

*Full Length Research Paper*

# Soil survey and characterization of soil of Argo-Gedilala Sub Watershed in Dugda District, Central Rift Valley of Ethiopia

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A detailed study on soil resources characterization based on the understanding of the soil system is not available at Dugda district. With the cognizance of this fact, the present study was conducted to characterize the morphological and physicochemical properties of soils, classify the soils according to World Reference Base for Soil Resources (WRB) of Argo-Gedilala Subwatershed in Dugda District of Oromia Regional State, Central Rift Valley of Ethiopia. Four slope classes were considered and one pedon was opened for each and described in the field on a standard description sheet for each slope category. Soil samples were collected from genetic horizons of each pedon for laboratory analysis of the selected physicochemical properties of the soils. The soils were classified into different Reference Soil Groups following the (WRB). The organic carbon (OC) content of the study area ranged from low to medium/moderate (0.64 to 1.83%). Total nitrogen (TN), available phosphorus (Av.P), cation exchange capacity (CEC) and percent base saturation (PBS) of the soils were in the range of (0.066-0.135%), (2.24-4.81 mgkg<sup>-1</sup>), (39.52-43.52) cmol(+)kg<sup>-1</sup> and (77.57- 89.8%), respectively. Accordingly, they were rated as low to medium, very low to low, high to very high and high to very high, respectively. The soil classification revealed that pedon 1 and pedon 2 were Cambic Chernic Phaeozems (Pantoclayic, Humic, Hypereutric); and pedon 4, Cambic Chernic Phaeozem (Pantoclayic, Humic); whereas, pedon 3 is found to be a kind of Luvic Phaeozem (Abruptic, Albic, Clayic, Differentic, Hypereutric). The soils of the study area had low organic matter, available P and total nitrogen content, which can be seen as production constraints of all cultivated lands. To overcome the identified limitations, increasing the organic matter levels through continuous application of manure.

**Key words:** Genetic horizons, morphological properties, pedon, physicochemical properties, slope.

## INTRODUCTION

Study and understanding of soil properties and its distribution over an area are useful for the development of soil management plan for efficient utilization of limited land resources, rehabilitation of degraded lands (Ashenafi et al., 2010) and implementing sustainable land uses (Jagdish et al., 2009). The systematic appraisal of

soil resources with respect to their extent, distribution, characteristics, behavior and use potential, is thus very important for developing an effective land use system and for augmenting agricultural production on a sustainable basis. Therefore, for developing site-specific technologies that are effective with greater impact, it is

imperative to have site-specific landscape information generated through detailed biophysical resources characterization. The soil and land resource inventory at regional are providing a basis for blanket recommendation of various package of practices including fertilizers and other inputs. For long the fertilizer recommendations in Ethiopia deal with only nitrogen (N) and phosphorus (P) application, and so far, it is assumed as standard for the country disregarding the mosaic soil nature of Ethiopia (Abdenna et al., 2013). However, fertility mapping project in Ethiopia reported that deficiency of K, S, Zn, B and Cu in addition to N and P in major Ethiopian soils were common (Ethio-SIS, 2014). Similarly, seven soil nutrients (N, P, K, S, Fe, Zn and B) were found to be deficient in the soils Tigray region (Ethio SIS, 2014)

Degradation of soil resources as a result of natural and anthropogenic factors is very common and low soil fertility is one of the bottlenecks to sustain agricultural production and productivity in Ethiopia. Hence, integrated soil nutrient management is an option as it utilizes available organic and inorganic nutrients to build ecologically sound and economically viable farming system (Gruhn et al., 2000). Despite the general understanding that land degradation is a threat to agricultural productivity, very few studies have been done to quantify the extent, rate (status) and processes of soil physicochemical depletion under different land uses and management practices in the country (Elias, 2002). Among these, the study conducted by Habtamu et al. (2014) and Berhanu (2016) indicated that conversion of natural ecosystem into crop/cultivated land ecosystem has resulted in deterioration of the soil resource base and most of the physicochemical properties of soils were considerably influenced by the different land uses.

In order to meet the increasing demand for food, the farming community has to produce more and more. However, under the present situation, where land has become a limiting factor, it is impossible to bring more area under cultivation to satisfy the growing demand (Fischer et al., 2002). Soil resource inventory through characterization of the resources provides an insight into the potentials and limitations of soil (Manchanda et al., 2002). Detail information on soil characteristics is required to make decision with regard to management practices for sustainable agricultural production, rehabilitations of degraded land (Dinku et al., 2014) and sound researches on soil fertility. Therefore, it is very useful to study and understand the properties of soil and their distribution over an area in order to develop management plans for efficient utilization of soil resources (Shi et al., 2005). Hence, this study was undertaken to investigate the morphological, physico-

chemical properties and to classify the soils of Argo Gedilala sub watershed in the Dugda District.

## MATERIALS AND METHODS

### Location and topography

Geographically, Argo-Gedilala sub watershed is found in Dugda District in the East Shewa Zone in the Regional State of Oromia in Ethiopian Great Rift Valley at western direction of the district (Figure 1). The district shares boundary line with Bora in the North and North West, Arsi in the East, Adam Tullu Jiddu Kombolicha district in the South and Southern Nations and Nationalities Peoples of Ethiopia (SNNP) in the west. The Capital town of the district is Meki, which is located 134 km in the southeast of the capital Addis Ababa.

The topography of the watershed is characterized by flat, level land, constituting plains to gently sloping and strongly sloping. The slope gradient of the study area ranges from 0 to 12%. On the basis of slope percentage, the study area has been classified into four slope classes: 0-1%, 1-2%, 2-5%, and 5-10%. However, the majority of the study area falls under the slope class of 5-12% and 2-5%, which covers 46.28 and 42.04% of the total study area, respectively

### Soil types of the study area

At district level, the area is covered by dark brown and sandy loam, clay loam and clay soils (DWOA, 2014), which are classified into Vertic Cambisols and Luvic Phaeozems, Lithosols (Leptosols) and Fluvisols. Fluvisols are derived from alluvium on the lakes shore. Geleyic Mollic Fluvisols are derived from lacustrine deposits along the shores of Lake Zeway. According to FAO (2006), Phaeozems accommodate dark soils rich in organic matter, which develop on eolian (loess), glacial till and other unconsolidated parent materials. Phaeozems are much like Chernozems and Kastanozems but are leached more intensively. Consequently, they have dark, humus rich surface horizons that, in comparison with Chernozems and Kastanozems, are less rich in bases. They are either free of secondary carbonates or have them only at greater depths and all have a high base saturation in the upper meter of the soil (FAO, 2006).

### Geology of the study area

As the study area is part of the central rift valley system of Ethiopia, the geology is complex (UNDP and FAO, 1984). The soils of the Rift Valley are largely derived from recent volcanic rocks and, in comparison to soils of other African countries; their base status is generally good. The volcanic rhyolite lava flows, basalt lava flows, ignimbrites and pumiceous pyroclastics form the volcanic massif of the Aluto Volcano and the sediments are distributed on the flat plains and depressions (EEPCo, 2013). Geologically, the watershed is covered by unconsolidated sediments and Acid/intermediate rocks

### Climate

Based on the climatological data of Ziway Meteorological Center,

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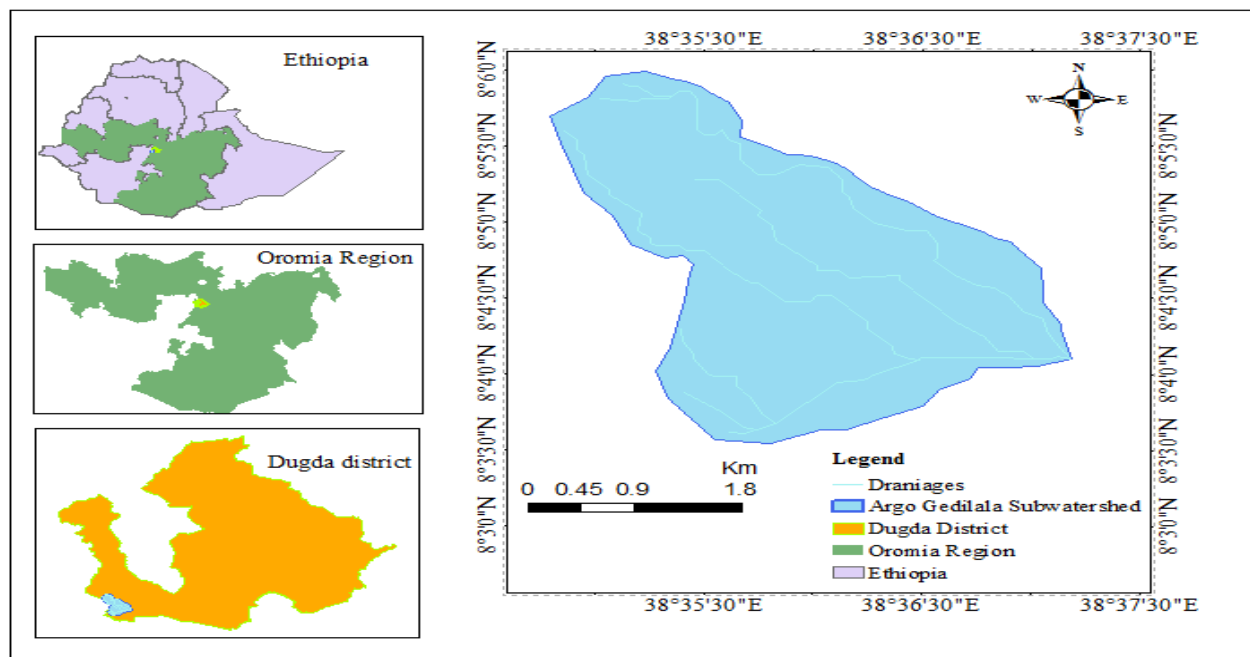


Figure 1. Location map of study area.

Table 1. Location and land use types of the selected pedon sites.

Pedon No	Latitude(m)	Longitude	Class name	Slope (%)	Area (ha)	Area (%)	Land use
Pedon 1	0454450	0893700	Flat, level and nearly level	0-1%	44.98	4.3	Cultivated
Pedon 2	0456186	0892976	Very gently sloping	1-2%	77.57	7.39	Cultivated
Pedon 3	0457116	0892473	Gently sloping	2-5%	441.13	42.04	Cultivated
Pedon 4	0455976	0891899	Sloping	5-12	485.76	46.28	Cultivated

Source: Field surveying, 2019.

the nearest weather station, the average annual rainfall in the district can be estimated to vary between 700 to 800 mm (DWOA, 2014). Agro-ecologically, the area is classified as semi-arid region. Rainfall mainly occurs in July and August, which is followed by a long period of dry season. The area is characterized by unimodal distribution of rainfall pattern. The July-August rainy season is the main season for crop production. Annually, the average minimum and maximum temperature in the project area is 15 and 28°C (DWOA, 2014), respectively.

### Site selection and soil sampling

#### Site selection

Preliminary subwatershed boundary was delineated and temporary pedon sites were identified using the topographic map of the study area (1:50,000) and Digital Elevation Model (DEM: 30 x 30 m resolution). Site characteristics (such as land use/land cover, slope gradient, surface drainage, and erosion) and surface soil characteristics (soil color, texture,) were well recorded. Moreover, about 45 auger observation points were described to confirm the final pedon sites

#### Pedon description and soil sampling

Four representative pedons (1.5 m width and 2 m length unless limited by continuous hard layer/bedrock) were opened and described on standard description sheet based on the FAO soil description guidelines (FAO, 2006). Site characteristics, the morphological properties of each genetic horizon within a pedon (soil horizon, depth, boundary, soil color, texture, structure and consistence) were recorded on a standard sheet. Moreover, the geographic coordinates (latitude and longitude), altitude and slope gradient of the pedons were recorded and georeferenced using Global Positioning System (GPS), altimeter and clinometers, respectively (Table 1).

Soil depth (cm) was determined following the thickness of the loose soil from the surface to a limiting impermeable layer. Soil color was measured both under dry and moist conditions using the Munsell Soil Color Chart (Munsell Color Company, 2000). Soil structures were studied in terms of type (shape), grade and size of aggregates whereas horizon boundaries were described in terms of depth, distinctness and topography. The soil consistency was identified at dry and wet moisture conditions. About a kg soil sample was taken from each genetic horizon of a pedon. A total of 16 soil samples were collected, properly labeled and packed in a

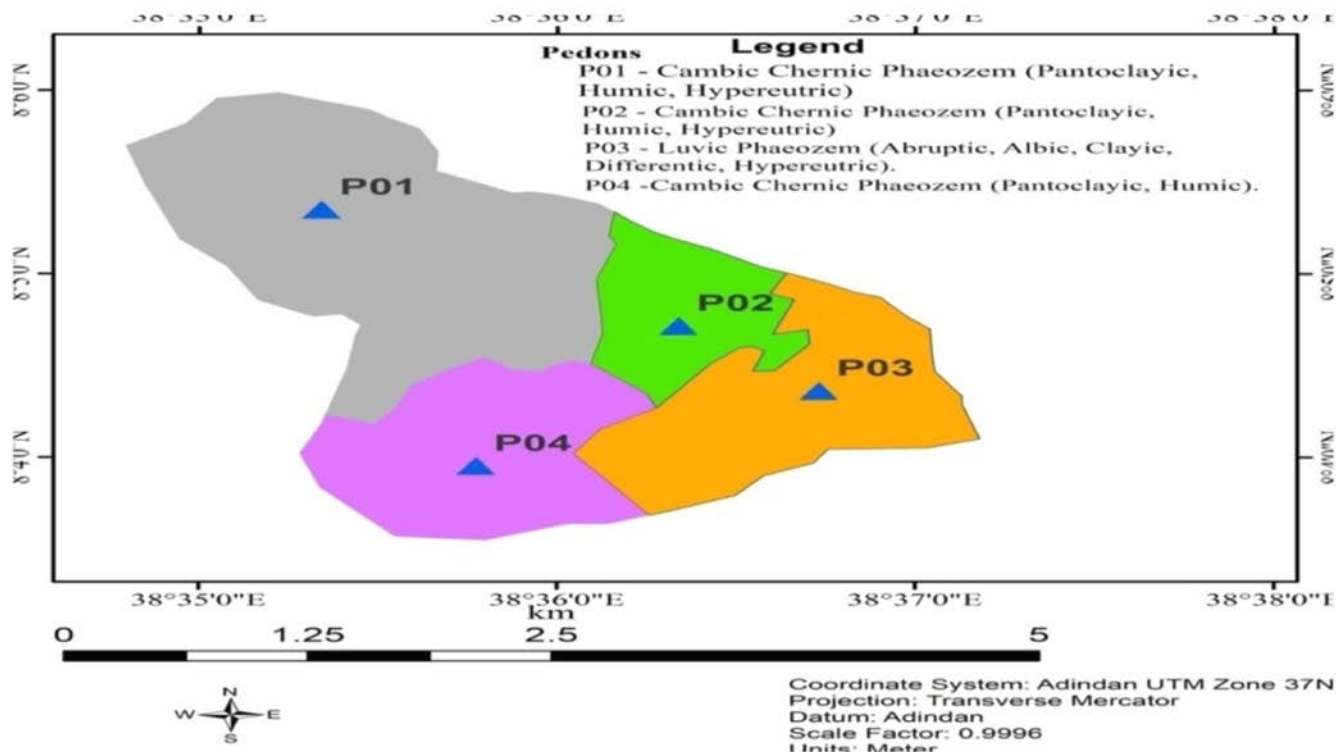


Figure 2. Soil classification map of Argo-Gedilala sub watershed.

polyethylene bag, and transported to Batu Soil Laboratory for analysis.

#### Soil sample preparation

The sampled soils were carefully bagged, labeled, packed and transported to the laboratory for analysis. The disturbed soil samples collected from each horizon were air-dried at room temperature, ground using mortar and pestle to pass through 2 mm sieve in the laboratory for all the selected soil parameters except for soil OC and total N prior to analysis. For the analysis of OM and total N, the soil samples were further passed through 0.5 mm sieve. Finally, the soil samples were analyzed for selected Physico-chemical properties

#### Soil classification and mapping

Considering the site characteristics, field description and the pedon description, a preliminary soil classification was made in the field. Based on the morphological, physical and chemical properties, the soils of the Subwatershed were finally classified into different units (major soils) following the WRB for Soil Resources (IUSS Working Group WRB, 2015). The presence or absence of specific diagnostic horizons, properties and materials were used to distinguish soil units and subunits as given in the employed classification system. Soil map was prepared using (DEM) to identify slopes, then after FAO slope classification was employed (to classify the slope of the study area in to different classes); 45 auger sample points were also used to identify the land mapping units. Finally, soil map of the study area was produced using Arc GIS 10.0 software. The maps produced include location of the study area, auger observation points, and soil map.

## RESULTS AND DISCUSSION

### Morphological characteristics of the soils

#### Soil depth and horizon designation

The locations of the pedons within the watershed are indicated in Figure 2. In most of the observation points throughout the watershed, the total effective soil depth was observed to be greater than 200 cm, although the identified genetic horizons had a variable thickness. Pedon 1 with its very deep horizon showed that the thickness of the darker surface horizon (A1) was 55 cm. Below this horizon, the 35 cm (55-90 cm) thick subsoil with many morphological similarities with the A1 was identified and designated to be the A2 horizon. Next to A2 horizon, the layer at 90-122 cm depth was identified as Cambic horizon and thus designated as Bw1; and the other layer at about 122-200 cm was similar and thus designated as Bw2 horizon as both have Cambic properties.

Similar to pedon 1, pedon 2 was also very deep (>200 cm). It was opened on very gently sloping landscape position (in the middle part of the watershed). The surface horizon (A1) had about 54 cm thickness. Except the differences in thickness and depth related location within the profile, all the layers below the 54 cm depth were found to be very similar with the layers below 55 cm in pedon 1 and hence were similarly designated as A2.

**Table 2.** Selected morphological characteristics of the soils.

Horizon	Depth (cm)	Horizon boundary		Munsell colour value		Structure			Consistence		
		Disti.	Top	Moist	Dry	Grade	Size	Shape	Dry	Moist	Wet
<b>Pedon 1</b>											
A1	0-55	C	S	10YR3/2	7.5YR3/2	MO	FI	GR	SHA	VFR	SST,SPL
A2	55-90	C	S	5YR2.5/1	5YR3/1	MO	ME	SB	SHA	FR	SST,SPL
Bw1	90-122	C	W	10YR5/3	2.5YR3/2	MS	ME	SB	HA	FR	SST,SPL
Bw2	122-200+	-		7.5YR5/4	5YR4/2	MO	FI	SB	HA	FR	VST,VPL
<b>Pedon 2</b>											
A1	0-54	C	S	10YR3/1	7.5YR2.5/1	MO	FI	GR	SHA	VFR	SST,SPL
A2	54-93	C	S	7.5YR2.5/1	2.5YR2.5/1	MS	ME	SB	SHA	VFR	SST,SPL
Bw1	93-133	C	S	2.5YR3/1	2.5YR3/1	WE	ME	SB	SHA	FR	SST,SPL
Bw2	133-200+	-		7.5YR3/2	5YR3/3	WE	FI	AB	SHA	VFR	SST,VPL
<b>Pedon 3</b>											
AE	0-43	C	S	10YR3/1	2.5YR6/1	MO	FI	G	SHA	VFR	SST,SPL
BAt	43-72	C	S	10YR3/2	7.5YR3/2	ST	ME	SB	SHA	FR	SST,SPL
Bt1	72-115	C	S	7.5YR2.5/2	10YR5/3	MO	ME	SB	HA	FR	SST,SPL
Bt2	115-200	-		7.5YR2.5/2	10YR5/3	MO	FI	AB	HA	FR	VST,VPL
<b>Pedon 4</b>											
Ap	0-25	C	S	10YR3/1	7.5R3/1	MO	FI	G	SHA	VFR	SST,SPL
A2	25-63	C	S	5YR2.5/2	5YR3/1	MS	ME	G	SHA	VFR	SST,SPL
Bw1	63-150	D	W	5YR3/2	5YR3/2	MS	ME	SB	HA	FR	SST,SPL
Bw2	150-190+	-		7.5YR3/2	5YR3/3	ST	ME	SB	HA	FR	VST,SPL

Disti = Distinctness, C =clear, D=Diffuse, Topo. = Topography, S =smooth, WE = weak, MO = moderate, ST = strong, MS = moderate to strong, ME = Medium, FI = Fine, FM = Fine medium, SB = sub-angular blocky, GR = Granular, AB = Angular blocky, SHA = Slightly hard, HA= Hard, VFR = Very friable, FR=Friable, SST=Slightly sticky, VST= Verysticky, SPL=Slightly plastic, W = Wavy (FAO, 2006)

In most of the observation points of pedon 4, the total depth was observed to be greater than 190 cm. The pedon was found in the west direction of pedon 3 on sloping topographic position. The darker uppermost horizon (Ap) of pedon 4 was 25 cm thick. The genetic horizons underlying this surface layer were morphologically similar to those encountered in pedons 1 and 2 at similar positions within the profile and were designated similarly.

The profile of pedon 3 had morphological features different from all the other three profiles (pedons). Its surface layer was at the depth of 0 to 43 cm and coarser in texture than the underlying layer and all the surficial horizons of the other three pedons. All the three horizons below this horizon had almost similar morphological features and were more clayey. Accordingly, the surface layer is considered as a type of eluviated horizon and hence designated

as an AE horizon; and all the three layers below were presumed to be a part of illuviated subsoil. Therefore, all were designated as types of illuvial horizons (BAt, Bt1, Bt2 in order of increasing depth).

#### Soil colour

The pedons showed great variability in relation to soil color patterns (Table 2). The surface

horizon of pedon 1 had dark brown (7.5YR3/2, dry) and very dark grayish brown (10YR3/2, moist). The color of the second horizon of this pedon was very dark gray (5YR 3/1) and dark reddish brown (5YR 2.5/1) for dry and moist soil respectively, whereby the brightness of profile increases with depth. The dry and moist color of the topsoil of pedon 2 was black (5YR 2.5/1, dry) and very dark gray (10YR 3/1 moist). The color of second horizon of this pedon was reddish black (2.5YR 2.5/1, dry) to black (7.5YR 2.5/1, moist); and the brightness of the profile color increased with depth also in this pedon. The color of the surface layer of pedon 3 was gray (2.5YR 6/1, dry) and very dark gray (10YR3/1, moist), respectively. The color of the second layer of this pedon was dark brown (7.5YR3/2, dry) and very dark greyish brown (10YR3/2, moist), and the color of the two brighter horizons below this horizon was found to be the same for both the moist and dry soil conditions. The dark color of the surface layers of the profiles could be attributed to their high organic matter content.

### **Soil structure and consistence**

There were variations in the grade, size and shape of the soil structure among pedons. The structure of all pedons in the surface soils was moderate to moderately strong granular, gradually changing in the subsurface from moderate to moderately strong angular blocky in pedon 1 to moderate to moderately strong, granular in pedon 2. The structures of pedons 3 and 4 were moderate to strong and moderate to moderately strong granular structure respectively (Table 3). Similar results were reported by Yitbarek et al. (2016) and Kebede et al. (2017) who found granular soil structure in the surface horizons that changed to angular and sub-angular structure in the subsurface pedons. The presence of OM in the surface soil might be attributed to the formation of a granular type of soil.

The dry consistence varied from slightly hard to hard, whereas the moist consistence varied from friable to very friable. On the other hand, the wet consistence ranged from slightly sticky/slightly plastic in the surface layers to very sticky/very plastic in the subsurface soil layers (Table 2). The very friable and friable consistence observed in the surface soils of the pedons could be attributed to the higher OM content (Table 5). In consent with this finding, the contribution of OM in modifying soil consistence was pointed out by Mulugeta and Sheleme (2010). Ashenafi et al. (2010) also reported that the friable consistence of the soils show workability of the soils at appropriate moisture content. In contrast, the sticky, very sticky, plastic and very plastic consistencies show the presence of high clay content, and difficulty to till when dry (Abay et al., 2015). The presence of very sticky and very plastic consistence could be indicative of the presence of smectitic clays in the soils (Ashenafi et

al., 2010); and the observed differences in soil consistence could probably be explained by the differences in particle size distribution, particularly type and amount of clay.

### **Horizon boundary, root distribution and related pedon characteristics**

Based on soil depth class described by USDA (2010), all the pedons are very deep (> 150 cm). For any given soil, the greater the rooting depth, the larger will be the quantity of soil water available to the crop. This is particularly important for annual crops as they have less time to develop deep and extensive rooting systems than perennial crops (FAO, 2003).

The differences in depth of the solum might have been due to the shape and slope length, which are important in influencing the rate at which water flows into or off the soil if the sites are unprotected. The running water, if the site is unprotected, may erode soils on slopes and form thinner surface layer. On the other hand, the increase in the thickness of surface layers in the landscape may be attributed to soil deposition at lower landscape position corroborating the previous findings of Sheleme (2010) and Dinku et al. (2014). Mulugeta and Sheleme (2010) also reported that landscape position influences runoff, drainage, soil temperature, soil erosion, soil depth and hence soil formation. The horizon boundary between surface and subsurface horizons in all pedons was clear with smooth topography, except in pedon 3 at which the surface horizon had clear while the subsurface horizons had diffuse wavy boundary. The differences in nature of the horizon boundaries may indicate the existence of variations in processes that have formed the soils partly reflecting anthropogenic impacts (Cools and De Vos, 2010). Since all the pedons were opened in cultivated land, many fine roots of different crops, weeds and grasses were observed in the surface horizons that decreased with a depth of the profiles. The pedons were not restricted by bedrock layers of parent materials and were very deep (> 200cm) as per the (FAO, 2006).

### **Physical soil characteristic**

#### ***Soil particle size distribution, bulk densities and total porosity***

All pedons had high clay and low sand content across the horizons. Clay accounted for over 50 percent by weight of the particle size of the soils at the surface horizons, except for pedon 3 with 16% clay content and silty ranged from 26 to 38 percent for all the pedons (Table 3). Although clay content increased with depth in the pedons, none of the fractions showed a consistent trend along toposequence; whereas the irregular trend with

**Table 3.** Selected physical characteristics of soils of the Argo-Gedilala subwatershed.

Horizon	Depth (cm)	Particle size distribution (%)			Textural class	BD (g/cm <sup>3</sup> )	TP	FC (%) v/v	PWP (%) v/v	AWC (Volume %)
		Sand	Silt	Clay						
Pedon 1										
A1	0-55	22	30	48	Clay	0.94	64.53	40	23	17
A2	55-90	20	30	50	Clay	1.05	60.38	44	26	18
Bw1	90-122	19	27	54	Clay	1.09	58.87	39	24	15
Bw2	122-200+	18	26	56	Clay	1.21	54.34	37	21	16
Pedon 2										
A1	0-54	27	31	42	Clay	0.98	63.02	36	25	11
A2	54-93	20	35	45	Clay	0.99	62.64	38	24	14
Bw1	93-133	18	38	44	Clay	1.2	54.72	40	23	17
Bw2	133-200	14	36	50	Clay	1.24	53.21	41	23	18
Pedon 3										
AE	0-43	56	28	16	Sandy loam	1.07	59.62	38	27	11
BAt	43-72	24	34	42	Clay	1.25	52.83	42	28	14
Bt1	72-115	20	32	48	Clay	1.28	51.70	41	30	11
Bt2	115-200+	16	35	49	Clay	1.28	51.70	41	28	13
Pedon 4										
Ap	0-25	28	30	42	Clay	1.15	56.60	41	32	9
A2	25-63	22	34	44	Clay	1.19	55.09	37	26	11
Bw1	63-150	21	33	46	Clay	1.23	53.58	39	26	13
Bw2	150-190+	17	31	52	Clay	1.23	53.58	44	24	20

BD = Bulk density, TP = Total porosity, FC = Field capacity, PWP = Permanent wilting point, AWHC = Available water holding capacity

depth might be due to variation in weathering of parent material and topographic influence (Sekhar et al., 2014). The general increase in clay content with depth might be attributed to the vertical translocation of clay through the processes of eluviation and illuviation. The bulk density of soils in the surface horizons ranged from 0.94 to 1.15 g cm<sup>-3</sup>, and the corresponding values for the subsurface horizon ranged from 1.19 to 1.28 g cm<sup>-3</sup> (Table 3). The relatively lower bulk density values (< 1 g cm<sup>-3</sup>) in the surface horizons of

pedons 1 and 2 could be related to the structural aggregation of the soils as a result of relatively high OM content (Table 5). The bulk density in soils, irrespective of landforms, increased with depth, which might be due to the weight of the overlying soil layers and the relatively low amount of OM in the subsurface soil layers. Similarly, Chaudhari et al. (2013) reported an increase in bulk density with pedon depth, due to changes in OM content, porosity, and compaction. Total porosity ranged from 56.6% in pedon 4 to 64.53%

in pedon 1 of the surface soil horizons. On the other hand, it varied from 51.70% in pedon 3 to 54.34% in pedon 1 of the subsurface soil horizons (Table 3).

#### **Soil water retention capacity**

The soil water content retained at field capacity (FC at 33 kPa) ranged from 36 to 44% whereas, at permanent wilting point (PWP) at 1500 kPa, it

**Table 4.** Soil pH and electrical conductivity of the soils.

Pedons	Horizons	Depth (cm)	pH(H <sub>2</sub> O)	EC(ds/m)
1	A1	0-55	6.84	0.07
	A2	55-90	7.02	0.06
	Bw1	90-122	7.45	0.08
	Bw2	122-200+	7.86	0.08
2	A1	0-54	6.95	0.06
	A2	54-93	7.09	0.07
	Bw1	93-133	7.5	0.11
	Bw2	133-200	7.36	0.1
3	AE	0-43	7.38	0.1
	Bat	43-72	7.7	0.14
	Bt1	72-115	7.92	0.23
	Bt2	115-200	7.93	0.27
4	Ap	0-25	7.76	0.12
	A2	25-63	7.73	0.14
	Bw1	63-150	7.94	0.14
	Bw2	150-190+	7.98	0.16

was between 21 and 30% for clay textural classes. The Available Water Content (AWC) ranged from 9 to 20% for the same textural classes and the values were influenced by organic matter and clay contents within the horizons (Table 3). In pedons 2 and 4, (AWC) increased with depth. Various reports (Gill et al., 2012; Nagaraju and Gajbhiye, 2014) indicated the positive relationship between clay content and the amount of water retained at -33 and -1500 kPa. The Available Water Holding Capacity (AWHC) of the soil on horizon basis could be rated as low, medium and high in accordance with Beernaert (1990), who rated available water content values <8,8-12,12-19,19-20 and > 21 volume percentage as very low, low, medium, high and very high, respectively.

## Chemical soil characteristics

### Soil pH and electrical conductivity

The pH values of the soils in the pedons ranged from neutral to moderately alkaline (6.84 - 7.98), in accordance with the rating of Jones (2003). The pH-H<sub>2</sub>O values varied from 6.84 to 7.76 in the surface layers and 7.02 to 7.98 in the subsurface horizons with increasing trend with depth in all pedons except for pedon 2 (Table 4). Increased soil pH in pedons with soil depth may indicate a presence of vertical movements of exchangeable bases and fewer H<sup>+</sup> ions release from the decomposition of organic matter, which is caused by decreased organic matter content with depth (Abay and

Sheleme, 2012).

Electrical conductivity (EC) of the soils showed very low values that ranged from 0.06 to 0.16 dS/m, indicating that the soils are not saline (FAO, 1988) (Table 4). Based on the salinity rating classified by Horneck et al. (2011), the EC results obtained in soils of the study area indicated that the concentration of soluble salts in soils of the watershed were below the levels at which most crop cultivation are affected.

### Soil organic carbon (SOC), total nitrogen (TN) and carbon to nitrogen ratio (C: N) and available phosphorus (Av, P)

The SOC in the study area were in the range between 1.83 to 0.64% in pedon 1 (0 - 55 cm and 122 - 200+ cm, respectively) (Table 5). It did not show a consistent trend across topographic positions, but it decreased with soil depth in all pedons. Relatively higher values were recorded in the soils on flat level slope class positions of the surface horizons. The lower value was recorded in pedon 1 at the subsurface layer on the flat topographic position. Generally, the SOC of the study area was between low and medium/moderate (Tekalign, 1991) who rated the values of OC as extremely very low (< 0.5%), low (0.5 - 1.5%), medium (1.5 - 3%) and high (> 3%). The (TN) content in the surface horizons of the soils ranged from 0.125% in pedon 3 to 0.135% in pedon 1, while in the subsurface horizons it ranged from 0.062% in pedons 2 and to 0.101% in pedons 1 (Table 5). Generally, TN content of the soils showed a decreasing trend with soil



**Table 5.** Soil organic carbon, total nitrogen, carbon to nitrogen ratio and available phosphorus of the soils.

Horizon	Depth (cm)	OC%	TN%	C:N	Av.P. (mgkg <sup>-1</sup> )
<b>Pedon 1</b>					
A1	0-55	1.83	0.135	13.56	4.81
A2	55-90	1.01	0.101	10.00	3.58
Bw1	90-122	1.0	0.088	11.36	3.24
Bw2	122-200+	0.64	0.067	9.55	3.01
<b>Pedon 2</b>					
A1	0-54	1.67	0.134	12.46	4.01
A2	54-93	1.01	0.093	10.46	3.41
Bw1	93-133	0.83	0.084	9.88	3.19
Bw2	133-200	0.7	0.062	11.29	3.13
<b>Pedon3</b>					
AE	0-43	1.47	0.125	11.76	3.98
BAt	43-72	0.92	0.092	10.00	3.11
Bt1	72-115	0.82	0.081	10.12	3.02
Bt2	115-200	0.81	0.072	11.25	2.86
<b>Profile 4</b>					
Ap	0-25	1.56	0.133	11.73	3.54
A2	25-63	1.47	0.091	16.15	3.09
Bw1	63-150	0.82	0.074	11.08	2.72
Bw2	150-190+	0.8	0.066	12.12	2.24

OC = Organic carbon, TN = Total nitrogen, C: N = Carbon to nitrogen ratio, Av. P = Available phosphorus.

depth.

The TN content of the surface horizons was higher as compared to the subsurface soil horizons and it followed a similar pattern with that of OC in all the studied pedons, implying that there is a strong relation between OC with TN in the soil system. In agreement with this result, Meysner et al. (2006) indicated that as much as 93 to 97% of the total N in soils is closely associated with OC. As per the rating set by Tekalign (1991), TN contents of the surface layers of pedons 1, 2, 3, and 4 were rated as moderate (0.12 -0.25%) while in the subsurface of all pedons it was within low range (0.05-0.21%). According to Chizoba (2014), the low levels of TN in the soils may also be due to intensive cropping practices without measures to build up soil nutrient reserves.

The C: N ratio in the surface horizons and subsurface horizons of all pedons was in narrow range which may be due to the effect of microbial activity that results in relatively fast decomposition of OM and the consequent CO<sub>2</sub> evolution, aeration during tillage and suitable soil pH range (6.7-7.3) to (7.4-8.0) could be some of the contributors that favor microbial activity which in turn favor fast OM decomposition and further become responsible for the narrow C: N ratio of the soils. Achalu et al. (2012) also reported a narrow C: N ratio at the surface soils of cultivated land as a result of enhanced

mineralization of OC than N due to better aeration during tillage and increased temperature.

### **Available phosphorus**

Available P content of soils in the surface horizon ranged from 3.54 mg kg<sup>-1</sup> in pedon 4 to 4.81 mg kg<sup>-1</sup> in pedon 1 while in the subsurface horizon it varied from 2.24 mg kg<sup>-1</sup> at 150 to 190+ cm depth in pedon 4 to 3.13 mg kg<sup>-1</sup> at 133- 200 cm depth in pedon 2 (Table 5). The available phosphorus (Av. P) content of the soils decreased with soil depth in all pedons. The higher Av. 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 NPS containing fertilizer and compost by farmers. Awdenest et al. (2013) also argued that the higher Av. P in the topsoil layer of farmland might be related to the application of animal manure, compost, household wastes like ashes and fertilizer for soil fertility management. This finding is also in line with Girma and Endalkachew (2013) who pointed out that the relatively higher phosphorus in topsoil might be attributed to external phosphorus supply, and phosphorus carried over from fertilization. Generally, according to Jones (2003), the Av. P contents of the

**Table 6.** Exchangeable cations, cation exchange capacity, percent base saturation and ESP of the soils pedons of Argo-Gedilala subwatershed.

Horizon	Depth (cm)	Ca	Mg	K	Na	CEC Soil	Clay	PBS	ESP
		(cmol <sup>(+)</sup> kg <sup>-1</sup> ) soil				(cmol <sup>(+)</sup> kg <sup>-1</sup> )		%	%
Pedon 1									
A1	0-55	22.9	9.66	0.69	0.22	41.49	73.3	80.67	0.51
A2	55-90	23.6	9.76	1.22	1.01	42.25	77.5	84.24	2.45
Bw1	90-122	24.2	9.99	1.34	1.22	42.58	72.5	86.31	2.89
Bw2	122-200+	24.52	10.89	1.47	1.05	43.52	73.8	87.16	2.59
Pedon 2									
A1	0-54	22.41	8.76	1.23	1.09	39.52	80.4	84.74	2.56
A2	54-93	23.46	9.22	1.69	1.51	41.01	83.5	87.49	3.77
Bw1	93-133	24.54	9.34	1.57	1.44	42.09	89.2	87.65	3.60
Bw2	133-200	25.64	9.64	1.76	1.68	43.12	81.4	89.80	4.29
Pedon 3									
AE	0-43	21.68	9.72	0.81	0.39	41.03	224.8	79.45	0.93
BAt	43-72	22.48	8.01	1.8	1.57	41.98	92.4	80.66	3.82
Bt1	72-115	22.52	9.8	1.86	1.32	42.01	81.6	84.50	3.22
Bt2	115-200+	23.56	9.03	2.5	1.88	42.22	82.1	87.57	4.92
Pedon 4									
Ap	0-25	20.48	10.3	0.92	0.41	40.41	83.4	79.46	0.96
A2	25-63	20.72	9.23	3.16	1.02	40.43	80.4	84.42	2.59
Bw1	63-150	20.85	8.34	1.69	1.49	41.73	84.6	77.57	3.57
Bw2	150-190+	21.41	8.02	2.42	1.9	40.75	73.1	82.82	5.03

CEC = Cation Exchange Capacity, ESP = Exchangeable Sodium Percentage, PBS = Percent Base Saturation.

soils in the watershed ranged from very low to low which is not within the optimum range for crop production. According to this author, the Av. P extracted by Olsen method is rated for Av. P < 3 mg kg<sup>-1</sup> as very low, 4-7 mg kg<sup>-1</sup> as low, 8-11 mg kg<sup>-1</sup> as medium, and > 12 mg kg<sup>-1</sup> as high. Phosphorus deficiency in Ethiopian soils is well documented in various research works (Melese et al., 2015; Kebede et al., 2017). Moreover, the low content of available P could be attributed to fixation by Ca content as Ca-P. Scholars reported that the Ca bounded (Ca-P) is the major inorganic

P fraction in alkaline soils (Landon, 2014). Moreover, the recycling of phosphorus in soil is considered slow because it gets fixed and absorbed on soil particles.

***Exchangeable bases, cation exchange capacity (CEC), percent base saturation (PBS) and exchangeable sodium percentage (ESP)***

The exchange complex was predominantly occupied by exchangeable Ca<sup>2+</sup> followed by Mg<sup>2+</sup>,

K<sup>+</sup>, and Na<sup>+</sup> (Table 6), which could be considered as essential for plant growth except Na<sup>+</sup>. These basic cations in productive agricultural soils are present in the order Ca<sup>2+</sup> > Mg<sup>2+</sup> > K<sup>+</sup> > Na<sup>+</sup> and deviations from this order can create ion-imbalance problems for plants (Bohn, 2001). Generally, the contents of exchangeable bases increased with increasing soil depth, perhaps due to leaching of exchangeable cations in the study area. Supporting to this finding, other authors (Ashenafi, et al., 2010; Nahusenay et al., 2014) indicated that accumulation of exchangeable Ca<sup>2+</sup>

**Table 7.** Diagnostic horizons, properties and materials identified and soil classification according to IUSS Working Group WRB (2015).

Pedon	Diagnostic horizon		Diagnostic properties	Diagnostic materials	Soil classification (RSGs)
	Surface	Subsurface			
1	Chernic	Cambic	-	Mineral	Cambic Chernic Phaeozem (Pantoclayic, Humic, Hypereutric)
2	Chernic	Cambic	-	"	Cambic Chernic Phaeozem (Pantoclayic, Humic, Hypereutric)
3	Mollic	Argic	A.T.D.	Albic	Luvic Phaeozem (Abruptic, Albic, Clayic, Differentic, Hypereutric).
4	Chernic	Cambic	-	Mineral	Cambic Chernic Phaeozem (Pantoclayic, Humic).

A.T.D. = Abrupt textural difference; RSG = Reference soil group.

with depth could be due to translocation from the overlying horizons. In accordance with the ratings of (FAO, 2006) the soils are categorized under very high with respect to Ca and Mg contents and high to very high in terms of K.

CEC of the soils of the study area in the surface horizons ranged from 39.52 cmol l<sup>(+)</sup> kg<sup>-1</sup> soil by pedon 2 (0–54 cm to 41.49 cmol l<sup>(+)</sup> kg<sup>-1</sup> soil at pedon 1(0-55 cm) while in subsurface horizons it ranged from 40.43cmol l<sup>(+)</sup> kg<sup>-1</sup> soil in by pedon 4 at a depth (150-190+ cm) to 43.52 by pedon 1 (90 - 120 cm) (Table 6 ), which was rated as high to very high according to Hazelton and Murphy (2007).

Following the variation in exchangeable bases and cation exchange capacity, (PBS) of the soils in the study area showed considerable variability within and among the pedons. Accordingly, in the study area varied from 77.57 to 89.80% in pedon 4 at (63 - 150 cm) depth and pedon 2 (133-200 cm) depth, respectively.

PBS of the soils in the subwatershed did not show any consistent trend with topographic position. However, it showed a consistent increasing trend with soil depth within the pedons except pedon 4. The increase with soil depth 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 with in high to very high range (Hazelton and Murphy, 2007). In general, the occurrence of higher percentage of the base saturation is almost in all soil profiles could be used as an indication of soil fertility and presence of high weather able minerals in the soil (FAO-WRB, 2006). The exchangeable Na content of the soils was low and the exchangeable sodium percentage (ESP) of the soils was also less than 15% (Table 7). This indicates that there is no sodicity problem in these soils. According to Brady and Weil (2002), ESP of 15% is considered as critical for most crops.

### Soil classification and mapping

The soils were classified based on both morphological

and physicochemical properties of soils following the WRB for soil resources (IUSS Working Group WRB, 2015). The identification of the diagnostic soil characteristics (diagnostic horizons, properties and materials) was performed based on the morphological profile description and physicochemical soil laboratory analysis data; and the presence or absence of specific diagnostic soil characteristics was employed to distinguish the reference soil groups (RSGs) as given in the employed classification system following the classification "Key" provided for the purpose (Table 7). All the pedons had granular structured dark surface horizons of ≥25 cm in thickness that have friable moist consistence and moist color notation of 10YR 3/2 by pedon 1, and a color notation of 10YR 3/1 by pedons 2, 3 and 4.

The organic carbon content of the surface horizons of the pedons ranged from 1.47% to 1.83% with percent base saturation values of greater than 50% or more throughout the profiles by 1M NH<sub>4</sub>OAc analysis method at pH7. Such morphological features indicate the existence of a chernic surface diagnostic horizon (epipedon) as a type of a mollic horizon.

Pedons 1 and 2 had very deep well drained effective soil depth of more than 200 cm, whereas pedons 3 and 4 had also very deep profiles with effective soil depth of more than 190 cm and similar internal drainage condition as that of pedons 1 and 2. Moreover, except by pedon 4, all the horizons below the uppermost layer had base saturation of greater than 80% (hypereutric). Except in pedon 3, the clay content of the profiles gradually increased with depth without any distinct difference in clay content; and the color brightness of the horizons increased with depth. Even though all the layers had higher clay content (>30%) starting at the soil surface, with the exception of pedon 3, no clay films (cutans, coatings) and no other morphological features that indicate either the presence of an argic, a vertic or any other diagnostic subsurface horizon or property could be observed throughout the profile. Additionally, the occurrence of any form of secondary (pedogenic) carbonates could not be observed throughout the profile of all pedons. Accordingly, the subsoil layers of pedons 1,

2 and 4 give a clue only to the presence of a cambic type diagnostic subsurface horizon without any additional diagnostic property that may be used for further interpretation. Therefore, in accordance with WRB for Soil Resources (IUSS Working Group WRB, 2015), pedon 1 and 2 were classified as Cambic Chernic Phaeozems (Pantoclayic, Humic, Hypereutric); and pedon 4, as Cambic Chernic Phaeozem (Pantoclayic, Humic).

The profile of pedon 3 had morphological features different from all the other three profiles (pedons). Its surface layer at the depth of 0 – 43 cm was lighter in color (2.5 YR 6/1 (gray) for dry soil) and coarser in texture than the underlying layer and all the surficial horizons of the other three pedons. All the three horizons below this horizon had almost similar morphological features and were more clayey; whereby the texture analysis results also confirmed the existence of distinct textural difference between the surface horizon and the other three horizons below it. Accordingly, the surface layer is considered as a type of eluviated A-type horizon and hence designated as an AE horizon since its A horizon features are clearly discernible in its structure and OC content. All the three layers below were presumed to be a part of illuviated subsoil due to their markedly higher clay content that showed the existence of an abrupt textural difference in relation to the presence of an argic (argillic) diagnostic subsurface horizon in the subsoil of the pedon. Therefore, all the subsoil horizons of this pedon were designated as types of illuvial horizons (BA<sub>t</sub>, B<sub>t1</sub>, B<sub>t2</sub> in order of increasing depth). However, the second horizon (BA<sub>t</sub>) has got some morphological features that qualify it for a mollic horizon; for example, its thickness and base saturation, the color notation of its soil material and its organic carbon content fulfill the diagnostic criteria of a mollic horizon. Based on the above information, the soil represented by the profile of pedon 3 is classified as Luvic Phaeozem (Abruptic, Albic, Clayic, Differentic, Hypereutric) (Figure 2).

## Summary

In most of the observation points, the soil depths of the pedons were found to be greater than 200 cm, although the identified genetic horizons had variable thickness. Difference in amount and distribution of particle size (clay, silt and sand) content with depth and across the soils was also recorded. Generally, clay size fraction dominated the texture of soils in the study area. The bulk density of the studied pedons' surface horizons ranged from 0.94 to 1.15 g cm<sup>-3</sup>, and the corresponding values for the subsurface horizon ranged from 1.19 to 1.28 g cm<sup>-3</sup> respectively, which indicated that the studied soils were within the suitable range for agricultural uses. The soil water content retained at field capacity (33 kPa) ranged from 36 to 44%; whereas, at permanent wilting

point (1500 kPa), it was between 21 and 32% for clay textural classes.

Soil reaction (pH) of the pedon ranged from moderately alkaline to neutral (6.84 - 7.98). The SOC content of soils were in the range of 0.64 to 1.83, which did not show consistent trend across topographic positions, but decreased with soil depth in all pedons. Available P of soils in the surface horizon ranged from 3.54 mg kg<sup>-1</sup> in pedon 4 to 4.81 in pedon 1, while in the subsurface horizon it ranged from 2.24 mg kg<sup>-1</sup> in pedon 4 to 3.58 mg kg<sup>-1</sup> in the pedon 1. It decreased with depth in all pedons, which ranged from very low-to-low and hence is not within the optimum range for crop production.

The soil classification revealed that pedon 1 and pedon 2 were Cambic Chernic Phaeozems (Pantoclayic, Humic, Hypereutric); and pedon 4, Cambic Chernic Phaeozem (Pantoclayic, Humic); whereas, pedon 3 is found to be a kind of Luvic Phaeozem (Abruptic, Albic, Clayic, Differentic, Hypereutric); which indicated that Phaeozems are the most likely dominant soils within the subwatershed studied.

## Conclusion

In conclusion, almost all of the studied soil properties varied from pedon to pedon most likely due to variation in slope gradient, elevation, parent material, and soil management practices. The soils of the study area were low in organic matter, available P and total nitrogen content in all the cultivated lands, which were identified as production constraints. Special emphasis should be given to soil OM management as it plays a major role in soil physical, chemical, and biological quality. Additionally, integrated soil fertility management should be implemented in the area to optimize and sustain crop production. It can also be recommended that increasing the level of organic matter through continuous application of manure, compost or by any other mechanism, should be integrated with the use of chemical fertilizers.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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