties among slope positions. In this study, we included another factor, the land use, to explain change in soil properties with their position over the landscape at different land-use units. The result showed a reasonable change in soil properties with changes in land use and slope position. For all slope positions, soil moisture content, porosity, and silt and clay proportion were lower in the cultivated land compared with grazing and

Table 9. Effect of LUT and slope position on selected soil chemical properties.

LUT/SLOPE	PH	EC	OC	TN	AP	CEC	CA	MG	NA	K	BS
Upper											
Forest	6	0.1	3	0.3	3	23	30	4	0	0.3	67
Grazing	5.5	0.1	2	0.2	2	17	29	4	0	0	62
Cultivated	5.3	0.1	1	0.1	2	11	19	3	0	0	53
Mean	5.5	0.1	2	0.2	3	20	25	3	0	0.3	72
SE	0.012	0.00	0.016	0.005	0.068	0.184	0.427	0.07	0	0.03	1.067
F	82	31	135	12	28	151	30	5.3	–	23	13
P	.000	.000	.000	.000	.000	.000	.000	.000	–	.000	.000
Sign	***	***	***	***	***	***	***	***	***	***	***
Middle											
Forest	5.7	0.16	3	0.3	4	27	37	4	0	0	78
Grazing	5.5	0.11	2.5	0.2	3	19	31	3	0	0.2	75
Cultivated	5.2	0.11	2	0.2	2	14	23	3	0	0	68
Mean	5.5	0.1	2	0.2	3	20	25	3	0	0.3	72
SE	0.012	0.00	0.016	0.005	0.068	0.184	0.427	0.07	0	0.03	1.067
F	82	31	135	12	28	151	30	5.3	–	23	13
P	.000	.000	.000	.000	.000	.000	.000	.000	–	.000	.000
Sign	***	***	***	***	***	***	***	***	***	***	***
Lower											
Forest	5.7	0.2	3	0.3	5	32	20	3	0	1	87
Grazing	5.4	0.11	2.6	0.2	3	21	22	3	0	1	87
Cultivated	5.0	0.11	2	0.2	2	15	16	3	0	0	77
Mean	5.5	0.1	2	0.2	3	20	25	3	0	0.3	72
SE	0.012	0.00	0.016	0.005	0.068	0.184	0.427	0.07	0	0.03	1.067
F	82	31	135	12	28	151	30	5.3	–	23	13
P	.000	.000	.000	.000	.000	.000	.000	.000	–	.000	.000
Sign	***	***	***	***	***	***	***	***	***	***	***

Abbreviations: AP, available phosphorous; CEC, cation exchange capacity; EC, electrical conductivity; LUT, land-use type.

forestland-use units. On the contrary, soil bulk density and the sand fraction was higher in the cultivated land than grazing and forestland units, relatively. The mean value of pH was lower in the cultivated land compared with grazing and forest covers, which indicates both forest and grazing LUTs were moderately acidic than the cultivated lands in Kabe watershed. As low pH affects the availability of nutrients particularly that of phosphorus, correction of the low pH through liming and application of organic materials is critical for sustainable management of these soils.

The decrease in soil organic matter in cultivated land unit might be caused by changes in the frequency and pattern of cropping, removal of crop residues, and faster decomposition and oxidation procedures with soil erosion on farmlands. On the contrary, cultivated areas with soil conservation practice showed an increase in soil organic matter. As a result, we advise the implementation of land conservation practice involving addition tillage minimization and crop rotation. Soils in the cultivated land are more acidic, pH < 5.4, than those of the forestland and grazing lands, which might increase the toxicity manganese and aluminum, slower microbial conversion of NH^{4+} to nitrate. Soil acidity could also be increased by liming the cultivation land, which in turn supplies essential plant nutrients such as Ca^{2+} and Mg^{2+}, and prevent Mn and Al^{-3} from being toxic to crop growth.

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Author Contributions

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Supplemental Material

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