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Agro-ecological assessment of physico-chemical properties of soils in Kulfo Watershed, South Western Ethiopia

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Variation in physical landscape of the highlands gives rise to variations in agro-climatic and soil parent materials in Ethiopia. The aim of this research is to characterize the physio-chemical properties of soils in Kulfo watershed. For the study, primary data from transect walks, composite soil samples and GPS points and secondary data from satellite imaginaries, National Metrological Agency and Central Statistical Agency were used. 36 composite soil samples (0-30 cm depth) were collected from three agro-ecologies (upland, mid and lowland) and analyzed in soil laboratory. Accordingly, the watershed is characterized into four agro ecologies: Lowland (20.9%), midland (35.9%), highland (37.4%) and cold high mountain areas (5.8%). Soil analysis revealed that dominantly the watershed is characterized as textually clay loam to sandy loam and there are no significant textural differences among soils in all agro-ecologies. The soil reaction varies from moderately acidic (with pH 5.4) to neutral (pH 7.3). The watershed is dominated by medium organic matter, low total nitrogen, very low available phosphorus (3.83-6.65 ppm), high potassium and very low to low cation exchange capacity. Soil and water conservation measures in the upland and use of organic manure in the lowland areas could be the viable options for rehabilitation of soil productivity.

Key words: GIS, remote sensing techniques, transect walk, composite soil sample.

INTRODUCTION

Ethiopia is located in the tropics; its impressive altitudinal variations within a short distance allow the country to enjoy both temperate and tropical climates, which gives varying biophysical resources (Gashaw, 2015). Similarly, the great topographic variation of Ethiopian highlands gives rise to the formation of different physical landscapes which are in turn the causes for variations in soil parent materials, agro ecological zones, flora and fauna (Mishra et al., 2004). Thus, the success or failure of agricultural production in the Ethiopian highlands is

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highly influenced by the unique topographic settings and varying biophysical features (Chamberlin and Schmidt, 2012). Soil being basic natural resource, its wellbeing is vital for increasing agricultural productivity and sustainable farm production. Researchers agreed that no agricultural system can be claimed to be sustainable without ensuring the sustainability of soil fertility (Arshad and Martin 2002). Ethiopian highlands are receiving high amount of rainfall, which causes leaching of basic soil nutrients. In addition, rugged terrain feature has significant effect on weathering of soils (Lloyd and Anthony, 1999).

The implication of heterogeneity of landscape and soil in the Ethiopian highlands is that within a given change in terrain, climate and land use/ cover types; it is likely that the direction and magnitude of soil properties will also change. At the end this can reduce soil physical and chemical properties in different land use types as observed in Arsi highlands of Ethiopia (Shimelis, 2008). A study conducted by Kiflu and Beyene (2013) in Southern Ethiopia reported that there is change in soil chemical properties (high soil pH reaction, EC, available P, exchangeable K and Ca) in enset (*Ensete ventricosum*) fields as compared to other fields.

Characterization of soils is fundamental to soil studies, as it is an important tool for soil classification, which was done based on soil properties. It also provides information for understanding the physical, chemical, mineralogical and microbiological properties of the soils (Ogunkunle, 2005). In addition, it can help to determine the types of vegetation and land use best suited to a location. Soil classification, on the other hand, helps to organize our knowledge, facilitates the transferring of experience and technology from one place to another and helps to compare soil properties. A soil characterization study therefore is a major building block for understanding the soil, classifying it and getting the best understanding of the environment.

Several studies in Ethiopia have disclosed that deforestation, over cultivation, expansion of cultivation on marginal lands and steep slopes, and overgrazing are the causes of serious soil erosion and the resultant loss of soil fertility (Lakew et al*.,* 2005; Fock and Cao, 2002). Similarly, Young (1989) and Aklilu (2006) argued that there is a causal link among population increase, limited access to land resource, and poverty and land degradation.

In line with this, studies conducted in Northern and Southern Ethiopia reported variation in measured soil properties over different slope types and terrains (Ali et al., 2010; Dessalegn et al., 2014). A recent study conducted in Wolaita Zone also noted similar findings on variation of soil properties across varying landscape features (Kibret and Fanuel, 2015). The study revealed higher concentration of available P, exchangeable K and extractable micro nutrients (B, Cu, Fe and Zn) in the soils on flat than on steep slope terrain. Different sources also confirmed that the amount and distribution of soil nutrients of an area is dependent on biophysical conditions of the area (Ali et al., 2010; Kibret and Fanuel, 2015; Dessalegn et al., 2014).

Due to historic settlement, obsolete farming practices and encroachment of farmlands into marginal and steep slopes, the study area experiences severe degradation in the form of removing fertile top soil, soil erosion and associated constraints of soil nutrient depletion. As a result, soil nutrient depletion is one of the major problems of sustainable agricultural productivity and status of food insecurity in the area.

Agriculture being the predominant economic activity in Ethiopia needs research based information and experimental data on soil physical and chemical properties, which provides a viable information on the status of soil nutrients and soil related problems (Lekwa et al., 2004; Fasina et al., 2007)). Therefore, this research gap has initiated the researchers to conduct a study on the assessment of agro-ecological characteristics of physio-chemical properties of soil in Kulfo watershed.

MATERIALS AND METHODS

Description of the study area

The study area is part of Gamo highlands, located in the North-western margin of the Rift Valley Lakes of Abaya and Chamo, Southern Ethiopia. Astronomically, it lies between 5°58' N - 6°15'N, latitude and 37°18'E - 37°36'E, longitude covering about 434.7 km^2 (Figure 1). The altitude ranges between 1182 (on the shores of Lake Chamo in the western margin) and 3384 m above sea level (on the peak of mountain Gughe, Gamo highlands).

The landform of Kulfo watershed is characterized by extensive plateaus and hills dissected by mountain ranges in the northern parts and rift valley plains in its southern margin. The geology of the study area is of two types. Majority of the watershed including its northern part is dominated by trap series of tertiary volcanic lava of Cenozoic era, while the southern rift valley Lake areas were dominated by deposition of quaternary sediments of alluvial and lacustrine deposits. The upstream consists of alkaline basalts, with interbedded pyroclastic and rare rhyolites, porphyritic amygdaloidal and olivine basalt (Southern Regional Atlas, 1985). According to the FAO classification system (FAO, 2012), the study watershed has eight major soil types, where *orthicacrisols* (59.9%), *dystricnitisols* (13.4%), *eutric fluvisols* (11.3%) and *dystricfluvisols* (9.5%) shared 94.1% of all soil types while the remaining, such as *leptosols, eutric nitisols* and *chromic vertisols* contributed 5.9% of the

Kulfo is a perennial river which is used for domestic purposes and for small scale irrigation in its lower course. Due to East ward inclination of the landscape, all tributaries of Kulfo river (*Yeremo, Baba, Gulando, Zegende, and Ambule),* which is originated from Laka Kuyle, Kacha Wusha and Dita ridges are making their way into Lake Chamo. The dominant vegetation covers in the watershed are Bamboo, Eucalyptus globulus trees, bushes, riverine trees and short mountain grasses. In the area rainfall distribution is bimodal with an average annual rainfall of 1390 mm in the upstream and 959 mm in the lower catchment. The annual average temperature in the upstream is 16.7°C, while it is 24°C in the downstream area Degradation of watershed in recent years has brought the long-term reduction of the quantity and quality of land and water resources. Changes in watersheds have resulted from a

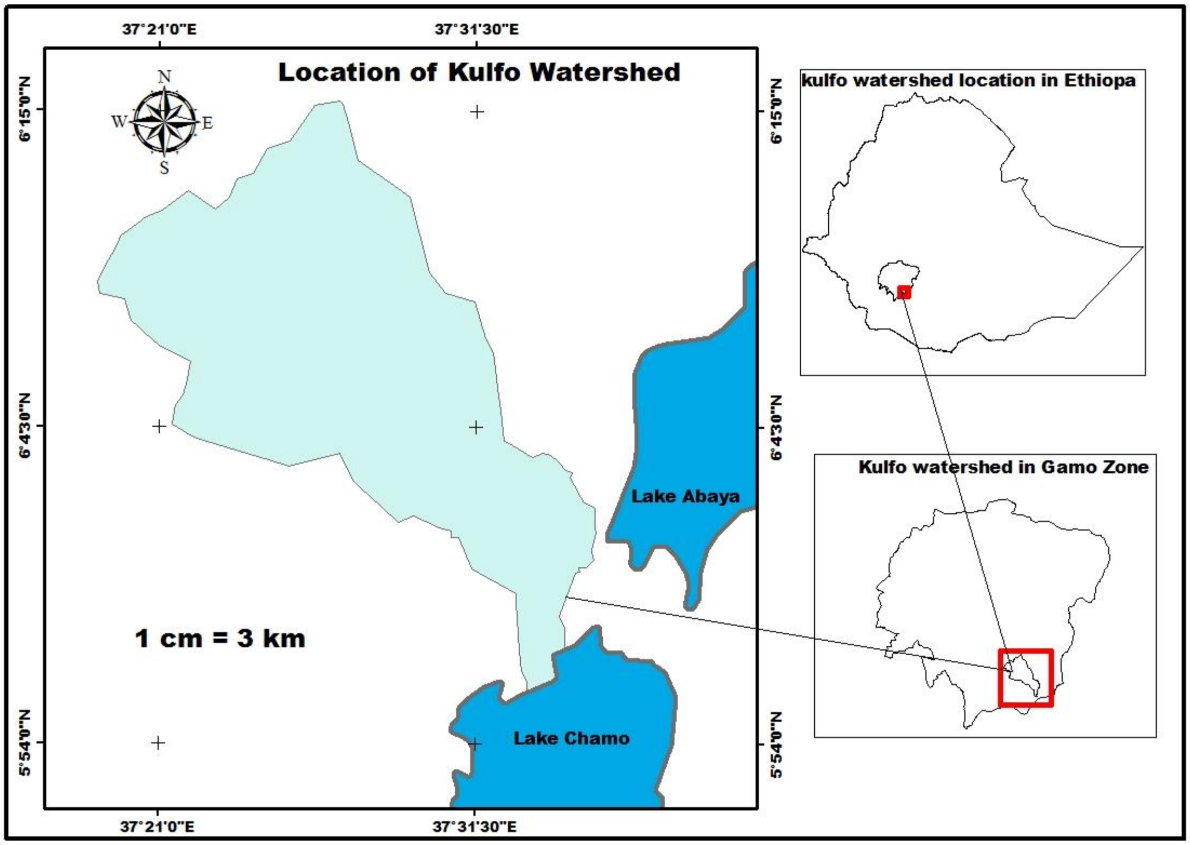

Figure 1. Location map of Kulfo Watershed, South Western Ethiopia.

range of natural and anthropogenic factors, including natural soil erosion, changes in farming systems, over abstraction of water, overgrazing and deforestation. Major land related constraints of the watershed are: cropland scarcity, soil erosion, declining pastures, deforestation and low crop yield. Small scale farming, such as barley (*Hordeumvulgare L.*), potatoes (*Solanum tuberosum L.*) and cabbage,enset (*Ensete ventricosum (Welw.)* along with livestock are the mainstay of smallholding farmers.

Data source

In order to achieve the objective of the study both primary and secondary data were used. The primary data were generated from transect walk, group discussion and soil sampling while secondary data were obtained from satellite imaginaries, climate data and Demographic data from CSA sources. Satellite imaginaries, grid based rainfall and temperature data obtained from National Meteorological Agency were used to characterize the biophysical landscape features of the study area.

Soil sampling

A first reconnaissance survey was conducted across the study area and 36 composite soil samples (0-30 cm depth) were collected in the year 2018 from the upland (18), midland (12) and lowland (6) agro ecologies of randomly selected land use/cover sites. Soil sample collection was performed by taking from each sampling category 1 kg representative composite soil in plastic bags, secured, labeled and transported to Arba Minch University Chemistry Department soil laboratory for analysis. Mainly more sample points were taken in the upstream part of the watershed (Figure 2), since it covers large area of the watershed and relatively characterized by poor productivity.

Laboratory analysis

Soil bulk density was measured using the core method (Blake, 1965). Soil texture was analyzed according to the procedures outlined by FAO (2012) using hydrometer method. The soil pH and ECe was measured using pH and EC portable meter. Soil organic carbon was determined using CNS analyzer (Blair and Carter, 1992). Potassium was determined by flame photometer. Available phosphorus was tested by Bray-1 and Olsen's method (Olsen et al., 1954). Total nitrogen was determined using modified Kjeldahl method (Jackson, 2005). The exchangeable bases (Na, K, Mg and Ca) in the soil were determined from the leachate of a 1M ammonium acetate (NH4OAc) solution. Exchangeable K and Ca were recorded from flame photometer (Rowell, 1994). Cation exchange capacity (CEC) was measured after leaching the ammonium acetate extracted soil samples with 10% sodium chloride solution. The percent base saturation of the soil samples

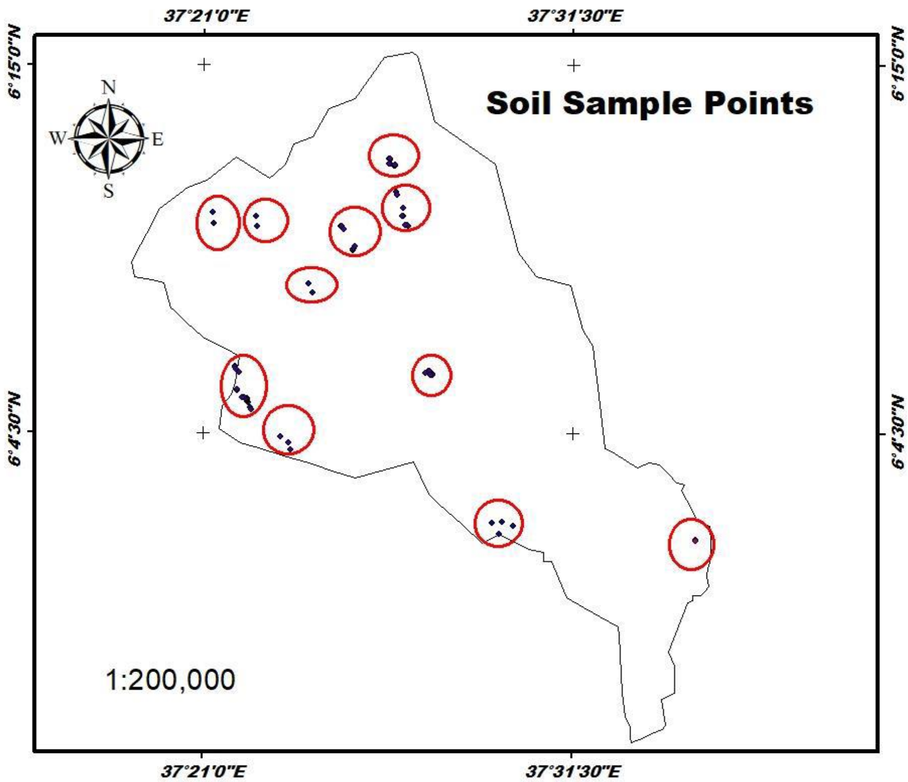

Figure 2. Sample points for soil sampling at Kulfo watershed.

was calculated from sum of the exchangeable cations (Na, K, Mg and Ca) as the percent of the CEC.

Data analysis

Climate and land use/ cover data were analyzed using GIS and Remote Sensing techniques in Arc GIS 9.3 software environment. Descriptive statistics were used to construct tables and figures to compare and contract soil nutrients across varying land use/ cover types. Based on laboratory and field data soil maps and soil nutrients were identified and presented in figures and maps.

RESULTS AND DISCUSSION

Agro-ecological zone

Kulfo watershed has diverse agro ecological zones ranging from dry *Kola* belt (500-1500 m) to a high *Dega* belt (3200-3700 m). Each belt is different in temperature and rainfall patterns. The boundaries between belts are also boundaries between agricultural crops. As shown in Figure 3, the watershed is characterized in four traditional agro ecological zones, namely Kolla (20.9%), *Weyna Dega* (35.9 %), Dega (37.4%) and High Dega, cold high mountain area (5.8%) related to the areas where soil samples were taken.

Climate condition

The degree and intensity of temperature determines the rate of evapotranspiration, soil moisture content and the humidity of the atmosphere. In the upstream the minimum and maximum temperature varies between 14.3 and 18.4°C. The annual mean temperature of the area is 16.7°C, which showed a slight annual variation (CV= 7.7%). The downstream areas got minimum (15.4^{O}C) and maximum (31.6°C) temperature in December and April months respectively. In this part of the watershed temperature condition is highly variable (CV= 50.2%) and showed a decreasing pattern from north to south (Figure 4).

The study watershed experienced two rainfall patterns. They are *Belg*, little rain season (March to May) and *Kiremt* (June, July and August), which is main rainy season. The fluctuation of rainfall in these seasons may impact on growing period and reliability of rainfall (Figure 5).

Soil characteristics

Texture

Soil texture being an important characteristic of soil which

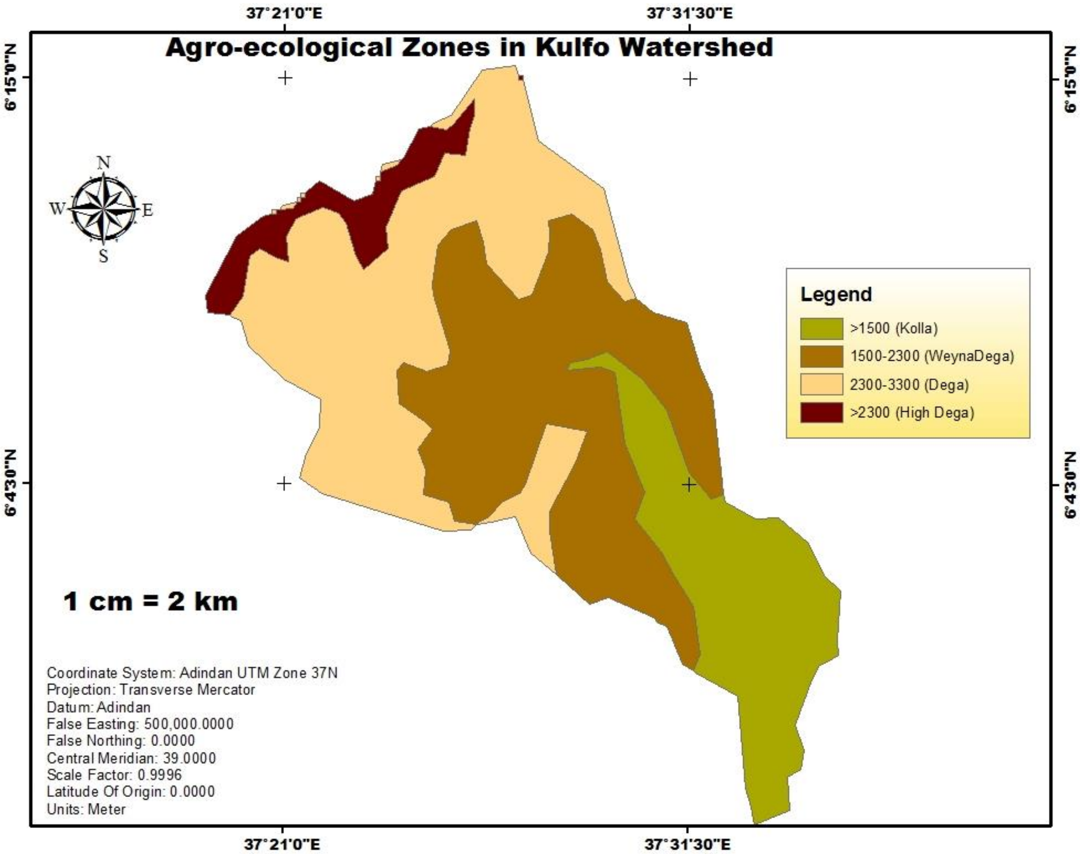

Figure 3. Agro-ecological zones of the watershed.

controls moisture holding capacity, the ease of tilling the soil and, the amount of aeration (Miller et al., 1997) is vital for soil fertility. The textural classes of surface soils on croplands are clay loam (upland) to sandy loam (downstream) as shown in Table 1. The study result revealed that soil texture classes in the upland are dominantly clay (33%) in texture, while it was sandy (65.8%) in the downstream. As stated by Miller et al. (1997) clay soil and silt soils have the ability to resist soil erosion and are less susceptible to erosion hazards. Thus from the findings it is possible to suggest that most soils in the upland areas can be grouped under less erodible soils. But poor adaptation of soil and water conservation measures is observed in the upland areas, which indicates that loss of nutrients followed by decline of the soil productivity is basic concern in the area.

Bulk density

Medium bulk density (1.11 to 1.2 g/cm^3) was recorded in three agro-ecologies; it implies the study soils have normal pore space and no limitation for aeration. The study further noted that the bulk density is not greater than the critical limits of 1.63 g/cm^3. As a result, in the study area compaction and drainage problems are minimum, it can create conducive environment for biological activity (Wemer, 1997) and infiltration.

Soil reaction

The laboratory result of soils in the croplands showed soil reaction between 5.4 (moderately acidic) to 7.3 (neutral). As stated in Table 1, most upland soils are acidic, which results from heavy rainfall condition (which leached down the soluble basic cation nutrients further down) as compared to the neutral soil behavior in the Lake shores of Lucastrine soil area. According to Smith et al. (1995) soil pH is highly sensitive to changing natural environment, repeated cultivation of the same plots and presence of heavy rainfall, which result in leaching of basic cations. As a result, soils of the uplands have lower pH and relatively acidic behavior. Contrarily, shore area soils have high pH, which is attributed to abundant soil bicarbonates. According to Brady and Weil (2008) most plants grow well in soils with pH between 6.5 and 7.5.

Thus, soils in the low-lying areas are conducive for crop

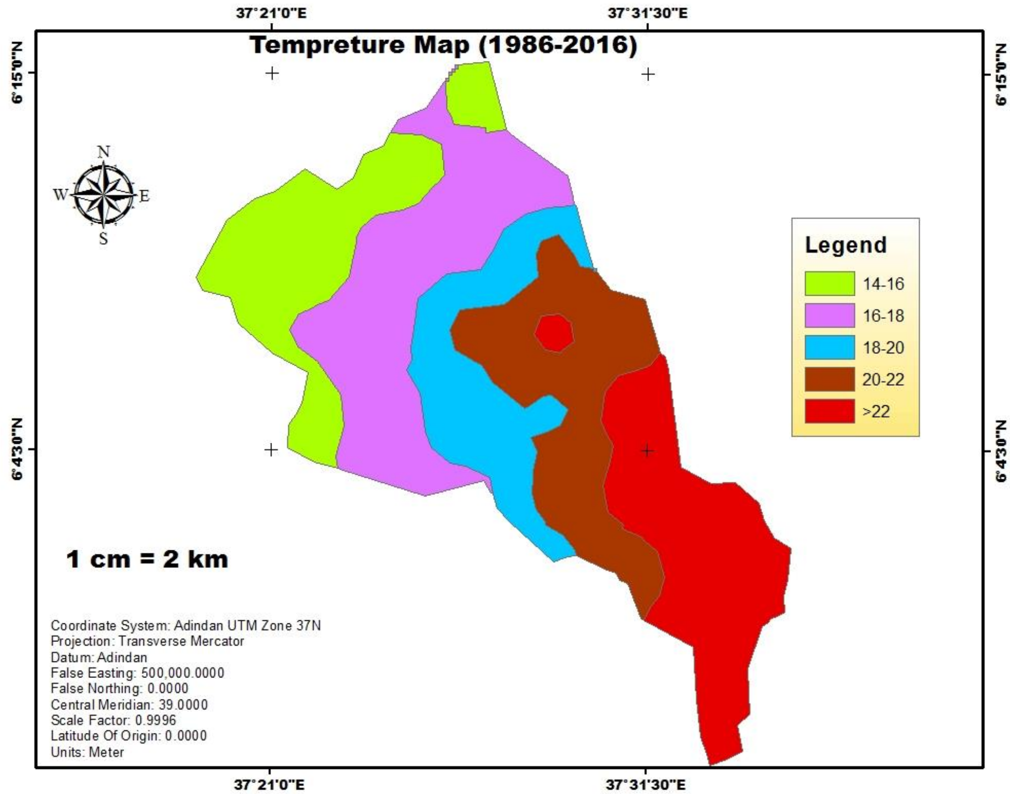

Figure 4. Temperature Map of the watershed (1986-2016).

cultivation.

Organic matter content

The analysis revealed that organic matter content of soil in the midlands and low lying areas of the croplands are medium to high in amount (2.38 to 3.21%) respectively. A study conducted by Alber and Ketterings (2008) reported that productive agricultural soils have organic content levels of 3 and 6%. Soil organic matter is an indicator of soil quality and controller of soil physical and chemical properties and source of essential plant nutrients such as N, S, P (Prasad and power, 1997).From the analysis it is possible to suggest that croplands in lowland area are agriculturally more productive as compared to the midland area probably due to the deposited nutrient rich soils materials brought from uplands by erosion and the fluvial nature of the original soil in the area.

Total nitrogen

The level of total Nitrogen in the study area is less than 0.1%, which is rated as very low in N content. Thus, according to Baize (1993) and Landon (2014) the amount of total nitrogen ranges between 0.1 and 0.2% considered as very low. Hence the result implies that surface soil in croplands of three sites requires nitrogen fertilizer for sustained crop production. As noted above, the organic matter amount of soils was medium to high, while contrary to expectation, the level of total nitrogen in all croplands was observed to be low. Thus, the amount of total nitrogen relationship in varying croplands showed weak relationship (r= 0.124). The low level of total nitrogen in three sample soils could be ascribed from low biomass return due to continuous farming and crop residue used for animal fodder and domestic purpose. This result is in line with the findings of Tuma (2013), a study conducted in Abaya-Chamo Basin and reported low level of total nitrogen and organic carbon in cropland soils due to repeated tillage.

Available phosphorus

Soil analysis revealed that available phosphorus on croplands was 3.83 and 6.65 (ppm) for midland and lowland areas respectively. This is considered to be very low to low P content and according to Baize (1993) it is below the critical minimum limit of < 7 mg/kg soil. Thus, the study soils are deficient in phosphorus nutrients and it

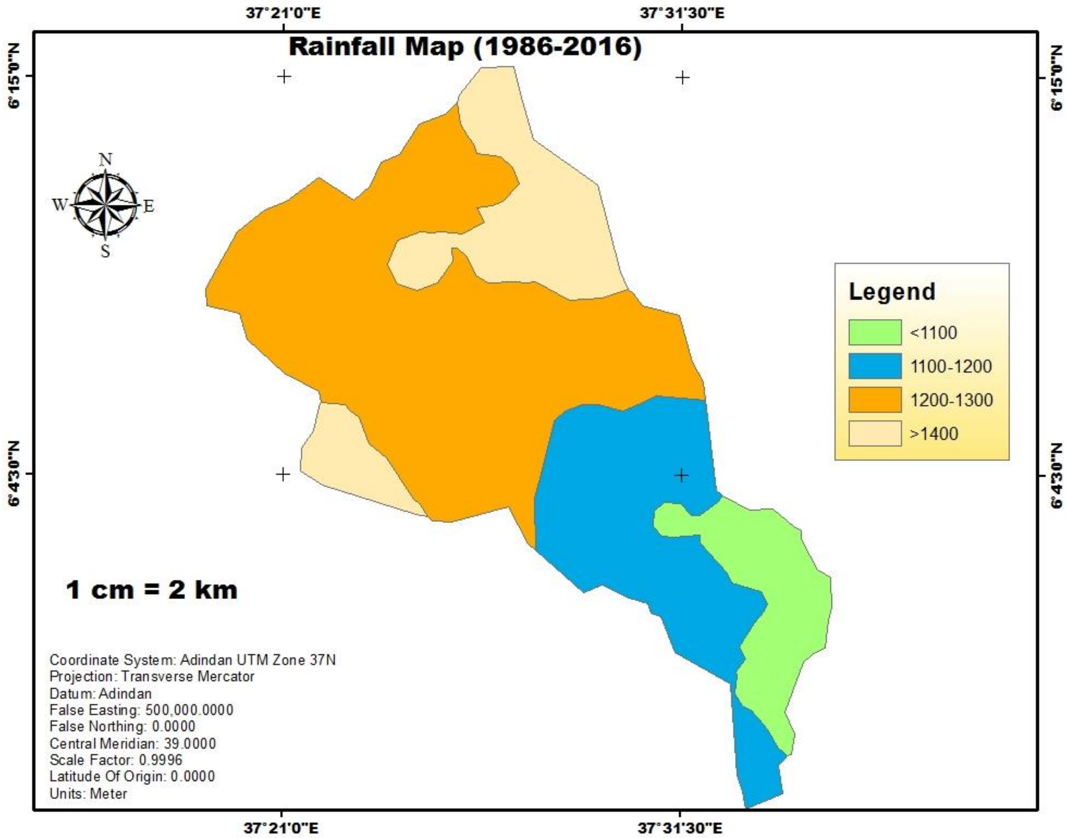

Figure 5. Rainfall Map of the watershed (1986-2016).

Table 1. Physicochemical properties of soils of Kulfo watershed respective to the agro-ecology.

Kebele	Crop land	Texture class	pH	OM	TN	AP	K^+	Ca^{2+}	Mg^2	Na^+	Bulk density	CEC
Kashaso (upland)	CL	Clay loam	5.4	2.71	0.06	4.46	2.97	3.00	13.76	0.52	1.14	4.51
MazoDoysa (midland)	CL	Clay loam	6.2	2.38	0.09	3.83	3.23	1.43	19.1	0.79	1.11	3.45
Walo (lowland)	CL	Sandy loam	7.3	3.21	0.1	6.65	5.13	7.9	19.64	1.25	1.20	7.16

CL = crop land, OM = Organic matter, TN = Total Nitrogen, AP= Available Phosphorus, CEC= cation exchange capacity.

should be supported by P fertilizer for optimum crop yields. As noted by Solomon and Lehmann (2000) the presence of sufficient amount of available P and total Nitrogen in the soil is due to management factor, soil organic matter, optimum climate (temperature and rainfall) condition of the area. Thus, it is observed from the analysis that for viable crop production the study soils have potential limitation of phosphorus soil nutrients. As reported by literature, Phosphorus, Nitrogen and Potassium are the three essential nutrients required by crop for optimum yields and physiological processes such as photosynthesis, root development and seed production (Johnson and Steen, 2000).

Cation-exchange capacity (CEC)

The result showed that the soils of the watershed have mean CEC of 5.04 cmol (+)/kg$^-$ with coefficient of variation of 0.42. This implies the amount of CEC was less variable throughout the study soils. The study further noted that the proportion of CEC (7.16) in the Lake area soils increased by 207.5% compared to midland soils, suggesting that the availability of CEC in the soil is influenced by depositional materials and fluvial soil sources in the Lake environment. According to FAO (2012) when CEC presence exceeds 10 cmol (+)/kg it is considered to be satisfactory for most crops. In this regard, the study surface soils were considered to be low, which was the reflection of low soil organic matter, relatively less clay content (33%) and low amount of cation exchange nutrients that are the major contributor of soil fertility (Oades et al., 1989; Joel et al., 2017).Thus for sustainable crop production, soil and water conservation measures and application of organic manure could be feasible options.

Exchangeable base (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+})

According to the ratings of Baize (1993) the level of exchangeable calcium of the study soils is from low (< 5 cmo1 (+)/ kg) to medium (7.9 cmo1 (+)/ kg), showing that the development of salt is relatively minimal.

Potassium is the other essential nutrient required by crop for optimum yields. It acts as a correction to the harmful effects of nitrogen and often required for crops receiving high amount of nitrogen (Sehgal, 1996). The level of potassium in the soil was 2.97 cmo1 (+)/kg and 5.13 cmo1 (+)/kg in the upland and lowland soils respectively. According to Baize (1993), this amount was considered to be very high (> 1.2 cmo1 (+)/kg). The study results further depicted that with the increasing soil reaction the presence of potassium mineral also increases.

Furthermore, the presence of exchangeable sodium was 0.52 cmo1 (+)/kg s (low) and 1.25 cmo1 (+)/kg (medium) for upland and Lake area soils respectively. According to Landon (1991), excess soluble salt was not a problem on the studied soils.

Base saturation

The percentage of the cation exchange capacity occupied by basic cations is what is termed as base saturation. In the classification of soil, Hazelton and Murphy (2007) used base saturation as an indication of soil fertility status of an area. Accordingly, base saturation of study soils is 20.25 and 33.92% for upland and lowland soils respectively. As a result, base saturation of the study soils is rated as very low to low. This is due to the influence of acidic soils of the area. Brady and Weil (2008) reported that highly weathered and acidic soils have low concentration of base saturation. This is in line with our findings that soils in Kulfo watershed are acidic and originally they are highly weathered soils.

Conclusion

The results of this study showed that the study watershed has diverse agro ecological zones ranging from dry Kola belt (500-1500 m) to a high Dega belt (3200-3700 m) showing difference in temperature and rainfall patterns. It was ascertained that there was significant variation of soil physio-chemical properties across the watershed and that most soils are acidic and deficient in essential soil minerals. Texturally the upland area is dominantly by clay and the lowland area by sandy in texture. Almost all of the agro-ecological zones of the watershed have a medium bulk density which implies that the soils have normal pore space and no limitation for aeration. The croplands in lowland area are agriculturally more productive as compared to the midland area due to the deposited nutrient rich soils materials brought from uplands by erosion and the fluvial nature of the original soil in the area. The level of total nitrogen and available phosphorus are low in the area demanding nitrogen and phosphorus supplements for sustained crop production. Thus, erosive landscapes and low soil nutrients are common problems observed in the study area, which needs proper intervention practices. Therefore, in order to ensure the productivity of cropland, restoration of deficient nutrients, reclamation of acidic soils and use of environmental restoration measures could be a viable option. In addition, further focus shall be given for slope and land use level studies of soil nutrients in the watershed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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