

Effects of land use and land cover on selected soil quality indicators in the headwater area of the Blue Nile basin of Ethiopia

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Abstract Understanding changes in soil quality resulting from land use and land management changes is important to design sustainable land management plans or interventions. This study evaluated the influence of land use and land cover (LULC) on key soil quality indicators (SQIs) within a small watershed (Jedeb) in the Blue Nile Basin of Ethiopia. Factor analysis based on principal component analysis (PCA) was used to determine different SQIs. Surface (0–15 cm) soil samples with four replications were collected from five main LULC types in the watershed (i.e., natural woody vegetation, plantation forest, grassland, cultivated land, and barren land) and at two elevation classes (upland and midland), and 13 soil properties were measured for each replicate. A factorial (2×5) multivariate analysis of variance (MANOVA) showed that LULC and altitude together significantly affected organic matter (OM) levels. However, LULC alone significantly affected bulk density and altitude alone significantly affected bulk density, soil acidity, and silt content. Afforestation of barren land with eucalypt trees can significantly increase the soil OM in the midland part but not in the upland part. Soils under grassland had a significantly

higher bulk density than did soils under natural woody vegetation indicating that de-vegetation and conversion to grassland could lead to soil compaction. Thus, the historical LULC change in the Jedeb watershed has resulted in the loss of soil OM and increased soil compaction. The study shows that a land use and management system can be monitored if it degrades or maintains or improves the soil using key soil quality indicators.

Keywords Soil degradation · Soil quality indicators · Land use and land cover · Altitude · Principal component analysis · MANOVA · Blue Nile

Introduction

Land degradation has become an important global concern because of its implications for food security and the environment. One of the major causes of land degradation is human activities. Human activities contributing to land degradation include deforestation, removal of natural vegetation, overgrazing, and agricultural practice without erosion control measures. Land use and land cover (LULC) change is the easiest detectable indicator of human activities on the land. LULC change affects soil quality (Alem and Pavlis 2014; Nosrati 2013; Singh et al. 2014), runoff and sedimentation rates (Leh et al. 2013; Liu et al. 2012), biodiversity (Hansen et al. 2004), and ecosystem services (Zhang et al. 2013).

Soil degradation is the key component of land degradation, and there is almost no form of land degradation

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that does not include soil degradation (Hartemink 2003). It is the decline in soil quality leading to a reduction in other components of land resources (e.g. vegetation, water, and air). Soil degradation processes involve chemical degradation (e.g., nutrient depletion and acidification), physical degradation (e.g., soil erosion, compaction, and waterlogging), and biological degradation (e.g., soil organic matter decline and depletion of soil fauna) (Lal et al. 1989). Regarding soil nutrient depletion, Ethiopia is among the sub-Saharan African (SSA) countries with very high nutrient depletion rates (Misra et al. 2003). This very high nutrient depletion is an indication of the prevailing unsustainable land use and management systems. In Ethiopia, land is used largely by smallholders for subsistence agriculture which is characterized by low yields resulting from little or no use of external inputs. In the absence of intensification, smallholders always seek more land for cultivation to meet the increasing demand for food caused by the growing population. Consequently, deforestation and conversion of grassland to cropland take place including in marginal lands. This leads to high soil erosion rates.

In the Ethiopian highlands (e.g., East Gojjam), soil degradation is severe (Bewket and Teferi 2009; Hurni 1988). The prevailing soil degradation has led to lower yield or higher costs of inputs. Consequently, the food security of present and future generations is being threatened, as the smallholder farmers in the area largely depend upon the land for their livelihood. Farmers are responding to soil degradation mainly by changing land use from cropland to plantation forest (e.g., *Eucalyptus globulus*). Apart from the range of timber and non-timber benefits of eucalyptus to rural households, its long-term effects on the soil have received little research attention. Eucalyptus plantation is a controversial issue and generates criticism concerning understory plant diversity and soil quality (Jagger and Pender 2003). Little systematic effort has been undertaken to prove whether or not eucalyptus plantation on cropland is a more sustainable form of land use than crop cultivation in the Gojjam highlands of Ethiopia (e.g., Bewket and Stroosnijder 2003). However, elsewhere in Ethiopia studies have provided empirical evidence for soil quality decline in soils under eucalyptus plantation (Demessie et al. 2012; Michelsen et al. 1993). Behera and Sahani (2003) indicated that the soil quality improvement caused by afforestation with eucalyptus plantation is less than that resulted from the spontaneous regeneration from exclosures. Thus, eucalyptus plantation

impacts on soils may not always be beneficial. As alternative to eucalyptus plantation, the establishment of exclosures on degraded lands can be effective in improving soil quality (Mekuria and Aynekulu 2013).

A land use and management system should be evaluated if it degrades or maintains or improves soil quality so as to support the design of site-specific and effective sustainable land management systems. Soil quality indicators (SQIs) used elsewhere may not be applicable to another area because indicators are purpose- and site-specific (Shukla et al. 2006). The selection of SQIs can be carried out using statistical procedure such as principal component analysis (PCA) or expert opinion to obtain minimum data sets (MDS). PCA is a multivariate statistical approach that transforms a number of possibly correlated variables into a smaller number of uncorrelated parameters called principal components (Field 2009). PCA has been used widely all over the world to select representative MDS soil properties (Shukla et al. 2006; Singh et al. 2014; Nosrati 2013).

Soil quality has two different aspects: (i) intrinsic soil quality which refers to the soil's natural composition, and (ii) dynamic soil quality covering the part influenced by soil users or managers (Larson and Pierce 1994). In other words, the dynamic soil quality is influenced by changes in land use and land cover or land management practices. For instance, removal of vegetative covers exposes the soil to the forces of erosion (Bewket and Teferi 2009; Haregeweyn et al. 2013), increases compaction (Bewket and Stroosnijder 2003), decreases sources of soil organic matter, and so on. These effects will ultimately lead to negative changes in soil quality indicators from the perspective of sustainable land use. Understanding changes in soil quality resulting from land use and land management changes is important as it provides information on the effectiveness of different land use options and hence modifies land management practices as needed to maintain or improve soil quality for sustainable land use. Effects of land use conversions on soil properties is inherently site-specific and highly dependent on the soil type under which the land use is established. Thus, there is an urgent need to assess the effects that different land use conversions have on soil quality.

The general objective of this study was to assess effects of land use and land management on selected key soil quality indicators. The specific objectives were to (i) identify key soil quality indicators using multivariate analysis and (ii) assess effects of land

use and land management changes on the selected soil quality indicators taking into account the influence of agroecology. The following section presents study area description and methodology of the study, followed by results and discussion sections. The final section concludes the study with some policy implications of the findings.

Materials and methods

Study area

The study area, Jedeb watershed, lies between 10° 23' to 10° 40' N and 37° 33' to 37° 60' E. It is situated in the southwestern part of Mount Choke, which is a headwater area of the Upper Blue Nile/Abbay in Ethiopia (Fig. 1). The watershed (about 296 km² in size)

comprises diverse topographic conditions with elevation ranging from 2172 m to nearly 4001 m (Fig. 1), and slopes ranging from nearly flat (<2°) to very steep (>45°). Altitude is an important parameter in soil genesis, as it provides a useful proxy for several factors such as geomorphology and climate of places. The total population in Weyna Dega zone and Dega zone (Fig. 1) of the watershed was 39,665 in 2007 with a population density of 215 persons/km² and 23,080 with a population density of 170 persons/km², respectively (CSA 2007). The soil units covering the Jedeb watershed are Haplic Alisols (54 %), Eutric Leptosols (24 %), and Haplic Luvisols (22 %) (BCEOM 1998b). The geological units in the watershed are Tarmaber Basalts-2 (less weathered, 94.2 % of the watershed), Tarmaber Basalts-1 (deeply weathered and appropriate for agricultural use, 4.4 %), Blue Nile Basalt (0.9 %), and Alluvium (0.5 %) (BCEOM 1998a).

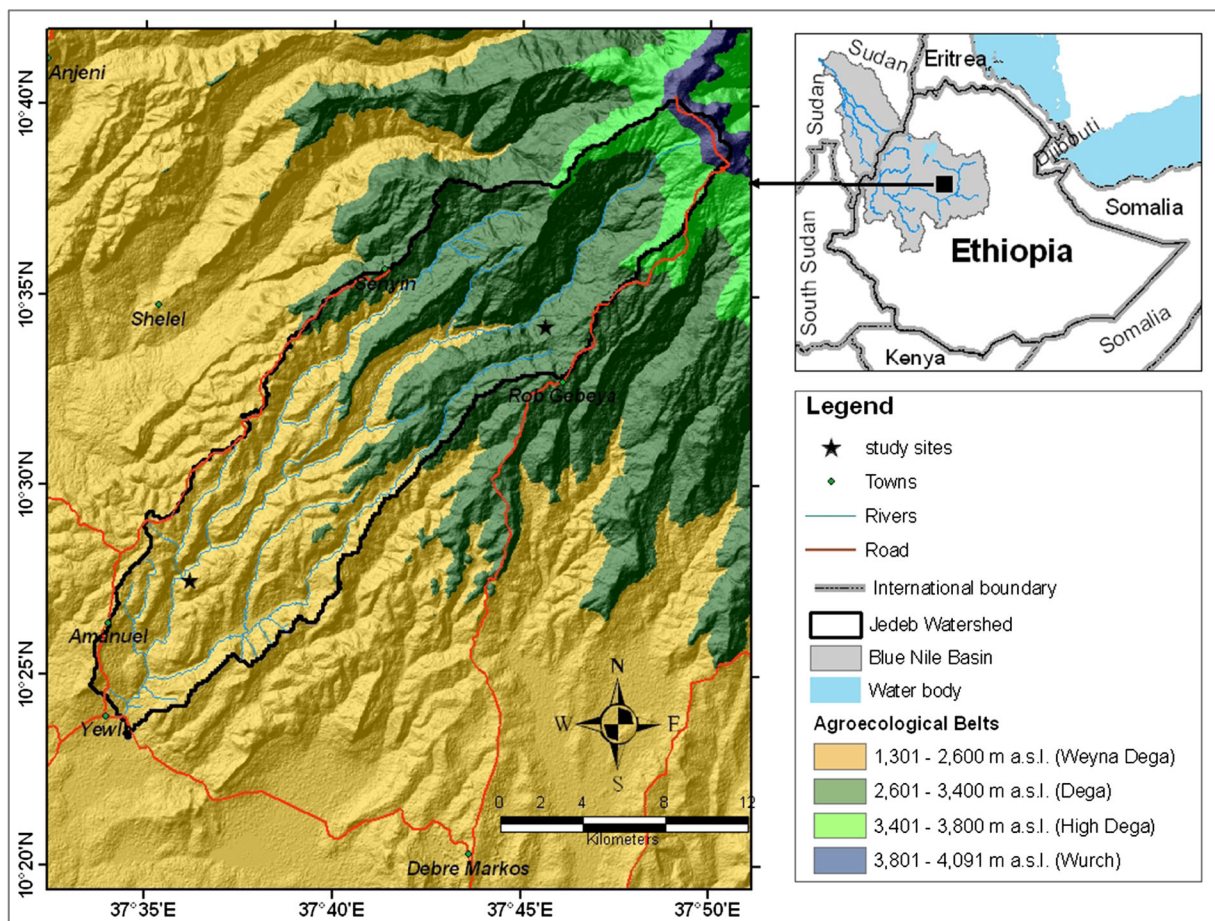


Fig. 1 Location of the study area, Jedeb watershed, central highland of Ethiopia

Land use and land cover change history

In this study, five land use and land cover (LULC) types were used for the purpose of assessing effects of land use and land cover on soil properties (Table 1). The LULC classes were obtained by aggregating the ten LULC classes in the watershed identified by Teferi et al. (2013). Black and white aerial photographs of 1957 Landsat image 2009 (TM) were used to derive the ten LULC classes, and to evaluate the changes between 1957 and 2009. Details of land use and land cover change analysis of the Jedeb watershed are given in Teferi et al. (2013). A considerable land use and land cover change was observed in the Jedeb watershed during the period 1957–2009. Cultivated land constituted the predominant type of land cover, and it accounted for approximately 53 and 70 % in the years 1957 and 2009, respectively. Cultivated land showed a ~27 % gain of the total area, while natural woody vegetation and grassland showed losses of ~13 and ~20 %, respectively (Fig. 2). Plantation forest also increased from 0 in 1957 to 3.4 % of the watershed in 2009. The contribution of cultivated land to the increase in plantation forest was 1.45 % of the total (largest proportion) (Teferi et al. 2013). This indicates that local people plant trees on their croplands instead of growing crops. The local people took this option when they believed that their land had become less fertile and not economical for crop production.

Soil sampling and analysis

Soil sampling Five main LULC types and two elevation classes were selected to study effects of land use and

land cover on key soil quality indicators. The LULC types were natural woody vegetation, plantation forest, grassland, cultivated land, and barren land (Table 1). The elevations of the specific sampling sites range from 2400 to 2500 m (midland) and 2900 to 3000 m (upland), which respectively represent the Dega and Weyna Dega agroecological zones (AEZs) (Fig. 1). For the unimodal rainfall region of Ethiopia, which also includes the Jedeb watershed, Hurni (1999) identifies the following agroecological zones: WeynaDega (midaltitude, 1300–2600 m above sea level (a.s.l.)), Dega (high-altitude, 2600–3400 m a.s.l.), High Dega (high-altitude, 3400–3800 m a.s.l.), and Wurch (>3800 m a.s.l.). The selected sites have a land use history of at least 23 years. The crop type on the cultivated land in both AEZs was *engido* (*Avena* spp.). The selected type of forest plantation was *Eucalyptus globulus* in both the midland and upland areas, as it is a widely planted tree in the Jedeb watershed.

Site selection was conducted based on 1:250,000 scale soil mapping units (SMUs) developed by BCEOM (1998b) because each mapping unit is characterized by similar major landform and major soils. One SMU (V/SeLp) that forms similar landform and soil type across the two elevation classes was selected from a total of 3 SMUs identified in the Jedeb watershed. Soil samples were taken from similar soil types (i.e., Leptosls) and slope classes (i.e., 15–30 %) at the two elevation classes.

In a factorial completely randomized design considering the five land use types and the two elevation classes with four replications, a total of 40 different sampling units ($n = 5 \times 2 \times 4 = 40$) were created. For each replicate, a sample was collected for laboratory analysis

Table 1 The five major land use and land cover types studied in the Jedeb watershed

Aggregated land use and land cover classes ^a	1957		1986		2009	
	km ²	%	km ²	%	km ²	%
Natural woody vegetation (NWW)	46.1	15.5	22.1	7.5	11.5	3.9
Plantation forest (PF)	0	0	2.1	0.7	10	3.4
Grassland (GL)	90.6	30.6	72.7	24.5	65.3	22
Cultivated land (CL)	158.4	53.4	197.2	66.5	206.2	69.5
Barren land (BL)	1.5	0.5	2.6	0.9	3.6	1.2

^a The original ten land use and land cover classes of Teferi et al. (2013) were aggregated into five classes. Woodland, ericaceous forest, riverine forest, and shrubs, and bushes were grouped into NWW; grassland, Afro-alpine grassland, and marshland classes were aggregated into GL; and Plantation forest, cultivated land, and barren land classes remain unchanged

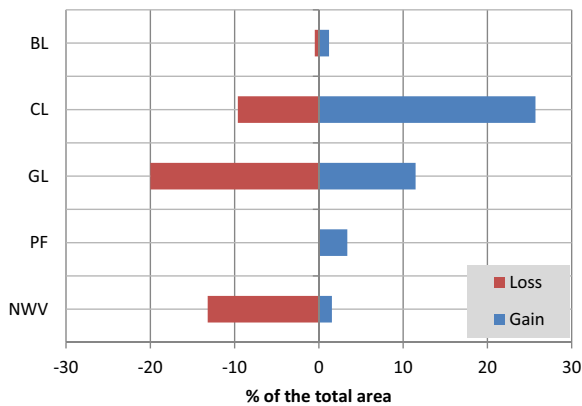


Fig. 2 Gains and losses of land use and land cover classes between 1957 and 2009 based on Teferi et al. (2013). *NWV* natural woody vegetation, *PF* plantation forest, *GL* grassland, *CL* cultivated land, *BL* barren land

within a 15 m × 15 m plot in the layer 0–15 cm (topsoil) using soil auger (10-cm diameter). Undisturbed soil samples were taken using cylindrical metal samplers (5 cm long with 5-cm diameter) for the purpose of soil bulk density determination using core method. Soil samples were analyzed using standard procedures (Klute 1986; Sparks et al. 1996) in laboratory for texture, pH, organic carbon, total nitrogen (TN), exchangeable bases (sodium, potassium, calcium, and magnesium), cation exchange capacity (CEC), and available phosphorus (Av.P).

Statistical analysis Various steps were followed to identify key soil quality indicators (SQIs). The sampling adequacy was evaluated using Kaiser–Meyer–Olkin (KMO) statistics. KMO represents the ratio of the squared correlation between variables to the squared partial correlation between variables (Kaiser 1970). The KMO statistic varies between 0 and 1. A value of 0 indicates that the sum of partial correlations is large relative to the sum of correlations, indicating diffusion in the pattern of correlations. Values between 0.5 and 0.7 are mediocre, values between 0.7 and 0.8 are good, values between 0.8 and 0.9 are great, and values above 0.9 are superb. Principal component analysis (PCA) was used as the method of factor extraction to group the measured ten soil properties into major varimax rotated components of the SQI. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. Only

factors with eigenvalues >1 were retained based on Kaiser’s recommendation (Kaiser 1960). Factor scores for each sample were computed using the regression method, and analysis of variance was conducted on the computed factors to determine which factors varied significantly with land use and land cover types. A two-way between-subjects multivariate analysis of variance (MANOVA) was conducted on the soil properties with high loadings (i.e., Bulk Density (BD), pH, organic matter (OM), and silt) in the statistically significant factors. One of the major advantages of using MNAOVA is that can single out group differences that may become masked with univariate statistical analyses. The statistical analysis was performed using SPSS software.

Results

Grouping of soil properties

A principal component analysis (PCA) was conducted on the ten soil parameters to determine the minimum data sets for soil quality assessment. The Kaiser–Meyer–Olkin (KMO) measure verified the sampling adequacy for the analysis, KMO=0.71, which is above the acceptable limit of 0.5 (Field 2009). Bartlett’s test sphericity was highly significant ($\chi^2(45)=164.45, P<0.001$), indicating that the correlations of the soil parameters were sufficiently large for PCA (Table 2).

Four components with eigenvalues greater than the Kaiser’s criterion of 1 were retained and in combination explained 78.82 % of the variability in the measured soil properties (Table 3). Component-1 explained nearly 36 % of variance with a high loadings (>0.7) from silt content, clay content, OM, BD, and pH (Fig. 3). Silt content was highly significantly correlated with clay ($r=-0.78$), OM ($r=0.66$), BD ($r=-0.41$), and pH ($r=-0.48$). Component-2 explained 18 % of the total variance with high loadings from C/N and TN, resulting from the highly significant correlation between them ($r=-0.596$). Component-3 accounted for nearly 15 % of the total variance with high loadings from available P and CEC, resulting from the highly significant negative correlation between them ($r=0.423$). Component-4 explained 10 % of the total variance with high positive loading from base saturation (Fig. 4).

The amount of variance in each soil parameter that can be explained by the retained four components is represented by the communality estimates. As can be

Table 2 Pearson correlation coefficients of the physical and chemical properties

	Silt	Clay	BD	pH	CEC	BS	OM	TN	C/N
Silt (%)	1								
Clay (%)	-.777***	1							
BD (g cm ⁻³)	-.412***	.625***	1						
pH	-.479***	.465***	.464***	1					
CEC (cmol kg ⁻¹)	-.068	-.109	-.092	.176	1				
BS (%)	-.164	.139	-.025	-.102	.192	1			
OM (%)	.663***	-.757***	-.640***	-.540***	.207*	-.060	1		
TN (%)	.263*	-.366***	-.319**	-.028	.190	-.061	.235*	1	
C/N	.263*	-.157	.015	-.229*	-.057	.000	.215*	-.596***	1
Av.P (ppm)	-.019	-.170	-.265**	.119	.423***	.100	.233*	.089	.010

The determinant of the correlation matrix is 0.009

*Correlation is significant at 0.1; **correlation is significant at 0.05; ***correlation is significant at 0.01 level of probability

seen in the communality estimates of Table 3, the four components explained >86 % of variance in BS, C/N, and TN; >82 % in organic matter and clay content; >70 % in soil pH, available P, and silt content; and >65 % in bulk density and CEC.

Table 3 The factor loadings after Varimax rotation and communality estimates (factor loadings over 0.7 appear bold)

Soil parameters	Rotated component loadings				Communality estimates
	1 ^a	2	3	4	
Clay (%)	.894	.073	-.127	.169	.848
OM (%)	-.877	.050	.223	-.023	.822
Silt (%)	-.833	.055	-.108	-.225	.759
BD (g cm ⁻³)	.749	.193	-.174	-.150	.651
pH	.718	-.141	.338	-.340	.765
C/N	-.231	.910	.015	-.043	.883
TN (%)	-.314	-.863	.111	-.086	.863
Av.P (ppm)	-.114	.026	.832	.014	.706
CEC (cmol kg ⁻¹)	-.020	-.102	.815	.123	.690
BS (%)	.067	.020	.135	.933	.893
Initial eigenvalues	3.548	1.833	1.458	1.043	–
Variance (%)	35.485	18.328	14.578	10.428	–
Cumulative variance (%)	35.485	53.812	68.390	78.817	–

^a Effects of land use and land cover (LULC), altitude (A), and interaction of the two (LULC x A) on component-1 are significant ($p < 0.05$)

A univariate ANOVA conducted on the component scores revealed that there were statistically significant main effects of LULC and altitude and interaction effect on component-1 only (S1). The other components were not significant, implying that the variation of the soil properties with high loadings in these components was not related to LULC or altitude. Therefore, only soil properties with high loadings in component-1 were analyzed in MANOVA.

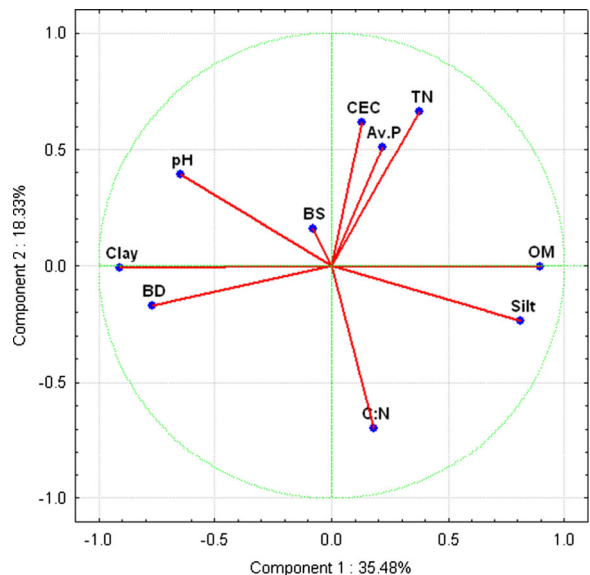


Fig. 3 Loading plot showing relationships among soil properties in component-1 and component-2, Jedeb watershed, central highlands of Ethiopia

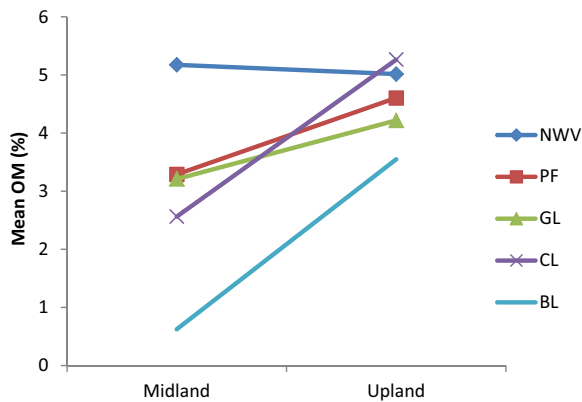


Fig. 4 Interaction plot for the mean soil organic matter (OM) content

Testing assumptions

The results of the evaluation of the assumptions of normality, linearity, and multicollinearity were satisfied. Based on a statistically non-significant Box’s test (Box’s $M=83.01, P=0.073$) (S2), the assumption of homogeneity of variance–covariance matrices was met. This means that the dependent variable (BD, pH, OM, silt) covariance matrices were equal across the levels of the independent variables (LULC and altitude). Separate Levene’s tests (S2) for each dependent variable found statistically non-significant ($P>0.05$) effect for all dependent variables, indicating equal variances for each dependent variable across the levels of LULC and altitude. Bartlett’s test of sphericity was statistically significant ($\chi^2=425, P=0.000$), indicating a sufficient correlation between the dependent variables to proceed with the MANOVA analysis.

Multivariate main effects and interaction effect

Table 4 presents the multivariate test results, all of which indicate statistically significant main effects (LULC, altitude) as well as the interaction effect. Since equality of variance–covariance matrices was evidenced with the non-significant Box’s M test, the most robust and commonly used statistic, the Wilks’ Lambda (Λ), was selected for further analysis. Using Wilks’s criterion, the multivariate main effect of land use was statistically significant ($\Lambda=0.23, F(16, 83)=3.206, P=0.000$), indicating the soil properties were significantly affected by land use. The multivariate main effect of altitude was also statistically significant ($\Lambda=0.235, F(4,$

$27)=21.98, P=0.000$). The multivariate interaction effect of LULC and altitude was statistically significant ($\Lambda=0.388, F(16, 83)=2.311, P=0.033$).

A series of univariate ANOVAs were conducted on each dependent variable separately as a follow-up test to the MANOVA in order to determine the locus of the statistically significant multivariate effects. Since the Leven’s test (S2) showed the homogeneity of variances among the groups on each dependent measure, it was possible to proceed with univariate ANOVAs with a Bonferroni adjusted alpha level of 0.025 (0.05/2). As can be seen in Table 5, the univariate interaction effect of altitude and land use on soil organic matter content was statistically significant ($F=3.884, p=0.012$).

Although the mean of the interaction of elevation and land use differs significantly on soil organic matter content, there is no indication of the location of this difference. To test for differences among specific interaction levels, least significant difference (LSD) post hoc comparisons were conducted on a new grouping variable that contains the ten levels of interaction. Out of 45 possible combinations of interactions, only 23 of them were found to be significantly different from each other with respect to soil organic matter content (Table 6).

A statistically significant mean difference in soil organic matter content between soils under midland natural woody vegetation and midland barren land was among the highest (mean = 4.55 %). There was a statistically significant mean difference in soil organic matter content between soils under upland cultivated land and midland cultivated land (mean difference = 2.7, $p=0.000$). Soils under upland cultivated land significantly contained more soil organic matter (mean = 5.26 %) than under midland cultivated land (mean = 2.56 %). The results also indicate that soils under upland natural woody vegetation had significantly higher soil organic matter content than those under all midland land use types except midland natural woody vegetation.

Since no other soil properties were statistically significant in the univariate interaction effect, it is possible to proceed to examine only the main effects of bulk density, soil pH, and silt content. The main effect of land use was statistically significant only for bulk density ($F=5.994, p=0.001$). The LSD post hoc test (Table 6) suggested that grassland (mean = 1.13 g cm⁻³) and barren land (mean = 1.20 g cm⁻³) had a significantly higher bulk density than did soils under natural woody vegetation (mean = 0.94 g cm⁻³). Barren land had a significantly

Table 4 Multivariate test results

Effect	Multivariate test	Value	<i>F</i>	Hypothesis df	Error df	Sig.
Land use and land cover (LULC)	Pillai's trace	1.015	2.549	16	120	.002
	Wilks' lambda	0.230	3.206	16	83	.000
	Hotelling's trace	2.366	3.770	16	102	.000
	Roy's largest root	1.924	14.434	4	30	.000
Elevation	Pillai's trace	0.765	21.984	4	27	.000
	Wilks' lambda	0.235	21.984	4	27	.000
	Hotelling's trace	3.257	21.984	4	27	.000
	Roy's largest root	3.257	21.984	4	27	.000
LCLC * E	Pillai's trace	0.806	1.892	16	120	.027
	Wilks' lambda	0.388	1.888	16	83	.033
	Hotelling's trace	1.129	1.800	16	102	.041
	Roy's largest root	0.553	4.144	4	30	.009

higher bulk density as compared to the remaining land cover types.

The main effect of altitude was statistically significant for soil pH ($F = 24.403$, $p = 0.000$), bulk density ($F = 40.796$, $p = 0.000$), and silt content ($F = 6.613$, $p = 0.015$). The midland part had a significantly higher soil pH (mean = 5) and bulk density (mean = 1.19 g cm^{-3}) than the upland part (mean pH of 4.5 and mean bulk density of 0.95 g cm^{-3}) of the watershed. The silt content of the upland part (mean = 40.5 %) was significantly higher than that of the midland part (mean = 26.9 %). The upland has a clay loam soil texture and the midland has clay soil texture. The mean physical

and chemical soil properties of the upland and midland of the Jedeb watershed are shown in S3.

DISCUSSION

This study assessed effects of land use and land management on selected key soil quality indicators using MANOVA. Analysis of variance on the principal components revealed that soil texture, organic matter content, bulk density, and soil pH were found to be appropriate soil quality indicators that are related to land use or/and altitude. The non-significant effects on the other components suggested that the variation in soil properties of the corresponding components could not be explained either by land use or altitude. The findings of this study are consistent with those of Tesfahunegn (2013), who investigated soil organic carbon, silt content, and bulk density as important parameters for the evaluation of sustainability of land use. Shukla et al. (2006) also found a similar result that soil organic carbon could play an important role for monitoring soil quality in relation to land use.

Effects of land use and land cover on soil quality indicators

Soil organic matter content

The impact of LULC on soil organic matter content was dependent on altitude, as indicated by the statistically

Table 5 Univariate test results

Source	Dependent variable	<i>F</i>	Sig.
Land use and land cover (LULC)	Bulk density	5.994	.001
	Soil pH	2.376	.074
	Organic matter	11.067	.000
	Silt content	0.969	.439
Elevation (E)	Bulk density	40.796	.000
	Soil pH	24.403	.000
	Organic matter	28.587	.000
	Silt content	22.814	.000
LULC * E	Bulk density	2.428	.070
	Soil pH	0.818	.524
	Organic matter	3.884	.012
	Silt content	1.509	.225

Table 6 Multiple comparison post hoc LSD test for the interaction effect of land use and altitude with respect to soil organic matter and for the main effect of land use on bulk density

Soil parameters	(I) Interaction	(J) Interaction	Mean Difference (I-J)	Sig.	
Soil organic matter content	Upland natural woody vegetation	Upland barren land	1.465	.041	
	Upland natural woody vegetation	Midland plantation forest	1.725	.008	
	Upland natural woody vegetation	Midland grassland	1.803	.013	
	Upland natural woody vegetation	Midland cultivated land	2.451	.001	
	Upland natural woody vegetation	Midland barren land	4.388	.000	
	Upland plantation forest	Midland cultivated land	2.041	.009	
	Upland plantation forest	Midland barren land	3.978	.000	
	Upland grassland	Midland cultivated land	1.655	.017	
	Upland grassland	Midland barren land	3.591	.000	
	Upland cultivated land	Upland barren land	1.714	.014	
	Upland cultivated land	Midland plantation forest	1.975	.002	
	Upland cultivated land	Midland grassland	2.053	.004	
	Upland cultivated land	Midland cultivated land	2.700	.000	
	Upland cultivated land	Midland barren land	4.637	.000	
	Upland barren land	Midland barren land	2.923	.000	
	Midland natural woody vegetation	Upland barren land	1.624	.024	
	Midland natural woody vegetation	Midland plantation forest	1.884	.004	
	Midland natural woody vegetation	Midland grassland	1.962	.008	
	Midland natural woody vegetation	Midland cultivated land	2.610	.001	
	Midland natural woody vegetation	Midland barren land	4.547	.000	
	Midland plantation forest	Midland barren land	2.663	.000	
	Midland grassland	Midland barren land	2.585	.000	
	Midland cultivated land	Midland barren land	1.937	.006	
	Bulk density	Grassland	Natural woody vegetation	0.144	.022
		Barren land	Natural woody vegetation	0.284	.000
Barren land		Plantation forest	0.178	.006	
Barren land		Grassland	0.140	.026	
Barren land		Cultivated land	0.166	.009	

significant interaction effect for soil organic matter content in the MANOVA. In general, upland LULC had higher soil organic matter content than the midland LULC. Apart from differences in LULC, this is mainly attributed to the influence of environmental factors on soil organic carbon concentration along altitudinal belts. Consistent with a study by Campos et al. (2013), the reduced soil organic matter decomposition rates as a result of lower temperatures in the upland part could contribute to the increase in the soil carbon. This finding lends strong support to implicate the interaction effects of LULC and (elevation) temperature on soil organic matter decomposition as discussed by various studies

(e.g., Garten Jr et al. 1999; Griffiths et al. 2009). Even within the same AEZ unit, LULC significantly affects soil organic matter content. For example, a significant mean difference in soil organic matter content between soils under midland natural forest and midland cultivated land was observed. This indicates that the loss of soil organic matter could be the result of a remarkable decline in the addition of plant residues to the soil. This result is consistent with the results of various researchers (Lal 2005; Lemenih and Itanna 2004; Muñoz-Rojas et al. 2012) who found a significant decline in soil organic matter content in the conversion of natural forest to cropland. Afforestation of barren land with

eucalyptus plantation can increase soil organic carbon content in the midland part. This is evident from the observed significant mean difference (mean=2.66 %) between soils under midland PF and midland barren land. However, there was no evidence that this effect is true for the upland area as well. The most likely explanation for this could be due to reduced decomposition rates and longer turnover times resulted from lower temperature in the upland area. This underscores the need for site-specific land management practice in afforestation programs of the area. Thus, instead of Eucalyptus plantation, other land management practices such as the establishment of exclosures (Mekuria and Aynekulu 2013) could be effective in restoring degraded areas of the upland part of the watershed. The upland cultivated land had significantly higher soil organic matter content than the midland cultivated land. This could be attributed to different rates of soil organic matter decomposition in the upland and midland part. Lemenih and Itanna (2004) also reported the existence of considerable differences in the amount of soil carbon along the elevation gradient in southern highlands of Ethiopia.

Soil compaction (bulk density)

Both LULC and altitude uniquely and significantly influenced bulk density. The highest significant difference in bulk density was observed in the conversion of natural woody vegetation to barren land. The conversion of natural forest to grassland in the Jedeb watershed was accompanied by significant changes in bulk density. Neill et al. (1997) also found a significant increase in bulk density after the conversion of forest to grassland. The compaction caused by cattle trampling in soils under grassland could be attributed to a significant higher bulk density. Therefore, one of the consequences of conversion of forest to grassland is soil compaction at least for the case of Jedeb watershed. Conversion to barren land also brings an increase in bulk density (compaction). According to Teferi et al. (2013), an area of 16 km² (5.4 %) of the watershed was converted from forest to grassland and then conversion to barren land during the period 1957–2009. This means that about 5.4 % had been degraded in terms of soil compaction. Thus, such types of unsustainable land use conversion need the attention of land users and land managers. Improved

grazing land management has to be designed especially in the upland part to minimize overgrazing which can lead to soil compaction.

Effects of altitude on soil quality indicators

Soil acidity

The non-significant effect of LULC and the significant effect of altitude on soil pH suggest that the variation in soil pH did not depend on land use types but on altitudinal variation. This result agrees with that of Bewket and Stroosnijder (2003) who found a non-significant difference in soil pH among different land use types in a nearby humid watershed. In contrast, Biro et al. (2013) found a significant difference in soil pH between land use types in semi-arid area of Sudan. The difference could be attributed to the difference in climatic condition between two areas. The mean soil pH of both the upland and the midland was less than 5, indicating the acidic nature of the soils of Jedeb watershed. This is largely attributed to the high rainfall (1400–1600 mm a⁻¹) resulting in leaching of exchangeable cations from the topsoil layer. The upland soil was significantly more acidic than the midland soil. Griffiths et al. (2009) also found significantly lower pH at higher elevations as compared to lower elevations. The problem of soil acidity may gradually lead to permanent soil degradation, unless the options of reducing the impact of soil acidity are designed. Maintaining the soil organic matter content can slow down the rate of acidification and prevent further leaching of important nutrients.

Bulk density

Upland soils had a significantly lower bulk density than the midland soils due to the apparent difference in the organic matter decomposition rates. Consequently, the upland area and the midland area of the watershed have different degrees of soil compaction. Thus, a distinction should be made based on AEZ during the selection of appropriate land management practices in the watershed. The midland part needs more efforts of reducing soil compaction than the upland part; i.e., what is best for the midland part may not work in the upland part. Barren lands in the midland part can be afforested with *E. globulus* plantation to increase the soil organic matter content and hence reduce soil compaction. On the other hand, in

grassland areas, soil compaction can be effectively reduced through adopting rotational grazing system or controlled grazing system.

Conclusions

The study showed that the application of multivariate techniques of PCA and MANOVA provides insight into the selection of SQIs. Organic matter content, bulk density, silt content, and soil pH were found to be appropriate SQIs to be used for evaluation of the sustainability of land use and management practices.

The impact of LULC on soil organic matter content was dependent on altitude, being higher in the upland LULC than the midland LULC. Additionally, the conversion of natural woody vegetation to cultivated land in the midland part decreases biomass productivity and reduces the quantity of biomass returned to the soil and, as a result, decreases the soil carbon. The decline in soil organic carbon in the midland part might bring adverse effect on soil structure. Therefore, conversion of degraded or marginal lands to restorative land uses should be adopted to minimize further depletion of soil carbon in the midland part. For example, this study showed that afforestation of barren land with eucalyptus plantation can increase soil organic carbon content in the midland part. However, there was no evidence that this effect is true for the upland area as well.

The conversions of natural woody vegetation to grassland and to barren land were accompanied by significant changes in bulk density. The compaction caused by cattle trampling in soils under grassland could be attributed to a significant higher bulk density. Therefore, one of the consequences of conversion of forest to grassland is soil compaction at least for the case of Jedeb watershed. Thus, such types of unsustainable land use conversion need the attention of land users and land managers. The upland area and the midland area of the watershed have different degrees of soil compaction. Thus, a distinction should be made based on AEZ during the selection of appropriate land management practices in the watershed. The midland part needs more efforts of reducing soil compaction than the upland part. Improved grazing land management has to be

designed to minimize overgrazing which can lead to soil compaction.

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