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Assessing soil quality of Abargay Rangeland in Farta District, Amhara Regional State, Ethiopia

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Rangelands provide many supporting, regulative and provisioning ecosystem services to man. The mounting anthropogenic pressure on them is, however, causing their degradation and decline in productivity. Assessment of their soil quality is important for identifying sustainable land management practices. The present investigation was, therefore, carried out to assess the soil quality of adjoining protected and unprotected units of Abargay rangeland, Farta District. Cluster sampling technique was used to draw soil samples for analyses of different soil quality indicators. The protected rangeland for the last thirty years indicated significantly higher clay and silt fractions, lower bulk density, higher total porosity, higher organic matter and nutrient (nitrogen, phosphorus and potassium) contents, compared to unprotected land. The composite soil quality index, based on scoring of soil quality parameters, viz., bulk density, pH, organic matter, total nitrogen, available phosphorus and available potassium was significantly higher for protected rangeland (0.61) compared to unprotected land (0.45). Accordingly, the quality of protected rangeland was rated as fair, while that of unprotected land as poor. The soil quality of surface layer was relatively better than subsurface layer. The unprotected rangeland had negative impact on different soil quality parameters and required to be put to enclosure to warrant invaluable ecosystem services. The single value soil quality index may be used for assessment and mapping of soil quality of rangelands in Farta, Amhara region.

Key words: Protected rangeland, unprotected rangeland, soil properties, soil quality, soil quality index.

INTRODUCTION

Rangelands having severe limitations of physiography, climate and soils are not suitable for cultivation, but serve as an important source of forage for free ranging wild and domestic animals, as well as a source of wood products, water and recreation (Lutta, 2015). Obviously, rangelands provide many supporting, regulative and provisioning ecosystem services to mankind (Teague et al., 2009). These lands occupy about 50% of the land mass in world, 65% in Africa and 62% in Ethiopia (Alemayehu, 1998), supporting the livelihood of approximately 2 billion people worldwide (Middleton et al., 2011). In Ethiopia, a large part of the rangeland is located in lowland arid and semi-arid regions with unreliable and erratic rainfall, and high temperature (Alemayehu, 1998). The rangelands, influencing greatly the agri-pastoral economy, have a larger role to play in sustaining socio-economic-environmental stability of the semi-arid to arid regions of the country.

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The increased anthropogenic pressure on the rangelands to meet the growing needs of livestock and human population, unfortunately, causes their widespread degradation as a result of increased soil erosion, compaction and runoff, loss of organic carbon and nutrients and reduction in biomass production (Panda, 2007). The continued degradation is fraught with adverse rangeland ecology and decline in soil quality, impacting the livelihood of pastoral communities in Ethiopia (Amaha, 2008; Teshome et al., 2009). Preserving rangeland soil quality is, therefore, vital to sustain livestock production and ensure food and nutritional security for Ethiopian people. The pastoral communities have some realization about the rangeland degradation by assessing their livestock production or health, forage availability and extent of travelling required in search of forage. However, the rangeland health could be assessed and monitored readily employing a simple soil quality index based on some relevant soil properties.

Soil quality is a combination of soil physical, chemical and biological properties that are able to change readily in response to variations in soil conditions (Masto et al., 2007). It is defined as the ability of soil to function within ecosystem boundaries to support healthy plants and animals, maintain or enhance air and water quality, and support human health and habitation (Karlen, 1997). A soil-quality indicator is a simple attribute of the soil which may be measured to assess quality with respect to a given function (Becker, 2013). But, the indicators need to be limited and manageable by different types of users, should be simple and easy to measure, economical, cover the largest possible situations (soil types), and be highly sensitive to environmental changes and soil management (Zornoza et al., 2015). Accordingly, soil scientists identified a minimum data set (MDS) of soil parameters that determined the major processes occurring in soil and could be used to quantify soil quality (Larson and Pierce, 1991). The integrated soil quality index (SQI) based on a combination of soil properties provides a better indication of soil quality than individual parameters (Karlen and Stott, 1994). The SQI helps to assess the soil quality of a given site or ecosystem and enables comparisons between the conditions at plot, field or watershed levels under different land use and management practices (Bajracharya et al., 2007; Aweke et al*.,* 2015). The SQI is, therefore, a useful way to determine land deterioration or improvement.

Soil quality research in Ethiopia and other Sub-Sahara countries is still in its infancy. Therefore, it should be a priority area to evaluate the effect of different land units and degree of management on soil quality in order to develop resource-friendly land management plans at local, district and national levels. Farta District has its own unique socio-cultural, biological and geomorphologic diversity. The economy of the district depends on agro-pastoral production system. Agricultural production, however, is limited in the area due to lack of integrated management practice and, livestock grazing is the main source of livelihood of the people. Rangelands of Farta district are under heavy grazing pressure round the year and suffer due to relentless soil erosion and land degradation. Researchers have identified overstocking as the main factor of deterioration of rangelands (Sharma and Minhas, 1993; Saleh et al*.,* 2009). The productivity of Abargay rangeland is decreasing continuously due to overgrazing and soil deterioration. The people are, as a result, being forced to abandon agro-pastoral occupation and search for alternative sources of income to sustain their livelihood. There is, thus, an urgent need to revive the fast-withering rangeland ecology to provide socio-economic-environmental stability in the area. Improvement of soil resource will go a long way in restoring the productivity of the rangelands. Before embarking upon a situation-specific and comprehensive soil resource improvement strategy, it is required to have a thorough evaluation of the soil characteristics/soil quality parameters under different soil units of area. Accordingly, the present study was envisaged to evaluate the soil quality under protected and unprotected lands in Abargay rangeland, representing Farta District, Amhara region, Ethiopia.

MATERIALS AND METHODS

Description of the study area

The general information for the study area was obtained from Farta Woreda Agricultural Office of Amhara Regional State of Ethiopia.

Location

Farta is one of the districts in South Gonder zone of Amhara Regional State. Debre-Tabor is the centre of the district and located at about 671 km north of Addis Ababa. The study was conducted at Abargay rangeland, in the district (Figure 1). The area is located 107 km east of Bahir Dar, the capital of the region, and 4.7 km east of Debre Tabor town. The site is situated at 11^0 51´ north latitude and $38^0$57′ east longitude and at 1970-2706 m above sea level.

Climate and vegetation

The rangeland comprised 85% area as highland (>2300 m) and 15% as midland (1800-2300 m). The rainfall pattern is bimodal having two seasons locally called Belg and Kiremet. Belg is a short rainy period lasting from March to April, and Kiremet is main rainy season lasting from June to mid-September. Majority of the farmers depend on summer rains. The mean annual temperature and rainfall range between 18-23°C and 1000-1400 mm, respectively. The rangelands are dominated by dwarf shrub grassland to shrub grassland and shrubby *Acacia commiphora* species and allied genera.

Land use

The study area involved both agricultural activities and livestock production system and divided into grazing land (691.6 ha),

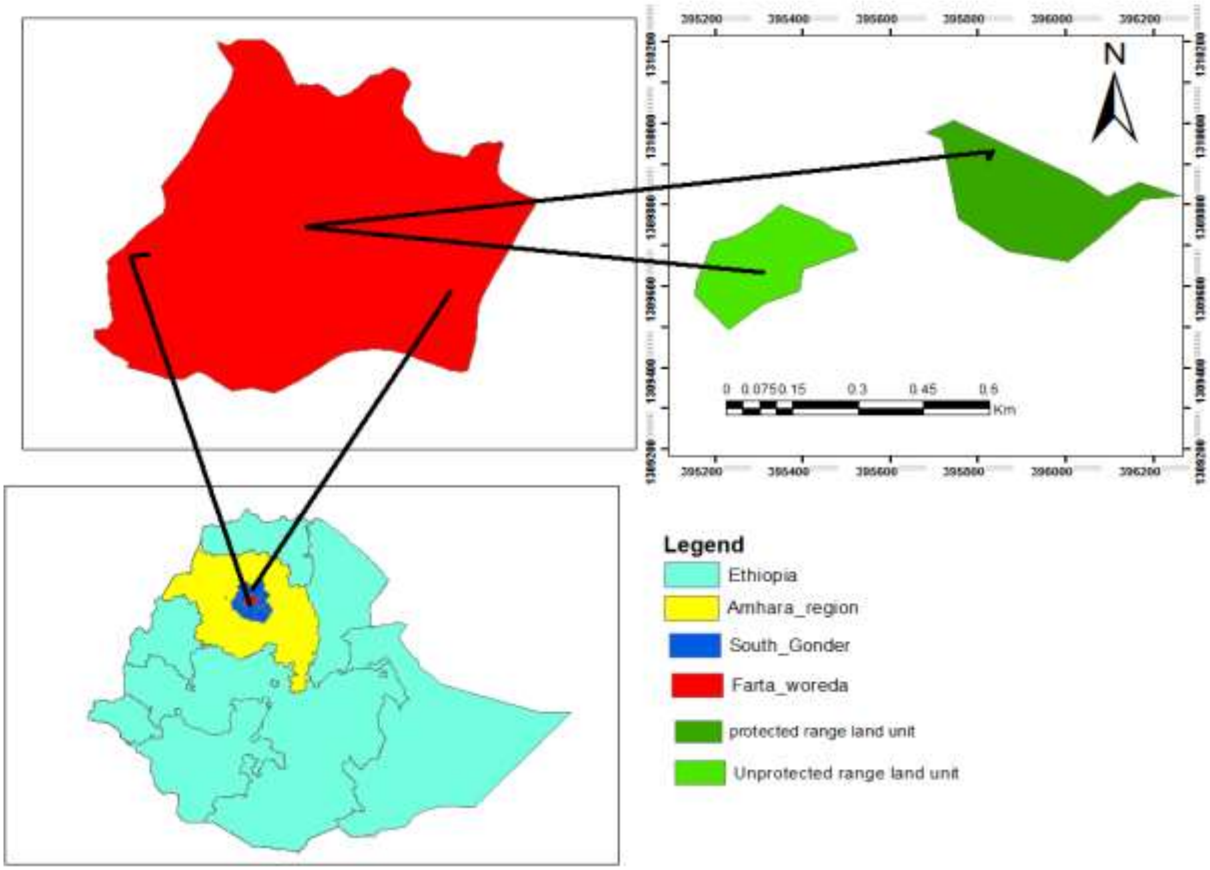

Figure 1. Map of the study area.
Source: EthioSIS (2018).

settlement (236.4 ha), forest cover (513.2 ha) and the water body (35 ha).

Soil type and topography

The soil of the rangeland belonged to Vertisols, with red, brown and black colour soils occupying 25, 64.5 and 10.5% area, respectively. The topography of the area comprised 55% flat, 44% mountain and 1% open valley.

Site selection and soil sampling design

Two adjacent sites of one hectare each under protected and unprotected rangelands, having the same slope, topography and aspect conditions were selected for the study. The protected rangeland was put to enclosure for the last 30 years, while the unprotected one was left to open grazing. Soil sampling was done by cluster sampling design (Thompson, 1991). The same design was modified by Alemayehu and Assefa (2016) to suit their small catchment size. The design was further modified in this study to suit still smaller catchment size. A cluster of 100 x 100 m with five cluster centroids of 20 × 20 m was marked for both protected and unprotected rangelands (Figure 2). The first tile (20 × 20 m) was established by fixing its central point at the centre of one hectare area. The area of this sampling plot was marked by using a 10 m radius from the cluster centre point. The centres of other four sampling plots were established at a distance of 30 m from the centre of the sampling plot to the north, south, east and west. From each cluster centroid, nine sub-soil samples each for 0-15 and 15-30 cm depths at regular interval were collected. The sub-samples were composited for each depth. Therefore, in all, 20 composite samples (2 rangeland units × 5 cluster centroids × 2 depths) were prepared for soil analyses.

Soil analysis

Physical and chemical properties

Selected soil physical and chemical properties were analyzed at Bahir Dar Soil Testing Laboratory of the Amhara National Regional State following standard laboratory procedures. Soil particle size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1972). Soil bulk density (BD) was measured by the core sampling method. The following formula was used to calculate soil BD:

$$BD\left(\frac{Mg}{m^3}\right) = \frac{Mass\ of\ oven\ dried\ soil\ (Mg)}{Volume\ of\ soil\ (m^3)}$$

Total Porosity of soil (TP) was calculated using the values of bulk density and particle density of the soil as follows:

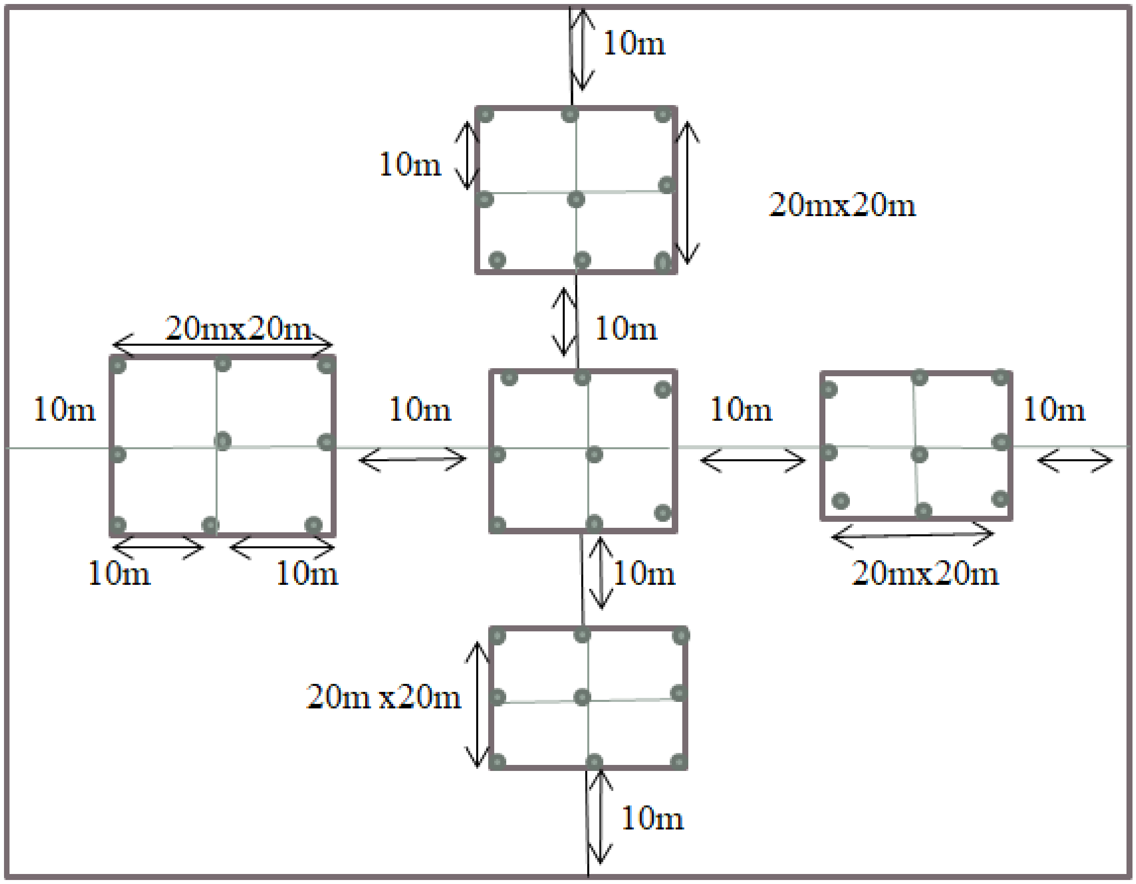

Figure 2. Soil sampling design for the study area.

$$TP(\%) = \left(1 - \frac{bulk\ density}{particle\ density}\right) * 100$$

Soil pH was determined potentiometrically in the supernatant suspension (1:2.5 soil to water ratio) using a glass electrode, soil organic carbon (OC) by the wet digestion method (Anderson and Ingram, 1994), total nitrogen by the wet-oxidation procedure of Kjeldahl (Bremner and Mulvaney, 1986), available phosphorus by Olsen extraction method (Olsen et al., 1954) and available potassium by flame photometer after extraction with 1N ammonium acetate at pH 7.

Soil quality index

Soil quality index was computed using the model proposed by Bajracharya et al. (2007) for hilly and mountainous region of Nepal Himalaya, having analyzed soil data for agricultural, forest and grazing lands. They developed a composite soil quality rating (SQR) value derived by summing the product of the weighting factors with the assigned parameter ranking values for the four most common soil parameters to arrive at a number between 0 and 1 (1 being best and 0 the worst possible soil quality). This approach was proposed as a simple and readily applicable, semi-quantitative approach to assessing overall relative soil quality from the perspective of production and susceptibility to erosion. The representation of the model used was as follows:

$$SQR = [(a * RSTC) + (b * RpH) + (c * ROM) + (d * RNPK)]$$

where: $RSTC$, RpH, ROM, and $RNPK$ are the assigned ranking values for soil textural class, soil pH, organic matter content, and soil fertility in respect of N (Nitrogen), P (phosphorus) and K (potassium); and a, b, c, and d, are weighting values corresponding to each of the four parameters. We preferred to use soil bulk density instead of soil textural class in the model as bulk density was thought to be more relevant physical parameter in the context of rangeland degradation and soil quality assessment. The bulk density, influenced greatly by stocking density, would reflect all the important physical soil processes like infiltration, storage and movement of water, runoff and soil erosion as well as proliferation of roots. The model for the present study was, therefore, as follows:

$$SQI = [(a * RBD) + (b * RpH) + (c * ROM) + (d * RNPK)]$$

where: RBD is the assigned ranking value for soil bulk density and other terms remain the same as for original model. The relative ranking of soil with respect to each parameter based on ranges of values is given in Table 1.

The ranges for organic matter, total nitrogen, available phosphorus and available potassium were assigned based upon corresponding ratings from very low to very high levels (Table 2) recommended by Ethiopian Soil Information System (EthioSIS, 2014). The critical levels established by EthioSIS are being used

Table 1. The ranges of soil parameters and corresponding ranking values.

Parameter	Ranking value				
	0.2	0.4	0.6	0.8	1.0
BD (Mgm^{-3})	>1.7	1.5-1.7	1.2-1.5	1.0-1.2	<1.0
Soil pH	<4.0	4.1-4.5	4.6-5.5	5.6-6.5	6.6-7.3
Soil organic matter (%)	<2	2-3	3-7	7-8	>8
Fertility (NPK)	Very low	Low	Optimum	High	Very high
SQI	Very poor	Poor	Fair	Good	Best

BD = bulk density; NPK = nitrogen phosphorus potassium; SQI = soil quality index.

Table 2. Critical levels used for classifying soil fertility parameters.

	OM (%)	TN (%)	AVP (mg kg^{-1})	AVK (mg kg^{-1})	pH	
Very low	<2	< 0.1	0-15	< 90	Strongly acidic	<5.5
Low	2-3	0.1-0.15	15-30	90-190	Moderately acidic	5.6-6.5
Optimum	3-7	0.15-0.3	30-80	190-600	Neutral	6.5-7.3
High	7-8	0.3-0.5	80-150	600-900	Moderately alkaline	7.3-8.4
Very high	>8	> 0.5	>150	>900	Strongly alkaline	>8.4

Source: EthioSIS (2014). OM = organic matter, TN = total nitrogen, AVP = available phosphorus, AVK = available potassium.

largely for soil fertility assessment and fertilizer recommendations for regional states of Ethiopia by Agricultural Transformation Agency (ATA) of Ministry of Agriculture, Ethiopia and other research workers (ATA, 2014; Lelago et al., 2016).

For bulk density, generally varying from 1.10 to 1.75 Mg m^{-3} for fine to coarse textured soils, the ranges for ranking purpose were assigned based on our judgment. Likewise, partial modification was made in pH ranges suggested by EthioSIS to have five rankings for acidic range of pH, as soils in the study area were acidic in nature. The assignment of weightages corresponding to each of the four parameters was done as suggested by Bajracharya et al. (2007). Of the soil parameters, organic matter was considered the most important parameter as it influenced many aspects of soil quality, such as, nutrient availability, aggregate stability, water retention, erosion susceptibility etc. Hence, it was given a weighting factor of 0.4 (c). The status of major nutrients N, P and K could be taken next in importance as adequate nutrient supply would govern the optimum level of forage production on the rangeland. Hence, it was given a weighting factor of 0.3 (d). Soil bulk density influencing different soil physical processes was given a weighting factor of 0.2 (a). Soil pH, viewed to be of lower degree of importance, but required to be within a critical range for optimum productivity and quality of soil, was given a weighting factor of 0.1 (b).

Statistical analysis

Prior to statistical analysis, treatments were arranged in factorial Randomized Complete Block Design format with rangeland unit and soil depth as factors. Two-way analysis of variance (ANOVA) was performed to assess the significance of differences in soil parameters between rangeland units and soil depth, using the General Linear Model (GLM) procedure (SAS, 2008). The separation of means was done by least significant difference (LSD) test after main effects were found significant at $p < 0.05$. Correlation coefficients (r) were computed to determine associations between different soil physical and chemical parameters.

RESULTS AND DISCUSSION

Physical properties of soil as affected by rangeland unit and soil depth

Soil texture

The relative proportion of sand, silt and clay particles in a soil determines its texture that influences greatly the water and nutrient holding capacity of soils. The soil textural fractions of sand, silt, and clay varied significantly with rangeland unit (Table 3). While the contents of both silt and clay were significantly higher under protected rangeland compared to unprotected one, the content of sand was significantly lower under protected than unprotected rangeland. The increase was 35 and 28% for silt and clay respectively, under protected than unprotected rangeland. The decrease in sand content was about 57% in the protected than the unprotected rangeland unit. The textural class was clay loam of the protected rangeland and sandy loam of unprotected rangeland. That means the soil under unprotected rangeland was relatively coarser compared to protected land due to more removal of fine soil fractions under surface erosional processes.

Such a trend in the relative proportions of textural separates is obvious, given the different management regimes of the land units. Although particle size fractions are inherent soil properties and are not subject to change, their variation sometimes could be associated with sheet and rill erosion processes under poor soil

Table 3. Effect of rangeland unit and soil depth on soil physical properties.

Rangeland unit	Sand (%)	Silt (%)	Clay (%)	Textural class	BD (Mgm^{-3})	TP (%)
Protected	39.6^{a}	31.4^{a}	36.0^{a}	Clay loam	1.03^{a}	61.4^{a}
Unprotected	53.7^{b}	24.6^{b}	15.4^{b}	Sandy loam	1.38^{b}	47.8^{b}
SEM (±)	0.001	1.650	0.834		0.045	1.698
P value (0.05)	0.000	0.000	0.000		0.000	0.000
Soil depth (cm)						
0-15	47.8^{a}	28.4^{a}	24.4^{a}	Sandy clay loam	1.17^{a}	55.8^{a}
15-30	45.5^{b}	27.6^{a}	27.0^{b}	Sandy clay loam	1.25^{a}	53.0^{a}
SEM(±)	1.650	0.834	0.001		0.045	1.698
P Value (0.05)	0.000	0.162	0.000		0.068	0.076

Figures followed by the same letter within a column for a given treatment and variable are not significantly different (p = 0.05) from each other; BD = bulk density, TP = total porosity.

management conditions. According to Yimer et al. (2015), soil erosion and selective removal of soil particles do affect the relative proportions of particle sizes and textural class. The unprotected rangelands, devoid of adequate vegetative cover and frequented by large number of livestock, are more prone to processes of soil erosion and carrying away of more dispersible silt and clay fractions with runoff waters. Relatively coarser texture of unprotected rangeland unit reflects deterioration in the water and nutrient holding capacity of soils and overall productivity of the rangeland. The 15-30 cm soil depth indicated significantly higher proportion of clay and lower of sand than 0-15 cm depth (Table 3). The higher content of clay in the lower depth might be due to deposition of clay (illuviation process) migrated from upper layer (eluviation process). The translocation of clay from upper layer would cause proportionate increase in the sand content in the upper layer. A similar observation was made by Mengistu (2014), who stated that the distribution of clay particles increased with depth with concomitant decrease in sand content in top layer. The silt content was, however, statistically similar in both the depths.

Bulk density

Bulk density (BD), reflecting compactness or pulverized state of soils, governs the water retention and transmission and root proliferation characteristics of soils. The soils with higher values of bulk density severely restrict root growth and reduce water storage in the soil profile. Bulk density value was significantly affected by rangeland unit ($p \leq 0.05$). It was significantly higher under unprotected rangeland unit (1.38 Mgm^{-3}) than protected rangeland (1.03 Mgm^{-3}) (Table 3). The higher bulk density under unprotected rangeland is consequent to compaction of soil brought about by trampling by large number of livestock grazing these lands, increased soil erosion removing fine fractions of soil, more rain drop impact on bare soils, mechanical crust formation as well as low incorporation of organic matter into these soils. The intensive grazing by livestock and small ruminants round the year on the communal pasture and rangelands leave them bereft of meaningful vegetation and litter cover. The exposed soils suffer a great deal of physical deterioration with increase in bulk density. This kind of phenomenon on rangelands has been reported by Saleh et al. (2009) and Chaudhari et al. (2013). The increased compaction of soils may affect adversely the hydrological functioning of the mountain ecosystems by influencing soil infiltrability, overland runoff, soil erosional processes, interflow and recharge of the ground strata. A significant reduction in the infiltrability of alpine pasture/rangeland soils with increasing stock density has been reported by Sharma and Minhas (1993) in Kinnaur high Himalaya, India. The bulk density was although higher for lower layer compared to upper layer, it was statistically non-significant on overall basis. The interaction effect of rangeland unit and depth on BD (Table 4) indicated that BD of the surface layer of unprotected land (1.35 Mgm^{-3}) was significantly higher than BD of subsurface layer of the protected land (1.07 Mgm^{-3}). That meant the extent of degradation in unprotected land was quite significant.

Total porosity

Total porosity (TP) was significantly ($p < 0.05$) affected by rangeland unit (Table 3). It was significantly higher under protected rangeland unit (61.0%) compared to unprotected rangeland (47.8%), an increase of about 28 percent. The higher porosity under protected rangeland was due to less anthropogenic pressure and physical deterioration of soils. Such a high porosity value reflects better soil structure as a result of less compaction effect

Table 4. Interaction effect of rangeland unit and soil depth on soil physical properties.

Rangeland unit	Soil depth (cm)	Soil parameter				
		Sand (%)	Silt (%)	Clay (%)	BD (Mgm^{-3})	TP (%)
Protected	0-15	40.6^{a}	31.0^{a}	34.0^{a}	0.99^{a}	62.6^{a}
	15-30	38.6^{a}	31.8^{a}	38.0^{b}	1.07^{a}	59.5^{a}
Unprotected	0-15	55.0^{b}	25.6^{b}	14.8^{c}	1.35^{b}	49.1^{b}
	15-30	52.2^{b}	23.4^{b}	16.0^{d}	1.42^{b}	46.5^{b}
LSD(P=0.05)		3.13	1.37	0.81	0.12	4.46
SEM (±)		17.9	0.83	2.39	0.04	1.7

Figures followed by the same letter within a column for a given treatment and variable are not significantly different (p = 0.05) from each other; BD = bulk density, TP = total porosity.

Table 5. Effect of rangeland unit and soil depth on chemical properties of soil.

Rangeland unit	pH	OM (%)	TN (%)	C: N ratio	AVP (mg kg^{-1})	AVK (mg kg^{-1})
Protected	5.0^{a}	4.2^{a}	0.21^{a}	11.57^{a}	12.4^{a}	52.3^{a}
Unprotected	5.4^{b}	2.7^{b}	0.13^{b}	11.75^{b}	2.5^{a}	48.4^{b}
SEM(±)	0.06	0.26	0.13	0.07	0.75	3.49
P value (0.05)	0.000	0.003	0.003	0.210	0.000	0.000
Soil depth (cm)						
0-15	5.1^{a}	3.7	0.18^{a}	11.65^{a}	10.6^{a}	51.8^{a}
15-30	5.3^{a}	3.2	0.16^{a}	11.67^{b}	4.3^{b}	48.9^{b}
SEM(±)	0.06	0.26	0.01	0.07	1.49	1.11
P Value (0.05)	0.080	0.260	0.290	0.860	0.000	0.000

Figures followed by the same letter within a column for a given treatment and variable are not significantly different (p = 0.05) from each other. OM = organic matter, TN = total nitrogen, C:N = carbon to nitrogen ratio, AVP = available phosphorus, AVK = available potassium.

of grazing animals, desirable particle size distribution as well as stability of aggregates and more biotic influences in terms of root penetration and activity of organisms (Cardoso et al., 2013). The porosity is important determinant of infiltration and runoff rates which ultimately would govern storage of water in the soil and its availability to biomass on the rangeland. The ideal porosity relationships retard the processes of soil erosion and degradation, enhance soil aeration and proliferation of roots of grasses and forages. The TP value although was higher for 0-15 cm depth (55.8 %) than for 15-30 cm depth (53 %), it was statistically non-significant (Table 3). The interaction effect of rangeland unit and depth on TP (Table 4) was similar to as interpreted for BD. The TP of surface layer of unprotected land (49.1 %) was significantly lower than porosity of subsurface layer of protected land (59.5%).

Chemical properties of soil as affected by rangeland unit and soil depth

Soil pH

The pH of soils differed significantly ($P<0.05$) on rangeland and was relatively lower in protected land (5.0) compared to unprotected land (5.4) (Table 5). Overall, the pH in the rangeland was strongly acidic as per ratings of EthioSIS (2014). The relatively lower value of pH in protected land could be ascribed to more accumulation of organic matter and its decomposition products, viz., carbonic acid, carboxylic acid and inorganic acids that cause significant reduction in soil pH. A highly significant negative relationship ($r = -0.84^{**}$) between pH and organic matter (Table 5) in this study suggested for such an occurrence. On the other hand, the increase in pH in unprotected rangeland might be due to addition of livestock urine that increased soil pH by hydrolysis of urine urea (Majid et al., 2011) and the deposition of cations from the manure (Mengistu, 2014). Accordingly, the increase in pH with increase in intensity of grazing has been reported by Zarekia et al. (2012). No significant variation ($p > 0.05$) was observed for soil pH with depth (Table 5). Though not significant, the overall mean of soil pH was slightly higher in 15-30cm soil depth (5.3) than in the 0-15cm soil depth (5.1). This increase in pH in subsurface depth could be attributed to leaching of base forming cations from the surface layer (eluviation process) (Zarekia et al., 2012).

Table 6. Interaction effect of rangeland unit and soil depth on soil chemical properties.

Rangeland unit	Soil depth (cm)	Soil parameter					
		pH	OM (%)	TN(%)	C:N ratio	AVP (mg kg^{-1})	AVK (mg kg^{-1})
Protected	0-15	4.9^{a}	4.7^{a}	0.24^{a}	11.6	18.2^{a}	55.1^{a}
	15-30	5.1^{a}	3.7^{a}	0.19^{a}	11.5	6.5^{b}	49.5^{b}
Unprotected	0-15	5.3^{b}	2.6^{b}	0.13^{b}	11.7	2.9^{c}	54.0^{c}
	15-30	5.5^{b}	2.7^{b}	0.13^{b}	11.8	2.0^{d}	42.8^{d}
LSD		0.25	1.1	0.06	0.42	0.14	0.61
SEM(±)		0.06	0.01	1.48	0.07	1.11	0.26

Figures followed by the same letter within a column for a given treatment and variable are not significantly different (p = 0.05) from each other. OM = organic matter, TN = total nitrogen, C:N = carbon to nitrogen ratio, AVP = available phosphorus, AVK = available potassium.

Soil organic matter

Soil organic matter (SOM) influencing a host of soil physical, chemical and biological properties is one of the important soil attributes for evaluating soil quality. The SOM contents in the rangelands could be described by the difference in soil depletion and biomass return (Tizita, 2016). The most obvious impact of grazing on the ecosystem is the removal of a major part of aboveground biomass by livestock. Under protected land, the input of aboveground biomass and litter fall into the soil increases its SOM content (Mekuria and Edzo, 2012). The dense root biomass of grasses is also an important contributor to higher carbon and SOM content on its decay (Zhang et al., 2015; Ryan et al., 2018). The ability of vegetation cover to buffer the soil microclimatic conditions (better temperature and moisture regimes), also facilitates low carbon losses and accumulation of SOM in soils (Ryan et al., 2018). Accordingly, the organic matter status of soils of protected rangeland (4.2%) was significantly higher than unprotected rangeland (2.7%); showing an increase of 59 percent in the former than the latter (Table 5). The SOM status of protected rangeland was rated as optimum, while that of the unprotected grazing land as low as per ratings of EthioSIS (2014). The SOM content was higher in 0-15cm depth (3.7%) compared to 15-30 cm depth (3.2 %), though, the increase was non-significant (Table 5). The higher amount of SOM in the upper soil layer could be associated with greater concentration of grass roots and detrital inputs of grass litter into the layer. It has been reported that about one-third of the total SOM gets accumulated in the upper 15 cm soil depth (Maharjan, 2010). The interaction between rangeland unit and soil depth (Table 6) indicated that SOM in 0-15cm soil depth of unprotected land (2.64%) was even less than the SOM in 15-30cm of protected land (3.73%), indicating that unprotected land was more exposed to soil resource deterioration.

Total nitrogen

The total N content of the soils showed significant variation ($p < 0.05$) across the rangeland units. The protected rangeland had significantly higher total N (0.21%) compared to unprotected rangeland (0.13%), an increase of over 85 percent (Table 5). The N status was categorized as optimum in protected rangeland and low in unprotected rangeland as per ratings of EthioSIS (2014). The nitrogen content of soils was closely linked to the amount of organic matter in the soil as indicated by highly significant and positive relationship of N with organic matter ($r = 0.99^{**}$). The presence of leguminous plants which have the capacity to fix nitrogen from the atmosphere through the root nodules might have also increased the total nitrogen content of the soil **(**Mekuria and Aynekulu, 2013). Hence, higher turnover of organic matter into the soils as well as more atmospheric N-fixation would have led to higher stocks of nitrogen in protected land. Similar findings have been reported by Mekuria and Edzo (2012) that total nitrogen was significantly higher in protected areas than in unprotected grazing lands. The soils under unprotected land unit have lower total nitrogen probably due to continuous overgrazing that resulted in the removal of grasses and organic matter from the soil.

The nitrogen content did not show significant variation with soil depth (Table 5), although the content was somewhat higher in 0-15 cm depth (0.18%) compared to15-30 cm depth (0.16%). The interaction between rangeland unit and soil depth on TN (Table 6) indicated that N content in surface layer of unprotected land (0.13%) was even less than the TN content in subsurface layer of protected land (0.19%). That showed unprotected land to be having more degree of soil resource deterioration.

Carbon to nitrogen ratio

A key factor influencing plant growth is the carbon to nitrogen ratio (C:N ratio), because the amount of available N, either present in the residue or in the soil, greatly affects the rate of decomposition of organic matter. A large organic C:N ratio indicates a material relatively low in N content and high in organic carbon. Generally, a C:N ratio less than 20:1 indicates a potential for net mineralization, whereas, C:N ratio greater than 30:1 indicates potential immobilization. In the present study, the C:N ratios of protected land (11.6) and unprotected land (11.7) differed significantly (Table 5), but were less than 20:1 indicating good mineralization potential for both the land units. However, the numerical value for unprotected rangeland unit was higher than protected land, which could be due to the rapid losses of N in unprotected land. The C:N ratios were similar and less than 20:1 for the two depths, indicating parallel decline in soil organic carbon and nitrogen content with depth.

Available phosphorus

The available phosphorus (P) content of soils was significantly affected (p≤0. 05) by rangeland unit and soil depth. The protected rangeland contained relatively higher concentrations of available P (12.4 mg kg^{-1}) compared to unprotected land (2.5 mg kg^{-1}) (Table 5). The sharp reduction in the available P status of unprotected land is due to greater removal of nutrient-bearing soil fractions through erosion-runoff process as suggested by Islam and Weil (2000). Moreover, the continuous intensive grazing by the livestock leaves very less opportunity for the addition of plant litter and its mineralization in the soils. Therefore, the available P content in soils, which is largely governed by the mineralization of organic-P fraction will tend to be low at any particular time under low organic matter soils (Stephen et al*.,* 2014). This was quite evident by highly significant and positive relationship of P with organic matter ($r = 0.73^{**}$). The low soil fertility in respect of P under unprotected land would tell upon its overall productivity. The effect is likely to be more pronounced on legume components requiring adequate P nutrition. The P content was significantly higher (10.6 mg kg^{-1}) in 0-15 cm soil depth compared to 15-30 cm depth (4.3 mg kg^{-1}) (Table 5). The decline in P content with depth could be due to reduced SOM content with depth. Overall, the P status of both protected and unprotected rangeland units was rated as very low (EthioSIS, 2014).

Available potassium

There was a significant difference (p≤0.05) in available potassium across rangeland units (Table 5). The protected rangeland had higher available K (52.3ppm) compared to unprotected land (48.4 ppm). The variation in available K contents between the rangeland units is, obviously, due to difference in grazing intensity. But unlike P, there was no greater difference in the available K status of the rangeland units, although the soil organic matter level was lower under unprotected land than the protected land. Such a behavior could be anticipated as availability of K in soils is governed more by the inorganic soil fraction (mineralogical composition) rather than by the organic fraction (Gebeyaw, 2007). The soil depth also influenced significantly the available K content in the soils (Table 5). The surface layer had significantly higher available K (52 ppm) compared to sub-surface layer (49 ppm). Both the rangeland units were very low in available potassium status as per ratings of EthioSIS (2014).

Soil quality index

The different soil physical and chemical parameters are the indicators of soil quality of different land-use systems. For the sake of simplicity and economics, however, the researchers advocate use of single value soil quality index (SQI) based on minimum data set. Accordingly, some of the most commonly used soil parameters were used to develop an index to reflect the quality or the condition of the soil with respect to its productivity and relative susceptibility to degradation. The overall value of SQI under protected rangeland (0.61) was significantly higher than the value under unprotected land (0.45) (Figure 3). The soil quality score was rated as fair for protected land and poor for unprotected land as per the score value given in Table 1. The good SQI of protected rangeland unit was apparently due to less anthropogenic influence on it and consequent better state of physical and chemical quality indicators. The unprotected land, on the other hand, is subject to greater livestock pressure and foraging for fodder and fuel wood, causing more soil erosion and degradation of soil resources. The rampant soil erosion renders soils coarser in texture and depleted of soil organic matter and nutrients. Similar values of SQI have been reported for 15 grazing (grass/shrub) land sites for Nepal Himalaya, with 20, 47 and 33 % of soils rated as poor, fair and good, respectively (Bajracharya et al., 2007). The overall value of SQI was significantly lower in 15-30 cm depth compared to 0-15 cm depth (Figure 4), as also reported by Gebreyesus (2014). The interaction effect of rangeland unit and soil depth on SQI (Figure 5), like other physical and chemical parameters, indicated quality of surface layer of unprotected land to be alike to sub-surface layer of protected land. It meant that unprotected land had suffered greater soil degradation, losing much of its surface layer.

In general, the low values of SQI for rangeland (both protected and unprotected land units) were primarily due to low contents of organic matter and nutrients. Similar observations have been made by Aweke et al. (2015) for other smallholder farmlands in Tigray, eastern Ethiopia, that low values of SQI for agroforesry-based land use (0.58) and dry land crop production system (0.47) were largely due to low levels of organic matter and nutrient stocks in soils. The unprotected rangeland with a poor SQI, indicated an immediate need for soil restoration following appropriate conservation measures to ensure

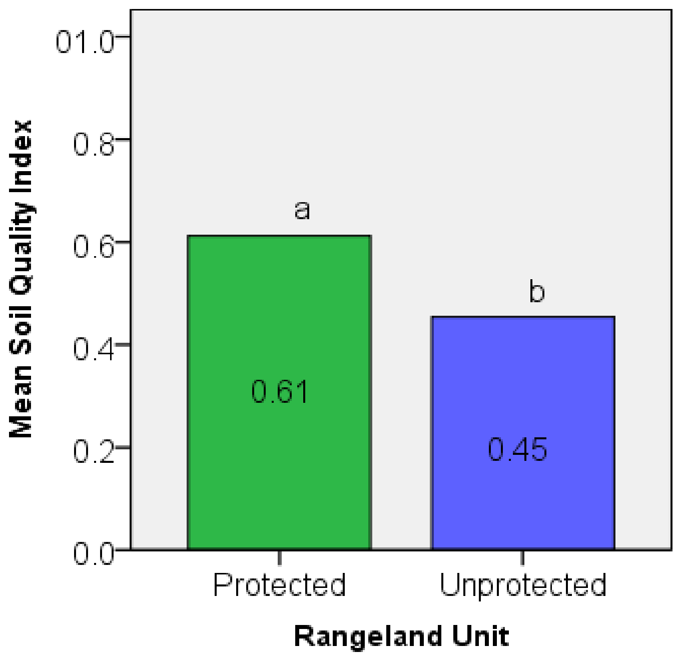

Figure 3. Soil quality index as affected by rangeland unit. Bars with different letters, a and b, are significantly different (p = 0.05).

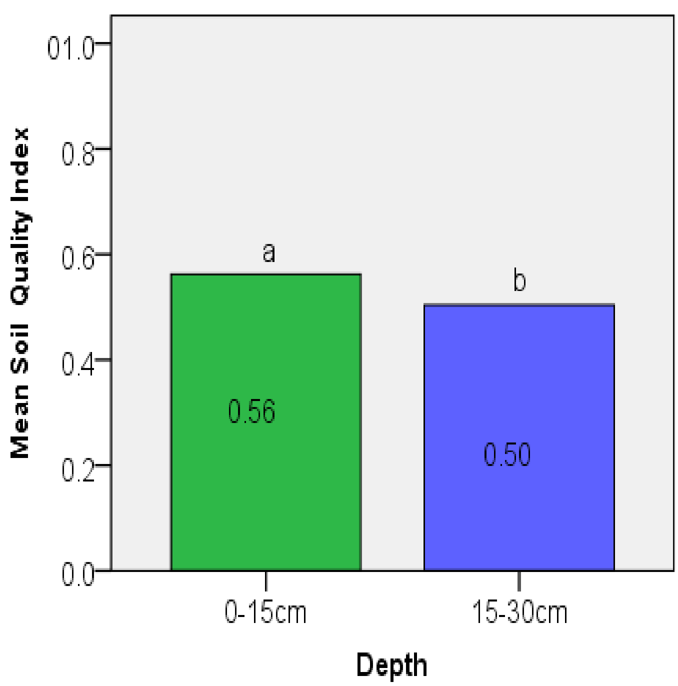

Figure 4. Soil quality index as affected by soil depth of rangeland. Bars with different letters, a & b, are significantly different (p = 0.05).

sites for Nepal Himalaya, with 20, 47 and 33% of soils rated as poor, fair and good, respectively (Bajracharya et

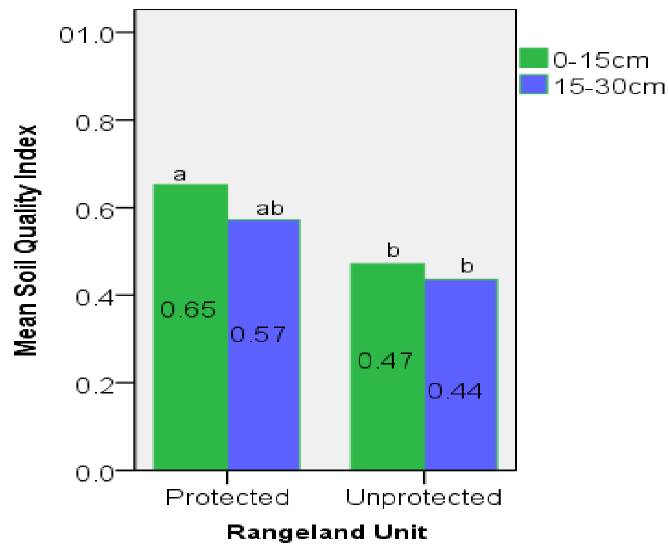

Figure 5. Soil quality index as affected by interaction of rangeland unit and soil depth. Bars with different letters, a & b, are significantly different (p = 0.05).

sustainable productivity and ecosystem services. The SQI indicating highly significant relationship with soil parameters, viz., organic matter (r = 0.93**), total nitrogen (r = 0.96**), available phosphorus (r = 0.57**) and pH (r = 0.89**), could be suggested as useful single value index for assessment and mapping of soil quality of rangelands in Farta, Amhara region.

Conclusion

Two adjacent protected (for the last thirty years) and unprotected land units in Abargay rangeland, Farta District, south Gondar, Ethiopia were evaluated for soil quality employing different soil quality indicators viz., soil texture, bulk density, total porosity, pH, organic matter content, total nitrogen, available phosphorus and available potassium. The soil quality index was also computed using scoring values for different soil properties. The protected land indicated more favourable values of soil quality indicators compared to unprotected land. The 0-15 cm soil layer indicated better soil quality than 15-30 cm soil layer. The protected rangeland was rated as fair and unprotected land as poor in soil quality based on soil quality index. Overall, the poor quality of unprotected rangeland as a result of deterioration in physical, chemical and biological environment of soils, would tell upon the productivity of rangeland and associated ecosystem services and livelihoods.

The rangeland in fair condition (protected area) could be used as a reference for rehabilitating the degraded land in the study area. The highly degraded lands should be designated as protected lands and put to enclosures, to ward off increasing anthropogenic pressure on them. Also, these lands need to be provided with appropriate rill and gully control soil conservation measures to restore their stability. To improve the fertility of the depleted soils, both organic and inorganic fertilizers need to be applied. Besides, the lands should be enriched with legume components that fix atmospheric nitrogen and enhance quality of the pasturage. Soil quality may be recognized as one of the criteria in the overall monitoring program of rangeland health and productivity. Soil quality index could be suggested as useful single value index for assessment and mapping of soil quality of rangelands in Farta, Amhara region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Alemayehu A, Assefa A (2016). Effects of land use changes on the dynamics of selected soil properties in Northeast Wellega, Ethiopia. Soil 2(1):63-70.

Alemayehu M (1998). The Borana and the 1991-1992 Drought: A Rangeland and Livestock Resource Study. Institute for Sustainable Development and French Catholic Committee against Hunger and for Development, Addis Ababa Ethiopia.

Amaha K (2008). Soil seed bank evaluation along degradation gradient in arid rangelands of the Somali region, eastern Ethiopia. Journal of Ecosystems and Environment 129(4):428-436.

Anderson JM, Ingram JS (1994). Tropical Soil Biology and Fertility: A handbook of methods (Second Edition). CAB International, Oxford, UK. 221p.

ATA (2014). Soil fertility status and fertilizer recommendation atlas for Tigray Regional State, Ethiopia. Ethiopian Agricultural Transformation Agency, Ministry of Agriculture, Addis Ababa, Ethiopia, 76p.

Aweke MG, Singh BR, Lal R (2015). Soil quality indices for evaluating smallholder agricultural land uses in Northern Ethiopia. Sustainability 7(3):2322-2337. DOI: 10.3390/su7032322.

Bajracharya RM, Sitaula BK, Sharma S, Jeng A (2007). Soil quality in the Nepalese context - an analytical review. International Journal of Ecology and Environmental Sciences 33(2):143-158.

Becker AH (2013). Soil quality in Rhode Island pastures grazed by different types of livestock. Open Access Master's Dissertation, University of Rhode Island.

Bouyoucos GJ (1972). The hydrometer as a new method for the mechanical analysis of soils. Soil Science 23(5): 343-354.

Bremner JM, Mulvaney CS (1986). Total Nitrogen. In: Page AL, Miller RH, Keeney DR (eds) Methods of Soil Analysis. American Society of Agronomy 2:595-624.

Cardoso E, Jurandy BN , Rafael LFV, Daniel B, Marina YHM, Cristiane AS, Paulo RLA, Asandra MP, André SN, Jamil DM (2013). Looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? Soil Health 70(4):274-289.

Chaudhari PR, Dodha V, Vidya D, Chkravarty M, Maity S (2013). Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. International Journal of Scientific and Research Publications 3(2):1-8.

EthioSIS (2014). Ethiopian soil information system team analysis. Ministry of Agriculture, Addis Ababa, Ethiopia.

EthioSIS (2018). Ethiopian Soil Information System. Ministry of Agriculture, Addis Ababa, Ethiopia.

Gebeyaw T (2007). Soil fertility status as influenced by different land uses in Maybar areas of South Wello zone, North Ethiopia. Dissertation Haramaya University, Soil Science, Ethiopia.

Gebreyesus BT (2014). Soil quality assessment strategies for evaluating soil degradation in northern Ethiopia. Applied and Environmental Soil Science 3:1-14.

Islam KR, Weil RR (2000). Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. Agriculture, Ecosystems and Environment 79(1):9-16.

Karlen DL (1997). Soil quality, concept, definition, and framework for evaluation. Soil Science Society of America Journal 61(1):4-10.

Karlen DL, Stott DE (1994). Framework for evaluating physical and chemical indicators of soil quality. In: Doran JW, Leman DC, Bezdicek DF, Stewart BA (eds) Defining soil quality for a sustainable environment, Proceedings of a symposium, Minneapolis, MN, USA, 4-5 November 1992. SSSA Special Publication no.35: 53-72.

Larson WE, Pierce FJ (1991). Conservation and enhancement of soil quality: Evaluation for sustainable land management in the developing world. International Board for Soil Research and Management Bangkok, Thailand 2:175-204.

Lelago A, Mamo T, Haile W, Shiferaw H (2016). Assessment and mapping of status and spatial distribution of soil macronutrients in Kambata Tembaro zone, Southern Ethiopia. Advances in Plants and Agriculture Research 4(4):305-317.

Lutta AI (2015). Effects of holistic grazing management on soil physicochemical properties and herbaceous vegetation production in Naibunga Conservancy, Laikipia County, Kenya. Msc Dissertation, Portland, Oregon, USA, Land Resource Management and Agricultural Technology.

Maharjan M (2010). Soil carbon and nutrient status of rangeland in upper Mustang. Msc Dissertation, Tribhuvan University Institute of Forestry Pokhara, Nepal.

Majid A, Ramdzani A, Ahmad HMH, Ridzwan AH, Mohammad KY (2011). Impacts of livestock grazing on selected soil chemical properties in intensively managed pastures of peninsular Malaysia. Pertanika Journal of Tropical Agricultural Science 34(1):109-121.

Masto RE, Chhonkar PK, Singh D, Patra AK (2007). Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. Agriculture, Ecosystems and Environment 118(1-4):130-142.

Mekuria W, Edzo V (2012). Restoration of native vegetation following exclosure establishment on communal grazing lands in Tigray, Ethiopia. Applied Vegetation Science 15(1):71-83.

Mekuria W, Aynekulu E (2013). Exclosure land management for restoration of the soils in degraded communal grazing lands in northern Ethiopia. Land Degradation and Development 24:528-538.

Mengistu CF (2014). Assessment of soil physical and chemical properties as affected by diferent land use types in Warandhab area of Wollega zone, Oromia Regional State. M. Sc. Dissertation, Haramaya University, Ethiopia.

Middleton N, Stringer L, Goudie A, Thomas D (2011). The Forgotten Billion: MDG Achievement in the Drylands. Document United Nations Convention to Combat Desertification, New York and Nairobi 1-67p.

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate. U.S. Department of Agriculture Circular No. 939:1-19.

Panda SC (2007). Soil Water Conservation and Dry Farming. Agrobios India. 520p.

Ryan CB, Danny JE, Kenneth WT, Leslie MR (2018). A global meta-analysis of grazing impacts on soil health indicators. Journal

Environmental Quality 47(4):758-765.
Saleh H, Seekh Al, Mohammad AG, Yousef AA (2009). Effect of grazing on soil properties at southern part of West Bank rangeland. Hebron University Research Journal 4(1):35-53.
SAS (2008). Statistical Analysis System, Version 9. USA: Inc., Cary, NC.
Sharma PD, Minhas RS (1993). Land use and the biophysical environment of Kinnaur district, Himachal Pradesh, India. Mountain Research and Development 13(1):41-60.
Stephen M, Ann V, Charles KG, Jesse TN, Vivian OW, Stefaan DN, Elizabeth M, Eric VR (2014). Impact of enclosure management on soil properties and microbial biomass in a restored semi-arid rangeland, Kenya. Journal of Arid Land 6(5):561-570.
Teague WR, Provenza F, Roath R (2009). Economic implications of maintaining rangeland ecosystem health in a semi-arid Savannah. Ecological Economics 68:1417-1429.
Teshome A, Abule E, Lisanework N (2009). Pastoralists perceptions and rangeland evaluation for livestock production in South Eastern Ethiopia. Livestock Research for Rural Development 21(7):1-13.
Thompson SK (1991). Adaptive cluster sampling: Designs with primary and secondary units. Biometerics 47:1103-1115.
Tizita E (2016). Dynamics of soil physico chemical properties in area closures at Hirna Watershed of West Hararghe zone of Oromia Region, Ethiopia. International Journal of Soil Science 11(1):1-8.
Yimer F, Alemu G, Abdelkadir A (2015). Soil property variations in relation to exclosure and open grazing land use types in the Central Rift Valley area of Ethiopia. Environmental Systems Research 4(1):17.
Zarekia S, Mohammad J, Hossein A, Seyyed AJ, Ali AJ (2012). Grazing effects on some of the physical and chemical properties of soil. World Applied Sciences Journal 20(2):205-212.
Zhang Y, Lu X, Yan Y, Sun J, Chen X, Wang X, Cheng G (2015). Short term grazing exclusion has an impact on soil properties and nutrients of degraded alpine grassland in Tibet, China. Solid Earth 6(4):1195-1205.
Zornoza R, Acosta JA, Bastida F, Domínguez SG, Toledo DM, Faz A (2015). Identification of sensitive indicators to assess the interrelationship between soil quality, management practices and human health. Soil 1(1):173-185.