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CHARACTERIZATION, CLASSIFICATION AND MAPPING OF SOILS OF MEGECHA MICRO-WATERSHED, EZHA DISTRICT, GURAGE ZONE, ETHIOPIA

MSc. THESIS

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NOVEMBER, 2023

WOLKITE, ETHIOPIA

WOLKITE UNIVERSITY

SCHOOL OF GRADUATE STUDIES

CHARACTERIZATION, CLASSIFICATION AND MAPPING OF SOILS OF MEGECHA MICRO-WATERSHED, EZHA DISTRICT, GURAGE ZONE, ETHIOPIA

A Thesis Submitted to School of Graduate Studies, Partial Fulfillment of the Requirements for the Degree of Master of College of Agricultural and Natural Resources Management Department of NRM in Soil Sciences

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NOVMBER, 2023

WOLKITE, ETHIOPIA

APPROVAL SHEET

SCHOOL OF GRADUATE STUDIES

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As Thesis research advisors, we hereby Certify that we have read and evaluated the Thesis entitled **"**Characterization, Classification And Mapping of Soils of Megecha Micro-Watershed, Ezha District, Gurage Zone, Ethiopia'' prepared under our guidance by Alemu Wegu Jeza**.** We recommend that it be submitted as fulfilling the thesis requirement of Natural Resource Management Department for defense.

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As members of the Board of Examiners of the MSc Thesis Open Defense Examination, we certify that we have read and evaluated the Thesis prepared by Alemu Wegu Jeza and examined the candidate. We recommended that the Thesis be accepted as fulfilling the requirement for the degree of Master of Science in Soil Science.

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Final approval and acceptance of the Thesis are contingent upon the submission of the final copy to the Council of Postgraduate Program (CPGS) through the school/department graduate committee of the candidate's major school/department.

DEDICATION

Bless be to my beloved Mother Shiwechi Abza and my Father Wegu Jeza to whom this thesis is proudly dedicated.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my work and that all sources of materials used for the thesis have been as expected acknowledged. This thesis has been submitted in partial fulfillment of the requirements for MSc degree in Soil Science at Wolkite University and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Alemu Wegu was born on July 19, 1992 from my mother Shiwechi Abza and my father Wegu Jeza in Ezha district, Gurage Zone of South Nations, Nationalities, and Peoples' Regional State. He attended his primary school education (1999-2006) at Yesray Elementary School and Junior, Secondary and Preparatory Education (2007-2010) at Agena Secondary and Preparatory School Education. He joined Wolayita Sodo University in November 2011 and graduated with BSc. degree in Natural Resource Management in July 2013.

After graduation the author was employed by Ezha Woreda Agriculture office in Gurage Zone as GIS profession from November, 2014 to 2017. From 2018 to 2021 he worked as head of natural resource management and head of Ezha Woreda Agricultural office. In October 2021, he joined the post graduate program at Wolkite University to pursue the MSc. study in Soil Science.

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LIST OF ABREVIATIONS AND ACRONMY

ATA	Agricultural Transformation Agent
CEC	Cation Exchange Capacity
CSA	Central Statistical Agency
CRSD	Consultants for Resource Survey and Development
EAC	Ethiopia Agricultural Census
ECACC	Ethiopia Central Agricultural Census Commission
EARO	Ethiopia Agricultural Research Organization
EEPRI	Ethiopian Economic Policy Research Institute
FAO	Food and Agriculture Organization
GIS	Geographical Information System
GPS	Global Positioning System
MASL	Meter Above Sea Level
MMWs	Megecha Micro Water shed
PBS	Percent Base Saturation
RSG	Reference Soil Group
SNNPRS	South Nations, Nationalities and Peoples' Regional State
SOM	Soil Organic Matter
SSDS	Soil Survey Division Staff
SSS	Soil Survey Staff
SAS	Statistical Analysis System
UNDP	United Nations Development Program
USAID	United States Agency For International Development
UTM	Universal Transverse Mercator
WRB	World Reference Base

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ABSTRACT

The study was conducted at Megecha Micro-Watershed Ezha District in Gurage Zone, Ethiopia. Because of a diversified geography, climatic conditions, and geology, Ethiopia has a variety of soil resources which were *studied at small scales 1:250,000, with high levels of generalization. Site specific soil characterization and classification can serve as initial step in creating baseline information for developing land use planning and management practices. Therefore purpose of this study was to characterize, classify and mapping soils of Megecha micro-watershed, to generate baseline information, for formulating the management alternatives for different soil types identified. Four representatives Pedon were opened at the upper, middle and low slope position and soil field description was made. A total of 17 disturbed and undisturbed soil samples were collected from each genetic horizon. The results of the study revealed that color, consistency, texture, bulk density (BD) and of the soils varied with the slope position and soil depth. Lower BD, darker red color and soft (dry) consistency were observed at the upper slope position whereas higher BD, very dark gray color and hard (dry) consistence were observed in the low slope areas. The depth of the soils was very deep (200+cm) and the textural classes varied from silt to clay, Soil reaction (pH) (5.3 to 6.3) categorized by moderately acid to slightly acidic, Soil organic carbon (SOC) (0.58 to 2.99%) content was categorized as low to high, Available Phosphorus (P) (0.28 – 1.20 mg kg^{-1}) was rated as inadequate range, Total Nitrogen (N) (0.02 to 0.27%) content was rated as very Low to high, C: N ratio varies from (6.43 to 29)) and found in low to high range*, *Soil CEC varied from (5 - 47 cmolc kg^{-1}) categorized as very low to very high and PBS (19.19 to 87. 19%) was categorized as very low to very high*. *Regarding the soil classification Pedon 1 classified as Chromic Alisols (Epidystric), Pedon 2, Chromic Alisols (Dystric), Pedon 3 Hablic Alisols (Dystric) and Pedon 4 Pellic Vertisols (Hypereutric).The soil map was developed for these identified soils types. Thus, in introducing new agricultural technologies like application of lime, use vermin compost and soil and water conservation practices were needed to the study area, the local variations in soils should be considered for a sustainable agricultural development.*

Keywords: *Watershed, Horizon, Physiochemical, Pedon, Soil, Soil Classification*

1. INTRODUCTION

1.1 Background and Justification

Soils are porous natural bodies composed of (inorganic and organic matter), liquid, and gases that occur on the land surface. Soils are vital components of environmental systems and supply livelihoods, services, and goods for humans and natural ecosystems. Soils are formed by numerous factors such as parent material, topography, climate, water, organisms, and time (Safwan *et al*., 2020). Soils have diverse morphological, physical, chemical, and biological properties. As a result, they differ in their responses to management practices, their inherent ability to deliver ecosystem services, as well as their resilience to disturbance and vulnerability to degradation (FAO, 2017). Soil types and characteristics show great variations across the various regions of Ethiopia. Natural conditions, such as geology, climate, topography, biotic, and land use/ land cover changes are largely responsible for creating regional and local differences in soil types and characteristics. Agricultural land productivity is related to these various soil characteristics (FAO/UNDP, 1984a, 1984b; Mesfin, 1998; Mitiku, 1987).

In developing countries like Ethiopia, the agricultural sector, which is soil based industry, is the backbone of their national economies. In Ethiopia, agriculture is accounting for nearly 40% of the gross domestic product (GDP), 75% of total employment, and about 80% of the export earnings of the country (USAID, 2021). This sector is, however, beset by several natural and anthropogenic factors that adversely affect its productivity. Periodic drought, traditional and rain-fed production systems (Woldeamlak and Stroosnijder, 2003) farming on steeper slopes and marginal lands, which in turn have brought disturbance to the ecosystems, particularly soils that are the determinant factors of agricultural production and productivity, (EAC, 2015). On the other hand, the proportion of land under cultivation has increased and the area of land under fallow has decreased, while competition has been increasing between various land use systems for food, fodder, fuel supply, and settlements (Yohannes, 1989).

Characterization of soils is fundamental to all soil studies, as it is an important tool for soil classification, which is done based on soil properties. Soil characterization also helps to document soil properties at research sites (Buol *et al*., 2003). The need to provide this information is more demanding than before because of the problem arising from the misuse of land resulting in land degradation. A soil mapping is a representation of soil type for a geographic area and/or of their properties like soil horizons, soil reactions (pH), textures, organic matter contents and soil colors.

Ethiopia has diverse soil resources largely because of diverse topography, climatic conditions and geology (Abayneh, 2001). The soil resource of the whole country was studied at a scale of 1:250,000, (Wijntje-Bruggeman, 1984). These studies are of small scale and not comprehensive enough to draw development planning at the watershed level. Consequently, sustainable soil management practices that are based on the understanding of soil systems are not available for most parts of the country (Fikre, 2003).

This calls for a need to study soils at local watersheds in order to contribute to an in increase agricultural productivity. One of the aims of soil survey is to pave the way forward to transfer technology and research findings through providing adequate soil information (SSS, 1999; FAO/WRB, 2006). The lack of detailed and site-specific studies on soils hinders technology transfer. In Ethiopia the types and the characteristics of soils are very variable because of this adequate knowledge on soil characteristics at large scale and/or local watershed/farm level is essential in tackling specific and local problems of agricultural production. Similar to the other parts of the country, information on soils of the Megecha micro watershed is generally inadequate and only available at smaller scales.

A proper understanding of the nature and properties of the soils of the country and their management according to their potentials and constraints is imperative for maximization of crop production to the potential limits (Abayneh *et al*., 2006a). However, the morphological, physical, and chemical characteristics of soils of the study site, Megecha micro-watershed in relation to nutrient retention and management alternatives are not well documented. The area needs proper land resources (soil, vegetation, and water) management methods and approaches, otherwise following the existing practices may affect the use value of the land due to irreversible natural resource degradation. The measures to be taken should also be in accordance with the constraints and potentials of soil types.

1.2. Statement of the Problem

Well-organized and systematic soil resource studies in Ethiopia started in the 1960s. In Ethiopia, there is inadequate and less available information on soils of similar to other parts of Ethiopia the central Ethiopia region in general and the Megecha micro-watershed area in particular. Among the limited studies and findings thereof is the soil map of the region (1:250,000 scale). These studies are of small scale with a generalized approximation, and not comprehensive enough to get detailed soil information at the farm level. On the other hand, the Ezha District is one of the areas of the region with a high potential for irrigated crop production due to its suitable topographic feature and availability of water resources. Nowadays, the area is becoming intensively cultivated and the center of attraction for commercial farms including private investors engaged in crop production and livestock production.

This study would be involved soil characterization and classification and mapping of soils of Ezha District Megecha micro-watersheds. In the past, the lack of detailed information on the type and characteristics of soils of the study site has been a serious drawback not only for proper implementation of the soil and water conservation activities but also for reliable interpretation of the overall agricultural production potential and limitation. In light of the above, it is of paramount importance to have an in-depth knowledge of the morphological, physical, and chemical characteristics of the soils of the research site and its surroundings, which is selected as the site of the present study. It will also be equally important to classify the soils using their inherent characteristics and in a manner that will ease communication and transfer of knowledge about such soils to farmers, stakeholders, and soil scientists. The results of such studies are expected to provide baseline information for future research efforts on the soil resources of the area. Therefore, the purpose of this study was to characterize and classify soils of Megecha micro-watershed, to generate baseline information, which would be important for formulating the management alternatives for different soil types identified. Therefore, the specific objectives of the study would be:

1. To characterize the soils of the Megecha micro-watershed
2. To classify and produce map of soils of the Megecha micro-watershed

2. LITERATURE REVIEW

2.1. History of Soil Survey and Classification

2.1.1. Soil Survey

A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of classification, plots the boundaries of the soils on a map, and makes predictions about the behavior of soils (FAO, 1991). Soil survey considers the different uses of the soils and how the management practices affect them. According to FAO (1993), the information collected in a soil survey helps in the development of land use plans and evaluates and predicts the effects of land use on the environment.

Early soil surveys were made to help farmers in order to locate soils responsive to different management practices and to help them decide what crops and management practices were most suitable for the particular kinds of soil on their farms (FAO, 1995). Numerous of the early workers were geologists because only geologists were skilled in the necessary field methods and in scientific correlation appropriate to the study of soils (Buol *et al*., 1997). They conceived soils as mainly the weathering products of geologic formations, defined by landform and litho logical composition. Most of the soil surveys published before 1910 was strongly influenced by the above concepts (FAO, 1991).

According to (Rai, 2002), the modern concept of soil surveys reveals a marked transition from earlier concepts to give emphasis to soil profiles and soils as independent bodies. The maps retained significant geologic boundaries as soil maps do today. Many of the surveys of that periodic soil properties help soil scientists make broad generalizations significant to farming and forestry practices. Soil survey maps and texts of the period show more recognition of other soil properties significant to farming and forestry than do earlier surveys and have value for broad generalizations about farming practices in large areas and allow providing excellent general maps for evaluating engineering properties of geologic material. In recent times soil survey involves thousands of different kinds of soils; as many as there are significantly different combinations of genetic factors (Buol *et al*., 1997).

The history of soil and evidence of its potential for use are contained in the properties soil scientists are able to identify through observation and research in the field and laboratory to determine the limitations, suitability, and potential for rural and urban land use of soils. As indicated by (FAO, 1995), soil surveys are very important tasks during land use planning time because surveys identify specifically the measurement and observations of the behavior and properties of soils at the location under study. These include; determining important characteristics of soils, classifying the soils into defined units, locating and plotting their boundaries on maps, and predicting their suitability for various uses.

2.1.2. Soil Characterizations

Soil can be characterized by its morphology in the field such as structure, color, consistence, texture, and abundance of roots, and biological activities. Its physical and chemical properties could be characterized in laboratory. These characteristics allow scientists to interpret how the ecosystem functions and make recommendations for soil use that have a minimal impact on the ecosystem. It can help them to determine the types of vegetation and land use best suited to a location (Globe, 2005).

Characterization of soils is fundamental to all soil studies, as it is an important tool for soil classification, which is done based on soil properties. Soil characterization also helps to document soil properties at research sites, which is essential for the successful transfer of research results to other locations (Buol *et al*., 2003). The need to provide this information is more demanding than before because of the problem arising from the misuse of land resulting in land degradation.

Soils widely vary in their characteristics and properties. In order to establish the interrelationship between their characteristics they require to be classified. Understanding the properties of the soils is important in respect of the optimum use they can be put to and for their best management requirements. Soil classification systems are established to help people predict soil behavior and to provide a common language for soil scientists. It helps to group together such soils as have comparable characteristics so that the knowledge regarding them is presented in a systematic manner (Brubaker *et al*., 1993; Brady & Weil, 2002, Balasubramanian, 2017).

2.1.3. Soil Classification

Soil classification is a century-old science that deals with the systematic categorization of soils based on the distinguishing characteristics as well as criteria that dictate choices in use (SSDS, 2000). It categorizes soils into groups at varying levels of generalization according to their morphological, physical, mineralogical, and chemical properties (Buol *et al*., 1997). The objectives of soil classification include organization of knowledge, ease in remembering properties, a clearer understanding of relationships, and ease of technology transfer and communication.

As of (FAO, 1991), recent soil classification systems classify soils based on quantitative characteristics defined as horizons, diagnostic, properties, and materials because the properties that result from soil processes are more easily quantifiable than a process of soil development. According to (SSDS, 2000), its operational materials are the characterization description, and interpretation of soil profiles, soil bodies, and patterns of soils. Therefore, soil genesis study is dependent upon the supportive and correlative activities of soil morphology, characterization, and soil geology. Basically, soil classification is carried out with the help of field mapping, observation of soil profile, and use of laboratory analysis (Buol *et al*., 1997).

Now a day in the world there are several approaches and classification schemes like USSR, Australian, Canadian, South African, etc., and most have been on a national basis (Foth, 1990). The classification schemes differ because they are based on different appreciation of soil formation, use different criteria, and have different hierarchical sub-divisions. The most common classification systems used worldwide are the FAO/UNESCO soil map of the world, and the Soil Taxonomy of the United States (Buol *et al*., 1997; Landon, 1991).

As (FAO/WRB, 2006) currently, the FAO/UNESCO classification has thirty-two major soil groupings of higher level, which are approximately equivalent to the “great group” level of Soil Taxonomy. In the world, the most systematic and comprehensive soil classification system is Soil Taxonomy (Buol *et al*., 1997). The criteria used for describing classes are objective and based on properties that are determined quantitatively, as well as their seasonally dynamic soil temperature and moisture regimes. The system contains six levels of categories, from highest to lowest levels of generalizations. These are order, suborder, great group, subgroup, family, and series. In order to classify any soil in this system, one has to proceed hierarchically from the higher level down to the lower, and must follow the specific procedures mentioned for each property, for that two different laboratory methods could possibly result in different values for the same parameter (Soil Survey Staff, 1999). They are comprehensive, including all naturally occurring soils in different parts of the world. Both classification systems are also commonly used in Ethiopia for all soil studies.

Soil classification deals with the systematic categorization of soils based on distinguishing characteristics as well as criteria that dictate choices in use. Soil classification is a dynamic subject, from the structure of the system itself to the definitions of classes, and finally the application in the field. Soil classification can be approached from the perspective of soil as a material and soil as a resource. According to (FAO, 1991), modern classification systems classify soils based on quantitative characteristics defined as diagnostic horizons, properties, and materials because the properties that result from soil processes are more easily quantifiable than a process of soil development.

All soils contain mineral particles, organic matter, water, and air. The combinations of these determine the soil's properties – its texture, structure, porosity, chemistry, and color. All soils are naturally variable; their properties changing across the landscape and vertically down the soil profile (Brubaker *et al*., 1993; Brady & Weil, 2002). Soils commonly occur in groups, each member of the group occupying a characteristic and different sequential topographical position from top to bottom of a slope, termed a topo-sequence. To classify soils and group those together in a meaningful manner different systems of soil classification have been used from time to time.

2.1.4. Soil mapping

A soil mapping is a representation of soil type for a geographic area and/or of their properties like soil horizons, soil reactions (pH), textures, organic matter contents and soil colors.

Traditionally, it is produced on the basis of field observations in a soil survey at a pre-determined scale (detailed, reconnaissance or exploratory surveys). The resulting maps are published with a soil report describing over the geographic area, as generalized at the scale of the map. The map legend commonly groups and describes the main soil types, of which the distribution, properties and capabilities are explained in the soil survey reports. Typically the results of traditional soil survey are presented as polygon maps (Biswajit and Divya 2020).

Nowadays, spatial statistics are commonly used to predict soil properties at various resolutions (100m, 250m, or 1km) as determined by user needs. Such digital soil mapping works commonly draws on large soil profile databases and a range of environmental covariates derived from remote sensing (e.g. elevation, slope, land cover and climates. Results are presented as grid (raster) maps, for pre-defined soil depth. Digital soil maps commonly show higher spatial detail than traditional soil maps do at similar resolution (or scale); the boundaries between classes are not sharp (discrete) but gradual (continuous). Soil maps produced using geo-statistical techniques include an estimate of the model uncertainty. Digital soil maps can be used to underpin a wide of applications (e.g. food security and soil carbon dynamics) (Panday *et al.*, 2018).

Soil mapping is very important for the correct implementation of sustainable land use management. In recent decades, soil mapping methods and data availability have increased exponentially, improving the quality of the maps produced. Despite these advances, local knowledge is a great source of information, refined for centuries and useful for soil mapping and the implementation of a sustainable land management. Local wisdom and experience should be an important aspect of soil mapping because farmers will be one of the major end-users of the maps produced and they should account for the farmers' reality. However, several problems have been identified in the spatial correlation between folk and scientific classification related to different cultural variables that influence local soil classification.

Digital Soil Mapping (DSM) is an important tool in soil survey and agricultural planning. It is the process which involves the creation and population of spatial soil information by the use of field and laboratory observations. It is also called as "predictive soil mapping" or "pedometric mapping". It provides detailed information regarding the different soil properties such as soil pH, soil moisture content, soil organic carbon, electrical conductivity (EC), cation exchange capacity (CEC), the nutrient concentrations in soil like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S) and other micronutrients, gypsum concentration, percentage of base saturation, concentration of heavy metals, nature of parent material, etc. through digital elevation models, geo-statistical modeling and spatial interpolations of the collected soil samples from a given area. Instruments like Portable X-Ray Fluorescence Spectrometer (PXRF) along with polynomial algorithms and different "R" software packages play an important role in Digital Soil Mapping.

Geo-statistical modeling tools like kriging, splines, simulation options, covariance functions, semi-variance functions and variograms are used in spatial interpolation of the collected data to generate digital soil maps. Here are three major components: digital soil mapping, soil management advice, and serving end-users undertaken by GSM and supported by its strong cyber infrastructure. Digital soil mapping is the prediction of soil properties from point data using a statistical algorithm which further helps in managing the soils in a more sustainable way (Panday *et al.*, 2018).

2.2. Processes of Soil Formation

Soils are dynamic in nature and form continuously over a long period of time (Rai, 2002). The process of soil formation is an ongoing process with several forces of nature working together to create soil from rock and rotting organic material (Buol *et al*., 1997). Most of the time soil types differ depending on the parent materials from which they came and from the surrounding environment. The way in which soil forms depends on parent material, climate, topography, living organisms, and time (Buol *et al*., 1997).

Soil formation, according to (Sharma, 2002) comprises two different processes. These are the changes from a consolidated mass (rock) not capable of growing plants to the development of an unconsolidated (loose) layer of material that can support plants if the climate is suitable and water is available, and the changes occurring within the loose material as time passes which is termed as soil development. (Brady and Weil, 2002) suggested that soil genesis (development) is brought about by a series of specific changes that can be grouped into four broad processes, namely addition, losses, transformations, and translocation of various inorganic and organic soil materials.

2.3. Factors Controlling the Genesis and Distribution of Soils

Soil is a function of five soil-forming factors namely climate, biological influence, topography, parent material, and time (Miller and Donahue, 1995; Sumner, 2000) and these factors control the distribution of the soil in a given area. In most parts, soils are the same, when all elements of the five factors are similar and this indicates that the distribution of the soil in a given area is controlled by soil-forming factors. It should be noted that these factors do not exert their influences independently, and as a consequence, interdependence is the rule (Brady and Weil, 2002).

According to (Ahmed, 2002), all five soil-forming factors in combination with various forms of anthropogenic activities act on and affect soil properties in a given locality. Regional patterns of climate, vegetation, and parent material can be used to predict the kinds of soil in large areas. In contrast, the local patterns of topography or relief, parent material and time, and their relationships to vegetation and microclimate can be used to predict the kinds of soil in small areas (SSDS, 2000).

According to (Brady and Weil, 2002), the nature of the parent materials profoundly affects the rate of chemical weathering and the natural vegetation as well as the characteristics of the soil. The younger the soil, the more the influence, and relationship with the soil parent material, but as weathering and pedogenic processes precede; the imprint of the parent material is less (Mesfin, 1998). This is in agreement with (Fanning and Fanning, 1989) who stated that as the soil gets older, the inherited properties typically become less obvious, as the environment (through the factors of climate, organisms, and relief) molds the soil.

As indicated by (Mohammed, 2003) in the highlands and middle altitudes areas of Ethiopia, the distributions of soils are related to parent material, and the major geological materials are tertiary and quaternary basalt, deposits, and granite rocks. Apart from that soils of the central, eastern, and northern highlands of the country are developed on hard basalt rocks or from their derivatives, whereas in the southwestern parts, they are formed from crystalline basement rocks (Mesfin, 1998). In addition, the soils of the northwestern highlands of the country are formed largely from volcanic origin, predominantly basalt (Yihenew, 2002).

According to (Mesfin, 1998), topographic variability has a significant impact on other soil-forming factors mainly on soil parent material, climate, and biota, which in turn influence the type and depth of soil to be formed. Moreover, topography is the major factor in determining soil genesis and distribution throughout the Ethiopian highlands (Mitiku, 1987; Mesfin, 1998). According to (Mohammed, 2003), a number of researchers and organizations classified some soils on the basis of their topographic positions. For instance, Nitosols, Acrisols, and Luvisols are developed on gentle slopes; and Leptosols, Cambisols, and Regosols are common on steep and colluvial foot slopes. In addition, poorly drained Vertisols are usually formed on the plateaus while Phaeozems occur only on gentle to steep slope terrains of intermediate altitudes (Mitiku, 1987).

Climatic differences coupled with a great variation in age and characters of parent materials lead to a wide diversity in soils (Mesfin, 1980). Basically, climate exhibits its influence on soil formation through the control of some of the chemical and physical reactions that take place in the soil system. According to (Mitiku, 1987), the depth of soil, organic matter (OM) content, pH, percent base saturation, and type of clay minerals is highly affected by the type of climate in a given area. The principal climatic variables influencing soil formation are effective precipitation and temperature, both of which affect the rates of chemical, physical and biological processes (Brady and Weil, 2002).

According to (Ahmed, 2002), the changes in soil physicochemical properties may be serious, particularly in high-altitude areas where the nature of the terrain and climatic elements act together to aggravate the situation. Owing to climatic variations within short distances in the highlands of Ethiopia, its influence on soil properties also varies (Mohammed, 2003). In line with this, most soils in the southern and western highlands of the country (high rainfall parts) are highly leached, whereas soils in the northern, central, eastern, and southeastern areas are less leached and have rich basic cations. On the other hand, areas with high rainfall plus high temperature throughout the year have developed deep soils due to rapid weathering (Tadesse, 2002).

The activity of living plants and animals and the decomposition of their wastes and residues have marked influences on soil development (Sharma, 2002). As indicated by Mesfin (1998) rearrangement of soil materials by plants and animals involves roughening of the soil surface, formation of botanically shaped peds, formation of channels and voids, the concentration of organic matter, and certain irregularities on the soil surfaces. According to (Ahmed, 2002) vegetation affects the amount and type of OM added to soil and this tends to significantly affect soil structure, color, pH, CEC, infiltration, and water-holding capacity of soils. Hence, soils formed under grass vegetation have thicker and dark surfaces while soils developed under forest tend to have thinner A-horizons (Parker, 2000). Land management by people also greatly affects the interaction between biota and soils, but action by the organic factor on initial material is, on the other hand, a prerequisite to soil formation (Buol *et al*., 1997).

The formation of the soil takes several centuries; it may take as much as a thousand years for a one-inch depth of soil to form on the Earth's surface in any given area (Rai, 2002). However, this soil can be lost in a very short period by erosion if not managed properly, and thus; this makes the soil to be a nonrenewable resource (Mitiku, 1987). Basically, the time span required for the formation and development of a given soil varies in accordance with the intensity of the soil-forming factors. As indicated by (Sharma, 2002), under ideal conditions, a recognizable soil profile may develop within 200 years, whereas under less favorable circumstances, the time may be extended to several thousand years. All soils begin with solid rock, hence from the very beginning of the earth, wind, running water, rain, earthquakes, landslides, and other forces of nature have changed rocks into soil.

2.4. Soil Physical and Chemical Properties

2.4.1. Soil Physical properties

Physical properties play an important role in determining soil’s suitability for agricultural, environmental, and engineering uses. The supporting capability; movement, retention, and availability of water and nutrients to plants; ease in penetration of roots, and flow of heat and air are directly associated with the physical properties of the soil. Physical properties also influence the chemical and biological properties (V.K. Phogat *et al*., 2015)

2.4.1.1. Soil color

Color reflects an integration of chemical, biological, and physical transformations and translocations that have occurred within the soil. The color of surface horizons reflects a strong imprint of biological processes, while subsoil color reflects more strongly in most soils the imprint of physicochemical processes. Black soil usually indicates the presence of higher OM whereas red color indicates the presence of free iron oxides which are common in well-oxidized soils (Buol *et al*., 1997). Therefore, soil color is heavily influenced by the type and amount of OM (Shields *et al*., 1968), iron oxides, and water content of the soil (Brady and Weil, 2002). Even from free iron itself, hematite gives a red color while goethite imparts a yellow color (Barber, 1984).

Soil color is also a derivative of the oxidation-reduction processes, the material from which it is derived, and OM content (Barber, 1984; Birkeland, 1984). As indicated by (Rai, 2002), it is very important in soil classification and a useful indicator of processes that are carried out in the soil system than direct physical importance. Soil color also can provide information about subsoil drainage and the moisture conditions of the soil. It can easily be identified in the field using a Munsell color chart (KIC, 2000). For example, in well-aerated soils, Fe^{3+} is present which gives the soil a yellow or reddish color while in poorly drained soils (anaerobic conditions), iron compounds are reduced and the neutral gray colors of Fe^{2+} or bluish-green colors of iron sulfides, iron carbonates, or iron phosphates are visible. The color of the soil associated with minerals inherited from parent materials may also influence color in horizons that have not been extensively weathered. For example, light gray or nearly white colors are sometimes inherited from parent material, such as quartz, while parent material such as basalt can imprint a black color to the subsoil horizons (Buol *et al*., 1997).

2.4.1.2. Soil depth

Soils on gentle slopes have a thicker depth than that soils on sloppy land (Bono and Seiler, 1984a; Belay, 2000; Engdawork, 2002). Most of the time, it is used for soil classification purposes where variations in depth to a contrasting layer are significant to soil use, management, or behavior. According to (FAO, 1991), terms of depth classes are generally used during the naming phase with some modifications. The depth of the topsoil varies due to factors such as erosion, vegetation cover and climate. The way we manage the soil on our farms can also determine the depth of topsoil. Mostly, the depth of the soils in Ethiopia is influenced by the relief (Mesfin, 1998). Most of the time, it is used for soil classification purposes where variations in depth to a contrasting layer are significant to soil use, management, or behavior.

2.4.1.3. Soil texture

Soil texture determines a number of physical and chemical properties of soils. It affects the nutrient and water-supplying capacity as well as microbial activities (Bezabih *et al*., 2014). (Chauhan *et al.*, 2014) reported that no variation occurs between the sand, silt and clay fractions of forest land and pasture land. Soil texture is one of the inherent soil physical properties less affected by management. In the subsurface horizons, however, slight differences were noticed. The clay percentage increased while the silt and the sand decreased from the surface to the subsurface horizons in all land use systems observed by (Gailyson, 2013).

Soil texture is the relative proportion of the various soils that separate sand, silt, and clay that make up the soil classes (Michael and Donald, 1996). According to the USDA classification system, soil texture refers to the weight proportion of the separates for particles less than 2 mm as determined from a laboratory particle size distribution. Field estimates should be checked against laboratory determinations in order to get precise information and the field criteria should be adjusted as necessary. At field conditions, sand particles feel gritty and can be seen individually with the naked eye. Silt and clay particles cannot be seen individually without magnification and they have a smooth feel to the fingers when dry or wet. According to (FAO, 1991), in some places, clay soils are sticky; in others, they are not. For instance, soils dominated by montmorillonite clay feel different from soils that contain similar amounts of kaolinite clay. These imply that type of clay mineral also affects the property of the soil.

2.4.1.4. Soil structure and consistency

The individual soil particles are not usually randomly arranged in field soils but are combined to form secondary soil particles called aggregates or peds (Scott, 2000). An aggregate is a group of primary soil particles (sand, silt, and clay) that cohere with each more strongly than with other surrounding soil particles (Kemper and Rosenau, 1986). A ped is a unit of soil structure formed by natural processes, in contrast to a clod, which is formed artificially (SSS of America, 1997).

Consistency refers to the cohesion among soil particles and the adhesion of soil to other substances or the resistance of the soil to deformation. Whereas soil structure deals with the arrangement and form of peds, consistence deals with the strength and nature of the forces between particles. Most of the time consistency is described for three moisture levels; wet, moist, and dry (Buol *et al*., 1997). The stickiness describes the quality of adhesion to other objects and the plasticity describes the capability of being molded by hand. Wet consistency is when the moisture content is at or slightly more than field capacity. Moist consistency is soil moisture content between field capacity and the permanent wilting point. When recording consistency, it is important to record the moisture status as well. Cementation is also considered when consistency is described in the field. Cementing agents are calcium carbonate, silica, oxides of iron, and aluminum.

2.4.1.5. Bulk and particle density

Bulk density (the mass of a unit volume of dry soil) is required for the determination of compactness or looseness, as a measure of soil structure. Bulk density is one of the major role played in soil fertility (Habtamu *et al*., 2014). This is the dry mass (weight) of soil per bulk volume (Michael and Donald, 1996). Mostly, the bulk densities increased with depth. Based on (USDA, 2008) classification, the optimum soil bulk densities for sandy, silty, and clayey soils are about 1.6, 1.4, and 1.1 g cm^{-3} respectively. Bulk density is a measure of the weight of the soil per unit volume, usually given on an oven-dry basis (Birkeland, 1999). The volume includes both solids and pores. Bulk density values are important in quantitative studies, such as in calculating the volumetric water content, total porosity, and mass of soil per unit area per unit depth and to indicate whether a given soil is too compact for root penetration or not.

Soil particle density is defined as the mass per unit volume of soil solids. Particle density is affected by the chemical composition and crystal structure of mineral and OM content. However, it is not affected by the structure of the soil (Brady and Weil, 2000; Hillel, 2004). As a result, soil particle density is relatively a permanent property. For most mineral soils developed from quartz, feldspar, micas, and colloidal silicates, particle density varies between 2.60 to 2.75 g/cm^3 (Foth, 1990; Brady and Weil, 2000). For general calculation purposes, a particle density of 2.65 g/cm^3 is used if the actual particle density is not determined.

2.4.1.6. Soil Porosity

The amount of pore space in soil, sediments, and rock is called porosity, which can also be defined as the percentage of a material's total volume that is taken up by pores. The empty space (voids) has a fantastic ability to hold water that seeps down from the land surface into the soil. For soils with the same particle density, the lower the bulk density, the higher the percent pore space (total porosity). According to (Brady and Weil, 2002), porosity depends on the size, shape, and arrangement of solid particles. For instance, coarse-textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in the former than in the latter. The total porosity of the soil can be used as an indication of the degree of compaction in soil in the same way as bulk density is used. It governs the essence of biological processes that supports life and biochemical and physical processes that determine environment quality (Lal and Shukla, 2004). From 30 to 50% of the total volume of soil in its natural field state, the pore space is occupied by air and water (Hillel, 1980). The pore spaces exist because of the particle and the disturbance including those due to roots, soil animals, swelling, cracking on shrinking, and tillage that alter the spacing of aggregates or particles (Rose *et al*., 1996).

2.4.2. Soil Chemical Properties

The occurrence of higher concentrations of organic matter in topsoil is due to the re-distributive effect of slope ((Esu *et al*., 2008). Organic matter is also known to decrease with depth in the pedon (Idoga and Azagaku, 2005). Organic matter is known to account for 90 to 98% and 60 to 75% of soil nitrogen and phosphorus respectively (Konnovora, 1966). It has been reported that calcium and magnesium dominate over potassium and sodium in the exchangeable complex of basement complex soils (Konnovora, 1966).

2.4.2.1. Soil reaction pH

Soil pH is the measure of the acidity or alkalinity of a soil, numerically equal to 7 for soils with a neutral pH, increasing with rising alkalinity and falling with increasing acidity. It is an easily measured indicator of the state of weathering in a given area. In slightly weathered soil, the surface soil pH is neutral to slightly alkaline (Buol *et al*., 1997).

2.4.2.2. Soil organic carbon and total nitrogen

Fertility is closely linked to soil organic matter, whose status depends on biomass input and management, mineralization, and leaching erosion (Roose and Barthes, 2001). It is well recognized that soil organic matter increases structure stability, resistance to rainfall impact, rate of infiltration, and fauna activities (Roose and Barthes, 2001). As reported by (Abayneh, 2001), soil OM depends on the rates of renewal (source) and loss (removal) of carbon from the soil and it decreases with the depth of the soil. The total nitrogen status of any soil is closely associated with the soil's organic matter (Graham, 2010). Nitrogen (N) is one of essential nutrient the elements that is taken up by plants in greatest quantity after carbon, oxygen, and hydrogen, but it is one of the most deficient macronutrients in crop production areas (Mesfin, 1998).

2.4.2.3. Available Phosphorus

Losses of phosphorus are usually due to the removal by crops (Enwezor, 1987). In acidic soils, much of the Phosphorus becomes fixed up by reaction with iron (Fe^{3+}), aluminum (Al^{3+}), and manganese to form insoluble compounds. Soils have a significant amount of phosphorus (P) which is not immediately available to crops and only a small fraction becomes available during crop season (Barber, 1984). This P occurs in numerous combinations with iron, aluminum, calcium, and other elements. The solubility of these compounds in water varies from sparingly soluble to very insoluble. The P content in soil solution is low as compared to other nutrients such as nitrogen, potassium, calcium, and magnesium (Tisdale *et al*., 1993).

2.4.2.4. Cation Exchange Capacity

According to (Abayneh 2001) reported that soils with large amounts of clay and OM have higher CEC than sandy soils with low OM. In the surface horizons of mineral soils, where the contents of OM and clay in the soil are significantly high, OM and clay fractions frequently contribute similar values to the CEC.

2.4.2.6. Exchangeable bases

The average potassium content of the soil is 1.2 % however; organic soil has low potassium (less than 0.03 %). While young soils having little weathering have higher than average potassium content (Barber, 1984). Sodium is found in very small amounts in humid regions, but it can be a major component of soils in arid and semiarid regions. Generally, the concentration of sodium in the soil is low, ranging from 0.1 to 1 %. The average concentration of sodium in the soil is estimated at about 0.63% (Barber, 1984; Tisdale *et al*., 1993).

According to (Enwezor, 1986) pointed out that the leaching of calcium and magnesium is largely responsible for the development of acidity in the soil due to high rainfall with the porous nature of the soil texture and the parent materials. In humid regions, calcium is leached and the exchange sites are taken by aluminum. In general, in soils that are neutral or only slightly acidic, calcium ions occupy most of the exchange sites on clays and organic matter (Wild *et al*., 1988). Total magnesium usually increases with an increasing percentage of soil clay. Calcium plus magnesium usually accounts for more than 60% of the exchangeable cations in soil with pH 5.5 or higher, however, the exchangeable magnesium is lower (Barber, 1984).

2.5. Classification of Major Soils of Ethiopian

The wide ranges of topographic and climatic factors, parent material, and land use have resulted in extreme variability of soils (FAO, 1984). In different parts of the country, different soil-forming factors have taken precedence. According to the Ministry of Agriculture about 18 soil types are identified throughout the country. A big proportion of the country's landmass is covered by lithosols (17.1%), Nitosols (12.2%), Cambisols (11.6%) regosols (10.9%), Vertisols (10.0%), and Fluvisols (8.3%) in order of their importance. Research showed that Potassium, Nitrogen, Cation Exchange Capacity, and organic matter contents of most Ethiopian highland soils are generally high by international standards (EARO, 1998), whereas their phosphorous content is low to very low (Haile, and O. Moog, 2016).

About 18 major soil groups are occurring in Ethiopia including; Leptosols, Nitisols, Cambisols, Vertisols, Xerosols, Solonchacks, Fluvisols, Luvisols, Regosols, Acrisols, Yermosols, Phaeozomes, Rendizinas, Andosols, Arenosols, Gleysols, Histosols and Chernozem (FAO/UNDP, 1984a). However, as indicated by the (Ethiopian Mapping Authority, 1988), the most important soils in Ethiopia are Leptosols, Nitosols, Vertisols, Cambisols, Fluvisols, and Luvisols.

2.5.1. Vertisols

In Ethiopia, Vertisols occur in a wide range of environmental conditions. Several studies documented their occurrences for example in the central (Dawit and Reed, 2002), northern (Belay, 1996), southeastern (Ahmed, 2002), and eastern (Eylachew, 1999; Mohammed, 2003) parts of the country. Hence, their formation is related to diverse moisture regimes that range from humid to semiarid climatic conditions.

2.4.2. Nitisols

Nitisols are the dominant soil types in western and southwestern Ethiopian highlands (Fikru, 1989; Belay, 1992). In addition, they are also found in the north-western, southern, central, and eastern highlands, where the annual rainfall is high (Fikru, 1989; Mesfin, 1998; Wakene, 2001; Ahmed, 2002; Biru *et al*., 2003). As a consequence of their occurrence in a range of climatic zones, Nitisols exhibit various physicochemical properties (Belay, 1992; Wakene, 2001; Ahmed, 2002; Dawit and Reed, 2002). Furthermore, management practices also contributed to the variation observed in the physical and chemical properties of Nitisols (Wakene, 2001; Ahmed, 2002). They primarily occupy slopes steeper than 5% and flat lands in association with Luvisols, Vertisols, or Gleysols (Yihenew, 2002). Ethiopian Nitisols have low bulk densities and high water retention capacities relative to their clay content (Mesfin, 1998; Yihenew, 2002). Nitisols have a depth of more than 1.5 m, and are clayey and red. Lined with good physical properties; they have high water-storage capacity, a deep rooting depth, and stable soil aggregate structure. Nevertheless, rates of decomposition of organic matter and leaching of nutrients are extremely fast. Acidity ranges from medium to strong, and pH is generally less than 6 (Israel *et al*., 2018).

2.4.3. Cambisols

Cambisols are weakly developed soils relating to their parent materials. Hence, the word cambric from Latin, Cambiare, which means to change, is coined for these soils (FAO, 2001) to reflect the presence of slight deviations from their parent materials. Cambisols are located on a wide variety of landscapes, parent material, vegetation types, and climatic regions. But they predominantly occur on the hills and mountains in the central, northeastern escarpment and north Ethiopia where slopes are steep that aggravate active geological and manmade erosion (Mesfin, 1998, Belay, 1998; Yihenew, 2002, Mohammed, 2003).

2.4.4. Leptosols

They are found under limited conditions of weathering processes, which is related to little water accumulation, and rapid rate of runoff on hard and steep slopes (Belay, 1997; Eylachew, 1999; Yohannes, 1999; Mohammed, 2003). Physically, this soil is characterized by a high stone content, limited depth, and low clay content. Chemically, with the exception of the western highland Leptosols, they are characterized by high cation exchange capacity (CEC) and high percentage base saturation (Yohannes, 1999; Eylachew, 1999; Engdawork, 2002). The physical limitation (depth restriction and stone content) and topographical position make these soils unsuitable for cultivation.

2.4.5. Regosols

Regosols are very weakly developed mineral soils in unconsolidated materials that are not very shallow, sandy, or with fluvic properties, and have no diagnostic horizons other than anarchic epipedon (FAO, 2001). The depth criterion separates Regosols from shallow soils, such as Leptosols, and the uniform distribution of clay from Cambisols (FAO, 2001).

2.4.6. Phaeozems

Phaeozems are soils having a mollic A- horizon with a well-structured dark-colored surface Horizon with a base saturation of 50% or more and a moderate to high (at least 0.6%) OC (FAO, 2001). In the Ethiopian highlands, these soils develop under a moist temperate climate where conditions allow for the accumulation of organic matter. They occur in a wide range of landscape positions ranging from flat alluvial to undulating (Mesfin, 1998; Engdawork, 2002). In northern highlands, they develop at the foot slopes of hills and piedmonts on depositional materials (Belay, 1997, 1998). Whereas in the east (Chercher highland) they occur in high altitude very steep slopes formed on basalt rock (Mohammed, 2003).

2.4.7. Fluvisols

Fluvisols are soils developed in alluvial deposits, recent fluvial, lacustrine or marine deposits (FAO, 2001). In Ethiopia, they occur in recent alluvial deposits on flat or nearly flat land scattered throughout the country on alluvial plains and valley bottoms (Weigel, 1986; Fikiru, 1989; Kefene, 1995; Mesfin, 1998; Engdawork, 2002; Mohammed, 2003).

2.4.8. Luvisols

Luvisols occur in low to moderate hills, dissected side slopes, foot slopes, and valleys formed from sites, basalt and tuffs, and dolerite. Those Luvisols that occur in the flatter landforms of valleys and foot slopes are slightly alkaline in reaction (7.3 to 8.3 in pH values) and have Vertic properties (Belay, 1996). In contrast, those that are found in the hills and steep slopes are slightly acidic to slightly alkaline in reaction (6.7-7.2 pH) and in some cases even acidic in reaction 5.5- 6.7. This latter case may be due to the leaching effects in relatively raised landforms. Similarly, Luvisols of central and eastern highlands are characterized by slightly acidic reactions except in a few cases where it is located in valley bottom foot slopes and flatter areas where the pH is slightly alkaline. Luvisols are potentially suitable for a wide range of agricultural uses because of their favorable physical characteristics and moderate chemical fertility (Mesfin, 1998).

3. MATERIAL AND METHOD

3.1. Description of the Study Area

3.1.1. Location and Topography

The study was conducted at the Megecha micro-watershed, which is located in Ezha District, Gurage Zone of Central Ethiopia Regional State of Ethiopia. The study area is located about 195 km away from Addis Ababa toward the southwest direction and along the main road that connects Wolkite with Butajira. The geographical location of the micro-watershed area extends from 8º 8' 00" to 8º 10' 30" N latitude and 37º 59' 00"to 37º 55' 59" E longitude. The study area lies at an altitude ranging from 1997 to 2252 meters above sea level (masl). The total area of the micro-watershed is about 727 hectares with slope ranging of (0 to 30%).

3.1.2. Climate

The study area experiences rainfall from March to April (small rainy season) and from June to September (main rainy season) and this indicates that in the area rainfall condition shows a bimodal distribution pattern, and the ten years mean annual rainfall is 1410mm. The ten years mean annual temperature was 26.2ºC, whereas the mean monthly temperature ranged from 18 to 29 ºC (SNNPR Meteorological Service Agency, 2023).

3.1.3. Soils of the Study Area

According to ATA, (2016) regional small scale study, the soil of study area indicates slight variation in physical and chemical properties but not the studied the soil type of the study area. Crop residues, leaf litter from multi-purpose trees and shrubs, household wastes, farmyard manures, and inorganic fertilizers like Di-Ammonia Phosphate (DAP), Nitrogen, Phosphorus, and Sulfate (NPS), and Nitrogen, Phosphorus, Sulfate, and Boron (NPSB) were used for soil fertility management in the study area.

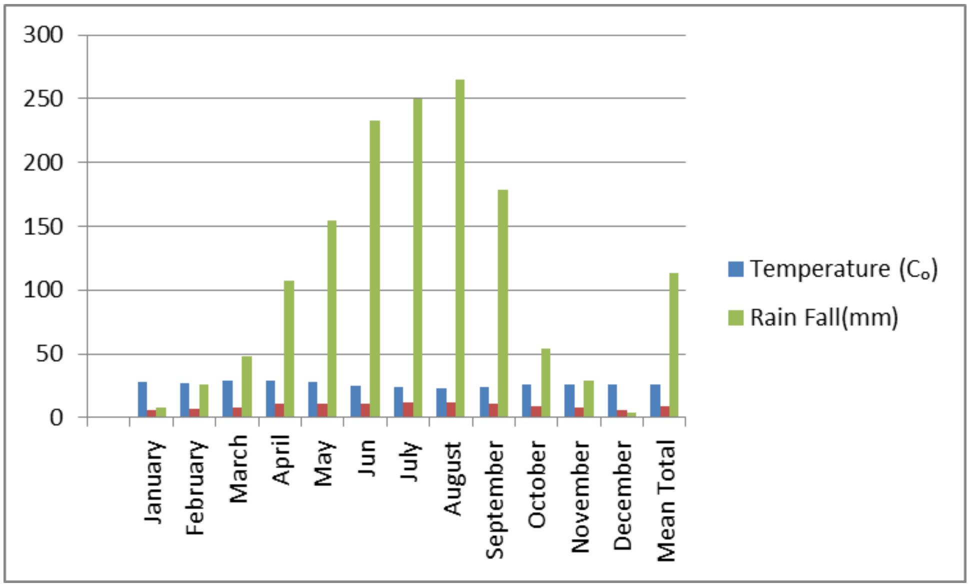

Figure 1 Ten years mean annual temperature and rain fall study area

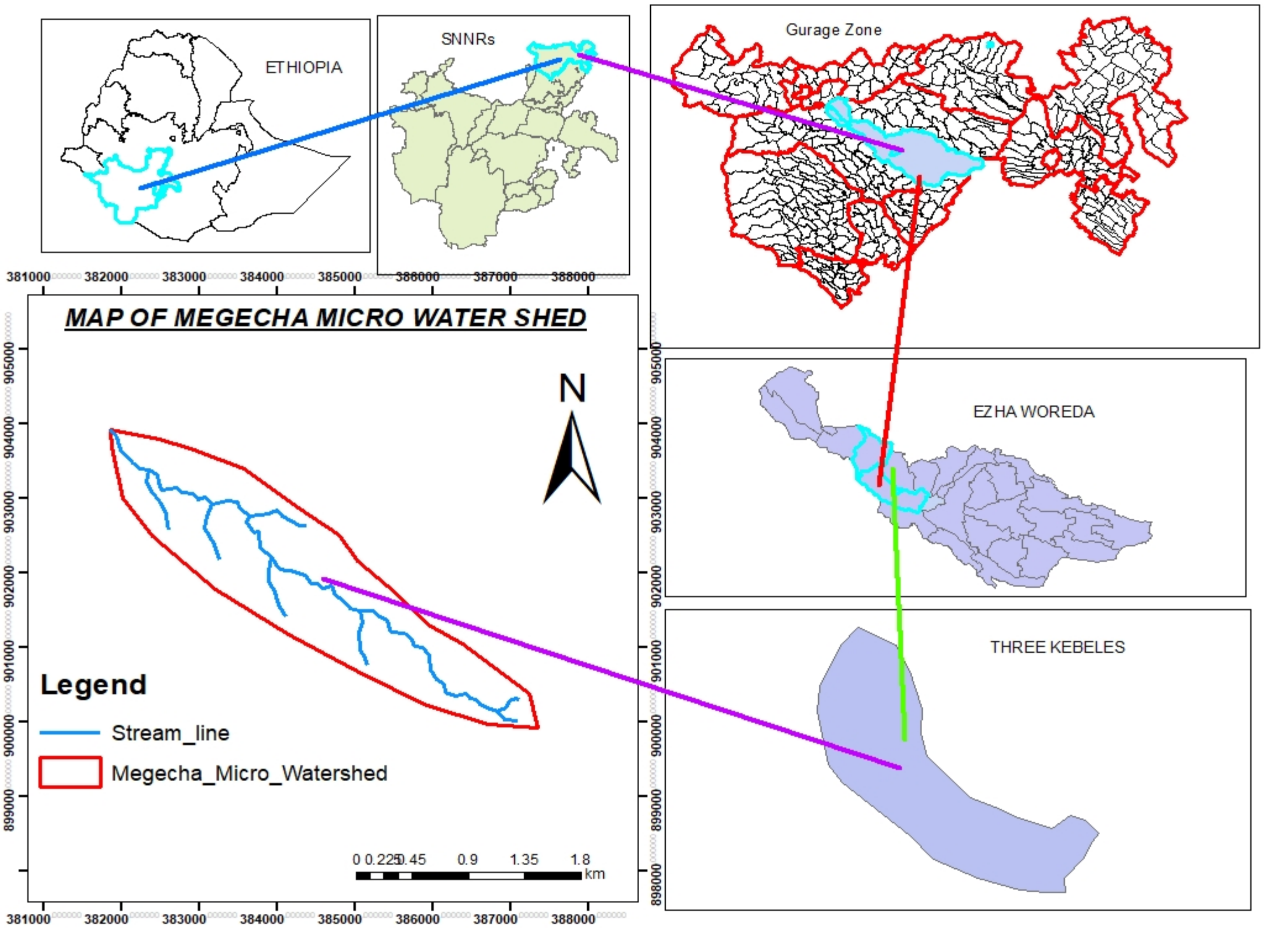

Figure 2 Map of the Study Site

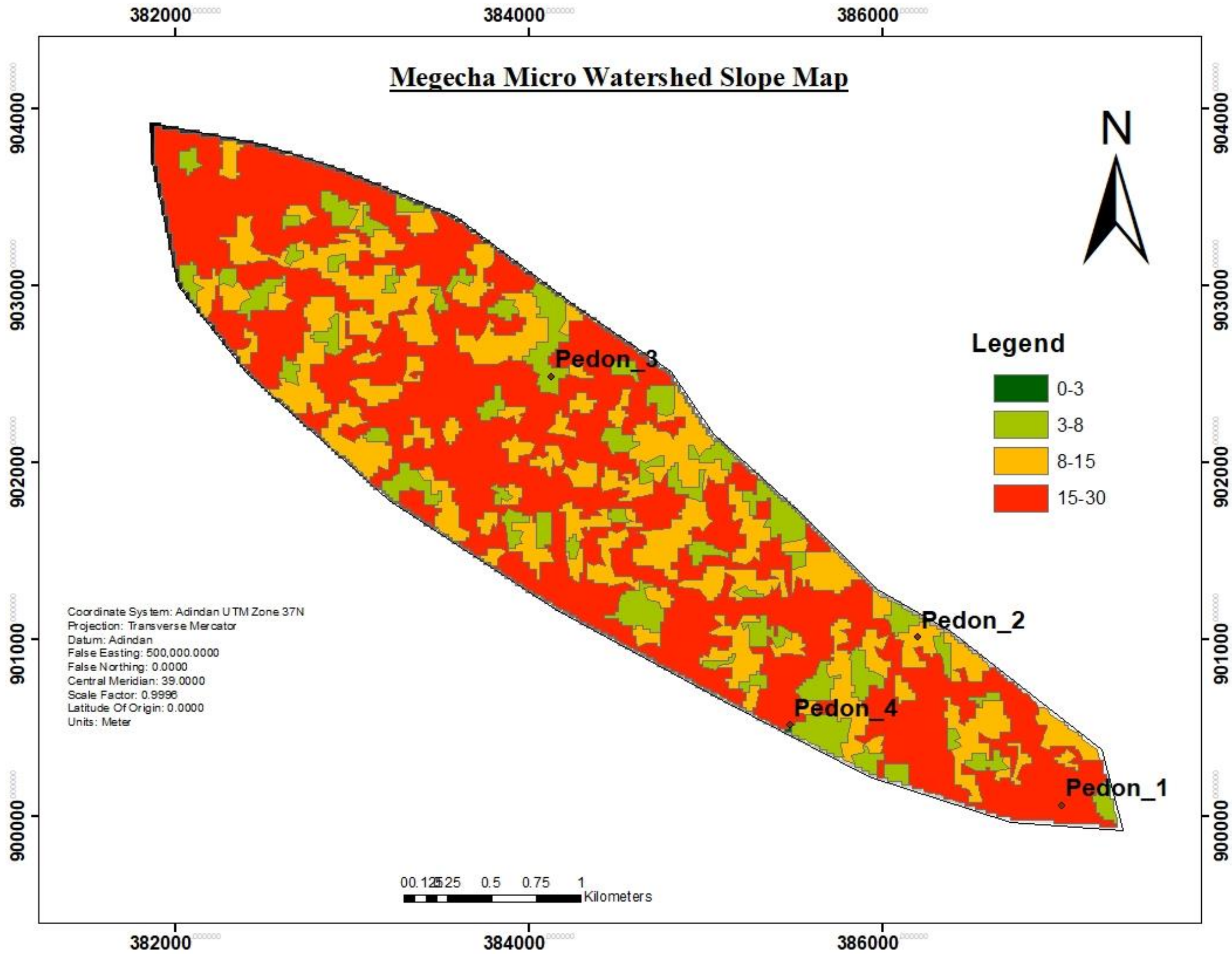

Figure 3 Megecha Micro Watershed slope classes map

3.1.4. Land use and vegetation cover

The major land use system in the study area was mixed livestock and crop production system. Major annual crops were maize (*Zea mays*), and wheat. Major perennial crops were Enset (*Ensete ventricosum*), Coffee (*Coffee arabica),* Khat (*Chata edulis* L.), Mango (*Mangifera indica linn)* and Avocado (*Persea americana*). Enset-based land use system is the dominant land use system in the study area which is considered a survival strategy by farmers. Though intercropping Enset with various crops is a common management practice. The micro-watershed contains a complexity of land use and vegetation that can be observed. The area is also a good representative of ecologies that experience high population pressure, acute land shortage problems. The land use dynamics in the area were minimal as compared to the information obtained from the farmers with the field survey. This suggests that much expansion of cultivation had occurred before. Major plantation trees and natural forest like *Juniperus procera, Eucalyptus globules,* and *Eucalyptus camaldunsis*. And the farmers practice livestock production and fattening activity.

In this area, *Eucalyptus globules* and *Eucalyptus camaldunsis* plantation is replacing the indigenous natural trees, and it is expanding on ridges, hillsides, backyards, stream banks, and gully sides. Along the river banks, there were different natural trees like, *Podocarpous gracilor*, *Ficus vasta*, and others tree were growing in this area. In general, the economy of the study area is largely based on subsistence crops, animal production activities, and *Eucalyptus camaldunsis* tree.

3.2. Field Survey, Site Selection, and Sampling

3.2.1. Field survey and site Selection

Before starting the main survey, a preliminary interpretation of the topographic map (scale 1:50,000) obtained from the Ethiopian Mapping Authority (EMA) was made in the office to conduct the fieldwork. The map units were delineated from the global Digital Elevation models (DEM) on the basis of topographic (slope classes) and land use/land cover patterns. The fieldwork was conducted with a reconnaissance survey for familiarization with the terrain of the study area. A free soil survey (traverse survey) method was employed to select profile excavation points as a major survey method along the landform, current land use, and management to detect variability of soils in the micro-watershed and in situ description of the observable site. The profile pits were cited based on the available land use in the area, the topography, and soil distribution, which were determined from 35 auger observation points were taken.

Before opening of the soil profile, auger observation and general visual reconnaissance survey of the site had physical characteristics, like color, texture, and soil depth variability were examined and a representative sample were identified. The profile pit sites and their positions were georeferenced using GPS. Slope classes of the micro watershed were classified by using the (FAO, 2016b) guideline, which includes four slope classes: 0-3% nearly level, 3-8% gentle sloping (undulating), 8-15% strongly sloping (rolling), 15-30% moderately strong sloping (hilly). Georefrenced raster data was used and GIS data of x-y coordinate point were used to have relatively accurate location information of the site.

3.2.2. Soil profile description and sampling

Based on physical observations, auger observations, and slope categories four representative soil profiles (length 2m x width 1.5m x depth 2m), were opened in the upper, middle and lower position. Two of them were opened from the middle position. Horizons designations and field soil classification were made in situ following standard procedures (FAO, 2006a). The morphological characteristics were studied in the field and the samples from each genetic horizon were collected following FAO soil description guidelines (FAO, 2006). The soils were classified based on procedures set by (WRB, 2015) legend for soil classification. Profile points were geo-referenced by using geographical positioning system (GPS).

3.3. Soil Sample Preparation and Analysis

Soil samples were air-dried, crushed with mortar and pestle, sieved through a 2 mm diameter sieve, and stored in carton boxes until required for analysis. Sample preparation was done in the Wolkite University Soil Laboratory. The bulk density (BD) of the soil was estimated from undisturbed soil samples, which were collected by using a core sampler following the procedures used by (Blake, 1965). Soil texture (soil particle size distribution) was determined by using the Bouyoucos hydrometer method (FAO, 1974).

All laboratory analyses were done following the procedures in the laboratory manual prepared by (Sahlemedhin and Taye, 2000). The pH of the soils was measured in water (1: 2.5 soils: water ratio) using a glass electrode attached to a digital pH meter (potentiometer). The organic carbon content of the soil was determined following the wet combustion method of (Walkley and Black, 1954). The total nitrogen content of the soil was determined by the wet-oxidation (wet digestion) procedure of Kjeldahl method (Jackson, 1973).

The available phosphorus content of the soil was determined by Olsen method (Olson *et al.*, 1954). Exchangeable cations and the cations exchange capacity (CEC) of the soil were determined following the 1 N ammonium acetate (pH 7.0) method (Frietal and Dews, 1970). The exchangeable potassium, and sodium, was measured by a flame atomic emission (flame photometer). The exchangeable calcium and magnesium were measured using the Ethylenediamineteraacetic acid (EDTA) method. Percent base saturation (PBS) was calculated from the sum of exchangeable bases as a percent of the sum of bases retained by the CEC sites.

3.4. Mapping

The study area was categorized and mapped into different slope positions using a digital elevation model (DEM). Representative pits were geo-referenced using GPS (Garmin 72) and were located on the map. Area class polygon soil map type was used. Finally, the soil map was prepared using Arc GIS software 10.7.1 version represented by vector GIS model.

3.5. Statistical Evaluation

Data obtained from field and laboratory analysis were subjected to simple linear correlation analysis to reveal the relationships between and among selected physicochemical properties of the soils. Statistical Analysis System (SAS) software for parametric model was employed to carry out the analysis.

4. RESULT AND DISCUSSION

4.1. Site characteristics

On the basis of major land characteristics and slope the study site was grouped into lower, middle, and upper slope units. Accordingly, the lower slope position was characterized by nearly level to gently sloping land (0 - 3%) with deep (200+ cm) soils, which occupied extensive areas in the northern and southeastern parts of the study area. The middle slope unit was on sloping to strongly sloping land (3 -15%) with deep soils (200+ cm) occupying south north and central parts of the study area. The upper slope unit was found on moderately steep (15 - 30%) landform and had deep soils (200+ cm) that occupied the southern part of the study area. Data on the physical characteristics of the site (Appendix 1 - 4) indicated that soils are well-drained, and well developed structure. In general, the site varied from the most intensively cultivated land to the land remaining fallow for several years of cutting grass and grazing land.

Table 1 Location and physiographic settings of the Pedons the study area

Pedon	Geographic location		Altitude (masl)	Physiographical position		Land use
	Longitude	Latitude				
Pedon 1	38º75'26.4" E,	8º 99'21.7"N	2252	MSS	Upper	Grazing
Pedon 2	38º58'48.0" E,	9º00'49.9" N	2178	SS	middle	Cropping
Pedon 3	38º37'88.8" E	9º01'84.6" N	2060	S	middle	Grazing
Pedon 4	38º 37'21E"	9º03'37.5"N	1997	GS	lower	Cropping

GS=gentle sloping, MS=moderately steep sloping, S=Sloping, SS=strongly sloping

4.2. Morphological properties of the studied soils

4.2.1. Horizon features and depth

The morphology properties of the study area are depicted in (Table 2). The depth of all the Pedons identified as very deep (>150cm) as per the rating of (FAO, 2000) and Abate, 2014. The horizons of Pedon were well differentiated. However, variations were observed in the thickness of horizons and across the studied Pedons. The thickness of the surface horizon ranged from 17cm to 40cm and the thickest 40cm surface horizon was observed in Pedon 3 of middle slope position. In the other hand the subsurface horizon thickness ranged from 11 to 99cm and the thickest subsurface horizon was observed in Pedon 2 of middle position ranged 99cm. Generally, the distinctness of the boundaries between the horizons was clear with smooth. Each soil horizon may be slightly or very much different from the other layer existing above or below it.

4.2.2. Soil color

The soil color (hue) was ranging between 2.5YR and 10 YR, with variable units of value and Chroma (Appendix 1 - 4). The values of the dry color of the Pedons were higher than the corresponding moist color, which is due to the fact that light reflection increase when the soil is dry. The surface horizons color of Pedon 1, Pedon 2, and Pedon 3 were red. Aerated, iron oxidation and adequate soil drainage are all indicated by the reddish color (Buol, 2006; Ali *et al*., 2010; Buol *et al.*, 2011; Abate, 2014). The lower slope Pedon 4 had dark brown and brown color. Furthermore, higher value and Chroma, as well as the absence of mottles in subsoil layers of all Pedons, revealed that the soils were well-drained in drainage conditions (Berhanu and Eyasu, 2021).

4.2.3. Soil structure and consistency

The surface horizons of Pedon-1 and Pedon-2 had weak, angular whereas Pedon 3 and Pedon 4 had moderate granular structures variations in the size of peds (Table 2 and Appendix 1 - 4). In the subsoil horizons, the structure was changed to moderate to strong, medium to coarse angular and sub angular blocky. The size of the peds was finer in surface horizons as compared to their subsequent subsoil layers. This could be attributed to continuous cultivation that decreases soil aggregates due to fragmentation by rapid wetting, exposing protected soil OM to microbial attack, and the direct impact of tillage implements, as mentioned by (Hamblin, 1985). Pedon 1 horizon A and B were described as a weak degree of aggregation compared to the other Pedons. Moreover, the vertical variations in grade and size of structure among horizons of the Pedons could be related to an increase in clay content with soil depth.

The consistence of soils was slightly hard (dry), friable (moist) and slightly sticky and slightly plastic (we) in the surface horizons of Pedon 1 and Pedon 2. The remaining Pedons surface horizons had hard (dry), firm (moist) and sticky and plastic (wet) consistence, considering the subsurface horizons of the Pedons, the hardness, firmness, sickness and plasticity were increased. (Table 2, Appendix 1 - 4). The reason for such change could be the incensement of clay contents down the profiles. Besides, the presence of sticky and plastic characteristics further suggests the occurrence of 2:1 type clay minerals in the studied soils, as mentioned by (FAO, 2006a).

4.2.4. Horizon boundary

The surface horizons and the subsurface horizons of Pedon 3 had diffused distinctness with smooth topography, whereas Pedon 1, 2 and 4 which showed a clear distinctness and smooth topography (Table 2, Appendix 1 - 4). The existing differences in boundary characteristics between topsoil and subsoil horizons could reflect the presence of distinct morphological features with profile depth.

Table 2 Selected morphological of the soil profile of MMWs

	Horizon	Depth (cm)	Color		Structure			Consistence			Texture(feel method)	HB
			Dry	Moist	Grade	Size	Type	Dry	moist	wet		
					Pedon 1 Upper Slope							
Pedon 1	AP	0-26	7.5YR 4/4	7.5YR3/4	WE	VM	GR	SHA	FR	SST, SPL	SI	CS
	B	27-82	7.5YR 4/3	7.5YR 3/3	WE	FM	AB	SH	FR	SST, SPL	L	CS
	Bt1	83-130	2.5YR 5/6	2.5YR 4/6	ST	MC	AB	VHA	VFI	VST, VPL	C	CS
	Bt2	130-200+	2.5YR 5/8	2.5YR 4/6	ST	MC	AB	VHA	VFI	VST,VPL	C	-
					Pedon 2 Middle Slope							
Pedon 2	AP	0-30	7.5YR 5/3	7.5YR 4/4	WE	VM	GR	SHA	FI	ST, PL	L	CS
	Bt1	31-60	2.5YR 3/3	2.5YR 3/2	MO	ME	GR	HA	FI	SST, SPL	CL	CS
	Bt2	61-100	2.5YR 4/4	2.5YR 3/4	ST	MC	SB	VHA	VFI	VST, VPL	C	CS
	B	101-200+	2.5YR 5/6	2.5YR 4/6	ST	MC	SB	VHA	VFI	VST, VPL	C	-
					Pedon 3 Middle Slope							
Pedon 3	A	0-40	2.5YR 4/3	2.5YR 3/3	MO	FM	GR	HA	FI	ST, PL	CL	DS
	Bt	41-94	2.5YR 4/6	2.5YR 3/6	ST	MC	SB	VHA	VFI	VST, VPL	C	DS
	B	95-140	2.5YR 4/6	2.5YR 3/6	ST	MC	SB	VHA	VFI	VST, VPL	C	DS
	Bw	141-200+	2.5YR 5/8	2.5YR 4/6	ST	MC	SB	VHA	VFI	VST, VPL	C	-
					Pedon 4 Lower Slope							
Pedon 4	AP	0-17	7.5YR3/1	7.5YR2/1	MO	VFM	GR	HA	FI	ST, PL	CL	CS
	B1	18-70	10YR 3/1	10YR 2/1	MO	FM	AB	HA	FI	ST,PL	CL	CS
	B2	71-93	7.5YR 4/2	7.5YR 4/1	ST	FM	GR	HA	FI	ST,PL	CL	CS
	B3	94-105	7.5YR 7/1	7.5YR 7/2	ST	MC	SB	EHA	VFI	VST,VPL	C	CS
	B4	106-200+	7.5YR 5/2	7.5YR 5/1	MO	FM	SB	HA	FI	ST,PL	CL	-

WE=Weak; MO=Moderate; MC=Medium and Coarser, FM=Fine and Medium, VFI=Very Fine; FI=Fine; ME=Medium, ST=Strong, B=Sub-angular Blocky. AB=Angular Blocky, GR=Granular, SHA= Slightly Hard; HA=Hard; VHA=Very Hard; FR=Friable; FI=Firm; VST=Very Sticky, ST=Sticky; SST= Slightly Sticky; VST=Very Sticky, NPL=None Plastic, PL=Plastic; SPL=Slightly Plastic. C=Clay, CL=Clay Loam, Si= Silt, L=Loam, HB=Horizon Boundary: DS=Diffused Smooth, CS=Clear and Smooth;

4.3. Physical Properties of the Soils

4.3.1. Particle size distribution

The clay content of surface horizons ranged from 19% in the upper slope to 36% in the lower slope position. The difference could be erosion in the upper slope and deposition in the lower slope. The clay content showed increasing trend down the profiles (Table 3). The possible reason could be clay illuvation and Insitu weathering. On the other hand, the sand and silt fractions showed an inconsistent trend with depth. The textural class of the surface horizons was clay loam for the lower and middle slope soils, while it was silt for the upper slope soil. In the subsurface horizons, soil texture was found to be clay to clay loam. As described by (Buol *et al.*, 2003), variations in textural class in the surface layer soils could be due to is an inherent characteristic of the soil. The clay content in the surface soil was 36% on the lower slope, 24% and 34% on the middle slope, and 19% on the upper slope, Pedons.

According to Hazelton and Murphy, (2016), the percentage of soil mineral particles (clay, sand, and silt) were categorized into very high (>50%), high (>40 %), moderate (25-40%), low (10-25%0 and very low (<10) for these the above three of soil particles. Across the profiles, the highest (61%) and the lowest (19%) clay contents were recorded in the subsoil horizons of Pedon 2 and surface horizon of Pedon 1, respectively. The highest sand content (44%) was obtained at A, horizons of Pedon 3 in the middle slope, while the very highest silt content (52%) was recorded at AP horizon of the Pedon 1 in the upper slope.

4.3.2 Silt to clay ratio

The silt to clay ratio of the surface and subsurface soils of the Pedons were in the range of 0.31 to 2.73 in Pedon 1 and 0.47 to 1.83 in Pedon (Pedon 2, 3, and 4) (Table 3). There was no clear trend of increase or decrease of silt to clay ratio with the Pedon horizon. According to (Ahukaemere *et al.*, 2017) soils with silt/clay ratio < 0.15 are considered to be highly weathered soils. (Van Womblike, 1962) used the silt/clay ratio as an index to estimate the degree of weathering and postulated that the higher the ratio, the lower the degree of weathering. Accordingly, higher silt/clay ratios from (0.3 to 2.73) in the subsoil layers, along with the resistant very thin composition of parent material (weather able materials), reflect that the soils are at the young to moderate stage of development. In line with this finding, (Shimelis, 2006) also reported a similar silt/clay ratio relationship with depth for gleyic Cambisols of the Megecha catchment of Tenocha the southwest Shewa area, Ethiopia. Results of the correlation analysis (Table 6) indicated clay fraction was negatively and significantly (r = -0.75***) correlated with sand and (r = -0.60*) silt fraction.

4.3.3. Bulk density, particle density, and total porosity

The bulk density of the surface horizons of the Pedons ranged from 1.06 g/cm^{-3}in the meddle slope to 1.60g/cm^{-3} in the lower slope (Table 3). There were increasing trend in the values of bulk density of the Pedons depth wise. The highest (1.85 g/cm^{-3}) bulk density value was obtained in the subsoil horizon of the lower slope area. The bulk density of Pedon 1 just fell above the lower limit of the optimum bulk density range (1.10 g/cm^{-3}). All the underling horizons bulk density varies from 1.35 to 1.53g/cm^{-3}, being the optimum bulk densities as rated by (Hazelton and Murphy, 2016).

The bulk density of the lower slope on all horizons of Pedons 4 was above the upper limits of the optimum bulk density range. This could be attributed to soil compaction as a result of continuous and intensive cultivation. The research findings of (McNabb *et al*., 2001) and Dec *et al*., 2008) showed that bulk density was increased by mechanical stresses through tillage-induced soil compaction. This is supported by several research reports (Babalola *et al*., 2000; Isirimah *et al*., 2003; Sintayehu, 2006; Uzoho *et al.,* 2007) indicating that poor vegetative cover results in soil compaction due to raindrop impact.

The relative increment in bulk density values of layers just below the topsoil could be attributed to an overburden effect on subsoil horizons as well as declining OM content with depth. The total porosity of the soils in the upper two horizons of Pedons varied from 58.5% in the surface horizon of Pedon 1 to 47.1% in the subsoil horizon (Table 3). The studied soils, except for Pedon 4, had surface horizons that fell above the ideal porosity value of soils (> 50%) for healthy root growth as proposed by (Lawrence, 1977).

Generally, a lower slope Pedon 4 was associated with the greater traffic-induced compaction associated with continuous cultivation practices might have contributed to the lower porosity of soils. Any factor that affects bulk density can also affect the pore space of soils, as both are inversely related to each other. In line with this study, (Alaoui and Goetz, 2007) and (Dec *et al*., 2008) reported that vehicular tillage-induced soil compaction could have reduced the volume of macro pores and pore continuity, thereby reducing the total porosity in the plow layer. An increasing trend in bulk density for lower slope areas would have created an unfavorable soil environment by limiting root growth and air circulation, which in turn have implications for agricultural productivity. The correlation matrix of soil properties has indicated that the bulk density was negatively associated with OC (r = - 0.96**).

Table 3 Particle size distribution, SI: C ratio, and Pb of the soils profiles at MMWs

Horizon	Depth (cm)	Particle size distribution			Textural class	SI:C ratio	Pb* g/cm^3	TP* (%)	MC
		Sand	Silt	Clay					
Pedon 1 Upper Slope									
AP	0-26	29	52	19	Si	2.73	1.10	58.5	0.284
B	27-82	36	45	19	L	2.34	1.15	56.6	0.281
Bt1	83-130	22	28	50	C	0.56	1.35	49.0	0.209
Bt2	131-200+	24	18	58	C	0.31	1.40	47.1	0.229
Pedon 2 Middle Slope									
AP	0-30	32	44	24	L	1.83	1.06	60.0	0.168
Bt1	31-60	37	25	38	CL	0.65	1.44	45.6	0.203
Bt2	61-100	20	29	61	C	0.47	1.45	45.3	0.277
B	101-200+	14	32	54	C	0.59	1.53	42.2	0.304
Pedon 3 Middle Slope									
A	0-40	44	22	34	CL	0.64	1.15	56.6	0.250
Bt	41-94	22	28	50	C	0.56	1.65	47.7	0.216
B	95-140	24	32	44	C	0.72	1.44	45.6	0.177
Bw	141-200+	12	28	60	C	0.47	1.50	43.4	0.187
Pedon 4 Lower Slope									
AP	0-17	34	30	36	C L	0.86	1.60	39.6	0.319
B1	18-70	36	27	37	CL	0.73	1.74	34.3	0.219
B2	71-93	39	26	35	CL	0.74	1.85	30.1	0.186
B3	94-105	30	26	44	C	0.59	1.52	42.6	0.142
B4	106-200+	30	28	42	CL	0.66	1.64	38.1	0.310

C =Clay, CL=Clay Loam, ρb = Bulk density, Si: C= Silt to Clay ratio, TP = Total porosity, MC= Moisture Content

4.4. Chemical Properties of the Soils

4.4.1. Soil reaction (pH)

The pH of surface soils varied from 5.3 in Pedon 2 to 5.7 in Pedon 3, which categorized under moderately acidic (Table 5).Generally, there were increasing trends in pH values with depth whereas increasing pH with decreasing slope. The pH of the Pedons of the study area ranged from moderately acidic to slightly acidic (Hazelton Murphy, 2016). In current study soil pH of <5.5 most probably indicates the presence of Al^{3+} and the removal of exchangeable cations. These results are in agreement with those of several other authors (Gebeyehu, 2006; Papiernik *et al*., 2007; Habtamu *et al*., 2009; and Fantaw and Abdu, 2011),who reported a substantial reduction of pH in surface soils subject to long-term cultivation compared to the uncultivated site.

4.4.2. Soil organic carbon, total nitrogen, and carbon to nitrogen ratio

The SOC content of the surface and subsurface soil horizons were in the low (0.58 to 2.99%) range as rated by (Hazelton and Murphy, 2016). The soil SOC content was in a decreasing trend as the soil depth increases for all Pedons (Table 4).The amount of soil organic carbon (SOC) was relatively higher in the surface horizons but became negligible in the subsoil horizons of the Pedons and with increasing depth. Considering the surface soils, the highest (2.99%) SOC content was recorded in the upper slope Pedon 1, whereas the lowest (2.29%) was recorded in the lower slope Pedon 4 (Table 4). In the subsoil horizon, the value of SOC varied from 0.58% to 2.35% throughout Pedon. An apparent change in OC content was observed in the surface soils of Pedons. According to (Hazelton and Murphy, 2016), the content of SOC rated from low to medium range. Soil organic carbon have the strong and positive correlation with total porosity (r = 0.65**) and CEC (r= 0.82***) and negatively correlated with bulk density (r=-0.65**) and pH(r= -0.81***) in the soil (Table 6). In fact, the areas experienced long-term cultivation practices that accelerated the rapid turnover rates of organic materials. Thus, intensive cultivation and mismanagement of crop residue are responsible factors for a drastic reduction of soil SOC content in the cultivated field. Many research reports elsewhere supported this finding (Gregorich *et al.*, 1997; Wakened and

Heluf, 2004; Ombina, 2008; David *et al*., 2009; Fantaw and Abdu, 2011). But Pedon 1 and Pedon 3 were grazing land.

The total N content of soils was directly associated with the SOC content along the profile depth. The highest (0.27%) value of total N was recorded in the surface horizon of Pedon 1, where the highest (2.99%) SOC value was also recorded (Table 4). The surface soils of the study site were varying from (0.21 to 0.27) ranging in medium to very high. In the subsoil horizons of all Pedons, the total N content decreased, ranging between 0.02% and 0.21%. Considering the ratings given in (Tekalign, 1991), Hazelton and Murphy, 2016) the current total N status of the soils of the study area can be rated as very low to very high. The very low level of total N, especially in the subsurface horizons of Pedon 4, might be attributed to its low level of SOC content. Moreover, the strong and positive correlation (r = 0.96***) between total N and SOC indicates that soil SOC is the main source of nitrogen in the soil (Table 4). Therefore, deficient soil N content tends to be a limiting factor for crop production. The carbon to nitrogen (C: N) ratio of soils varied from a narrow (6.43) to (29) and showed an irregular variation with the depth of Pedon 2, 3, and 4 (Table 4). As described by (Havlin *et al.* 1999), soil C: N ratios should range from 10:1 to 12:1 for optimum mineralization and improved nitrogen availability to plants.

4.4.3. Available phosphorus

The Olsen available phosphorous content of the soil in all Pedons irregularly increases with depth. The available P of the site varies from the range of 0.28 to 1.20mg kg^{-1}. The least and the highest was recorded in Pedon 2 (Table 4). The low available P indicated the results could be related to the acidic properties of the soils and the type of clay mineralogy of the soils. Through the hydrolysis of aluminum, the low soil pH improves the solubility of aluminum oxides and hydroxides. The Al^{+3}P is attached to Al and is therefore less available for absorption by plants when (aq) enters the soil solution and interacts with solution P to generate insoluble Al-phosphate (AlPO4. (H2O)(s). Olsen available P values for soil samples taken from all Pedons were in the inadequate range (10 mg kg^{-1} soil), according to (FAO's standard ratting, 2006b). The fixation of P by Al^{+3} in the low soil pH range was the most likely cause of the low value of soil accessible P. Acidic tropical soils are known to have issues with phosphorus fixation. P insufficiency is one of the bottlenecks as a result (Berhanu and Eyasu, 2021). According to (Melese, *et al.*, 2015), (Daniel, and Tefera, 2016), and (Mesfin *et al*., 2017), Ethiopian soils are deficient in phosphorus. These findings are equivalent to those of these studies. Due to the declining soil organic matter (OM) level, low external P source inputs, and clay mineral fixation, which were found to the available P exhibits a declining trend across surface soils whereas increase with profile depth at subsoil horizons,.

Table 4 pH, Organic carbon, total N and available P contents of the soils of MMWs

Horizon	Depth cm	pH 1:2.5H_2O	OC %	TN %	C: N Ratio	Available P $mgKg^{-1}$
			Pedon 1 Upper Slope			
AP	0-26	5.4	2.99	0.27	11.07	0.36
B	27-82	5.6	1.85	0.16	11.56	0.82
Bt1	83-130	5.8	0.82	0.07	11.71	0.50
Bt2	131-200+	5.9	0.75	0.06	12.50	0.36
			Pedon 2 Middle Slope			
AP	0-30	5.3	2.58	0.25	10.32	0.28
Bt1	31-60	5.7	2.35	0.21	6.43	0.40
Bt2	61-100	5.9	1.67	0.15	11.13	0.46
B	101-200+	5.9	0.86	0.06	14.33	1.20
			Pedon 3 Middle Slope			
A	0-40	5.7	2.95	0.24	12.30	0.50
Bt	41-94	5.8	1.46	0.20	7.30	0.48
B	95-140	6.0	0.99	0.08	12.37	0.46
Bt	141-200+	5.9	0.68	0.06	11.33	0.88
			Pedon 4 Lower Slope			
AP	0-17	5.4	2.29	0.21	10.90	0.46
B1	18-70	6.2	1.09	0.09	12.11	1.20
B2	71-93	6.1	0.68	0.06	11.33	0.36
B3	94-105	6.2	0.63	0.03	21.00	0.50
B4	106-200+	6.3	0.58	0.02	29.00	0.86

PH, =Soil reaction, OC= Organic Carbon, TN= Total Nitrogen and P=Available Phosphors, C:N= Carbon to Nitrogen ratio

4.4.4. Exchangeable bases

The analytical values of exchangeable bases (Na, K, Ca, and Mg) indicated that exchangeable Mg followed by Ca was the dominant cations in the exchange complex of soils at the study site (Table 5). Exchangeable Ca and Mg together accounted for more than 93% of the exchangeable bases of the total cations at the exchange sites of soils, whereas the monovalent (K and Na) occupied a small proportion (6-7%) of the total exchangeable bases in the exchange site. The abundance of exchangeable bases followed the decreasing order: Mg > Ca > K > Na in most of the horizons except the surface horizon of Pedon 2, in which exchangeable Ca dominates the other cations. Mg was trace or nil in the surface horizons of Pedon 2 and the subsurface horizons of Pedon 4.

A/ Exchangeable Ca and Mg

The amount of exchangeable Ca showed random pattern of distribution along the slope; it followed an increasing trend with the depth of the studied Pedons. Throughout the horizons, the highest values of exchangeable Ca (12.50 cmolc kg^{-1}) in the subsurface of Pedon 1 measured, whereas (10.0 cmolc kg^{-1}) subsurface horizons were measured in the lower slope Pedon 4 (Table 5). On the other hand, the magnitude of exchangeable Ca showed an increasing trend along the slope direction (table 5). Compared between the Pedons, the highest (9.00 cmolc kg^{-1}) and lowest (1.00 cmolc kg^{-1}) values of exchangeable Mg were recorded in the surface and subsurface horizon layers of Pedon 4 and Pedon 2, respectively. Similar to exchangeable Ca, the amount of exchangeable Mg increased invariably with increasing depth, while it was inconsistent with the Pedons' depth. The Ca: Mg ratio of soils fell from (0.33- 7.50) below the optimum as proposed by (Landon, 1991) for most crops except in Pedon 2. According to the same author’s suggestion, lowering the ratio level below 3:1 results was in the unavailability of Ca and P. Hence, a lower Ca: Mg ratio indicates the probable limitation of Ca uptake due to an excess amount of exchangeable Mg in the soil. The domination of exchangeable Mg in the exchange complex would result from an imbalance of cations, which would probably limit plant growth. Furthermore, the abundance of this cation in the soils could be related to the existence of Mg-rich parent materials from which the soil was formed.

B/ Exchangeable K

Exchangeable K occupied 2.3-6.4% of the total exchangeable bases site of the soils. Across the horizons of all Pedons, the amount of exchangeable K varied from 0.02 cmolc kg^{-1} to 1.32cmolc kg^{-1}. In considering the surface horizon, the highest value 1.25 cmolc kg^{-1} was recorded (Table 4). In the mineral horizons of all Pedons, the exchangeable K content increased with increasing profile depth. According to (FAO, 2006b) nutrient ratings (Appendix), the exchangeable K values in all horizons of the all studied Pedons fall within medium to very high (0.3->1.2), except B4 horizon of pedon P-4which ranges in low (0.02) range. Therefore, K content is adequate for the production of most crops and K deficiency would not be expected in the studied soils. In general, the result confirms the common belief that Ethiopian soils contain sufficient K for crop production but contradicts that of (Shimelis, 2006), who reported K deficiency in Cambisols of the southwest Shewa area. Higher content of exchangeable K in the soil suggests the existence of potassium-bearing minerals such as feldspars and micas in the studied site (Havlin *et al*., 1999).

C/ Exchangeable Na

Exchangeable Na showed systematic patterns of distribution among the Pedons and within horizons decrease with increasing depth (Table 5). The exchangeable Na content of the soils ranged from 0.11 to 0.28 cmolc kg-1 on the surface and from 0.18 to 0.44 cmolc kg-1 in the subsoil horizons. Considering the ratings of (FAO, 2006b), the amount of exchangeable Na can be categorized as low to medium classes. However, the presence of exchangeable Na in appreciable quantities, particularly in proportion to the exchangeable K, may have an adverse effect on nutrient balance in the soil. In general, quantities of exchangeable basic cations were relatively lower in the surface horizons of all Pedons and showed an increasing trend with profile depth. The possible reason for increasing the concentration of the exchangeable bases with soil depth could be the low degree of weathering which contributed to the slow release of nutrients in the deep subsoil layers. Low contents of exchangeable bases in the upper horizons of all Pedons may also reveal high removal (leaching) of cations and that the soils seem to be at an older stage of formation.

4.4.5. Cations exchange capacity and base saturation

A/ Cations exchange capacity of soil

The CEC of soils measured at pH 7.0 qualifies for the high CEC class (25 - 40 cmolc kg^{-1}) for surface horizons all the Pedons as per the ratings set by (Hazelton and Murphy, 2007). Throughout the horizons of all Pedons, the highest CEC value (47.0 cmolc kg^{-1}) was recorded in AP horizon of Pedon 1, followed by 36.0 cmolc kg^{-1} and 34.0 cmolc kg^{-1} in the surface soil horizons of Pedon 3 and Pedon 2 respectively were rated as high (Table 5). In the subsurface soils ranged from 5 $cmolckg^{-1}$ to 30 $cmolckg^{-1}$ were recorded in the study site. The CEC of soil values was profoundly affected by soil depth that decreased almost consistently from 47.0 and 5.0 cmolc kg^{-1} soils in the surface horizons from 36.0 to 5.0cmol kg-1 and in subsoil horizons of Pedons in the middle Pedon 2 and lower slopes Pedon 4, respectively. Thus, the drop-down in CEC values in the subsoil layers could be attributed to the decline of OC contents with depth and may be unanalyzed acidic cations(Al and Mn) . Moreover, the CEC of soil followed the trend exhibited by the exchangeable basic cations, reflecting that basic cations are the main ion contributors in the exchange complexes or unreactive form.

Considering the surface soil layers, the highest CEC (47.0 $cmolkg^{-1}$) of soil was recorded in the upper slope Pedon 1. According to (Hazelton and Murphy, 2016) the CEC rated from medium to very high (27-47$cmolkg^{-1}$) in the studied site surface soils. In favor of this study, (Alemayehu, 2007) and (Fentaw and Yimer, 2011) have reported that the depletion of OM as a result of intensive cultivation could have been attributed to the lower CEC of the soils. The correlation matrix of soil properties (Table 6) has indicated that the CEC of soil was negatively associated with available P (r = -0.37) and Pb (r = -0.59*), while it was positively associated with OC (r = 0.82***), total N (r = 0.84***), TP (r = 0.60*) pH (r = 0.77**), and exchangeable Mg(r= 0.05).

B/ Base saturation

Across the soil profiles, the highest PBS values (87.19%) was obtained in the B3-horizon of the lower slope Pedon 4, while the lower PBS were 19.19 in the upper slope Pedon 1 (Table

5). Soils with base saturation greater than 60% rated as fertile soils, as suggested by (Landon, 1991). Pedon 4 had high base saturation percentages which indicate the fertility status of the soil. In addition, the base saturation of soils can also indicate the degree of leaching of exchangeable bases and their replacement by exchangeable acidity (FAO, 2006b). Following base saturation as a criterion of leaching status (Appendix 5) by (Hazelton and Murphy, 2007), the studied Pedons were highly leached soils except for Pedon 4, which is weakly leached (60–87%) throughout their horizons. In fact, the study area is characterized by a medium amount of annual rainfall.

Table 5 Exchangeable bases, CEC, and base saturation of the soil Profiles of MMWs

Horizon	Depth Cm	Exchangeable Base (cmolc, Kg^{-1})					Ca/Mg	CEC ($cmolcKg^{-1}$)	PBS (%)
		Na	K	Ca	Mg	TEB (%)			
				Pedon 1 Upper Slope					
AP	0-26	0.26	0.36	3.50	4.90	9.02	0.71	47	19.19
B	27-82	0.35	0.40	5.00	7.50	13.25	0.67	32	41.40
Bt1	83-130	0.37	0.41	12.50	2.50	15.78	5.00	26	60.70
Bt2	130-200+	0.39	0.45	8.50	4.50	13.84	1.89	23	60.17
				Pedon 2 Middle Slope					
AP	0-30	0.13	0.28	5.00	5.00	10.41	1	34	30.61
Bt1	31-60	0.16	0.35	7.20	Ni	7.71	Ni	31	24.87
Bt2	61-100	0.18	0.41	7.50	1.00	9.09	7.50	26	35.00
B	101-200+	0.19	0.50	3.00	7.00	10.69	4.28	25	42.76
				Pedon 3 Middle Slope					
A	0-40	0.11	0.48	2.50	7.50	10.59	0.33	36	29.41
Bt	41-94	0.15	0.50	5.00	6.00	11.65	0.83	30	38.83
B	95-140	0.19	0.64	5.50	5.500	11.83	1	27	48.81
Bw	141-200+	0.20	0.60	4.50	4.00	9.3	1.12	19	48.95
				Pedon 4 Lower Slope					
AP	0-17	0.28	1.25	10.00	9.00	20.53	1.11	31	66.22
B1	18-70	0.35	1.30	12.10	7.00	20.75	1.73	27	76.85
B2	71-93	0.41	1.18	10.50	7.50	19.59	1.40	24	81.62
B3	94-105	0.44	1.32	7.55	9.00	18.31	0.50	21	87.19
B4	105-200+	0.31	0.02	2.50	Ni	2.83	Ni	5	56.60

NI=Not identified, TEB=Total Exchangeable Bases; Cation Exchange Capacity, PBS=Percentage Base Saturation

Table 6 Simple linear correlation coefficient between selected physiochemical properties

	Sand	Silt	Clay	Pb	TP	PH	OC	T N	P	Na	K	Ca	Mg	CEC	PBS	MC
Sand	1.00															
Silt	-0.03ns	1.00														
Clay	-0.75**	-0.60**	1.00													
Pb	0.05ns	-0.56	0.31	1.00												
TP	-0.05	-0.57*	0.31ns	0.99***	1.00											
PH	0.004	0.58*	-0.55*	0.69**	0.82***	1.00										
OC	0.35	0.47	-0.55*	-0.65**	0.65**	-0.81***	1.00									
TN	0.26	0.48	0.47	-0.58*	-0.85***	0.84***	0.96***	1.00								
P	-0.08	-0.04	0.06	0.32	0.43	0.43	-0.39	-0.44	1.00							
Na	0.19	-0.14	-0.09	0.34	0.44	0.43	-0.54*	-0.59	0.08	1.00						
K	0.24	-0.27	-0.03	0.54	0.27	0.26	-0.23	-0.22	0.09	0.47	1.00					
Ca	0.14	-0.33	-0.11	0.42	0.17	0.17	-0.28	-0.24	-0.11	0.57*	0.60*	1.00				
Mg	0.59*	-0.03	-0.49	0.23	0.12	0.05	0.07	-0.01	0.19	0.25	0.63*	-0.05	1.00			
CEC	-0.08	0.54*	-0.40	-0.59*	-0.57	0.77**	0.82***	0.84***	-0.37	-0.33	0.00	-0.05	0.6	1.00		
PBS	0.18	-0.46	0.12	0.68*	0.54*	0.62*	-0.70**	-0.71**	0.19	0.79***	0.75**	0.63**	0.40	-0.54*	1.00	
MC	0.14	0.21	-0.19	-0.05	-0.20	0.20	0.25	0.19	0.32	-0.09	-0.29	-0.27	-0.03	0.04	-0.70	1.00

4.5. Classification of soils of Megecha micro watershed

The morphological characteristics investigated in the field and physicochemical results obtained from laboratory analyses were used for the classification of the soils of the Megecha micro watershed. The studied soils were classified at the subgroup or subunit level according to WRB (IUSS Working Group, 2015) legend. Accordingly, the presence or absence of specific diagnostic horizons, properties, and qualifiers were used to distinguish soil units as given in the employed classification system.

Pedon 1, 2 and 3 had Argic Munsell colour hue redder than subsurface diagnostic horizon with high-activity clays (high CEC) and low base saturation (< 50%). Therefore, the three Pedons classified under Alisols. Pedon 1 and Pedon 2 had between 25 and 150 cm of the soil surface a layer, ≥ 30 cm thick, that had, in ≥ 90% of its exposed area, a.5YR and a Chroma of > 4, which qualified chromic principal qualifier. The Pedon 1 had low (< 50%) base saturation in the upper two horizons, which qualified Epidystric supplementary qualifier. And hence Pedon 1 classified as Chromic Alisols (Epidystric). Pedon 2 had low base (< 50%) saturation throughout the horizons, which qualified Dystric supplementary qualifiers. As a result, Pedon 2 classified as Chromic Alisols (Dystric). Pedon 3, which qualified Haplic principal qualifier because its properties were not, qualifies the WRB standards and Dystric supplementary qualifier classified as Haplic Alisols (Dystric). Pedon 4 had Vertic horizons starting from less than 100 cm from the soil surface and had greater than 30% clay between the soil surface and the Vertic horizons throughout. Cracks were the common feature of the pedon. Therefore, the Pedon classified as Vertisols. Pedon 4 had in the upper 30 cm of the soil a Munsell colour value of ≤ 3 and a Chroma of ≤ 2(moist), which qualified Pellic principal qualifiers. The base saturation of Pedon 4 was greater than 50% throughout between 20 and 100 cm from the mineral soil surface and greater than 80% in some layer between 20 and 100 cm from the mineral soil surface, which qualified Hypereutric. As a result, Pedon 4 classified as Pellic Vertisols (Hypereutric).

Table 7 Diagnostic horizons, Diagnostic properties, and soil of MMWs based on WRB (FAO, 2015)

Pedon	Surface Diagnostic properties	Subsurface Diagnostic horizon	WRB(IUSS Working group, 2015)	Area(Ha)
P-1	-	Argic	Chromic Alisols (Epidystric)	333.3
P-2	-	Argic	Chromic Alisols (Dystric)	190.4
P-3	-	Argic	Haplic Alisols (Dystric)	198.2
P-4	-	Vertic	Pellic Vertisols (Hypereutric)	4.5

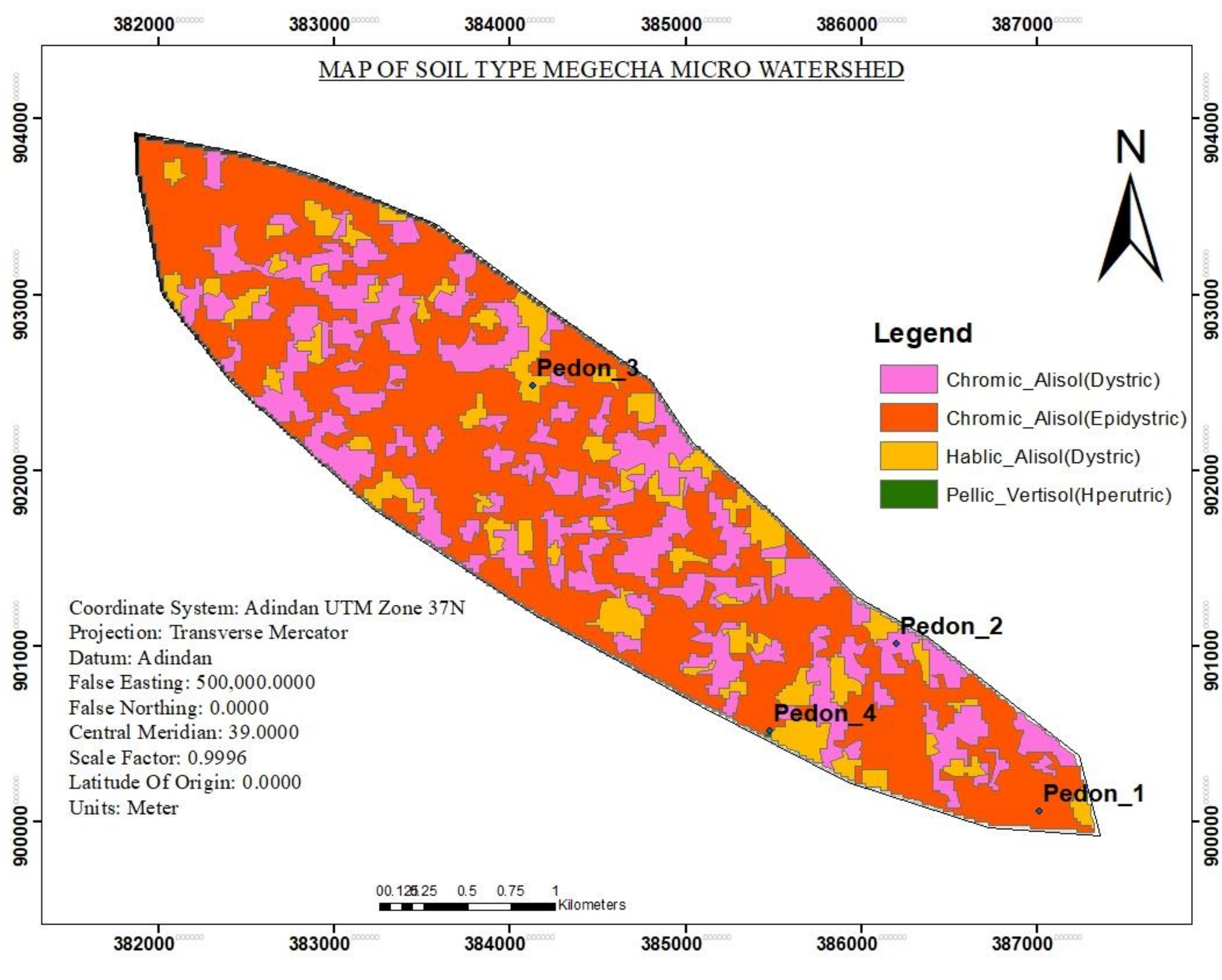

Figure 4 Soil Type Map and Area of the Megecha micro watersheds

5. SUMMARY AND CONCLUSION

5.1. Summaries and conclusion

Successful agriculture requires the sustainable use of soil because the soil is an important nonrenewable land resource, determining the agricultural potential of a given area. Hence, the study and understanding of soil properties are crucial for the development of soil management plans for the efficient utilization of land resources. Therefore, a field survey was carried out to study the morphological and physicochemical properties of the soils of the Megecha micro watershed area. Accordingly, all Pedons were characterized by deep soil and thick horizons except the surface layer AP horizon of Pedon 4.

The soil color (dry) ranged from dark reddish brown (5YR 3/4) in Pedon 1 to very dark gray (10YR 3/1) in Pedon 4 high Munsell values and Chroma, as well as the absence of mottling in the subsoil Pedons, revealed that the soils were in well-drained condition. Generally, the soil structure was sub-angular and blocky, with varying sizes and grades. Similarly, soil consistency (dry) changed from slightly hard to very hard in the subsoil horizon of Pedons. The consistency (wet) also showed various grades of slightly stickiness and slightly plasticity to very sticky and very plasticity along the profile depth. Variations in the wet consistency of soils along the profile depth could be attributed to a change in the particle size distribution of the soil.

Particle size, bulk density, and porosity were highly affected along the slope, particularly in the surface horizons. The textural class of the soils in the surface horizons was silty in P-1, while all other Pedons were clay and clay loam, changing from clay loam to clay with increasing depth. The surface horizons of P-4 had higher bulk density and lower porosity values as compared to those of other Pedons. These might cause unfavorable soil conditions by limiting root growth and air circulation, which in turn have negative implications for agricultural productivity.

Soil chemical properties (total N, OC, CEC, and Exchangeable Base) were significantly influenced by variations in land use and management, particularly in surface horizons.

Higher contents of OC, as well as total N, were measured in the uncultivated soils than in the cultivated soils. This is an indication of unsustainable management of soil organic matter (OM) at the study site, where intensive tillage practices coupled with frequent farming with less management are the major problems.

Exchangeable basic cations (Ca, Mg, K, and Na) were generally in higher quantities in the lower soil horizons of all the Pedons and showed increasing trend with profile depth. The possible reasons for the increment of exchangeable bases down the profile could be due to the prevalence of strongly to gently sloping topography at the soil sampling sites, a low leaching conditions and low erosion that might have allowed basic cations to settle and concentrate in the lower soil profile. Similarly, the CEC of soil followed the magnitude of exchangeable basic cations, reflecting that basic cations are the main ion contributors in the exchange complexes. The highest CEC of soil in the AP horizon of P-1 which may be due to the relatively higher OC contents of the soils, whereas the substantial reduction of CEC values with the depth of P-4 could be attributed to lower contents with depth. Available P showed an increasing trend with an increasing soil depth of Pedons, ranging from 0.28 to 1.2 mg kg^{-1}.

Finally, the results obtained from the field as well as laboratory analyses were used to classify the soils of the site according to the WRB legend. The Pedon 1 had low (< 50%) base saturation in the upper two horizons, which qualified Epidystric supplementary qualifier hence Pedon 1 was classified as Chromic Alisols (Epidystric). Pedon 2 had low base (< 50%) saturation throughout the horizons, which qualified Dystric supplementary qualifiers. As a result, Pedon 2 classified as Chromic Alisols (Dystric). Pedon 3, which qualified Hablic principal qualifier and Dystric supplementary qualifier classified as Hablic Alisols (Dystric). Pedon 4 had Vertic horizons starting from less than 100 cm from the soil surface and had greater than 30% clay between the soil surface and the Vitric horizons throughout. As a result Pedon 4 was classified as Pellic Vertisols (Hypereutric).

5.2. Recommendation

In general, the information generated from the present study on soil characteristics would be helpful for the proper implementation of agricultural activities and a reliable interpretation of the overall agricultural research findings in the area. Results of the study, however, provide only baseline information for future research efforts on soil resources of the studied site, and it needs more detailed and frequent investigation on the constraints related to soil fertility and its management to derive the appropriate recommendations for improving the soil productivity of the studied site and the surroundings. Therefore, further detailed studies that include plant response should be conducted to examine fertility status at specific times to give a sound conclusion on the sustainable use of the land.

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7. APPENDICES

Appendix table 1 Description of soil site and soil profile opened at upper slope position

Pedon no_1	P-1
Date of description	07/08/2014
Author	Alemu Wegu
Location	Geche of Ezha Woreda Gurage Zone Ethiopia.
Coordinates	38°75’26.4” E, 8°99’21.7”N
Elevation	2225masl
Surrounding landform	Medium Steep
Physiographic position	Upper slope
Land use/cover	Cutting grass and grazing
Slope gradient and aspect	15-30% south to north
Moisture condition	Moist
Drainage condition	Well drained
Parent material	Unknown
Groundwater depth	None/ Not observed
Rocky outcrop	None
Erosion	Sheet erosion
Surface stoniness	None
Soil type: WRB	Chromic Alisols (Epidystric)

Horizon	Depth (cm)	Profile description
AP	0-26	clear and smooth boundary, Brown (7.5YR 4/4) dry, dark brown (7.5YR 3/4) moist, silt loam, none mottling, weak, granular, very fine and medium size structure, slightly hard (dry), friable (moist), slightly sticky, slightly plastic (wet), interstitials, very fine and common porosity, very fine and fine, common roots
B	27-82	clear and smooth boundary, Brown (7.5YR 4/3) dry, dark brown (7.5YR 3/3) moist, silt clay, none mottling, weak, blocky granular, fine and medium size structure, hard (dry), friable (moist), slightly sticky, slightly plastic (wet), interstitials, very fine and common porosity, very fine and few, few roots, termite & few bacterial activities
Bt1	83-130	clear and smooth boundary, red (2.5YR 5/6) dry, red (2.5YR 4/6) moist, clay, none mottling, strong, blocky granular, medium and coarse, size structure, very hard (dry), very firm (moist), very sticky, very plastic (wet), interstitials, very fine and common porosity, none roots, & none bacterial activity
Bt2	131-200+	clear and smooth boundary, red (2.5YR 5/6) dry, red (2.5YR 4/6) moist, clay, none mottling, strong, blocky granular, medium and coarse size structure, very hard (dry), very firm (moist), very sticky, very plastic (wet), interstitials, very fine and common porosity, none roots, & none bacterial activity

Appendix table 2 Description of soil site and soil profile opened at middle slope position

Pedon no_2	P-2
Date of description	10/09/2014
Author	Alemu Wegu
Location	Sham of Ezha Woreda Gurage Zone Ethiopia.
Coordinates	38°58°48.0” E, 9°00’49.9”N
Elevation	2178masl
Surrounding landform	Strongly Sloping
Physiographic position	Middle slope
Land use/cover	Cropping
Slope gradient and aspect	8-15% south to north
Moisture condition	Moist
Drainage condition	Well drained
Parent material	Unknown
Groundwater depth	None/ Not observed
Rocky outcrop	None
Erosion	Sheet erosion
Surface stoniness	None
Soil type: WRB	Chromic Alisols(Dystric)

Horizon	Depth (cm)	Profile description
AP	0-30	clear and smooth boundary, Brown (7.5YR 5/3) dry, brown (7.5YR 4/4) moist, silt, none mottling, weak, granular, very fine to medium size structure, slightly hard (dry), friable (moist), none sticky, none plastic (wet), interstitials, very fine and common porosity, very fine and fine, common roots, & termite and few bacterial activities
Bt1	31-60	clear and smooth boundary, dark reddish brown (2.5YR 3/3) dry, dark reddish (2.5YR 3/2) moist, silt, none mottling, moderate, granular, medium size structure, hard (dry), friable (moist), slightly sticky, slightly plastic (wet), interstitials, very fine and common porosity, very fine and few roots, none bacterial activity
Bt2	61-100	abrupt and smooth boundary, reddish brown (2.5YR 4/4) dry, dark reddish brown (2.5YR 3/4) moist, silt loam, none mottling, strong, blocky sub granular, medium to coarse size structure, very hard (dry), very friable (moist),very sticky, very plastic (wet), interstitials, very fine and common porosity, medium and very few roots, & termite and very few bacterial activities
B	101-200+	abrupt and smooth boundary, red (2.5YR 5/6) dry, red (2.5YR 4/6) moist, silt loam, none mottling, strong, blocky sub granular, medium to coarse size structure, slightly hard (dry), very friable (moist), very sticky, very plastic (wet), interstitials, very fine and common porosity, none roots, & none bacterial activity

Appendix table 3 Description of soil site and soil profile opened at middle slope position

Pedon no_3	P-3
Date of description	25/09/2014
Author	Alemu Wegu
Location	Dera of Ezha Woreda Gurage Zone Ethiopia.
Coordinates	38°37’88.8” E, 9°01’84.6”N
Elevation	2060 masl
Surrounding landform	Sloping
Physiographic position	Middle slope
Land use/cover	Grazing land and cropping
Slope gradient and aspect	3-8% south to north
Moisture condition	Moist
Drainage condition	Well drained
Parent material	Unknown
Groundwater depth	None/ Not observed
Rocky outcrop	None
Erosion	Sheet erosion
Surface stoniness	None
Soil type: WRB	Hablic Alisols

Horizon	Depth (cm)	Profile description
AP	0-40	Diffused and smooth boundary, Reddish brown (2.5YR 4/3) dry, dark reddish brown (2.5YR 3/3) moist, silt, none mottling, moderate, granular, fine and medium size structure, hard (dry), friable (moist), sticky, plastic (wet), interstitials, very fine and common porosity, medium and many roots, & termite and very few bacterial activities
Bt	41-94	Diffused and smooth boundary, red (2.5YR 4/6) dry, dark red (2.5YR 3/6) moist, silt, none mottling, strong, blocky sub granular, medium to coarse structure, very hard (dry), very friable (moist),very sticky, very plastic (wet), interstitials, very fine and common porosity, fine and common, termites and very few activities
B	95-140	Diffused and smooth boundary, reddish (2.5YR 4/6) dry, dark red (2.5YR 3/6) moist, silt, none mottling, strong, blocky sub granular, medium to coarse size structure, very hard (dry), very firm (moist),very sticky, very plastic (wet), interstitials, very fine and common porosity, very fine and few roots, & none termite activity
Bw	141-200+	Diffused and smooth boundary, red (2.5YR 5/8) dry, red (2.5YR 4/6) moist, silt loam, none mottling, strong, blocky sub granular, medium to coarse size structure, very hard (dry), very firm (moist), very sticky, very plastic (wet), interstitials, very fine and common porosity, very fine and very few roots, & none termites activity

Appendix table 4 Description of soil site and soil profile opened at lower slope position

Pedon no_4	P-4
Date of description	28/08/2014
Author	Alemu Wegu
Location	Yewahenye of Ezha Woreda Gurage Zone Ethiopia.
Coordinates	38̊37’21’’E, 9̊03’37.5’’N
Elevation	1997masl
Surrounding landform	Gentle slope
Physiographic position	Lower slope
Land use/cover	Cropping
Slope gradient and aspect	0-3% north to south
Moisture condition	Moist
Drainage condition	poor drained
Parent material	Unknown
Groundwater depth	None/ Not observed
Rocky outcrop	None
Erosion	Sheet erosion
Surface stoniness	None
Soil type: WRB	Pellic Vertisols

.

Horizon	Depth (cm)	Profile description
AP	0-17	clear and smooth boundary, very dark gray (7.5YR 3/1) dry, black(7.5YR 2.5/1) moist, silt clay loam, none mottling, moderate, granular, fine and medium size structure, hard (dry), firm (moist), sticky, plastic (wet), interstitials, very fine and common porosity, very fine and fine, common roots, & none bacterial activity
B1	18-70	clear and smooth boundary, very dark gray (10YR 3/1) dry, black(10YR 2/1) moist, heavy clay, none mottling, moderate, blocky granular, fine and medium size structure, hard (dry), firm (moist), sticky, plastic (wet), interstitials, fine and common porosity, fine and few roots, none bacterial activity
B2	71-93	clear and smooth boundary , brown (7.5YR 4/1) dry, dark brown(7.5YR 4/2) moist, sandy clay loam, none mottling, strong, sub granular, fine to medium size structure, hard (dry), firm (moist), sticky, plastic (wet), interstitials , fine porosity, none roots, & none bacterial activity
B3	94-105	clear and smooth boundary , light gray(7.5YR 7/1) dry, pinkish gray (7.5YR 7/2) moist, medium clay, none mottling, strong, blocky sub granular, medium and coarse size structure, extremely hard (dry), firm (moist), very sticky, very plastic (wet), interstitials ,very fine and common porosity, none roots, & none bacterial activity
B4	106-200+	clear and smooth boundary , brown(7.5YR 5/2) dry, gray (7.5YR 5/1) moist, clay loam, none mottling, moderate, blocky sub granular, fine to medium size structure, hard (dry), very firm (moist), sticky, plastic (wet), interstitials ,very fine and common porosity, none roots, & none bacterial activity

.

Appendix table 5 Essential nutrient rating and soil property

Rating	OM (%)	TN (%)	K ($cmol_cKg^{-1}$	Ca	Mg	CEC	PBS (%)	P ($cmol_cKg^{-1}$
V. low	<0.86	<0.05	<0.2	<2	<0.3	<6	0-20	-
Low	0.86-2.59	0.05-0.12	0.2-0.3	2-5	0.3-1.0	6-12	20-40	<5
Medium	2.59-5.17	0.12-0.25	0.3-0.6	5-10	1.0-3.0	12-25	40-60	5-10
High	>5.17	>0.25	0.6-1.2	10-20	3.0-8.0	25-40	60-80	>10
V. high	-	-	>1.2	>20	>8.0	>40	>80	-

Source: ([a]Tekalign, 1991);([b]FAO, 2006); (Olsen *et al*. 1954);([d] Hazelton and Murphy, 2007); ([e] Jones, 2003).

Appendix table 6 Mean monthly temperatures and rainfall of the Ezha area from 2011 to 2020

Month	Temperature (C_o)		Rain Fall(mm)
	Max T	Min T	
January	27.9	5.5	7.8
February	27.1	6.8	25.7
March	29.3	8.0	48.1
April	28.5	10.7	106.9
May	28.4	11	154.3
Jun	25.0	11.3	232.8
July	23.6	12.1	250.0
August	23.1	11.7	264.6
September	23.5	11.3	178.3
October	26.4	9	54.3
November	25.5	7.7	28.7
December	26.3	6.2	3.8
Mean Total	26.2	9.3	112.9

Source; - SNNPR Meteorological Service Agency (2023)

Appendix table 7 Megecha micro watershed GPS points for opened pit and auger observation

No.	x-coordinate	y- coordinate	Elevation in m
1	387938	899302	2254
2	387092	899522	2199
3	387578	899619	2222
4	387303	900141	2210
5	386423	900777	2170
6	385515	901450	2108
7	384925	902042	2095
8	384453	902621	2063
9	384066	903104	2039
10	383732	903218	2022
11	383430	903298	2028
12	382125	903619	1986
13	383007	904038	2038
14	386529	899693	2193
15	386219	900197	2157
16	385790	900663	2151
17	385287	900953	2132
18	384439	901715	2097
19	384183	901929	2085
20	383940	901531	2078
21	383473	902566	2054
22	384360	902418	2068
23	383973	902898	2037
24	383646	903014	2020
25	383340	903091	2024
26	382033	903412	1997
27	386436	899484	2194
28	386122	899991	2157
29	385697	900458	2148
30	385193	900747	2129
31	384344	901507	2095
32	384090	901726	2083
33	383851	901323	2077
34	383378	902359	2057
35	382309	902949	2022

Appendix table 8 GPS points to develop the soil map of Megecha micro watershed

No	X-coordinate	Y-coordinate
1	388356	898819
2	388319	898780
3	387506	899813
4	386200	899300
5	386700	899200
6	385807	901286
7	384000	901300
8	383700	901300
9	383400	902400
10	384700	901000
11	382879	903909
12	383123	903650
13	384568	902262
14	383777	903155
15	383710	902798
16	383579	902553
17	382758	903744
18	383200	902800
19	383600	902800


P-1 MMWs P-2 MMWs


P-3 MMWs P-4 MMWs

Figure 5 Pedon That Opened At the Study Site