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Pedological characteristics and classification of soils along landscape at highlands of Tsegede, Western Zone of Tigray, Ethiopia

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ABSTRACT

Dynamics and distribution of soil characteristics as influenced by landscape /topographic features in acidic soils of Tsegede area in Northern Ethiopia has limited information. This study was conducted to characterize soil properties and classify major soil types. Four representative profiles along top sequence from varying slope positions crest at (Chegarkudo), upper slope and middle slope at (Endassilassie) and lower slope at (Intabela) were opened and described in-situ for morphological properties of soils and sampled horizon-wise for physico-chemical soil properties' analysis. The results showed that soils at crest and upper-slope position were characterized by shallow depth, whereas those at middle and lower-slope positions exhibited relatively deep. The soil consistence ranges from slightly hard to hard (dry), friable to very friable (moist), yellowish red to dark red brown (dry) in color, moderate medium sub-angular to strong thick angular blocky in structure. The pH of surface soil ranged from 5.14 to 5.74 which was strongly acidic to slightly acidic and varied from clay loam to clay in texture, organic carbon, exchangeable bases and cation exchange capacity varied with profile depth. Based on the world reference base legend, the soils were classified as Skeletic Leptosols about 3756 ha, Cambic Leptosols about 1926 ha, Dystric Cambisols about 1883 ha and Leptic Cambisols about 1966 ha.

Keywords: Top-sequence; Soil-classification; Pedogenic; Physico-chemical; Morphological properties; pH; Profile; Soil types; Slope position.

1. Introduction

Soil is a basic need for sustainability growth and life supporting system of humans and other animals [1]. Characterization of soil is essential to all soil studies, as it is an important tool for soil classification, which is done based on soil properties. It also provides detailed information for understanding soil properties, transferring experience and technology [2] and required for planning and implementing sustainable land use, provide information related to potentials and constraints of the land use and sound researches on soil fertility status [3-5]. All soils are naturally dynamic with their properties changing across landscape and vertically down the soil profile [6]. Improved mechanism for predicting adequate soil Information is by using biophysical and climatic characteristics that have well-known strong relationships with soil properties [7]. Dessalegn, Beyene [4] observed topography as the main factor inducing soil property variation along a topo sequence due to different factors along a topo sequence of Ele watershed, Southern Ethiopia.

Soil types and their properties indicate great variations across the regions of Ethiopia, mainly due to topographic, geologic and climatic variability [4, 7, 8]. Many studies of soil properties at watershed level Sheleme [6] also reported that topographic position largely governs the variation in types and features of soils. In Ethiopia, the studies that have been carried out mostly at small scale could not be relevant for site specific land use and soil management. Therefore, acceptable knowledge on soil characteristics at large scale and watershed level or farm level is essential undertaking to solve specific local problem of agricultural production [9].

However, no information is presented on soil characterization and classification in situation of study area. Then detailed study on characterization and classification of the major soil type vital for soil properties and fertility management at specific study area in Tsegede is necessary.

1.1. Study objectives

This study, therefore, was involved at the research field with the objectives: (i) To characterize the morphological and physical soil-properties of the soil profiles along the landscape under different sloping positions; (ii) To characterize the soil chemical properties of the soil profiles along the landscape under different sloping positions; and (iii) To classify the soils types according to World Reference Base Legend [10].

2. Materials and Methods

2.1. Site descriptions

The study site is located at Tsegede district in Tigray region, Northwest Ethiopia (Figure 1). The study area was conducted at the three Kebeles; namely, Chegarkudo, Endassilassie and Intabela (Figure 1) are geographically situated between 37°16'0" to 37°30'0" East longitude and 13°18' 40"- 13°22' 0" North latitude and has an altitudinal range of 2319 to 2939 m a.s.l. The study site also characterized by diverse physio-geographic features with high and rugged mountains, flat topped plateau, deep gorges, incised river valleys and rolling plains and the major geologic parent materials of the area are principally basic volcanic rocks (pyroxene-olivine basalt) [11]. The study site receives about 2,320 mm of rainfall per year with mean annual temperature of 15 °C (Tigray Meteorological Service Center, 2019). Crops grown in the district are mostly wheat (*Triticum spp.)*, barley (*Hordeum vulgare*), teff (*Eragrostis tef*), finger millet (*Eleusine coracanaa*), faba bean (*Vicia faba*), field pea (*Pisum sativum*), noog (*Guizotia abyssinica*) and linseed (*Linum usitatissimum*). The major indigenous forest trees found in the study area include *Juniperus procera, Acacia abyssinica*, *Faidherbia albidia* and *Eucalyptus* trees.

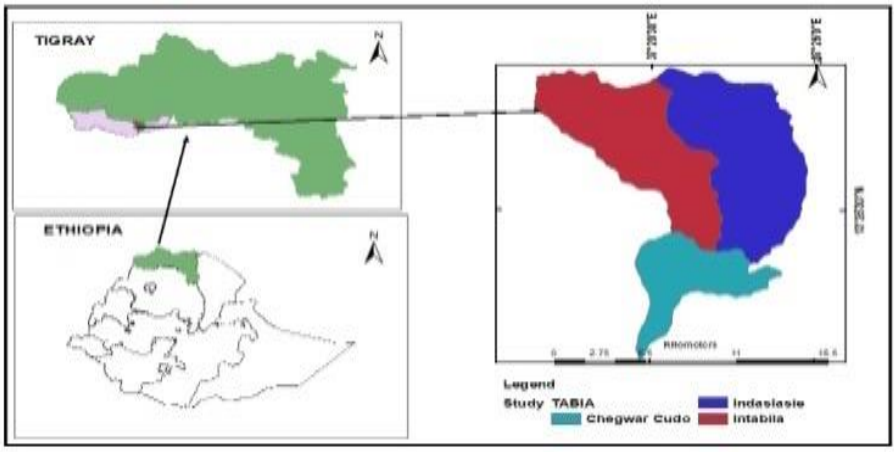

Figure 1. Map of the study area

2.2. Site selection, soil survey, profile description, and classification

To identify profile excavation point sites and to describe variability in major soils, the topo-sequence free soil survey method [12] was followed in the three kebelles. Based on the topographic setup and slope position sampling sites were separated in to four groups (crest, upper slope, middle slope and lower slope) [13] (Figure 2). The topo sequence of pit excavation was divided into three slope categories: nearly flat (1-2%), gently sloping (2-5%) and sloping (5-15%) [14]. After the investigation of the mapping units, further soil identification was done using soil profile pits which were excavated at the representative sites and categorized into four soil units (Table 1).

A representative of four soil profiles, 1.5 × 2 m, were opened Profile Ch01 (Chegarkudo) at crest; Profile En02 (Endassilasie) at upper-slope; profile En01 (Endassilasie,) at middle slope and profile It01 (Intabela) from lower-slope were described in-situ, for morphological characteristics, and samples were taken from every identified horizon following the guidelines for field soil description FAO [14].

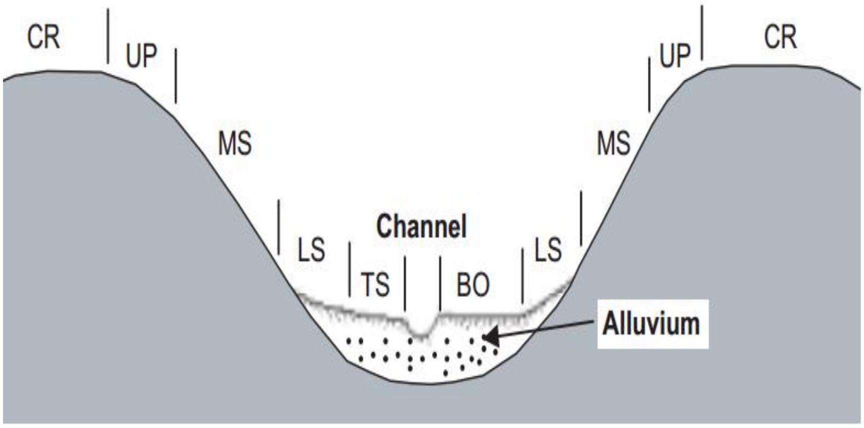

Figure 2. Slope position (Source: Schoeneberger et al., 2002)

Note: CR=Crest (summit), UP=Upper slope (shoulder), MS=Middle slope (back slope), LS=Lower slope (foot slope)

Morphological and physical properties including other relevant site information were recorded on a standard profile description sheet. The colors of each diagnostic horizon (moist and dry) conditions were done under uniform conditions using the Munsell soil color chart. Finally, a total of seven both disturbed and undisturbed soil samples were collected from each genetic horizon for laboratory analysis and bulk density determination, respectively. During site mapping and data collection all necessary information such as slope and geographic coordination of the land unit boundaries were taken using clinometers and global positioning system (GPS), respectively.

The soils of the study area were classified according to FAO [10] based on their morphological characteristics, physical and chemical characteristics. The auger points and identified map units' coordinates were recorded in excel spread sheet, and later displayed in Arc map. Depends on soil-landscape relations, soil boundaries were identified in each topographic position. The individual map units were later polygonized and their area was determined. Each polygon was labeled with the classified soil mapping unit (Figure 3).

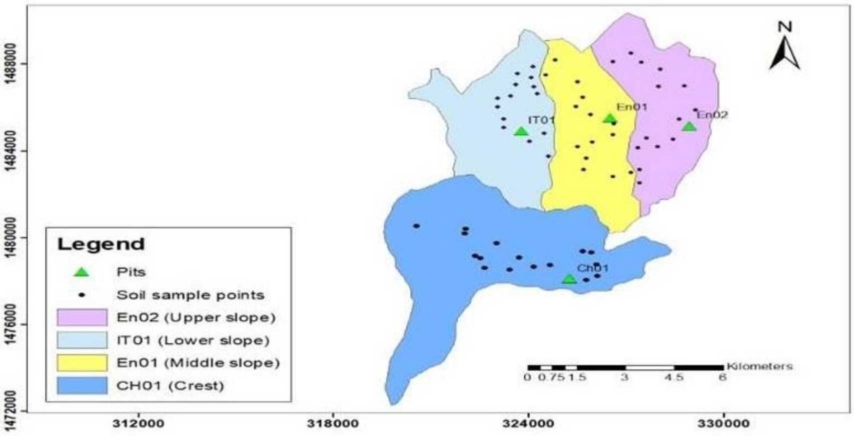

Figure 3. Slope position and profile points of the study area

Table 1. Location and general features of pit excavation sites

Profile	Mapping unit	Slope gradient		Soil depth horizon (cm)			Class	Geographic location	
		%	Class	A	B	C		Longitude	Latitude
Ch01	Crest	10	S	9	-	9^+	VS	37° 22'.35	12° 22'.163
En02	Upper slope	3	GS	10	12	22^+	VS	37°24'.450	13°25'.210
It01	Lower slope	3	GS	10	46	56^+	S	37° 22'.48	13° 25'.744
En01	Middle slope	1	NF	20	36	56^+	S	37°23'.312	13° 25'.911

Profile	Altitude (m)	Parent material	Land use	Erosion status
Ch01	2898	Basalt	Cultivated	Sever
En02	2612	Basalt	Cultivated	Moderate
It01	2412	Basalt	Cultivated	Moderate
En01	2498	Basalt	Cultivated	Slight

Note: S=sloping, GS=gently sloping, NF=nearly flat, VS=very shallow and S=shallow.

2.3. Laboratory analysis of soil samples

The disturbed soil samples were air dried at room temperature, ground, and passed through a 2 mm sieve for analysis of physio-chemical properties. However, a 0.5 mm sieve was used for analysis of organic carbon (OC). The bulk density of undisturbed soil sample was determined by core method [15]. The Bouyoucos hydrometer method was used for the determination of soil particle size (soil texture) [16]. Soil pH-H_2o was measured using a pH meter equipped with combined glass electrode [17] and Organic carbon (OC) was determined by the wet acid dichromate digestion method [18]. Available P was determined using the Bray II method of extraction [19] using ascorbic acid as a reductant in the presence of antimony and determined spectrophotometrically.

The cation exchange capacity (CEC) was determined by replacing exchangeable cations with ammonium acetate (NH_4OAc) 1 M leaching at pH 7, removal of excess sodium (Na) by alcohol, and determining Na and K concentration by flame photometry [20] and Ca^{2+} and Mg^{2+} in the filtrates were determined by Versenate titration (DTPA). Exchangeable acidity was determined by saturating soil samples with potassium chloride solution and titrating with sodium hydroxide as described by Mclean [21].

3. Results and Discussion

3.1. Morphological properties

The profiles of the study sites were maintained in different morphological properties of soil horizons, color, structure and consistency varied along the topo sequence (Table 2). The depth of soils on crest and upper slope profiles (profile Ch01 and En02) were relatively less than that of middle and lower slope profiles (profile It01and En01). Based on soil depth class described by USDA (2010), the soils of the study area were very shallow to shallow which was varied from 9 to 56 cm affected by topography and landscape positions, runoff, drainage, soil erosion, soil depth and hence soil formation at lower slope might have resulted in a relatively deeper soils and better soil development. The results obtained in agreement with the findings of Mulugeta and Sheleme [8] and Alemayehu et al. [22].

The soils in higher topographic/ or slope positions had high amount of coarser materials and soils having >60% gravels can be classified as extremely gravelly soils [23]. Profiles with shallow depth (<20 cm), which may limit the root penetration for deep rooted crops [24]. Then this report was in agreement with the present study observed at crest/upper slope profiles (Ch01 and En02). In contrast, relatively deep solum and fewer amounts of coarser materials in profiles En01 and It01 suggest that the rate of weathering process rise toward the lower slope area [22].

A munsell color chart reveals that the soil colors of the study area varied from reddish-yellowish (7.5 YR 6/6) for dry and brown (7.5 YR 4/4) for moist conditions, in surface horizon at profile Ch01 and red (10YR,5/8) to reddish brown (5YR,5/4), red(2.5YR,4/6) to dark red brown (5YR,3/2) for dry and moist soil condition from profile It01 in the surface and sub-surface horizons respectively. Surface color (dry) varied from dark red brown (5YR,3/4,) in profile En01 to yellowish (10YR,4/4) in profile En02; while the sub-surface soil color varied from dark red (7.5YR,3/6) in profile En01 to strong brown (7.5YR,5/8) in profile En02 (Table 2). This variation in colour influenced by chemical transformation, mineralogical composition, organic matter content, topographic position, texture makeup and moisture content of the soils. The results of the study are in line with findings of Ali et al. [3], Mulugeta and Sheleme [8], Alemayehu et al. [22]. According to Teshome et al. [2], the bright colored (red, reddish, reddish yellowish and reddish brown), in surface and sub-surface horizons indicates the release of iron oxides and their occurrence in various hydrated forms due to difference in drainage of the soils. The brighter matrix colour in the profiles might be due to presence of low OM content and higher free iron oxides in the surface and sub-surface horizons [25].

The distinctness of horizon boundary between surface and sub-surface horizons in all profiles were clear with smooth topography, except in sub surface horizon of profile En02 (Table 2). The soil structure of profile It01 was strong, medium sub-angular blocky that changed to strong, medium angular blocky in the sub-surface horizon. In profile En01 and En02, the surface soil structure was characterized as strong, medium sub-angular blocky without any change across sub-surface horizon whereas profile Ch01 had medium, very coarser angular-blocky. The structure of sub-surface horizon of all the profiles irrespective of the topography was more developed as compared to surface horizons, mainly due to the deposition of fine materials from top to lower layer. These findings are in conformity with those reported by Kiflu and Beyene [26].

The dry soil consistence was almost hard/slightly hard while the moist and wet soil consistence was dominated by friable/very friable and slightly sticky and slightly plastic along the profile. The surface layer of profile Ch01 had hard (dry), friable (moist), slightly sticky and slightly very plastic (wet) consistence. Likewise, the soil profiles It01 and En01 were marked by slightly hard (dry) and hard (dry); very friable (moist) and, friable (moist); and slightly sticky and slightly plastic (wet) regardless of changes in depth (i.e. surface and subsurface horizon), respectively. Similarly, profile En02 indicated that its surface horizon was hard (dry), its subsurface horizon slightly hard (dry) with same condition of friable (moist), slightly plastic and slightly sticky (wet) consistence.

Generally, very friable and friable consistence indicates the composition of different particle sizes, the occurrence of organic materials, and microbiological activities in the soil. It was observed that the friable consistence in the surface soils of the profiles could be attributed to the higher OM contents and the soils are workable at appropriate moisture content. Similar findings were also reported by Ali et al. [3] for soils in Delbo Wegene watershed, Wolaita

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zone and Mulugeta and Sheleme [8] in soils of Kindo Koye Watershed in Southern Ethiopia. In spite of high clay contents (Table 2) of (up to 75%), the soil materials were slightly sticky/plastic due to clay minerals mainly of kaolinite and oxides of iron and aluminum, which have little capacity to grow stickiness/plasticity and to swell and contract on wetting and drying [27].

Table 2. Morphological characteristics of soil profiles

Soil description			Profile: Ch01			Profile En 02			ProfileEn01			Profile It01		
Horizon			**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Depth(cm)			9	-	9^{+}	10	12	22^{+}	10	46	56^{+}	20	36	56^{+}
Horizontal	**Distinct.**		C	-	-	C	C	-	C	C	-	C	C	-
Boundary	**Topography**		S	-	-	S	Ir	-	S	S	-	S	S	-
Coarse	**Abundance %**		D			Co	F	-	F	F	-	F	VF	
fragments	**Size (mm)**		Cg			Fg	Fg	-	Fg	Fg	-	VFg	VFg	
	Weathering		Sw	-	-	SW	W	-	SW	SW	-	SW	SW	
Colour	**Dry**		7.5YR,6/6	-	-	10YR,4/4	10YR,5/4	-	5YR,3/4	7.5YR,3/6	-	10R,5/8	5YR,5/4	-
munsell code	**Moist**		7.5YR,4/4	-	-	7.5YR,5/8	7.5YR,6/8	-	5YR,4/6	10 R,4/6	-	2.5YR,4/6	5YR,3/2	-
Carbonates by HCl			N	-	N	N	N	N	N	N	N	N	N	N
Structure	**Grade**		M	-	-	S	M		S	S	-	S	S	
	Size		VC	-	-	M	M	-	M	M	-	M	M	
	Type		AB	-	-	SAB	SAB	-	SAB	SAB	-	SAB	AB	
Consistence	**Dry**		H	-	-	H	SH	-	SH	H		SH	H	
	Moist		F	-	-	F	F	-	F	F		VF	VF	
	Wet	**Stickiness**	SS	-	-	SS	SS	-	SS	SS		SS	SS	
		Plasticity	SP	-	-	SP	SP	-	SP	SP		SP	SP	
Diagnostic horizon			-			-			Cambic			Cambic		
Diagnostic property			Continuous rock			Cambic			Cambic			Cambic		
RSG group			Leptosol			Leptosol			Cambisol			Cambisol		
Soil unit (Mapping unit)			Skeletic Leptosol (Loamic)			Cambic-Leptosol (Dystric, Loamic)			Dystric -Cambisol (Humic)			Leptic -Cambisol (Loamic)		

Soil unit (Mapping unit), Skeletic Leptosol (Loamic), Cambic-Leptosol (Dystric, Loamic), Dystric-Cambisol (Humic), Leptic-Cambisol (Loamic).

Note: Hor. Boundary: C= clear, S= smooth, Ir= irregular, Coarse fragment: Abundance %: D= dominant, Co= common=few, VF= very few, Size (mm): Cg=coarser gravel, F= fine gravel, VF= very fine gravel, Weathering state: SW= strong weathered, W= weathered, Structure: Grade: S=strong= moderate, Size (mm): VC= very coarser=medium, Type: AB=Angular blocky, SAB=Sub-angular blocky, Consistence: H= Hard, SH=Slightly hard= Friable, VF= Very friable, SS=Slightly sticky, SP=Slightly plastic.

3.2. Physical properties of the soils

3.2.1. Particle size distribution and bulk density

Both the crest and upper slope young profiles were characterized by moderate gravel content throughout the solum with a tendency to slightly increase in depth. The soil texture varied from clay loam in the surface horizon to clay in the sub-surface horizon of all the profiles (Table 3). The clay content ranged from 29 to 75% in the different profiles hence highest clay content was observed at sub surface horizon in profile En01 and lower content was from the surface horizon of Ch01. In profile En01 clay increased down the profile which ranged from 57 to 75%, while it was decreased with depth in profile It01 from 69 to 57% and in En02 from 37 to 33%. The clay content at middle and lower slope (profile En01 and It01) showed visible increase with topographic position which might be due to the erosion and accumulation in influencing the pedogenic processes. Similar findings were also reported by Mulugeta and Sheleme [8]. Increase in clay content with depth might be attributed to the vertical translocation or transformation of clay through the pedogenic eluviation-illuviation processes.

Higher clay content in the B horizon in profile En01 must be as a result of illuviation and predominated in situ pedogenetic formation of clay [28-30]. However, vertical movement of clay down the profile was not evident in profile It01, as clay content did not increase in the B-horizons. Accordingly, the accumulation of clay in the sub-soil horizons of the profiles could have been due to predominant in situ synthesis of clay from the weathering of primary minerals in B horizons similar with the findings of Sheleme [25] in different topographic positions of soils along Humbo Larena-Ofa Sere, Southern Ethiopia.

The bulk density varied from 0.27 to 0.34 gcm^{-3} on the surface and from 0.29 to 0.37 gcm^{-3} in the sub-surface horizons of the soil profiles (Table 3). In all profiles, the lowest bulk densities were found at the surface horizons which could be related to the structural aggregation of the soils as a result of relatively high OM content which was also reported by Debele et al. [24] and profiles of different topographic positions have bulk density increased with depth possibly correlated to weight of the overlying soil and the relatively low amount of OM in the subsurface soil layers. This finding is in agreement with that of Fekadu et al. [31] who reported increased bulk density with soil depth as a result of increasing compaction, decreasing rooting effect, and organic matter content.

Table 3. Selected physical properties of soil profiles

Soil description		**Profile Ch01**	**Profile En 02**		**Profile En01**		**Profile It01**	
		Horizon						
		A	**A**	**B**	**A**	**B**	**A**	**B**
Particle distribution (%)	Sand	44	40	36	20	14	22	22
	Silt	27	23	31	11	23	11	19
	Clay	29	37	33	57	75	67	59
	Texture class	Clay loam	Clay	Clay loam	Clay	Clay	Clay loam	Clay loam
Bulk density (gcm^3)		0.34	0.27	0.29	0.31	0.33	0.32	01.37

3.3. Soil chemical properties

3.3.1. Soil reaction and available phosphorus

The pH values of the soils in the profiles (Table 4) ranged from strong acidic to slightly acidic (5.14– 5.74), in accordance with the rating of Jones [32]. The pH values varied from 5.45 to 5.74 in the surface layers and 5.14 to 5.7 in the sub surface horizons with an increasing trend with depth in profiles En01 and En02, while in profile It01 it showed decreasing pH pattern. The increased pH values with soil depth might be due to low OM content and decomposition and related to the accumulation of the basic cations with soil depth as suggested by Ayalew and Beyene [33].

The low pH could be due to the high rainfall in the study area that increased leaching of the basic cations from the soil surface. Similarly, many studies in different parts of Ethiopia reported very low pH for acid soils [8]. The available P is low range from 1.74 to 7.63 mg kg^{-1}. This may be due low pH in and also supported by Berhe [34] in acidic areas of Tsegede.

3.3.2. Soil organic carbon, cation exchange capacity, exchangeable bases and exchangeable acidity

The organic carbon (OC) content varied depth-wise from 2.88 to 1.77%, 3.23 to 1.38% and 1.65 to 2.85% in the upper, middle and lower topographic positions, respectively and 2.93% in the surface layer of profile Ch01 (crest) (Table 4). The highest OC content (3.23%) was observed in surface horizon and lowest organic carbon (1.38%) was observed in sub surface horizon of profile En01. According to the ratings suggested by Tadesse [35], the OC contents of the soils in the study area varied as low to moderate content. It did not show a consistent trend across topographic positions. Similar observation was reported by [24]. Generally, OC decreased with soil depth in profile En01, En02 and increased with depth in profile It0. This was attributed to the addition of farmyard manure and plant residues to surface horizons of En01 and En02 which resulted in higher OM than that of sub surface horizons. These observations are in accordance with results of Basavaraju et al. [36] in soils of Chandragiri Mandal of Chittor district of Pradesh in India.

The cation exchange capacity of the surface horizons and sub-surface horizons ranged from 8.8 to 19.6 and 8.6 to 16.2 cmol (+) kg^{-1}, respectively. The surface horizon of profile Ch01 (19.6 cmol (+) kg^{-1}) exhibited a higher cation exchange capacity values compared to others followed by profile En01 (13.4 cmol (+) kg^{-1}) and the lowest was at profile En02 (8.8 cmol (+) kg^{-1}). The CEC of the soils in all the profiles did not show any regular pattern with topographic positions (Table 4). However, regular trend with depth particularly in the soils of the upper (En02) and middle (En01) slope positions was observed decreasing with depth, which could be attributed to decreased OM with increasing depth. The results are in agreement with the findings of Mulgeta and Sheleme [8] who reported no consistent in topographic positions in soils of Kindo Koye Watershed in Southern Ethiopia.

According to Hazelton and Murphy [37], the CEC of the surface and sub-surface soils generally rated from low to medium, ranging from 8.6 to 19.6 cmol (+) kg^{-1} of soil. The higher values of CEC in the crest (19.6 cmol (+) kg^{-1}) might be attributed to better organic carbon content and less nutrient reduction through crop removal, as reported by Beyene (2017). Whereas, in surface and sub-surface profile It01 and En01 of the lower and middle slope positions might be due to the deposition of various cation-rich materials and leaching of basic cations from surface layers. Similar observation was made by Fekadu *et al*. [31] in acidic soils of Yikalo sub-watershed in Lay Gayint district, North-western highlands of Ethiopia. The low amount of CEC in the soils of the study area could be due to the presence of high rainfall that is leaching basic cations and increased the acidic cations contributed to lowering the soil pH.

Percent base saturation was found to vary from 18.75 to 42.7%, rating from very low to moderate in accordance to Hazelton and Murphy [37]. The percent base saturation decreased with depth in lower slope profiles En01 and It01, while it increased in upper slope topographic position in profile En02 due to higher clay content and subsequent accumulation of soluble bases. The A horizon of crest slope position profile (Ch01) is less base saturated than A horizon of lower slope profile (It01), indicating high degree of leaching losses in steep slope. These findings are in conformity with those reported by Sitanggang et al. [38]. According to Sekhar *et al.* [39], the higher values of base saturation were due to higher amount of exchangeable Ca occupying the exchange sites on the colloidal sites. Moreover, the low base saturation of the soils might indicate the leaching of bases due to high rainfall in the study area which resulted in unbalanced availability of exchangeable bases for uptake by plants.

The principal cations occupying the exchange site was dominated by Ca followed by Mg, K and Na in all surface and sub-surface profiles (Table 4). Based on the effect of topographic positions, the content of exchangeable Ca decreased from the crest to the lower slope. The consistent low accumulation of Ca with lower slope could be ascribed by replacement of acidic cations such as Al^{+3} and H^{+}. This result is in contrast with findings of Fekadu *et al.* [31] and Nahusenay *et al.* [40] who reported that exchangeable Ca increased from upper slope to lower slope due to the removal from upper slopes and accumulation in lower slopes as the study area receives high amount of rainfall. According to the nutrient ratings by Roy et al., [41], the soils were medium in Ca and low to medium in Mg in surface horizons of all profiles. The exchangeable Ca, Mg and K contents of the soils are above the critical values of 1.4-2.8 and 0.4–1.8 cmol (+) kg^{-1}, respectively [42]. The Ca:Mg ratio in surface soils of profile En02 and En01 was in the range between 2.5 and 6 respectively, which is within the acceptable range for crop production. The exchangeable acidity and exchangeable Al of the studied soils were found to be in the range of 1.9– 4.3 cmolc kg^{-1} and 0.16 –3.48 cmolc kg^{-1}, respectively. The range of exchangeable acidity and exchangeable Al were similar with Berhe [34] in acidic soils of Tsegede. The variability in exchangeable Al and exchangeable acidity in soils were probably due to low soil pH [43].

Table 4. Selected Chemical properties of soil profiles

Soil description		Profile Ch01	Profile En 02		Profile En01		Profile It01	
		Horizon						
		A	A	B	A	B	A	B
pH (H_2o)		5.74	5.51	5.7	5.45	5.48	5.45	5.14
CaCO3 (%)		3.3	5.2	4.3	4.72	3.8	4.3	5.2
Available P(mgkg^{-1})		3.49	4.73	1.74	6.8	2.32	7.63	5.06
OC (%)		2.93	2.88	1.77	3.23	1.38	1.66	2.85
Exchangeable bases (cmolc kg^{-1})	Ca	2.8	2.4	1.6	2	2.2	2.2	1.4
	Mg	1.8	0.4	0.8	0.8	1	1.8	1.4
	Na	0.37	0.06	0.34	0.33	0.08	0.05	0.09
	K	0.72	0.68	0.93	0.69	0.23	0.1	0.18
Ca: Mg		1.6	6	2	2.2	2	1.2	1
PBS		29.9	40.2	42.7	28.5	27	32.2	19
Exchangeable-Al (Cmolc kg^{-1})		0.16	0.48	0.56	0.88	0.48	3.48	2.44
Exchangeable acidity (Cmolc kg^{-1})		2.9	4	4.3	2.9	2.7	3.2	1.9
CEC (Cmolc kg^{-1})		19.6	8.8	8.6	13.4	13	12.8	16.2

3.4. Soil Classification and Mapping

The morphological properties in the field description and the physicochemical analysis results of the samples collected from every identified horizon were used for the soil classifications (Figure 4). The soil mapping unit is represented by soil profile Ch01 slope of 10%, limitation of depth by continuous rock within 9 cm of the soil depth

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from the surface, strongly eroded area and abundant coarse fragments (>40%) throughout and high extent of rock outcrops. The layer was low in thickness with clay in texture, high CEC, high OM and moderately angular blocky structure. The layer was therefore qualified for Skeletic and considering these features, the soils mapping unit met the requirement for Skeletic Leptosols of the FAO [10].

The soil mapping unit represented by soil profile En02 has gently slope (3%), very shallow in depth with common coarse fragment (5-15%) in sub-surface layers and moderately sub-angular blocky. Furthermore, it was characterized by slightly hard, friable and slightly stickiness and plastic. Therefore, the soils are classified as Cambic Leptosols which is limited in depth by continuous hard rock within 22 cm from the soil surface. Profile En01 is restricted in depth of 56cm, has high clay content at sub-horizon than the overlying horizon that may be caused by an illuvial accumulation and strong sub-angular blocky in structure. The soil was low in OC and low in PBS. The sub-surface horizon has pedogenetic transformation of the rock, indicating that the soil profile was developed through sub-surface soil formation following initiation of structure and color change. The profile consists of the diagnostic criteria for cambic sub-surface horizon. Furthermore, the profile has a base saturation of less than 50%, which qualifies for Dystric principal qualifier. Thus, the soil is classified as Dystric Cambisols (Humic) [10].

Profile It01 was characterized by clay loam and clay in texture in surface and sub-surface horizon, respectively. It has gently slope of 3%, shallow effective soil depth (56 cm) and change in soil structure from medium sub-angular to strong medium sub angular in the subsoil, cation exchange capacity of greater than 16.2 cmol (+) kg^{-1} has been identified as cambic subsurface horizon. The soil profile had a continuous rock starting within 100 cm of the soil surface and qualifies for the leptic prefix qualifier. Finally considering the above criteria the soils are represented by Leptic Cambisols [10] (Figure 4).

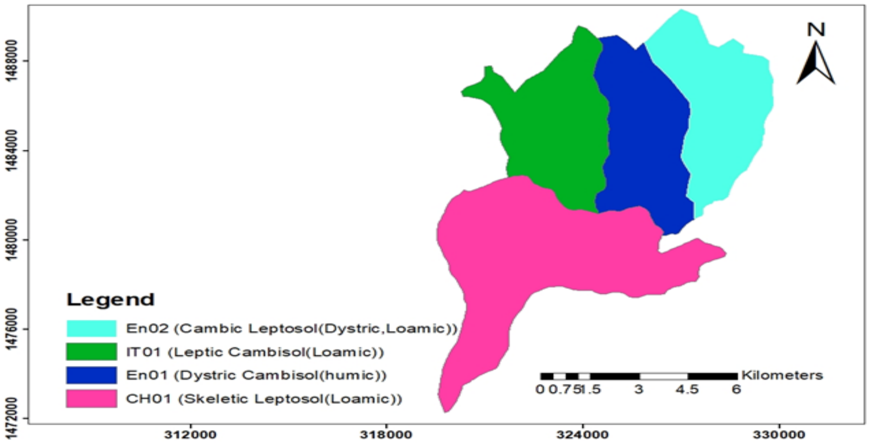

Figure 4. Soil map of the study area

4. Conclusion

Topography influenced on the characteristics of the soils in the studied site. The four studied profiles along the top sequence varies in their profile depth, horizon features and some physicochemical properties of soils. Profile-Ch01 (Skeletic Leptosol) and En02 (Cambic Leptosol) located on crest and upper-slope, were characterized by relatively shallow depth with truncated A-horizon. Conversely, profile En01 (Dystric Cambisols) and profile It01(Leptic

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Cambisols) situated on middle and lower-slope had reddish colour, relatively thick A-horizon and deep soil profile, indicating better soil development; this is mainly linked with the gradual accumulation of soil materials from upper-slope.

Declarations

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Competing Interests Statement

The authors declare having no competing interest with any party concerned during this publication.

Consent for Publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors took part in literature review, analysis and manuscript writing equally.

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