Hindawi
Applied and Environmental Soil Science
Volume 2019, Article ID 2306019, 11 pages
https://doi.org/10.1155/2019/2306019

Research Article

Effects of Land Uses on Soil Quality Indicators: The Case of Geshy Subcatchment, Gojeb River Catchment, Ethiopia

Melku Dagnachew,[1,2] **Awdenegest Moges**,[3] **and Asfaw Kebede Kassa**[2]

[1]*Department of Natural Resources Management, Wolaita Soddo University, Wolaita Soddo, Ethiopia*
[2]*Haramaya Institute of Technology, Haramaya University, Dire Dawa, Ethiopia*
[3]*Hawassa Institute of Technology, Hawassa University, Hawassa, Ethiopia*

Correspondence should be addressed to Melku Dagnachew; melku1980@gmail.com

Received 17 November 2018; Accepted 21 February 2019; Published 1 April 2019

Guest Editor: Mirko Castellini

Land degradation caused by improper land use management is a critical worldwide problem that has revived the issue of resources sustainability. Soil degradation, which involves physical, chemical, and biological degradation, is the key component of land degradation. Assessment of soil quality (SQ) indicators that distinguish soil degradation in different land use (LU) types is enviable to achieve sustainable land management strategies. The objective of this study was to assess the effects of land uses on soil quality indicators in the Geshy subcatchment of the Gojeb River Catchment, Omo-Gibe Basin, Ethiopia. The LU types identified for evaluation included natural forest, cultivation, and grazing lands. Accordingly, a total of 54 soil samples (three LU types × three slope classes (blocks) × three replications × two soil depths) were collected with an "X" plot design for data analysis. Statistical differences in SQ indicators were analyzed among LU types, slope classes, and soil depths and tested using univariate analysis of variance and Pearson's correlation coefficient, following the general linear model. The results showed that a number of SQ indicators were significantly influenced by LU changes and soil depths. The sand, dry soil bulk density (ρ_b), volumetric soil water contents (VSWC), total porosity, water infiltration rates, cumulative infiltration, and total nitrogen showed significant variations between the natural forest and the other LU types and soil depths ($p < 0.05$). However, silt, clay, soil pH, SOC contents, carbon-to-nitrogen ratio, and available phosphorus did not show significant variations between LU types and soil depths ($p > 0.05$). The overall qualities of the soils under the cultivation land were inferior in VSWC, TP, water infiltration rates, SOC contents, and TN soil attributes of the adjacent natural forest and grazing lands. The studied soils were found to be dominantly of clays with slightly acidic and low SOC contents and slow in their infiltration rate. Thus, integrated and sustainable land management, aimed at enhancing proper LU systems, is crucial for the sustainable ecosystem functioning and is the most effective way in reversing of soil quality deterioration.

1. Introduction

Land degradation is a critical worldwide problem that has revived the issue of resources sustainability. Soil degradation, the key component of land degradation, involves biological, chemical, and physical soil degradation [1, 2]. This could be resulted from increasing population pressure and land use (LU) changes, coupled with biophysical, social, economic, and political factors [3, 4]. Soil degradation is defined as "a change in the soil health status resulting in the diminished capacity of an ecosystem to provide goods and services for its beneficiaries" [5] that provokes soil-quality deterioration. Soil degradation, which could result in reduced soil productivity, food insecurity, economic losses, and recurrent droughts, affects millions of Ethiopian livelihood [1]. Soil quality (SQ) depletion, caused by water erosion due to rugged topography, mismanagement of land resources, and loss of vegetation cover, is the most critical type of soil degradation threatening Ethiopian highlands [6–9]. In Ethiopia, the transformation of natural ecosystem into an agricultural landscape due to deforestation has potentially affected the soils' capability to supply ecosystem services [10]. They also reported that unsustainable and sedentary farming practices would have a detrimental effect on SQ. Therefore, the key determinant issues are to maintain SQ for healthy ecosystem services [11].

Karlen et al. [12] defined SQ as "the ability of a specific kind of soil to function within managed or natural ecosystem boundaries to sustain animal and plant productivity, enhance or maintain air and water quality, and support human health and habitation." SQ, encompasses biological, chemical, and physical qualities of soils [13], is crucial to investigate the extent of soil degradation for identifying land management technologies [8, 14]. SQ can be categorized as inherent and dynamic SQ [15]. The former shows little change over time and is considered as almost static such as mineralogy and particle size distribution mainly influenced by pedogenic processes [16, 17], whereas the later one changes with respect to land use and soil management [18].

The central aims of SQ assessment are to maintain quality environment and biodiversity conservation for agroecosystems productivity and natural ecosystems health [19]. SQ cannot be directly determined, but can be inferred by measuring soil physical, chemical, and biological properties [20]. SQ measurement requires identification of specific "indicators," called "soil quality indicators," that can be quantitatively measured over time [21]. SQ indicators are those soil properties and processes that have the greatest sensitivity to the change in LUs and management practices on a short-term period [13, 16]. SQ indicators condense an enormous complexity in the soil and are the measurable soil properties that affect the capacity of a soil to perform a specified function [22].

Previous studies revealed that severe SQ deterioration was observed due to soil erosion, LU changes, deforestation, and overgrazing [8, 14, 23]. The transition from forest to another agricultural use leads to a significant reduction and changes in soil qualities [24, 25]. Studies have also reported the significant influence of LU changes on SQ indicators [10, 26–28]. The study in Blue Nile Basin of Ethiopia showed that the change in LUs and management systems influenced the key SQ indicators significantly [9]. Studies elsewhere [29–32] revealed that LU changes affected significantly the SQ. The most frequently used SQ indicators are soil pH, total nitrogen (TN), and soil organic carbon (SOC). SOC is a strong indicator of a soil's chemical, biological, and physical processes [27, 32]. Recently, Lozano-Baez et al. [33] showed relevant results that soil physical and hydraulic properties of different forest restoration strategies provided the opportunity to supplying ecosystem functions as rainwater infiltration.

In the Geshy subcatchment, population growth and settlement followed by the 1984/85 droughts and famine in Ethiopia have resulted in massive deforestation, significant land use changes and soil degradation [23, 34]. Though the government has been investing huge finance and labor on sustainable land management (SLM) to tackle land degradation, scientific evidence on the effects of LU changes on SQ indicators is lacking. Proper understanding and quantifying changes in SQ resulting from LU changes are imperative because it provides information on the success of different LU options and modifies land management practices as needed to improve SQ for SLM. Effects of LU conversions on SQ are highly dependent on the soil type and inherently site-specific. Thus, there is an urgent need to assess the effects that different LU conversions have on SQ. However, no study has been conducted to evaluate the LU changes effects on SQ indicators in the Geshy Subcatchment. Therefore, the objective of this study was to investigate the effects of LUs on selected SQ indicators in the Geshy Subcatchment of the Gojeb River Catchment, Ethiopia.

2. Materials and Methods

2.1. Study Area Description. The study was conducted at Geshy subcatchment, which is a part of the Gojeb River Catchment of the Omo-Gibe basin in Ethiopia and is located in between Bonga and Jimma towns and about 420 km in southwest direction of Addis Ababa city, Ethiopia. The Omo-Gibe basin, third largest perennial river in Ethiopia next to the Baro Akobo and Blue Nile rivers, is lied between 5°31′ to 10°54′N and 33°0′ to 36°17′E and covers about 79,000 km^2 of land area in South and Southwest Ethiopia [35]. The Gojeb River Catchment is located between 7°00′–7°50′N latitude and 35°30′–37°20′E within Omo-Gibe Basin of Ethiopia and covers a total area of 6932.345 km^2 with altitudinal ranges from 817 to 2500 m. The Geshy subcatchment, a total 9,628.5 ha, is located between 07°22′–7°26′N latitude and 36°12′–36°24′E longitude within Gojeb River Catchment with altitude ranges from 1300 to 2000 meters a.s.l (Figure 1).

The small tributaries along with the mainstream, Geshy River, are from the west, southwest, south, and south-east of Geshy River that flows to the Gojeb River at its outlet [34].

Agroecologically, the Geshy subcatchment is characterized by the *wet/moist (woina dega)* regime [34, 36]. The coolest months extend from June to August in the middle of the main rainy season, and the hottest months are from February to May recorded at Dirri meteorological stations. The rainfall is unimodal with low rainfall from November to February and the wettest months between May and September. The mean annual and monthly rainfall of 1762 mm and 136.3 mm and monthly mean maximum and minimum temperature of 25.3°C and 15°C (Figure 2), respectively, were recorded at Dirri meteorological station [34].

Geologically, Geshy subcatchment is included within the major formations of the Southwestern Highlands of Ethiopia which are principally of the Precambrian basement complex, the Tertiary Volcanic Rocks and Quaternary Sediments. The Precambrian origin consists of a variety of volcanic, intrusive rocks, and sedimentary [37]. The most important rocks in the highlands of the Geshy subcatchment are the Tertiary Volcanic Rocks and they are mainly Alkali Olivine Basalt and Tuffs that form the rich agricultural soils [23]. In Geshy subcatchment, the most commonly identified soil are Cambisols, Vertisols, Regosols, Fluvisols, and Leptosols [36]. The dominant land use classes are forest land, shrublands, cropland, woodland, and swamp area (Table 1) [23]. The total population of the subcatchment is 14518 of which 7261 are men with a total of number of 3060 households of which 2793 men [34].

2.2. Methods

2.2.1. Soil Sampling and Data Collection. In the Geshy subcatchment, a reconnaissance survey was conducted to

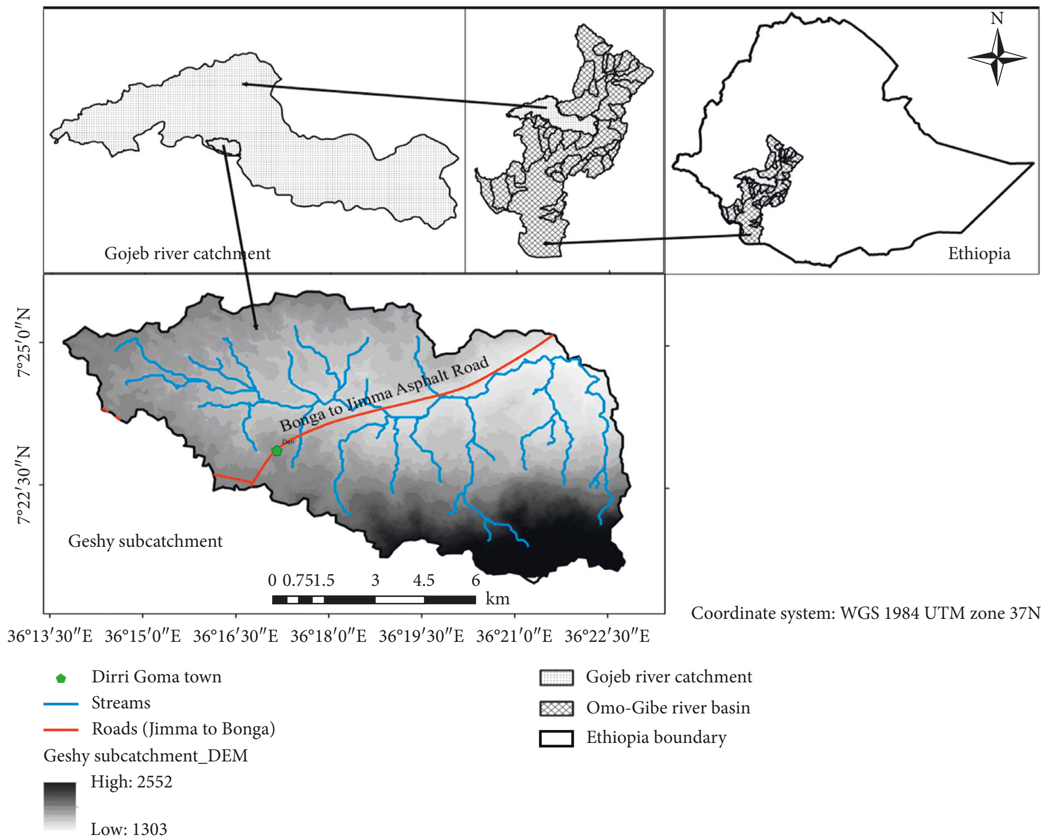

Figure 1: Study map of the Geshy subcatchment, Gojeb River Catchment, Ethiopia.

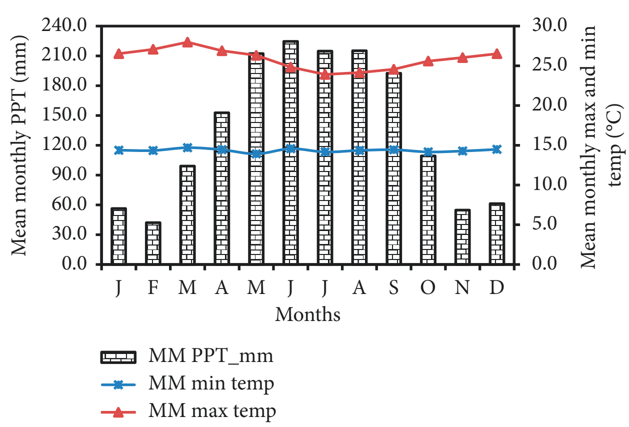

Figure 2: Mean monthly precipitation (mm) and mean monthly maximum and minimum temperature (°C) at Dirri meteorological station, Geshy subcatchment [34].

Table 1: Land uses description in the Geshy subcatchment, Ethiopia.

No.	LULC classes	Descriptions
1	Cultivation land	Arable and fallow land that grows annual and perennial crops such as permanent fruit trees on the small or commercial level
2	Natural forest land	Natural vegetation area composed of undisturbed and disturbed, either or mix of evergreen, deciduous, and semideciduous with the area exceeding 0.5 ha, height ≥ 2 m, and canopy cover ≥20%
3	Grazing land	Land with shrubs/bushes canopy covers ≥10% of bush, shrubs, and trees ≥10%. Grassland areas with/without scattered trees (<10 trees/ha), mainly short grasses used for grazing

determine the representative land use types and soils sampling plots. Different soil-sampling methods can have their own merits and draw backs. Judgment sampling has been suggested to select representative sites [38]. Sample sites were characterized, and information about LU and slope classes were recorded following Abegaz et al. [39] and Winowiecki [40] approaches. Judgment sampling was used to take representative soil samples from three LUs (natural forest land (FL), grazing land (GL), and cultivated land (CL); Table 1), three slope classes (Lower, 3–8%; middle, 8–15%; and upper slope positions, 15–30%), two soil depth ranges (0.0–0.20 and 0.20–0.40 m), and three replication each LU type and slope class. Thus, a total of 54 soil samples (three LU types × three slope classes (blocks) × three replications × two soil depth ranges) were collected with an "X" plot design for data analysis between January and February 2016. The upper 5 cm soil layer was removed to exclude debris, litters, and nematodes. Then, 2 kg of soil samples was taken from four corners and centre of a square plot of size 15 m × 15 m located near the centre of each land uses. The soil samples were thoroughly mixed, composited as a single sampling point, air-dried, labelled, and bagged for laboratory analysis.

Moreover, 54 undisturbed soil samples were taken at the centre of sampling plot using a core ring sampler to determine dry soil bulk density and soil water content.

2.2.2. Soil Laboratory. The dominant LU types (natural forest land, grazing land, and cultivated land), slope classes (3–8, 8–15, and 15–30%), and soil depths (0–0.20 and 0.20–0.40 m) were independent variables (factors), while SQ indicators were the dependent variables. A total of 54 soil samples were air-dried, crushed, and sieved through a 2 mm mesh sieve to remove stones, roots, and large organic residues for laboratory analysis. The selected SQ indicators considered were dry soil bulk density (ρ_b), particle size distributions (PSD), volumetric soil water contents (VSWC), total porosity (TP), soil reaction (pH), soil organic carbon (SOC), total nitrogen (TN), carbon-to-nitrogen ratio (C : N ratio), and available phosphorus (Av. P). The ρ_b was measured from undisturbed soil samples collected using a core sampler after drying the core samples in an oven at 105°C [40] at the soil laboratory centre of Jimma Agricultural Research Centre, Ethiopia. ρ_b was calculated as the mass of oven-dried soil (105°C) divided by the core volume of 102.1 cm^3 [41, 42].

$$\rho_b\left(\mathrm{gcm}^{-3}\right) = \frac{M_s}{V_b}, \tag{1}$$

where ρ_b = dry soil bulk density (gcm^{-3}), M_s = mass of soil after over dry (g), and V_b = bulk volume of the soil (cm^3).

Total porosity was estimated from bulk density and particle density (assuming, particle density = 2.65 gcm^{-3}). Hence, total porosity (%) = (1 − Bulk density/Particle density) ∗ 100.

The gravimetric soil water content (GSWC, %) was determined following the method described in [43]. Before the soil was oven-dried, the initial weights were measured followed by oven-drying for 24 hours at 105°C, and weighing the oven-dried soil. However, in relation to agricultural and engineering functions, volumetric is more relevant than a gravimetric basis to express soil moisture content and was determined by multiplying the gravimetric soil moisture content with dry soil bulk density and divided it by 1 gcm^{-3} density of water [43]. The GSWC was determined as follows:

$$\mathrm{GSWC}\,(\%) = \frac{W_{\mathrm{wet}} - W_{\mathrm{dry}}}{W_{\mathrm{dry}}}, \tag{2}$$

where GSMC = gravimetric soil water content on a mass basis (%), W_{wet} = the weight of the wet soil sample (g), and W_{dry} = the weight of the dried soil sample (g).

Soil reaction (pH) and PSD were determined using 1 : 2.5 (w/v) H_2O suspension glass electrode and hydrometer by the Reeuwijk [44] and Haldar and Sakar [45] methods, respectively. The SOC is determined by the Walkley and Black [46] method, TN by the Kjeldahl method as described in Blake [40]. The available phosphorus (Av. P) was determined following the Olsen procedure [47]. The analysis was done at National Soils Testing Laboratory Centre following standard procedures, Addis Ababa, Ethiopia.

2.2.3. Infiltration Measurements. Appropriate field sampling sites, based on microtopography similarity, were thoroughly identified within three slope classes (upper, middle, and lower classes) within the ranges of slope gradient from 3% to 20%. Infiltration measurements were taken from three LU types (natural forest land, cultivated land, and grazing land) and the three slope classes with three replications measurements (3 LU types × 3 slope classes × 3 replicates = 27). The cumulative infiltration, I (L), and infiltration rate ($\mathrm{L{\cdot}T^{-1}}$), t (T) being the time, were measured in triplicate using the double- or concentric-ring infiltrometer [48]. The diameters of the outer and inner rings are 53 and 28 cm, respectively. The rings are driven approximately 0.05 m into the soil using a metal plate and sledgehammer [49]. Both the outer and inner cylinders were filled with water at 0.20 m above the soil surface at the same time. When the head level approached 0.05 m above the soil surface, the rings were refilled every time. During infiltration measurement, water level changes are recorded at 0, 01, 02, 05, 10, 20, 30, 45, and 60 min of time increments to calculate cumulative infiltration and infiltration rate [50, 51]. The infiltration rate was measured from the beginning of the experiment until the steady-state infiltration rate (SIR) was reached during dry and sunny weather condition.

2.2.4. Statistical Data Analysis. In the Geshy subcatchment, all statistical analyses were carried out using Statistical Packages for Social Science (SPSS) version 20 for Windows. Statistical variations in SQ indicators (PSD, dry soil bulk density, total porosity, VSWC, infiltration rate, cumulative infiltration, Soil pH, SOC, TN, Av. P, and C : N ratio) among the three LU types, three slope classes, and two soil depths were analyzed by univariate ANOVA following the GLM procedure. Prior to doing the ANOVA, all datasets on SQ indicators were tested for normality. When the means exhibited significant differences, the data were further analyzed using Tukey's post hoc honest significance difference test ($p < 0.05$) to assess variations between the three land uses. Correlations among SQ indicators were analyzed by using Pearson's correlation coefficient.

3. Results and Discussion

3.1. Physical Soil Quality Indicators

3.1.1. Particle Size Distribution (PSD, %). In the Geshy subcatchment, the particle size distribution was assessed using the proportion of three mineral particles, namely, clay, silt, and sand fractions in a soil. Tables 2 and 3 show the results of soil physical quality indicators with respect to land uses. The ANOVA indicated that sand fractions varied significantly with LU types and depths ($p < 0.05$), while clay and silt fractions varied significantly only with depths. The overall mean value of sand fractions was significantly lowest under the cultivated land (25.61%) and the highest in grazing land (29.89%) (Table 2). The clay and silt fractions did not show any statistical variation with LU types ($p > 0.05$). In the studied soil, clay fraction was by far the highest fraction under all LU types. The particles size classes across all LU

Table 2: Soil physical quality indicators in relation to the land use and soil depths (mean ± SE).

SQI	Depth (cm)	Land uses			
		Forest land	Cultivation land	Grazing land	Overall
Sand (%)	0–20	28.78 (±1.427)	27.89 (±1.427)	33.11(±1.427)	29.93 (±0.824)[a]
	20–40	26.56 (±1.149)	23.33 (±1.149)	26.67 (±1.149)	25.52 (±0.664)[b]
	Overall	27.67 (±0.922)[ab]	25.61 (±0.784)[b]	29.89 (±1.194)[a]	
Silt (%)	0–20	27.78 (±1.883)	34.67 (±1.883)	30.33 (±1.883)	30.96 (±1.087)[a]
	20–40	26.22 (±1.856)	24.34 (±1.856)	28.00 (±1.856)	26.18 (±1.072)[b]
	Overall	27.05 (±0.868)[a]	29.50 (±1.744)[a]	29.17 (±1.548)[a]	
Clay (%)	0–20	43.33 (±2.262)	37.44(±2.262)	36.56 (±2.262)	39.11 (±1.306)[b]
	20–40	47.22 (±2.222)	52.33 (±2.222)	45.33 (±2.222)	48.30 (±1.283)[a]
	Overall	45.28 (±1.425)[a]	44.89 (±2.378)[a]	40.94 (±1.735)[a]	
Textural classes	0–20	Clay	Clay loam	Clay loam	Clay loam
	20–40	Clay	Clay	Clay	Clay
	Overall	Clay	Clay	Clay	
Bd (g/cm^3)	0–20	1.07 (±0.033)	1.18 (±0.031)	1.23 (±0.031)	1.16 (±0.019)[b]
	20–40	1.25 (±0.040)	1.22 (±0.040)	1.34 (±0.040)	1.27 (±0.018)[a]
	Overall	1.16 (±0.033)[b]	1.20 (±0.020)[b]	1.28 (±0.026)[a]	
VSWC (%)	0–20	37.71 (±2.665)	28.10 (±2.665)	30.62(±2.623)	32.14 (±1.515)[b]
	20–40	48.28 (±2.687)	44.33 (±2.687)	43.49 (±2.687)	45.39 (±1.515)[a]
	Overall	42.99 (±2.760)[b]	36.22 (±2.187)[b]	37.06 (±2.337)[b]	
TP (%)	0–20	59.61 (±1.159)	55.46 (±1.130)	53.76 (±1.160)	56.27 (±0.652)[a]
	20–40	52.86 (±1.159)	53.79 (±1.248)	49.30 (±1.159)	51.98 (±0.721)[b]
	Overall	56.27 (±1.285)[a]	54.62 (±0.582)[a]	51.53 (±0.994)[b]	

Means within rows and columns followed by different letters are significantly different ($p < 0.05$) with respect to land use and soil depths.

Table 3: Water infiltration rate (IR, mm/hr) and cumulative infiltration (CI, cm) of soils in relation to slope positions and land use types at 1 min (initial) and 60 min (steady state) (mean ± SE).

Soil quality indicators	Time (min)	Land uses		
		Forest land	Cultivation land	Grazing land
IR (mm/hr)	1	60.0 (±0.000)[a]	60.0 (±0.000)[a]	53.3 (±4.410)[a]
	60	4.52 (±0.134)[a]	2.53 (±0.240)[c]	3.29 (±0.089)[b]
CI (cm)	1	0.99 (±0.105)[a]	0.94 (±0.050)[a]	0.83 (±0.044)[b]
	60	8.87 (±0.461)[a]	6.72 (±0.188)[b]	5.71 (±0.230)[c]
Soil quality indicators	Time (min)	Slope classes		
		Upper	Middle	Lower
IR (mm/hr)	1	60.00 (±0.000)[a]	53.33 (±4.410)[a]	60.0 (±0.000)[a]
	60	3.89 (±0.254)[a]	3.49 (±0.293)[b]	2.96 (±0.359)[c]
CI (cm)	1	0.99 (±0.045)[a]	0.83 (±0.044)[b]	0.94 (±0.041)[ab]
	60	7.70 (±0.629)[a]	6.81 (±0.597)[b]	6.79 (±0.364)[b]

Means followed by the same letter(s) across rows for each time (minutes) have not a statistically significant difference ($p > 0.05$) in relation to land use types and slope positions.

types are clay, indicating the homogeneity of soil forming processes and similarity of parent materials [52]. Clay-dominated soils are an indicator of high SQ because such soils are described as fertile and higher water-holding capacity, which is in line with other studies [24]. Clay fraction was significantly higher in the subsoil surface than the top surface which might be due to clay translocation from the top layer to the sublayer [8].

3.1.2. Soil Bulk Density (ρ_b, gcm^{-3}), Volumetric Soil Water Content (%), and Total Porosity (%). The soil, ρ_s, an index of soil quality, is an indicator of soil compaction and a determinant of soil's mechanical resistance to root growth [53, 54]. The ANOVA showed that dry soil bulk density, VSWC, and TP varied significantly with LU types and soil depths ($p < 0.05$). The overall mean soil ρ_s under the grazing land (1.28 ± 0.026) is significantly higher than that under the forest land (1.16 ± 0.033) followed by cultivated land (1.20 ± 0.020, Table 2), which might be resulted from compaction of soil due to excessive livestock trampling and low SOC. Moreover, ρ_s is statistically higher ($p < 0.05$) in the subsoil surface than that in the top soil layer ($p < 0.05$, Table 2), indicating the increasing tendency of ρ_s with depths as a result of overlying weight of the soil and the corresponding reduction of SOC content [8]. In the study sub-catchment, the increasing of ρ_s with soil depths could be associated with the reduction SOC concentration in the subsequent layers. Pearson's correlation also revealed a converse association between ρ_s and SOC ($p < 0.01$, Table 4),

Table 4: Pearson's correlation coefficient between soil quality indicators of land uses.

	pH	Sand	Silt	Clay	BD	VSWC	TP	SOC	TN	C/N
Sand	0.10									
Silt	−0.31*	0.19								
Clay	0.18	−0.69**	−0.84**							
BD	0.21	−0.46**	−0.23	0.41**						
SMC	−0.02	−0.17	−0.37**	0.37**	0.195					
TP	−0.21	0.46**	0.22	−0.41**	−1.00**	−0.192				
SOC	0.18	0.61**	−0.06	−0.30*	−0.42**	−0.30*	0.42**			
TN	0.24	0.63**	−0.05	−0.314*	−0.38**	−0.34*	0.38**	0.95**		
C/N	−0.26	−0.26	−0.09	0.202	−0.06	0.215	0.06	−0.20	−0.46**	
Av. P.	0.29*	0.02	−0.10	0.058	0.117	−0.091	−0.12	0.02	0.07	−0.17

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). Values are Pearson correlation coefficient (r) $n = 54$.

which may reflects SOC content changes with the change of ρ_s value. Consistently, studies have reported the strong significant association of SOC and ρ_s [55–57]. In all LU types, ρ_s was generally within the optimal range ($1.00 \le \rho_s \le 1.40\ g/cm^3$) for maximum crop production and good root development [54, 58, 59] and rated as low for clay soils [43, 60] using different soil physical indicators obtained from soil water retention curve + soil bulk density (BD), and stepwise discriminate analysis (SDA) showed that ρ_s had a high discriminating capability of synthesize part of the data variability together with the plant available water (PAWC). Therefore, ρ_s was specifically suggested in assessing the soil physical quality of clay soils (fine textured soils).

The ANOVA indicated that VSWC varied significantly with LU types (p = 0.027) and soil depths (p = 0.000). The VSWC was found to be significantly higher under forest land than in grazing and cultivation LUs due to higher SOC and decreased soil bulk density (Table 2). This is similar with other studies [61] that higher SOC increases the soil moisture content through improvements in soil structure. The VSWC showed significant difference with soil depths: higher in subsurface soil because of the relatively higher fine particle fractions (clay) in the subsurface soil giving a better water holding capacity. Moreover, the increased amounts of soil water content with depths could be due to the downward movement of water through gravity and less evaporation in the subsoil layer. Similar studies [42, 62] also reported that the subsoil layer had a higher soil moisture content than the above layer. The overall mean value of the total porosity (TP, %) of the forest, cultivated, and grazing land soil was 56.27 (±1.285), 54.62 (±0.582) and 51.53 (±0.994), respectively (Table 2). The ANOVA showed an overall significant variation of TP of the soil with LUs (p = 0.001) and soil depths (p = 0.000). Accordingly, the overall mean of TP under grazing land is significantly lower than that under forest and cultivated lands, but it did not show any significant variation among forest and cultivated land, though its value in forest land is relatively higher than cultivation land.

The high TP of the forest soil could be attributed to higher OM content, as it is affected by the levels of organic matter and bulk density [55, 63]. Thus, a decline in porosity and the corresponding rise in ρ_s are manifestations of removal of organic matter. Pearson's correlation coefficient has indicated a positive correlation of organic carbon ($p < 0.01$) and a strong inverse association of ρ_s ($p < 0.01$; Table 4) with total porosity, suggesting TP be a function of SOM content. Generally, in this study, a significant lower TP and higher ρ_s of the grazing and cultivated land soil suggests increasing runoff which enhances erosion, because of the reduction of water holding capacity and soil infiltration with increasing ρ_s [64].

3.1.3. Infiltration Rate. Water infiltration rate (mm/hr) and cumulative infiltration (cm) varied significantly with LUs, slope classes, and time as well as their interaction effects ($p < 0.05$). Accordingly, both water infiltration rate and cumulative infiltration in the forest lands ($4.52\ mm{\cdot}hr^{-1} \pm 0.134$, $8.87\ cm \pm 0.461$) were significantly higher ($p < 0.05$) than cultivated ($2.53\ mm{\cdot}hr^{-1} \pm 0.240$, $6.72\ cm \pm 0.188$) and grazing lands ($3.29\ mm{\cdot}hr^{-1} \pm 0.089$, $5.71\ cm \pm 0.230$) (Table 3 and Figures 3 and 4). Similarly, their values in the grazing land ($4.52\ mm{\cdot}hr^{-1} \pm 0.134$, $8.87\ cm \pm 0.461$) were significantly higher ($p < 0.05$) than those in the cultivated land ($2.53\ mm{\cdot}hr^{-1} \pm 0.240$, $6.72\ cm \pm 0.188$), respectively. On the contrary, water infiltration rate and cumulative infiltration in the upper slope position ($3.89\ mm{\cdot}hr^{-1} \pm 0.254$, $7.70\ cm \pm 0.629$) were significantly ($p < 0.05$) higher than that in the middle ($3.49\ mm{\cdot}hr^{-1} \pm 0.293$, $6.81\ cm \pm 0.597$) and lower slope positions ($2.96\ mm{\cdot}hr^{-1} \pm 0.359$, $0.83\ cm \pm 0.044$), respectively. According to Landon [38] rating classification, the infiltration rate is slow ($0.1–8\ mm{\cdot}hr^{-1}$) soils under all land uses and slope positions (Table 3), which can be taken as the normal range for clay soils.

In many cases, the infiltration rate is found to be slow both in soils under open-grazing and cultivation. The slow infiltration rate could result in limited deep percolation, surface water losses, and yield reduction [38] and the nature of soil textural class and clay soils. These observations would agree with the view that the reduction in infiltration rate which might be due to a change in LU type from forest to cultivation or grazing may be resulted from compaction and surface horizon structure degradation [65].

The soil shearing and pulverization by cultivation may reduce the macropore space and produce a discontinuity in pore space between the cultivated surface and the subsoil

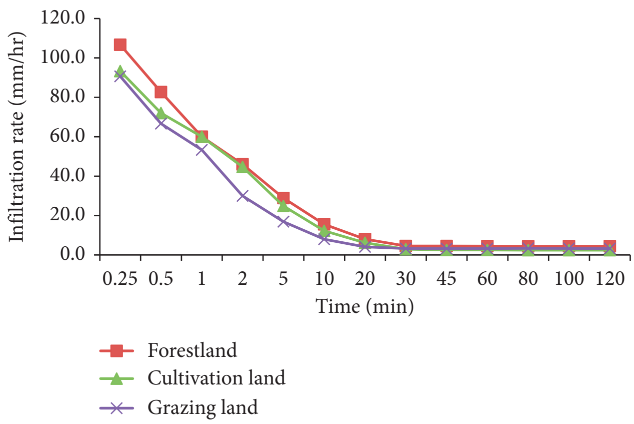

Figure 3: Infiltration rate curves for land use types, Geshy subcatchment.

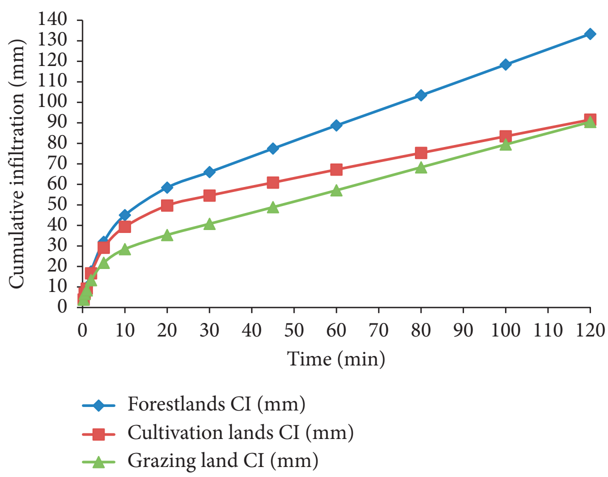

Figure 4: Cumulative infiltration curves for land use types, Geshy subcatchment.

surface [64], thereby reducing the infiltration rates [66]. Animal trampling causes increases in ρ_s by compacting the soil surface, especially grazing soils [67], influencing the size, distribution, and amount of pores and infiltration rates [64]. The low amount and slow water movement in the studied soils are good indicators of the effect of land changes from native forest lands coupled with poor land management practices on water movement in the soil system. The higher VSWC in the forest lands and cultivation lands than in the grazing lands could be due to the lower ρ_s and higher SOC contents resulting lower surface runoff, higher water holding capacity, and infiltration. In line with our findings, for example, Castellini et al. [68] showed similar results for a conversion of Mediterranean maquis and/or natural forest into agropastoral lands is a Mediterranean environment.

3.2. Chemical Soil Quality Indicators

3.2.1. Soil pH (H_2O). Soil pH did not show any significant variation across LU types and soil depths ($p > 0.05$) but varied significantly with replication ($p = 0.015$). Though not statistically significant, soil pH was slightly lower in the forest land (5.98) than in the cultivated land (6.04, Table 5). The insignificant difference of soil pH with LU types could be due to less leaching of base-forming cations [42]. The soil pH is higher in the surface than in the subsurface soil layer which could be due to the higher SOC in the upper soil surface. Generally, the studied soil was found to be slightly acidic (6.0–6.6) [38, 69] which could be characterized by the high rainfall study area which is adequate to remove basic cations from surface horizons of the soils.

3.2.2. Soil Organic Carbon (SOC, %). The SOC content is the major soil biological and chemical quality indicator and strongly and indirectly affects soil physical quality [54]. The SOC content did not show significant variation with LU types ($p = 0.183$) but varied significantly with soil depths ($p = 0.000$). Though not varied statistically ($p > 0.05$), SOC content in the forest land (2.88%) is relatively higher than that in the cultivated and grazing land. The SOC content is decreased significantly with increasing soil depths (Table 5). In the upper soil layer, SOC contents were significantly higher in the forest land (3.36%) and grazing land (3.16%) than in the cultivated land (2.88%). In the subsoil layer, the SOC content showed no significant variations across all LU types ($p > 0.05$, Table 5). The lowest SOC in the cultivation lands could be because of organic material reduction and cultivation of farm land continuously for long years which resulted in high oxidation rate of SOM and green materials removal [6, 8, 70]. In consistence, other studies [8, 70, 71] reported significantly lower SOC content in the croplands than in the forest and grazing land. Cultivation promotes SOC loss due to exposure of microaggregate organic carbon to microbial decomposition by changing the moisture and temperature regimes [8]. The SOC content is higher in the forest land than cultivated land which might be because of the higher accumulation of SOM [6, 8] and anthropogenic factors such as removal of animal and plant organic sources [55]. The reduction of SOC in the grazing land could be due to loss of OM input because of browsing by animals and uncontrolled livestock grazing [8, 70]. According to Landon [38] rating, the studied soil is low (2–4%) in SOC content across all LU types or depths which might be due to intensive agricultural production systems, heavy animal encroachment, and human interference.

3.2.3. Total Nitrogen (TN, %) and Carbon-to-Nitrogen Ratio (C : N Ratio). The ANOVA revealed that TN (%) content varied significantly with LU types ($p = 0.042$) and soil depths ($p = 0.000$). The overall mean TN under forest land (0.26%) followed by grazing land (0.23%) was statistically higher than cultivated land (0.22%; Table 5). Moreover, the overall mean value of TN in the top surface (0.28) is statistically higher than the lower surface layer (0.19). Similarly, in the top surface layer, TN under forest land (0.31) followed by grazing land (0.29) is statistically higher than cultivated land (0.25; Table 5). However, in the lower surface layer, no significant variations were recorded across all LU types. The higher TN content in the forest land is the result of higher

Table 5: Soil pH, SOC, TN, C : N ratios, and Av. P in relation to the land use types and depths (mean ± SE).

PSQI	Depth (cm)	Land uses			
		Forest land	Cultivation land	Grazing land	Overall
$pH\text{-}H_2O$	0–20	6.04 (±0.096)	6.07 (±0.096)	6.00 (±0.096)	6.04 (±0.054)[a]
	20–40	5.92 (±0.107)	6.01 (±0.107)	6.03 (±0.107)	5.99 (±0.060)[a]
	Overall	5.98 (±0.064)[a]	6.04 (±0.027)[a]	6.02 (±0.100)[a]	
SOC (%)	0–20	3.36 (±0.143)	2.88 (±0.143)	3.16 (±0.143)	3.13 (±0.088)[a]
	20–40	2.40 (±0.202)	2.21 (±0.202)	2.06 (±0.202)	2.22 (±0.115)[b]
	Overall	2.88 (±0.154)[a]	2.54 (±0.128)[a]	2.605 (±0.202)[a]	
TN (%)	0–20	0.31 (±0.014)	0.25 (±0.014)	0.29 (±0.014)	0.28 (±0.009)[a]
	20–40	0.21 (±0.017)	0.19 (±0.017)	0.18 (±0.017)	0.19 (±0.010)[b]
	Overall	0.26 (±0.014)[a]	0.22 (±0.012)[b]	0.23 (±0.019)[ab]	
C : N ratio	0–20	10.67 (±0.301)	11.78 (±0.301)	11.00 (±0.301)	11.15 (±0.190)[a]
	20–40	11.56 (±0.415)	11.89 (±0.415)	11.67 (±0.415)	11.70 (±0.232)[a]
	Overall	11.11 (±0.241)[a]	11.83 (±0.326)[a]	11.33 (±0.198)[a]	
Av. P (ppm)	0–20	0.80 (±4.934)	10.95 (±4.934)	8.27 (±4.934)	6.67 (±2.864)[a]
	20–40	1.02 (±2.666)	5.13 (±2.666)	4.94 (±2.666)	3.69 (±1.525)[a]
	Overall	0.91 (±0.23)[a]	8.04 (±2.835)[a]	6.61 (±3.844)[a]	

The overall means within rows and columns followed by different letters are significantly different ($p < 0.05$) with respect to land use and soil depths.

SOM content and the presence of leguminous plants which have the capacity of nitrogen fixation [42]. An addition of a relatively higher plant residue and a minimal rate of decomposition might be responsible for the higher amount of TN in forest soil [72]. The soil TN content has revealed variations among the LU types with a similar pattern of distribution as that of SOC content (Table 5). Pearson's coefficient of correlation also has indicated an overall significant positive correlation between the soil TN and SOC contents under different LU types ($r = 0.953$; $p < 0.01$; Table 4). The decline of SOC and TN content in the cultivated land could be due to the burning and removal of the biomass above ground by harvesting crop residue, insufficient replenishment through manure or fertilizers and overgrazing by livestock. The studied soil is rated as medium (0.2–0.5) in TN content [69]. Similar findings elsewhere [55] revealed that the low level of SOC and TN in the cultivated land soil suggests degrading effects due to a long history of crop cultivation. Other authors [14, 73] also reported that TN content of soils under cultivation was lower compared to contents in the natural forest soils.

Carbon-nitrogen (C : N) ratio, an indicator of nutrient immobilization and mineralization [74], measures the relative nitrogen content of organic materials [43]. In the Geshy subcatchment, the C : N ratio has shown no significant difference with LU types ($p = 0.120$) and soil depths ($P = 0.059$). Yet, the numerical values for land uses are highest for cultivated soils and lowest for forest soils which might be attributed to the rapid loss of TN in the former. In the top surface layer, C : N ratio is significantly higher in cultivated land (11.78) followed by grazing land (11.00) than forest land soils (10.67) (Table 5). Thus, the impacts of LU types and depths were more prominent in soil TN than SOC. The Pearson correlation result confirmed a significant converse association of SOC with TN ($r = -0.464$, $p < 0.01$, Table 4). Other studies [14, 71] also revealed that C : N ratio did not show a significant variation with land uses. In the study subcatchment, the C : N ratios were higher than the normal range 10 : 1 on average [69] that indicates organic matter is not fully decomposed through various microbial activities. Logsdon [75] reported higher C : N ratios indicating that nitrogen is immobilized at higher C : N values because of the formation of only slightly biodegradable complexes.

3.2.4. Available Phosphorus (Av. P, ppm). The Av. P contents did not show any significant difference between various LU types and depths ($p > 0.05$). Numerically, Av. P appeared to be higher in the cultivation (8.04 ppm) than the other LU types which could be resulted from the application of organic (e.g., compost, manure, and household wastes), and inorganic fertilizers (e.g., urea ($CO(NH_2)_2$) and diammonium phosphate (DAP)) on the cultivation land. Hence, the lowest (0.91 ppm) and highest (8.04 ppm) Av. P contents were observed in the forest and cultivation land, respectively (Table 5). Similar findings [8, 70] revealed that Av. P is significantly higher in the farmland than forest and grazing lands which might be due to the application of compost, animal manure, and household wastes. The reason for the lower Av. P content in the forest land could be phosphorus fixation. According to Landon [38] rating, the overall Av. P was low (<5 ppm) under forest and medium (5–15) under cultivated and grazing land. In the Geshy subcatchment, the deficiency of available P in the forest lands might be resulted from the inherent low-P status of the parent materials and erosion losses by water. The available P is found to be low in the majority of Ethiopian soils as consequences of crop harvest, soil erosion, and P fixation [8].

4. Conclusions

In Geshy subcatchment, most soil quality indicators are significantly varied among land uses soil depths and slope classes. Soil quality indicators such as sand fractions, dry soil bulk density (ρ_s), VSW contents, TP, water infiltration rates and cumulative infiltration, and TN varied significantly with soil depths and LU types. However, silt and clay fractions, soil pH, SOC contents, carbon-to-nitrogen ratio, and available P did not show any significant variations with LU types and soil depths. The overall qualities of the soils under the cultivated land were inferior in VSWC, TP, water infiltration rates, SOC contents, and TN soil attributes of the adjacent natural forest and grazing lands. In Geshy subcatchment, the studied soils were characterized by dominantly of clay fractions, slightly acidic, low SOC contents, and slow infiltration rate. The significantly higher values of ρ_s in grazing land and top surface might be attributed to excessive livestock trampling and its tendency to increase with depth soil and the corresponding decrease in SOC content. The increasing of VSW contents with soil depth could be attributed to the higher clay fractions in the subsurface soil and downward water movement coupled with the presence of less evaporation from the subsoil. Soils under all land use and slope classes are slow (low) in their infiltration rate which may indicate high surface water losses and limited deep percolation. The low amount and slow movement of water are good indicators of the effect of land use changes from native forest lands to grazing and cultivation lands coupled with lack of appropriate land management practices on water movement in the soil system.

The slightly acidic nature of the studied soils could be resulted from the high rainfall which is adequate to remove basic cations out of the surface horizons of the soils. The low SOC content, TN, C : N ratio, and available phosphorus across all LU types or depths indicated the threatened of soil quality by various factors such as the human interference, continuous animal encroachment, and intensive agricultural production systems. The decline of TN and SOC content in cultivation lands could be caused by the burning and removal of the biomass, insufficient replenishment. Thus, integrated and sustainable land management, aimed at enhancing proper land use system, is vital for the sustainable ecosystem functioning and is the most effective way in reducing soil erosion and reversing of soil quality deterioration.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was made possible by a research grant from the Sustainable Land Management program, Ministry of Agriculture and Natural Resources, and Italian Contribution to the Education Sector Development Programme (ESDP) in collaboration with Haramaya University, Ethiopia. We are also indebted to the English proofreading professional (Tages Abo, Ph.D.) for valuable comments and suggestions.

References

[1] D. Mengistu, W. Bewket, and R. Lal, “Conservation effects on soil quality and climate change adaptability of Ethiopian watersheds,” *Land Degradation & Development*, vol. 27, no. 6, pp. 1603–1621, 2015.

[2] T. M. Mighall, I. D. L. Foster, K. M. Rowntree, and J. Boardman, “Reconstructing recent land degradation in the semi-arid Karoo of South Africa: a palaeoecological study at Compassberg, Eastern Cape,” *Land Degradation & Development*, vol. 23, no. 6, pp. 523–533, 2012.

[3] A. Cerdà, H. Lavee, A. Romero-Díaz, J. Hooke, and L. Montanarella, “Preface,” *Land Degradation & Development*, vol. 21, no. 2, pp. 71–74, 2010.

[4] Y. Mohawesh, A. Taimeh, and F. Ziadat, “Effects of land use changes and soil conservation intervention on soil properties as indicators for land degradation under a Mediterranean climate,” *Solid Earth*, vol. 6, no. 3, pp. 857–868, 2015.

[5] FAO, *Soil Degradation*, FAO, Rome, Italy, 2019, http://www.fao.org/soils-portal/soil-degradation-restoration/en.

[6] G. Girmay, B. R. Singh, H. Mitiku, T. Borresen, and R. Lal, “Carbon stocks in Ethiopian soils in relation to land use and soil management,” *Land Degradation & Development*, vol. 19, no. 4, pp. 351–367, 2008.

[7] E. Karltun, M. Lemenih, and M. Tolera, “Comparing farmers’ perception of soil fertility change with soil properties and crop performance in Beseku, Ethiopia,” *Land Degradation & Development*, vol. 24, no. 3, pp. 228–235, 2013.

[8] A. Moges, M. Dagnachew, and F. Yimer, “Land use effects on soil quality indicators: a case study of Abo-Wonsho Southern Ethiopia,” *Applied and Environmental Soil Science*, vol. 2013, Article ID 784989, 9 pages, 2013.

[9] E. Teferi, W. Bewket, and B. Simane, “Effects of land use and land cover on selected soil quality indicators in the headwater area of the Blue Nile basin of Ethiopia,” *Environmental Monitoring and Assessment*, vol. 188, no. 2, pp. 1–12, 2016.

[10] Y. T. Delelegn, W. Purahong, A. Blazevic et al., “Changes in land use alter soil quality and aggregate stability in the highlands of northern Ethiopia,” *Scientific Reports*, vol. 7, no. 1, pp. 1–12, 2017.

[11] S. Bringezu, H. Schütz, W. Pengue et al., “Assessing global land use: balancing consumption with sustainable supply. A UNEP report of the working group on land and soils of the international resource panel,” p. 46, 2014.

[12] D. L. Karlen, M. J. Mausbach, J. W. Doran, R. G. Cline, R. F. Harris, and G. E. Schuman, “Soil quality: a concept, definition, and framework for evaluation (a guest editorial),” *Soil Science Society of America Journal*, vol. 61, no. 1, p. 4, 1997.

[13] E. Armenise, M. A. Redmile-Gordon, A. M. Stellacci, A. Ciccarese, and P. Rubino, “Developing a soil quality index to compare soil fitness for agricultural use under different managements in the Mediterranean environment,” *Soil and Tillage Research*, vol. 130, pp. 91–98, 2013.

[14] T. Yitbarek, H. Gebrekidan, K. Kibret, and S. Beyene, “Impacts of land use on selected physicochemical properties of soils of Abobo area, western Ethiopia,” *Agriculture, Forestry and Fisheries*, vol. 2, no. 5, p. 177, 2013.

[15] C. A. Seybold, J. E. Herrick, and J. J. Brejda, “Soil resilience: a fundamental component of soil quality,” *Soil Science*, vol. 164, no. 4, pp. 224–234, 1999.

[16] M. R. Carter, E. G. Gregorich, D. W. Anderson, J. W. Doran, H. H. Janzen, and F. J. Pierce, “Concepts of soil quality and their significance,” in *Soil Quality for Crop Production and*

Ecosystem Health, E. G. Gregorich and M. R. Carter, Eds., pp. 1–19, Elsevier, Amsterdam, Netherlands, 1997.

[17] D. Vasu, S. K. Singh, S. K. Ray et al., "Soil quality index (SQI) as a tool to evaluate crop productivity in semi-arid Deccan Plateau, India," *Geoderma*, vol. 282, pp. 70–79, 2016.

[18] A. Golchin and H. Asgari, "Land use effects on soil quality indicators in north-eastern Iran," *Soil Research*, vol. 46, no. 1, pp. 27–36, 2008.

[19] E. K. Bünemann, G. Bongiorno, Z. Bai et al., "Soil quality-a critical review," *Soil Biology and Biochemistry*, vol. 120, pp. 105–125, 2018.

[20] D. L. Karlen, S. S. Andrews, and B. J. Wienhold, "Soil quality, fertility and healthhistorical context, status and perspectives," in *Managing Soil Quality: Challenges in Modern Agriculture*, P. Schjønning, S. Elmholt, and B. T. Christensen, Eds., pp. 17–33, CABI Publishing, Wallingford, UK, 2004.

[21] C. A. Seybold, M. J. Mausbauch, D. L. Karlen, and H. H. Rogers, "Quantification of soil quality," in *Soil Processes and the Carbon Cycle*, pp. 387–404, CRC Press, Boca Raton, FL, USA, 1997.

[22] S. Ayoubi, F. Khormali, K. L. Sahrawat, and A. C. R. de Lima, "Assessing impacts of land use change on soil quality indicators in a loessial soil in Golestan Province, Iran," *Journal of Agricultural Science and Technology*, vol. 13, pp. 727–742, 2011.

[23] M. A. Denboba, "Forest conversion-soil degradation-farmers' perception nexus: implications for sustainable land use in the southwest of Ethiopia," *Ecology and Development Series*, no. 26, 2005.

[24] G. B. Tesfahunegn, "Soil quality indicators response to land use and soil management systems in northern Ethiopia's catchment," *Land Degradation & Development*, vol. 27, no. 2, pp. 438–448, 2016.

[25] F. Yimer and A. Abdelkadir, "Soil property changes following conversion of acacia woodland into grazing and farmlands in the Rift Valley area of Ethiopia," *Land Degradation & Development*, vol. 22, no. 4, pp. 425–431, 2011.

[26] S. Ishaq, F. Begum, K. Ali et al., "Assessment of soil quality under different land use practices in Altit Valley, Hunza Nagar,Gilgit-Baltistan," *Journal of Biodiversity and Environmental Sciences*, vol. 6, no. 1, pp. 454–459, 2015.

[27] T. G. Pham, H. T. Nguyen, and M. Kappas, "Assessment of soil quality indicators under different agricultural land uses and topographic aspects in Central Vietnam," *International Soil and Water Conservation Research*, vol. 6, no. 4, pp. 280–288, 2018.

[28] X. Zhao, P. Wu, X. Gao, and N. Persaud, "Soil quality indicators in relation to land use and topography in a small catchment on the Loess Plateau of China," *Land Degradation & Development*, vol. 26, no. 1, pp. 54–61, 2015.

[29] S. Alem and J. Pavlis, "Conversion of grazing land into Grevillea robusta plantation and exclosure: impacts on soil nutrients and soil organic carbon," *Environmental Monitoring and Assessment*, vol. 186, no. 7, pp. 4331–4341, 2014.

[30] S. C. P. Castilho, M. Cooper, A. Dominguez, and J. C. Bedano, "Effect of land use changes in eastern amazonia on soil chemical, physical, and biological attributes," *Soil Science*, vol. 181, no. 3-4, pp. 133–147, 2016.

[31] A. K. Singh, L. J. Bordoloi, M. Kumar, S. Hazarika, and B. Parmar, "Land use impact on soil quality in eastern Himalayan region of India," *Environmental Monitoring and Assessment*, vol. 186, no. 4, pp. 2013–2024, 2014.

[32] D. D. Chen, S. H. Zhang, S. K. Dong, X. T. Wang, and G. Z. Du, "Effect of land-use on soil nutrients and microbial biomass of an Alpine region on the northeastern Tibetan Plateau, China," *Land Degradation and Development*, vol. 21, no. 5, pp. 446–452, 2010.

[33] S. Lozano-Baez, M. Cooper, S. Frosini de Barros Ferraz, R. Ribeiro Rodrigues, M. Castellini, and S. Di Prima, "Recovery of soil hydraulic properties for assisted passive and active restoration: assessing historical land use and forest structure," *Water*, vol. 11, no. 1, p. 86, 2019.

[34] M. D. Alemu, A. Kebede, and A. Moges, "Farmers' perception of soil erosion and adoption of soil conservation technologies at Geshy sub-catchment, Gojeb River catchment, Ethiopia," *Agricultural Sciences*, vol. 10, no. 1, pp. 46–65, 2019.

[35] K. Wolka, G. Sterk, B. Biazin, and M. Negash, "Benefits, limitations and sustainability of soil and water conservation structures in Omo-Gibe basin, Southwest Ethiopia," *Land Use Policy*, vol. 73, pp. 1–10, 2018.

[36] T. Abebe, *Soil Analysis, Mapping, and Interpretation of the World Bank-funded 20 SLMP Watersheds of Ethiopia, Final Soil Report*, Sustainable Land Management, Ministry of Agriculture, Addis Ababa, Ethiopia, 2013.

[37] A. Tafesse, *Agroecological zones of south western Ethiopia*, Ph.D. Thesis, University of Trier, Trier, Germany, 1996.

[38] J. R. Landon, *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*, Longman Scientific and Technical, Essex, NY, USA, 1991.

[39] A. Abegaz, L. A. Winowiecki, T.-G. Vågen, S. Langan, and J. U. Smith, "Spatial and temporal dynamics of soil organic carbon in landscapes of the upper Blue Nile Basin of the Ethiopian Highlands," *Agriculture, Ecosystems & Environment*, vol. 218, pp. 190–208, 2016.

[40] L. Winowiecki, *Landscape-Scale Assessments of Soil Health: Local Determinants of Soil Organic Carbon in Ethiopia*, International Center for Tropical Agriculture (CIAT), Nairobi, Kenya, 2015.

[41] G. Blake, "Bulk density," in *Methods of Soil Analysis, Part 1. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling*, C. A. Black, Ed., American Society of Agronomy, Madison, WI, USA, 1965.

[42] F. Yimer, G. Alemu, and A. Abdelkadir, "Soil property variations in relation to exclosure and open grazing land use types in the Central Rift Valley area of Ethiopia," *Environmental Systems Research*, vol. 4, no. 1, p. 17, 2015.

[43] P. Hazelton and B. Murphy, "Interpreting soil test results: what do all the numbers mean?," *European Journal of Soil Science*, vol. 58, no. 5, pp. 1219-1220, 2007.

[44] L. Reeuwijk, *Procedures for Soil Analysis*, ISRIC, FAO, Wageningen, Netherlands, 2002.

[45] Haldar and Sakar, *A Physical and Chemical Method in Soil Analysis: Fundamental Concepts of Analytical Chemistry and Instrumental Techniques*, New Age International (P) Ltd. Publisher, New Delhi, India, 2005.

[46] A. Walkley and I. A. Black, "An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29–38, 1934.

[47] S. R. Olsen, C. V. Cole, F. S. Watanabe, and L. A. Dean, "Estimation of available phosphorus in soils by extraction with sodium bicarbonate," *Journal of Chemical Information and Modeling*, vol. 939, p. 19, 1954.

[48] A. R. Bertrannd, "The rate of water intake in the field," in *Methods of Soil Analysis, Part I. American Society of Agronomy*, USDA, Washington, DC, USA, 1965.

[49] J. Lai and L. Ren, “Assessing the size dependency of measured hydraulic conductivity using double-ring infiltrometers and numerical simulation,” *Soil Science Society of America Journal*, vol. 71, no. 6, p. 1667, 2007.

[50] A. Abdelkadir and F. Yimer, “Soil water property variations in three adjacent land use types in the Rift Valley area of Ethiopia,” *Journal of Arid Environments*, vol. 75, no. 11, pp. 1067–1071, 2011.

[51] F. Yimer, I. Messing, S. Ledin, and A. Abdelkadir, “Effects of different land use types on infiltration capacity in a catchment in the highlands of Ethiopia,” *Soil Use and Management*, vol. 24, no. 4, pp. 344–349, 2008.

[52] H. D. Foth, *Fundamentals of Soil Science*, John Wiley and Sons, New York, NY, USA, 8th edition, 1990.

[53] M. Castellini, L. Giglio, M. Niedda, A. D. Palumbo, and D. Ventrella, “Impact of biochar addition on the physical and hydraulic properties of a clay soil,” *Soil and Tillage Research*, vol. 154, pp. 1–13, 2015.

[54] W. D. Reynolds, C. F. Drury, C. S. Tan, C. A. Fox, and X. M. Yang, “Use of indicators and pore volume-function characteristics to quantify soil physical quality,” *Geoderma*, vol. 152, no. 3-4, pp. 252–263, 2009.

[55] T. Gebrelibanos and M. Assen, “Effects of land-use/cover changes on soil properties in a dryland watershed of hirmi and its adjacent agro-ecosystem, northern Ethiopia,” *International Journal of Geosciences Research*, vol. 1, no. 1, pp. 45–57, 2013.

[56] Y. G. Selassie and G. Ayanna, “Effects of different land use systems on selected physicochemical properties of soils in northwestern Ethiopia,” *Journal of Agricultural Science*, vol. 5, no. 4, 2013.

[57] Y. G. Selassie, F. Anemut, and S. Addisu, “The effects of land use types, management practices and slope classes on selected soil physicochemical properties in Zikre watershed, North-Western Ethiopia,” *Environmental Systems Research*, vol. 4, no. 1, p. 3, 2015.

[58] M. A. Arshad, B. Lowery, and B. Grossman, “Physical tests for monitoring soil quality,” in *Methods for Assessing Soil Quality*, J. W. Doran and A. J. Jones, Eds., vol. 49, pp. 123–141, Soil Science Society of America, Madison, WI, USA, 1996.

[59] M. Castellini, M. Niedda, M. Pirastru, and D. Ventrella, “Temporal changes of soil physical quality under two residue management systems,” *Soil Use and Management*, vol. 30, no. 3, pp. 423–434, 2014.

[60] M. Castellini, A. M. Stellacci, E. Barca, and M. Lovino, “Application of multivariate analysis techniques for selecting soil physical quality indicators: a case study in long-term field experiments in Apulia (southern Italy),” *Soil Science Society of America Journal*, 2019.

[61] K. Z. Mganga, N. K. R. Musimba, D. M. Nyariki et al., “Different land use types in the semi-arid rangelands of Kenya influence soil properties,” *Journal of Soil Science*, vol. 2, no. 11, pp. 370–374, 2011.

[62] B. Fu, J. Wang, L. Chen, and Y. Qiu, “The effects of land use on soil moisture variation in the Danangou catchment of the Loess Plateau, China,” *Catena*, vol. 54, no. 1-2, pp. 197–213, 2003.

[63] S. L. Liu, X. D. Guo, B. J. Fu, G. Lian, and J. Wang, “The effect of environmental variables on soil characteristics at different scales in the transition zone of the Loess Plateau in China,” *Soil Use and Management*, vol. 23, no. 1, pp. 92–99, 2007.

[64] A. A. H. Abdel-Magid, G. E. Schuman, and R. H. R. Hart, “Soil bulk density and water infiltration as affected by grazing systems,” *Journal of Range Management*, vol. 40, no. 4, pp. 307–309, 2014.

[65] C. C. Jimenez, M. Tejedor, G. Morillas, and J. Neris, “Infiltration rate in andisols: effect of changes in vegetation cover (Tenerife, Spain),” *Journal of Soil and Water Conservation*, vol. 61, no. 3, pp. 153–158, 2006.

[66] K. Broersma, J. A. Robertson, and D. S. Chanasyk, “Effects of different cropping systems on soil water properties of a boralf soil,” *Communications in Soil Science and Plant Analysis*, vol. 26, no. 11-12, pp. 1795–1811, 1995.

[67] M. A. Taboada and R. S. Lavado, “Grazing effects on the bulk density in a natraquoll of the flooding pampa of Argentina,” *Journal of Range Management*, vol. 41, pp. 500–503, 2007.

[68] M. Castellini, M. Iovino, M. Pirastru, M. Niedda, and V. Bagarello, “Use of BEST procedure to assess soil physical quality in the Baratz Lake catchment (Sardinia, Italy),” *Soil Science Society of America Journal*, vol. 80, no. 3, pp. 742–755, 2016.

[69] J. R. Landon, *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*, Routledge, Abingdon, UK, 2014.

[70] F. Yimer, S. Ledin, and A. Abdelkadir, “Changes in soil organic carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, South-eastern highlands of Ethiopia,” *Forest Ecology and Management*, vol. 242, no. 2-3, pp. 337–342, 2007.

[71] A. Moges and N. M. Holden, “Soil fertility in relation to slope position and agricultural land use: a case study of umbulo catchment in southern Ethiopia,” *Environmental Management*, vol. 42, no. 5, pp. 753–763, 2008.

[72] S. e. Khresat, J. Al-bakri, and R. Al-tahhan, “Impacts of land use/cover change on soil properties in the Mediterranean region of northwestern Jordan,” *Land Degradation & Development*, vol. 19, no. 4, pp. 397–407, 2008.

[73] Y. Abera and T. Belachew, “Effects of land use on soil organic carbon and nitrogen in soils of the bale, Southeastern Ethiopia,” *Tropical & Subtropical Agroecosystems*, vol. 14, no. 1, pp. 229–235, 2011.

[74] N. C. Brady and R. R. Weil, *The Nature and Properties of Soils*, Macmillan Publishing Co., New York, NY, USA, 13th edition, 2002.

[75] S. Logsdon, “Encyclopedia of soil science,” *Soil Science Society of America Journal*, vol. 72, no. 3, p. 862, 2008.