Original Research Article

Impact of topography on soil properties in DelboAtwaro subwatershed, southern Ethiopia

Abstract

Soil characterization and classification are prerequisite for better agricultural productivity and soil fertility management in a sustainable manner. This study was carried out to characterize and classify DelboAtwaro, subwatershed in southern Ethiopia. Three slope categories were considered and three representative pits (Pedons) opened i.e. one in each slope. Pedons were described according to FAO (2006) and WRB (2014), in the study site, and then soil samples were collected from identified horizons of each pedon analyzed for selected physicochemical properties. The pedons showed variability in physical, chemical and morphological characteristics of the soils in the study site. Based on the field as well as the laboratory soil analysis result the soil textural class was clay both in surface and subsurface layers. The soil chemical reaction was moderately acidic to neutral in reaction (pH 6.1-7.0). The organic carbon (OC) content varied from 1.23 to 1.78% among topographic positions, respectively. Cation exchange capacity (CEC) of the soils ranged between 39.8 to79.9 cmol (+) kg^{-1} (medium to optimum), while percent base saturation (PBS) ranged from 23.7 to 40.7%. The dominance of the exchangeable bases was in decreasing order Ca>Mg> K>Na. The soils were ranged from low to optimum in TN, and very low to low in available P, while the concentrations of micronutrients in the soils were optimum (Fe), very high (Mn), sufficient (Zn) and optimum (Cu). The soil had a mollic epipedon with humic diagonstic properties in the subsurface. Hence the soil was classified as Rhodic Nitisols (Haplic) (US, MS and LS) according to the WRB for soil resources. In general, slope and land use influenced soil properties across the different topographic positions of Delbo Atwaro subwatershed suggesting the need for integrated soil fertility management practices to maintain soil organic matter and nutrients in a sustainable manner.

Keywords: *Soil characterization, classification, Pedons, Soil properties, Topographic position*

1.1. Introduction

In Ethiopia, the economy is primarily based on agricultural production. Agriculture accounts, on average, for about 33.9% of Gross Domestic Product (GDP) (H.Plecher, 2020). Ethiopia has great agricultural potential because of its vast areas of fertile land, diverse climate and large available labor pool (IMF, 2009). Despite this potential, Ethiopian agriculture remained underdeveloped with low agricultural production and productivity. The low agricultural production in the country could be related to various factors including the dependency of agriculture on rainfall, lack of modern technology, inappropriate land management practices, absence of proper information on soil characteristics and management practices and soil fertility depletion, Sanchez et al. (1997).

Soil types and characteristics show great variations across the various regions of Ethiopia (Ali et al., 2010). Natural conditions, such as geology, climate, topography, biotic and land use/land cover changes are largely responsible in creating regional and local differences in soil types and characteristics. Agricultural land productivity is related to these various soil characteristics. For instance, Nitisols and Acrisols in the western and southwestern parts of the country occurring on gentle slope to mountainous topography are used for growing cereals and coffee, whereas Vertisols occupying area with lower slope are used for poor drainage tolerantcereal crop production and animal grazing (FAO/UNDP, 1984a, b; Mesfin, 1998; Mitiku, 1987).

In a given geographic location, where diverse physiographic features like steep slopes, hilly lands and mountainous surfaces are prevalent, the role played by topographic features (slope steepness and elevation differences), climatic elements (rainfall and temperature) and vegetation cover on influencing soil properties is immense (Ahmed, 2002). Soil condition tend to vary with topography because the orientation of the hilly surfaces on which soils form can significantly affect the microclimate and the adjacent vegetation distribution that eventually results in the variation of soil properties (Foth 1990). Within specific geographic region, topography affects depth of the solum, thickness and organic matter contents of the surface soil horizon, relative moisture of the soil profile, soil aeration and color of the profile, soluble salt content and characteristics of the initial soil parent material (Buol et al., 1997). On hilly surfaces like steep slopes and mountainside areas, the steepness of slope and altitudinal variation, high potential erodibility and geologic activity tend to keep soils relatively young (Demel, 2001).

Several studies have been conducted to determine dominant controlling factors on soil properties within landscape (Fantaw et al., 2006; Mulugeta and Sheleme, 2010; Dinku et al., 2014). Dinku et al. (2014) regarded topography as the dominant factors influencing soil property variation along a toposequences due to its influence on runoff, drainage and soil erosion, and consequently on soil development. Many soil properties including particle size distribution, pH, organic carbon, total nitrogen, available phosphorus, exchangeable cations and cation exchange capacity vary with slope position(Mulugeta and Sheleme, 2010; Dinku et al., 2014; Teshome et al., 2016). The studies demonstrated strong relationships among topographic positions and soil properties, such that the distribution of a particular soil property may vary with topographic attributes. Different soil properties along landscape affect the patterns of plant production, litter production and decomposition, which have effects on carbon and nitrogen contents of soils (Mulugeta et al., 2012). Soil properties such as clay content and its distribution with depth, sand content and pH were highly correlated with landscape position (Wang et al., 2000; Mulugeta and Sheleme,2010) while organic matter varied with slope position (Mille et al., 1998).The depth of A-horizon decreased with increasing slope gradient, whereby the soils at shoulder are shallow due to erosion while those on foot slopes are thicker due to deposition (Mulugeta and Sheleme,2010).

Many research results showed that the success in soil management to maintain soil quality depends on the understanding of how soils respond to agricultural use and practices over time (Wakene, 2001). Since, physical, biological and chemical properties influence the different uses and productivity of the soil. Knowing the major soil type in a specific area helps to forecast the potential opportunities, limitations and required management actives for sustainable development. Soil erosion is one of the biggest global environmental problems resulting in both on-site and off-site effects (Guo et al., 2015; Sutherland and Ziegler, 2007). The economic implication of soil erosion is more serious in developing countries specially, Ethiopia because of lack of capacity to cope with it and also to replace lost nutrients (de Mûelenaere et al., 2014; Gessesse et al., 2014; Lanckriet et al., 2014). In the study site, soil area exposed to stress such as accelerate soil erosion by water, soil acidification resulting in a loss of soil nutrients, and reduced crop yields. Agricultural activities such as shifting cultivation, without adequate fallow periods, intensive cultivation, absence of soil conservation measures and inappropriate fertilizer use lead to intense land degradation within the study area. Land degradation manifests itself through soil erosion, nutrient depletion and loss of organic matter, acidification (Bewket and Teferi, 2009; Haile and Fetene, 2012). The soil loss rate by water ranges from 16 to over 300 Mg ha^{-1} yr^{-1} in Ethiopia, mainly depending on the degree of slope gradient, intensity and type of land cover and nature of rainfall intensities (Tamrie, 1995; Tesfaye et al., 2014). Knowledge of the distribution of soil types in the landscape can be used in combination with other layers of information to aid in management decisions. The objective of this research therefore, was initiated to characterize the morphological, physical and chemical properties, classify and mapping the soils of the Dalbo Atwaro to reveals its agricultural potential for sustainable development according to the FAO/WRB soil classification system.

Therefore, this study was conducted to characterize and classify the soils in the study site DelboAtwaro subwatershed, southern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Areas

The study was conducted at DelboAtwaro subwatershed located in southern, Ethiopia (Figure 1).

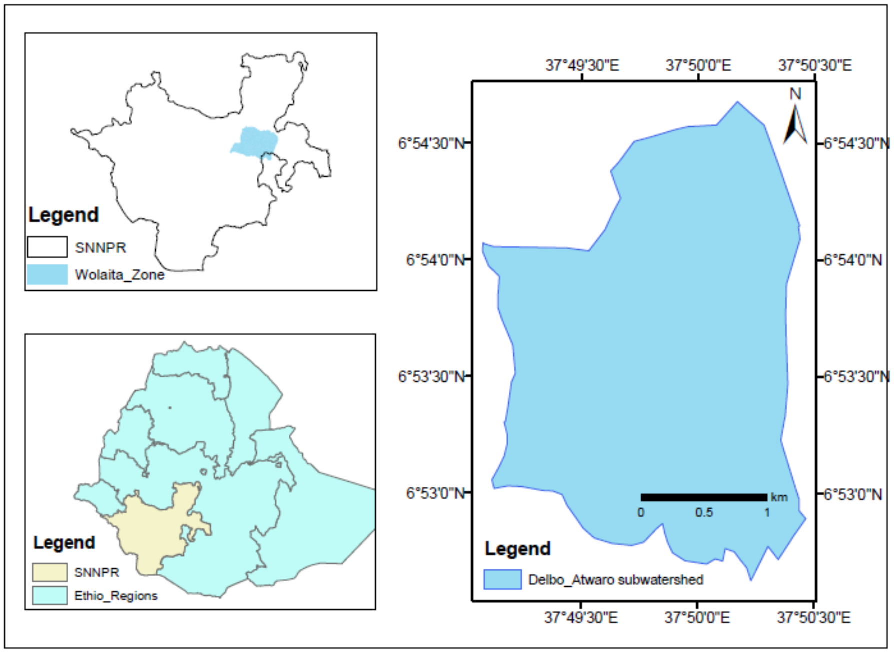

Figure 1.Location map of the study site

The DelboAtwaro study site exists in Soddo ZuriaWoreda,Wolaita Zone, southern Ethiopia. It is found at about 10 km east of Soddo town and is located at 6^0 53' 40'' N and 37^0 49' 49'' E. The altitude is ranging from 1500 to 3500 ma.s.l having a Woina-dega to Dega climatic characteristics. The mean annual precipitation of the site is 1297 mm with bimodal distribution and the mean annual temperature is 20^0C (Wolaita sodo meteorology station, 2008-2018).

The dominant soils of the Wolayita area are reported to be Nitosols and dominant parent material in the study site is basalt (FAO/UNESCO, 1974), which are sesquioxidic and moderately to strongly acidic (Mesfin, 1998).

The main crops growing in the study site include; cereals like Tef (*Eragrostisteff*), Maize (*Zea mays* L.), wheat (*Triticumaestivium*), sorghum (*Sorghum bicolor*), barely (*Hordium vulgaris*), and pulses like (bean (*Viciafaba*), filed pea (*Pisumsativum*), haricot bean (*Phaseolus vulgaris*), chickpea (*cicerarietimum*), root crops like potato (*Solanum tuberosum*), sweet potato (*Ipomeabatatas*) and enset (*Ensetventricosum*).

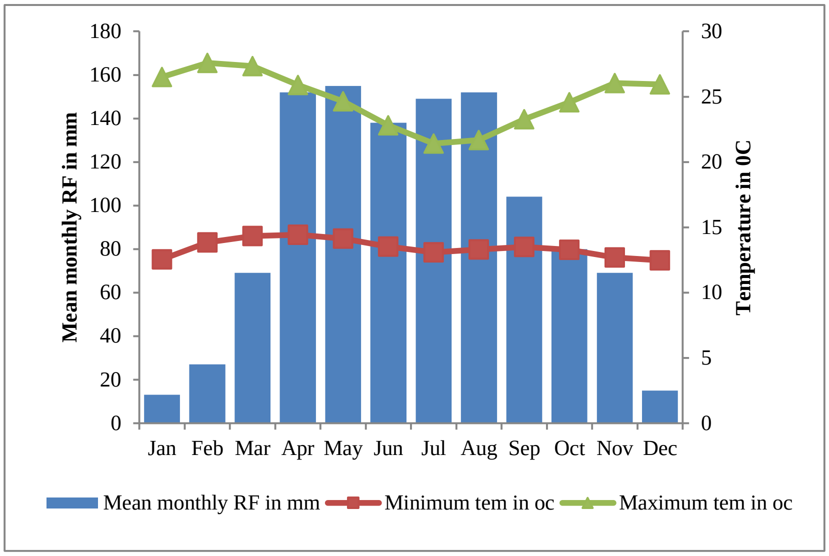

Figure 2.Ten years (2008-2018) mean monthly rainfall, maximum and minimum temperatures of the DelboAtwaro subwatershed

2.2. Selection and Description of the Pedons

Based on the topographic map of the study site pedons of 2*1.5*2m was excavated by hand digging. The three toposequences were selected along east-west facing slopes encompassing landform components from upper slope to bottom slope of the subwatershed (Figure3). Representative pedons were selected based on site and soil profile characterization following the Guidelines for Field Soil Descriptions (FAO, 2006). The land units were identified on the basis of topographic features and land/soil characteristics using field observations and topographic maps. Soil auger observations were implemented using ‘Edelman auger’ to identify variation in soil depth and texture characteristics along the slope gradient. Points with the same soil depth and texture classes in a given slope category were considered as a pedon. The Pedon observation points were geo-referenced with the help of geographical positioning system (GPS) and located on the 1:50,000 scale base three soil pits were opened and the soil profiles of all pedons were described *in situ* following the Guidelines for Field Soil Descriptions (FAO, 2006) and the soil colour was determined using Munsell soil colour chart (Munsellcolour company, 2002).

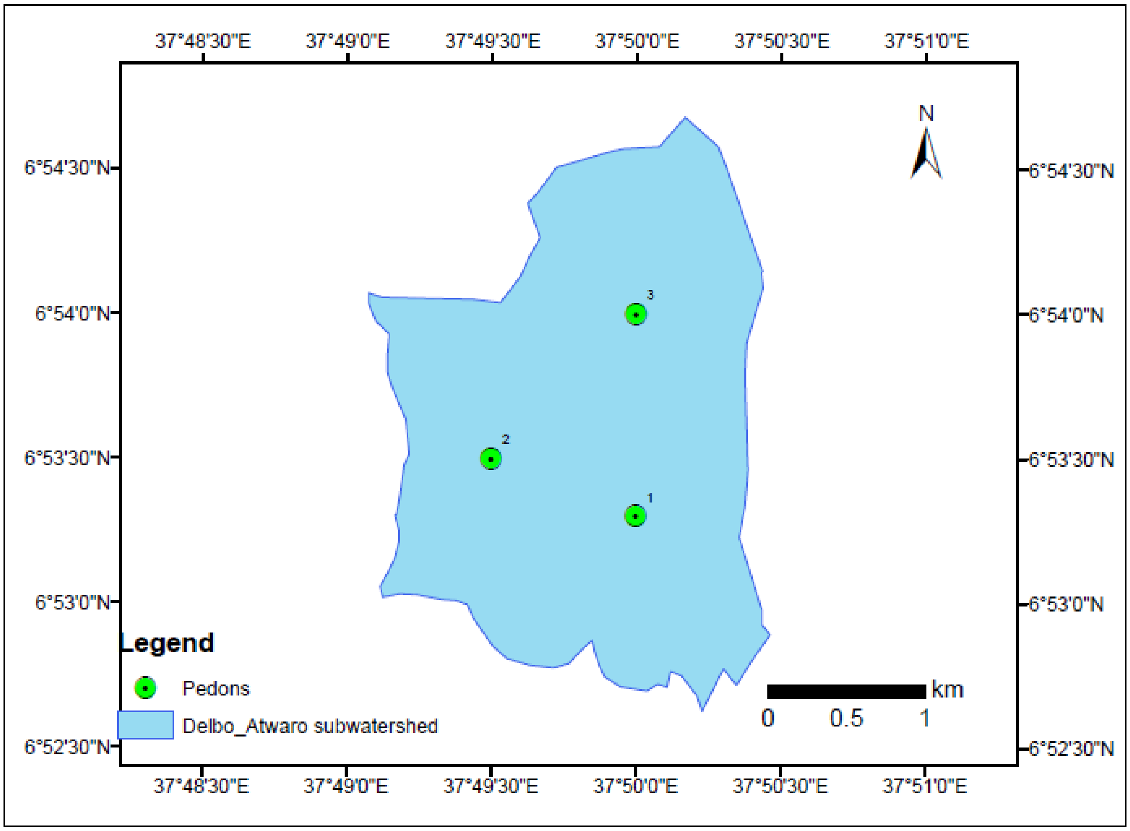

Figure 3.Pedons sites

2.3. Soil Sampling and Sample Preparation

Soil samples were collected from every identified horizon. A total of 12 disturbed and 12 undisturbed soil samples were collected from recognized genetic horizons of the 3 representative pits. All soil samples were air dried ground and passed through a 2mm sieve. For the determinations of total nitrogen (TN) and organic carbon (OC), a 0.5 mm sieve was used. Analyses of physicochemical properties were carried out at Hawassa University following standard laboratory procedures.

2.4. Laboratory Analysis

Particle-size distribution was determined by modified hydrometer as outlined by Sahlemedhin and Taye (2000)Soil bulk density was determined by the undisturbed core sampling method after drying the soil samples in an oven at 105^{o}C to constant weights, while particle density was assumed to be 2.65 Mg m^{-3}. The pH of the soils was measured in water and potassium chloride (1M KCl) suspension in a 1:2.5 (soil: liquid ratio) using a glass-calomel combination electrode (Van Reeuwijk, 1992).The electrical conductivity (EC) of soils was measured from a soil water ratio of 1:2.5 socked for one hour as described by Sahlemdhin and Taye(2000). The OC content of the soils was determined by wet digestion method (Walkely and Black, 1934) while total N was determined by Kjeldahl wet digestion and distillation method (Bremner and Mulveny, 1982) and available P by modified Olsen method (Olsen and Sommers, 1982). Cation exchange capacity and exchangeable bases were extracted by 1 M ammonium acetate (pH 7) method (Van Reeuwijk, 1993). In the extract, Ca and Mg were determined by atomic absorption spectrophotometer (AAS) and exchangeable K and Na by flame photometer.Available micronutrients (Fe, Cu, Zn and Mn) were extracted by diethylene triaminepentaacetic acid (DTPA) as described by Tan (1996) and all were quantified using atomic absorption spectrophotometer.

2.5. Data Analysis

Simple linear correlation analysis was carried out to assess the relationships between and among selected physicochemical properties of the soils according to the procedures described by Gomez (1984) and used in the interpretations of data.

3. Results and Discussion

3.1. Site Characteristics of the Pedons

The site characteristics of the pedons indicated differences in slope, permeability and extent of water erosion. The Pedons at US, MS and LS were on upper, middle and lower landscape positions and had slopes of 20,15 and 5 respectively, and all the pedons were well drained (Table 1). The slope and parent material are the major contributing factors for the difference in the site characteristics. Parent materials determine certain soil properties and drainage condition such as clay mineralogy, which is among other factors to determine the type of soil (Dinku et al., 2014; David, 2005).

The US and MS pedons showed signs of accelerated water erosion as evidenced by gullies on the surrounding landscape, while the soils at other site (LS) in different physiographic topographic positions were experiencing no water erosion that showed continuous deposition of materials from the nearby the mountains. Similarly, Sheleme (2017) also reported that soils on depression landscapes are influenced by deposition of materials originating from the surrounding high-slopes.

Table 1 Location and site characteristics of the pedons

Pedon	Lat (Decimal Degree)	Long (Decimal Degree)	Altitude (ma.s.l)	Slope (%)	Land form	Surface drainage	Erosion	Local name of the soils	Parent materials
US	6.888333	37.83333	2152	20	Strongly sloping	Well drained	Moderate water erosion	Chincha Biita	Basalt volcanic material
MS	6.891667	37.82500	2136	15	Strongly sloping	Well drained	Moderate water erosion	Chincha Biita	Basalt volcanic material
LS	6.9000	37.83333	2120	5	Sloping	Well drained	Slightly/ sheet erosion	Chincha Biita	Basalt volcanic material

US=upper slope; MS= Middle slope; LS=lower slope;

3.2. Morphological Characteristics of the Soils

The morphological properties of soils; depth, horizon, color, structure, consistency and horizon boundary varied along the toposequence at the study site. All the pedons had very deep profile (>200 cm) Table 2. Pedon (1) was characterized by Ap, AB, Bt and C; P2 by Ap, A, AB and Bt and P3 by Ap, Ah, B and Bt2 (Table 2). The soil morphological properties varied along the different slope positions at the study site and within the horizons, soil depths, color, structure, and consistency and horizon boundaries in accordance with FAO (2006).

The pedons showed a great variability in relation to soil color patterns (Table 2). Surface soil coloris varies 5YR 3/3 (dark reddish black) in P1, 2.5YR2.5/3 (dark reddish brown) in P2 and 5YR3/3 (black)in P3.Generally, surface horizons had darker color as compared to their subsurface counterparts which could be attributed the relatively higher organic matter contents in the surface horizons. In line with this findings, many authors reported that surface horizons have darker color than the corresponding subsurface horizons as a result of relatively higher soil OM contents (Ashenafi*et al.*, 2010; Mulugeta and Sheleme, 2010; Dinku*et al.*, 2014). Soil color differences were also observed among the slope position, which might be due to drainage conditions. Dengiz*et al*. (2012) indicated that soil color could be related to OM, water logging, carbonate accumulations and redoximorphic features. Additionally, Nuga*et al.* (2006) also reported that drainage condition and physiographic position may have major influence on the soil color.

The pedons had intermediate to deep soil profiles (50 to 200 cm) (Table 2).The thickness of the solum varied along the toposequence, whereby the shallowest (20 cm) solum with lithic contact within the 50 cm depth was observed at the upper slope, while deep (>75 cm) surface layers were noted on middle and lower slopes (Table 2).The shallow depth at the upper positions may limit the root penetration for deep rooted crops (Table 2).The variation in the depth of solum might have been due to the landscape configurations (Slope gradient and length), which are important in influencing the rate at which water flows into or off the soil if the sites are unprotected Borderson (1994)also reported landscapes position influences runoff, drainage, soil temperature, soil erosion, soil depth and hence soil formation as described by Mulugeta and Sheleme (2010).

The distinctness of horizon boundary between surface and subsurface horizons were gradual smooth boundary in the P1; clear smooth boundary at the surface and diffuse smooth boundary in the sub-surface in the P2 and clear smooth boundary in the surface and gradual smooth boundary in the sub-surface in the P3 (Table 2). The differences in nature of the horizon boundaries may indicate the existence of variations in processes that have formed the soils and partly reflecting anthropogenic impacts in addition to the nature (Cools and De Vos, 2010). Based on abundance of roots, biological activity was relatively higher in the surface horizons and decreased with depth of the pedons. This, indeed, could be associated with decreasing root biomass, aeration, nutrients and management effects down the soil profiles. The size of roots in different horizons of the pedons also varied from very fine to course in size and few to common in quantity.

There were significant variations in the grade, size and shape of the soil structure among pedons (Table 2). The soil structure in the surface layers of the pedons varied from fine granular to weak moderate angular block and sub-angular blocky in their structure. On the other hand, in the subsurface horizons it ranged from weak moderate angular and sub-angular blocky to strong fine angular blocky (Table 2). The better developed structure of the subsurface layers could be due to the relatively higher clay content of the subsurface horizons than that of the surface horizons (Ahn, 1993).

The soil consistence in the pedons varied among the topographic positions(Table 2).The soil consistencies characterized by friable to firm (moist) and slightly sticky/ non-plastic to slightly sticky/ slightly plastic at upper slope, whereas the middle topographic position pedons exhibited very friable to firm (moist) and slightly sticky/ slightly plastic to sticky/ plastic consistence.

The observed differences in soil consistence could probably be explained by the differences in particle size distribution, particularly clay content, OM and nature of the clay particles. The findings are in agreement withMoradi (2013) who indicated that soil consistence varied with soil texture. Similarly, Mulugeta and Sheleme (2010) also observed friable consistence in the surface layers of pedonsand attributed to the higher soil OM content.

3.3. Physical Characteristics of the Soils

The field as well as laboratory textural class determinations revealed that the soils are dominated by clay fraction and accordingly, the textural class of the soils in all pedons was clay (Table 4).

This could be attributed to the basaltic parent material, which weathers into fine-textured soils (Buol et al., 2003).The soils at all slope positions showed discernible increase in clay content with depth indicating high rates of clay formation in subsoil horizons.

Table 1 Selected morphological characteristics of the soils in DelboAtwaro subwatershed, southern Ethiopia

Pedon	**Horizon**	**Depth**	**Soil colour (moist)**	**Structure**			**Consistence**			**Root abundance**	**Horizon Boundary**
				Grade	Size	Shape	Moist	Wet Stickiness	Plasticity		
(P3)US	Ap	0-22	5YR3/3 (black)	MO	FN	GR	FR	SST	NPL	F	C, S
	Ah	22-68	5YR3/4(dark reddish brown)	MO	F N	SAB	FR	SST	SPL	F	G, S
	Bt1	68-120	2.5YR2.5/3 (dark reddish brown)	MO	F N	SAB	FR	ST	PL	VF	D, S
	Bt2	120-195+	2.5YR2.5/4(dark reddish brown)	MO	F N	AB	FI	ST	PL	VF	--
(P2)MS	Ap	0-30	2.5YR2.5/3(dark reddish brown)	WE	VFN	SAB	VFR	SST	SPL	F	C, S
	A	30-75	2.5YR 4/4(reddish brown)	ME	VFN	AB	VFR	ST	PL	F	D,S
	AB	75-130	2.5YR2.5/3(dark reddish brown)	MO	FN	SAB	FR	SST	SPL	F	D,S
	Bt	130-180+	2.5YR3/3(dark reddish brown)	MO	FN	AB	FR	ST	PL	F	---
(P1)LS	Ap	0-20	5YR 3/3 (dark reddish black)	MO	VFN	GR	FR	SST	NPL	F	G,S
	AB	20-86	2.5YR3/3(dark reddish brown)	MO	ME	AB	FR	ST	PL	F	G, S
	Bt	86-160	7.5YR 4/4(brown)	MO	FN	SAB	FI	ST	PL	F	G, S
	C	160-200+	7.5YR4/4 brown)	WE	FN	AB	VFR	ST	PL	VF	--

Note: ST= strong, MO= moderate, WE=weak, FN= fine/thin, ME=medium, WE= wedge-shaped, AB= angular blocky, MA=massive, SAB= sub-angular blocky, CR= crumb, GR= granular, 2*: HA=hard, SHA= slightly hard, LO= loose, SO= soft, VHA= very hard, FI=firm, VFR=very friable, FR= friable, VFI=very firm, NST= non-sticky, SST=slightly sticky, ST= sticky, VST= very sticky, NPL=non-plastic, SPL= slightly plastic, PL= plastic, VPL= very plastic, C=clear, D=diffused, S=smooth, W=Wavy, G=Gradual, S= Smooth

Change in clay percentage down the profile suggests pedogenic eluviation-illuviation processes (Mulugeta and Sheleme, 2010). But, vertical migration of clay down the profile was not evident in the present study, as clay cutans or clay skins were not observed in the B-horizons during description of the profiles in the field. Thus, the accumulation of clay in the subsoil horizons of the pedons could have been due to predominant *in situ* synthesis of clay from the weathering of primary minerals in B horizons. A negative and highly significant (r= -0.831, p <0.05) correlation was observed between clay and sand indicating that removal of clay resulted in relative increment of sand in the surface layers. This finding is in agreement with Satyavathi and Suryanarayan (2003), who reported that the surface enrichment of sand fraction in red soils was due to the removal of finer particles by eluviations and surface runoff. Positive and significant (r= 0.861 p <0.05) correlation also prevailed between clay and silt (Table 7) indicating that upon weathering, some silt sized particles may contribute to an increase in clay percentage.

The silt/clay ratio ranged from 0.22 to 0.68 across the profiles. This ratio is one of the indices to assess the rate of weathering and determines the relative stage of development of a given soil. According to Young (1976), a ratio of silt to clay below 0.15 is considered as low and is indicative for advanced stage of weathering and/ or soil development, whereas a ratio greater than 0.15 indicates that the soil is young containing easily weatherable minerals. Ashaye (1969) reported that the silt/clay ratio <1 could mean that the soil had undergone feraliticpedogenesis. Accordingly, the silt to clay ratio of the soil under study is generally below a unity indicating that the soils are at an advanced stage of development (Abayneh, 2005; Basava*et al.*, 2005).

The bulk density of soils in the surface horizons ranged from 1.00 to 1.07g cm^{-3}, while the corresponding values for the subsurface horizon ranged from 1.01 to 1.11 g cm^3(Table 3). The bulk density values did not exhibit consistent relation with topographic positions, and the lowest and the highest bulk density values were recordedat the middle slope position. However, the bulk density values showed discernible increments with depth across all the pedons (Table 3). This could be attributed to reduced OM content, aggregation and root penetration in the subsurface layers compared to their surface counterparts and weight of the overlying soils. The correlation analysis also revealed negative and significant (r= -0.273, $p<0.05$) relationship between bulk density and OC (Table 7). Additionally, the bulk density values of cultivated soils were higher than the uncultivated soils, which could be associated with degradation of OM and compaction by tillage implements. According to the rating given by White *et al.* (1997), the bulk density values of the most studied soils in the sites were within the suitable range (1.0 – 1.5g cm^{-3}) for agricultural use. Hence, the results indicate the absence of excessive compaction and restriction to root development in all the pedons corroborating the report by (Werner, 1997).

Table 2Selected physical characteristics of the soil in pedons at DelboAtwaro, southern Ethiopia

Pedon	Horizon	Depth	Sand (%)	Silt (%)	Clay (%)	Textural class	Silt/Clay	Bulk density (g/cm^3)
(P3)US	Ap	0-22	28	22	50	Clay	0.44	1.07
	Ah	22-68	32	15	53	Clay	0.28	1.08
	Bt1	68-120	26	19	55	Clay	0.30	1.11
	Bt2	120-195+	29	13	58	Clay	0.22	1.11
(P2)MS	Ap	0-30	28	24	49	Clay	0.45	1.04
	A	30-75	31	17	52	Clay	0.33	1.06
	AB	75-130	28	16	56	Clay	0.29	1.06
	Bt	130-180+	29	13	58	Clay	0.22	1.07
(P1)LS	Ap	0-20	33	27	40	Clay	0.68	1.00
	AB	20-86	36	22	42	Clay	0.52	1.01
	Bt	86-160	32	20	48	Clay	0.50	1.02
	C	160- 200+	33	17	50	Clay	0.33	1.03

Upper slope; MS =Middle slope; LS= Lower slope

3.4. Chemical Characteristics of the Soils

3.4.1 Soil pH, electrical conductivity, Organic carbon, TN% and available Phosphorus of the study sites

The pH values of the soils in the pedons ranged from moderately acidic to neutral (6.02 to 7.23), in accordance with the rating of (Jones, 2003; Tekalign, 1991). The pH-H_2O values varied from 6.10 to 7.00 in the pedons with increasing trend with depth in all pedons as depicted in the Table 4. The soil pH was positively and highly significantly correlated (r= 0.547; r=0.432, $p<0.05$)

with both K and OC, respectively, while it was a negatively and significantly (r= -0.479; r=-0374, p <0.05) correlated with Fe and Mn respectively (Table 7).

With the respective of the topographic slope positions, the soils of all pedons showed very low electrical conductivity values that ranged from 0.02 to 0.80mS/cm, indicating that the soils are not salt affected (FAO, 1988). The low electrical conductivity could be due to high rainfall at the study area and free drainage conditions, which favor leaching of released bases with percolating water.

The organic carbon (OC) content varied from1.23 to 1.78 in the pedons among three topographic positions (Table 4). It did not show consistent trend across topographic positions, but it decreased with soil depth in all. According to the ratings suggested by Tekalign (1991) and EthioSIS (2016) the OC contents of the soils in the study area can be categorized in to a low. This finding is in agreement with the report of Wakene and Heluf (2004) with respect to intensive cultivation and that Habtamu et al. (2009) on land clearing for cultivation, which aggravate OM oxidation and hence reduces OC content.

The total N content of the soils ranged from 0.12 to 0.22% across the different topographic positions (Table 4) and could be rated as low to medium in accordance with Hazelton and Murphy (2007) stated as N <0.2, 0.2-0.5, and >0.5% as low, medium and high, respectively.
According to Hartz (2007) soils with less than 0.07% total N have limited N mineralization potential, while those having greater than 0.15% total N would be expected to have a significant amount of nitrogen mineralization during the succeeding crop cycle. Accordingly, most of the soils in the study area have a good potential of N mineralization. The distribution pattern of total N with soil depth was similar to that of OC. In general, the OC and TN increased with decreasing

slope gradient, which could be attributed to the transport of organic materials from areas having higher slopes to landscape with gentle or flat gradient corroboting the previous findings (Sheleme, 2011; Dinku et al., 2014).

The carbon to nitrogen ratio C/N showed wide variation and irregular distribution with soil depth (Table 4). The C/N ratio content of the soils among pedonswas ranged from 7.6 to 11.5 across the different topographic positions (Table 4). Generally, the C/N ratio of the studied soils were very low in accordance with the ratings suggested by Hazelton and Murphy (2007), where a number of 10-12 is considered as normal for arable soil. The narrow C/N ratio at the surface layers might be due to the effect of microbial activities that result in relatively fast decomposition of OM and the consequent CO_2 evolution (Alem*et al*., 2015). The present finding is in agreement with that of Nahusenay*et al.* (2014) showing high C/N ratio of the soils indicating the OM was not fully decomposed and N loss was apprehended.

Table 3Organic carbon (OC), TN%, and pH, EC (mS/cm), C/N and Av.P (mg/kg) of the study site

Pedon	**Slope position (SP)**	**Horizon**	**Depth**	**pH**	**EC(mS/cm)**	**TN (%)**	**OC (%)**	**C/N**	**Av.P (mg/kg)**
P3	US	Ap	0-22	7.0	0.41	0.19	1.78	9.4	12.8
		Ah	22-68	6.7	0.08	0.16	1.68	10.5	14.1
		Bt1	68-120	6.7	0.34	0.14	1.49	10.6	14.0
		Bt2	120-195+	6.5	0.13	0.12	1.36	11.0	15.5
P2	MS	Ap	0-30	6.5	0.15	0.17	1.62	9.5	19.0
		A	30-75	6.8	0.11	0.14	1.54	11.0	13.5
		AB	75-130	6.6	0.14	0.13	1.50	11.5	13.0
		Bt	130-180+	6.2	0.11	0.12	1.23	10.3	11.0
P1	LS	Ap	0-20	6.3	0.2	0.22	1.77	8.0	13.0
		AB	20-86	6.6	0.19	0.22	1.67	7.6	12.0
		Bt	86-160	6.1	0.8	0.17	1.56	9.5	10.6
		C	160- 200+	6.3	0.02	0.14	1.42	10.0	11.2

pH = Power of hydrogen; EC= Electrical conductivity; OC=Organic carbon; Total nitrogen= TN%; and available phosphorus =Av.P.

Available P content of the soils in the pedons ranged from 10.6 to 19.0(mg/kg) (Table 4) and was from very low to low the majority being in very low category as per the rating suggested by Cottenie, 1980 and EthioSIS, 2016. Generally, the available P content of the soils decreased with profile depth in all pedons except P3. The higher available P recorded in the surface compared to the subsurface horizons could be attributed to the relatively higher OC contents in the surface layers, and application of P containing fertilizer and compost by farmers. This finding is in line with that of Awdenegest*et al.* (2013) who argued that the higher available P in the top soil layer of farm land may be related to the application of animal manure, compost, household wastes like ashes and DAP fertilizer for soil fertility management. The results revealed that the available P could not be the limiting nutrients for crop production in the area.

3.4.2 Cation exchange capacity (CEC), exchangeable bases (ECB) and percent base saturation (PBS)

The cation exchange capacity (CEC) of the soils ranged from 23.70 to 40.70cmol (+) kg^{-1}(Table 6) which the CEC of the study sites were categorized under medium to optimum range, according to Landon (1991) classified cation exchange capacity (CEC) <5, 5-15, 15-25, 25-40 and >40 cmol (+) kg^{-1}soil as very low, low, medium, high and very high. This might be (associated to soil OC and relatively high clay content and the predominance of the 2:1 clay minerals. Also, positive and significant correlation (r=0.314) between pH and CECof the soils in the study sites among pedons. This study is in line with that of Abebe et al., 2012; Havlin et al., 1999 and Tagbaru, 2014. Cation exchange capacity is very important soil property influencing soil structure stability, nutrient availability, soil pH and the soil’s reaction to fertilizer and other ameliorant (Hazelton and Murphy, 2007). The high CEC results showed that the soil of the study area had good nutrient retention and buffering capacities

Exchangeable K status was ranged from 0.033 to 1.39cmol (+) kg^{-1}(Table 5). According to the critical level adopted by EthioSIS, 2016 the study sites were ranged from very low to optimum. While the contents of exchangeable Ca, Mg and Na varied from 9.8 to 16.4, 5.05 to 8.35, and 0.1 to 0.42 cmol (+) kg^{-1}, respectively. Generally, the contents of exchangeable bases increased with increasing soil depth, perhaps due to leaching of exchangeable cations. And the large presence of calcium throughout the study sites relative to others cations could be due to the nature of parent material,

According to Sims (2000) the ranges of critical values for K, Ca and Mg for optimum crop production are; 0.28 - 0.51, 1.25 - 2.5, and 0.25 - 0.5 cmol (+) kg^{-1} soils, respectively. Accordingly, the exchangeable K, Ca and Mg contents of the surface layers of the soils are above the critical values. The Ca/Mg ratio of the soils was in the range of 1.81 to 2.01. As per Eckert (1987) ratings soils having Ca/Mg ratio of <4:1 are suspected to have Mg induced Ca deficiency; Ca/Mg >8:1 ratio Ca induced deficiency of Mg; and 4-8 ratio is as optimum. Accordingly, the results indicate Mg induced Ca deficiency in the soils. The results suggest the need for soil management to balance the cations for optimum crop production, although their absolute values are above the critical levels.

The percent base saturation of the soil of the study area varied from 39.8 to 79.9% with an increasing trend with depth, which might be due to leaching of bases from the overlying layers and subsequent accumulation in the subsurface horizons. The percent base saturation in the soils of the area was also in the moderate to very high range in accordance with Hazelton and Murphy (2007). Consequently, the soils of the study area could be categorized as fertile soil in line with the rating of Landon (1991) who suggested soils having greater than 60% base saturation as fertile

Table 4Exchangeable bases, Cation Exchange Capacity (CEC), and Percentage of base saturation (PBS) of soils in DelboAtwaro subwatershed, southern Ethiopia.

Pedon	**Horizon**	**Depth**	**Exchangeable bases (cmol (+) kg^{-1}**				**Sum of Exchangeable bases cmol (+) kg^{-1}**	**CEC cmol (+) kg^{-1}**	**BS (%)**	**Ca/Mg**
			Ca	Mg	Na	K				
US	Ap	0-22	11.4	6.15	0.21	0.63	18.4	37.3	49.3	1.85
	Ah	22-68	15.6	8.25	0.13	0.83	24.8	39.3	63.1	1.89
	Bt1	68-120	16.4	8.35	0.23	0.33	25.3	37.4	67.6	1.96
	Bt2	120-195+	12.6	6.85	0.27	0.45	20.2	38.7	52.2	1.84
MS	Ap	0-30	10.4	5.65	0.40	0.52	17.0	40.2	42.3	1.84
	A	30-75	11.6	6.15	0.31	0.4	18.5	40.7	45.5	1.89
	AB	75-130	9.8	5.05	0.42	0.46	15.7	39.4	39.8	1.94
	Bt	130-180+	15.4	8.15	0.40	0.56	24.5	38.1	64.3	1.89
LS	Ap	0-20	14.6	7.25	0.35	1.1	23.3	30.4	76.6	2.01
	AB	20-86	10.2	5.65	0.10	1.39	17.3	30.9	56.0	1.81
	Bt	86-160	12.4	6.24	0.15	1.09	19.9	24.9	79.9	1.99
	C	160- 200+	11.6	6.14	0.20	0.95	18.9	23.7	79.7	1.89

3.4.3 Selected extractable micronutrients

The concentrations of available micronutrients were in the order of Mn> Fe > Cu> Zn in the entire slope positions, whereas Zn was the smallest. As shown Table 6, the extractable Mn ranged from 105.0 to 142.0(ppm) for the study sites. According to Karitun et al. (2013), critical level for MnAI is 25.When MnAI status of the soils of the study sites were compared with the critical level, it was more than critical level. This indicated that Mn toxicity is one of the factors that contribute to the low crop production and productivity in the study sites. The result of this study is in line with the finding of Eyob Tilahun et al. (2015) and Wondosen Tena and Sheleme Beyene (2011) who was reported that amount of extractable Mn are generally high in the tropical soils and Mn toxicity is even more common than deficiency. Liming can be used o reduce Mn extractable and availability of Mn.

Extractable Fe varied from 99.0 to 140.0 (ppm) with a mean value of 119.33 (ppm) as shown in Table 6. It was observed that all of the soils in the pedons were found to be optimum in extractable Fe status. This finding is in agreement with the results of Haque et al. (2000), Abayneh (2005), Eyob et al. (2015) and Hilette et al. (2015) who reported that Fe was adequate in the soil samples collected from different regions of the country. The existence of adequate Fe content in the soils may be due to the parent material that contains minerals like Feldspar, Magnetite, Hematite and Limonite which together constitute the bulk of trap rock in these soils (Vijaya Kumar et al., 2013). Also, soil reaction (pH) of the study area may contribute to the high amount of extractable Fe since the pH of the majority of soils in the study area is less than 7 that can enhance the solubility of Fe. Diatta (2014) and Diatta et al. (2014) reported that soil reaction (pH) is of prime importance in controlling towards the availability of micronutrients, since it affects directly their solubility as well as activity in the soil environment.

Extractable Cu varied from 10.8 to 15.6(ppm) with a mean value of 13.26 (ppm) as shown in Table 6. It was observed that all of the soils in the pedons were found to be optimum in extractable Cu status according to the critical level adopted by EthioSIS (2014).

Extractable Zn varied from 9.6 to 14.6 (ppm) with a mean value of 11.3 (ppm) as shown in Table 6. It was observed that all of the soils in the pedons were found to be optimum to high range in extractable Zn status according to the critical level adopted by EthioSIS (2014). As shown in Table 6, the study sites were optimum to high in Zn status. The result of this study shows that Zn was in a sufficient range in soils of all the study sites. This may be due to the soil conditions such as low pH and parent materials of soil that are high in Zn content. Certain soil conditions reduce the availability of Zn, notably high pH (Jones, and Eck, 1973). Thus, a high incidence of Zn deficiency often occurs on calcareous or limed soils. The present study soils were neither limed nor calcareous and the pH values in the majority of the soils were not too high to precipitate available Zn. According to Fisseha (1992) soil micronutrients are influenced by several factors among which soil OM content, soil reaction and clay contents are the major ones.

3.4.4 Relationship between available micronutrients and some soil properties

The micronutrient content of soils is influenced by several factors among which soil organic carbon content, soil reaction and clay content are the major ones (Fisseha, 1992). Therefore, an attempt was made to examine the relationship between copper, zinc, iron and manganese and some soil properties (pH, organic carbon and particle size) by simple correlation analysis (Table 7), to identify the soil factors involved in regulation of amounts of extractable Cu, Zn, Mn and Fe in soils. Significant and positive ($p<0.05$) relationship of extractable Cu and Zn with organic carbon ($r = 0.284$; $r= 0.32$), respectively was observed (Table 7).

The results were in close agreement with findings of Yadav (2011); Khalifa et al. (1996), Eyob Tilahun et al. (2015) and Kumar et al. (2013). The reason for this might be the ability of SOC to form natural chelates that can maintain micronutrients in an available form. Also, organic carbon controls the affinity, attraction strength of micronutrients with most functional groups (Jean et al., 2014).

The negative correlation of extractable Fe and Mn with soil pH was observed (Table 7). This indicates that there is precipitation of extractable micronutrients into insoluble products when pH rises. The activity of Mn and Fe decreases 100-fold for each unit increase in soil pH (Lindsay, 1978). Many researches revealed that soil pH is negatively correlated with Fe content (Wang et al., 2009; Sharma et al., 2004; Najafi-Ghiri et al., 2013). The availability of micronutrients Fe and Mn decreases as the soil pH increases due to the hydrolysis reactions (through the splitting of water molecules in their hydration shells) (Sinskey, 2009). Iron, Copper, Zinc and Manganese were negatively and significantly related with silt and sand but positively correlated with clay (Table 7).

Table 5 Micronutrients contents of the soils in DelboAtwaro subwatershed soils as influenced by topographic position and parent material

Pedon	**Horizon**	**Depth**	**Micronutrients (ppm)**			
			Fe	Cu	Zn	Mn
(P3)US	Ap	0-22	100	12.2	12.4	114
	Ah	22-68	105	14.6	14.6	130
	Bt1	68-120	121	10.8	10.2	142
	Bt2	120-195+	134	14.6	9.8	133
(P2)MS	Ap	0-30	129	12.4	12.4	126
	A	30-75	105	15.6	10.6	119
	AB	75-130	130	13.4	11.8	105
	Bt	130-180+	112	10.8	10.2	124
(P1)LS	Ap	0-20	99	15.2	9.8	131
	AB	20-86	122	13.6	11.4	129
	Bt	86-160	140	11.8	9.6	138
	C	160- 200+	135	14.2	12.8	125

Fe=Iron; Cu=Copper; Zn=Zinc;Mn=Manganese

3.5. Soil classification

According to FAO- WRB all pedons had well-structured dark surface horizons of more than 25 cm in thickness having color values and chroma of less than 3 when moist. The surface layers of the pedons contained more than 0.6% of OC; base saturation (by 1M NH4OAc, pH 7) of >50 % or more throughout the horizons (Table 4 and 5) meeting the criteria for Mollic diagnostic horizons.

Pedon 1,2 and 3 had deep, well-drained soil with an effective depth of 200+cm; a subsurface horizon thicker than 30 cm with more than 30% clay; moderate to strong angular blocky structure, slightly plastic and sticky, friable with shiny ped faces; silt/clay ratio of <0.54 meeting the criteria for Nitic sub-surface horizon. The pedon had a gradual smooth and clear smooth boundary between the surface and subsurface layers; without ferric, plinthic or vertic horizon, and there was no gleyic color pattern starting within 100 cm of the surface meeting the requirements of Nitisols (FAO, 2014). Furthermore, the subsurface layer started at 98 cm; it had high Fe content; dark reddish brown (2.5YR3/4 moist) to color; qualifying for rhodic prefix. Thus, the soils represented by this pedon were classified as Rhodic Nitisols (Haplic) according to the World Reference Base for Soil Resources (FAO, 2014).

4. Conclusion

Soil utilization in a scientific way is the best option in the crop production system. Therefore, to make better production and utilize the soil resource in a sustainable manner, the knowledge of this resource is indispensable. In view of this, characterization and classification were conducted in the site DelboAtwaro subwatershed, southern Ethiopia.

Soil of the study site showed variability in distribution, which was conditioned by topographic features. The studied soils were formed from volcanic rock dominantly basalt parent material. The topography of the area had influenced the soil formation, whereby the soils in the higher slope positions were developed from *in situ* weathering of the parent material, whereas continuous deposition of materials from the upper slope resulted in development of different soil types in the lower slope positions. The major limitations for augmenting agricultural production at three sites DelboAtwaro subwatershed on a sustainable basis are low level of organic carbon, total nitrogen was ranged from low to medium; available phosphorus was ranged from very low to low; optimum in both copper and iron; very high in a manganese and exchangeable potassium was ranged from very low to optimum. Magnesium induced deficiencies of basic cations, particularly K and to a lesser extent Ca, is expected in the soils at different topographic positions. Thus, integrated nutrient management should be employed to manage the cation balances and build up soil organic matter, as it influences the soil's physical, chemical and biological quality.

In general, the observed relationship between features of landscape, soil characteristics and soil types will help to advance soil-landscape relations in the study area and show a less costly way of acquiring soil formation. These are critical for making informed decisions with respect to management practices for sustainable agricultural production.

Table 6Correlation between properties of soils in study at DelboAtwaro, southern Ethiopia

Parameters	S/C	BD	pH	EC	TN	OC	C/N	Av.P	Ca	Mg	Na	K	CEC	Ca/Mg	Fe	Cu	Zn	Mn	Sa	Silt	Clay
silt/clay	1.00																				
Bulk density	-.810**	1.00																			
pH	.685*	-.761**	1.00																		
EC	0.02	0.15	-0.2	1.00																	
TN	0.31	0.07	0.08	0.27	1.00																
OC	.630*	-0.28	0.43	0.25	.847**	1.00															
C/N	-0.08	-0.27	0.19	-0.2	-.92**	-.579*	1.00														
Av.	0.40	-0.56	0.33	-0.2	-0.05	0.17	0.15	1.00													
Ca	0.18	-0.27	-0.1	0.02	-0.17	-0.18	0.11	-0.13	1.00												
Mg	0.19	-0.34	-0.1	-0.0	-0.20	-0.22	0.12	-0.08	.984**	1.00											
Na	-0.11	-0.04	-0.1	-0.3	-0.36	-0.32	0.33	0.34	-0.08	-0.11	1.00										
K	-0.22	0.55	-0.3	0.22	.737**	0.42	-.81**	-0.46	-0.14	-0.16	-0.57	1.00									
CEC	0.35	-.764**	.601*	-0.3	-0.36	-0.07	0.52	.608*	0.08	0.15	0.47	-.757**	1.00								
Ca/Mg	-0.08	0.29	-0.4	0.43	0.03	0.07	0.04	-0.34	0.44	0.27	0.16	0.06	-0.33	1.00							
Fe	-0.53	0.48	-0.4	0.21	-0.36	-0.47	0.20	0.03	-0.38	-0.39	-0.07	0.04	-0.37	-0.04	1.00						
Cu	-0.05	0.07	0.16	-0.4	0.17	0.28	-0.03	0.12	-0.23	-0.22	-0.07	0.21	-0.02	-0.08	-0.2	1.00					
Zn	0.46	-0.32	0.42	-0.4	0.06	0.33	0.08	0.21	-0.16	-0.09	-0.25	0.06	0.15	-0.41	-0.1	0.18	1.00				
Mn	-0.08	0.08	-0.3	0.34	0.13	-0.06	-0.27	0.04	.583*	0.57	-0.45	0.25	-0.34	0.24	0.20	-0.19	-0.35	1.00			
Sand	-0.39	.583*	-0.3	-0.1	0.56	0.29	-.625*	-0.43	-0.18	-0.18	-0.53	.891**	-.624*	-0.06	-0.3	0.52	0.10	0.16	1.00		
Silt	0.37	0.07	0.03	0.31	.859**	.771**	-.77**	0.18	-0.20	-0.28	-0.03	0.44	-0.30	0.21	-0.23	0.03	-0.07	0.12	0.23	1.00	
Clay	-0.08	-0.35	0.13	-0.2	-.93**	-.72**	.90**	0.12	0.23	0.29	0.30	-.797**	0.55	-0.14	0.21	-0.29	0.02	-0.2	-.68*	-.86**	1.

****. Correlation is significant at the 0.01 level (2-tailed).**

***. Correlation is significant at the 0.05 level (2-tailed).**

Data Availability

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

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