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# Effects of soil depth on the dynamics of selected soil properties among the highlands resources of Northeast Wollega, Ethiopia: are these sign of degradation?

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## Abstract

This study was conducted with an aim to analyze the spatial variability of soil properties with depth under four prominent land use patterns viz., forestland, grazing land, cultivated land and bush land of Northeast Wollega. Soil samples were collected from the land uses at two depths (0–15 and 15–30 cm) in replicates and totally 40 composite soil samples were collected. Statistical analysis revealed significant variation in soil properties with along the selected land uses. Topsoil layer had significantly greater OM, TN, AP, sand, silt, $Mg^{2+}$, $K^{+}$ and $Mg^{2+}$ concentrations than the subsoil layers. However, clay under all land uses and CEC under bush land and grazing land revealed reverse trends. Organic matter and CEC have stronger correlations with most of soil properties in the topsoil than in the subsoil while clay has no significant correlation with selected soil properties except with sand fraction in the sampled depths. Hence, the correlation among the selected soil properties also varies with soil depth. In general, the spatial variability of soil properties indicates that they were strongly affected by external factors (agricultural treatments and soil management practices) and internal factors (soil type and depth).

## 1 Introduction

In tropical and subtropical highlands, soils are highly weathered, well-drained and low in the availability of major soil nutrients, especially N and P (USDA, 1999). As the interaction between natural and anthropogenic management system persists (Assefa and van Keulen, 2009), soil undergoes vertical exchange of materials which in turn resulting in physical and chemical changes from surface soil to sub-soils (Brady and Weil, 1999). The reasons for these are addition of organic matter from plant growth to the top soil, weathering of rocks and minerals, decomposition of organic matter, and translocation of soluble components by leaching, which in turn responsible for the differentiation of soil layers (Foth, 1990). Human management system such as frequent





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plowing and tillage for the purpose of cultivation, grazing or similar uses also changes the proportions of many soil properties with changing depths (Ali et al., 1997; McCarthy et al., 2013). Ali et al. (1997) have reported that soil weathering differentials between the soil profiles have caused changes in clay, CEC, organic matter and K. Islam and Weil (2000) stated that tillage mechanically disintegrates soil particles and modifies soil conditions for plant growth and intensive leaching, and hastens organic matter decomposition. Sheet erosion and intensive leaching process leads to higher concentration of clay content and lesser concentration of calcium, magnesium, potassium and sodium in the subsoil than the topsoil (Adeboye et al., 2011). In Kobamo basin of Nigeria, Abubakar (1997) has studied vertical distribution of soil nutrients along different land use types and reported that sand content of both topsoil and subsoil is higher in cultivated land than the contents in forestland. However, silt and clay fractions are higher in forest land than the contents in cultivated land in both depths. It has also been reported that various nutrient elements such as N, P, $Ca^{2+}$, $Mg^{2+}$ and $K^{+}$ showed 3 to 43 % declining trend as soil depth increases. Lalisa et al. (2010) also reported that OC, TN and TP declined with depth for cereal farm; but these nutrients increased by 48.1, 63.4 and 20.4 %, respectively across the depth in the pasture land. Exchangeable cations decreased with depth except $Ca^{2+}$ in wood lots, $K^{+}$ in homesteads and $Na^{+}$ in cereal farms. CEC, however, decreased in all the land uses with depth by about 19 % (Lalisa et al., 2010).

The associations among the soil properties also vary with the variation of depth. In surface soil layer, CEC is strongly associated with organic matter than clay (McAlister et al., 1998). In the subsoil, since there is higher clay and relatively lower OM, CEC was strongly correlated with clay than organic matter (Jin et al., 2011). These observations have supported the thought that soil properties react to depths across the various land use types.

In the Northeast Wollega, Ethiopia, each year approximately 1.5 % of forestland was converted to other land covers. In comparison, 85 % of the loss goes to agricultural land that has been cultivated for years. This change has been linked to tree mortality and mineral mining. The size of agricultural land expands further, because of uncontrolled farming and settlement distributions. Also, there is no available study that examines dynamics of soil properties with depth among resources of highlands at the site. On the other hand, understanding the effects of soil depth on the dynamics of soil properties under different land covers is essential to establishing appropriate management options aimed at sustaining soil health and restoring degraded soils in the highlands. Therefore, the objective of this study was to examine the effects of soil depth on some selected soil properties and compare them under different land covers.

## 2 Materials and methods

### 2.1 Study area

The study area, covering 14 979 ha, is located between 9°45′ and 10°00′ N and 37°00′ and 37°15′ E (Fig. 1). Administratively, the Jarte area belongs to Horo-GuduruWolega zone, Oromia Regional State of Ethiopia. Geologically, the area belongs to the trap series of tertiary volcanic eruptions (ORLEPB, 2013). Its topography is typical of volcanic landscapes, which were later deeply incised by streams, resulting in the current diversity of landforms. The soils have developed from volcanic ashes and reworked materials resulting from tertiary volcanic eruptions and sedimentation processes (ORLEPB, 2013). Nitosols are the dominant soil type, mainly on undulating to steep slopes. Relatively flat areas and especially those closer to river valleys, are largely covered by well-developed Vertisols. As a result of degradation, the soils on steep slopes appear to have been downgraded to Regosols and Cambisols. Its altitude ranges between 1800 and 2657 m. Mean annual temperatures range between 22 and 28 °C. Annual rainfall, which is heavy during the summer months (June–August) ranges between 1750 and 2000 mm (EMS, 2013). For 2013, the population of the study area was projected to 58 339 of which only 10.09 % was urban population (CSA, 2013). The same document reported that the population of the district has increased by 39 % from 1980 to 2013.





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Except for a small percentage of the population living in the urban area, the inhabitants are farmers engaged in mixed crop-livestock farming system.

### 2.2 Soil sampling

Four adjacent sites were selected in this study from Jarte area, each located within the four different land use types, representing forestland, cultivated land, grazing land and bush land. Each land use has been divided into five tiles (100 m × 100 m in size). Within each tile four sub-plots were established, each with an area of 100 $m^2$, one in the center and three on a radial arm with 120° angles between them (Vågen et al., 2013). This form of sampling allows the assessment of variability of soil properties at different spatial scales (in our case depth variation among land uses at site level).

Soil sampling was carried out in February 2014 from each of the four land use types. At every sampling plot, soil samples were collected from five spots (north, south, east, west and center of the plot) within the land use and composite samples were prepared by hand mixing depending on depth strata. Totally, we had 40 composite soil samples. For every land use plots, soil samples were taken at two depths: 0–15 cm (topsoil layer) and 15–30 cm (subsoil layer) using soil auger. The two depths are deliberately chosen for two main reasons. Firstly, the 0–15 cm represents the average plough layer in the area while the 15–30 cm depth is the layer where the clay particles leached from the topsoil accumulate. Secondly, samplings at these predetermined depths enhance comparability of soil properties with depth among the studied land uses.

### 2.3 Soil analysis

Soil sample were analyzed following standard procedures as applied to tropical soils (Abubakar, 1997) for particle size distribution, cation exchange capacity (CEC), exchangeable Na, K, Ca and Mg, total nitrogen (TN), soil organic carbon (OC) and available P at the National Soil Laboratory Centre of the Ministry of Agriculture (MoA), Addis Ababa, Ethiopia. Disturbed soil sample were air-dried and grounded to pass through





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a 2 mm sieve prior to any laboratory analysis (Boyer, 1972). Black et al. (1965) procedures have been used for particle size analysis (Bouyoucos Hydrometer Method); total nitrogen (following Kjeldhal procedure); and CEC and exchangeable Ca, Mg, K and Na (by the ammonium acetate at pH 7). Percentage organic carbon was estimated based on the Walkey–Black Method (Walkey and Black, 1934) and equivalent % content of SOM was determined by multiplying the % OC by the Van Bermmelen factor of 1.724 (Thompson and Troeh, 1978). Phosphorous was determined by means of Olsen method (Olsen et al., 1954).

### 2.4 Statistical analysis

The data was organized and entered into Statistical Package for Social Sciences (SPSS) software version 20.0 for windows. Independent samples *t* test was under taken to test the significance of the effects of soil depth, along with the impact of land use differences, on the variation of soil textural class, soil PH, available P, soil organic matter content (%), total Nitrogen (%), CEC Cmol $kg^{-1}$, and Exchangeable bases ($K^{+}$, $Ca^{2+}$, and $Mg^{2+}$) Cmol $kg^{-1}$ at the 0.05 level. The independent variable (i.e. soil depth) has two groups: topsoil (0–15 cm) and subsoil (15–30 cm). Independent samples *t* test was used in this study because the data meet the six different assumptions of independent *t* test such as measurement at interval level, two category of independent variables, independence of observations, absence of outliers, normal distributions of independent variable and homogeneity of variance. Bivariate correlation analysis was conducted to assess the relationships between the studied soil properties. Variation in soil properties with depth across the land uses were computed by taking the surface layer (0–15 cm depth) as reference groups. Hence, for a given soil property, the variation expresses how much it increased or decreased in percent in relation to the reference group (Eq. 1).

$$R_{\text{sub}}\ \% = \frac{Q2 - Q1}{Q1} \times 100 \qquad (1)$$

where, $R_{sub}$ = Variation in % of soil properties in subsoil layer compared to topsoil properties
$Q1$ = value of soil property in the surface soil layer
$Q2$ = value of soil property in the subsurface soil layer.

## 3 Results and discussion

### 3.1 Variations in soil properties with depth

#### 3.1.1 Particle size distributions

The mean particle size distribution of the top and sub soils corresponds respectively to sandy loam and clay loam on forest lands. It corresponds to clay loam in both top and sub soils of grazing land, while it corresponds to sand and sand loam respectively in top and sub soils of bush land, and in both layers of cultivated soils it clearly corresponds to clay (Table 2). The proportion of sand fraction was the highest (73.6 % in the topsoil and 62.8 % in subsoil) under bush land and the lowest (29.6 % in topsoil and 26.8 % in subsoil) under cultivated land (Table 2). Silt and clay fractions, however, showed opposite trends. Silt was the highest (32.8 % in topsoil and 28 % in subsoil) under forestland and lowest (12.8 % in topsoil and 14.4 % in subsoil) under bush land (Table 2). Clay was the highest (42 %) under cultivated land in topsoil and under grazing land (47.6 %) in the subsoil (Table 2). It was the lowest in both topsoil (13.6 %) and subsoil (22.8 %) under bush land. The highest and the lowest values of respectively sand and clay fractions in topsoil of bush land might have been attributed to relatively higher rate of down ward erosion or destruction of clay in the top soil (Siddique et al., 2014) and slow rate of weathering process. This land use also described by unstable soil fractions because of steeper slope and impact of human and livestock interventions (Table 1). This finding contradicts with the result of Abubakar's (1997) study that reported sand content was the highest in the cultivated land and the lowest in forestland for both top and sub soils.

The percentage changes in sand particle size distribution of subsoil from topsoil were decreasing in all land uses. The change was the highest in forestland (−31 %; $P < 0.01$) and the lowest in cultivated land (−10 %) (Fig. 2). On the other hand, the percentage changes in clay particle size distribution of subsoil from topsoil were increasing in all the four land uses. The change was the highest in forestland (133 %; $P < 0.01$) and the lowest in cultivated land (11 %) (Fig. 2).This finding revealed that soil particle size distributions significantly changes between sampling depths in the three land-uses. The change is, however, at varying rates. These variations might be caused by variation of land-covers overlying the surfaces. Studies in Ethiopia (e.g. Belay, 2002; Woldeamlak and Stroonijer, 2003; Eyayu et al., 2009; Asmamaw and Mohammed, 2013) and in Nigeria (Abubakar, 1997) on spatial variability of soil properties have shown similar changes.

### 3.1.2 Organic matter

OM was the highest (9.0 % in topsoil and 4.2 % in subsoil) under forestland and was the lowest (3.0 % in topsoil and 2.0 % in subsoil) under bush land (Table 2). The percentage changes in OM content of subsoil from topsoil were decreasing in all land uses. This implies that the surface soil layer is the most biologically active of the soil profile. The litter on the soil surface beneath different canopy layers and high biomass production caused high biological activity in the topsoil layer. The change was the highest in forestland (−54 %; $P < 0.01$), followed by grazing land (−50 %; $P < 0.01$), bush land (−32 %; $P < 0.01$) and the lowest in cultivated land (−26 %; $P < 0.05$) (Fig. 2). The highest change of OM with depth under forest land might be attributed to continuous accumulation of un-decayed and partially decomposed plant and animal residues mainly in the surface soils of forestland, high rate of interception and infiltration and/or absence of erosion (Morgan, 2005). However, the decrease of organic matter was gradual in cultivate land as compared to other land uses. The possible explanation for this may be the prevalence of active erosion, decomposition process and disturbances by tillage implements. Tillage combines different soil layers. It, therefore, results into rapid decomposition of soil organic matter and reduce the contribution of organic and microbial process to nutrient cycling (Yifru and Taye, 2011; Bhuyan et al., 2013).

### 3.1.3 Total nitrogen (TN)

TN was the highest (0.44 % in topsoil and 0.21 % in subsoil) under forestland and was the lowest (0.14 % in topsoil and 0.11 % in subsoil) under bush land (Table 2). Similar to organic matter, the percentage changes in TN content of subsoil from topsoil were decreasing in all land uses. Thus, TN is higher in topsoil than in the subsoil probably be as a result of losses in organic matter by mineralization in the subsoil. The change was the highest in forestland (−52 %), followed by grazing land (−46 %), cultivated land (−24 %) and the lowest in bush land (−21 %) (Fig. 2). The change in TN was highest under forestland may be because of abundance of legume plants and Azotobacter algae (able to fix atmospheric nitrogen), decaying plant and animal matter, and nitrogen compounds produced by thunderstorms (Hall, 2008).

The lowest change of TN under cultivated land compared to forestland and grazing land implies that fertilizer applications may not have replaced the total N lost due to harvest removal, leaching, and humus losses associated with cultivation (Eyayu et al., 2009). Farmyard manures and organic matter from which TN for crop production synthesized and mineralized in cultivated land is also low. In the study area, dung and urine from animals concentrated in stock camps, under trees and near gateways. As informed by elders, this system had been used as a method to restock N in the soil lost due to crop harvest. Thus, cultivated land often supplied with soluble form of nitrogen, namely nitrate ($NO_3$), or ammonium ($NH_4$). This could be attained directly by adding fertilizers such as urea, various ammoniums or nitrate salts such as ammonium nitrate, potassium nitrate, calcium ammonium nitrate or as anhydrous ammonia to be agriculturally productive.

### 3.1.4 Available phosphorous (AP)

AP was the highest (3.7 ppm) under cultivated land in the topsoil and under the forestland (1.84 %) in the subsoil. It was the lowest (1.49 ppm in topsoil and 0.76 ppm in subsoil) under bush land (Table 2). Thus, AP was one of the major nutrients which exist in low proportions in the study area. It is below the requirements even for the low demanding crops. According to Tisdale et al. (1993) plants' demands to AP vary where low demanding crops require concentration of $P > 8$ ppm, moderate-demanding crops > 14 ppm and crops with high demanding crops > 21 ppm. This was found probably due to the deficiency of the soil to absorb or retain phosphorous since soils of the study area are acidic and clayey; its deficiency also attributed to human management systems such as deforestation, overgrazing, over cultivation and erosion which in turn, reveals the prevalence of land degradation (McAlister et al., 1998; Brady and Weil, 1999).

The percentage changes in AP content of subsoil from topsoil were decreasing in all land uses. The change was the highest in both cultivated and forestland constituting −59 % each, followed by bush land (−49 %) and the lowest in grazing land (−34 %) (Fig. 2). Highest decline of AP in cultivated land is most likely to appear due to the surface of the cultivated land is continuously supplied with inorganic fertilizer and removed by annual crops. Hence, cultivated land should be supplied with inorganic fertilizer to increase the concentration of P in the soil solution that required by crops. This finding also corroborates the reports of similar and recent studies (Woldeamlak and Stroosnijder, 2003; Yifru and Taye, 2011).

### 3.1.5 Cation Exchange Capacity (CEC)

CEC was the highest (32.85 Cmol kg$^{-1}$) under forestland in topsoil and under grazing land (26.93 Cmol kg$^{-1}$) in the subsoil and was the lowest (7.37 Cmol kg$^{-1}$ in topsoil and 8.68 Cmol kg$^{-1}$ in subsoil) under bush land (Table 2). The percentage changes in CEC content of subsoil from topsoil were increasing under forestland (31 %; $P < 0.05$) and cultivated land (15 %); however, decreasing under bush land (−18 %) and grazing land (−5 %) (Fig. 2).The changes were the highest under forestland (31 %) and the lowest under grazing land (−5 %). The topsoil of forestland and cultivated land has higher CEC than subsoil probably because of the presence of higher organic matter on the surfaces of forestland and AP in the cultivated land use. Thus, CEC of the subsoil layer are influenced by OM of the soil (Adeboye et al., 2011). Under grazing land and bush land, however, CEC showed the opposite trend where its content increases and organic matter declines with depth. The CEC of these land uses in the subsoil may be influenced by clay content. Thus, the variability of CEC with depth among different land uses imply the difference in the ability of the soil to hold positively charged ions affecting the stability of soil structure, nutrient availability, soil pH and soil's response to fertilizers (Crewett et al., 2008). This study, therefore, suggests that clay and OM could be the main factors that influence CEC in the soil. This finding is also supported by McAlister et al. (1998) who justified that CEC of soils varies with the changes of clay percentage, the type of clay, soil pH and amount of organic matter.

### 3.1.6 Exchangeable basic cations ($K^+$, $Ca^{2+}$ and $Mg^{2+}$)

Exchangeable potassium ($K^+$) was the highest (0.14 Cmol $kg^{-1}$ in topsoil and 0.12 Cmol $kg^{-1}$ in the subsoil) under cultivated land and the lowest (0.03 Cmol $kg^{-1}$ in topsoil and 0.02 Cmol $kg^{-1}$ in the subsoil) under bush land (Table 2). The percentage changes in $K^+$ content of subsoil from topsoil were decreasing in all land uses. The change was the highest in grazing land (−58 %) and the lowest in cultivated land (−14 %), while it was intermediate in the forestland (−54 %) and bush land (−33 %) (Fig. 2). The highest content of $K^+$ under cultivated land in both sampled depths may be related to frequent supply of fertilizers i.e. urea and DAP (up to 100 kg $ha^{-1}$ each) applied to cultivated land. Whereas, the lowest value of $K^+$ in both sampled depths under bush land was attributed to high browsing, erosive nature of the soil (sandy soil) and high level erosion (Table 1). In addition, the highest variability of $K^+$ with depth under grassland may be attributed to cattle manure supplied to the topsoil.

Exchangeable calcium ($Ca^{2+}$) was the highest (12.81 Cmol kg$^{-1}$ in topsoil and 8.13 Cmol kg$^{-1}$ in subsoil) under forestland and the lowest (0.54 Cmol kg$^{-1}$ in topsoil and 0.34 Cmol kg$^{-1}$ in subsoil) under bush land (Table 2). The percentage changes in $Ca^{2+}$ content of subsoil from topsoil were decreasing in all land uses. The change was the highest in forestland and bush land (−37 %) and the lowest in cultivated land (−17 %), while it was intermediate in the grazing land (−37 %) (Fig. 2). The highest content of $Ca^{2+}$ in forestland was may be attributed to leaves from plant falls, macro fauna and soil micro flora and microbial activities common in this land use (Table 1). However, under bush and cultivated lands, the opposite trend could be observed.

Exchangeable magnesium ($Mg^{2+}$) was the highest (4.80 Cmol kg$^{-1}$ in topsoil and 3.24 Cmol kg$^{-1}$ in subsoil) under grazing land and the lowest (0.55 Cmol kg$^{-1}$ in topsoil and 0.12 Cmol kg$^{-1}$ in subsoil) under bush land (Table 2). The percentage changes in $Mg^{2+}$ content of subsoil from the topsoil were decreasing in all land uses. The change was highest (−78 %) in bush land and the lowest (−2 %) in the cultivated land, while it was intermediate in grazing land (−33 %) and forestland (−24 %) (Fig. 2). In general, exchangeable cations show a similar declining pattern in the subsoil from the topsoil. Reasons for such change could be as a result of localized enrichments of cation containing minerals of the parent rock (Korkanc et al., 2008). Exchangeable cations could also be added by outside sources attributed to human management such as through fall, plant and animal residues, chemical fertilizers (on cultivated land), animal manures and wood ashes (Korkanc et al., 2008). But in the subsoil, their values were declined probably due to leaching, decomposition, plant root uptake, runoff and erosion. Thus, the concentrations of basic cations in the soil provide a very good assessment of soil fertility because individual cations are an indication of nutrient status and balance (Siddique et al., 2014).

Unlike $Ca^{2+}$, $Mg^{2+}$ and $K^{+}$, $Na^{+}$ was not detected from the soil of the study area. $Na^{+}$ is toxic to many plant species and has a lethal effect on soil structure advancing the dispersal of aggregates. Hence, soil of the area is not sodium-affected (sodic) soil.





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## 3.2 Relationship between soil properties

This section offers information on the relationship among the soil properties with depth. Organic matter was correlated positively significantly with most of soil properties (Fig. 3a) except sand and clay in both sampled depths. It, however, negatively correlated with sand and clay. Expectedly, OM was highly positively correlated with TN in the sampled depths. It was very highly positively correlated at 0–30 cm ($r = 0.93$, $P < 0.01$) followed by subsoil ($r = 0.91$, $P < 0.01$) and topsoil ($r = 0.90$, $P < 0.01$) (Fig. 3a). It was very weakly negatively correlated with clay in topsoil ($r = -0.1$), but positively in subsoil ($r = 0.26$), while at 0–30 cm, it was very weakly negatively correlated with sand ($r = -0.01$).

CEC was correlated positively significantly with most of the soil properties at both sampling depths except sand. It, however, correlated negatively with sand at both sampling depths. CEC was very highly positively correlated with $Mg^{2+}$ ($r = 0.94$, $P < 0.01$) in subsoil and with TN ($r = 0.91$, $P < 0.01$) in topsoil and 0–30 cm ($r = 0.87$, $P < 0.01$) (Fig. 3b). It was very weakly correlated with clay in top soil ($r = 0.12$), subsoil ($r = 0.36$) and 0–30 cm ($r = 0.14$) (Fig. 3b). TN was correlated positively significantly with selected soil properties except sand in topsoil and subsoil, sand and clay at 0–30 cm. It, however, correlated negatively with sand at both sampling depths. TN was very highly positively correlated with OM at 0–30 cm ($r = 0.93$), subsoil ($r = 0.91$) and topsoil ($r = 0.90$) (Fig. 3c). It was correlated very weakly positively with clay in topsoil ($r = 0.1$) and subsoil ($r = 0.33$), while they were negatively correlated at 0–30 cm ($r = -0.1$) (Fig. 3c). AP was correlated positively significantly with most of the soil properties at both sampling depths. It, however, correlated negatively with sand at both sampling depths. AP was highly positively correlated with $K^+$ in topsoil ($r = 0.77$) and 0–30 cm ($r = 0.72$), and with OM ($r = 0.63$) in subsoil (Fig. 3d). It was very weakly positively correlated with clay in topsoil ($r = 0.21$) and subsoil ($r = 0.36$), while they were negatively correlated at 0–30 cm ($r = -0.04$) (Fig. 3d).

$Ca^{2+}$ was correlated positively significantly with most of the soil properties at both sampling depths. It, however, correlated negatively with sand and clay at both sampling depths. $Ca^{2+}$ was very highly positively correlated with CEC ($r = 0.90$) in topsoil (Fig. 3e). It was very weakly positively correlated with clay in the subsoil ($r = 0.01$), while they were negatively correlated in topsoil ($r = -0.1$) and at 0–30 cm depth ($r = -0.1$) (Fig. 3e). $Mg^{2+}$ was correlated significantly with most of the selected soil properties at both sampling depths except sand. It, however, correlated negatively with sand and clay at both sampling depths. $Mg^{2+}$ was highly positively correlated with OM ($r = 0.84$) in topsoil and very highly with CEC ($r = 0.94$) in subsoil, while it was highly correlated with CEC ($r = 0.87$) at 0–30 cm (Fig. 3f). $Mg^{2+}$ was, however, very weakly positively correlated with clay at both sampled depths (Fig. 3f).

The correlation matrix shows that OM, CEC and $Ca^{2+}$ are fundamental elements since they are significantly correlated with most of soil properties (Assefa and van Keulen, 2009). The negative correlation of most of selected soil properties with clay and sand fraction at both sampling depths may be attributed to the parent materials from which sand and clay fractions are formed (Thapa and Yila, 2012). Sandy soils are loose and course textured; they don't retain moisture as are formed by the disintegration and weathering of rocks such as limestone, granite, quartz and shale (Crewett et al., 2008; Ozcan et al., 2013). The weak correlation between organic matter and clay in the subsoil may be attributed to the opposite pattern in percentage change of organic matter (decreasing) and clay (increasing) in subsoil from the topsoil. In the subsoil, the soil was characterized by poor drainage, high water logging, poor aeration and workability where crop cultivation could be supported by supplying compost and gypsum (FiBL, 2012; Thapa and Yila, 2012).This finding corroborates that of McCarthy's et al. (2013) and McAlister et al. (1998) studies that stated sand and clay are negatively correlated with most of soil properties. The finding of our study, however, contradicts the fact that SOM positively correlated with clay content. FAO (2005, 2006) found that decomposition process in the subsoil is slow as a result of bonds between the surface of clay particles and organic matter. But, in the study area SOM may be influenced by repetitive tillage, burning of vegetation and biomass production for agricultural production than soil texture.

However, it is difficult to generalize and explain on which sampled depths that correlation coefficient of selected soil properties would be stronger. Either, it could be safe to generalize that correlation among selected soil properties vary with depth (Fig. 3a–f). For instance, organic matter has stronger correlation with most of soil properties, such as CEC, $Ca^{2+}$, $Mg^{2+}$ and pH in the topsoil than in the subsoil whereas it is strongly correlated with N, $K^{+}$ and AP at 0–30 cm. This implies that organic matter is mainly present in the topsoil layer and subjected to a continuous transformation process. These circumstances could also be revealed in other empirical studies (McAlister et al., 1998; McCarthy's et al., 2013) that revealed the influence of SOM on other physico-chemical properties. Similarly, CEC strongly correlated with OM, TN, K, Ca, AP, pH and silt in the topsoil that subsoil whereas it has stronger correlation with Mg, sand and clay in the subsoil than topsoil layer (Fig. 4).

### 3.3 Is spatial variability of soil properties sign of degradation?

This study suggests that soil is a complex medium which react to environmental process and conditions being at the interface of the earth and its environment. The pedogenic processes operating within the natural environments, both top and sub-surfaces can be addition, transformation, transfer and loss of materials within the soil (Ellis and Mellor, 1995). Materials added to top-and sub-soil can be locally derived or transported from elsewhere. On topsoil it usually takes the form of plant litter and animal droppings. Local derivations of subsoil, however, comprise plant roots, soil fauna and micro-organisms. The nature of transported materials also varies with depth. Wind-blown leaves, stem carried by running water, a dead tree falling down a steep slope or manure added to the soil to assist cultivation are active in topsoil, while transported materials appears in solution, or as small particles in water draining laterally through the subsoil (Miller and Donahue, 1997). It appears, therefore, there are more additions of soil materials in the topsoil than subsoil.

Transformation, also known as mineralization, are an important sources of plant nutrients such as nitrogen and phosphorous, cations such as $Ca^{2+}$, $Mg^{2+}$ and $K^{+}$. It will undergo once materials has been added to a soil by weathering or by the formation of clay minerals. The weatherability of soil minerals are influenced by their chemical characteristics, pH conditions and environmental factors. This process is active under forestland and responsible for the increment of clay minerals with depth. Materials within a soil are transported within soil layers either in solution or suspension. This process is known as leaching and occurs in a downward, lateral or upward direction. Essential nutrients and cations will gradually be lost via leaching (ground drainage waters), increasing acidity and plant root uptakes. They will be stored in the plants or returned to the surface soil via plant litters. Mechanical transfers of soil properties are faster under cropland and hence lower variability with depth. This may be happened due to bioturbation, soil mixing by burrowing animals and human activity. Ploughing (cultivation practices) can typically mix soil to depth of 20–50 cm. On the contrary, bioturbation effect is lower under forestland where additions are via the surface and materials remain for longer time without bioturbation. Transformation, transfer and losses are highest under cropland than other land-use types. This suggests the prevalence of soil degradation as more lands are claimed for crop production.

## 4 Conclusion

This study shows that selected soil properties vary with depth among different land-use types. The variation was highest under forestland and lowest under cropland. OM, TN, AP, $K^{+}$, $Ca^{2+}$, $Mg^{2+}$, sand and silt decrease with depth. Clay increased with depth in all land-uses. CEC increased under forestland and cultivated land, while the opposite trends were revealed under shrubland and grazing land. $Na^{+}$ is not available in the soils of sampled depth among the land-use types. The correlation matrix suggests OM, CEC and $Ca^{2+}$ are fundamental soil properties in both sampled depths. Even though clay and sands are formed from different soil-forming parent materials, they



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have negative relationship between with most of selected soil properties. This implies that the relationship between soils properties are determined by soil-forming process shaped by addition, transformation, transfers and losses processes. These processes produce soil horizons giving rise to different soil types.

The impact of human activities on soil-forming processes can be direct or indirect, or deliberate or unintentional. Vegetation clearance derived by population growth implies the greatest indirect human impact on soils. These caused soil degradation via vegetation removal by felling, burning or grazing of animals. This, in turn, decreased the thickness of litter layers and then speed up leaching processes. Improving soil quality for agricultural production, therefore, can be the direct and deliberate influence. Tillage is practiced to prepare seed bed, control weeds, increase water infiltration, make furrows for drainage and bury crop residues. These are responsible for the transformation, transfer and losses of soil properties under cropland. However, weed control by tillage and hand are still common in the highlands of tropical area. This study, therefore, recommends tillage and crop rotations as improvement of land management. Tillage rotation implies deep-plow every few years; less tillage other years. The reasons for recommending tillage rotation are due to the fact it reduces soil erosion, compaction and stores water in the root zone. Crop rotation should adopt certain crops that could control weeds than herbicides.

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**Table 1.** A brief descriptions of the four land use types in the Jarte Area.

| Land use type | Description |
|---|---|
| Forest land | Areas covered with long and dense trees forming closed canopy or nearly closed canopy (70–100 %), and without apparent and reported human impacts. This unit also includes undercanopy trees mixed with short bushes and open areas. Dominant tree species in this group include *Celtisaafricana*, *Calpurinasubdecandra* and *Crotonmycrostachyus*. In addition, leaves from plants fall, macrofauna (worms, large insects, etc.); soil microflora (bacteria, fungi, algae, etc.) and microbial activities are common in this land use. No sign of rill or sheet erosion. |
| Grazing land | Formerly this land use was under forest cover. Since 40 years back, this land use evolved with permanent grass cover, with continuous grazing systems (information from local elders). Cattle dung is continuously collected as a source of household energy from this land use. Short grass species dominate this land unit. In some places rill erosions are observed. |
| Cultivated land | Formerly this land use was under forest cover and this land use evolved since 40 years back with continuous plowing, clearing and removal of above ground biomass (yield and crop residue), disposing and leveling of farming fields (information from local elders). Weathered fragmented rock materials are common in the plowing soil layer. Structural soil conservation (rock and earth terracing) practices are common. For the last 30 years Urea and DAP (up to 100 kg $ha^{-1}$ each) and cattle manure have been applied. This unit includes areas used for rain-fed agriculture. Major crops grown include cereals (maize, teff, and barley), legumes (beans, pea) and oil crops (neug). |
| Bush land | Areas with more than 50 % shrub canopy (mixed with some trees) and less than 50 % grass cover. The dominant plant forms, i.e., the shrubs, constitute the non-herbaceous plants that branch out at the base of their stem and usually grow only to heights of less than 5 m (Belay, 2002). Scattered large trees can sometimes be found, and browsing by livestock is common. This area is characterized by steep slope, high erosion rate and sandy soils; woody plants collected for fire wood and fencing. |





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**Table 2.** Soil properties at 0–15 and 15–30 cm depth at different land use types in Jarte Area.

| Land use type | Depth (cm) | Soil fraction (%) Sand | Silt | Clay | Textural class | Organic Matter (%) | Total Nitrogen (%) | AP (PPM) | C : N Ratio | CEC Cmol(+) $kg^{-1}$ | Exchangeable bases Cmol (+) $kg^{-1}$ $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | pH (1 : 2.5 $H_2O$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FL | 0–15 | 51.6 | 32.8 | 15.6 | Sandy loam | 9.04 | 0.44 | 3.60 | 12.1 | 32.85 | 0.13 | 12.81 | 3.96 | 6.1 |
| | 15–30 | 35.6 | 28.0 | 36.4 | Clay loam | 4.15 | 0.21 | 1.84 | 11.6 | 22.54 | 0.06 | 8.13 | 3.02 | 5.9 |
| BL | 0–15 | 73.6 | 12.8 | 13.6 | Sandy | 2.79 | 0.14 | 1.49 | 12.0 | 7.37 | 0.03 | 0.54 | 0.55 | 5.4 |
| | 15–30 | 62.8 | 14.4 | 22.8 | Sandy loam | 2.03 | 0.11 | 0.76 | 11.0 | 8.68 | 0.02 | 0.34 | 0.12 | 5.2 |
| GL | 0–15 | 38.4 | 26.8 | 34.8 | Clay loam | 7.31 | 0.37 | 2.09 | 11.9 | 25.65 | 0.12 | 5.98 | 4.80 | 5.7 |
| | 15–30 | 27.6 | 24.8 | 47.6 | Clay loam | 3.67 | 0.20 | 1.39 | 10.5 | 26.93 | 0.05 | 4.10 | 3.23 | 5.6 |
| CL | 0–15 | 29.6 | 28.4 | 42.0 | Clay | 4.59 | 0.25 | 3.70 | 10.8 | 20.19 | 0.14 | 4.08 | 1.71 | 5.4 |
| | 15–30 | 26.8 | 26.4 | 46.8 | Clay | 3.43 | 0.19 | 1.52 | 10.7 | 17.19 | 0.12 | 3.38 | 1.66 | 5.4 |

Notes: FL = Forestland, CL = Cultivated Land, GL = Grazing Land, BL = Bush Land, AP = Available Phosphorous, C : N = Carbon : Nitrogen ratio, CEC = Cation Exchangeable Capacity, $K^+$ = Potassium, $Ca^{2+}$ = Calcium, $Mg^{2+}$ = Magnesium.





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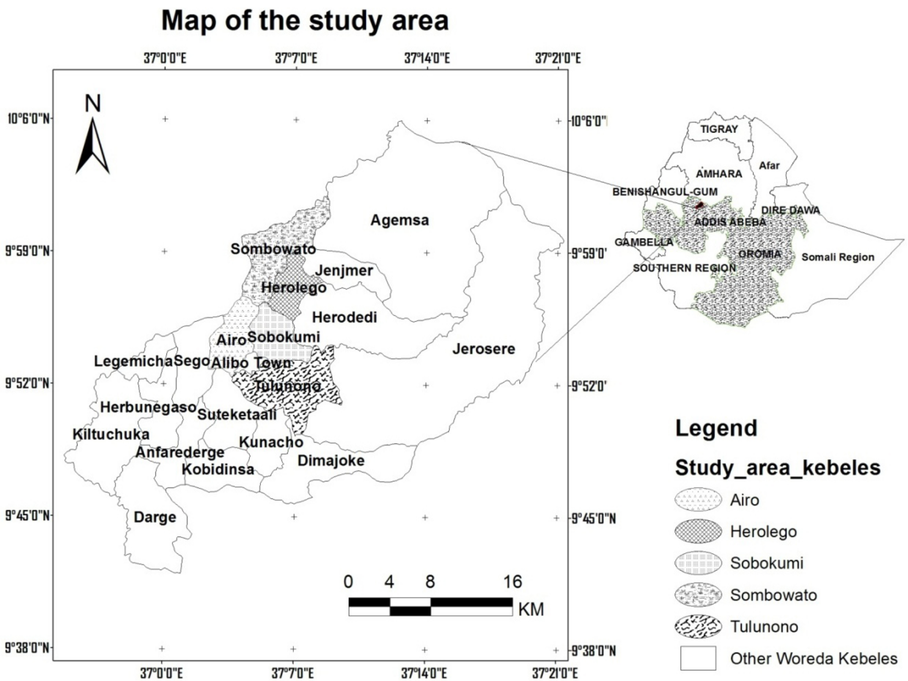


**Figure 1.** Location study area.





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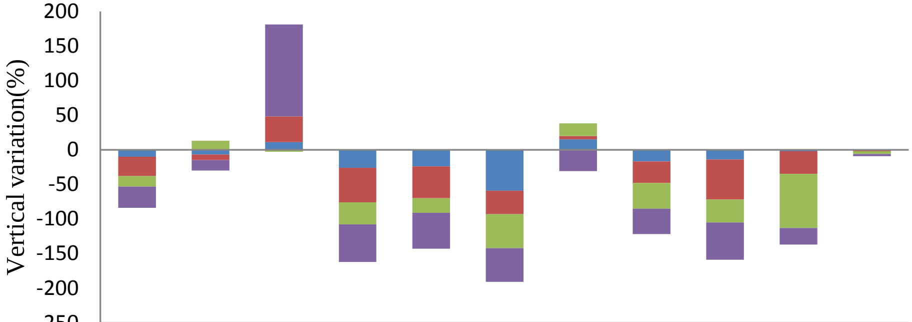


| | Sand | Silt | Clay | OM | TN | AP | CEC | Ca2+ | K+ | Mg2+ | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FL | -31 | -15 | 133 | -54 | -52 | -49 | -31 | -37 | -54 | -24 | -3.3 |
| BL | -15 | 13 | -2.97 | -32 | -21 | -49 | 18 | -37 | -33 | -78 | -4 |
| GL | -28 | -8 | 37 | -50 | -46 | -34 | 5 | -31 | -58 | -33 | -2 |
| CL | -10 | -7 | 11 | -26 | -24 | -59 | 15 | -17 | -14 | -2 | 0 |

**Figure 2.** Variation (%) in soil properties between 15–30 and 0–15 cm soil depth compared to values of 0–15 cm soil depth in the study area.





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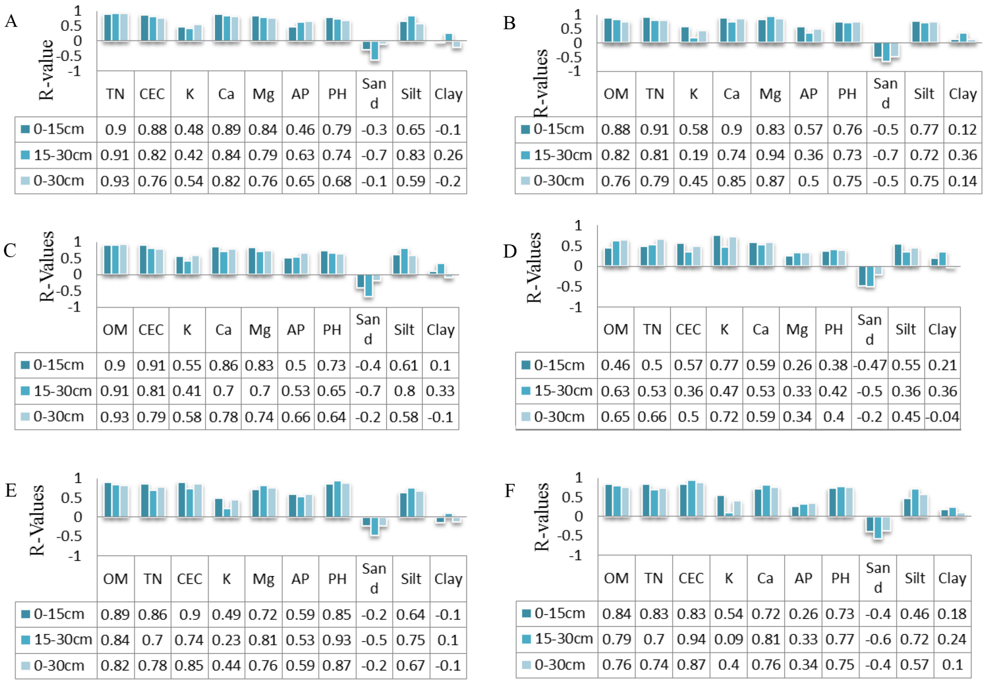


A

| | TN | CEC | K | Ca | Mg | AP | PH | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-15cm | 0.9 | 0.88 | 0.48 | 0.89 | 0.84 | 0.46 | 0.79 | -0.3 | 0.65 | -0.1 |
| 15-30cm | 0.91 | 0.82 | 0.42 | 0.84 | 0.79 | 0.63 | 0.74 | -0.7 | 0.83 | 0.26 |
| 0-30cm | 0.93 | 0.76 | 0.54 | 0.82 | 0.76 | 0.65 | 0.68 | -0.1 | 0.59 | -0.2 |

B

| | OM | TN | K | Ca | Mg | AP | PH | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-15cm | 0.88 | 0.91 | 0.58 | 0.9 | 0.83 | 0.57 | 0.76 | -0.5 | 0.77 | 0.12 |
| 15-30cm | 0.82 | 0.81 | 0.19 | 0.74 | 0.94 | 0.36 | 0.73 | -0.7 | 0.72 | 0.36 |
| 0-30cm | 0.76 | 0.79 | 0.45 | 0.85 | 0.87 | 0.5 | 0.75 | -0.5 | 0.75 | 0.14 |

C

| | OM | CEC | K | Ca | Mg | AP | PH | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-15cm | 0.9 | 0.91 | 0.55 | 0.86 | 0.83 | 0.5 | 0.73 | -0.4 | 0.61 | 0.1 |
| 15-30cm | 0.91 | 0.81 | 0.41 | 0.7 | 0.7 | 0.53 | 0.65 | -0.7 | 0.8 | 0.33 |
| 0-30cm | 0.93 | 0.79 | 0.58 | 0.78 | 0.74 | 0.66 | 0.64 | -0.2 | 0.58 | -0.1 |

D

| | OM | TN | CEC | K | Ca | Mg | PH | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-15cm | 0.46 | 0.5 | 0.57 | 0.77 | 0.59 | 0.26 | 0.38 | -0.47 | 0.55 | 0.21 |
| 15-30cm | 0.63 | 0.53 | 0.36 | 0.47 | 0.53 | 0.33 | 0.42 | -0.5 | 0.36 | 0.36 |
| 0-30cm | 0.65 | 0.66 | 0.5 | 0.72 | 0.59 | 0.34 | 0.4 | -0.2 | 0.45 | -0.04 |

E

| | OM | TN | CEC | K | Mg | AP | PH | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-15cm | 0.89 | 0.86 | 0.9 | 0.49 | 0.72 | 0.59 | 0.85 | -0.2 | 0.64 | -0.1 |
| 15-30cm | 0.84 | 0.7 | 0.74 | 0.23 | 0.81 | 0.53 | 0.93 | -0.5 | 0.75 | 0.1 |
| 0-30cm | 0.82 | 0.78 | 0.85 | 0.44 | 0.76 | 0.59 | 0.87 | -0.2 | 0.67 | -0.1 |

F

| | OM | TN | CEC | K | Ca | AP | PH | Sand | Silt | Clay |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-15cm | 0.84 | 0.83 | 0.83 | 0.54 | 0.72 | 0.26 | 0.73 | -0.4 | 0.46 | 0.18 |
| 15-30cm | 0.79 | 0.7 | 0.94 | 0.09 | 0.81 | 0.33 | 0.77 | -0.6 | 0.72 | 0.24 |
| 0-30cm | 0.76 | 0.74 | 0.87 | 0.4 | 0.76 | 0.34 | 0.75 | -0.4 | 0.57 | 0.1 |

**Figure 3.** Correlation for selected soil properties in 0–15, 15–30 and 0–30 cm depth with SOM **(a)**, CEC **(b)**, TN **(c)**, AP **(d)**, Ca **(e)**, and Mg **(f)** in Jarte Area.