DYNAMICS OF SELECTED SOIL QUALITY INDICATORS IN RESPONSE TO LAND USE/COVER AND ELEVATION VARIATIONS IN WANKA WATERSHED, NORTHWESTERN ETHIOPIAN HIGHLANDS

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Abstract

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Soil quality (SQ) dynamics assessment vis-à-vis land use/land cover (LULC) and elevation variations in Ethiopia is desirable as elevation impact on land use is highly pronounced. This study examined SQ indicators dynamics across LULC and elevation variations. For this, surface soil samples (0–20 cm) were collected from the recognized LULC categories of different elevations in Wanka watershed, northwestern Ethiopian highlands. Both disturbed and undisturbed soil samples that were taken from three adjacent LULC (natural forest, grazing and cultivated lands) and elevation (2238–2300, 2400–2600, and 2700–2800) classes analysed for the selected physico-chemical SQ indicators. Two-way ANOVA, Tukey's multiple comparison test and SQ deterioration index were computed. The impact of LULC and elevation was found significant on key SQ indicators. In cultivated and grazing lands, soil organic matter (SOM) and soil nutrients like total nitrogen declined significantly ($p < 0.01$). Conversely, bulk density increased significantly ($p < 0.01$). The divalent basic cations (Ca^{2+} and Mg^{2+}), cation exchange capacity and pH significantly ($p < 0.01$) decreased in upper elevation. Synergetic effect of LULC and elevation variations was found significant ($p < 0.01$) on SOM, total nitrogen, available phosphorus, water content at field capacity and soil particle distribution (silt and clay). Thus, elevation specific land management strategies that improve these SQ indicators need to be emphasized.

Key words: soil quality, soil quality deterioration index, cultivated land, grazing land, natural forest land.

Introduction

Soil quality (SQ) assessment in light of land use variation is very critical in tropical regions to improve land-use decisions (Sağlam et al., 2015; Yimer et al., 2006; Fu et al., 2000). In this region, conversion of natural land covers especially natural forests into cultivated land (CL)

is very intense and eventually result in SQ deterioration (Guillaume et al., 2016; Islam, Weil, 2000). Land use/land cover (LULC) change in sub Saharan African region has brought failure of soils to provide essential ecosystem services and subsequently SQ decline has been a major challenge (Diao et al., 2010). In this context, SQ can be considered as the capacity of soil to function in response to land management and stress made by natural and human induced factors, which can be evaluated using SQ indicators (Schjønning et al., 2004). It consists of physical, chemical and biological indicators that react to changes in soil conditions (Sağlam et al., 2015).

The issue of SQ in Ethiopia is very critical as soil resource has been under great stress due to human population and livestock pressure, which eventually results in over exploitation and mismanagement for several decades (Gelaw et al., 2015; Eyayu et al., 2009). A significant amount of CL is under severe nutrient depletion and physical degradation due to unsustainable land use system like expansions of CL to fragile lands (Teferi et al., 2016; Gelaw et al., 2015; Teshome, 2013).

LULC variation is the foremost factor of SQ dynamics at catchment scale (Wang et al., 2001) and information on responses of SQ indicators is essential to develop sustainable land management plan (Ayalew, Kassahun, 2016; Karlen et al., 2003). However, this issue has been given little attention as great emphasis has been given to physical soil erosion problem for several decades (Karlen et al., 2003).

The impact of LULC and elevation variations on SQ indicators is site specific (Teferi et al., 2016), and hence, there is discrepancy in the findings. Some studies revealed that LULC variation has adverse impacts on SQ indicators (Gebrelibanos, Assen, 2013; Asmamaw, Mohammed, 2013; Lemenih, Itanna, 2004). Conversely, some others reported that LULC variation has no impact on some SQ indicators. For example, Ashagrie et al. (2005) reported that soil organic carbon and total nitrogen have shown no change after the conversion of natural forest to eucalyptus plantation in Munesa area of Ethiopia. Similarly, despite authors like Ayalew and Kassahun (2016) and Hussien et al. (2015) reported that clay content was significantly higher in CL, others (Eyayu et al., 2009; Woldeamlak, 2003) reported lower clay content in CL. Likewise, while Guteta and Abegaz (2017) and Teshome (2013) reported higher available phosphorus in forest lands, others like Asmamaw and Mohammed (2013) reported that it is higher in CL. Moreover, several studies that have been conducted on SQ dynamics in Ethiopia overlooked soil-LULC and elevation interaction (Abegaz et al., 2016; Teferi et al., 2016; Asmamaw, Mohammed, 2013; Gebrelibanos, Assen, 2013; Teshome, 2013; Tesfahunegn, 2013; Eyayu et al., 2009; Ashagrie et al., 2005; Lemenih et al., 2005; Lemenih, Itanna, 2004). These studies emphasized on LULC dynamics and slope aspect impact on SQ indicators. Therefore, the present study was aimed to assess the effect of LULC and elevation variations, and their interactions on selected SQ indicators in Wanka watershed, northwestern Ethiopian highlands.

Materials and methods

Description of the study area

Wanka watershed lies between 11°29'24" and 11°42'36" North latitudes, and 37°58'12" and 38°14'24" East longitudes (Fig. 1). It is one of the head streams of the Blue Nile (Abay) basin and covers a total area of 252 km². The watershed

Fig. 1. Location of the Wanka watershed.

is a part of the extensive Afro-Arabian plateau, which is characterized by the uplifting of landmasses and out pouring of lava (Mohr, 1971). Like that of the other headstreams of Blue Nile (Abay) basin, it is characterized by diverse topographic conditions. The elevation ranges from an altitude of 2,238 to 4,086 meter above sea level (m.a.s.l) and it experiences subtropical to Alpine climatic conditions. The soil units of the watershed are Chromic Luvisols (41.1%), Eutric Leptosols (34.12%) and Haplic Luvisols (24.84%) (FAO, 1990). The natural vegetation of the watershed include grass, bushes, natural and plantation trees (*Eucalyptus globulus* and *Cupressus lusitanica*). The main natural tree species include: weyra (*Olea africana*), yabesha tid (*Juniperus procera*) and yabesha girar (*Acacia abyssinica*).

The mean annual temperature of Wanka watershed is 17.3 °C. The mean annual minimum and maximum monthly temperature are 8.4 and 26 °C, respectively. The annual rainfall recorded for the years 1994 through 2015 revealed that the mean annual rainfall of the watershed is 1320 mm. The rainfall pattern is unimodal with one major (summer) rainy season, which extends from June to August, and sometimes it extends up to September. About 80% of the total annual rainfall takes place from June to August, peaking in July (369.4mm) (NMSAE, 2015).

Soil sampling

Three adjacent LULC types (natural forest, cultivated and grazing lands) that were in similar slope gradient both in the upper, middle and lower part of the watershed were selected for soil sampling (Table 1). The elevation of the sampled sites ranges were 2238–2300 m a.s.l (lower), 2400–2600 m a.s.l. (middle) and 2700–2800 m a.s.l. (upper). According to Hurni (1998), the agro ecological zones of Ethiopia include: weyna dega (mid altitude, 1300–2600 m 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.). Cultivated and grazing lands had been part of the adjacent forest cover before several years (information from key informants). The bench mark natural forest in both elevation classes mainly consisted of *Juniperus procera* (yabesha tid) and *Olea europaea* (Woyera). Moreover, the sampled CL in the 3 elevation classes of the watershed were under the cultivation of Teff (*Eragrostis abyssinica*).

T a b l e 1. Description of major LULC types in the Wanka watershed, north western highlands of Ethiopia.

Land use/cover type	Description
Cultivated land	Land that has been used for annual crops cultivation.
Natural forest land	Land use type in which human interference is very minimal and covered with thick growth of natural vegetation (trees and undergrowth).
Grazing land	Land that serves as common grazing land. It is void of big vegetation like tress, bushes rather it predominantly covered by very short grass.

A composite soil sample with 5 subsamples in 10 m * 10 m plot size was collected at each site. Four replications of cultivated land, as it has the largest area coverage, and three replications each for natural forest and grazing lands were sampled at each elevation class. A total of 30 disturbed samples were collected after the harvesting period (January) at surface depth (0 to 20 cm) using auger. Topsoil is the most common sampling depth for soil testing as it contains significant proportion of soil nutrients and is very sensitive to land use changes (Abegaz et al., 2016; Andrews et al., 2002). Sub samples were mixed thoroughly (clods carefully crushed) and approximately half to one kg of composite sample from each sample plot was prepared, put in plastic bag, labelled and carried to the laboratory for analysis. In addition, the undisturbed core samples from each sampled land use type in the respective elevation classes were taken at the centre of each plot with cylindrical metal samplers (5 cm length with 5 cm diameter) for bulk density (BD) analysis.

Soil analysis

Sixteen SQ indicators were analysed at Adet Agricultural research centre soil laboratory, Ethiopia following standard soil laboratory analysis procedures. Soil water content at field capacity (FC) and permanent wilting point (PWP) were determined at 1/3 and 15 bars, respectively, by pressure membrane suction method and available water content (AWC) was determined by calculating their differences (Estefan et al., 2013). Bouyoucos hydrometric and core sample method were respectively used to determine the soil particle size distribution and BD (Estefan et al., 2013). Total porosity was calculated by assuming a particle density of 2.65 g cm⁻³, that is, $P = (1 - BD/PD) * 100$, where P = total porosity (%), BD = the bulk density (g cm⁻³) and PD = particle density (gcm⁻³) (Landon, 1991). Soil pH was measured in 1:2.5 soil–water ratio suspension (Van-Reeuwijk, 2002). As suggested by Carter and Gregorich (2006), Kjeldahl, Olsen and Walkley-Black oxidation methods were respectively used to determine soil total nitrogen (TN), available phosphorus and organic carbon. Soil organic matter (SOM) was determined by multiplying organic carbon (%) by a constant 1.724 (Carter, Gregorich, 2006). Cation Exchange Capacity (CEC) and exchangeable bases (K⁺, Mg²⁺, Ca²⁺ and Na⁺) were examined using ammonium acetate extraction method (at pH 7) as described in Estefan et al. (2013). Exchangeable K⁺ and Na⁺ were measured by flame photometer, and Ca²⁺ and Mg²⁺ using atomic absorption spectrometry. Then, the percentage of base saturation was calculated by dividing the summation of exchangeable cations to CEC and multiplied by 100 (Estefan et al., 2013).

Statistical analysis

Two-way ANOVA was computed to test the effect of variations of LULC and elevation, and their interactive effect on mean values of the selected SQ indicators. Tukey's post hoc multiple comparison test was used to differentiate mean variation of SQ indicators that showed statistically significant differences in the analysis of variance. Statistical analysis was performed using SPSS version 23.

Soil quality deterioration index

SQ deterioration index (DI) of each selected SQ indicator obtained by computing the percentage of difference between mean value of each selected SQ indicators under different LULC and adjacent bench mark soil (Gui et al., 2009; Lemenih et al., 2005; Islam, Weil, 2000). Then DI of each selected SQ indicator were added and averaged to obtain the cumulative DI (Lemenih et al., 2005; Wang et al., 2001). Out of the sixteen measured SQ indicators, po-

rosity, BD, SOM and soil nutrients (available phosphorus, TN, CEC, Ca²⁺, Mg²⁺ and K⁺) were selected to calculate DI based on experts' opinion (Andrews et al., 2002), and these SQ indicators are very sensitive to land use changes and often used to compute DI (Gui et al., 2009).

Results

Physical SQ indicators

Particle size distribution

The overall distribution of soil separates in the study watershed significantly ($p < 0.01$) varies across LULC and elevation variations, but their interactive effect was significant ($p < 0.01$) merely on silt and clay contents (Table 3). While sand and clay contents were significantly higher in CL than NFL ($p < 0.01$) and GL ($p < 0.05$), silt content was found significantly ($p < 0.01$) higher in NFL than other LULC types, and in GL than CL ($p < 0.05$) (Tables 2 and 4).

T a b l e 2. Mean values of the selected SQ indicators across LULC and elevation classes of the Wanka watershed, north western highlands of Ethiopia.

SQ indicators	LULC classes			Elevation classes		
	CL	NFL	GL	Upper	Middle	Lower
Sand (%)	35	28	33	35	33	29
Silt (%)	29	42	34	34	35	36
Clay (%)	36	30	33	31	33	35
BD (g/cm ³)	1.28	0.98	1.18	1.1	1.19	1.22
Total Porosity (%)	52	63	56	60	55	54
FC (%)	44	51	42	44	48	45
PWP (%)	22	24	26	22	25	25
AWC (%)	22	27	16	23	23	20
pH H ₂ O (1:2.5)	5.9	6.5	6	5.9	6.2	6.3
SOM (%)	2.3	7.2	3.9	4.8	3.5	4.4
Av. Ph (ppm)	11.6	12.3	5.3	4	21	4.7
TN	0.20	0.59	0.25	0.42	0.27	0.31
C/N ratio	11.7	12.7	15.4	12.8	12.9	13.5
CEC (Cmol _c kg ⁻¹ soil)	33.8	43.1	34.6	30.6	37.6	42.4
Ca ²⁺ (Cmol _c kg ⁻¹ soil)	23.9	32	22.5	20.9	26.3	30.8
Mg ²⁺ (Cmol _c kg ⁻¹ soil)	5.3	6.4	5.6	4.5	5.5	7.1
K ⁺ (Cmol _c kg ⁻¹ soil)	0.82	0.82	0.81	0.82	0.82	0.80
Na ⁺ (Cmol _c kg ⁻¹ soil)	0.13	0.12	0.14	0.13	0.13	0.13
PBS (%)	91	92	85	86	89	91

Notes: SQ – soil quality; CL – cultivated land; GL – grazing land; NFL – natural forest land; LULC – land use and land cover; BD – bulk density; Av.ph – available phosphorus; TN –total nitrogen; C/N – carbon nitrogen ratio; CEC – cation exchange capacity; Ca²⁺ – exchangeable calcium; Mg²⁺ – exchangeable magnesium; K⁺ – exchangeable potassium; Na⁺ – exchangeable sodium; PBS – percent base saturation.

T a b l e 3. Two-way analysis of variance (ANOVA) result of the selected SQ indicators (0–20 cm depth) under three LULC and elevation classes of the Wanka Watershed, northwestern highlands of Ethiopia

SQ indicators	LULC (df = 2)		Elevation (df = 2)		LULC * Elevation (df = 4)	
	F-Statistic	P-value	F-Statistic	P-value	F-Statistic	P-value
Sand (%)	10.082	0.001**	6.612	0.005**	2.233	0.092 ^{ns}
Silt (%)	28.692	0.000**	1.024	0.373 ^{ns}	6.046	0.001**
Clay (%)	20.060	0.000**	6.234	0.006**	16.880	0.000**
BD (g/cm ³)	34.625	0.000**	9.400	0.001**	2.555	0.062 ^{ns}
Porosity (%)	33.653	0.000**	9.856	0.001**	2.567	0.061 ^{ns}
FC (%)	12.563	0.000**	1.833	0.179 ^{ns}	19.344	0.000**
PWP	4.216	0.025*	1.497	0.242 ^{ns}	8.642	0.000**
AWC	33.484	0.000**	2.553	0.096 ^{ns}	9.793	0.000**
pH H ₂ O (1:2.5)	20.462	0.000**	9.856	0.001**	3.816	0.014*
SOM (%)	49.042	0.000**	5.429	0.010**	7.942	0.000**
Av. Ph (ppm)	22.061	0.000**	111.39	0.000**	17.326	0.000**
TN (%)	30.569	0.000**	3.772	0.036*	4.570	0.006**
CEC (Cmol kg ⁻¹ soil)	6.066	0.007**	8.253	0.002**	1.403	0.260 ^{ns}
Ca ²⁺ (Cmol kg ⁻¹ soil)	10.102	0.001**	9.477	0.001**	2.193	0.097 ^{ns}
Mg ²⁺ (Cmol kg ⁻¹ soil)	1.556	0.229 ^{ns}	10.751	0.000**	.434	0.783 ^{ns}
PBS (%)	11.375	0.000**	5.936	0.008**	2.341	0.081 ^{ns}

Notes: ** – significant at P < 0.01; * – significant at P < 0.05; ns – not significant; df – degree of freedom.

Bulk density (BD) and Total porosity

The highest (1.28 g/cm³) and lowest (0.98 g/cm³) mean values of BD across all LULC and elevation classes of Wanka watershed were recorded in CL and NFL respectively. It was found significantly (p < 0.01) higher in CL than NFL and GL. Similarly, it was significantly higher in lower elevation than upper (p < 0.01) and middle (p < 0.05) elevation classes (Table 4). In contrast with NFL, BD increased by 30.6 % and 20.41% in CL and GL respectively (Fig. 2).

Field capacity (FC), permanent wilting point (PWP) and available water holding capacity (AWC)

Water retention capacity of soil at FC and AWC was significantly (p < 0.01) influenced by LULC variation. The interactive effect of LULC and elevation variation on both FC, PWP and AWC was also statistically significant (p < 0.01), but the effect of elevation position was found to be statistically insignificant (p > 0.05) (Table 3). Tukey’s multiple comparison test (Table 4) revealed that FC was significantly (p < 0.01) higher in NFL than CL and GL. Conversely, while PWP was significantly (p < 0.05) higher in GL than CL, AWC was significantly (p < 0.01) higher in NFL than GL.

T a b l e 4. Results of Tukey’s post hoc multiple comparisons test of statistically significant SQ indicators in the Wanka watershed, northwestern highlands of Ethiopia.

SQ indicators	LULC		Elevation position	
	Sig. contrasts of LULC classes	P-value	Sig. contrasts of elevation differences	P-value
Sand (%) Silt (%)	Cultivated and Natural forest lands	0.000**	Lower and upper	0.003**
	Grazing and Natural forest lands	0.017*		
	Cultivated and Natural forest lands	0.000**		
	Grazing and natural forest lands	0.000**		
	Cultivated and grazing lands	0.019*		
Clay	Cultivated and Natural forest lands	0.000**	Upper and lower	0.001**
	Cultivated and grazing lands	0.025*		
	Grazing and Natural forest lands	0.004**		
BD (g/cm³)	Cultivated and Natural forest lands	0.000**	Lower and upper	0.001**
	Natural forest and Grazing lands	0.000*	Middle and upper	0.015*
Porosity (%) FC PWP AWC (%)	Cultivated and Natural forest lands	0.000**	Lower and upper Middle and upper	0.001** 0.011*
	Natural forest and Grazing lands	0.000*		
	Natural forest and cultivated lands	0.002**		
	Natural forest and Grazing lands	0.000**		
	Cultivated and grazing lands	0.020*		
	Cultivated and Natural forest lands	0.002**		
	Cultivated and Grazing lands	0.001**		
pH H ₂ O (1:2.5)	Cultivated and Natural forest lands	0.000**	Lower and upper	0.001**
	Natural forest and Grazing lands	0.000**	Middle and upper	0.008**
SOM (%)	Cultivated and Natural forest lands	0.000**	Upper and middle	0.008**
	Natural forest and Grazing lands	0.000**		
	Grazing and cultivated lands	0.012*		
Av. Ph (ppm)	Cultivated and Grazing lands	0.000**	Middle and lower	0.000**
	Natural forest and Grazing lands	0.000**	Middle and upper	0.000**
TN (%)	Cultivated and Natural forest lands	0.000**	Upper and middle	0.028*
	Natural forest and Grazing lands	0.000**		
CEC (Cmol _c kg ⁻¹ soil)	Natural forest and cultivated lands	0.015*	Lower and upper	0.001**
	Natural forest and Grazing lands	0.014*	Middle and upper	0.038*
Ca ²⁺ (Cmol _c kg ⁻¹ soil)	Natural forest and cultivated lands	0.009**	Lower and upper	0.000**
	Natural forest and Grazing lands	0.001**	Middle and upper	0.041*
Mg ²⁺ (Cmol _c kg ⁻¹ soil)			Lower and upper	0.000**
			Lower and middle	0.023*
PBS (%)	Cultivated and Grazing lands	0.001*	Upper and lower	0.003**
	Natural forest and Grazing lands	0.000*		

Notes: ** – significant at P < 0.01; * – significant at P < 0.05.

Chemical SQ indicators

Soil pH, Soil organic matter (SOM) and Total nitrogen (TN)

The pH value in Wanka watershed was found in the range of 5.9 and 6.5 (Table 2). It was significantly affected by LULC (p < 0.01), elevation (p < 0.01) and their interaction (p < 0.05) (Table 3). Similarly,

Fig. 2. Deterioration indices of the selected soil quality indicators for CL and GL in Wanka watershed, northwest-highlands of Ethiopia.
Notes: CL – cultivated land; GL – grazing land; SQ – soil quality.

LULC variation and their interactive effect on SOM was significant ($p < 0.01$). It was significantly ($p < 0.01$) higher in NFL than CL and GL, and in GL ($p < 0.05$) than CL (Tables 2 and 4). Compared with NFL, it decreased considerably (68%) in CL (Fig. 2). SOM also showed an increment in the upper elevation than middle and lower elevation of the study area. It was significantly higher ($p < 0.01$) in the upper elevation than the middle elevation. LULC ($p < 0.01$), elevation ($p < 0.05$), and their interaction ($p < 0.01$) also significantly affect TN (Table 3). TN in NFL (0.59%) was significantly ($p < 0.01$) higher than GL (0.25%) and CL (0.20%) (Tables 2 and 4). In CL and GL of Wanka watershed, the amount of TN rated as low and medium (Landon, 1991), respectively, and in reference to NFL, it declined by 66 and 58% in CL and GL, respectively (Fig. 2). It was also found significantly ($p < 0.05$) higher in the upper elevation than in the middle elevation (Table 4).

Available phosphorus (Av.ph) and Carbon nitrogen ratio (C/N)

Available phosphorus was significantly ($p < 0.01$) higher in NFL than GL, and in CL than GL (Table 4). In contrast to the soil under the NFL, it was reduced by 6 and 57% respectively in CL and GL. Available phosphorus was also significantly ($p < 0.01$) higher in the middle than other elevation classes. Conversely, the effect of LULC, elevation and their interactive effect was statistically insignificant on the C/N ratio. Except in the GL (15.4) of lower elevation, the C/N ratio in the Wanka watershed was found to be optimum (ranged 11.7 to 13.7) for most cultivated crops.

CEC, exchangeable cations and PBS

Cation exchange capacity (CEC) in NFL was found to be significantly higher than CL and GL at $p < 0.05$ (Table 4). There was also significant increment of CEC in the lower elevation. Its mean value in upper, middle and lower elevation were $31 \text{ Cmol}_c \text{ kg}^{-1} \text{ soil}$, $39 \text{ Cmol}_c \text{ kg}^{-1} \text{ soil}$ and $42 \text{ Cmol}_c \text{ kg}^{-1} \text{ soil}$,

respectively (Table 2). It was significantly lower in the upper ($p < 0.01$) and middle ($p < 0.05$) elevation than in the lower elevation (Table 4).

Effect of LULC variation was found significant on Ca^{2+} , but not on Mg^{2+} and K^+ . Exchangeable Ca^{2+} was significantly ($p < 0.01$) higher in soils under NFL than CL and GL (Table 4). In CL, while Ca^{2+} decreased by 25%, K^+ showed slight increment (1.2%). On the other hand, in the grazing land, K^+ and Ca^{2+} reduced respectively by 1.2 and 30% (Fig. 2). Similarly, despite it not being statistically significant, Mg^{2+} was found lower in CL.

Percent base saturation (PBS) in the study watershed was generally high (Landon, 1991). The mean value of PBS across all LULC and elevation classes ranged from 85 to 92% (Table 2). PBS was significantly ($p < 0.01$) higher in NFL and CL than in GL (Table 4). The factor may be the prevalence of relatively higher basic cations in these LULCs. On the other hand, PBS was significantly ($p < 0.01$) higher in the lower elevation than upper elevation.

Soil quality deterioration index

SQ deterioration indices (DI) result revealed that there was a declining trend of most of the selected SQ indicators in CL and GL. Highest negative DI values were mainly recorded for SOM (-68%) and TN (-66%) in CL, and available phosphorus (-57%) and TN (-58%) in GL. In contrast with other SQ indicators, the deterioration of available phosphorus in CL is lowest (Fig. 2). This is perhaps due to the application of Diammonium Phosphate (DAP) chemical fertilizer. DI of BD both in CL and GL disclosed SQ reduction (compaction increment). It increased by 31 and 20% in CL and GL respectively (Fig. 2).

Discussion

Soil particle size distribution

Silts are the most mobile elements by erosion, and hence, lower silt content in CL and GL implies erosion is high in these land uses, particularly in CL. On the other hand, sand and clay contents were found significantly ($p < 0.01$) higher in the upper and lower elevations, respectively (Table 4). This could be attributed to the clay removal by erosion, leaving behind sand fractions in the upper elevation and subsequently accumulated in the lower elevation. The impact of elevation variation on clay particles movement towards lower elevation might be enhanced by poor land management practices in the CL of upper elevation of Wanka watershed. Yimer et al. (2006) also reported a higher proportion of clay contents in lower elevation of CL in the south-eastern highlands of Ethiopia. Variation in the distribution of soil separates across LULC and elevation classes has its implication on the SQ. For example, high sand content in CL of Wanka watershed affects water holding capacity of a soil, and subsequently, water and nutrient availability for growing plants (Hussien et al., 2015).

Bulk density and total porosity

High BD in CL of lower elevation most likely arises from SOM deficiency as BD and SOM have an inverse relationship (Awotoye et al., 2011). In the study area, there was a significant

($p < 0.01$) inverse correlation between BD and SOM ($r = -0.72$) (data not shown). Higher BD in CL of Wanka watershed signifies the severity of adverse impact on rooting depth, soil porosity, infiltration, water and plant nutrient availability for crops. Porosity also varied significantly ($p < 0.01$) across both LULC and elevation variations, but their interactive effect was found insignificant ($p > 0.05$) (Table 3). Total porosity (63%) in NFL (Table 2) was found significantly ($p < 0.01$) higher than soil under CL and GL. Similarly, it was significantly higher in upper elevation than lower ($p < 0.01$) and middle ($p < 0.05$) elevation classes (Table 4). This explains that higher levels of SOM produce better proportions of total porosity. SOM maximize total porosity (Guo et al., 2016), and in Wanka watershed, significant ($p < 0.01$) positive association ($r = 0.71$) (data not shown) was observed between total porosity and SOM. Soil management induced problems like intensive tillage without appropriate soil management may accelerate SOM degradation and compaction.

Field capacity (FC), permanent wilting point (PWP) and available water holding capacity (AWC)

The possible factor for higher FC and AWC in NFL than CL and GL could be due to the prevalence of higher content of silt and SOM in NFL. Loam and silt loam soil (Asmamaw, Mohammed, 2013) and soil with high SOM content (Adugna, Abegaz, 2016) have high AWC. Moreover, despite it not being statistically significant, AWC is lower in CL than NFL. High AWC in the soil is very critical for plant growth and crop production, and hence, the measures that increase AWC (e.g., conservation) in LULC types other than NFL need to be practiced in Wanka watershed. Conservation regulates water infiltration and drain away from CL (Asmamaw, Mohammed, 2013).

Soil pH, Soil organic matter (SOM) and Total nitrogen (TN)

Significantly ($p < 0.01$) higher pH in NFL than CL and GL (Table 4) was observed in the study watershed. Relatively lower pH value in CL than other land uses in Wanka watershed may be resulted from the mining of basic cations by crops, intense ploughing and continuous application of chemical fertilizers. Continuous use of chemical fertilizer rich in nitrogen has an acidifying effect on soil (Savci, 2012). Despite the fact that the pH value in the CL was found lower than other land uses, it was found optimum for most crops. Hence, it has no adverse impact on SQ and agricultural productivity in the existing condition. According to Landon (1991), pH values between 5.5 and 7 is preferred for most crops. But the lower pH value in CL may potentially reduce SQ unless necessary measure is taken in the study area. Little removal of base forming minerals by erosion and recycling of nutrients by decomposition of basic cation rich plant residues bring higher pH value in NFL (Abraham et al., 2012). On the other hand, pH value was found significantly ($p < 0.01$) lower in the upper elevation than the lower and middle elevation classes. This might be due to the fact that soluble basic ions (Ca^{2+} , Mg^{2+}) migrate down to lower elevation due to erosion and leaching as rainfall increases with increasing altitude. In Wanka watershed, this might be accentuated by poor land management.

The amount of SOM in NFL, GL and CL of Wanka watershed respectively were rated as high, medium and low (Landon, 1991). Low SOM content in CL might be due to low input of organic fertilizers (crop residues and manure), rapid decomposition and mineralization of organic matter due to intensive tillage (Aghasi et al., 2011). This implies high soil nutrients depletion in CL as SOM is the foremost indicator of SQ. It determines structural stability, moisture retention, nutrient status and biological activity of the soil (Schjønning et al., 2004). Elevation difference also had a significant impact on SOM. It was significantly higher ($p < 0.01$) in the upper elevation than in the middle elevation, and this in turn resulted in higher TN in upper elevation. The most likely reason for high SOM could be low decomposition and mineralization rate of organic matter due to relatively low temperature condition. TN was found significantly lower in CL than the other LULC of the study area, perhaps due to crop uptake of nutrients and less return via organic fertilizers like crop residues and manure. On the other hand, relatively higher TN in GL than CL could be attributed to the recycling of nitrogen via animal waste of free grazing cattle (Ashagrie et al., 2005).

Available phosphorus (Av.ph) and Carbon nitrogen ratio (C/N)

According to Landon (1991), for most cereal crops and grass, the adequate amount of available phosphorus is > 8 ppm, but in the lower and upper elevation GL of Wanka watershed, it was found to be below the critical value. This may be due to overgrazing, which brings loss of phosphorus (due to compaction and erosion) and absence of any phosphorus inputs (fertilizers) that substitute this loss (Adugna, Abegaz, 2016). Conversely, significantly ($p < 0.01$) high available phosphorus in middle than upper and lower elevation classes could be attributed to the nature of parent material and the land management practice of the area. Presence of higher available phosphorus in NFL and CL than GL may also attribute to low mining of available phosphorus by existing plants (Woldeamlak, 2003) or due to the addition of phosphorus through the application of fertilizer in CL. Amount of available phosphorus in top soil layer is a function of intensity of land use, management practice, organic matter or microbial biomass and history of land use (e.g., application of artificial fertilizer) (Schjønning et al., 2004). C/N ratio in Wanka watershed was slightly higher in GL and this disagreed with the findings of Gebrelibanos and Assen (2013), who reported low C/N ratio in GL. The rise of C/N ratio in GL of the study watershed might be due to the prevalence of higher undecomposed straw and lower mineralization (Landon, 1991).

CEC and exchangeable cations

High (> 40 Cmol_c kg⁻¹soil) (Landon, 1991) CEC in NFL of Wanka watershed most likely resulted from high SOM content of the soil as CEC is a function of SOM and clay fraction (Aghasi et al., 2011). The correlation coefficient results showed a significant ($p < 0.05$) positive association ($r = 0.46$) between SOM and CEC (data not shown). CEC also significantly increased in lower elevation than upper (0.01) and middle ($p < 0.05$) elevations as there was clay fraction increment in lower elevation.

The decline trend of exchangeable cations (Ca, Mg) in CL of the study watershed may be due to continuous cultivation coupled with limited application of organic fertilizers (e.g., less recycling of crop residues). As observed during the soil sample collection, farmers used crop

residue mainly for animals feed instead of recycling it in the soil. In CL, there is a reduction of significant amount of soil nutrients with minimal return rate every year, and this subsequently diminishes SQ substantially (Duguma et al., 2010). The other possible reason may be losses of nutrients through leaching in CL that is accentuated by tillage as high leaching is associated with losses of exchangeable bases (Abegaz et al., 2016). This finding agreed with the finding of Wang et al. (2001) who reported that while soil under NFL with high total exchangeable bases had a better quality, soil in continuous CL had low total exchangeable bases and in turn poor quality in southern Tanzania. The divalent exchangeable cations (Ca^{2+} and Mg^{2+}) showed a decreasing trend with increasing elevation. Exchangeable Ca^{2+} and Mg^{2+} were lower in upper than the lower elevation significantly ($p < 0.01$). This is perhaps due to high leaching as rainfall increases with increasing elevation. In addition, lower cations in upper elevation of Wanka watershed may be associated with lower pH. Soils with low pH have low availability of Ca^{2+} , Mg^{2+} and phosphorus (Wang et al., 2001).

The overall DI values in Wanka watershed implies the existing land uses (CL and GL) are accelerating deterioration of SOM, TN and available phosphorus and increased soil compaction. Total DI of both CL (-21%) and GL (-24%) are rated as high negative DI (Wang et al., 2001). Similar findings were reported by several authors (Eyayu et al., 2009; Gui et al., 2009; Lemenih et al., 2005; Wang et al., 2001). High negative DI values is an indication of high SQ deterioration, which might have resulted from lack of appropriate soil management that maximize soil nutrient availability after the conversion of NFL to other LULC types (Schjønning et al., 2004; Fu et al., 2000).

Conclusion

The study disclosed that the impact of LULC and elevation variations is considerable on key SQ indicators. Declining SOM, TN, available phosphorus and increasing BD in CL of the study watershed signifies the impediment of infiltration and nutrient availability for crops. This could be attributed to soil management induced problems like over cultivation without appropriate soil management. This implies that prior emphasis needs to be given to CL, and hence, strategies that maximize SOM and reduce soil compaction like application organic fertilizers and minimum tillage should be emphasized. Elevation impact was also found significant on basic cations (Ca^{2+} and Mg^{2+}), CEC and pH. Their reduction in higher elevation of the study area implies the need for elevation specific land management interventions. Decline of pH value in the CL of upper elevation has an implication of reduction of microbial activities that increase SQ (reduction of microbial conversion of NH_4^+ to nitrate (NO_3^-), and the decline of base cations and crop yield. Thus, lime application in the CL as well as soil and water conservation measures like terrace need to be encouraged in the upper elevation. Moreover, further investigation about the effect of variation in LULC and elevation on SQ indicators in the sub surface soil layer of the study area is required, as SQ is not entirely a reflection of surface layer.

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