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# Characterization, Classification and Mapping Soil Resources of Leka Dullecha District, East Wollega Zone, Western Oromia

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**Abstract:** For making decisions on agricultural production and other land use types, understanding the types and characteristics of soils is essential. This study was conducted with the aim of characterization and classification of soils of Leka Dullecha district and produces a map of these soils. Based on slope, geology, land form, soil depth, color, texture, and structure, soil mapping units were categorized (USDA soil textural classes). Understanding the relationships and interactions between the various soil qualities was made easier by the separation of the study site into SMUs. Cambisols, Acrisols, Nitisols, Lixisols, Vertisols, Fluvisols, and Leptosols were the seven main soil types discovered at the study location. The pH ranged from 4.0 (highly acidic) to 6.3 (moderately acidic), with a value of 4.9 as the average. Mean total nitrogen was found to be 0.06% (low) and 0.41% (high) in the SMU3 and SMU10, respectively with the mean values of 0.24. Soils of all SMUs had a fairly medium to high exchangeable Ca and Mg content. The CEC of the soils ranged from 1.08 to 27.94cmol$_c$ kg$^{-1}$ with a mean value of 15.9. OC was positively and significantly correlated with TN ($r^2$ = 0.999) at $p < 0.001$. Besides, CEC was significantly and negatively correlated with EA ($r^2$ = -0.397) at $p < 0.05$. The concept of soil–landscape relationships helps to categorize highly variable soils into relatively distinct management zones. Therefore, soil classification was developed to aid in land management.

**Keywords:** Classification, Characterization, Digital Soil Mapping Unit, Major Soils

## 1. Introduction

One of the major challenges to the holistic management of soils rests upon the spatial variability of soils across landscape. Hudson, contended that soil survey is a scientific strategy based on the concepts of factors of soil formation coupled with soil–landscape relationships [1]. As a result, soil–landscape interface is an integral part of geo-ecological model and can be understood through detailed soil survey and modeling. Knowledge of the kinds and properties of soils is critical for decision making with respect to crop production and other land use types. It is through precise measurement and full understanding of the nature and properties of soils as well as proper management of the nutrient and moisture requirements that one can maximize crop production to the allowable potential limits [2]. In order to evaluate the quality of our natural resources and their potential to produce food, fodder, fiber and fuel for the present and future generations, detailed information on soil properties is required.

The art of soil survey and classification involves dividing soils of a varying landscape into more or less distinct classes that require comparatively similar management practices [3]. A report [4] indicated that fields that have a high degree of spatial variability in soil properties could be better managed using site specific management zones. Because of spatial variability of soils, sampling the soil at a finite number of places or points in time yields incomplete pictures and thus spaces between sampling points need to be predicted [5].

Assessment of soil for land use planning is increasingly important due to increasing competition for land among many land uses and the transition from subsistence to market based farming in many countries [6]. Soil classification, therefore, is the basis for efficient land suitability evaluation, planning, and management. Soil classification is important in identifying the most appropriate use of soil, estimating production potential, extrapolating knowledge gained at one location to other often relatively little known locations, and providing a basis for future research needs [7]. Soil characterization is required to classify soils, and determine chemical and physical properties not visible in field examination [8].

The World Reference Base for Soil Resources (WRB) is universally accepted comprehensive soil classification system that enables people to accommodate their national classification system [9] and is widely adopted in Ethiopia. The FAO, created soil maps at a scale of 1:2,000,000 which are too coarse in resolution to provide sufficient soil data for specific locations [10]. Furthermore, the soil–landscape relations at a detailed scale of 1:50,000 rarely exist for Ethiopian soils in general and are non-existent in the highlands of western Ethiopia in particular. Therefore, the study was conducted with the aim of characterization and classification of soils of Leka Dullecha district and produces a map of these soils.

## 2. Materials and Methods

### *2.1. Site Description*

The study was conducted in Leka Dullecha covering 61678. 57 ha of land and suited in East Wollega zone of Oromia Regional State. Getema town, which is the capital of the District, is situated at about 356 km distance from Finfinnee. The RF type is unimodal and the annual RF ranges from 1500mm - 2500mm. The District is under intensive agriculture. The major crops grown in the area are: maize, sorghum, teff, barley, wheat, sesame, coffee and beans.

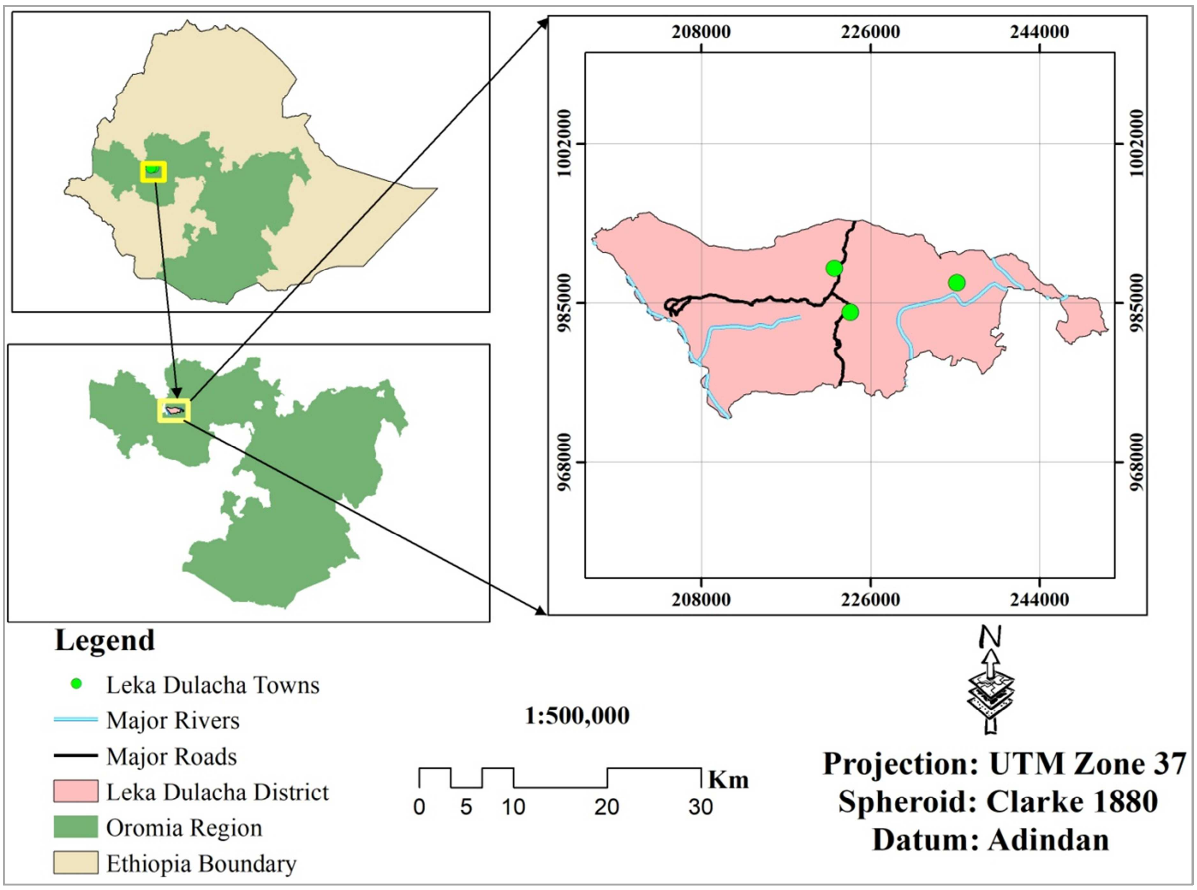


***Figure 1.*** *Location map of the study area.*

### *2.2. Methodology*

#### *2.2.1. Pre-fieldwork*

A base map of landform and land use land cover were created using ARC GIS 10.3 software by overlaying a 30-m resolution LANDSAT ETM+ and Google earth imagery. The slope of the study site was classified from 30-m resolution DEM using Global Mapper 13.1 software. The base maps produced for slope, landform and LULC were used for planning of the survey activities. The number of soil augering points was estimated based on 1.5km × 1.5km grid size and distributed on the base map. The observation was aimed at verification of landscape units and delineation of the newly identified landscape units. A grid approach was used to depict soil variability in the field at finer resolution.

#### *2.2.2. Fieldwork*

A preliminary reconnaissance survey was conducted to have a clear visual image of topographic configuration of the study area. The conceptual model used in this study was a discrete model of spatial variation [11], which assumes that the landscape can be divided into distinct polygons of 'natural' soil bodies. To map the soils of the entire study area, soil augering description following grid survey a technique was employed [12]. The landscape variables such as elevation, landform, slope steepness, micro-topography, land use type, vegetation type, PMs, presence of rock outcrops, stoniness, surface crack and crusting, erosion status, surface drainage and flooding conditions at every auger observation point were described according to FAO guideline [9].

Additionally, soil parameters such as $CaCO_3$ content, soil depth, soil color, texture, structure, horizon development and profile stoniness were measured. Hence, combining soil and landscape information such as landform, slope, soil depth and soil texture that were obtained from characterization of auger observation points the entire study site was classified into 28 major mapping units. In each soil mapping unit (SMU), one to two soil profile pits of 1.5 X2 m were dug to at least 2 m depth. Accordingly, 29 soil profile pits were dug for the whole study site. These soil profiles were used for full description of the soils in the field and for taking soil samples from genetic depths for physical and chemical laboratory analysis [9]. In the site, recording explanatory pedogenetic variables for every profile pits and preliminarily soil classification was performed following world soil reference base.

#### *2.2.3. Post Field Work*

Soil samples collected during the fieldwork were brought to the laboratory, air-dried, sieved to 2 mm and prepared for analysis. Soil tests were performed for selected soil physical and chemical parameters following standard laboratory methods and procedures. Final soil reclassification was made based on the laboratory result. The distribution of soils across the landscape was mapped based on the relationship between soil and landscape variables. The final soil map was produced at scale of 1:50,000.

### *2.3. Geo-Statistical Analysis and Soil Mapping*

Geo-statistical analysis was performed using the ordinary kriging interpolation technique within the spatial analyst extension module in ArcGIS 10.4 software package to determine the spatial variability of soil properties. Hereafter, the final soil map was produced where predictions were made for a discretization grid. The conceptual model used in this study was a discrete model of spatial variation [11] which assumes that the landscape can be divided into distinct polygons of 'natural' soil bodies.

## 3. Results and Discussions

### *3.1. Soil Mapping Units*

Twenty eight soil mapping units (SMUs) were identified in the site. Soil mapping units were classified based on slope, geology, landform, soil depth, color, structure and texture (USDAsoiltexturalclasses) (Figure 2). SMU1 occurred on gentle slopes (0-2%) dominated by moderately deep to very deep effective depth (>150cm) loam soils. SMU2 moderately dissected plateau sandy clay loam, 0-2% slope, very strongly acidic, moderately deep to deep phase (Leptic-Humic Acrisols). SMU3 labeled as Leptic Acrisols constitute the largest portion (13.75%) of the total study area. They occurred on a 15-30% slope, moderately deep effective soil depth of 50-100cm, well drained, texture of sandy loam, weak fine to medium granular structure, moist surface color of black (10YR2/1). SMU4 moderately dissected plateau sandy clay loam, 2-8% slope, slightly acidic, moderately deep to deep phase (Humic-Chromic Acrisols). SMU5 Upstream lowland plains and plateau loam, sandy loam and clay loam, 2-8% slope, extremely acidic, very deep to deep phase (Umbric-Chromic Acrisols). SMU6 Upstream lowland plains and plateau loam, 2-8%, very strongly acidic, very deep to deep phase (Humic-Chromic Acrisols). SMU7 moderately dissected plateau sandy loam, loam and clay loam 8-15% slope, moderately acidic, deep to very deep phase (Humic-Chromic Acrisols). SMU8 moderately dissected plateau clay, 2-8% slope, very strongly acidic, very deep phase (Chromic-Dystric Cambisols). SMU9 moderately dissected plateau sandy loam and sandy clay loam, >30% slope, strongly acidic, moderately deep phase (LepticCambisols).

SMU10 High to mountainous relief hills, clay, 15-30% slope, very strongly acidic, deep to very deep phase (Chromic-Eutric Cambisols). SMU11 moderately dissected plateau loam and sandy loam, 15-30% slope, strongly acidic, moderately deep to deep phase (Leptic Cambisols). SMU12 moderately dissected plateau clay loam, 2-8% slope, very strongly acidic, very deep phase (Mollic Cambisols). SMU13 Upstream lowland plains and plateau sandy clay, 2-8% slope, moderately acidic, very deep phase (Mollic Cambisols). SMU14 High to mountainous relief hills clay, 8-15% slope, strongly acidic, moderately very deep phase (Mollic-Rhodic Cambisols). SMU15 moderately dissected plateau clay, 8-15% slope, very strongly acidic, deep phase (Mollic-Chromic Cambisols). SMU16 moderately dissected plateau sandy clay loam, 0-2% slope, very strongly acidic, deep phase (Umbric Fluvisols). SMU17 up-stream lowland plains and plateau sandy clay loam, >30% slope, very strongly acidic, very shallow phase (Dystric Leptosols). SMU18 upstream lowland plains and plateau loam, 0-2% slope, extremely acidic, very deep phase (Humic Lixisols). SMU19 High to mountainous relief hills loam, clay loam and sandy loam, 15-30% slope, strongly acidic, moderately deep to very deep phase (Humic Lixisols and Humic Chromic Lixisols). SMU20 High to mountainous relief hills loam, 2-8% slope, very strongly acidic, very deep phase (Humic-Rhodic Lixisols). SMU21 Upstream lowland plains and plateau sandyloam, 2-8% slope, strongly acidic, very deep phase (Humic-Chromic Lixisols). SMU22 moderately dissected plateau clay loam, 0-2% slope, very strongly acidic, moderately deep to deep phase (Umbric

Nitisols). SMU23 moderately dissected plateau sandy loam and clay loam, 15-30% slope, moderately acidic, deep to very deep phase (Mollic Nitisols). SMU24-moderately dissected plateau clay and loam, 2-8% slope, extremely acidic, moderately deep to very deep phase (Mollic-Rhodic Nitisols). SMU25 high to mountainous relief hills clay loam, sandy clay and sandy clay loam, 8-15% slope, strongly acidic, very deep phase (Mollic-Rhodic Nitisols). SMU26 upstream lowland plains and plateau loam, clay loam, 0-2% slope, very deep, extremely acidic, gilgai phase (Pellic-Mesotrophic Vertisols). SMU27 upstream lowland plains and plateau clay loam, 2- 8% slope, strongly acidic, very deep, gilgai phase (Mesotrophic Vertisols). SMU28 upstream lowland plains and plateau clay loam, 2-8% slope, strongly acidic, deep, gilgai phase (Pellic-Mesotrophic Vertisols) (Table1).

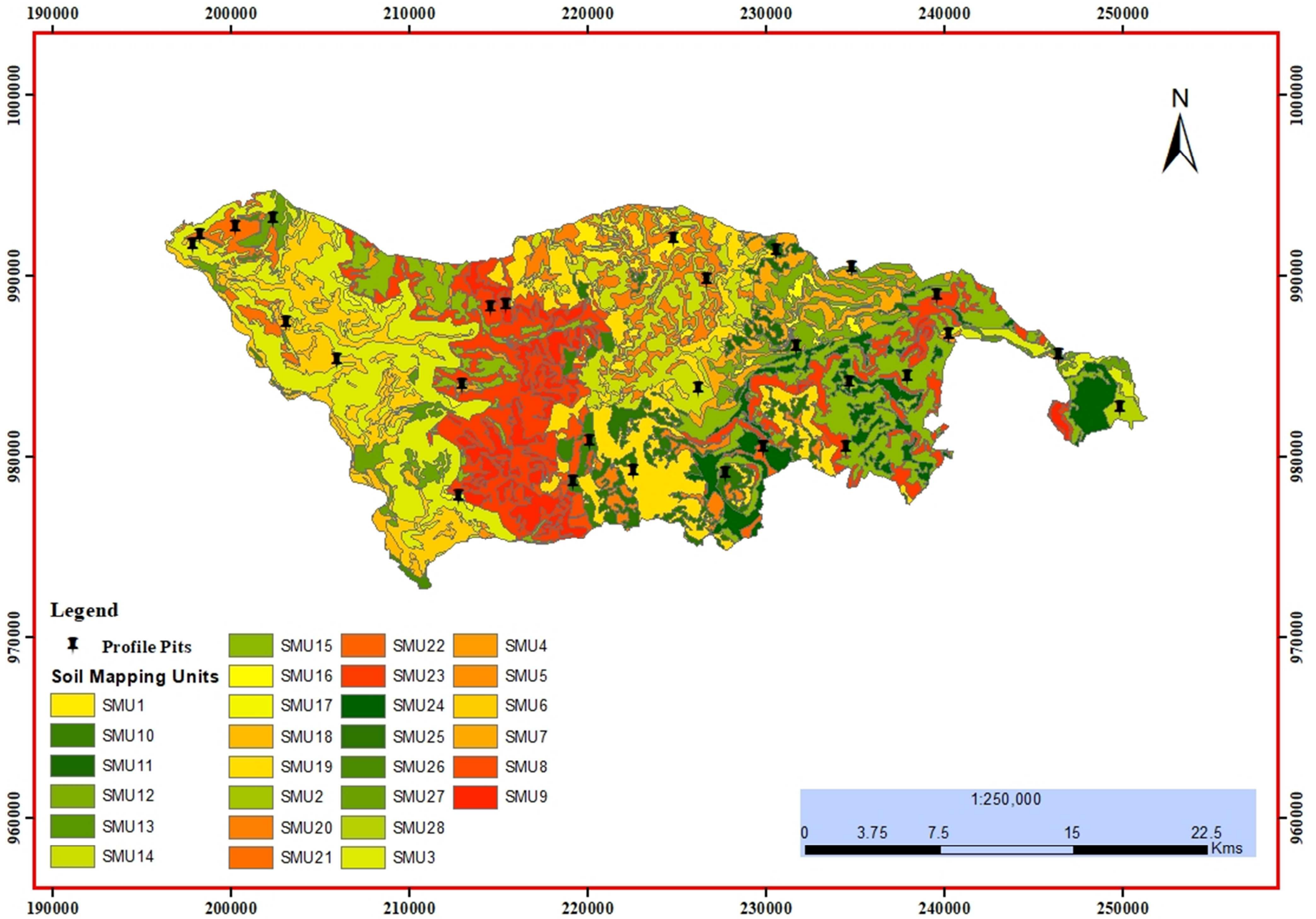


***Figure 2.*** *Distribution of soil mapping units (SMU) and profile pit points across landscape in the study area.*

### *3.2. Major Soils*

In the study site, seven major soil types namely Cambisols, Acrisols, Nitisols, Lixisols, Vertisols, Fluvisols, and Leptosols. Covering 30.24% of the total area, Cambisols stand as the dominant soil type in the study site followed by Acrisols (22.12%), while Leptosol constitutes only 0.4% of the total area (Table 2 and Figure 3). Cambisols-soils containing Chromic-Dystric/Mollic-Eutric/Mollic-Rhodic surface horizon and cambic and leptic sub surface horizon were observed over different landforms (SMU 8, 9, 10, 11, 12, 13, 14 and 15) including level plain and plateaus. This indicated that Cambisols formation was not limited by land form and slope variations. Chromic- Dystric Cambisols designated by SMU8 were developed moderately dissected plateau enriched with clay where as Leptic Cambisols (Eutric) designated as SMU10 were identified at upper slope position of plateaus in the cultivated land having >30% slope. Covering 18649.64ha w/h becomes 30.24% of the total area.

***Table 1.*** *Soil mapping units, major soil types and soil series with qualifiers, and selected physical and morphological properties.*

| SMU | Major soil types and soil series | Land cover (%) | DominantColor | | DominantTexture | |
|---|---|---|---|---|---|---|
| | | | Surface | Sub-surface | Surface | Sub-surface |
| SMU1 | UmbricAcrisols | 1.56 | 7.5YR2.5/3 | 5YR2.5/1 | L | CL |
| SMU2 | Leptic-HumicAcrisols | 0.15 | 7.5YR3/2 | 2.5YR3/6 | SCL | C |
| SMU3 | LepticAcrisols | 13.76 | 10YR2/1 | 10YR3/2 | SL | SCL |

| SMU | Major soil types and soil series | Land cover (%) | DominantColor | | DominantTexture | |
|---|---|---|---|---|---|---|
| | | | Surface | Sub-surface | Surface | Sub-surface |
| SMU4 | Humic-ChromicAcrisols | 0.39 | 7.5YR3/1 | 5YR4/4 | SCL | SCL |
| SMU5 | Umbric-ChromicAcrisols | 0.14 | 5YR2.5/2 | 5YR3/3 | SL | CL |
| SMU6 | Humic-ChromicAcrisols | 7.45 | 5YR4/4 | 2.5YR3/4 | L | L |
| SMU7 | Humic-ChromicAcrisols | 3.66 | 7.5YR3/2 | 7.5YR3/1 | SL | SCL |
| SMU8 | Chromic-DystricCambisols | 1.54 | 5YR3/3 | 5YR3/4 | C | SL |
| SMU9 | LepticCambisols | 4.87 | 10YR2/1 | 5YR3/4 | SL | SL |
| SMU10 | Chromic-EutricCambisols | 1.01 | 7.5YR2.5/3 | 5YR3/4 | C | CL |
| SMU11 | LepticCambisols | 0.92 | 7.5YR3/2 | 7.5YR3/1 | L | L |
| SMU12 | MollicCambisols | 3.33 | 5YR2.5/2 | 5YR3/3 | CL | L |
| SMU13 | Mollic Cambisols | 0.41 | 7.5YR3/2 | 10YR3/1 | SC | L |
| SMU14 | Mollic-Rhodic Cambisols | 6.84 | 5YR3/3 | 5YR3/4 | C | SL |
| SMU15 | Mollic-Chromic Cambisols | 11.32 | 5YR3/2 | 5YR3/3 | C | CL |
| SMU16 | Umbric Fluvisols | 0.5 | 5YR3/3 | 5YR3/4 | SC | SCL |
| SMU17 | Dystric Leptosols | 0.4 | 5YR3/4 | a | SCL | a |
| SMU18 | Humic Lixisols | 1.15 | 5YR3/2 | 2.5YR3/4 | L | C |
| SMU19 | Humic Chromic Lixisols | 9.34 | 5YR3/2 | 5YR2.5/2 | SL | CL |
| SMU20 | Humic-Rhodic Lixisols | 5.88 | 5YR3/3 | 5YR3/4 | L | L |
| SMU21 | Humic-Chromic Lixisols | 1.49 | 7.5YR3/2 | 5YR2.5/2 | SL | L |
| SMU22 | Umbric Nitisols | 0.23 | 2.5YR2.5/3 | 2.5YR4/6 | CL | C |
| SMU23 | Mollic Nitisols | 12.55 | 7.5YR3/3 | 5YR3/4 | CL | C |
| SMU24 | Mollic-Rhodic Nitisols | 4.88 | 2.5YR3/4 | 2.5YR3/3 | C | C |
| SMU25 | Mollic-Rhodic Nitisols | 3.4 | 5YR3/3 | 5YR3/4 | C | C |
| SMU26 | Pellic-Mesotrophic Vertisols | 0.35 | 10YR2/1 | 10YR2/1 | L | C |
| SMU27 | Mesotrophic Vertisols | 2.01 | 10YR4/3) | 7.5YR3/2 | CL | C |
| SMU28 | Pellic-Mesotrophic Vertisols | 0.47 | 10YR2/1 | 10YR3/1 | CL | C |

SMU, Soil mapping Unit; CL, Clay loam; L, Loam; SCL, Snady clay loam; C, Clay; SL, Sandy Loam; SC, Sandy Clay; S, Sandy. Though the dominant colour was expressed based on Hue, it did not mean that soils with similar Hue had the same colour, because they differ in 'value' and 'chroma' resulting in colour variation with depth within soil profiles and among SMUs. [a]SMU 17 (Leptosols) did not show subsurface colour and texture, since subsurface horizons were absent.

The RSG of the Acrisols holds soils that are characterized by accumulation of low activity clays in an *argic* subsurface horizon and by a low base saturation level. Acrisols of the study area are the dominant soils found in the form of Humic-Chromic Acrisols, Umbric-Chromic Acrisols, Leptic Acrisols, Humic-Abruptic Acrisols, Leptic Humic Acrisols, Humic-Rhodic Acrisols, Umbric-Rhodic Acrisols, and Umbric Acrisols distributed in all the landscape units (SMU 1, 2, 3, 4, 5, 6, and 7). This soil has an areal extent of 16724.92 (27.12%) of the major soils of the districts.

Nitisols are deep, well-drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30 percent clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny, polyhedric ('nutty') elements. Nitisols are strongly weathered soils. The Nitisols of the study area are found in the form of Mollic Nitisols, Umbric Nitisols and Mollic-Rhodic Nitisols covering 12992.02ha (21.06%) of the total area. Distributed in all the major soil and landscapes units of upstream and downstream lowland plains and plateau, moderately dissected plateau, and high to mountainous relief.

Lixisols of the study area is found in the form of Humic Lixisols, Humic-Chromic Lixisols and Humic-Rhodic Lixisols designated in the soil mapping units of SMU 18, 19, 20 and 21. It covers 347, 424 hectares (12.7%) of the total area. This mapping unit has a texture of loam, 0-2% slope, very deep effective soil depth of >150cm, well drained, moderate medium sub angular blocky structure, moist surface colour of black to dark reddish brown (10YR2/1 to 5YR3/2).

It is distributed in the form of Mesotrophic Vertisols and Pellic-Mesotrophic vertisols labelled by SMU 26, 27 and 28. Constitute 1745.44ha (2.83%) of the total study area. They occurred on gentle slopes (1–2%) dominated by very deep (>150 cm) loamy and clay soils. They were widespread at lower slope position. Driessen, P. et al. [27], states the environment of Vertisols is depressions and level to undulating areas, mainly in tropical, semi-arid to sub humid and Mediterranean climates with an alternation of distinct wet and dry seasons.

Fluvisols were other major soils widely distributed along a riverside intensively cultivated during dry season and flooded during rainy season. It is found in the form of Umbric Fluvisols in moderately dissected plateau developed on volcanic materials and covering the total area of 306.17ha (0.50%) of the total area. Although Umbric Fluvisols of the SMU16 were identified in the plain and depression landforms enclosing 0–2% slope. Because of seasonal deposition of finer soil materials, they showed loamy soils deeper than 200 cm.

As soils of the study site were highly variable, it was difficult to recommend holistic management practice for the entire landscape. For this reason, the study site was classified into definite soil types at suitable scale for management. Understanding the role of several soil properties together, and their interactions, may help to explain the cause of variation in soil productivity as defined by site-specific management zones. Management zones are needed when variation in soil characteristics that affect crop production like texture, soil fertility, acidity and so on is widespread [13, 14]. Following classification of the landscape into SMUs or management zones, critical levels and ranges of soil properties were used for management decisions. In that way, mean values of soil parameters under each SMU were compared with the critical values adopted by scholars. This comparison helped to identify the limitations and potentials of each mapping unit. That means, management requirement for each SMU would vary based on the critical levels. For instance, the pH of SMU9 was rated as strongly acidic; the pH of SMU1, SMU5 and SMU7 was slightly acidic; and the rest of the SMUs were moderately acidic based on the rating adopted [15]. This indicated that SMU9 was not suitable for most crops and, thus, requires application of chemical amendments such as lime. The productivity of slightly acidic SMUs might also benefit from application of chemical amendments but still they could be cultivated by growing of acid tolerant crop varieties.

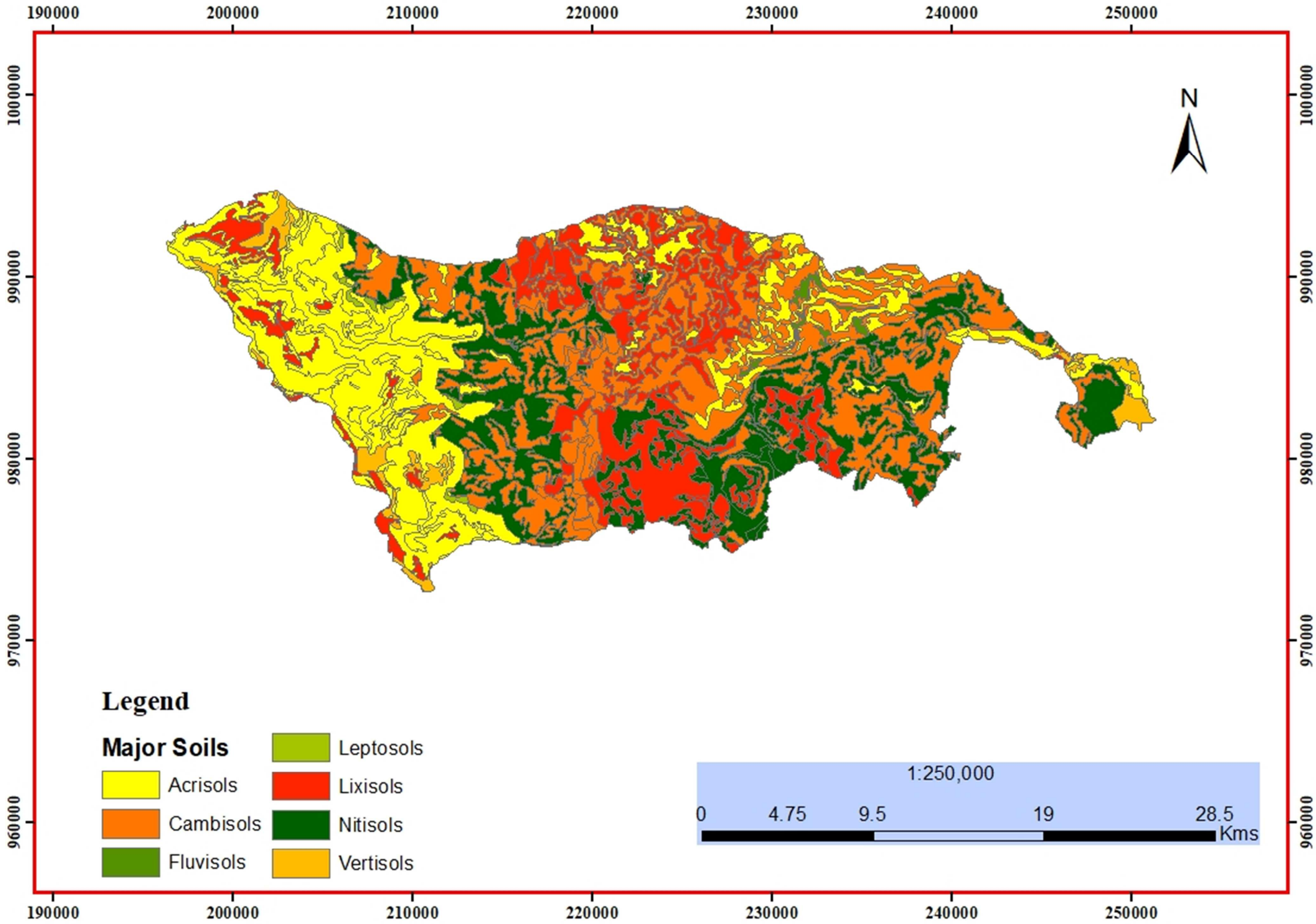


***Figure 3.*** *Map of distribution of major soils across the study area.*

### *3.3. Observed Variation in Soil Properties*

By dividing the research area into mapping units, it was possible to better understand individual soil attributes and soil-landscape connections. Soil fertility assessment for the top plow layer of the mapping units was carried out after the study site was divided into SMUs. The fertility status of the mapping units varied. The analysis's findings indicated that the most prevalent surface soil textural classes in the region were clay loam, loam, clay, silt clay, silt clay laom, and silt loam. Table 2 shows that, when the entire research region was taken into account, the pH ranged from 4.0 to 6.3, with an average value of 4.9. K and P deficiencies may have been caused in the majority of SMUs by an increase in soil acidity and a decrease in OC. Except for SMU 9 and 11, all of the SMUs had mean values of accessible phosphorus that ranged from very low to low, according to Karltun, E. et al. [16]. However, variations in soil nutrient levels among the different SMUs shown in Table 1 point to the necessity of variable rate fertilizer recommendations. This could be a result of P being fixed in acidic soils. Additionally, due to the effects of a plentiful agricultural yield, poor land management, and soil erosion, the availability of P in the majority of Ethiopian soils is continuously declining [17-19]. Variation in available P content of the SMUs could be due to differences in strength of acidity, organic matter content, rocks, and amount of residual p-fertilizers found in the soils.

***Table 2.*** *Minimum, maximum, mean, standard deviation and coefficient of variation of selected soil chemical properties for surface soils of the study area.*

| Statistic | pH (1:2.5) | EA (cmol(+)$Kg^{-1}$) | T.N | O.C | Av.P (ppm) | Na | K | Ca | Mg | CEC | BS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % | | | (cmol(+)$Kg^{-1}$) | | | | | |
| Min. | 4 | 0.1 | 0.06 | 0.68 | 1.75 | 0.1 | 0.01 | 0.43 | 0.35 | 1.08 | 17.6 |
| Max. | 6.3 | 9.4 | 0.52 | 5.99 | 42 | 0.45 | 2.31 | 19.55 | 7.79 | 27.94 | 61.6 |
| Mean | 4.9 | 1.76 | 0.24 | 2.75 | 9.2 | 0.23 | 0.64 | 10.94 | 4.09 | 15.9 | 32.47 |
| SD (±) | 0.61 | 2.47 | 0.08 | 0.93 | 11.41 | 0.11 | 0.6 | 5.83 | 2.28 | 8.25 | 11.74 |
| CV | 0.12 | 1.38 | 0.33 | 0.33 | 1.22 | 0.45 | 0.92 | 0.52 | 0.55 | 0.51 | 0.36 |

EA, exchangeable acids, OC, organic carbon; TN, total nitrogen; av. P, available phosphorus; CEC, cation exchange capacity; BS, Base saturation; Min, Minimum; Max, maximum; SD, Standard deviation; CV, Coefficient of variation

The medium to high CEC in soils of the study site might be ascribed to dominance of clay soils as OC content was generally low. We found that OC, av. P and to some extent K were the most limiting soil parameters in almost all SMUs. Traditional crop residue burning after harvest and exhaustive grazing by livestock might be the main causes of extremely low soil OC in cultivated lands. High prevalence of soil erosion, possibly due to overgrazing leading to low herbaceous cover, accounts for low soil OC stocks across different land cover types [20, 21]. Agricultural practices like tillage can also accelerate depletion of soil nutrients and OC stocks [22]. Hence, land management practices such as conservation tillage, controlled grazing, crop residue incorporation and protecting land use change would be important strategies used to increase soil OC stock. Decrease in OC had possibly caused for K deficiency in most SMUs. According to the research [23] ratings, mean TN was found to be 0.06% (low) and 0.41% (high) in the SMU3 and SMU10, respectively with the mean values of 0.24% and other SMUs contain optimum TN.

All SMU soils exhibited a reasonably medium to high exchangeable Ca and Mg content according to the article [24] categorization. For the majority of crops, an exchangeable Ca value of at least 5 15.74 cmol (+)/kg soil is regarded as sufficient. Exchangeable Ca ranged from 0.43 cmol (+)/kg (low) to 15.74 cmol (+)/kg (high) based on identical author evaluations, with a mean value of 10.94 cmol (+)/kg. It is thought that exchangeable magnesium that is larger than 1 cmol (+)/kg soil is sufficient for plant feeding [25].

***Table 3***. *Ratings for mean values of selected soil chemical properties based on the critical values adopted by [24] for exchangeable bases (Ca, Mg, K, Na) and CEC; [25] and OC; [26] for av. P; [15] for TN and soil pH.*

| SMU | pHRating | T.N | O.C | CEC | Av.P (ppm) | Na | K | Ca | Mg | BS (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | (cmol$_c$(+)$Kg^{-1}$) | | (cmolc(+)$Kg^{-1}$) | | | | |
| SMU1 | vsa | h | l | m | l | l | m | l | l | l |
| SMU2 | sa | l | vl | m | m | l | vl | m | h | m |
| SMU3 | ma | h | m | h | h | m | h | h | h | h |
| SMU4 | sla | m | l | h | l | l | l | m | h | m |
| SMU5 | sa | m | l | m | m | l | vl | m | h | m |
| SMU6 | sa | h | l | h | l | vl | h | m | m | l |
| SMU7 | ma | m | l | m | l | l | h | h | m | m |
| SMU8 | sa | m | l | m | l | l | m | l | l | l |
| SMU9 | sa | h | l | h | h | m | vl | h | h | m |
| SMU10 | sa | l | vl | vh | l | m | vl | h | h | m |
| SMU11 | sa | h | l | h | h | m | l | h | h | m |
| SMU12 | sa | h | l | vh | l | l | m | h | h | m |
| SMU13 | ma | h | l | vh | m | l | m | h | h | m |
| SMU14 | sa | m | l | m | l | l | vl | m | h | m |
| SMU15 | ma | m | l | vh | l | m | h | h | h | m |
| SMU16 | sa | m | l | vh | l | l | vl | vl | l | vl |
| SMU17 | sa | m | l | m | l | l | m | l | l | l |
| SMU18 | sa | h | l | h | l | m | h | h | h | h |
| SMU19 | sa | m | l | h | l | m | m | h | h | m |
| SMU20 | sa | h | l | vh | l | m | h | h | h | m |
| SMU21 | vsa | h | l | h | l | l | l | h | h | m |
| SMU22 | sa | m | l | h | l | vl | h | m | m | l |
| SMU23 | sla | m | l | h | l | l | vh | h | h | h |
| SMU24 | vsa | m | vl | m | l | l | m | l | l | l |
| SMU25 | vsa | m | l | h | l | l | vl | h | h | m |
| SMU26 | sa | m | l | h | m | l | m | m | h | m |
| SMU27 | sa | m | vl | h | l | m | l | h | h | m |
| SMU28 | ma | m | l | h | l | l | m | m | m | l |

SMU, Soil Mapping Units; Sla, slightly acidic; Vsa, very strongly acidic; ma, moderately acidic; vl, very low; l, low; m, medium; h, high; vh, very high

Magnesium that might be exchanged was found in the soils of the the study area in amounts ranging from 0.35 to

7.79 cmol (+)/kg, with a standard deviation of 0.55. The exchangeable potassium in the study area's surface soils is classified on a scale from low to high, according to the research [25]. The average exchangeable K concentration (0.64 cmol/kg) was at its highest point; nevertheless, due to crop removal of exchangeable cations without replenishment, vertical movement, or leaching, there may be an increasing loss of all exchangeable cations in the study area. Potassium uptake would decrease as Ca and Mg levels rose; conversely, uptake of these two cations would rise as K levels rises [26].

The CEC of the soils ranged from 1.08 to 27.94cmol$_c$ kg$^{-1}$ (Table 2), and with a mean value of 15.9. They were higher in the highland areas than the lowlands. Pearson correlation matrix presented in Table 4 shows that OC was positively and significantly correlated with TN ($r^2 = 0.999$) at $p < 0.001$. Besides, exchangeable CEC was significantly and negatively correlated with EA ($r^2 = -0.397$) at $p < 0.05$. The moderate to high CEC in soils of the study site might be ascribed to dominance of clay soils as OC content was generally low. According to the research [28], CEC depends on the nature and amount of colloidal particles.

***Table 4.*** *Person correlation matrix among measured soil chemical properties.*

| Variables | pH (1:2.5) | EA (cmol (+) Kg$^{-1}$) | T.N % | O.C | Av.P (ppm) | Na (cmol(+)Kg$^{-1}$) | K | Ca | Mg | CEC | BS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH (1:2.5) | 1 | | | | | | | | | | |
| EA | -0.271 | 1 | | | | | | | | | |
| T.N | 0.199 | -0.029 | 1 | | | | | | | | |
| O.C | 0.182 | -0.037 | 0.999** | 1 | | | | | | | |
| Av.P | 0.221 | -0.141 | 0.443** | 0.440** | 1 | | | | | | |
| Na | -0.011 | -0.089 | 0.280 | 0.278 | 0.503** | 1 | | | | | |
| K | 0.376* | -0.300 | 0.466** | 0.472** | -0.002 | 0.092 | 1 | | | | |
| Ca | 0.263 | -0.302 | 0.308 | 0.304 | 0.108 | 0.353 | 0.313 | 1 | | | |
| Mg | 0.269 | -0.284 | 0.297 | 0.289 | 0.164 | 0.373 | 0.233 | 0.944** | 1 | | |
| CEC | 0.266 | -0.397* | 0.226 | 0.224 | -0.057 | -0.010 | 0.163 | 0.717** | 0.686** | 1 | |
| BS | 0.251 | -0.071 | 0.216 | 0.204 | 0.237 | 0.445* | 0.244 | 0.725** | 0.754** | 0.115 | 1 |

EA, exchangeable acids, TN, total nitrogen OC, organic carbon;; Av.P, available phosphorus; CEC, cation exchange capacity; BS, Percent Base saturation.

# 4. Conclusion and Recommendations

Soil and landscape information was the basis for delineating the landscape units. 28 SMUs and Seven major soils were identified in the study area. The SMU3 comprised largest areal coverage, while SMU5 constitutes the smallest. The major soils investigated were Cambisols constituting the largest (30.24%) area of the study area; whereas Leptosols the smallest (0.4%) of the total area. The soil units were related to landform. Vertisols developed from alluvial deposits were distributed mainly on flat lands of savannah grasslands. Cambisols were observed at a variety of landforms including level plain, depressions and plateaus and over a wide range of slope gradient. On the other hand, Fluvisols were dominant at the floodplains of very gentle slope and valley position of the catenae. Strong soil variation was observed within and among SMUs.

The division of the study site into SMUs helped to understand the interrelations and interaction between soil properties. It also exposed the relationship between landform and other factors in shaping the nature of soil formed. Soil organic carbon and available phosphorus were the most limiting soil properties in all of the SMUs. Overgrazing, monocropping, cultivation of steep slopes and soil erosion, and other agricultural practices were the main causes of low soil fertility. The concept of soil–landscape relationships helps to categorize highly variable soils into relatively distinct management zones. Therefore, soil classification was developed to aid in land management.

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