

Research Article

Characterization, Classification and Mapping of Soil Resources in Adami Tulu Jido Kombolcha District of East Shewa Zone, Oromia

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Abstract

A study was undertaken in Adami Tulu Jido Kombolcha District of Oromia region, Ethiopia, to investigate the site, morphological and physico-chemical characteristics, classification and mapping of soils. Fourteen soil pedons at representative sites were described and 66 disturbed and undisturbed soil samples from identified horizons were taken for laboratory analysis. The data obtained showed that the soils varied from moderate to very deep, well drained, the surface soil color at (dry) varied from light gray (10YR 7/2) to very dark brown (7.5YR 2.5/2); at moist varied from brown (10YR4/3) to black (10YR2/1), while the subsurface color varied from white (10YR 8/1) to black (7.5YR 3/1,) at dry conditions and at moist condition the color varied from light gray (7.5YR 7/2) to black (7.5YR 2.5/1), the structure in the surface layers of the pedons 1, 2, 3, 6, 14 had weak fine granular and gradually in subsurface changed to Moderate fine sub angular blocky in the same pedons; Strong fine granular at surface changed to strong fine sub angular blocky in pedon 4; Strong fine angular blocky in pedon 5 and moderate medium granular in pedon 7 and 8 at surface and subsurface without gradual change. The values of the determined soil physical characteristics revealed that sand, silt, clay, bulk density and total porosity ranged from 34 to 81.78%, 9.22 to 48%, 5 to 28%, 0.95 to 1.31 g cm⁻³, 50.56 to 64.15% respectively. Moreover, the soils were neutral (pH 6.7 to 7.3) to strongly alkaline (pH >8.0), salt free (< 1dsm⁻¹) except pedon 9 and 10 near to lake Abjeta. Soil organic matter content ranged from very low to moderate in and total N ranged very low to moderate, available phosphorus ranged from very low to low respectively. Soil exchangeable Ca²⁺ ranged from moderate to high (5.13 to 21.8 cmol(+) kg⁻¹), high to very high in exchangeable K (0.65 to 3.46 cmol(+) kg⁻¹), moderate to high in Mg (1.28 to 6.7 cmol(+) kg⁻¹), low to very high in exchangeable Na (0.13 to 10.1 cmol(+) kg⁻¹) and, moderate to high CEC (13.13 to 38.88% cmol(+) kg⁻¹) and moderate to very high PBS (50.92 to 97.69%), respectively. Soil of the district was classified as chromic vertisols, Luvic phaeozems, vitric andosols, Solonetz and mollic andosols.

Keywords

Soil Characteristics, Soil Classification, Soil Mapping

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1. Introduction

Soil is a slowly renewable dynamic natural resource that determines the ultimate sustainability of any agricultural system. Water movement, water quality, land use, and vegetation productivity all have relationships with soil. Soils provide food, fodder and fuel which is necessary for basic human and animal needs [16]. However, due to the increasing rate of the population demanding for food, the nutrients have been depleted and the productive capacity of soils has diminished through changes in soil characteristics. This demands systematic evaluation of soil resources with respect to their extent, distribution, characteristics, and use potential, which is very important for developing an effective land-use system for augmenting agricultural production on a sustainable basis [15].

Agriculture must feed, clothe and provide energy to a rapidly increasing world population while minimizing environmental and other unwanted impacts. After long stagnation, crop production in Ethiopia started to show considerable growth only recently although a range of policies and investments have been pursued over the past four decades [3]. Low agricultural productivity and related shortage of additional cultivable lands are also common problems to most Sub-Saharan African (SSA) countries [6, 17]. From the many reasons suggested for the current low agricultural production and productivity in SSA, the major ones are land degradation, nutrient mining, recurrent droughts, variable rainfall and crop pest damages [5, 11].

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 [4] and implementing sustainable land uses [12]. 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 and larger level are providing a basis for blanket recommendation of various package of practices including fertilizers and other inputs. Fertilizer recommendations in Ethiopia deal with nitrogen (N) and phosphorus (P) dosages only, and so far it is assumed as standard for the country disregarding the mosaic soil nature of Ethiopia [1].

The coupling of soil characterization, soil classification and soil mapping provides a powerful resource for the benefit of mankind especially in the area of food security and

environmental sustainability. Soil characterization provides the information for our understandings of the physical, chemical, mineralogical and microbiological properties of the soils humans depend on to grow crops, sustain forests and grasslands as well as support homes and society structures [14]. Soil classification, on the other hand, helps to organize our knowledge, facilitates the transfer of experience and technology from one place to another and helps to compare soil properties. According to [9] some different uses of soil characterization data include to aid in the correct classification of the soil and enable other scientists place the soils in their taxonomies or classification systems and to serve as a basis for more detailed evaluation of the soil as well as gather preliminary information on nutrient, physical or other limitations needed to produce a capability class. Soil characterization study, therefore, is a major building block for understanding the soil, classifying it and getting the best understanding of the environment [8]. Hence this study is initiated to conduct the activity for Adami Tulu Jido Kombolcha District with the following objectives.

Objectives

1. To characterize and classify soils of the District
2. To Map soil types of the District

2. Materials and Methods

2.1. Description of the Study Area

Geographically, Adami Tulu Jido Kombolcha District is found in East Shewa Zone of the Oromia Regional State (Figure 1), in the Ethiopian Great Rift Valley. The geographical location of the study area lies between the Universal Transverse Mercator (UTM) coordinates of 7°00'–8°30' north latitude and 38°00'–39°30' east longitude with an elevation that ranges from 1500 to 2300 m.a.s.l. The District receives annual rainfall from 500 to 900 mm and its map is indicated below.

The topography of the district is characterized by flat, level land, gently sloping, constituting plains to strongly sloping and steep slope. The area is a good representative of ecologies that experience high population pressure, soil fertility depletion and food shortages due to low production and strong crop-livestock interactions. Attributed to the long history of crop cultivation and deforestation of the soils of most parts of the area are found to be exposed to wind and water erosion at the District.

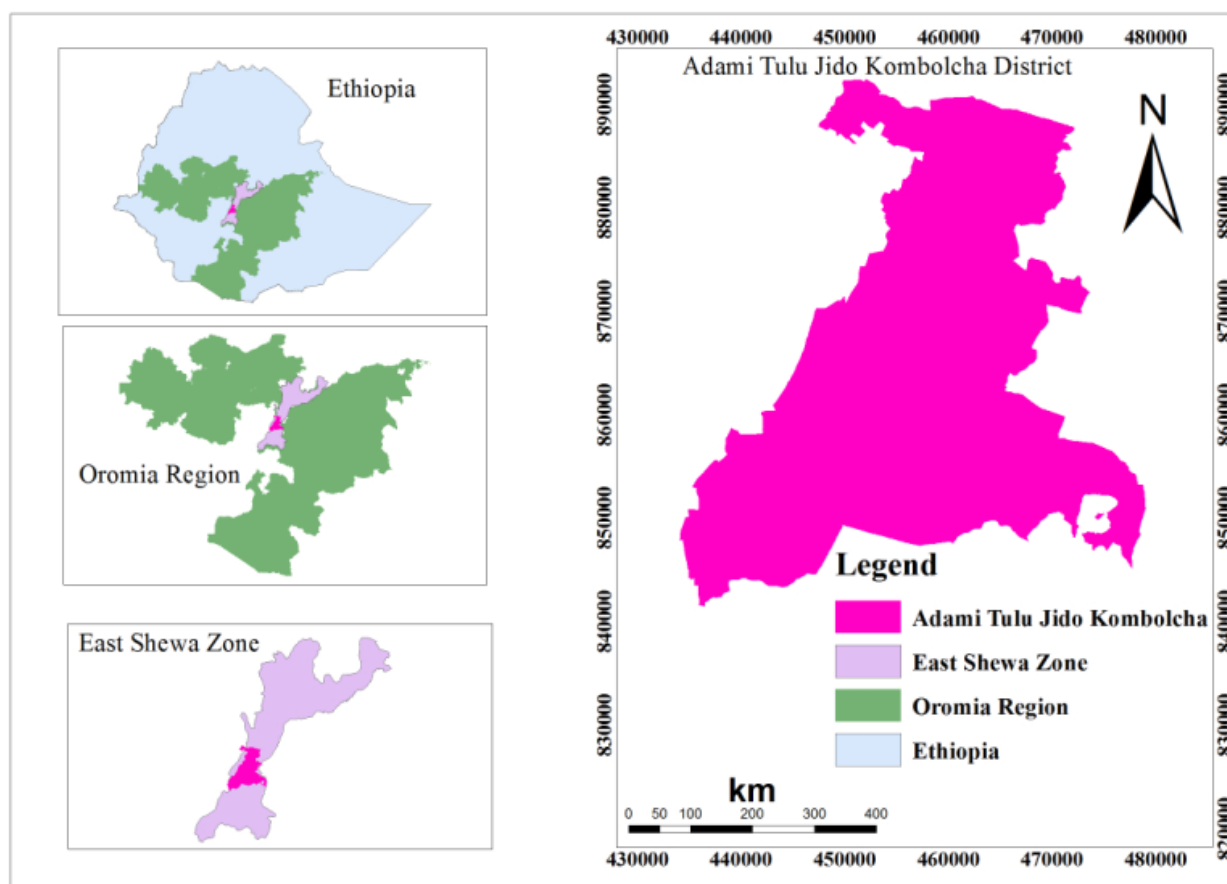


Figure 1. Location map of the study area.

2.2. Geology

The site's geology is mainly volcanic rocks and some lacustrine and alluvial sediment. 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 [7].

2.3. Climate and Hydrology

The agro-ecological zone of the district is semi-arid and sub-humid in which 90% of the area is lowland while the remaining 10% is intermediate [13]. The study area is characterized by two seasons, rainy (summer) and dry (winter) seasons which fall under uni-modal rainfall pattern. The rainy and dry periods are locally known as 'gana' and 'Bona', respectively. As per the information obtained from the area, most of the time the rainfall pattern for the growing season is characterized by erratic and uncertainty both in amount and distribution and starts from April 15 (2nd decade)

if it is early or in 2nd and 3rd decade of May if it is late and extending to September and the dry season covers the rest. May is the hottest month and December is the coolest month. Maximum amount of rainfall for the area is observed in the month of July followed by August. The mean minimum and maximum annual temperatures of the area are ranged from 11.4 °C to 15.8 °C and 25.3 to 29.3 °C, respectively with average temperature 20.5 °C and by having relative humidity of growing period 77%.

2.4. Site Selection, Pedon Description and Soil Sampling

1. Site Selection

Before starting the field characterization and field work, a preliminary interpretation of topographic map of the study area (1:50,000), Preliminary district boundary was delineated and temporary pedon site were identified using topographic map of the study area (1:50,000) and Digital elevation model (DEM: 30 x 30m resolution) and soil mapping units were prepared.

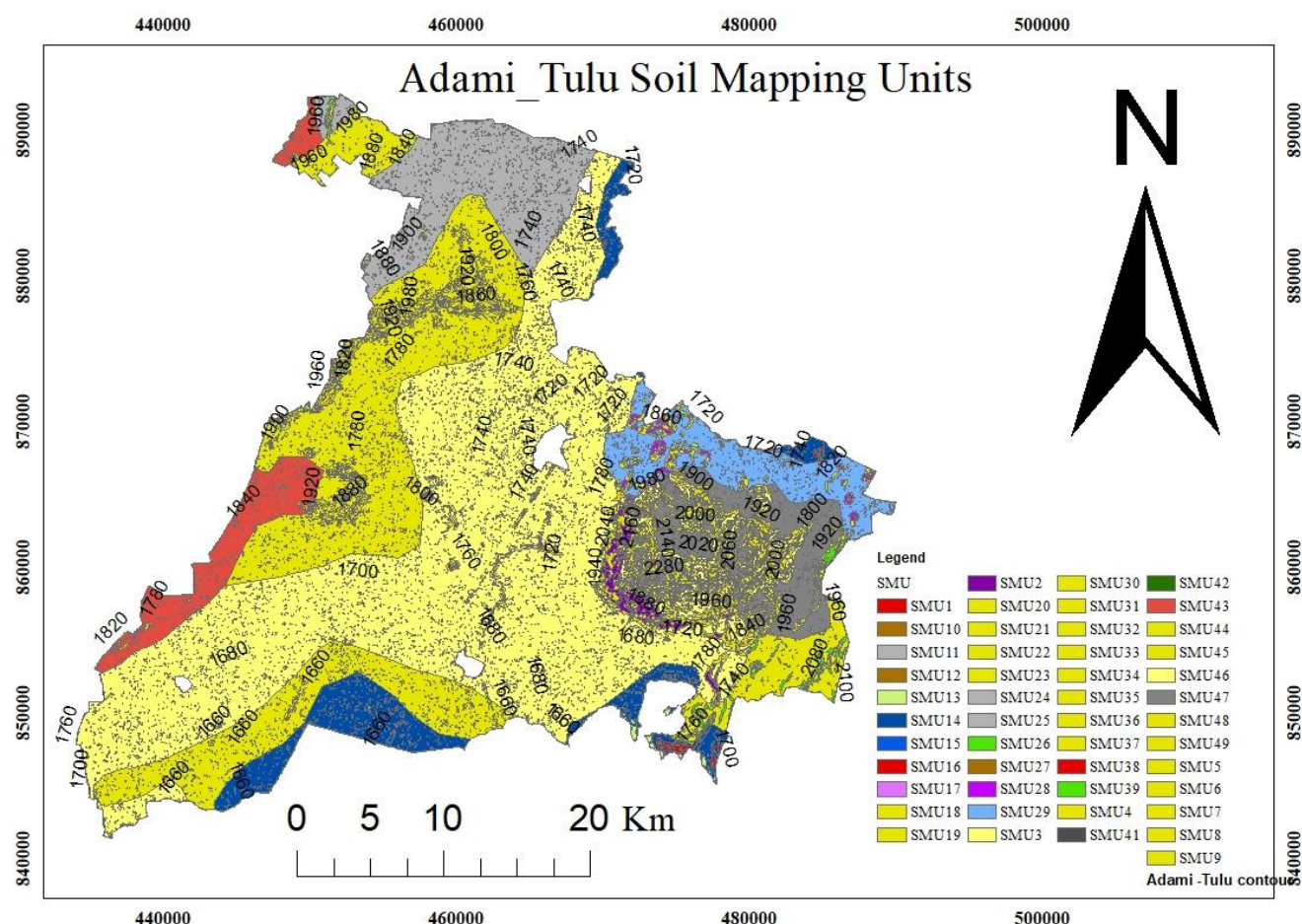


Figure 2. Soil mapping Units of the study area.

Site characteristic such as: land use /land cover, slope class, surface drainage and surface soil characteristic (soil color, texture) were well recorded. The topographic map was used to identify preliminary land use, slope class, drainage, agro-ecologic zones and to fix tentative sampling sites for pedons which are mostly based on slope of the study area. After office work and preparation of materials and prior to the opening of soil pedons, field physical observation and surveying were done by transect walk and with the help of the map of the area to consolidate and determine representative sampling sites of the area. Based on the heterogeneity and homogeneity of the soils, tentative soil map was prepared to determine as to which specific areas should be selected as representative sites of the study area for pedon preparation/excavation. The basis for the classification and then locating soil pedon sites were surface characteristics and slope classes.

2. Pedon Description and Soil Sampling

Fourteen representatives pedons (1.5m width and 2m length unless limited by continuous hard layer /bedrock) were opened and described on standard description sheet based on FAO soil description guidelines [10]. Site characteristics, the morphological properties of each genetic horizon within a pedon such as:-(soil horizon, depth, boundary, soil color, texture, structure and consistence) were recorded

on standard sheet. More over the geographic coordinates, altitude the pedons were recorded and georeferenced using GPS respectively.

The pedon site was georeferenced with the help of Arc GIS 10.3.1. at different slope gradient and located on the appropriate scale base map. Representative soil samples were collected from each identifiable and demarcated genetic horizon or soil layer of the pedon in each of the mapping units for characterization of their physiochemical properties that are relevant to the objectives of the study. A total of 66 disturbed and 66 undisturbed (core) soil samples were sampled depth wise from each evident genetic horizon of the representative pedon. The undisturbed (core) soil samples were for the determination of bulk density.

Morphological characteristics such as depth of solum and horizon, structure, color, horizon boundary, consistence etc. were described in the field during soil sample collection and pedon characterization. Soil depth was determined following the thickness of the loose soil from the surface to a limiting impermeable layer (for plant roots and/or percolating water). Soil color was measured both under dry and moist conditions using the Munsell Soil Color Chart (Munsell Color Company). Routine cross checks were done for accuracy of the colors. Soil structure was studied in terms of: type (shape), grade and size of aggregates whereas horizon boundaries were de-

scribed in terms of depth, distinctness and topography. The soil consistence was identified at dry and wet moisture conditions. Morphological soil properties were studied based on the guidelines of [10].

Soil Sample Preparation and Laboratory Analysis

Soil sample preparation

The sampled soils were carefully bagged, labeled and the packed samples were transported to the laboratory for analysis. The disturbed soil samples collected from each horizon were air dried at room temperature, grounded using mortar and pestle and made 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 following the standard analytical procedures.

3. Results and Discussions

3.1. Morphological Characteristics of Soil Pedons

1. Soil color and Soil structure and consistence

By using Munsell Color Chart, the surface soil color (dry) varied from light gray (10YR 7/2) in pedon 1 to very dark

brown (7.5YR/2.5/2) in pedon 5; at moist soil color conditions varied from brown (10YR4/3) in pedon 5 to black (10YR2/1) in pedons 1, 2, 3, 4, 8 and 11, while the subsurface color varied from white (10YR 8/1) in pedon 2 and 3 to black (7.5YR 3/1,) in pedon 4 at dry conditions and at moist condition the color varied from light gray (7.5YR 7/2) in pedon 6 and 10 to black (7.5YR 2.5/1) in pedon 1& 4, (10YR 2/1) in pedon 3, 12, 14 respectively (Table 1 below).

There was a difference in size, grade as well as shape of soil structure within each pedon among horizons and among soil pedons of the district. Accordingly, the structure in the surface layers of the pedons 1, 2, 3, 6, 14 had weak fine granular and gradually in subsurface changed to Moderate fine sub angular blocky in the same pedons; strong fine granular at surface changed to strong fine sub angular blocky in pedon 4; Strong fine angular blocky in pedon 5 and moderate medium granular in pedon 7 and 8 at surface and subsurface without gradual change.

Results in soil consistence, characteristic outcomes in the surface layers varied from loose in pedon 9 and 10 to hard (HA) in pedon 4 and 5 when dry; when wet varied from non-sticky/ non plastic in pedon 9 and 10 to stick/plastic in pedons 2, 4, 5 and 14. In the subsurface horizons it varied from none sticky and none plastic when wet in pedons (1, 2, 3, 6, 9 and 10) to sticky and plastic when wet in pedons (4, 5 and 14); but when dry, it ranges from loose in pedon 1, 2, 3 and 10 to very hard in pedon 2 and 3 (Table 1 below).

Table 1. Morphological characteristics of soil pedons of Adami Tullu Jido Kombolcha District.

	Depth (cm)	Horizon bound. Color				Structure			Consistence		
		D.	T.	dry	moist	Grad	Size	Shape	dry	wet	
										Stick	Plastic
Pedon 1											
Ap	0-17	D	S	10YR7/2	10YR2/1	WE	FI	GR	SO	SST	SPL
A	17-40	D	S	7.5YR7/3	7.5YR3/1	MO	FI	SB	SHA	SST	SPL
A1	40-73	D	S	7.5YR7/1	10YR4/1	MO	FI	AB	SHA	NST	NPL
Bw1	73-120	G	S	7.5YR6/2	7.5YR2.5/1	MO	FI	GR	SHA	NST	NPL
Bw2	120+			7.5YR7/2	10YR5/3	MO	FI	GR	LO	NST	NPL
Pedon 2											
Ap	0-23	D	S	10YR5/3	10YR2/1	WE	FI	GR	SO	ST	PL
A	23-54	G	S	10YR4/2	10YR2/2	MO	FI	SB	SHA	SST	SP
A1	54-107	C	S	10YR6/2	10YR4/2	WE	FI	GR	LO	NST	NPL
Bw1	107-150	C	S	10YR7/2	10YR4/3	ST	FI	SB	HA	NST	NPL
Bw2	150+			10YR8/1	10YR6/3	ST	FI	AB	VHA	NST	NST
Pedon 3											

	Depth (cm)	Horizon bound. Color				Structure			Consistence		
		D.	T.	dry	moist	Grad	Size	Shape	dry	wet	
										Stick	Plastic
Ap	0-18	D	S	7.5YR4/3	10YR2/1	WE	FI	GR	SO	SST	SPL
A	18-40	G	S	7.5YR4/1	10YR2/1	MO	FI	SB	SO	SST	SPL
A1	40-72	G	S	5YR6/2	10YR3/2	MO	VFI	SB	SHA	SST	SPL
Bw1	72-118	C	S	10YR8/1	10YR6/3	ST	FI	SB	VHA	NST	NPL
Bw2	118+			Glauy7/1	10YR6/2	WE	VFI	SB	LO	NST	NPL
Pedon 4											
Ap	0-25	D	S	5YR3/1	10YR2/1	ST	FI	GR	HA	ST	PL
A	25-60	D	S	7.5YR3/1	7.5YR2.5/1	ST	FI	SB	HA	ST	PL
A1	60-90	C	S	7.5YR3/2	7.5YR2.5/2	MO	FI	SB	HA	ST	PL
A2	90-115	C	S	7.5YR6/3	2.5YR4/4	ST	FI	SB	SHA	SST	SPL
Bw1	115-160	C	S	7.5YR7/6	10YR4/4	MO	FI	AB	SHA	SST	SPL
Bw2	160+			7.5YR6/4	10YR3/6	MO	FI	AB	SHA	SST	SPL
Pedon 5											
A _p	0-40	D	S	7.5YR2.5/2	10YR4/3	ST	FI	AB	HA	ST	PL
A	40-75	D	S	7.5YR4/2	10YR3/1	ST	FI	AB	HA	ST	PL
A ₁	75-120	D	S	10YR5/1	10YR3/1	MO	FI	SB	HA	ST	PL
Bw1	120-170	G	S	7.5YR4/2	7.5YR2.5/2	MO	FI	SB	SHA	SST	SPL
Bw2	170+			10YR6/1	7.5YR4/1	MO	FI	AB	SHA	SST	SPL
Pedon 6											
A _p	0-20	C	S	10YR5/2	7.5YR2.5/2	WE	FI	GR	SHA	SST	SPL
A	20-90	G	S	10YR7/3	2.5YR5/4	MO	FI	SB	SHA	SST	SPL
A1	90+			Gley 8/10y	1 ¹ 7.5YR7/2	WE	FI	GR	SO	NST	NPL
Pedon 7											
Ap	0-35	C	S	10YR5/4	10YR3/3	MO	ME	GR	SHA	SST	SPL
A	35-75	C	S	10YR5/3	7.5YR3/1	MO	ME	GR	SHA	SST	SPL
Bw1	75-110	G	S	10YR7/2	7.5YR3/3	ST	ME	AB	HA	SST	SPL
Bw2	110+			10YR6/3	7.5YR3/1	ST	ME	SB	HA	SST	SPL
Pedon 8											
A	0-60	D	S	7.5YR5/1	10YR2/1	MO	ME	GR	SHA	SST	SPL
A1	60-100	D	S	7.5YR5/3	10YR3/1	MO	ME	GR	SHA	SST	SPL
B	100-150	D	S	7.5YR7/1	7.5YR3/2	MS	ME	AB	HA	SST	SPL
B1	150-180+			7.5YR7/3	7.5YR4/4	ST	ME	SB	HA	SST	SPL
Pedon 9											
Ap	0-10	C	S	2.5YR6/2	7.5YR3/1	MO	FI	AB	LO	NST	NPL
A	10-20	C	S	2.5Y7/3	7.5YR4/2	MO	FI	P	SHA	NST	NPL

		Horizon bound. Color				Structure			Consistence			
		Depth (cm)	D.	T.	dry	moist	Grad	Size	Shape	dry	wet	
											Stick	Plastic
A1	20-35	C	S	2.5Y6/1	7.5YR3/2	ST	FI	P	SHA	NST	NPL	
A2	35-50	G	S	2.5Y5/3	7.5YR4/1	ST	ME	P	SHA	NST	NPL	
A3	50-80	D	S	2.5Y6/2	7.5YR6/1	ST	ME	P	SHA	NST	NPL	
Bw1	80-105	D	S	2.5Y6/3	10YR6/3	ST	ME	AB	HA	NST	NPL	
Bw2	105-130	D	S	2.5Y5/3	10YR7/4	ST	ME	AB	HA	NST	NPL	
Bt1	130+			2.5Y5/3	10YR/6/3	ST	FI	AB	HA	NST	NPL	
Pedon 10												
Ap	0-15	C	S	2.5Y6/2	5YR3/1	WE	VFI	AB	LO	NST	NPL	
A	15-37	G	S	2.5Y7/2	7.5YR5/3	WE	VFI	P	LO	NST	NPL	
A1	37-104	C	S	10YR6/2	7.5YR7/2	WE	FI	P	SHA	NST	NPL	
A2	104-164	C	S	GLEY 7/10	2. GLEY15/N	WE	VFI	P	SO	NST	NPL	
Bw1	164+			2.5Y7/2	10YR6/1	WE	ME	GR	SHA	NST	NPL	
Pedon 11												
Ap	0-25	C	S	10YR5/3	10YR3/1	MO	ME	GR	SHA	SST	SPL	
A	25-60	G	S	7.5YR4/2	10YR2/2	MO	FI	GR	SHA	SST	SPL	
A1	60-110	G	S	5YR4/4	7.5YR2.5/2	MO	FI	SB	HA	SST	SPL	
Bw1	110+			5YR4/4	5YR2.5/2	MO	FI	SB	HA	SST	SPL	
Pedon 12												
Ap	0-25	D	S	10YR5/3	10YR2/2	MO	FI	AB	SO	SST	SPL	
A	5-44	D	S	10YR5/3	10YR2/1	MO	FI	ABGR	SO	SST	SPL	
A1	44-55	D	S	10YR5/2	10YR2.5/2	MO	FI	GR	SO	SST	SPL	
A2	55-68	D	S	10YR5/2	10YR3/2	WE	FI	GR	SO	SST	SPL	
Bw1	68+			10YR5/1	10YR3/3	WE	FI		SO	SST	SST	
Pedon 13												
Ap	0-18	C	S	10YR4/3	10YR3/3	MO	FI	AB	SHA	SST	SPL	
A	18-40	G	S	10YR6/3	10YR3/3	MO	VFI	AB	SHA	SST	SPL	
A1	40-60	G	S	10YR5/3	10YR2/2	WE	VFI	AB	SO	SST	SPL	
Bw1	60+			10YR5/3	10YR2/2	WE	FI	AB	SO	SST	SPL	
Pedon 14												
Ap	0-15	D	S	10YR5/3	7.5YR2.5/2	WE	FI	GR	SHA	ST	PL	
A	15-50	D	S	10YR5/3	7.5YR2.5/2	MO	FI	SB	SHA	ST	PL	
Bw1	50-100			10YR5/3	10YR2/1	WE	FI	SB	SHA	ST	PL	

Abbreviations and notes: structure: FI=fine, WE=weak, MWE= moderately weak, VFI= very fine, SB=sub-angular blocky, GR=granular, AB= angular blocky, Grad=grade, Sha=shape Consistence: SO= soft, SST=slightly sticky, ST= sticky, PL=plastic, SPL=slightly plastic, MOH= moderately hard, SHA= slightly hard, SST=slightly sticky, SPL= slightly plastic, Horizon boundary: D=diffuse, D. =distinctness, T. =topography, G=gradual (5-15cm), A= abrupt (0-2cm), C=clear (2-5cm), S= Smooth, W=wavy, I= irregular

2. Horizon boundary, root distribution and some pedon characteristics

The boundaries of surface and subsurface horizons in Pedons (1, 4, 5, 8, 12 and 14) were diffuse and smooth without any change and also boundaries of surface and subsurface were the same that clear and smooth in pedon 7 and 9. Pedons 2 and 3 had diffuse and smooth lower boundaries of surface horizons grading to gradual and smooth in the subsurface horizons. Pedons 6, 10, 11 and 13 had clear and smooth lower boundaries of surface horizons grading to gradual and smooth in subsurface horizons.

As all the pedons were opened in cultivated land, few fine roots of different crops, weeds and grasses were observed in the surface horizons and subsurface horizons but decreased with depth of the pedons. Similarly, the biological activity (few earthworm channels, termite mounds channels) was higher in the surface and subsurface horizons and decreased with depth of the pedons especially in pedon 11, 12 and 14.

3.2. Soil Physical Characteristics

1. Particle size distribution and soil textural class

The particle size distribution analysis result revealed that in the surface layer all pedons were being sandy loam except pedon 4 and 8 which is clay loam and pedon 9 and 10 were

sandy clay loam; pedon 14 was loam; whereas in subsurface the texture of horizons of pedon 2, 3, 6, 9, 10 11 and 12 were sandy loam; the left pedons were characterized by loam, clay loam, sandy clay loam and sandy loam (Table 2).

2. Bulk and Particle Densities

The bulk density of soils in the surface horizons ranged from 0.95 to 1.18 g cm⁻³, in pedon 8 and 4 respectively and the corresponding values for the subsurface horizon ranged from 0.96 to 1.31 in pedon 9 and 11 respectively gcm⁻³ (Table 2) Following the variation in bulk density; total porosity of the soils also indicated differences within the horizons of pedon and among the pedons. Accordingly, in surface horizons it ranged from 55.47% in pedon 4 to 64.15% in pedon 8 (Table 2) while in subsurface horizons it ranged from 50.56% in pedon 11 (110+ cm) to 63.77% in pedon 9 (35-50cm) (Table 2). Nevertheless, this variation did not exhibit any consistent trend with topographic position and with soil depth in all pedons of the study area except pedon 12, 13 and which decreases down soil profiles. The higher value of total porosity in the surface horizons could be due to the effect of management, penetration of crop roots that loosen the soil as well as comparatively higher OM content of the district. This is in line with the finding of [2] who reported decrease in total porosity with soil depth as a result of increasing compaction, decreasing of rooting effect and organic matter content.

Table 2. Physical characteristics of soil of Adami Tullu Jido Kombolcha district.

Horizon	Depth (cm)	Pb (g/cm³)	TP (%)	Particle size (%)			Textural classes
				Sand	Silt	Clay	
Pedon 1							
Ap	0-17	1.05	60.38	68	20	12	Sandy loam
A	17-40	1.07	59.62	36	46	18	Loam
A1	40-73	1.08	59.24	67	22	11	Sandy loam
Bw1	73-120	1.1	58.49	69	18	13	Sandy loam
Bw2	120+	1.11	58.11	55	28	17	Sandy loam
Pedon 2							
Ap	0-23	1.04	60.76	73	20	7	Sandy loam
A	23-54	1.05	60.38	69	24	7	Sandy Loam
A1	54-107	1.06	60	53	36	11	Sandy loam
Bw1	107-150	1.09	58.87	51	32	17	Sandy loam
Bw2	150+	1.1	58.49	51	32	17	Sandy loam
Pedon 3							
Ap	0-18	0.98	63.01	59	32	9	Sandy loam
A	18-40	1.01	61.89	67	22	11	Sandy Loam
A1	40-72	1.04	60.76	69	18	13	Sandy loam

Horizon	Depth (cm)	Pb (g/cm ³)	TP (%)	Particle size (%)		Clay	Textural classes
				Sand	Silt		
Bw1	72-118	1.11	58.11	59	26	15	Sandy loam
Bw2	118+	1.18	55.47	55	28	17	Sandy loam
Pedon 4							
Ap	0-25	1.18	55.47	44	30	26	Clay loam
A	25-60	1.26	52.45	42	30	28	Clay loam
A1	60-90	1.22	53.96	44	29	27	Clay loam
A2	90-115	1.15	56.60	56	28	16	Sandy loam
Bw1	115-160	1.04	60.76	54	30	16	Sandy loam
Bw2	160+	1.1	58.49	68	26	6	Sandy loam
Pedon 5							
Ap	0-40	1.05	60.38	56	30	14	Sandy loam
A	40-75	1.07	59.62	34	48	18	Loam
A ₁	75-120	1.102	58.42	36	46	18	Loam
Bw1	120-170	1.103	58.38	54	27	19	Sandy Loam
Bw2	170+	1.106	58.26	56	24.5	19.5	Sandy loam
Pedon 6							
Ap	0-20	1.01	61.89	64	30	6	Sandy loam
A	20-90	1.02	61.51	68	24	8	Sandy loam
A1	90+	1.11	58.11	69	23	8	Sandy loam
Pedon 7							
Ap	0-35	1.01	61.89	54	34	12	Sandy loam
A	35-75	1.04	60.76	48	44	8	loam
Bw1	75-110	1.08	59.25	56	32	12	Sandy loam
Bw2	110+	1.12	57.74	69	23	8	Sandy loam
Pedon 8							
Ap	0-60	0.95	64.15	42	30	28	Clay loam
A	60-100	0.98	63.02	44	28	24	clay loam
B1	100-150	1.125	57.55	58	30	12	Sandy loam
B2	150-180	1.135	57.17	42	32	26	Clay loam
Pedon 9							
Ap	0-10	1.03	61.13	44	28	24	Sandy Clay Loam
A	10-20	1.06	60.00	45.5	30	24.5	Sandy clay loam
A1	20-35	1.10	58.49	42	32	26	Sandy clay loam
A2	35-50	0.96	63.77	41.5	32	26.5	Sandy clay loam
A3	50-80	0.98	63.02	69	23	8	Sandy loam
Bw1	80-105	1.02	61.51	58	32	10	Sandy loam
Bw2	105-130	1.01	61.89	54	32	14	Sandy loam

Horizon	Depth (cm)	Pb (g/cm ³)	TP (%)	Particle size (%)			
				Sand	Silt	Clay	Textural classes
Bt1	130+	1.05	60.38	59	29	12	Sandy loam
Pedon 10							
Ap	0-15	1.07	59.62	70	18	12	Sandy clay loam
A	15-37	1.10	58.49	63.78	27.22	9	Sandy clay loam
A1	37-104	1.12	57.74	66	24	10	Sandy clay loam
A2	104-164	0.98	63.02	63	27	10	Sandy loam
Bw1	164+	0.98	63.02	57	30	13	Sandy loam
Pedon 11							
Ap	0-25	1.15	56.60	58	36	6	Sandy loam
A	25-60	1.18	55.47	56	28	16	Sandy loam
A1	60-110	1.203	54.60	69	23	8	Sandy loam
Bw1	110+	1.31	50.56	68	24	6	Sandy loam
Pedon 12							
Ap	0-25	1.02	61.51	65.78	29.22	5	Sandy loam
A	25-44	1.15	56.60	63.78	29.22	7	Sandy loam
A ₁	44-55	1.21	54.34	61.78	29.22	9	Sandy loam
A2	55-68	1.24	53.21	69.78	21.22	9.5	Sandy loam
Bw1	68+	1.27	52.1	65.78	25.22	11	Sandy loam
Pedon 13							
Ap	0-18	1.03	61.13	65.78	29.22	5	Sandy loam
A	18-40	1.08	59.25	47.78	45.22	7	Loam
A1	40-60	1.20	54.72	81.78	9.22	9	Sandy loam
Bw1	60+	1.23	53.6	53.78	35.22	11	Sandy loam
Pedon 14							
Ap	0-25	1.03	61.13	49.78	45.22	5	Loam
A	25-50	1.2	54.72	48.78	45.22	6	Loam
Bw1	50-100+	1.28	51.7	47.78	45.22	7	Loam

3.3. Soil Chemical Characteristics

1. Soil pH, EC, TN, OC and Av. P

The pH-H₂O values of the surface horizons of the soils ranged from 6.72 in pedon 8 to 10.2 in pedon 10, in the sub-surface horizon it ranged from 6.95 in pedon 1 to 10.91 in pedon 9 (Table 3 below). The soil pedon 9 and 10 opened at the lower altitude of the district had relatively higher pH-H₂O (10 & 10.2) on the surface than those of the upper pe-

dons 4 and 8. The pH-H₂O values showed a slightly increasing trend with soil depth in pedon 1, 2, 3, 6, 7, 8, 9, 10 and pedon 11 and 13 shows decreasing trend; whereas in pedons 4, 5, 12 and 14, it did not show any consistency with increasing depth. As per ratings of [18], most of pH-H₂O range of the studied soils at surface fall under the moderately alkaline (7.4-8.0) and only two pedons (Pedon 9 & 10) falls under strongly alkaline (>8.0) soil reaction range, which is fairly optimal for availability of most nutrients and activities of microorganisms (Table 3).

Table 3. Soil chemical parameters of the district.

Horizon	depth (cm)	pH (H ₂ O)	EC (ds/m)	TN (%)	OC (%)	Av.P (mgkg ⁻¹)	Ca cmol(+) kg ⁻¹	Mg	Na	k	CEC	PBS%	ESP%
Pedon 1													
Ap	0-17	6.92	0.16	0.13	2.3	8.25	14.2	2.84	0.47	2.63	23.13	87.07	2.33
A	17-40	6.95	0.164	0.11	2.02	8.33	15.2	2.81	0.62	1.81	23.42	87.28	3.03
A1	40-73	7.35	0.17	0.08	1.03	6.46	9.64	1.67	0.63	1.54	17.55	76.81	4.67
Bw1	73-120	7.55	0.254	0.03	0.12	5.32	7.88	1.58	0.55	1.13	15.43	72.20	4.94
Bw2	120+	7.64	0.23	0.022	0.04	4.82	7.13	1.45	0.72	1.04	13.38	77.28	6.96
Pedon 2													
Ap	0-23	7.45	0.152	0.143	1.65	9.5	12.3	2.79	0.54	1.84	19.14	91.27	3.09
A	23-54	7.65	0.211	0.12	1.31	8.95	13.6	2.18	0.61	1.80	21.45	84.8	3.35
A1	54-107	7.68	0.281	0.031	0.12	8.12	12.5	2.21	0.252	1.12	17.73	90.71	1.57
Bw1	107-150	7.84	0.29	0.024	0.09	6.5	9.41	1.74	0.281	1.05	14.83	84.16	2.25
Bw2	150+	7.84	0.293	0.032	0.04	4.5	7.12	1.71	0.32	2.13	13.84	81.50	2.84
Pedon 3													
Ap	0-18	7.09	0.118	0.145	1.64	7.25	14.84	1.56	0.87	2.19	19.92	97.69	4.6
A	18-40	7.55	0.143	0.134	1.22	5.33	12.3	1.4	0.93	1.83	17.34	94.93	5.65
A1	40-72	7.64	0.174	0.084	1.13	4.46	12.7	1.28	0.35	1.93	17.44	93.23	2.15
Bw1	72-118	7.71	0.177	0.063	0.12	1.32	9.48	1.94	0.3	1.42	18.13	77.05	8.1
Bw2	118+	7.76	0.189	0.081	0.08	1.82	6.45	2.35	0.34	1.7	13.13	82.56	3.13
Pedon 4													
Ap	0-25	6.8	0.116	0.141	2.62	8.83	21.8	4.3	0.68	2.34	32.78	88.83	2.34
A	25-60	7.65	0.144	0.133	2.59	8.16	21.1	6.34	0.69	1.78	32.68	91.52	2.31
A1	60-90	7.63	0.170	0.072	1.38	7.34	19.8	6.7	0.69	2.21	31.56	93.16	2.35
A2	90-115	7.52	0.187	0.061	1.33	5.13	19.2	6.5	1.31	2.14	31.13	93.64	4.49
Bw1	115-160	7.24	0.188	0.060	1.22	3.14	17.3	5.7	1.46	2.22	29.77	89.62	5.47
Bw2	160+	7.74	0.23	0.054	1.2	3.13	14.3	5.7	1.52	2.5	27.73	86.62	6.33
Pedon 5													
AP	0-40	7.95	0.151	0.158	2.03	8.53	20.8	3.57	0.64	2.54	31.55	87.32	2.32
A	40-75	8.55	0.157	0.142	2.21	7.24	19.3	4.12	0.567	2.64	31.05	85.75	2.13
A ₁	75-120	8.65	0.17	0.085	0.07	4.52	15.3	4.82	0.621	3.01	26.21	90.62	2.61
Bw1	120-170	7.81	0.274	0.072	0.14	4.32	13.2	5.72	0.68	3.18	25.02	91.05	2.98
Bw2	170	8.04	0.268	0.045	0.11	2.36	10.2	5.75	0.78	3.21	23.73	84.03	3.91
Pedon 6													
Ap	0-20	7.45	0.22	0.137	2.81	9.25	17.2	4.5	1.12	1.81	27.52	89.5	4.55
A	20-90	7.85	0.251	0.084	1.34	6.66	14.1	4.32	1.31	1.78	24.84	86.6	6.09
A1	90+	7.87	0.273	0.062	1.31	6.32	12.44	3.34	1.35	1.64	19.73	95.13	7.19
Pedon 7													

Horizon	depth (cm)	pH (H ₂ O)	EC (ds/m)	TN (%)	OC (%)	Av.P (mgkg ⁻¹)	Ca cmol(+) kg ⁻¹	Mg	Na	k	CEC	PBS%	ESP%
Ap	0-35	7.19	0.12	0.18	2.05	8.72	14.78	4.82	0.13	2.03	23.56	92.36	0.6
A	35-75	8.1	0.16	0.23	1.84	8.62	14.5	4.8	0.56	2.98	24.59	92.88	2.45
Bw1	75-110	8.14	0.19	0.11	0.63	6.46	12.54	3.7	0.84	1.15	19.48	93.58	4.61
Bw2	110+	8.22	0.21	0.06	0.42	4.41	8.23	4.12	1.16	2.17	17.21	91.12	7.4
Pedon 8													
A	0-60	6.72	0.31	0.24	2.85	7.95	19.78	3.82	0.18	1.11	27.36	90.97	0.72
A1	60-100	7.65	0.39	0.21	1.94	8.12	19.23	3.91	0.66	1.08	28.57	87.08	2.65
B1	100-150	7.74	0.45	0.11	0.75	8.46	14.13	2.21	0.64	1.02	19.47	92.45	3.55
B2	150-180	7.82	0.63	0.06	0.04	5.31	9.45	2.51	1.26	0.65	14.84	93.46	9.08
Pedon 9													
Ap	0-10	10	3.55	0.08	1.2	6.02	8.51	2.5	10.1	2.2	39.88	60.96	43.33
A	10-20	10	4.01	0.11	0.85	5.84	8.01	3.4	9.92	2.12	38.82	60.41	42.3
A1	20-35	10.01	4.12	0.03	0.32	3.14	7.14	3.4	9.87	2.41	37.58	59.1	43.25
A2	35-50	10.1	4.14	0.02	0.12	4.34	7.12	3.12	8.85	2.44	36.85	58.43	41.11
A3	50-80	10.41	5.05	0.1	0.06	2.12	6.5	3.3	8.62	1.24	33.25	59.13	43.85
Bw1	80-105	10.63	5.03	0.02	0.042	2.32	6.55	3.2	7.94	1.54	31.95	60.2	41.3
Bw2	105-130	10.69	5.01	0.03	0.04	1.33	5.45	2.2	7.12	1.38	27.25	59.27	44.08
Bt1	130+	10.91	5.26	0.01	0.022	2.12	5.13	2.1	6.86	1.46	27.32	56.92	44.12
Pedon 10													
Ap	0-15	10.2	1.21	0.11	1.28	9.27	7.42	1.85	9.5	2.17	38.28	54.70	45.37
A	15-37	10.12	1.12	0.11	1.01	8.4	7.33	1.75	9.3	2.14	38.11	53.84	45.32
A1	37-104	10.38	1.2	0.04	0.23	5.7	6.81	1.55	8.7	2.13	37.53	51.13	45.34
A2	104-164	10.41	2.21	0.023	0.055	6.3	6.74	1.5	8.12	2.11	35.53	51.98	43.96
Bw1	164+	10.65	2.24	0.02	0.05	3.28	6.65	1.43	7.68	2.15	35.17	50.92	42.88
Pedon 11													
Ap	0-25	8.89	0.26	0.23	1.94	7.25	18.78	3.83	0.36	1.92	25.83	96.36	1.45
A	25-60	8.55	0.06	0.11	0.8	7.04	16.85	3.8	0.64	2.93	25.23	96.00	2.64
A1	60-110	7.74	0.1	0.04	0.65	6.74	16.65	2.62	0.59	3.06	26.54	86.36	2.57
Bw1	110+	7.64	0.11	0.02	0.23	6.54	13.74	2.82	0.55	3.12	22.12	91.45	2.72
Pedon 12													
Ap	0-25	7.8	0.12	0.145	2.72	4.72	12.54	2.35	0.261	3.46	22.46	82.86	1.4
A	25-44	7.65	0.14	0.133	2.09	3.75	12.11	2.35	0.500	3.35	22.23	82.38	2.73
A ₁	44-55	7.63	0.15	0.072	1.28	3.24	10.13	1.58	0.935	1.34	20.45	69.1	6.685
A2	55-68	7.42	0.17	0.061	0.52	3.21	8.84	1.57	0.826	1.13	19.97	61.84	6.68
Bw1	68-90+	7.74	0.18	0.060	0.4	2.26	7.88	1.57	0.674	0.95	18.26	60.7	6.1
Pedon 13													
AP	0-18	7.59	0.11	0.125	2.41	3.42	12.15	1.57	0.304	3.36	21.23	81.9	1.75

Horizon	depth (cm)	pH (H ₂ O)	EC (ds/m)	TN (%)	OC (%)	Av.P (mgkg ⁻¹)	Ca cmol(+) kg ⁻¹	Mg	Na	k	CEC	PBS%	ESP%
A	18-40	7.56	0.15	0.092	2.16	3.14	11.76	1.57	0.370	3.23	21.15	80.01	2.18
A1	40-60	7.55	0.17	0.081	1.64	1.54	10.44	2.35	0.391	2.41	20.01	77.95	2.5
Bw1	60+	7.50	0.24	0.072	1.52	2.94	9.41	2.35	0.761	2.24	19.75	74.74	5.15
Pedon 14													
Ap	0-15	7.59	0.14	0.123	2.23	3.21	11.85	1.58	0.326	2.71	19.18	85.85	1.98
A	15-50	7.29	0.066	0.092	2.81	3.05	9.22	2.74	0.346	2.59	19.1	78.0	2.32
Bw1	50-100+	7.48	0.17	0.072	2.1	2.42	9.02	3.53	1.39	1.16	17.89	84.40	9.2

The overall slightly variation of the EC values for surface horizon of the soils ranged from 0.11 in pedon 13 to 3.55 mmh in pedon 9 at the shore of lake Abjeta; while subsurface EC ranged from 0.060 mmh in pedon 11 to 5.26 mmh in pedon 9 (Table 3). There was increasing trend of EC down the horizons in pedons 2, 3, 4, 5, 6, 7, 8, 12 and 13, whereas, in others pedons there was no increasing/decreasing trend.

2. Soil Organic Carbon, Total Nitrogen and Available Phosphorus

The organic carbon content in the surface horizons of the soils ranged from 1.2% in pedon 9 to 2.85% in pedon 8, whereas in subsurface it ranged from 0.022% in pedon 9 (beyond 130+ cm at horizon 8) to 2.81 in pedon 14 (15-50 cm) (Table 3). The Organic carbon content of the soils of study area showed decreasing trend with soil depth in all soil horizons throughout Pedons of the study area except Pedon 5 and 14 which are inconsistency with soil depth. The OC content of the soils of the district were in the range of moderate at the surface except pedon 9 and 10 which are classified under low; whereas at the subsurface soil horizons it ranged from very low to moderate in the study area (Table 3 above). The total nitrogen in the surface horizons of the soils ranged from 0.08% in pedon 9 to 0.24% in pedon 8, whereas in the subsurface horizons it ranged from 0.01% in pedon 9 (130+ cm at the bottom of horizon) to 0.23% in the pedon 7 (35-75 cm) (Table 3). Generally, total N content of the soils was comparatively higher in the surface horizons and showed a decreasing trend with soil depth in most pedons of the study area excluding pedon 2, 3, 7 and 9. As per total N (%) content rating set by [18], the total N content of the soils is under medium range at surface of pedons except pedon 9 and 10 which found at low, while in the subsurface of pedons of district it was rating from very low to moderate.

The available phosphorus (Av.P) content of the soils in the surface horizons ranged from 3.21mgkg⁻¹ in pedon 14 to 9.5mgkg⁻¹ in pedon 2, while in the subsurface horizons it ranged from 1.32mgkg⁻¹ in pedon 3 (72-118cm) to 8.95

mgKg⁻¹ in pedon 2 (23-54cm) (Table 3). There was inconsistency trend of this parameter with soil depth in soil pedons 2, 3, 8, 9, 10 and 13 down the soil profiles of study area; the rest soil pedons had decreasing trend down the soil horizons. According to (Cotteine, 1980) available phosphorus in the study area ranged from very low to moderate. The higher available phosphorus content in surface horizon of all pedons as compared to the subsurface horizons could be attributed to the application of phosphorus containing fertilizers and animal manure to improve production as per information obtained from stakeholders, as well as relatively higher OC content. This is in agreement with the finding of [2] who reported that the higher available phosphorus in the top soil layer of farmland which may be due to the application of animal manure, compost, household wastes like ashes and ammonium phosphate (DAP) fertilizer for soil fertility management.

3. Exchangeable Cations, Cation Exchange Capacity and Percent Base Saturation

The exchangeable Ca content of the soils in surface horizons ranged from 7.42 cmol(+) kg⁻¹ soil in pedon 10 to 21.8 cmol(+) kg⁻¹ soil in pedon 4 and in subsurface horizons it ranged from 5.13 cmol(+) kg⁻¹ soil in pedon 9 to 21.1 cmol(+) kg⁻¹ soil (25-60 cm depth) in pedon 4. Exchangeable K ranged from 1.11 cmol(+) kg⁻¹ soil in pedon 8 to 3.46 cmol(+) kg⁻¹ soil in pedon 12 at the surface and at subsurface it ranged from 0.65 cmol(+) kg⁻¹ in pedon 8 (150-180 cm depth at the bottom of profile) to 3.35 cmol(+) kg⁻¹ in pedon 12. As per rating set by [10], the soils in the study area were in the range of moderate to very high in their exchangeable Ca and very high in their exchangeable K contents with some horizons fall under high rating (Table 3 above).

The exchangeable Na content of the soils ranged from 0.13 cmol(+) kg⁻¹ soil in pedon 7 to 10.1 cmol(+) kg⁻¹ soil in pedon 9 at the surface pedons and at subsurface horizons Na ranged from 0.252 cmol(+) kg⁻¹ in pedon 2 to 9.92 cmol(+) kg⁻¹ in pedon 9; while exchangeable Mg had the values at surface ranged from 1.56 cmol(+) kg⁻¹ soil in pedon 3 to 4.82 cmol(+) kg⁻¹ soil in pedon 7; at the subsurface horizons it

ranged from 1.28 cmol(+) kg⁻¹ in pedon 3 to 6.7 cmol(+) kg⁻¹ in pedon 4.

The cation exchange capacity (CEC) of the soils of the study area in the surface horizons ranged from 19.14 cmol (+) kg⁻¹ soil in pedon 2 to 38.88 cmol (+) kg⁻¹ soil in pedon 9; while in subsurface horizons it ranged from 13.13 cmol (+) kg⁻¹ soil in pedon 3 to 38.82 at pedon 9 (Table 3 above). The CEC of the soils of the study area were moderate to high in surface and subsurface horizons for all pedons.

The percent base saturation (PBS) in surface horizons varied from 54.70% in pedon 10 to 97.69% in pedon 3; while the subsurface PBS varied from 50.92% in pedon 10 to 96.00% in pedon 11; it was within the range of moderate to very high (Table 3) based on ratings set [10].

3.4. Soil Classification

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.

Accordingly, some of the pedons had granular structured dark surface horizons of ≥ 25 cm in thickness that have moist color notation of 10YR (2/1, 4/3, 3/3, 3/1, 2/2) by pedon 4, 5, 7, 8 11 and 12 with the surface horizons of < 25 cm in thickness that have color notation of 10YR 2/1, by pedons 1, 2 and 3, and 7.5YR2.5/2, 7.5YR3/1, 5YR3/1, 10YR3/3, 7.5YR2.5/2 by pedon 6, 9, 10, 13 and 14 respectively.

The organic carbon content of the surface horizons of the pedons ranged from 1.2% to 2.85% with percent base saturation values of greater than 50% or more throughout the profiles by 1M NH₄OAc analysis method at pH7. Such morphological features indicate the existence of a chernic surface diagnostic horizon as a type of a mollic horizon.

Pedons 2, 4, 5, 8 and 10, 12, 13 and 14 had well drained effective soil depth of more than 150cm, whereas pedons, 6, 7 and 11 had soil depth of 90+, 110+ cm and similarly pedon 3, 2, 9 had soil depth of 118, 120 and 130 cm respectively. Moreover, all the pedon horizons below the upper most layer had base saturation of greater than 80% (hypereutric). Most of the pedons had cambic horizon with the textural classes of sandy loam with a munsell color of hue ≥ 2.5 moist and chroma ≥ 1 at moist with a clay content of $\geq 4\%$. Pedon 9 and 10 had a texture of sandy clay loam or finer, a clay increment downs the profile, an angular blocky structure at the surface horizons and prismatic structure for the subsurface horizons. The profile had exchangeable sodium percentage (ESP) greater than 42 throughout the profile. Moreover, the color of

the surface horizon ranged between brown and black. According to WRB (FAO, 2014) such characteristics are typically natric. It has a high content of exchangeable Na and in some cases, a relatively high content of exchangeable Mg. The soil is classified under Solonetz with Haplic and Arenic prefix and suffix qualifiers.

Pedon, 5, 12, 13 and 14 had a texture of sandy loam and loam a clay increment down the profile, an angular blocky structure at the surface horizons having between 25 and 150 cm of the soil surface a layer, ≥ 30 cm thick with Munsell colour hue redder than 7.5YR and a chroma of > 4 , both moist also having a vertic horizon starting ≤ 100 cm from the soil surface. Accordingly, such characteristics are typically classified as Chromic Vertisols (haplic, hypereutric).

Pedon 1, 2, 3 and 4 has a relatively thick, dark-colored surface horizon with a high base saturation and the color notation of its soil material and its organic carbon content fulfill the diagnostic criteria of a mollic horizon. 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. All the pedon layers were presumed to be a part of alleviated subsoil due to their markedly higher clay content that showed the presence of an argic (argillic) diagnostic subsurface horizon in the subsoil of the pedon. Based on the above information, the soil represented by the profile of pedon 1, 2, 3 and 4 is classified as Luvic Phaeozem (Clayic, and Hypereutric).

Pedon 6 had textural class of sandy loam or finer or loamy with Munsell colour hue ≥ 2.5 units redder, moist; or a Munsell colour chroma ≥ 1 unit higher, moist; or a clay content $\geq 4\%$. moist color notation of 10YR 3/2 by horizon 1 and a color notation of 10YR 3/1 with a combined thickness of ≥ 30 cm (in Cambisols ≥ 15 cm), of which ≥ 15 cm (in Cambisols ≥ 7.5 cm) have *andic* properties with no argic properties. The soil is classified Vitric Andosols (vitric principal qualifier and Arenic/clayic supplementary qualifier).

Pedon 11 had organic carbon content of the surface horizons of the pedons ranged from 1.94% to 0.23% in sub surface horizon with percent base saturation values of greater than 50% or more throughout the profiles by 1M NH₄OAc analysis method at pH7. Additionally, the occurrence of any form of secondary (pedogenic) carbonates could not be observed throughout the profile of all pedons. The pedons had granular structured dark surface horizons of ≥ 25 cm in thickness with moist color notation of 10YR 3/2 fulfilled mollic horizon and one or more layers with *andic* or *vitric* properties with a combined thickness of *either* ≥ 30 cm, within ≤ 100 cm of the soil surface and starting ≤ 25 cm from the soil surface with no argic properties. The soil is classified as Mollic Andosols (vitric, clayic) qualifiers.

Pedon 7 and 8 had well drained effective soil depth with 110 and 180 cm respectively. The pedons had granular structured gradually changed to angular and sub angular blocky

with dark surface horizons of ≥ 25 cm in thickness with moist color notation of 10YR 3/2. The Pedons had organic carbon content of the surface horizons of the pedons ranged from 2.05 to 0.42% at pedon 7 and 2.85 to 0.22% at pedon 8 in sub surface horizon with percent base saturation values of greater than 50% or more throughout the profiles by 1M NH₄OAc analysis method at pH7 respectively fulfilled mollic horizon. Moreover, the pedons horizons below the

uppermost layer had base saturation of greater than 80% (hypereutric). Most of the pedons had cambic horizon with the textural classes of sandy loam and clay loam with a munsell color of hue ≥ 2.5 moist and chroma ≥ 1 at moist with a clay content of $\geq 4\%$ one or more layers with *andic* or *vitric* properties with a combined thickness of *either* ≥ 30 cm. The soil is classified as mollic Andosols (vitric, clayic) qualifiers.

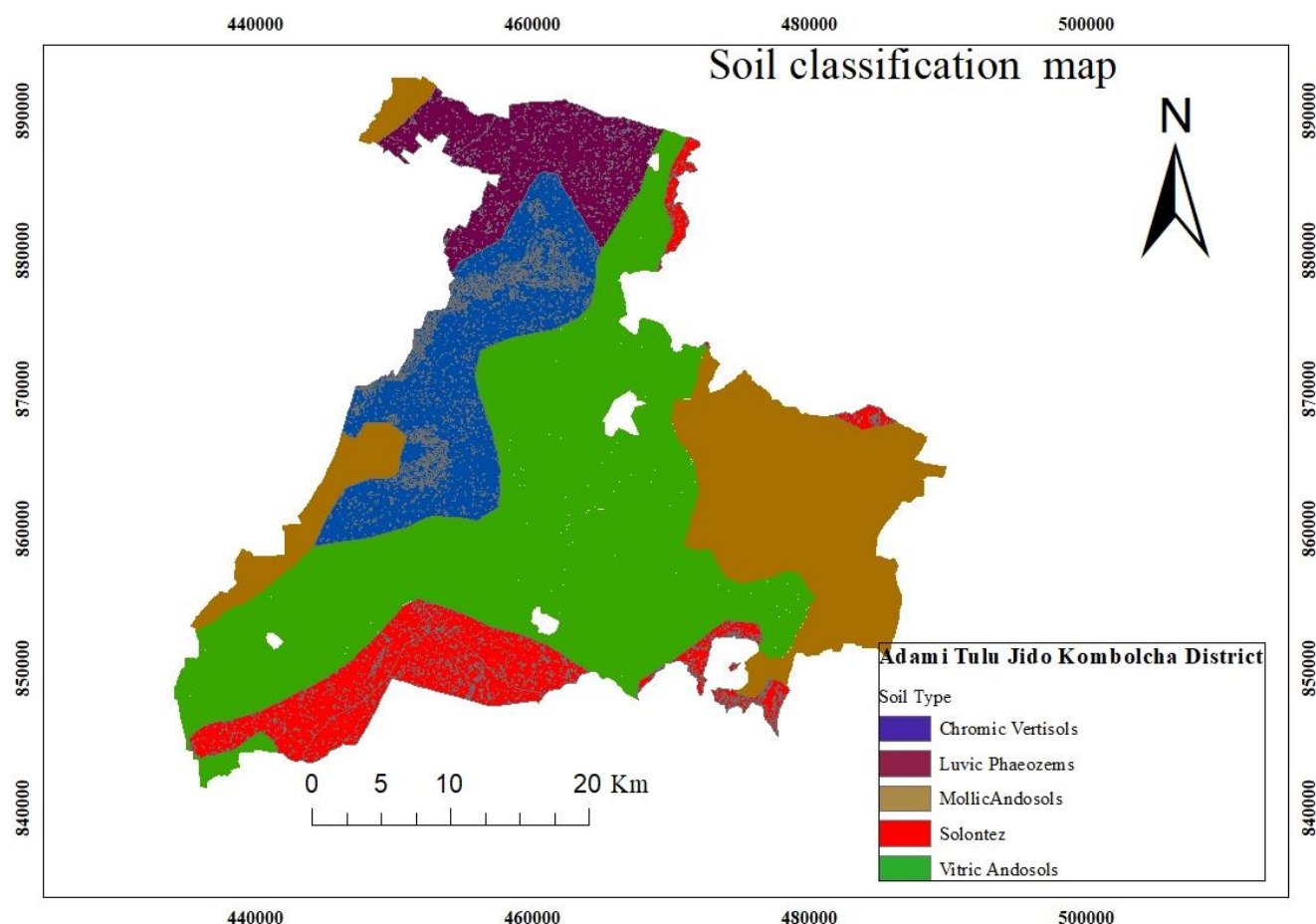


Figure 3. Soil classification map of Adami Tulu Jido Kombolcha District.

4. Conclusion

The soil morphological characteristics (horizon, horizon boundary, depth, color, structure, texture, structure and consistence), Soil physical characteristics (Particle size distribution and soil textural class, bulk and particle densities and soil total porosity), and soil chemical characteristics (Soil pH, electrical conductivity, TN, OC, Av. P, Exchangeable Cations, Cation Exchange Capacity and Percent Base Saturation) and slope were described. The bulk density of soils in the surface horizons ranged from 0.95 to 1.18 g cm⁻³, in pedon 8 and 4 respectively and the corresponding values for the subsurface horizon ranged from 0.96 to 1.31 in pedon 9 and 11

respectively g cm⁻³. Total porosity of the soils in surface horizons ranged from 55.47% in pedon 4 to 64.15% in pedon 8; while in subsurface horizons it ranged from 50.56% in pedon 11 to 63.77% in pedon 9.

The OC content of the soils of the District were in the range of moderate at the surface except pedon 9 and 10 which are classified under low; whereas at the subsurface soil horizons it ranged from very low to moderate, total N content of the soils in the district is under medium range at surface of pedons except pedon 9 and 10 which found at low, while in the subsurface of pedons of District it was rating from very low to moderate. The available phosphorus (Av.P) content of the soils in the surface horizons ranged from very low to moderate.

5. Recommendations

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.

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Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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