AGRO-ECOLOGICAL ASSESSMENT OF PHYSICO-CHEMICAL PROPERTIES OF SOIL IN KULFO WATERSHED, SOUTH WESTERN ETHIOPIA

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Abstract

The great variation in physical landscape of the Ethiopian highlands gives rise to the formation of different relief features, which are inurn causes for variations in agro-climatic and soil parent materials of the country. The aim of the research was to characterize the physio-chemical properties of soils in Kulfo Watershed, Southwest Ethiopia. In the study both primary and secondary data were used. The primary data was generated from Kebele transect walks, composite soil sample and Soil GPS points of varying land use/ cover types, while secondary data was obtained from satellite imaginaries, National Metrological agency and Central Statistical Agency etc. 36 composite surface soil samples (0-30cm depth) were collected from varying land use/ cover types of three agro-ecologies of the watershed namely, upland, mid and lowlands. Collected soil data Were analyzed in soil laboratory of Arba Minch University. The study result revealed that Kulfo watershed was characterized into four traditional agro ecologies, namely lowland (20.9%), midland (35.9 %), highland (37.4%) and cold high mountain areas (5.8%). The soil analysis results showed that dominantly soils of the watershed are characterized as texturally clay loam to sandy loam and they have no significant textural class difference among soils in all agro-ecologies. The soil reaction varies from moderately acidic (with pH 5.4) to neutral (pH 7.3) status.Grid based climate analysis showed that precipitation and temperature pattern showed gradual decrease from northern to the southern parts of the watershed.Furthermore, the analysis showed that soil chemical properties in the watershed are dominated by medium organic matter, low total nitrogen, very low available phosphorus (3.83-6.65ppm), high potassium and very low to low CEC content. Therefore, in order to rehabilitate theproductivity of soil-chemical properties the application of Soil and Water Conservation measures in the upland, use of organic manure in the low lying areas could be the viable options for promising crop yield in the area

Keywords: GIS and Remote Sensing Techniques, physio-chemical properties, transect walk, Agro ecology, Kulfo Watershed.

INTRODUCTION

Ethiopia's location in the tropics coupled with impressive altitudinal variations within a short distance allows the country to enjoy both temperate and tropical climates, which give varying biophysical resources (Gashaw, 2015). Similarly, the great topographic variation of Ethiopian highlands gives rise to the formation of different physical landscapes which in turn became 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 highly influenced by the unique topographic settings and varying biophysical features (Chamberlin and Emily, 2012). Because soil is a basic natural resource, its wellbeing is vital for increasing agricultural productivity and sustainable farm production. Researchers agree that no agricultural system can be claimed to be sustainable without ensuring the sustainability of soil fertility (Arshad and Martin, 2002). Ethiopian highlands receive 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 reduces oil 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 classifications done based on soil properties. It also provides information for understanding of 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 also helps to organize our knowledge, to facilitate the transfer of experience and technology from one place to another, and h 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 for 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 study conducted in Wolaita Zone also noted similar findings on variation of soil properties across varying landscape features (Fanuel, 2015). In this case, Fanuel's findings 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 and Beyene, 2010; 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 ether in the form of removing fertile top soil or soil erosion and associated constraints of soil nutrient depletion. As a result, soil nutrient depletion is one of the major problem for sustainable agricultural productivity and status of food insecurity in the study area.

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

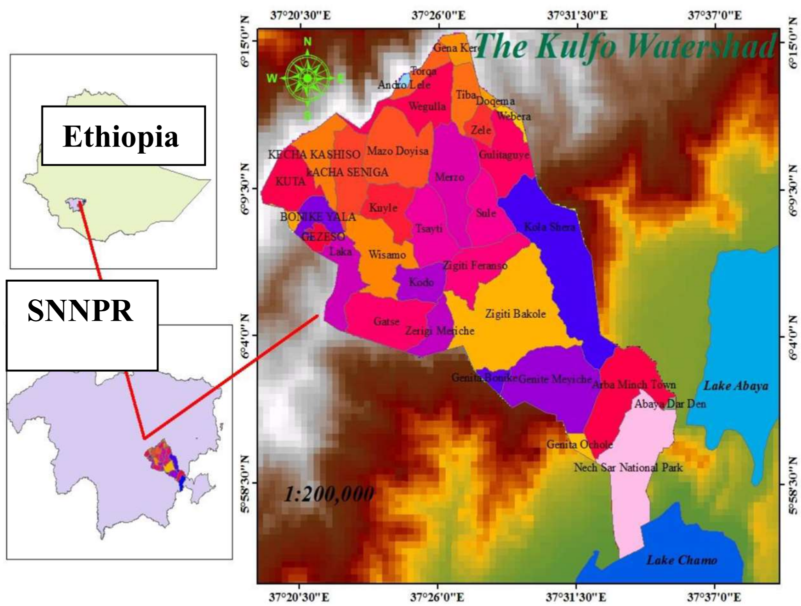

Figure 1: Location of Kulfo Watershed, South Western Ethiopia

METHODOLOGY

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(Figure1). The altitude ranges from 1182 (on the shores of Lake Chamo in the western margin) to 3384 m above sea level (on the peak of Mt. Gughe, Gamo highlands)

The landform of Kulfo watershed is characterized by extensive plateaus & 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 FAO classification of soil, the study watershed has eight major soil types of which *orthicacrisols (59.9%), dystricnitisols (13.4%), eutric fluvisols (11.3%), dystric fluvisols* (9.5%) shared 94.1% of all soil types while the remaining, such as *leptosols, eutricnitisols and chromic vertisols* contributed 5.9% of the total (own survey of soil map).

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 originate 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 was 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 was 16.7^0, while it was 24^0c in the downstream area (Chencha and Arba Minch metrological stations, 2018). Rain fed small scale farming such as barley (*Hordeumvulgare L.*), potatoes (*Solanum tuberosum L.*), cabbage, and *enset* (*Ensete ventricosum (Welw.)* along with livestock are the mainstay of smallholding farmers. Kulfo watershed has a population of 315,731 of which 50.3 % and 49.7 % are female and male respectively.

Data Source

In order to achieve the objective of the study, both primary and secondary data were used. The primary data was generated from transect walk, group discussion, and soil sampling while secondary data was obtained from satellite imageries, climate data, and demographic data from CSA sources. Satellite imageries and 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

First reconnaissance survey was conducted across the study area. 36 composite soil samples (0-30cm depth) were collected from the upland, midland and lowland agro ecologies of randomly selected land use/cover sites by team of researchers, key informants, and agricultural extension agents for laboratory analysis. 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's Chemistry Department soil laboratory.

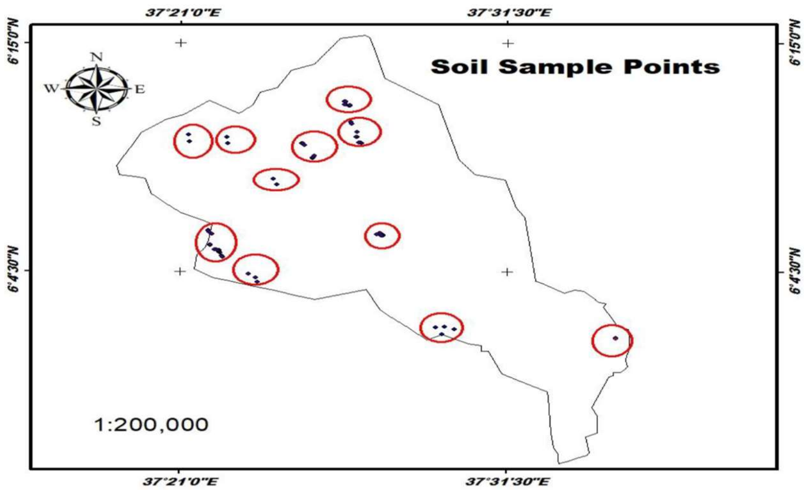

Figure 2: Sample Points for Soil Sampling at Kulfo watershed

Source: Field Survey, 2017

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 by 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, 1967). 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 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 technique 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 elaborated in narration form.

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 belts are different in temperature and rainfall pattern. The boundaries between belts are also boundaries between agricultural crops. As shown on 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%).

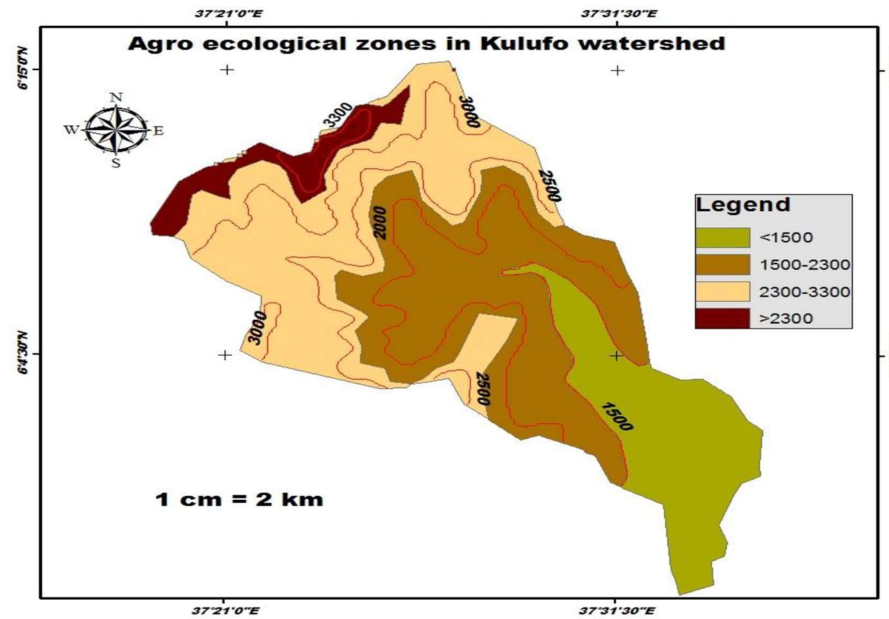

Figure 3: Agro-ecological zones of the watershed
Source: Arc GIS 9.3 analysis

Drainage Characteristics

Kulfo is a perennial river which is used for small scale irrigation in the lower course. Due to East ward inclination of terrain, all streams that originate from Laka, Kuyle, Kacha-Wisha and Dita uplands make their way to the south-eastern direction and empty into Lake chamo. Perennial streams such as Yeremo, Baba, Gulando, Zegende, and Ambule and its sub streams are tributaries of Kulfo (Figure 4).

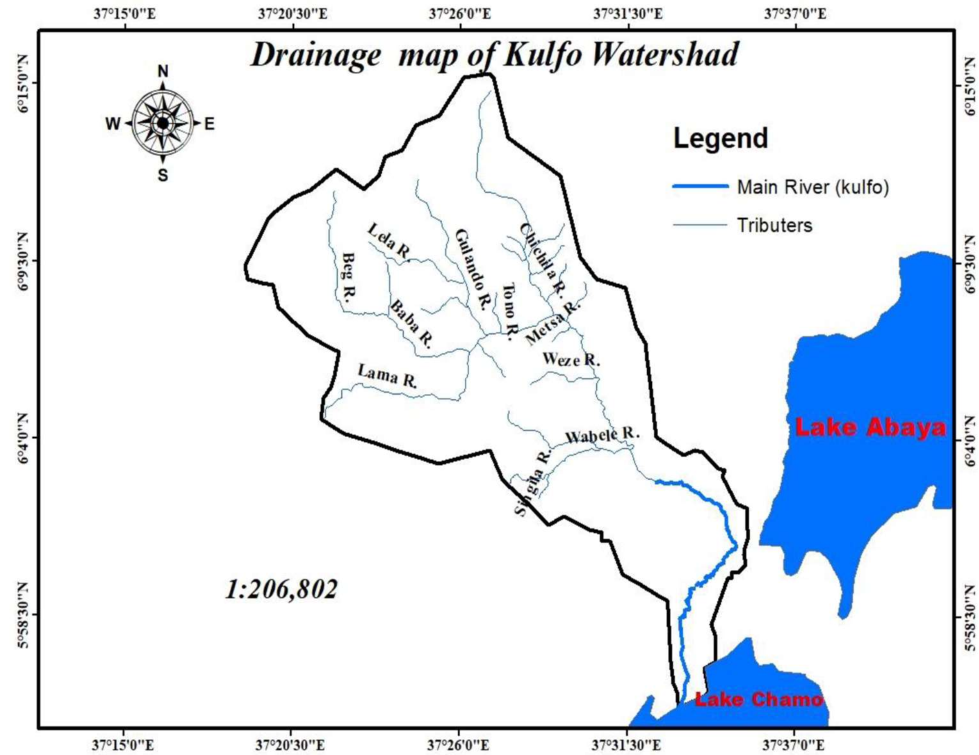

Figure 4: Drainage map of Kulfo watershed

Climate Condition

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.

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^{0}c and 18.4^{0}c. The annual mean temperature of the area is 16.7^{0}c, which showed a slight annual variation (CV= 7.7%). The downstream areas got minimum (15.4^{o}c) and maximum (31.6^{o}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.

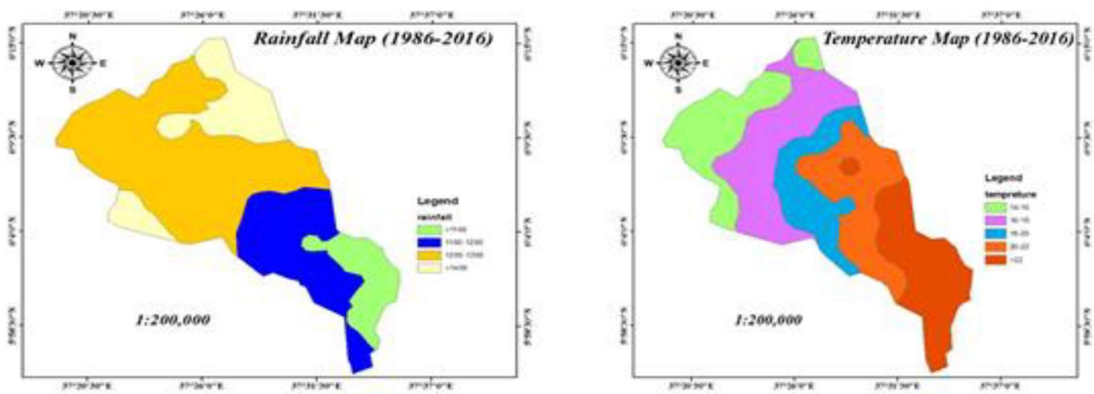

Figure 5: Rainfall Map (1986-2016) Temperature Map (1986-2016)

Soil Characteristics

Texture: Soil texture being an important characteristics of soil that 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 on 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, it is possible to suggest from the findings that most soils in the upland areas can be grouped under less erodible soils

***Bulk Density*:** Medium bulk density (1.11 to 1.2 gcm$^{3-)}$ was recorded in three agro-ecologies, which implies the study area soils have normal pore space and no limitation for aeration. The study further noted that the soils bulk density is not greater than the critical limits of 1.63 g/cm3. As a result, in the study area, compaction and drainage problems are minimum. This 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 on Table 1, most upland soils are acidic, which resulted 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 results 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. As a result, soils in the low-lying areas are conducive for crop cultivation.

Table 1

Characteristics of soil physicochemical properties (0.30cm) in percentage

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 area(lowland)	CL	Sandy loam	7.3	3.21	0.1	6.65	5.13	7.9	19.64	1.25	1.20	7.16

Source: Analysis of composite soil sample, kulufo watershed

Organic matter content*:* Laboratory result showed that organic matter content of soil in the midlands and low lying areas croplands are medium to high in amount (2.38 % to 3.21 %) respectively. A study by Alber and Ketterings (2008) reported productive agricultural soils have organic content levels of 3% and 6%. Soil organic matter indicators of soil quality, controllers of soil physical and chemical properties, and sources 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 soil 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. According to Baize (1993) and Landon (2014), the amount of total nitrogen that range between 0.1% and 0.2% are considered to be 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 were 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 to low biomass return due to continuous farming and crop residue use for animal fodder and domestic purpose. This result was in line with the findings of

Tuma (2013). Tuma in his study conducted in Abaya-Chamo Basin reported low level of Total nitrogen and organic carbon in cropland soils due to repeated tillage.

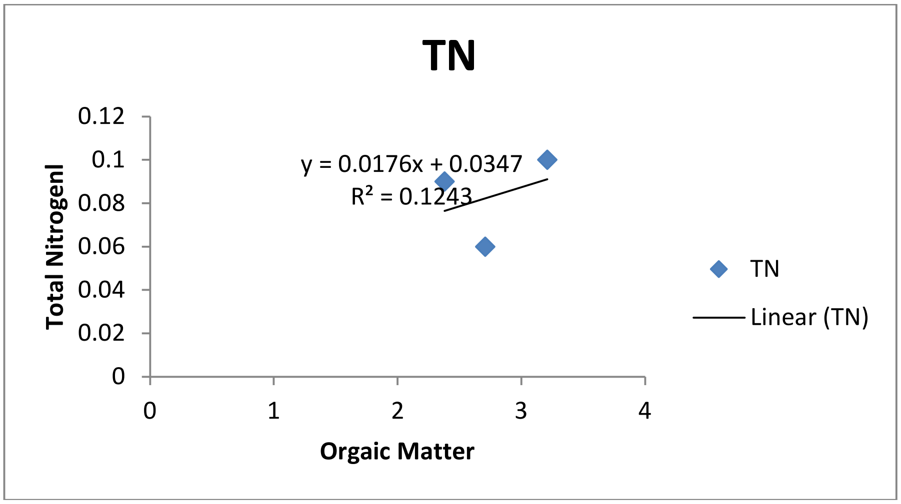

Figure 6: Organic carbon and Total nitrogen on croplands

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 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 analytical result revealed that the study soils have mean CEC of 5.04 meq/100gm/kg soil with coefficient of variation of 0.42, which implies the amount of CEC was less variable throughout the study soils. The statistical analysis of ANOVA also showed insignificant variation at 0.01 alpha levels in the CEC among 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 cmo/ kg^{-1} , 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 contributors 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 (Ca2+, Mg2+, K+ and Na+): The exchangeable basic cations are determinants of CEC of the soil. The total basic cations of upland and lowland cropland soils are 20.25 meq/100gm and 33.92 meq/100gm respectively. The cause for relatively low amount of basic cations in the croplands lands of upland area could be ascribed by the presence of excess amount of rainfall, which leached down the cation minerals to 'B' horizon or it was washed away by surface erosion leaving behind solid aluminum and hydrogen ions (acidic cations). Contrarily, basic cations are found in large amount in lowland soils. According to the ratings of Baize (1993) the level of Exchangeable calcium of the study soils is from low (< 5 cmo1 (+)/ kg soil) to medium (7.9 cmo1 (+)/ kg soil amount, 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 corrective 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 soil in upland and lowland soils respectively. According to Baize (1993), this amount was considered to be very high (> 1.2 cmo1 (+)/kg). The study result further depicted that the presence of potassium mineral also increases with the increasing soil reaction.

Furthermore, the presence of exchangeable sodium was 0.52 cmo1 (+)/kg soil (low) and 1.25 cmo1 (+)/kg soil (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, which was in line to our findings that soils in Kulfo watershed are acidic and originally highly weathered soils.

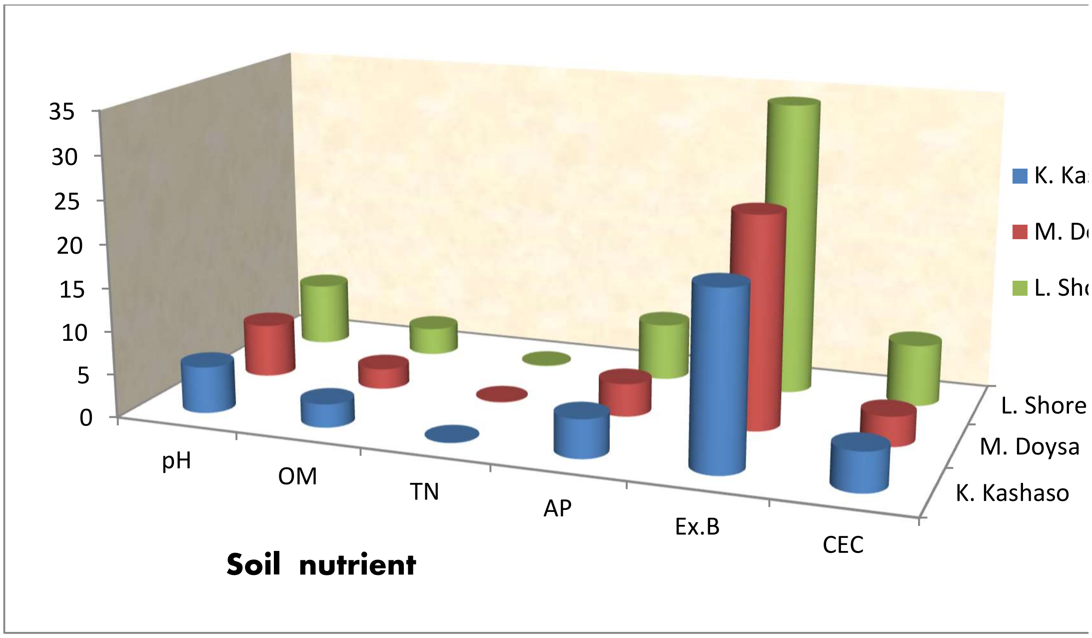

Figure 7: Chemical properties of soils in sample kebeles of Kulfo watershed

***Note**: pH-soil reaction, OM-organic matter, TN- total nitrogen, AP- available phosphorus, Ex. B- exchangeable Base & CEC- cation Exchange capacity*

CONCLUSIONS

The study was carried out in Kulfo watershed to determine the agro ecological assessment of physio-chemical properties of soil. It was ascertained that there was significant variation of soil physio-chemical properties across the watershed showing that most soils are acidic and deficient in essential soil minerals. Erosive landscapes and low soil nutrients are common problems observed in the study area which need proper intervention practices. Therefore, in order to ensure the productivity of cropland, restoration of deficient nutrients, and reclamation of acidic soil the use of environmental restoration measures could be a viable option. In addition, further focus should be given for slope & land use level studies of soil nutrients in the watershed.

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