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Soil Classification in Yigossa Watershed, Lake Tana Basin, Highlands of Northwestern Ethiopia

Gizachew Ayalew[1], Yihenew G. Selassie[2], Eyasu Elias[3] & Chiristy Van Beek[4]

[1] Amhara Design and Supervision Works Enterprise (ADSWE), Bahir Dar, Ethiopia

[2] College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia

[3] Capacity Building for Scaling up of Evidence-Based Best Practices in Agricultural Production in Ethiopia (CASCAPE) project, Addis Ababa, Ethiopia

[4] ALTERA, Wagenigen University and Research, Wagenigen, The Netherlands

Correspondence: Yihenew G. Selassie, College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia. E-mail: yihenewgs@gmail.com

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Abstract

A study was conducted in 2013 at Yigossa watershed, Northwestern Ethiopia to study the morphological and physicochemical characteristics and classify soils using FAO/WRB criteria. Four soil profiles, at slope classes of 0-2, 2-5, 5-8 and 8-15% were described in-situ using FAO/WRB guideline. Soil samples were collected from pedogenic horizons and analyzed for soil color, bulk density, texture, structure, pH, organic carbon (OC), total nitrogen (TN), available phosphorus (AvP), cation exchange capacity (CEC), exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and percent base saturation (PBS). FAO/WRB soil classification legend was used to classify the soils. Geographical Information System (GIS) software was employed to produce slope and soil maps of the watershed. Results of the study indicated that Yigossa soil profile No. 4 and No. 2 (i.e., YSP-4 and YSP-2) were very shallow (< 30 cm) and moderately shallow (50-100 cm), respectively; whereas profile No. 1 and No. 3 (i.e., YSP-1 and YSP-3) were very deep (> 200 cm). Surface soil color was 5YR4/3 for YSP-1 and 2.5YR3/3 for YSP-2 and it was 10YR4/2 and 10YR 2/1 for YSP-3 and YSP-4, respectively. All profiles, except YSP-4, were clay in texture. Highest and lowest bulk density values of 1.48 g cm^{-3} in YSP-3, and 0.7 g cm^{-3} in YSP-1 and YSP-4 were recorded. Highest OC (2.3%) and TN (0.2%) were registered at the surface of YSP-3. Highest CEC (36.2 $cmol_c$ kg^{-1}) and PBS (83%) were recorded from subsurface horizons of YSP-3. Generally, YSP-1, YSP-2, YSP-3 and YSP-4 were identified as Nitisols, Luvisols, Gleysols and Regosols at 2-5, 5-8, 0-2 and 8-15% slope classes, respectively.

Keywords: soil analysis, soil classification, soil profile, slope, Yigossa watershed, Northwestern Ethiopia

1. Introduction

Agriculture is the mainstay of the Ethiopia's economy where its production is highly dependent on natural resources (Akililu & Graaff, 2007). However, the country remained unable to feed its people (Fasil, 2002). Soil resources significantly affect agricultural productivity. On the other hand, soil degradation caused by a number of socio-economic factors such as deforestation, over cultivation, over population, over grazing and other inappropriate farming practices reduced productive capacity of the soil (Gete & Hurni, 2001; Rajesh et al., 2003; Kumar et al., 2014).

Detailed soil data and information is inevitable to address the soil evaluation, fertility guidance and advise land users on how to use the land in the best possible way (Burrough, 1996). In other words, non-use of soil data and information could bring soil and soil-related environmental problems like nutrient depletion (Onweremadu, 2006), compaction, flooding and poor crop yields (Zinck, 1990; Chintala et al., 2014; Prasad, 2014). The current soil map of Ethiopia is not comprehensive enough to provide detailed site specific soil data and information for policy makers and draw development planning at watershed level. Therefore, the quality of the map increasingly used for agriculture land suitability analysis is questionable.

The existing soil map of Ethiopia has limited use in supporting soil conservation and management interventions. Therefore, to use and manage different soil types, understanding the properties, characteristics and classification of the soils is required. In addition, most current knowledge and skills about the soils resided with farmers and agricultural advisors obtained through experience have not easily been documented to allow the transfer of soil and crop technologies elsewhere. Moreover, the presence of different soil types requires locally specific management methods. Therefore, it was important to collect reliable soil data and information for regional and site specific uses.

Improved understanding of the genesis of soils and their relationships leads to improvements in their use and management. However, little emphasis has been given to soil genesis and classification studies in the highlands of Ethiopia (Mitiku, 1987). The call for providing this soil information is more demanding for the Yigossa watershed in Dera district than before because of the problem arising from misuse of land, resulting in soil degradation. Hence, much research is needed to be done at watershed level to understand the soil genesis and classification for providing better exploitation of research investigations (Mesfin, 1998). Therefore, the main objective of this research was to study the morphological and physicochemical characteristics, and classify the soils of Yigossa watershed.

2. Materials and Methods

2.1 Description of the Study Watershed

Yigossa watershed is located in Dera district, Amhara National Regional State, at about 30 km far from the regional capital, Bahir Dar (Figure 1). The study watershed is geographically positioned within $11^o46'24.5''$-$11^o48'40.8''$ latitude, $37^o30'40.3''$-$37^o34'15.6''$ longitude and has altitudes ranging from 1802 to 1970 meters above sea level. The total area is about 1092.68 ha of land including Metsele, Zhara and Wenchite *kebeles*. It is also dominated by a land with 2-5% slope and intensive crop cultivation. The foot slope borders Lake Tana, the source of the Blue Nile River.

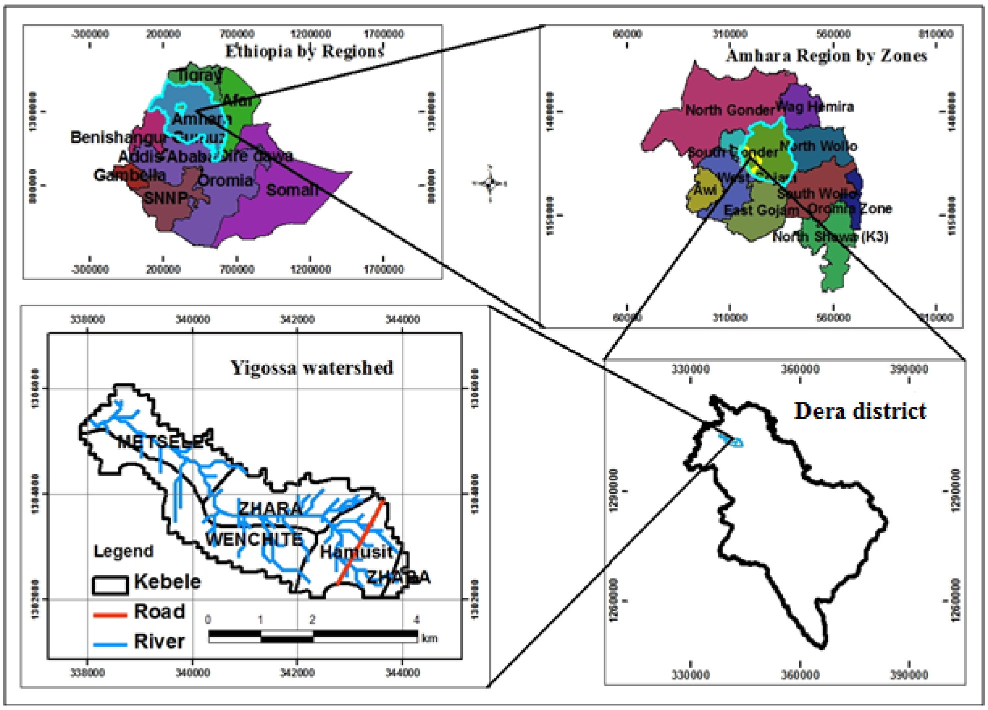

Figure 1. Location map of the study watershed

The agro-climatic resource of the Amhara Region is available at scale of 1:250,000 developed from long-term records (1994-2003) of annual rainfall and temperature data collected from Bahir Dar Metrological Station. Accordingly, annual mean minimum and maximum temperature of the watershed are 17.5 ^oC and 20 ^oC, respectively; whereas the average annual rainfall ranges from 1200-1500 mm (DSA & SCI, 2006). Based on the traditional agro-climatic classification of Ethiopia, the climate of the watershed is moist tepid.

The geological formation of the watershed generally belongs to the basaltic Tapp Series of the Tertiary volcanic eruptions in general and Gunna mountain shield volcano in specific. The volcano corresponds to the eruptive events that occurred during the early Miocene to Pliocene period and classified in the shield group basalt (BCEOM, 1999; Kieffer et al., 2004). The common litho type for this material is basaltic origin. The soil of the watershed was previously characterized by Luvisols, clay in texture with depth of over 150 cm at scale of 1:250,000 (DSA & SCI, 2006).

The farming system of the watershed can be characterized as crop-livestock mixed with intensive crop cultivation. Intensive cultivated areas occur on gentle sloping areas where as moderately cultivated areas are found steeply sloping areas. Maize (*Zea mays* L.), *teff* (*Eragrostis tef* Zucc.), finger millet (*Eleusine coracana* L.) and rice (*Oryza sativa* L.) are the major crops grown. Cattle, equine, and small ruminants graze on communal grazing areas during the rainy season while crop fields are privately owned. The natural vegetation has almost been completely cleared. However, trees and shrubs such as eucalyptus spp, juniperus spp, acacia spp, *bissana* (*Croton macrostachys* L.) and *warka* (*Ficus vasta* L.) as a homestead plantation are the most common species in the watershed.

2.2 Methods of the Study

2.2.1 Soil Profile Description

Yigossa watershed was stratified into four slope classes as there is strong relationship between slope and soil types and their characteristics (FAO, 1998). The slope classes were 0-2% (foot slope), 2-5% (gentle sloping), 5-8 % (sloping) and 8-15% (strongly sloping). Slopes maps were extracted from digital elevation model (DEM) having 30×30 m resolution with the help of Geographical Information System (GIS) software. Based on soil color, texture and slope, tentative major soil types and their boundaries were identified and delineated in the field by auguring through intensive traversing and purposive soil survey method. In addition, soil depth from road cut, gullies and river cuts were used to locate delineation points. Soil profiles having a depth of 2 m and a width of 1m, unless limited or impracticable due to stoniness, were opened and *in situ*, described for soil morphological and physicochemical characterizations in each slope classes following FAO (2006) guideline. A total of 8 undisturbed and 19 disturbed soil samples were collected and analyzed in soil laboratory. The soil profile pit sites are presented in Figure 2.

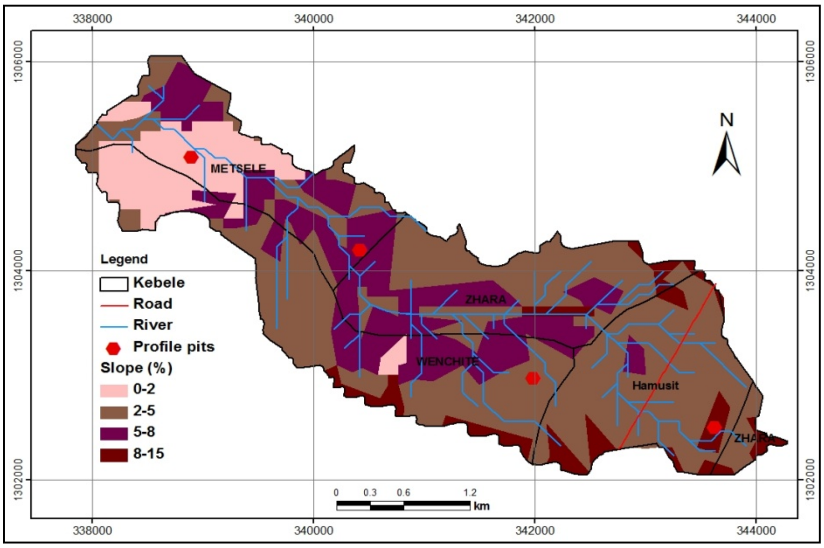

Figure 2. Soil profile locations in different slope classes

2.2.2 Soil Analysis

The soil samples collected from the soil profiles were air dried at room temperature and ground to pass through 2 mm sieve for all the soil parameters except for total nitrogen (TN) and organic carbon (OC) that passed through 0.5 mm sieve. Soil bulk density was determined by the method as described in Black (1965) where first undisturbed soil samples taken by core sampler of known volume (height 5 cm and diameter 7.2 cm) weighed at field moisture condition. The soil samples were then oven dried at 105 °C for 72 hours until constant weight was obtained and the oven dried samples were weighed again. Bulk density was then computed by dividing the weight of oven dried soil samples to the volume of the sampler. Soil texture was determined by the hydrometer method as described in Bouyoucos (1962). Hydrogen peroxide was used to destroy organic matter and sodium hexa-metaphosphate as dispersing agent. Then, hydrometer readings after 40 seconds and 2 hours were used to determine the silt plus clay, and clay particles in suspension, respectively, whereas the percent of silt was calculated from the difference. Finally, soil textural classes were determined following the textural triangle of USDA system as described in Rowell (1997). Soil pH was measured potentiometrically using a digital pH meter in the supernatant suspension of 1:2.5 (soil: water ratio) (Chintala et al., 2012a).

The organic carbon (OC) content was analyzed following the wet digestion method described in Walkley and Black (1934) which involves digestion of the OC in the soil samples with potassium dichromate in sulphuric acid solution. The Kjeldahl procedure was followed for the determination of total nitrogen (TN) that follows oxidizing of the same with concentrated sulphuric acid and converting the nitrogen in the organic compounds into ammonium sulphate during the oxidation (Bremner & Mulvaney, 1982). Available phosphorus (P) was determined by Bray II method in which available P was determined by shaking the soil sample with extracting soil solution of $0.3N$ ammonium fluoride in $0.1N$ hydrochloric acid as described in Bray and Kurtz (1945). The available P extracted then was measured by spectrophotometer (Murphy & Riley, 1962). Exchangeable bases of the soils were extracted by excess ammonium acetate ($1M$ NH_4OAc at pH 7) solution and measured by atomic absorption spectrophotometer (Ca^{2+} and Mg^{2+}) and flame photometer (Na^+ and K^+) (Chintala et al., 2012a; Chintala et al., 2012b). The cation exchange capacity (CEC) was determined from ammonium-saturated samples that were subsequently replaced by Na^+ from a percolating sodium chloride solution (Chintala et al., 2013a). The excess salt was removed by 96% ethanol and the NH_4^+ that is displaced by Na^+ was measured by the Kjeldahl procedure (Chapman, 1965). The percentage of base saturation (PBS) of the soils was computed by dividing the concentration of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) by the value of CEC and multiplied by 100 (Bohn et al., 2001).

2.2.3 Soil Classification

Spatial soil classification was made at scale of 1:25,000 based on the information obtained from field soil profile morphological description and laboratory analysis result following FAO/WRB (1998) soil classification legend.

3. Results and Discussion

3.1 Morphological and Physicochemical Characteristics of Yigossa Soil Profile-1

The depth of Yigossa soil profile-1 (YSP-1) was very deep (> 200 cm) (Table 1). This could be caused by deep diffuse of colluvial materials. Similar observations were made by Sawhney et al. (2000) and Mahapatra et al. (2000) in submontane tract of Punjab. The textural class varied fro heavy clay at the surface to clay in the underlying horizons. The bulk density (BD) ranged from 1.27 g cm^{-3} at the surface to 0.7 g cm^{-3} in the deep horizons which could be the migration of finer particles down the profile and accumulation of sandy particels ar the surface. The surface soil color was 5YR 4/3 for YSP-1 and 2.5YR 3/3 for YSP-2. Similarly, it was 10YR4/2 and 10YR2/1in YSP-3 and YSP-4, respectively. The color patterns could be due to chemical and mineralogical composition, topographic position, textural makeup and moisture regimes of the soils (Fisher & Binkley, 2000). The nutty angular blocky structure with shiny ped faces in the profile could reflect the existence of relative accumulation of clay and biological pedoturbation (FAO, 1998). Singh and Agrawal (2003) reported structural variability could be due to moisture, soil OM and clay contents. Heavier and higher clay contents recorded in the profile was corresponding to the finding of Getachew and Heluf (2007) in Nitisols of Ayehu research substation. The migration and accumulation of clay in the subsurface could be contributed by the in-situ synthesis of secondary clays, the weathering of primary minerals, or the residual concentration of clays from the selective dissolution of more soluble minerals (Buole et al., 2003).

Table 1. Soil physical characteristics of the YSP-1

Depth (cm)	Textural analysis (%)			Textural Class	BD (g cm^{-3})	Color	Structure
	Sand	Silt	Clay				
0-25	9	25	66	Heavy clay	1.27	5YR 4/3	Crumb
25-50	3	17	80	Clay	0.9	7.5YR 4/3	Moderate angular blocky
50-75	5	15	80	Clay	0.8	7.5YR 4/4	Moderate angular blocky
75-100	3	15	82	Clay	0.7	7.5YR 4/6	Weak angular blocky
100-125	7	13	80	Clay	0.7	7.5YR 5/4	Weak angular blocky
125-200^+	3	15	82	Clay	0.7	7.5YR 5/3	Fine sub angular blocky

Higher percentage of sand was noticed at the surface indicating that larger in size and heavier in weight particles will not be easily illuviated down the soil profile. Silt exhibited an irregular trend with depth that could be due to temporal variation in weathering. The result was in agreement with the finding of Naidu (2002) in Karnataka. Similar results were also reported by Arun et al. (2002) in India. The decrease pattern of bulk density values in the profile reflects the general increase in contents of sand. This implies that no excessive compaction and restriction to root development (Werner, 1997). Similarly, Wakene (2001) reported that lower bulk densities were observed at subsurface in Bako area, Ethiopia.

As indicated in Table 2, the irregular pattern of pH values with soil depth might be due to downward movement of bases and clay adsorbed sporadically at different layers. This is in agreement with Buole et al. (2003). The organic carbon (0.5% to 1.45%) and total nitrogen (0.04% to 0.12%) contents varied irregularly with the soil depth. However, higher organic carbon and total nitrogen were recorded at the surface layer which could be attributed to the addition of farmyard manure and plant residues. Similar result was obtained by Getachew and Heluf (2007) in Ayehu, Ethipia. This pattern suggested that the main source of organic carbon and total nitrogen is organic matter. Available P at soil surface was greater than that of the subsoils due to greater biological activities, accumulation of organic materials and the increment of sand content. Similarly, Tekalign et al. (1988) reported that phosphorus is usually greater in the top soil than that of the subsoils due to sorption of the added P in the later. Higher CEC and organic carbon recorded at surface shows the strong association between organic carbon and CEC (Chintala et al., 2013a). However, lower CEC recorded at the sub soils could be due to the decrease in organic carbon and clay colloids to hold cations against leaching (Idoga & Azagaku, 2005; Chintala et al., 2013a). The range of CEC indicates that the dominant clay mineral of the soil is low activity clay. The base saturation reflecting the dominance of basic cations is an indicator of illuviation of basic cations translocated after intensive leaching from the surfaces.

Table 2. Soil chemical characteristics of YSP-1

Depth (cm)	pH (H_2O)	OC (%)	TN (%)	Ava. P (mg kg^{-1})	Exchangeable bases (cmol$_c$ kg^{-1})					CEC (cmol$_c$ kg^{-1})	PBS (%)
					Ca^{2+}	Mg^{2+}	Na^+	K^+	Sum		
0-25	5.56	1.4	0.12	7.90	10.53	1.05	0.30	1.54	13.41	20.6	65
25-50	5.76	0.9	0.08	5.37	9.81	1.29	0.19	2.45	13.74	18.0	76
50-75	5.36	0.5	0.04	3.78	9.80	1.16	0.07	2.45	13.48	18.4	73
75-100	5.54	0.8	0.07	4.25	10.32	1.23	0.14	2.56	14.26	19.4	74
100-125	5.15	0.9	0.07	5.25	9.58	1.21	0.07	2.42	13.27	16.6	80
125-200$^+$	5.16	0.6	0.05	2.66	9.16	0.91	0.01	2.10	12.18	18.8	65

3.2 Morphological and Physicochemical Characteristics of Yigossa Soil Profile-2

As shown in Table 3, the depth of YSP-2 was moderately shallow (50-100 cm). Reddish brown color was found throughout the profile that could be due to low organic matter content and the occurrence of various hydrated iron oxide forms. The result was in conformity with the findings of Walia and Rao (1996) and Sidhu et al. (1994) at Uttar Pradesh in northern India. Moderate to strong granular and blocky soil structure observed within the profile could reflect the existence of clay. Clay soil texture class could be probably due to clay migration within the profile. The profile had high clay and base saturation greater than 35%. This could be attributed to eluviations of clay size particles. The accumulation of clay in the subsurface could have been contributed by the *in situ* synthesis of secondary clays or the weathering of primary minerals from dissolution of more soluble minerals of coarse grains (Buole et al., 2003). The contents of silt were high in the profile and revealed an irregular decrease with depth. This decrease may reflect the weathering process of silt to clay size particles in the sub soils. As indicated in Table 3, the BD values of YSP-2 ranged from 1.14 g cm^{-3} at the surface to 1.00 g cm^{-3} in the sub surface suggesting a decrease in sand contents with increasing depth. This result was supported by Swarnam et al. (2004). Conversely, this result disagreed with Brady and Weil (2002) who indicated that bulk density increased with increasing soil depth.

Table 3. Soil physical characteristics of YSP-2

Depth (cm)	Particle size analysis (%)			Textural Class	BD (g cm^{-3})	Color	Structure
	Sand	Silt	Clay				
0-15	15	1.14	52	Clay	1.14	2.5YR 3/3	Strong granular
15-30	7	1.07	80	Clay	1.07	2.5YR 3/4	Moderate angular blocky
30-45	7	1.01	74	Clay	1.01	2.5YR 4/3	Fine angular blocky
45-70	5	1.00	78	Clay	1.00	2.5YR 4/4	Weak angular blocky

As revealed in Table 4, the pH values of YSP-2 varied from 5.55 to 5.92 (slightly acidic) which could be due to the leaching of basic cations particularly Ca^{2+} and Mg^{2+}. This is in agreement with the finding of Buole et al. (2003). The contents of soil organic carbon showed a similar pattern as pH values. This could be attributed to the vertical migration of finer organic colloids. It may also implicate presence of historically deposited organic matter. The lower content of organic carbon may indicate little return of decomposable matter from cultivated crops as well as existence of high rates of oxidation and degradation accentuated through long periods of cultivation. The low content of total nitrogen could be associated with degradation of total nitrogen content coupled with little nitrogen fertilization occurred in the area. This result is in line with the findings of Belay (1996) in Tigray region. The level of available P was generally low (Table 4). This might be due to its fixation by Al and Fe in acidid soils (Tisdale et al., 2002). Cation exchange capacity varied from 16.2 to 22.2 $cmol_c\ kg^{-1}$ and showed an irregular variation with depth of the profile. Relatively higher pH and PBS values recorded at surface might be due to the accumulation of basic cations from weathering of its parent materials (Brady & Weil, 2002). Similar observations were also made by Foth (1990) and Pillai and Natarajan (2004).

Table 4. Soil chemical characteristics of YSP-2

Depth (cm)	pH (H_2O)	OC (%)	TN (%)	Available P (mg kg^{-1})	Exchangeable bases ($cmol_c\ kg^{-1}$)					CEC ($cmol_c\ kg^{-1}$)	PBS (%)
					Ca^{2+}	Mg^{2+}	Na^+	K^+	Sum		
0-15	5.92	0.8	0.07	4.37	11.17	0.93	0.14	2.23	14.47	18.80	77
15-30	5.71	0.6	0.05	5.49	10.55	1.23	0.58	0.88	13.24	18.40	72
30-45	5.55	0.5	0.05	3.6	9.55	1.12	0.74	0.76	12.17	22.20	55
45-70	5.68	0.6	0.05	4.6	10.1	0.96	0.27	0.79	12.12	16.20	75

3.3 Morphological and Physicochemical Characteristics of Yigossa Soil Profile-3

The depth of YSP-3 was very deep (> 200 cm) and profile development varied from 25 to 125 cm soil layers (Table 5). This may be caused by deep diffuse of alluvial-colluvial materials. The soil color varied from grayish yellow brown (10YR4/2) to black (10YR2/1) that might be due to the presence of organic matter and hydrated iron oxides (FAO, 1998) and the extended saturation by water, high organic matter and reduced iron content. This result was in line with the findings of Mohammed et al. (2005) in Chercher highlands of Ethiopia. The greenish and bluish shades are attributed to the influences of various iron-based compounds. The mottling or redoximorphic features observed in the subsoil may be due to loss or gain of iron and/or manganese (Fanning & Fanning, 1989). According to Foth (1990), reddish color is also due to the presence of oxidized iron compounds. Hence, the possible reason for the relative dark color could be due to differences in forms of iron oxide. The brown color observed in the profile indicates low contents of OM that lightens its color. Organic matter and clay in the profile might be the reasons why the topsoil and subsoil were structurally developed and stabilized. The desirable effects of OM in the formation of soil granules and in stabilizing soil aggregates have also been reported (Daniel et al., 2000). The amount of clay of YSP-3 ranged from 52 to 60% with clay texture. Its bulk density values varied between 1.2 to 1.48 g cm^{-3} at subsurface and surface, respectively. This implies that no excessive compaction and restriction to root development (Werner, 1997). Higher bulk density recorded at the surface could be caused by repetitive cultivation and intensive reduction processes in the surface layer and translocation and precipitation of iron and manganese compounds in the subsoil (FAO, 1998).

Table 5. Soil physical characteristics of YSP-3

Depth (cm)	Particle size analysis (%)			Textural class	BD (g cm^{-3})	Color	Structure
	Sand	Silt	Clay				
0-25	5	37	58	Clay	1.48	10YR4/2	Strong angular blocky
25-50	7	33	60	Heavy clay	1.38	10YR3/2	Moderate angular blocky
50-75	11	31	58	Clay	1.3	10YR3/4	Fine angular blocky
75-200^{+}	13	35	52	Clay	1.2	10YR2/1	Weak angular blocky

Soil organic carbon (OC) and total nitrogen (TN) showed irregular pattern with depth at YSP-3 (Table 6). However, its content recorded at the surface was relatively higher than the sub-surface. This finding was in agreemnt with the works of Mitiku (2000); Abayneh (2001) and Ahmed (2002). In other study, OC in the soils of inter-hill valleys exhibited an irregular trend with depth (Bhaskar et al., 2004). The lower concentration of available P in the subsoil is attributed to the increment of clay content and clay type which can cause high P fixation and less mineralization of organic matter. Available P can increase as organic P is mineralized or when sorbed P becomes available (Chintala et al., 2013b). On other hand, available P at soil surface was greater than that of the subsoils due to sorption of the added P, greater biological activities, high inherent P content of the parent material and increased mineralization. This result was in line with the findings of Tekalign et al. (1988). Based on FAO (1998) ratings, the PBS values were high (> 50%) throughout the profile. Higher pH values and PBS of sub surface might be due to less H^{+} ions released and influx of basic cations from the adjacent slopes. This is in agreement with Buole et al. (2003) and Chintala et al. (2010).

Table 6. Soil chemical characteristics of YSP-3

Depth (cm)	pH (H$_2$O)	OC (%)	TN (%)	Avaialable P (mg kg^{-1})	Exchangeable bases (cmol$_c$ kg^{-1})					CEC (cmol$_c$ kg^{-1})	PBS (%)
					Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum		
0-25	5.77	2.3	0.2	10.50	15.08	3.84	0.60	0.82	20.34	32.8	62
25-50	7.12	0.7	0.06	2.78	20.68	4.78	1.15	0.84	27.44	34.6	79
50-75	7.12	1	0.08	2.31	18.89	4.45	1.15	0.86	25.35	33.8	75
75-200^{+}	8.30	0.5	0.04	0.37	21.68	4.84	2.50	0.91	29.93	36.2	83

3.4 Morphological and Physicochemical Characteristics of Yigossa Soil Profile-4

Profile YSP-4 had very shallow soil depth (< 30 cm) with young age and/or slow soil formation by colluvial deposits (Table 7). The soil color of the surface was black (10YR 2/1) and the color becomes brownish black (10YR 3/2) down to depth indicating low in organic matter content. This finding was similar with the works of Belay (1996). The surface and subsurface had moderate granular and angular blocky structures due to organic matter and clay contents. The texture class varied from loam in the surface to clay loam in subsurface which was similar with the finding of DSA and SCI (2006) and Mohammed et al. (2005). The amount of clay increased with depth of the YSP-4 from 22% in the surface to 32% in the subsurface that shows stages of weathering and a presence of vertical movement of clay size particles.

Table 7. Soil physical characteristics of YSP-4

Depth (cm)	Particle size analysis (%)			Textural Class	BD (g cm^{-3})	Color	Structure
	Sand	Silt	Clay				
0-15	37	41	22	Loam	0.7	10YR 2/1	Moderate granular
15-30	31	37	32	Clay loam	0.7	10YR 3/2	Weak angular blocky

The pH values in YSP-4 revealed a decreasing trend with depth, ranging from 6.14 in the surface to 5.62 in the subsurface (Table 8). This suggested that lateral water transport was not a significant hydrologic process at this landscape and lateral transport of weathered solutes was minimal. The available P content varied from 5.37 mg kg^{-1} in the surface to 20.1 mg kg^{-1} in the subsurface, indicating an increasing trend with depth of this soil. This could be due to the influence of soil parent material on pH value which eventually increased P availability (Chintala et al., 2012b; Chintala et al., 2013b). The result disagreed with the finding of Tekalign et al. (1988). Higher OC and TN might be due to nutrient bio-cycling (Ogunwale et al., 2002). Higher CEC could reflect the increased clay colloids. On the other hand, the low base saturation within the sub surface is likely a result of the lateral flow of water down slope and removing soluble cations. Percent base saturation (PBS) values of the surface and subsurface recorded were high (> 50%). This may be due to weathering of parent materials, leaching and accumulation of basic cations from the adjacent mountains.

Table 8. Soil chemical characteristics of YSP-4

Depth (cm)	pH (H_2O)	OC (%)	TN (%)	Available P (mg kg^{-1})	Exchangeable bases (cmol$_c$ kg^{-1})					CEC (cmol$_c$ kg^{-1})	PBS (%)
					Ca^{2+}	Mg^{2+}	Na^+	K^+	Sum		
0-15	6.14	1.2	0.11	5.37	12.81	3.32	0.04	1.27	17.44	26	67
15-30	5.62	1.1	0.09	20.1	12.54	3.52	0.26	1.12	17.44	30.8	57

3.5 Soil Classification

Based on the field observations and laboratory analysis, Yigossa soil profile 1 (YSP-1) could be categorized as Nitisols following FAO/WRB (1998) soil classification legend. This is because Nitisols have clayey soil texture with nitic horizon, red in color, more than 30 percent clay with nutty blocky structure and shiny ped faces. This result was in harmony with the finding of Gete (2000) in Anjeni watershed. As per the soil classification legend, YSP-2 could be classified as Luvisols. This result was complaint with the finding of Belay (1996) because Luvisols are developed on very gently to gently sloping lands. In other study, at scale of 1:250,000, DSA and SCI (2006) indicated only Luvisols are found in Yigossa watershed. Whereas YSP-3 fulfills the criteria for Gleysols since the profile has gleyic characteristics evidenced by reductomorphic and oximorphic mottles conditioned by excessive wetness at shallow depth; heavy clay surface layers, no diagnostic horizons other than histic and mollic. Gleysols are generally considered to be comparatively fertile because of their fine soil texture, slow rate of organic matter decomposition and influx of ions. They have greater CEC and PBS of 50% from soil surface. Finally, YSP-4 fulfils the criteria to call it as Regosols as they are unconsolidated mineral material, shallow to moderately deep soil, well drained and brown in color. These soils are loam, clayey in texture, moderate and angular blocky structure. This finding was in conformity with the conclusion of Gete (2000) that the upper slopes of Anjeni watershed that were covered Regosols. On the other hand, Kassa and Mulu (2012) showed that Regosols develop in association with Leptosols occurred at 3-8% slope in Tigray Region. Hence, the soil types identified in the watershed were Luvisols (630.86 ha), Nitisols (256.95 ha), Gleysols (125.55 ha) and Regosols (79.33 ha) at slopes of 2-5, 5-8, 0-2 and 8-5%, respectively (Figure 3).

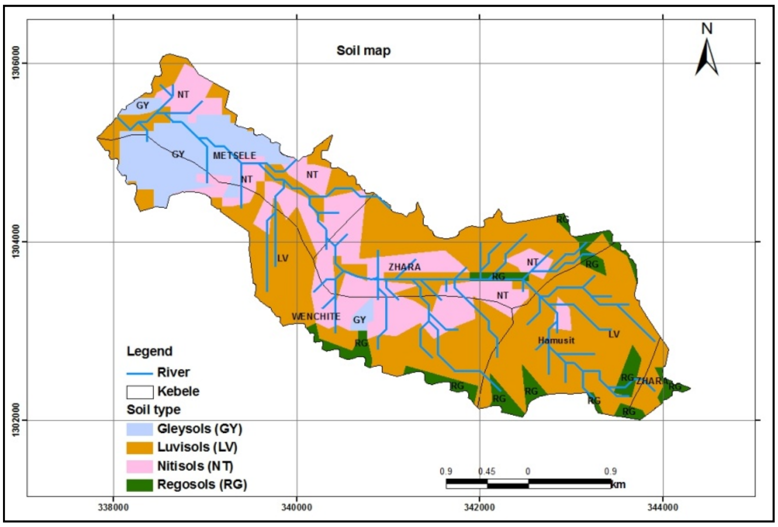

Figure 3. Major soil types identified in the study watershed

4. Conclusions

On the basis of the soil profile descriptions and laboratory analysis, Nitisols, Luvisols, Gleysols and Regosols were identified in gentle slope, sloping, foot slope and strongly sloppy areas of Yigossa watershed, respectively. It is also possible to conclude that slope has a major effect on soil formation and its characteristics.

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