JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

# ESTIMATION OF ANNUAL SOIL EROSION FROM UPPER FINCHA’A CATCHMENT BY USING RUSLE

By: TESFAYE DARSE

A thesis Submitted to the School of Graduate Studies of Jimma University, Jimma Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

March, 2022
Jimma, Ethiopia

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Main Advisor: EfremWakjira (Assistance Prof)
Coadvisor: Mr. Mahmud Mustefa

## DECLARATION

I, the undersigned, declare that this research entitled to “Estimation of Annual Soil Erosion from Upper Fincha’aa catchment By Using Rusle” with GIS, Remote Sensing techniques and has never been submitted at any University, for any degree or other purposes.

Researcher’s Name Signature Date
**Tesfaye Darse** ______________ April, 2022
Advisors’ Name Signature Date
**EfremWakjira(Assistance Prof)** ___________________ April, 2022
**Mr. Mahmud Mustefa** ___________________ April, 2022

As thesis research advisors, we hereby certify that we have read and evaluated this thesis, and prepared under our guidance, by Tesfaye Darse, entitled “Estimation of Annual Soil Erosion from Upper Fincha’a catchment By Using ” Using RUSLE through the Application of GIS Technique‖ and we recommend that it can be submitted as fulfilling the thesis requirement.

Advisors’ Name Sign Date

Main Advisor

EfremWakjira (Assistance Prof) ___________________ April, 2022

Co-Advisor

Mr. Mahmud Mustefa (MSc.) _____________________ April, 2022

As members of the Board of Examiners of the MSc Thesis Open Defense Examination, we Certify that we have read, evaluated the Thesis prepared by Tesfaye Darse and examined the candidate. We recommended that the Thesis be accepted as fulfilling the requirement for the degree of Master of Science in Hydraulic Engineering.

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Final approval and acceptance of the thesis is contingent upon the submission of final copy of the thesis to council of graduate studies (CGS) through the departmental or school graduate committee (DGC or SGC) of the candidate.

## ABSTRACT

*Quantifying the amount of the soil loss using GIS and RUSLE helps to substantiate investment in sustainable land management for the benefit it's to land users.* Soil erosion is recognized as one of the world's most serious environmental and economic problems. It *deteriorates the soil quality, loss of nutrients ,changes in physical, chemical and biological processes and reducing agriculture productivity resulting in global food insecurity .Like other highland parts of Ethiopia, the soil erosion by water is the major factor for soil loss in the Fincha'a catchment. Hence, the general objective of this research is to Estimate average Annual Soil Erosion from Upper Fincha'a catchment By Using Revised Universal Soil Loss Equation (RUSLE. Geographic Information System (GIS) with (RUSLE) was used to estimate average annual soil loss, sediment yield at the outlet and identify the most vulnerable area of soil erosion in the Fincha'a catchment. Data that are used for this study was gathered from different sources such as National Mapping Agency, National Meteorological service Agency, Ministry of Water, Irrigation and Electricity of Ethiopia. Types of data used was the monthly precipitation of 24 year (1991-2015) for seven stations, soil data, Digital Elevation Models (30 x 30m), Land use and land cover data of the study area. Eventually, each of the RUSLE factors, with associated attribute data were digitally encoded in a GIS database to create five thematic map layers of each factor. By integrating these five map layers in GIS raster calculator, the required spatially distributed annual average soil loss rate was determined. The result showed that the potential annual soil loss rate of the watershed varies from 0 to 375 ton/ha/yr and the mean annual soil loss rate was found to be 31 ton/ha/yr. The total annual soil erosion from the entire watershed area was about 4.08 Million tons annually. The estimated sediment yield at watershed outlet was about 386628.6 ton/yr from 1318 square kilometer by using Sediment Delivery Ratio (SDR) technique. . In present study areas that were highly vulnerable to soil erosion were characterized by steep slopes, very low vegetation cover, and high rainfall. The result shows that, it could be difficult to maintain the sustainability of the soil productivity if the specified much of soil removed annually. It also reveals that most of the watershed erosion severity evaluated under low and moderate soil erosion severity classes covering 46 % of the watershed areas which is due to the effect of Cropland and Sparse forest which shows less vulnerable to soil erosion. In the soil loss rate map of upper Fincha'a watershed, the* steep slope lands of northwest and northeast *areas which were identified as extensive soil loss. Hence, those areas needs immediate attention and priorities when implementing soil conservation and management activities before the area jumps to recover soil degradations.*

**Key words:** *Fincha'a Watershed; Soil Erosion; RUSLE; GIS; Annual soil loss rate*

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| | |
|---|---|
| ASTER | Advanced Space borne Thermal Emission and Reflection Radiometer |
| ArcGIS | Arc Geographic Information System |
| ANSWERS | Areal Nonpoint Source Watershed |
| CREAMS | Chemical runoff and erosion from agriculture |
| DEM | Digital Elevation Model |
| GIS | Geographic Information System |
| LULC | Land Use Land Cover |
| MUSLE | Modified Universal Soil Loss Equation |
| PSIAC | Pacific Southwest Interagency Committee |
| RUSLE | Revised Universal Soil Loss Equation |
| SDR | Sediment Delivery Ratio |
| SCRP | Soil Conservation Research Project |
| TM | Thematic Mapper |
| SLEMSA | Soil Loss Estimation for Southern Africa |
| UROSEM | European Erosion Simulation |
| USLE | Universal Soil Loss Equation |
| UTM | Universal Transvers Marketer |
| WEPP | Water Erosion Prediction Project |

# 1. INTRODUCTION

## 1.1. Background

Soil erosion is one of the global threats that causes land degradation and negative impact on the environment by threatening the natural environment, agriculture and economy (Gamtesa and Birhanu 2019). Often defined as a geomorphological and land degradation process, soil erosion presents a major threat to natural and managed ecosystems (Poesen *et al.*,2018 ). The factors affecting soil erosion are soil, topography, climate and vegetation Properties of soils such as structure, biological and chemical composition, organic matter, texture, moisture content and density directly affect the infiltration capacity of soil as well as its dispersion and transportation. Natural hazards caused by soil erosion are grouped as on-site ( changes of soil physical and chemical properties) or off-site such as damage to hydraulic structures downstream, diversion of streams, deposition on riverbeds and reservoirs, and floods (Kisan *et al.*, 2016).

Soil erosion problem is occurring in most of the world's agricultural regions, and the problem is growing as more marginal land is brought into production and less crop residues are returned to the soil for protection and improvements. In the world 80% of agricultural land suffers from moderate to severe erosion which induced loss of productivity. In Africa, soil erosion is one of the top-ranked problems affecting agricultural sectors (Yesuph & Dagnew, 2019) and water resources such as lakes and reservoirs and Ethiopia is not exceptional in the problem. Specially, its effects are more visible in developing countries due to their incapability to replace lost soils and nutrients of farming area. The decrease in agricultural productivity (Girmay *et al.*, 2020), ecosystem disturbances, and water resources pollutions are some of the major ill impacts of soil erosion that are commonly happening in the world (Borrelli *et al.*, 2020). It is also one of the biggest threats in Ethiopian highland which threatens agricultural productivity. According to the Ethiopian highland reclamation study report, 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation (Assefa *et al.*, 2015).The topographic conditions, land use land cover, the intensity of the rainfall, and the soil characteristics are major significant factors of soil erosion (Yan et al., 2018).

Throughout the world, researchers have been using different models for the estimation of annual average soil loss. EURO-pean Soil Erosion Model (EUROPSEM), Limburg Soil Erosion Model (LISEM), Soil and Water Assessment Tool (SWAT), and Water Erosion Prediction Project (WEAP) are commonly used soil loss model (Fayas *et al.*, 2019). The application of integrated Geographical Information System (GIS) and remote sensing technologies in areas of the earth's surfaces are getting global attention and are widely used (Enea *et al.*, 2018), (Singh & Panda, 2017). The simple empirical function called Universal Soil Loss Equation (USLE) is the most commonly used model for loss assessment and later changed into Revised Universal Soil Loss Equation (RUSLE) was adapted to different catchments in Ethiopia (Dinka, 2020).

The exposure to erosion and Sediment contribution from those tributary Rivers varies depending up on the existed situation of the catchments. Therefore, conducting this research contributes to identify the most sever soil erosion areas in the specified catchment. Knowing and identifying the most prone area, is very important to take interventions measures in line with it used for identified erosion vulnerable area.

In Ethiopia, a number of studies indicate the existence of sever soil erosion in the highland areas and sedimentation in the low land areas of the country (Kebede *et al*., 2015). For instance some of the evidence research shows that an average annual soil loss rate of 35 t /ha/yr (FAO, 1986); 42 t /ha/yr 1 (Hurni, 1993) and 57 t /ha/yr (Girmay, 2009) were reported. In addition to this, other researches also show that soil erosion rate ranges from 16 to 300 t /ha/yr (Hurni, 1986) and 130 to 170 t /ha/yr 1 (Gete, 2000) in the highland areas of the country. Related study also indicates the existence of sever problems on agricultural lands due to removal of fertile soil and sedimentations on the water bodies and reservoirs in Ethiopia (Kebede, 2012).

As a result of the topographic conditions, the intensity of rainfall, a traditional way of agricultural practices, and the nature of the soil in this catchment; the majority of the agricultural lands are prone to water derived erosion. Therefore, for this particular study area, an integrated GIS and RUSLE model-based soil loss quantification model was used to develop a spatially varied soil erosion severity map which is very important for sustainable land resources management strategies. Quantifying the amount of the soil loss using GIS and RUSLE helps to substantiate investment in sustainable land management for the benefit it's to land users. Appropriate soil conservation measures bring economic advantages to the land users. Some strategies are adopted to mitigate the impacts of soil erosion in a properly managed watershed. However, such management practices are directly dependent on information related to soil loss estimations and mapping (Ganasri and Ramesh, 2016), which are not frequently available to the watershed of interest (Markose; Jayappa, 2016). Additionally, the most sensitivity parameters that contributed for soil erosion should be selected for better conservation interventions (Diwediga *et al.*, 2018). Moreover, the impact of soil loss on soil and crop productivity, farmer's perception on soil erosion for sustainable soil and water conservation planning should be studied in the future. RUSLE was used to develop erosion hazard maps using land-use change and to identify sustainable land management options for erosion and sediment control (Senanayake *et al.*, 2019).

In Fincha'a catchment, there were an attempt of study to address the estimation of annual average soil loss using some models but, what have to differ from current study is that the previous study done by Gamtesa and Birhanu, (2019), was did not consider sediment yield and its effects at outlet of fincha'a catchment.

Upper Fincha'a Catchment has high rain fall which was contribute to high soil erosion impact due to the area had high slope ,sparse vegetation cover ,had soil type which contains high silt content and due to this reason the was vulnerable with soil erosion. This study was conducted in this Catchment where the soil is highly vulnerable to erosion, however, where such studies are not undertaken. In this study, it was used integrated RUSLE model, GIS and remote sensing to estimate average annual soil loss, sediment yield at outlet and to identify the vulnerable area with soil erosion. The estimated soil loss rate and the spatial patterns are generally realistic, compared to previous studies on some of Ethiopian basins and watersheds.

## 1.2. STATEMENT OF THE PROBLEM

Soil erosion is a natural process of removal of soil material and transportation through the action of erosive agents such as water, wind, gravity, and human disturbance and it has been accelerated by human activities such as intensive agriculture, improper land management, deforestation, and cultivation on steep slopes (Kadupitiya, 2018). Degradation of agricultural land by soil erosion is a worldwide phenomenon leading to loss of nutrient rich surface soil, increased runoff from more impermeable subsoil, and decreased water availability to plant (Ganasri and Ramesh, 2016).

On the highlands of Ethiopian, a number of research reports pertaining to the peril of soil erosion at various spatial and temporal scales (Erkossa *et al*., 2015; Gelagay 2016; Haregeweyn *et al*., 2017). All these highlighted that erosion-caused land degradations are by far the major problems, which deprive soil's fertility, water holding capacity, and its biodiversity (Fenta *et al*., 2016;). However, the extent and magnitude varies from one part of the country to another depending on the farming practices, population pressure, type and susceptibility of the soils to erosion, local climate, the general terrain configurations, and variations in agro-ecological setting of the area .All this implies that location specific soil erosion studies are still substantial in Ethiopia for arresting the problem of soil loss. The present study focuses on the estimation of annual soil loss and sediment yield of upper Fincha'a catchment with identifying the current problem of the catchment due to soil erosion and sedimentation effects. Upper Fincha'a catchment, soil erosion and sedimentation affects volume of the reservoir, as it will be beyond the capacity of dead storage of the reservoir unless it is prevented . The reduction reservoir volume due to soil erosion is the major problem in the reservoir operation. Knowing the amount of sediment is very important for reservoir planning, operation and management. Therefore, given the increasing threat to land resources, especially due to population growth and expansion of agriculture, it is important to provide information to support policy decision and background for further research and development intervention.

## 1.3. Objectives

### 1.3.1 General Objective

The general objective of this thesis is to estimate the annual soil erosion from upper Fincha'a catchment by using Revised Universal Soil Loss Equation (RUSLE).

### 1.3.2. Specific objective

Moreover, the specific objectives of this research include:

1. To estimate annual average soil loss rate
2. To determine the yearly sediment yield at the outlet of the catchment
3. To identify the most vulnerable area of soil erosion

## 1.4. Research Questions

1. What is the mean annual rate of soil loss in the study area?
2. How much will be the amount of total annual soil loss that leaves from the catchment?
3. Which part of the catchment is vulnerable to soil erosion?

## 1.5. Significance of the study

As observed from the result of different studies conducted, the problem of soil erosion in Ethiopia is increasing from time to time with its cause and consequences. For instance, according to Gashew (2017) soil erosion in Ethiopia will reduce the potential productivity of the land by 10% in 2010 and by 30% in 2030. Hence, modeling the annual average soil loss rate plays a vital role in order to recover the potential productivity of the land by applying different soil conservation techniques depending up on the result to be obtained. The result of the study will open the gate and gives information for both government and public to plan appropriate soil conservation practice in the watershed and reducing fertile soil loss from cultivation lands and increasing crop production for farmers.

## 1.6. Scope of the study

This study was a watershed level study and focuses mainly on the estimation of annual average soil loss rate due to water erosion, identification of the most vulnerable region in the watershed. The study watershed covers an area of 1318 km$^2$. In this study, the sediment yield and sediment delivery ratio also evaluated. This task was done by the use of RULSE model with GIS technique.

### 1.7. Organization of the research

The research paper was organized in five separate sections. The first section is introduction with some details about background, statement of the problem, objectives, significance of the study scope of the study and structure of the thesis. The second section discusses about related literature on problems of the soil erosion and different approach of modeling soil loss rate. The methodology, data preparation and analysis including the study area description were presented in the third section. The fourth section was concentrated on results and discussion of the study. The final chapter includes conclusions and recommendations based on the results of the study and findings.

### 1.8. Limitations of the study

Though, the study has a significant role in providing the information about the status of soil erosion of the study area in order to plan and implement an environmental protection programs on time, it has also some limitations. Among the limitations, the soil erosion prediction model (RUSLE) applies only for water erosions; like sheet and reel erosions. Hence, it doesn't consider soil erosion due to wind, land slide and mass movements of soil. The model also neglects certain interactions between RUSLE factors in order to distinguish more easily the individual effect of each. Among the significant constraints, getting the most recent Landsat image was also one of the difficulties. RUSLE, however, has a few drawbacks such as, its output quality is mainly determined by the input data and the directions it is given by the expert during processing, which could lead to personal bias and error. RUSLE fails to take effects of gully erosion and dispersive soils into account (Sharma *et al.*, 2018). According to a comparative study of various soil erosion models, RUSLE's sensitivity is far less to rainfall than to land cover than process-based models. RUSLE's application is limited to the estimation of annual soil loss in longer time period for smaller areas. RUSLE/USEL model lacks runoff factor, consequentially it may overestimate soil loss. In addition, it does not consider various parts and decomposition states of plant materials in its decomposition parameter. Moreover, it does not predict sediment pathways from hill slopes to water bodies.

# 2. LITERATURE REVIEW

## 2.1. Soil Erosion

Soil erosion is a global environmental problem that affects the provisioning and regulation of various ecosystem services (Bezabih *et al.,* 2016; Borrelli *et al.,* 2017; Hassen and Assen 2018). It is explained as the detachment, transportation, and deposition of soil materials by water, wind, ice, or gravity (Boakye *et al.,* 2020). It is determined by factors such as Land Use Land Cover (LULC) changes, slope length and steepness, climate change, and soil properties (Lafforgue 2016).

Soil erosion and the associated sediment yield are confirmed to have many environmental repercussions or actions (Ionita *et al.,* 2015). For instance, scholars affirm that soil loss has not only on-site impacts of increasing soil nutrient loss and reduced productivity of land (Fenta *et al.,* 2020) but also off-site impacts of damaging infrastructure and deposition of sediment in downstream water resources (Haregeweyn *et al.,* 2017). Studies also attest that soil erosion and the resulting sedimentation have undesirable impacts on water holding capacity, water quality, and recreational value of downstream lakes and reservoirs ( Desta and Lemma 2017; Issaka and Ashraf 2017). In general, soil erosion and sediment yield have impacts of reducing ecosystem services and functions (Haregeweyn *et al.,* 2015).In line of this the upper Fincha'a catchment also has such like problem.

Many studies reported the effect of soil erosion on agricultural land and water resources. For instance, Tully *et al*.,(2015) reported that more than 2/3rd of cropland degradation and the resulting productivity loss in Africa resulted from soil erosion. Besides, Degife *et al.,*(2019) revealed that the loss of Lake Cheleleka and the degradation of the surrounding wetlands in the Central Rift Valley region of Ethiopia which was resulted from the erosion and deposition of sediment from the surrounding farmlands. Moreover, Moussa (2018) reported that Aswan High Dam of Egypt has lost 4% of its water storage capacity over 48 years; Khashm el-Girba reservoir of Sudan has lost 53% of its water storage capacity in 46 years; Sennar reservoir of Sudan has lost 85% of its water storage capacity in 85 years, and Angereb reservoir in Ethiopia has lost 46% of its water storage capacity in 19 years due to problems of sedimentation.

A quantified estimation annual average of soil erosion, estimation of sediment yield, identification of the sources of sediments and knowing area vulnerable to soil erosion are of great interest in water resources management as well as planning for design. It helps to address the problem through proper planning and allows the design of better strategies for reducing the impacts on downstream irrigation, water treatment, recreation, and reservoir performance (Sharp *et al*. 2018).

## 2.2. Erosion and transport processes

The process of erosion can be described in three stages: detachment, transport and deposition. Detachment of sediment from the soil surface was originally considered to be exclusively the result of raindrop impact, although the importance of overland flow as an erosive agent has now been recognized. Rainfall detachment is caused by the locally intense shear stresses generated at the soil surface by raindrop impact (Loch and Silburn, 1996). Likewise, overland flow causes a shear stress to the soil surface which, if it exceeds the cohesive strength of the soil, termed the critical shear stress, results in sediment detachment. In different situations, the major processes leading to sediment detachment will differ.

## 2.3. Types of Soil Erosion

There are four main types of erosion processes: sheet, rill, gully and in-stream erosion.

Sheet erosion refers to the uniform detachment and removal of soil, or sediment particles from the soil surface by overland flow or raindrop impact evenly distributed across a slope (Hairsine and Rose, 1992a). Together with rill erosion, sheet erosion is often classified as ‘overland flow’ erosion, detaching sediment from the soil surface profile only. For purposes of simplification, the two processes are often considered together in erosion modeling.

Rill erosion occurs when water moving over the soil surface flows along preferential pathways forming an easily recognizable channels (Rose, 1993). These rills are generally small erosion features, and have been defined as being flow channels that can be obliterated by tillage. Rill initiation is controlled by the cohesive strength of the soil and the shear forces exerted on the soil. Flow in rills acts as a transporting agent for the removal of sediment downslope from rill and interill sources, although if the shear stress in the rill is high enough the rill flow may also detach significant amounts of soil (Nearing *et al.*, 1994).

Gully erosion, in contrast to rill erosion, describes channels of concentrated flow that are too deep to be obliterated by cultivation. The amount of sediment from gully erosion is usually less than from upland areas, but the annoyance from having fields or developed areas divided by large gullies is often a greater problem (Fangmeier *et al*., 2006). Gully development is considered to be controlled by thresholds, as with rills, although these thresholds have been related to slope and catchment area rather than flow erosivities.

In-stream erosion involves the direct removal of sediment from stream banks (lateral erosion) or the streambed. Sediment also enters the stream due to slumping of the stream bank resulting from bank erosion undercutting the stream bank. During high flow periods, a large proportion of the sediment that is transported through the stream network can originate from the stream channel. The potential exists to lump stream bank erosion processes with gully erosion for description by considering either as a specific form of the other. These erosion types do not necessarily occur in isolation from one another. They are influenced by the landscape factors as well as rainfall characteristics. Loch and Silburn (1996) stated that the development of rill and gully erosion requires the concentration of flow and discharges that exceed critical thresholds, and as such will occur as the length of the slope increases. As will be discussed in later sections, most erosion models tend to predict erosion for one of these erosion types, or at most a couple. In a catchment scale modelling exercise, this raises the possibility that in certain areas of the catchment the processes considered by the model being used are not truly representative of the processes actually occurring in the catchment

Soil erosion is the physical movement of soil particles from one location to another, primarily due to forces of water or wind. There are two main types of erosion: geologic and accelerated erosion. Geologic erosionis a normal process of weathering that generally occurs at low rates in all soils as part of the natural soil-forming processes. It occurs over long geologic time horizons and is not influenced by human activity.

### 2.3.1. Soil Erosion Caused Due To Water

Rainfall Intensity and Runoff: Both rainfall and runoff factors must be considered in assessing a water erosion problem. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter can be easily removed by the raindrop splash and runoff water; greater raindrop energy or runoff amounts might be required to move the larger sand and gravel particles. Detachment of soil particles from aggregates primarily by raindrops and flowing water and their transport by runoff water are involved in soil erosion by water (Khan, 2014).

Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short-duration, high-intensity thunderstorms. Although the erosion caused by long-lasting and less-intense storms is not as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time. Runoff can occur whenever there is excess water on a slope that cannot be absorbed into the soil or trapped on the surface. The amount of runoff can be increased if infiltration is reduced due to soil compaction, crusting or freezing. Runoff from the agricultural land may be greatest during spring months when the soils are usually saturated, snow is melting and vegetative cover is minimal. Erosion process starts when raindrops hit the ground surface and detach soil particles by splash.

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. The soil erodibility value refers to the influence of soil properties on soil loss during storm events on highland areas (Wischmeier and Smith 1978). It is the sensitivity of the soil to erosion, easy removal of the silt, and the amount of runoff assumed in an individual rainfall contribution (Kayet *et al*., 2018). Is the K-factor implies the properties of the soil and vulnerability of soil particles to be detached and transported by rainfall-runoff. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils. It is related to the integrated effects of rainfall, runoff, and infiltration on soil loss, accounting for the influences of soil properties on soil loss during storm events on upland areas.

Slope Gradient and Length**:** Naturall**y** the steeper the slope of a field, the greater the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. In a hilly area, when the slope length increases, soil runoff in the downslope direction per unit area also increases. While the slope steepness increases, the runoff velocity is increased. When the slope increases, runoff water will find a path nearby increasing soil erosion and reducing infiltration ( Ganasri and Ramesh,2016) .The slope length and steepness would increase the velocity of runoff by reducing infiltration, which cause severe damage to the soil as well as livelihoods. The ground cover from plants or mulch helps to reduce the runoff velocity. Hence, it is vital to make policy changes on land-use and soil conservation measures to minimize the severity of damages in terms of the effect of rainfall variation in hill slopes.

Vegetation**:** Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate. Although plant roots do not have a prominent effect on splash erosion, some plants have better-rooting patterns, so they hold the soil in better and prevent the formation of rills, gully and shallow landslides (poesen *et al*.,2018).Therefore, he suggests that more attention should be given to examining the effect of root characteristics and soil erosion rates in different soil types.

## 2.4. Factors Affecting Soil Erosion

Generally there are five primary types of Factors that affected soil erosion. These are Climatic factor, Soil, topography, land use and agricultural support practice.

### 2.4.1 Rainfall erosivity factor

Rainfall erosivity (R) represents the potential of rainfall to cause erosion in a given unprotected soil. The rainfall erosivity factor (R) describes the relationship between the rainfall intensity and the soil responses to it (Abdulkadir *et al.,* 2019).The R factor, which is influenced by rainfall intensity and raindrop size takes into account both total precipitation and raindrops kinetic energy. Rainfall erosivity is the capability of rainfall to cause soil loss from hill slopes by water. Modern definitions of rainfall erosivity began with the development of the Universal Soil Loss Equation (USLE), where rainfall characteristics were statistically related to soil loss from thousands of plot-years of natural rainfall and runoff data. USLE erosivity combines the energy of the rainfall and the maximum continuous 30-min intensity in the event.Energy of rainfall is estimated as a function of the storm intensity through the rainfall event. The USLE erosivity has been used effectively for conservation planning purposes for more than 5 decades. When the USLE was replaced by the Revised Universal Soil Loss Equation (RUSLE), a new energy-intensity equation was adopted. Calculations of erosivity as a whole are entirely based on rainfall intensities, and erosivity is an empirically-based index. The science indicates that the direct role of kinetic energy of rainfall as the driver of hill slope erosion in all cases is not warranted by the overall evidence, because many times the kinetic energy of raindrops is not the driving force behind rill erosion. The USLE erosivity empirically explains much of the variance in the soil loss from natural rainfall erosion plots.

The greater the intensity and duration of a rainstorm will have the higher the erosion potential. The impact of raindrops on the soil surface can break down soil aggregates and disperse the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter are easily removed by the raindrop splash and runoff water. Soil movement by rainfall (raindrop splash) is usually greatest and most noticeable during short-duration, high-intensity thunderstorms. Surface water runoff occurs whenever there is excess water on a slope that cannot be absorbed into the soil. Reduced infiltration due to soil compaction, crusting or freezing increases the surface runoff and soil erosion. Runoff from agricultural land is greatest when compared with other land areas.

### 2.4.2 Soil Erodibility Factor

Susceptibility of soil to agent of erosion - is determined by inherent soil properties e.g., texture, structure, soil organic matter content, clay minerals, exchangeable cations and water retention and transmission properties. The ability of soil particles in persisting against rainfall is different in different soil types and this property is expressed in terms of erodibility factor(Ayenew et al., 2018).Climatic erosivity includes drop size distribution and intensity of rain, amount and frequency of rainfall, run-off amount and velocity, and wind velocity. Important terrain characteristics for studying soil erosion are slope gradient, length, aspect and shape. Ground cover exerts a strong moderating impact on dissipating the energy supplied by agents of soil erosion. Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Texture is the principal characteristic affecting erodibility, but structure, organic matter and permeability also contribute. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand and certain clay-textured soils. Tillage and cropping practices that reduce soil organic matter levels, cause poor soil structure, or result in soil compaction, contribute to increases in soil erodibility. The formation of a soil crust, which tends to seal the surface, also decreases infiltration.

### 2.4.3 Slope Length and Slope Steepness Factor (LS)

The topographic factor (LS) represents the intrinsic impact of the terrain on soil erosion with respect to the direct surface runoff movement on a hillslope; this representation is considered by means of the slope steepness (S) and slope length (L) factors (Biswas; Pani, 2015).

### 2.4.4 Cover Management Factor

The vegetation cover and management factor represent the effect of cropping and management practices in agricultural management, and the effect of ground, tree, and grass covers on reducing soil loss in non-agricultural situation. The P factor was considered to be 1 no erosion control practices were identified. As the vegetation cover increases, the soil loss decreases and the vegetation cover factor together with slope steepness and length factors is most sensitive to soil loss.

### 2.4.5 Conservation practice factor

The conservation practice factor (P) is also called as support factor. It represents the soil-loss ratio after performing a specific support practice to the corresponding soil loss, which can be treated as the factor to represent the effect of soil and water conservation practices. The P factor varies from 0 to 1 and expresses the potential of the surface and management practices to reduce soil erosion (Oliveira *et al.*, 2014). The lower the P factor, the more effective the conservation practice is in terms of reduction in the soil erosion (Bagherzadeh, 2014).Several studies have also considered this factor as 1 due to the lack of significant erosion control practices, such as Abdo and Salloum (2017a) .The lower the value is the more effective the conservation practices area.

## 2.5. Impact of soil erosion

Soil erosion has different effects on the environment. Some of the effects are; water resource disturbance, flood risk, river sedimentation, siltation of water storage structures and soil loss (topsoil) as a result of this the nutrients will gone and this lead to loss of productivity .

### 2.5.1. Reduction of productivity

Soil erosion affects and challenges the world’s environment and natural resources (Borrelli, P.; Robinson, D.A.; Fleischer,2017), and economic and environmental dimensions with negative impacts can affect soil erosion, further resulting in low agricultural productivity, ecological collapse and high sedimentation (Pham, T.G.; Degener, J.; Kappas, M.,2018). Approximately 84% of the degraded lands around the world are associated with the most relevant issues about the environment with water and wind as the main agents of erosion .following are the major effects of soil erosion.

### 2.5.2 .Water bodies’ sedimentation

Sedimentation is the end product of soil erosion and becoming an intensified case. Soil erosion is the main part of the initial process of sediment delivery to rivers; in this initial process, displaced soil particles are transformed into sediments due to the influence of an agent of erosion.The amount of sediments can decrease the potential storage capacity of reservoirs and the performance of hydraulic structures (Vaezi, A.R.; Abbasi, M.; Keesstra, S.; Cerda, 2017).The soil particles can be eroded by these erosive agents transported through the processes of sheet, rill, and gully erosion. Once eroded, sediment particles are transported through a river system and are eventually deposited in (water bodies) reservoirs, in lakes, or at sea. This portion of the eroded material that transported through the stream network to some point of interest is referred to as the sediment yield and subsequent sedimentation decrease the carrying capacity of water bodies.According to Amayou (2016), study on Establishing optimal reservoir operation of Fincha`a – Amerty Reservoirs he assigned reduction of effective Volume of the reservoir was due to sediment problem which comes mainly from the sediment load from the river and from the adjacent farming lands. The present study was designed mainly to estimate amount of sediment yield from upper Fincha'a watershed by integrating RUSLE model with GIS and Remote Sensing techniques. These studies are highly important for identifying highly eroded areas and planning and implementation of watershed management strategies and policies by giving attention for more erosion prone areas of the watershed.

## 2.6. Soil Erosion Prediction Models

Numerous erosion and soil erosion models have been developed in the past decades, utilising different scientific methods and modeling approaches. In general, three different kinds of models exist.

### 2.6.1. Empirical models

Empirical models are generally the simplest of all three model types. They are based primarily on the analysis of observations and seek to characterize response from these data (Wheater *et al.*, 1993). The computational and data requirements for such models are usually less than for conceptual and physics-based models, often being capable of being supported by coarse measurements.Many empirical models are based on the analysis of catchment data using stochastic techniques, and as such are ideal tools for the analysis of data in catchments. Parameter values in empirical models may be obtained by calibration, but are more often transferred from calibration at experimental sites. They are particularly useful as a first step in identifying sources of sediment and nutrient generation. Empirical models are often criticized for employing unrealistic assumptions about the physics of the catchment system, ignoring the heterogeneity of catchment inputs and characteristics, such as rainfall and soil types, as well as ignoring the inherent non-linearity in the catchment system .While these criticisms are valid, insufficient meteorological networks and the spatial heterogeneities of soils, for example, often mean that the more complex and dynamic models are, in this sense, no more superior than empirical models. Such models are generally based on the assumption of stationary; that is, it is assumed that underlying conditions remain unchanged for the duration of the study period. This assumption limits the potential for such models to be applied for predicting the effects of catchment change. Empirical models also tend not to be event-responsive, ignoring the processes of rainfall-runoff in the catchment being modeled.

Nonetheless, empirical models are frequently used in preference to more complex models as they can be implemented in situations with limited data and parameter inputs, and are particularly useful as a first step in identifying sources of sediment and nutrient generation.. Hence, prediction of sediment delivery at these scales is commonly based on empirical methods that are applied uniformly in a region.

Empirical models are easily applied due to their simple structures and reliability (Chen; Zha, 2016).Several empirical models have been discussed in the literature, such as the: Musgrave Equation, Bureau of Land Management (BLM), Ephemeral Gully Erosion Model (EGEM), Erosion Potential Method (EPM), Erosion Productivity Impact Calculator (EPIC), Food and Agriculture Organization Model, Geoland 2 (G2), Musgrave Model, Pacific Southwest Interagency Committee (PSIAC), Revised Universal Soil Loss Equation (RUSLE), Scalogram Model, Soil Loss Estimation for Southern Africa (SLEMSA), Stehlik Model, Universal Soil Loss Equation (USLE) (Fakhri *et al.,* 2014).

### 2.6.2. Physical models

Physics-based models are based on the solution of fundamental physical equations describing stream flow and sediment and associated nutrient generation in a catchment. In contrast to empirical models, physically- based models describe the set of mechanisms controlling the water erosion process, thus better representing the physical world. Among these models, Perović et al. (2013), highlight the Areal Non-point Source Watershed Environment Response Simulation (ANSWERS), Chemical Runoff and Erosion from Agricultural Management System (CREAMS), European Erosion Simulation (EUROSEM), Griffth University Erosion System Template (GUEST), EROSION 3D, Kinematic Erosion Simulation (KINEROS), Limburg Soil Erosion Model (LISEM), Modular Soil Erosion System (MOSES), Pan-European Soil Erosion Risk Assessment (PESERA), and Water Erosion Prediction Project (WEEP).  In practice, the large number of parameters involved and the heterogeneity of important characteristics, particularly in catchments, means that these parameters must often be calibrated against observed.

### 2.6.3. Conceptual models

Conceptual models are typically based on the representation of a catchment as a series of internal storages. They usually incorporate the underlying transfer mechanisms of sediment and runoff generation in their structure, representing flow paths in the catchment as a series of storages, each requiring some characterization of its dynamic behavior. Traditionally, conceptual models lump representative processes over the scale at which outputs are simulated (Wheater *et al.*, 1993).  Recently developed Conceptual models are typically based on the representation of a catchment as a series of internal storages. They usually incorporate the underlying transfer mechanisms of sediment and runoff generation in their structure, representing flow paths in the catchment as a series of storages, each requiring some characterization of its dynamic behavior. Conceptual models tend to include a general description of catchment processes, without including the specific details of process interactions, which would require detailed catchment information. Conceptual models have elements from empirical and physical models (Fakhri *et al.*, 2014). These authors point out the following conceptual models: Agricultural Non-Point Source Model (AGNPS), Large Scale Catchment Model (LASCAM), Simulator for Water Resources in Rural Basin-Soil and Water Assessment Tool (SWRRB-SWAT), Topographical Model (TOPMODEL), and Water and Tillage Erosion Model (WATEM).There are gaps in the methodology applied of study areas covered. For example,According to Gamtesa and Birhanu, (2019) study on Assessment of Soil Erosion in Fincha'a Watershed Using RUSLE and GIS Techniques they did not consider the effects of Sediment Yield and sediment delivery ratio in methodology while present study was applied effects those in methodology.

### 2.7. Application of RUSLE (Revised Universal Soil Loss Equation)

The Universal Soil Loss Equation (USLE) model was developed in 1978 as concerns about soil loss due to agricultural practices increased in the United States. The original research for the study of this empirical model can be traced back to Wischmeier and Smith (1978). Its main focus was to predict soil erosion for conservation planning technology purposes, especially sheet and rill erosion (Lal, 1999). Gebeyehu *et al.* (2017) have been attempted to determine RUSLE's P-factor for stone bunds and trenches in range land and crop land in Northern Ethiopia.

## 2.8. Application of GIS and RS for mapping of erosion vulnerable area

The potential utility of RS and GIS techniques for quantitative assessment of soil erosion vulnerable area (Saha*et al*, 1991; Mongkoisawat *et al.*, 1994).RS and GIS techniques becomes an effective analytical tool that makes the watershed management relatively simpler because of its improvement from time to time.

## 2.9. Review of previous study in the study area

### Assessment of Soil Erosion in Fincha'a Watershed Using RUSLE and GIS Techniques

The Assessment of Soil Erosion in Fincha'a Watershed Using RUSLE and GIS Techniques study was conducted by Gamtesa and Birhanu *et a.,l* (2019). The general objective of the study was designed mainly to estimate amount of soil loss from Fincha'a watershed by integrating RUSLE model with GIS and Remote Sensing techniques. According to those study revealed that the farmland was highly vulnerable to erosion than other land use and land cover types. These techniques are highly important for identifying highly eroded areas and planning and implementation of watershed management strategies and policies by giving attention for more erosion prone areas of the watershed. The present study focuses on the estimation of annual soil loss and sediment yield of upper Fincha'a catchment with identifying the current problem of the catchment due to sediment and soil erosion effects while previous study did not calculate sediment yield outlet, sediment deliver ratio and did not consider the effect of those in the study area. RUSLE is a science based tool that has been improved over the last several years. It is a computation method which may be used for site evaluation and planning purposes and to aid in the decision process of selecting erosion control measures. It provides an estimate of the severity of erosion. All the collected data were converted into a raster grid with 30 m × 30 m cells for the use.The overall methodology proceeded as A digital elevation model (DEM) with 30 x 30 meter resolution was implemented for catchment delineation and analysis of the LS-factor of the study area. The land use/ land cover map was used for the analysis of C-factor and the Soil map of the study area was also used for the analysis of the K-factor. The analysis of R-factor was derived from mean annual rainfall data of the nearby rain gauge stations. Eventually, each of the RUSLE factors, with associated attribute data were digitally encoded in a GIS database to create five thematic map layers of each factor. Finally by integrating these five map layers in GIS raster calculator, the required annual average soil loss rate was determined. Accordingly, the result of the analysis for the existed conditions depicted that the amount of soil loss from the study area ranges from 1 to 375 to/ha/yr with average annual soil loss rate of 31 to/ha/yr from the whole catchment. The estimated soil loss rate and the spatial patterns are generally realistic, compared to previous studies on some of Ethiopian basins and watersheds. For instance, soil loss rate estimated by Hurni (1985) for Ethiopian highlands ranges from 0.0 to 300 t ton/ha/yr. Temesgen (2017) also reveals that the soil loss rate ranges from 0 to 237 ton/ha/yr.

Unlike the findings of this study, some studies however, report a rather higher rate of erosion in different parts of Ethiopian watersheds. The result in this study is somehow lower than the estimates for Chemoga watershed with 93 ton/ha/yr Zerihun et al. (2018) for Dembecha district 49 ton/ha/yr , Gelagay and Minale (2016) for Koga watershed 47 ton/ha/yr. On the contrary relatively lower soil loss results were reported by Gashaw et al. (2017) 23.7 ton/ha/yr for Geleda watershed and Miheretu and Yimer (2018) 24.3 ton/ha/yr for Gelana sub-watershed and Haregeweyn et al. (2017) 27.5 ton/ha/yr for Upper Blue Nile Basin. This could be attributed to highland mountainous and steep slope conditions to gather with relatively higher rainfall in upper Fincha'a watershed. This variation of results comes from the actual existing condition of the watersheds.

# 3. MATERIAL AND METHODOLOGY

## 3.1. Study area description

### *3.1.1. Location*

The upper Fincha’a watershed is located between 9°10'30’’and 9°46'45’N latitude and 37°03'00” and 37°28'300’’Elongitudes in Horo Guduru Wollega Zone of Abbay Chomen and Hareto District.Based on a dataset from ten meteorological stations for the period from 1991 to 2015 (Table 3.1), the mean annual rainfall in the study region varied between 1016.16 mm in Gebete and 1842.4 mm in Neshe.

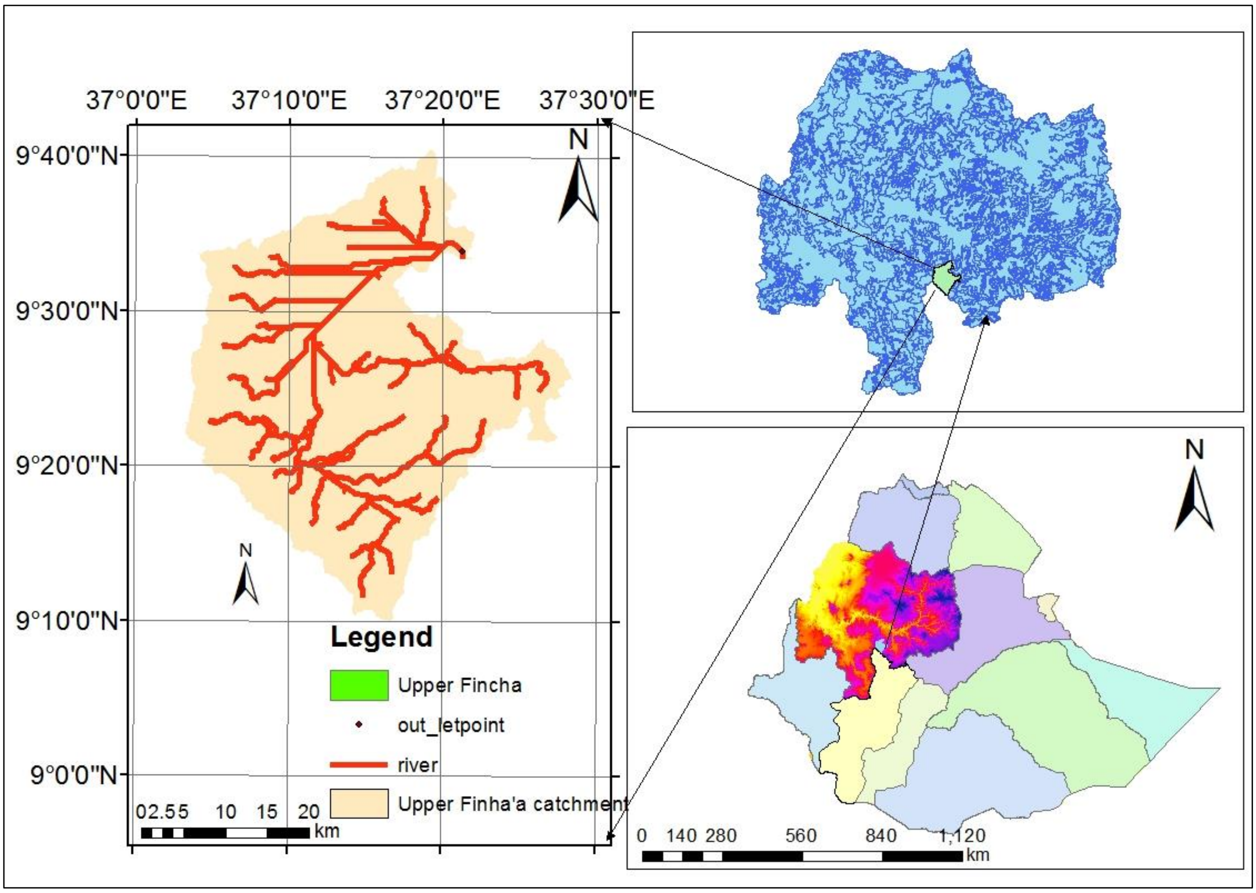

Figure 3.1: Location map of the study area

### 3.1.2. Topography

Elevation in the watershed ranges between from 2197 to 3213 m above sea level from (Figure 3.2). The study area covers about 1318 square kilometers.

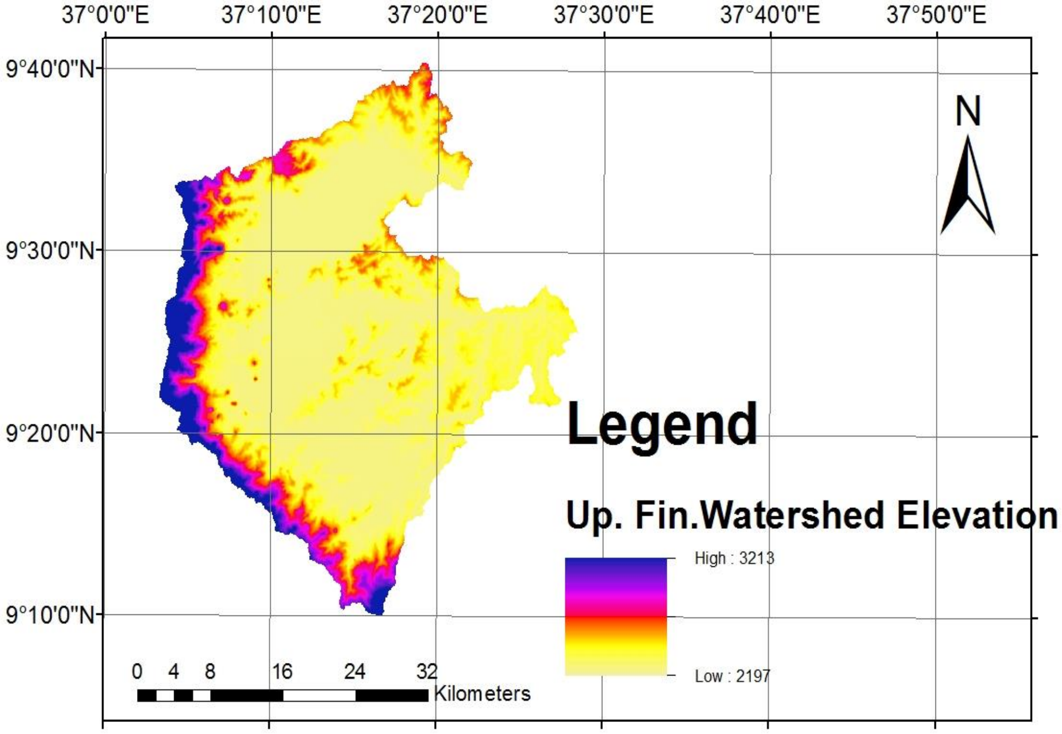

Figure 3.2. Topography of Fincha'a catchment

### *3.1.3. Climate*

The climate of Ethiopia is mainly controlled by seasonal migration of Inter-tropical convergence zone and its associated atmospheric circulation but the topography has also an effect on the local climate. The upper Fincha'a catchment area is located on the highland plateau characterized by a subtropical climate, with an average annual rainfall of about 1784.9 mm, and with an average minimum and maximum air temperature of 14.6 $^0$C and 17.7 $^0$C respectively. Maximum temperature observed from February to April while the minimum recorded in July to August. The relative humidity is highest in July to September with the minimum in February to April.

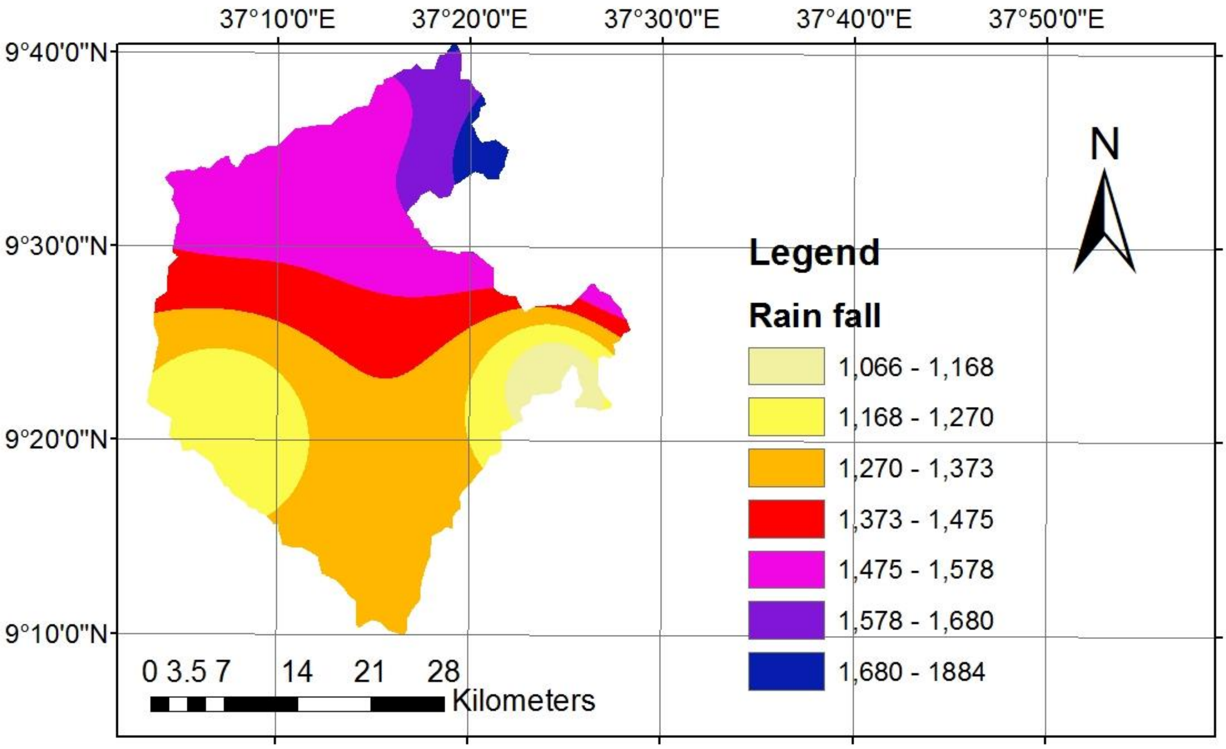

Figure 3.3 precipication map of Upper fincha'a watershed

### 3.1.4. Soil and Geology

Quaternary volcanic rocks overlay the older Tertiary volcanic cover much of the upper Fincha'a watershed boundary. The soils of the area was dominated by Dystric Leptosols ,Eutric Leptosols, EutricVertisols,HaplicAlisols,Haplic phaeozems,Haplic luvisols,marsh and Water body.

### 3.1.5 Socioeconomic condition

The Upper Fincha'a Watershed administratively located in Horo GuduruWollega Zone of Abbay Chomen District. The major means of livelihoods for people residing in the watershed include crop and livestock production, use of Natural resources and small businesses. The major crops grown in the areainclude Tef (Eragrostistef), Maize (Zea mays), Barley (Hordeumvulgare), wheat (Triticumaestivum), Faba bean (Viciafaba), and field pea (Pisumsativum). According to sources from theWoreda agricultural offices, the major domestic livestock populations used as means oflivelihood include and verified during field survey was cattle, goat, sheep, horse, mule, donkeyand poultry. Livestock provides meat, milk, butter, hides and eggs production for means of livelihood and income generation. The community in the area uses forests for several purposes.

## 3.2. Data Sources and materials used

Data that are used for this study is gathered from different sources such as Internet, National Mapping Agency, National Meteorological Agency, Ministry of Water Irrigation and Electricity of Ethiopia. Collection of both quantitative and qualitative data should be roughly at the same time in the design. The quantitative data which is generate from household survey and secondary sources (like National Meteorological service Agency and satellite image).

Likewise, data such as the soil map (1:50,000) obtained from Fincha'a catchment master plan, Digital Elevation Model (30 m× 30 m) will be downloaded from Global land cover facility (www.landcover.org) which was resampled to 30 × 30 meter spatial resolution, LULC with spatial resolution of 30 meter of the downloaded from global land cover facility topographic map (1:50,000) taken from Ethiopian Ministry of Water Resources and Energy (MWRE)and twenty four years (1991-2015) rainfall data records from ten rain gauge stations obtained from from National Meteorological service Agency, soil data from Ethiopian Ministry of Water Resources and Energy (MWRE) which clipped from Abbay basin, Other published research and unpublished materials such as research reports, census reports and journal obtained from different sources will also employed to estimate the mean annual soil loss.

## 3.3. The Digital Elevation Model (DEM)

Digital Elevation Models do play a fundamental role in mapping. The digital description of the three dimensional surface is important for several applications. The DEM files may be used in terrain analysis, with the generation of graphics displaying slope, direction of slope (aspect), and terrain profiles between designated points. The DEM for this study is extracted from Global Land Cover Facility (www.landcover.org) with 30x30 meter resolution by Ethiopian Mapping service Agency which currently used for this study to develop map of water delineation of study area ,topographic parameters such as slope gradient, slope length (slope map).

## 3.4. Land use and Land cover Data

The Landsat TM satellite images have been taken from Ethiopian Mapping Agency which was used to develop land use and land cover map of the upper Fincha'a watershed and has cell size 30mx30m resolutions.

Table 3.1.Land use and Land cover Upper Fincha'a watershed

| Land use | area sq km | % of total |
|---|---|---|
| Cropland | 736 | 55.8 |
| Open shrub | 19 | 1.4 |
| Bare Soil | 0.04 | 0.0 |
| Closed shrub | 81 | 6.1 |
| Closed grass | 90 | 6.8 |
| Dense Forest | 84.56 | 6.4 |
| Sparse Forest | 189 | 14.3 |
| Water body | 109 | 8.3 |
| wetland | 1.4 | 0.1 |
| woodland | 8 | 0.6 |
| total | 1318 | 100.00 |

The study watershed LULC was classified into ten classes, namely Cropland, Open shrub ,Bare Soil ,Closed shrub, Closed grass ,Dense Forest ,Sparse Forest, Water body ,wetland and woodland . Cropland and Sparse Forest is the dominant land use type in the study area which covers 736 square kilometer (55.8%) and 189 square kilometer (14.3%) of the total study area, respectively; while other land use covers 29.1% (Table 3.1)

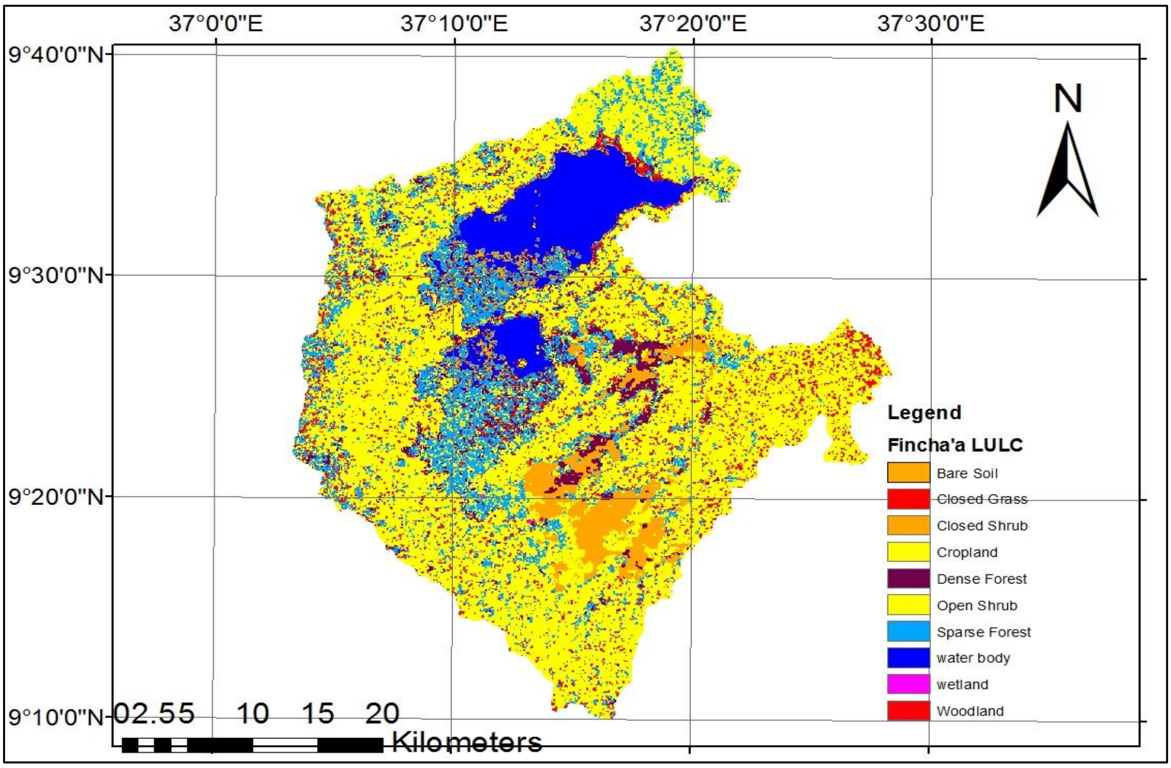

Figure 3.4: Land use /Land cover types of the study area.

### 3.5. Software and tools used for the study

For the success of this research the Arc GIS 10.3, RUSLE and Arc Hydro extension software and tools. Geographic Information Systems are databases that have a spatial component for the storage and processing of the data. So that, they have the potential to store and create maps. There are a number of strengths that GIS technologies have a number of advantages in watershed management studies by allowing improved database organization and storage. Obtaining different variables which is important for watershed studies has been difficult to do from paper maps and aerial photographs as it subjects to errors related to manual operations and it is proved to be time-consuming. ArcGIS10 was used for the generation of R, K, LS, and C layers, generation of potential gully location, integration of layers, reclassification of derived datasets and weighted overlay analysis. Watershed, Micro and sub watersheds delineation were performed using Arc hydro extension with in ArcGIS10.3. For digital image processing including preprocessing of satellite image data, masking the image with the watershed boundary enhancement, visual interpretation.

## 3.6. Method of data analysis

The overall methodology involved the use of the RUSLE model in a GIS environment, with factors obtained from meteorological stations, soil surveys, topographic maps, Satellite Images, Digital Elevation Model and results of other relevant studies. For this study the GIS layers built for each factors of the model and combined by cell-grid modeling procedures in ArcGIS to estimate annual soil loss, sediment yield and identify area of vulnerability with soil erosion. The model used to estimate the average annual rate of soil loss from the watershed and to locate the special distribution of the erosion hot spot areas within the watershed (Farhan and Nawaiseh 2015). All derived maps was projected into World Geodetic Systems WGS1984 Zone 37N and held in grids of 30-m cell size.

## 3.7. Determination of RUSLE Parameters

### 3.7.1. Rainfall Erosivity (R)

The rainfall erosivity (R-factor) is a measure of the erosivity of local average annual Precipitation and runoff to cause soil erosion in a given circumstances. The monthly amounts of precipitation for the watershed were collected over 24 years covering the period(1991-2015) was collected from seven rain gauge stations derived from National Meteorological service. The mean annual rainfall excel point data was first added to ARCGIS and exported to shape file, interpolated to generate continuous rainfall data for each grid cell by “3D Analyst Tools Raster inverse distance weighted( IDW) Interpolation” in ArcGIS environment. Then, the R-value shown in (table 4.1)corresponds to the mean annual rainfall of the watershed was found using map algebra or raster calculation of ArcGIS environment with the R-correlation established in Hurni (1985) to Ethiopia condition.

$R = -8.12 + 0.562 * P$-----------------------------------------------------------------------------------------(1)

Where R is the rainfall erosivity factor and P is the mean annual rainfall (mm)

### 3.7.2. Soil Erodibility Factor (K)

The K factor represents the influence of different soil properties on the slope's susceptibility to erosion (Renard et al., 1997). Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called the soil erodibility factor (K). Soil erodibility factor (K) in RUSLE accounts for the influence of soil properties on soil loss during storm events on upland areas. Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic matter and chemical content of the soil (Morgan, 1995). The physical, chemical and mineralogical soil properties and their interactions that affect K values are many and varied. It is therefore unlikely that a relatively few soil characteristics will accurately describe K values for each soils.

Therefore, the soil erodibility (K) factor for the study area was estimated as a qualitative index that was adapted to Ethiopia by Hurni (1985) based on the color of the soil. The soil feature map of the study area is obtained by clipping the FAO soil map of Ethiopia with the study watershed in the GIS environment. Then, K value is assigned for each of the soil types based on their colors. Finally, the resulting shape file was changed to grid file or raster with a cell size of 30 x 30 meters. The raster map is then classified into three distinct classes based on their erodibility value. These researchers recommended K-factor values based on easily observable soil color as an indicator for the erodibility of the soil in the highlands of Ethiopia, and they suggested calibration based values of K-factor based on soil color for Ethiopian soil conditions. Based on the existing soil types in the study area, the respective K-factor values were assigned for each type of soil. Then, the respective K-factor map was generated to consider the effects of soil type on soil erosion as one factor (Table 3.2).To overcome unavailability of such data, Helden (1987) suggested K factor values for use in strength, infiltration capacity and organic matter and chemical content of the soil (Morgan, 1996).

Table 3.2. Soil Erodibility factor (Modified from Hellden, 1987)

| Soil color | black | brown | red |
|---|---|---|---|
| K value | 0.15 | 0.2 | 0.25 |

### 3.7.3. Slope length and steepness factors (LS)

LS-factor is the ratio of soil loss per unit area from a field slope to that of the standard field slope (22.1 m long and 9% slope) (Wischmeier & Smith 1978). This factor is a combined factor of slope length (L) and slope steepness (S). A slope length is the distance from the point of origin of overland flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well-defined channel. Slope steepness is the gradient from point of origin of flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well-defined channel (Wischmeier & Smith 1978).The slope length and slope steepness factors are commonly combined in a single index as LS and referred to as the topographic factor. Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff water enters a well-defined channel that may be part of a drainage network. Slope steepness has been considered as one of the most model parameters in RUSLE analysis due to the fact that the steeper the slope of a field, the more it is pushed down hill, the faster the water runs and the greater will be the amount of soil loss from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff.

A flow direction and flow accumulation map were processed and generated from digital elevation model data after fill operation in Arc Hydro tools of the GIS extension to use as an input for the calculation of the LS-factor. In order to generate the map of the LS-factor, Equation (2) was used in the raster calculator of the GIS database. The equation was developed by Wischmeier & Smith (1978).

$LS = (FA * \text{cell size}/22.1)^{0.6} *(0.065 + 0.045\ S + 0.0065\ S^2)$ ----------------------------------------(2)

Where, FA is flow accumulation is the number of cells contributing to flow in to a given cell and derived from the DEM after conducting fill, flow direction and flow accumulation processes in ArcGIS environment. Cell size is the size of the cells being used in the grid based representation of the landscape and S is slope in percent. Finally, the LS factor map was derived using the above formula in ArcGIS spatial analysis raster calculator function (Figure 4.4).

### 3*.7.4 Cover Management Factor (C)*

The C-factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow with the same rainfall (Wischmeier and Smith, 1978). The type of Land cover (crop type) and tillage make the greatest difference in the amount of erosion that occurs in a given area. Land cover has a profound impact on erosion and deposition. Surface cover, such as vegetation or plant residue may intercept and reduce raindrop erosivity, increase infiltration, slow down runoff and reduce transporting capacity of water flow. As much as is available of current LU and LC data, which Show the current condition of the study area, are needed to determine this factor. In this study the land use/land cover map of produced by EMA was used for preparing c-factor map and C-value. The raster land use/land cover map was converted to a vector format or the study area of cover management data masked to LULC of Landsat image in spatial analyst tools and a corresponding C-value was assigned to each land use classes based on cover values proposed by Hurni(1985) and from reported values in different study areas,(Table 4.3). Finally, using reclassification and vector to raster conversion the land use/ land cover map was converted to C factor map **(**Figure 4.5).

### 3.7. 5 Support Practice Factor (P)

The P factor takes into account support practice effects on soil erosion. These practices generally affect the amount, flow pattern, rate or direction of surface runoff (Reynard and Foster 1983). Specific cultivation practices affect erosion by modifying the flow pattern and the direction of runoff and, by reducing the amount of runoff (Renard et al., 1994). The conservation practices factor (p-values) reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. It depends on the type of conservation measures implemented, and requires mapping of conserved areas for it to be quantified. The p-factor map generated is used for understanding the conservation practices being taken up in the study area. The P-value ranges from 0 to 1 depending on the soil management activities employed in the specific plot of land. In this study area, there is only a small area that has been treated with terracing through the agricultural extension program of the government, and these are poorly maintained as implementation was performed with participation of the local people. As data were lacking on permanent management factors and there were no management practices, in this study P-values suggested by Bewket and Teferi (2009), and Wischmeir and Smith,(1978), were used, that considers only two types of land uses (agricultural and non-agricultural) and land slopes. Thus, the agricultural lands are classified into six slope categories and assigned P-values while all non-agricultural lands are assigned a P-value of 1.00 (Table 4.4 and Figure 4.6). The P-factor value could be thus used for understanding the conservation practices being taken up in the study area.

Water body, grazing, shrub and forest built-up areas lands were therefore referred as other land and given the P-value regardless of the slope class they have, but cultivated land of the watershed was categorized into six slope class and given P-values as discoursed by Wischmeier and Smith. Lastly, the classified land use land cover and slope thematic map has been converted in to vector format and the corresponding P values were assigned to the combination of each land use land cover and slope classes. By merging LULC class and slope, the Support Practice Factor map layer was produced (figure 4.6).

## 3.8. Estimation of Soil Loss (A)

The main factors affecting soil erosion are topography, climate, soil, vegetation, land use, and man-made developments (Shen and Julien 2013). Predictions of soil erosion and sediment yield are necessary for guiding the making of rational decisions in conservation planning. The overall methodology involved the use of the RUSLE in a GIS environment with factors obtained from meteorological stations, soil map, topographic map, Satellite Images and DEM. Annual soil loss rate was determined by a cell-by-cell analysis of the soil loss surface by multiplying the respective RUSLE factor values (R, K, LS, C and P) interactively by using “Spatial Analyst Tool Map Algebra Raster Calculator” in ArcGIS 10.3 environment .Using the nearest-neighbor method, all the datasets utilized in this study were resampled to the same spatial resolution of 30 × 30 m and reprojected to the World Geodetic System (WGS) 1984 Universal Traverse Mercator (UTM) zone 37 North Hemisphere because they were acquired from different sources with different spatial resolutions. According to Renard *et al.* (1997), the empirical equation of RUSLE model is given by Eq. (3).

$$A = R \cdot K \cdot LS \cdot C \cdot p \text{------------------------------------------} (3)$$

Where: - A is the annual average soil loss rate (t/ha /year), R is the rainfall-runoff erosivity factor MJ mm/ha year, K is the soil erodibility factor t ha / MJ mm, LS is the slope length and steepness factor, C is the cover management factor, and P is the conservation practice factor.

The factors L, S, C, and P are all dimensionless.

## 3.9. Estimation of Sediment Yield

The sediment delivery ratio (SDR) denotes the ratio of the sediment yield at a given stream cross section to the gross erosion from the watershed upstream from the measuring point (Julien and Frenette 1998). Using the empirical equations, the sediment yield at the watershed outlet was calculated as follows

$$SDR = A^{-0.2} \text{------------------------------------------} (4)$$

Where, SDR denotes the sediment delivery ratio and A area of the watershed. The SDR physically means the ratio of the sediment routed to the outlet over the watershed, both overland and channel. It is a measure of sediment transport efficiency which accounts for the amount of sediment that is actually transported from the eroding sources to a catchment outlet compared to the total amount of soil that is detached over the same area above that point. The sediment delivery ratio value in a given watershed indicates the integrated capability of a catchment for storing and transporting the eroded soil. SDR compensates for areas of sediment deposition that become increasingly important with increasing catchment area and therefore, determines the relative significance of sediment sources and their delivery.

Sediment yield is dependent on gross soil loss in the watershed and on the transport of eroded material out of the watershed. The total amount of sediment that is delivered to the outlet of the Watershed is known as the sediment yield.

Sediment yield is commonly estimated by the following empirical formula:

$SY=E*(1/A^{0.2})$ ------------------------------------------------------------------------------------------(5)

Where, SY= Sediment yield (ton/ha/yr) at the watershed out let; E = the gross soil erosion(ton/yr); A = watershed area (ha).

## 3.10. Soil erosion vulnerability

Soil vulnerability is the capacity of one or more of the ecological functions of the soil system to be harmed. It is a complex concept which requires the identification of multiple environmental factors and land management at different temporal and space scales. The employment of geospatial information with good update capabilities could be a satisfactory tool to assess potential soil vulnerability changes in large areas. In present study areas that were highly vulnerable to soil erosion were characterized by steep slopes, very low vegetation cover, and high rainfall.

In this study, the overall methodology RUSLE was used to generate the spatially varied soil erosion severity map of annual soil loss by combining five factors , calculate sediment yield and to identify vulnerable area to soil erosion. This study was employed both quantitative and qualitative data analysis techniques. The procedure used is given in the flow chart blow (figure 3.5 ) to estimate the six parameters of the RUSLE; like rainfall-runoff erosivity (R), soil erodibility (K), slope length and steepness or topographic factor (LS) or, cover management (C), and support practice factor (P).

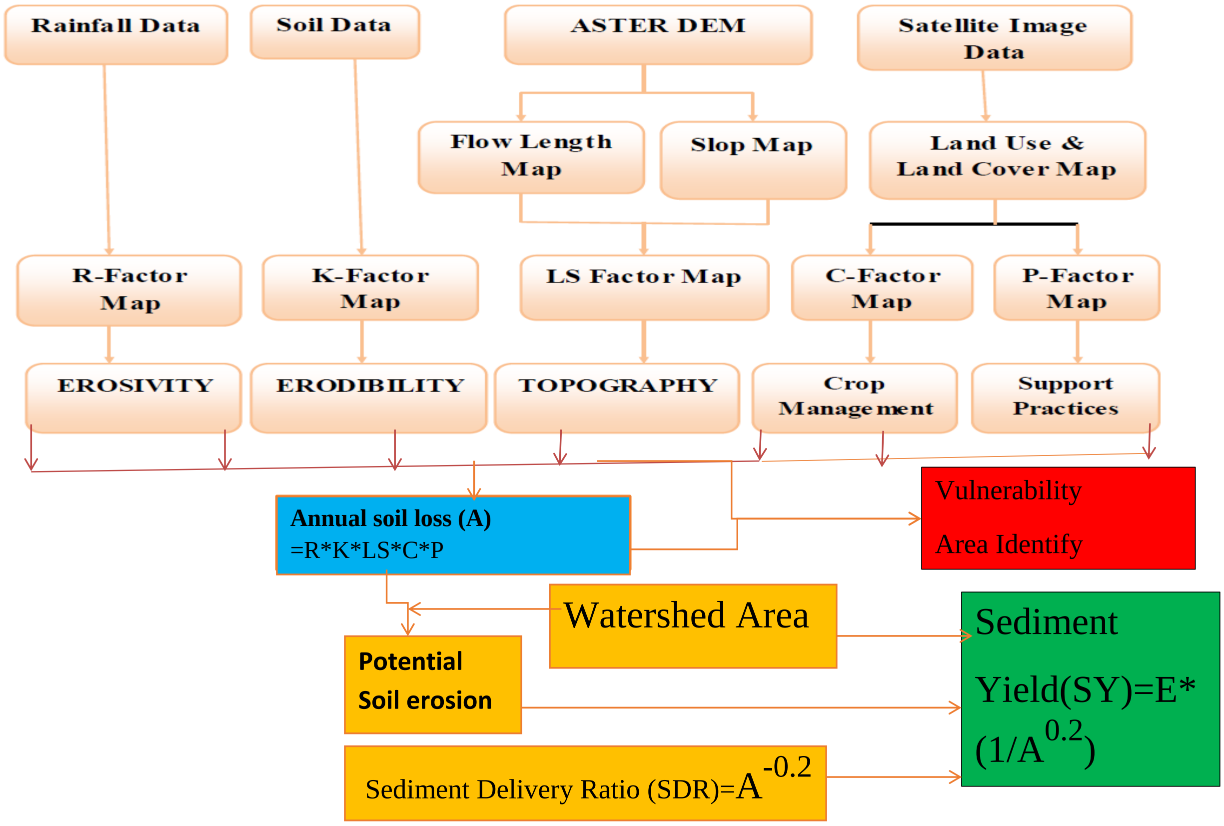

Figure 3.5. Flow chart of the determinations of soil loss using RUSLE in Arc GIS: Israel (2019)

## 3.11. Validation of model results

The numerical data outputs of similar research works in the Ethiopian highlands were used to validate the model output because of there is a lack of measured data specific to the study area . One of the limitations of the RUSLE and perhaps many soil erosion models is the lack of data for validating the model outputs. Benavidez et al. (2018) indicated that validating the soil erosion rates estimated by the RUSLE is difficult because of the lack of easily available measured soil erosion records, especially in data-sparse regions. The soil loss estimates can also be validated by comparing results with soil erosion studies of similar watersheds or larger-scale national or regional scale (Panagos et al. 2015; Nakil and Khire 2016). In this study, due to a lack of measured data specific to the study area, the validity of the model outputs was compared with the results of other studies conducted in Ethiopia to check the validity of the outputs. The estimated mean annual soil loss value for Upper Fincha’a watershed which is 31 ton/ha/ is reasonable comparatively with other studies finding by applying similar analysis method in the Ethiopian highlands. In addition, field observations were carried out to identify severely erosion affected areas. The field visits were accompanied by color printed model output maps of soil erosion and sediment yield maps to prove it on the ground but I did not used this color printed model output map .

# 4. RESULT AND DISCUSSION

## 4.1 Rainfall Erosivity (R)

In the study area, the long-term mean annual rainfall amount was varied between 1066.16 to 1842.4mm. Owing to variation in mean annual precipitation amount within the study area, variations in rainfall erosivity were observed (Table 4.1). Accordingly, the rainfall erosivity, as estimated from mean annual total rainfall of the respective stations, varied from 591.06 MJmm/ha yr at Gebete to 1027.31 MJmm/ha.yr at Neshe. The calculated values in (Table 4.1) show that as the mean annual rainfall increases the rainfall erosivity also increases. Following this, the rainfall erosivity is high at the northeast including neshe and low to the northwest towards Gebete (Figure 4.2). Therefore, based on the results the northeastern part of the study area receives relatively higher rainfall that have high erosive power. The areas in between the two extremes (Neshe and Gebete ), shares the values of erosivity in between the maximum and minimum erosivity value distributed spatially.

Table 4.1. Average rainfall and erosivity values

| Name of station | Location | | Altitude (m) | Average rainfall (mm) | R-factor values (MJ mm /ha h. yr ) |
|---|---|---|---|---|---|
| | Latitude | Longitude | | | |
| Hareto | 293528.82 | 1034098.05 | 2260 | 1168.63 | 648.65 |
| Shambu | 293788.96 | 1058565.78 | 2460 | 1531.2 | 852.41 |
| Homi | 306992.00 | 1064041.45 | 2371 | 1524.78 | 848.81 |
| Neshe | 310030.95 | 1075308.09 | 2060 | 1842.4 | 1027.31 |
| Fincha'a | 321142.74 | 1058293.75 | 2248 | 1784.9 | 994.99 |
| Kombolcha | 332343.84 | 1050758.45 | 2341 | 1696.4 | 945.26 |
| Gebete | 325315.64 | 1037683.27 | 2497 | 1066.16 | 591.06 |

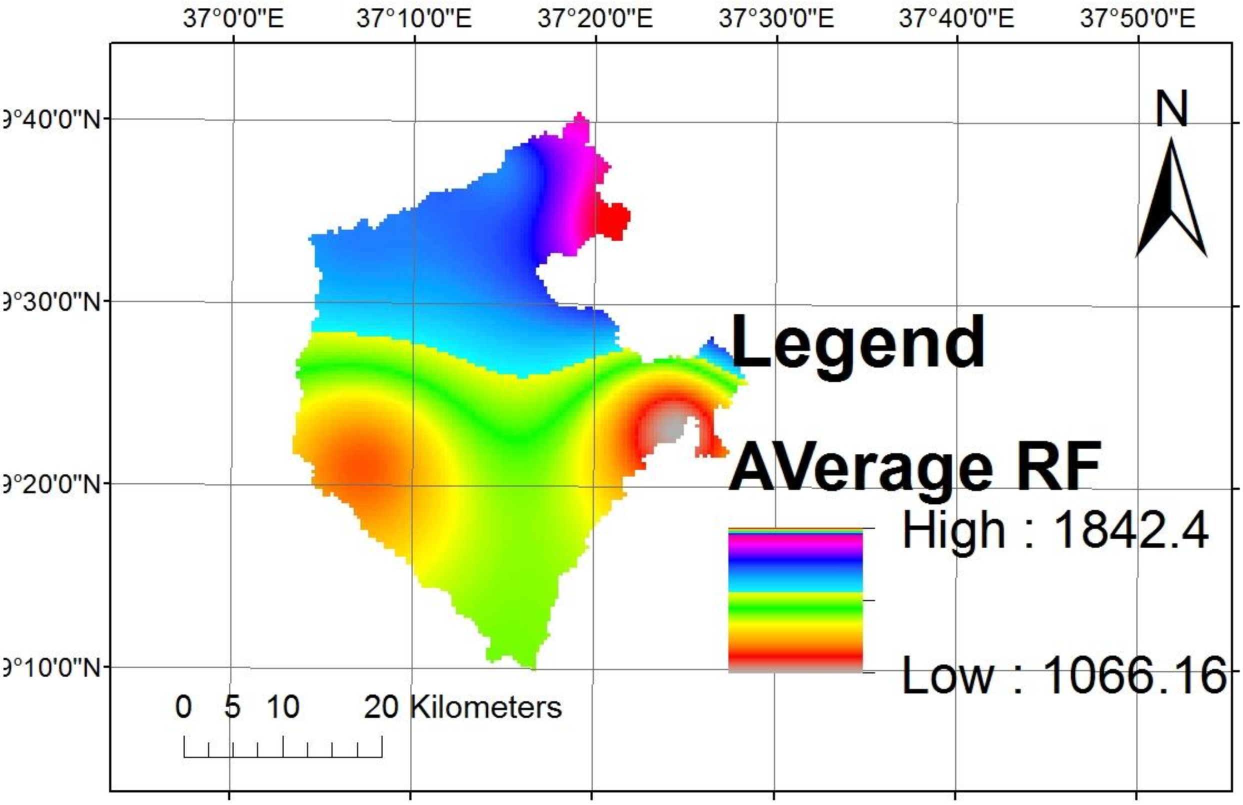

Figure 4.1 Average rain fall value

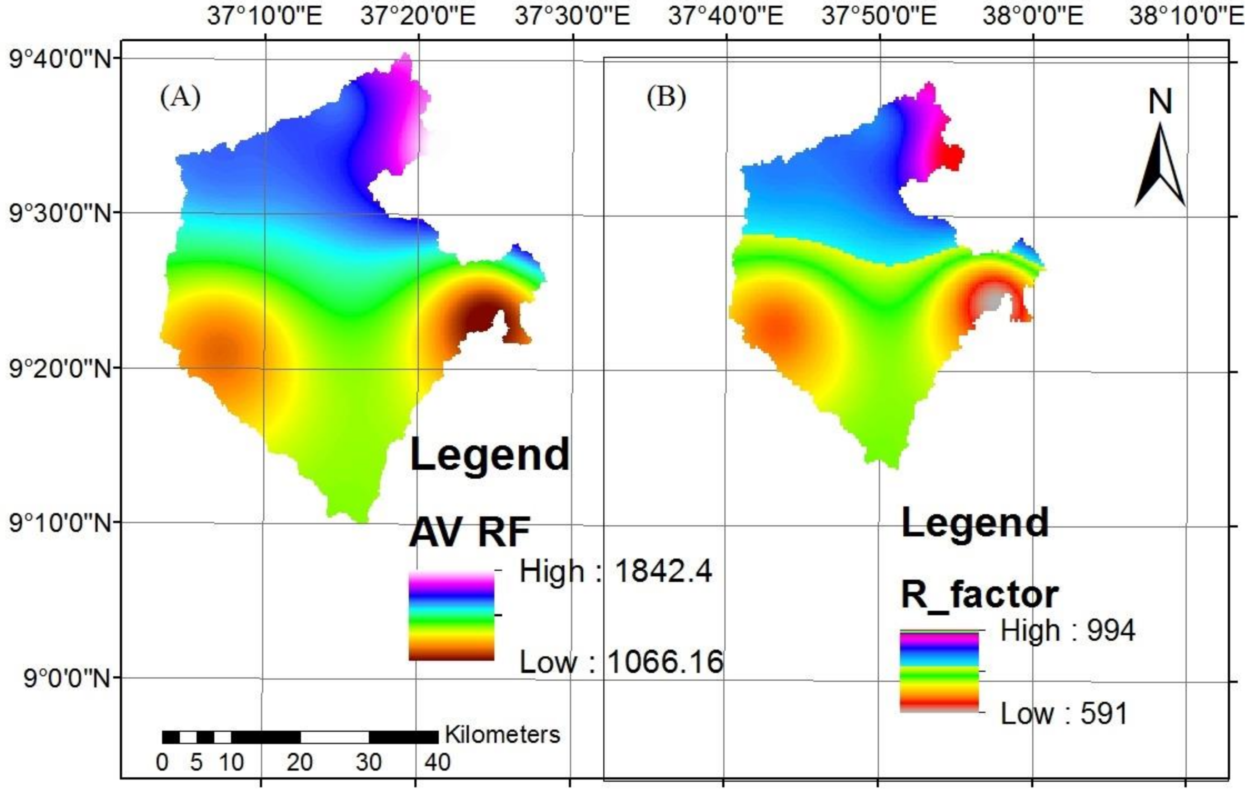

Figure 4.2 Erosivity factor map (A) respective Average rain fall map (B)

## 4.2. Soil Erodibility Factor (K)

From the digital soil map data obtained by clipping from Abbay basin Dystric Leptosols ,Eutric Leptosols,EutricVertisols,HaplicAlisols, Haplic phaeozems ,Haplic luvisols ,marsh and Water body were recognized in the study area . From (figure 4.3)Dystric Leptosols are mostly found south and west of the study area, Eutric Leptosols found in the west ,EutricVertisols found in the south west ,HaplicAlisols found in the all corners part of the study area , Haplic phaeozems found in the ,Haplic luvisols found in the south part ,marsh found in the north part and Water body found in the south part of the study area. As can be seen from ( Figure 4.3 and table 4.2) the soil erodibility values of the study area ranges from 0.00 metric ton/ha.MJ.mm, the lowest to 0.25 metric tons/ha MJ.mm, the highest. The values indicate that water body and marsh land have lower erodibility value, while the Haplic Alisosols higher k value are have relatively higher erodibility value. This implies that the soils which have lowest value of k-value are more resistant to erosion because of their low detachability, has more organic content, high infiltration and low content of silt rate while the high value of k-value are more susceptible to erosion under similar conditions that affect soil loss. Although the highest K-factor value of the study area K= 0.25 metric tons/ha MJ.mm , it is relatively low compared to the standard maximum value

(K=1). In this study,the Haplic Alisosols soil type result shows high value of k which indicates highly vulnerable to erosion because they have low aggregate stability and low infiltration rate which may lead to high runoff and soil loss. Soils having high silt content (K= 1) are the most erodible of all soils as they cause a decrease in infiltration. Hence, soil loss in the study area is expected to be relatively low compared with areas that may have a K-value close to the maximum. Soil erodibility factor map of the watershed is shown in figure 4.3.

Table 4.2 Soil types based on colors and their Erodibility factors

| Soil types | Soil color | K-factor values(metric ton/ha.MJ.mm) |
|---|---|---|
| Dystric Leptosols | brown | 0.2 |
| Eutric Leptosols | brown | 0.2 |
| EutricVertisols | black | 0.15 |
| HaplicAlisols, | red | 0.25 |
| Haplic phaeozems | black | 0.15 |
| Haplic luvisols | brown | 0.2 |
| marsh | | 0.24 |
| Water body | | 0 |

Source: Hurni (1985), Lewoye T. and ·Rishikesh B. (2021)

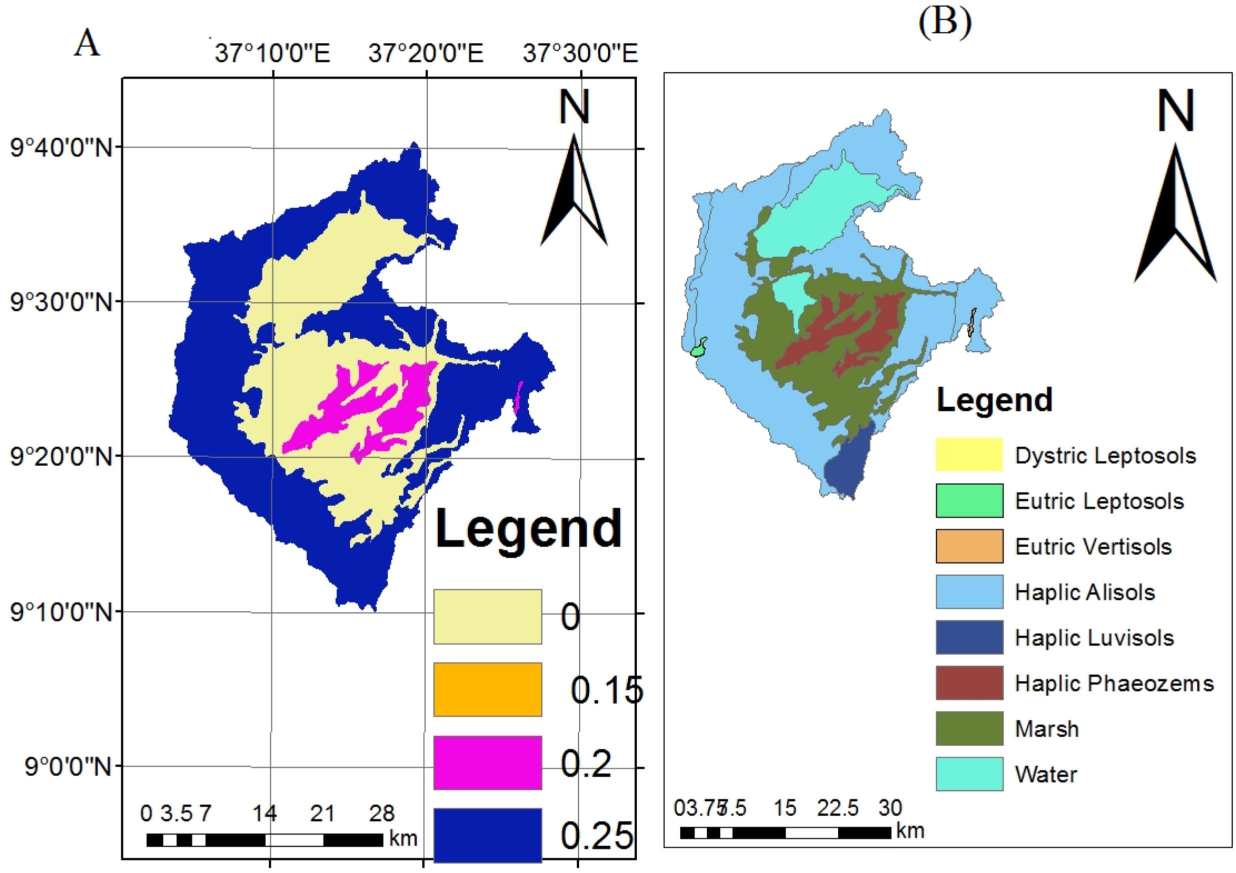

Figure 4.3 K-factor map (A) respective Major Soil types in the study area (B)

### 4.3. Slope length and steepness factors (LS)

The slope length and slope steepness factors are commonly combined in a single index as LS and referred to as the topographic factor. The LS-factor value of the study area ranged from 0 to 236 (Figure 4.4). All corner parts of the study area are characterized flat and gentle slopes except west part, North West, south west are characterized by steep slopes and some fragmented hills. As illustrated in Figure 4.4, the corner parts of the study area has been flat and gentle slopes which had lower LS-factor value of 0 to 5.5 while the higher LS- factor values of 53.8 to 236.8 were mostly observed. This is because, as the slope gradient increases, the value of LS-factor also increases. Consequently, soil erosion also increases. Therefore, at the area, where smaller LS-factor values existed, the expected soil erosion due to this factor would be less and at the area where, larger LS-factor values existed, the expected soil erosion would be more. In follows of this the area vulnerable with soil erosion was west, northwest and southwest part of the catchment because of they had steep slope which more conservation need practice.

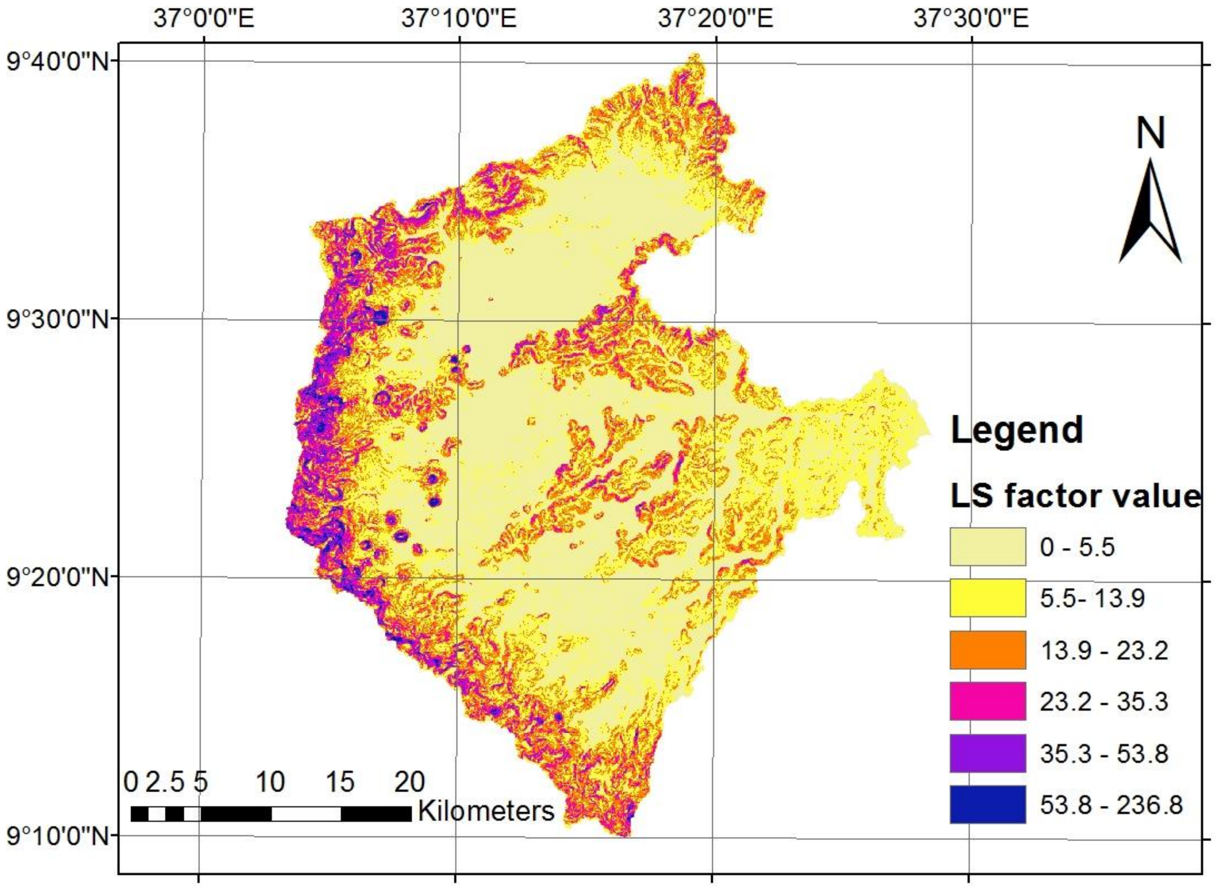

Figure 4.4 LS- factor map of the study area

## 4.4. Cover Management Factor (C)

As shown in (Figure 4.5) the C-factor values of the study area ranges from 0.001 to 0.6. The estimated Cover Management (C)factor of the study area shows that northeastern corner and Central parts were covered by water body, northern part were covered by dense forest, North West which has low C-factor values. Sparse forest found all parties of study area except east part of the study area. In this study bare soil has the higher c-factor which has the higher the soil loss had been found upper part of the study area. It was exposed to erosion because the higher the C-value, the higher the soil loss would be occurred. Therefore, soil cover in the form of crop plants, cover crops, mulches, or residues can protect soils from wind and water erosion, enhance water infiltration, and help maintain or increase organic matter. Thus, they have low C-factor values that have low contributions to the soil loss.

Table 4.3 Cover Management Factor (C)

| Land cover/use type | Cover Management Factor (C) values | Source/References |
|---|---|---|
| Cropland | 0.15 | Hurni (1988) |
| Open shrub | 0.014 | CGIP (1996) |
| Bare Soil | 0.6 | BCEOM (1998) |
| Closed shrub | 0.01 | Eweg and van Lammeren (1996) |
| Closed grass | 0.05 | CGIP (1996) |
| Dense Forest | 0.001 | Hurni (1988); Zerihun et al.,(2018) |
| Sparse Forest | 0.02 | Hurni (1988) |
| Water body | 0 | Hurni(1985) |
| wetland | 0.001 | Wischmier and Smith (1978) |
| woodland | 0.06 | Eweg and van Lammeren (1996) |

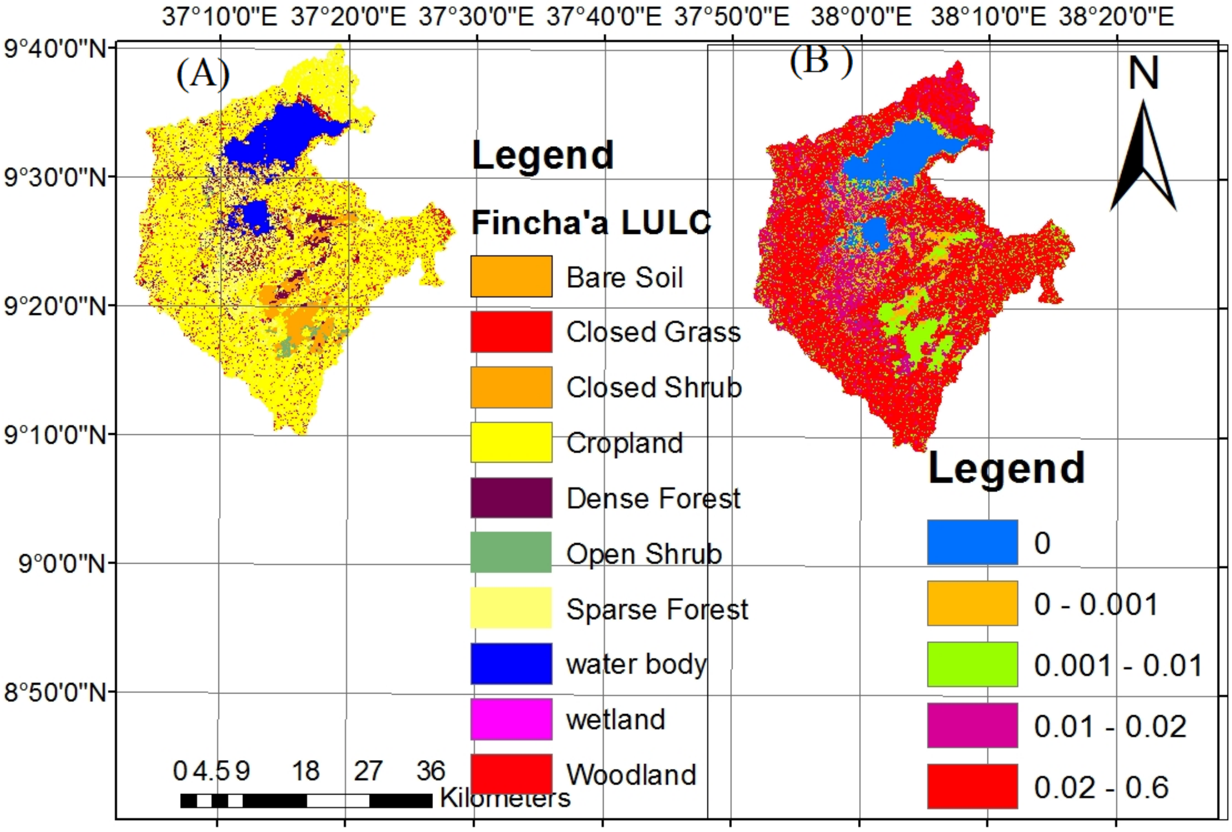

Figure 4.5 LULC map of study area (A) with respective C factor map (B)

## 4.5. Support Practice Factor (P)

A combination of LULC classes and slope was used in computing P factor and provided us with Conservation factor maps for the watershed. These value were added in attribute of land cover type based on reference available in various literature and the map for conservation practice was prepared .As we can see from (Figure 4.6 ) the P-factor values of the study area was ranged from 0.11 to 1. The P-factor values were found to be low in the central part of watershed corner of northeastern, western, northwestern and southeastern part of the study area which shows the Conservation practice was highly done were p factor value approach to zero while most corner part of south, southwestern and northwestern the P-factor values were high because there was no conservation practice was done so the p factor value approach to one.

Table 4.4 Land Management Factor (P) values

| Land use land cover type | Slope (%) | P factor |
|---|---|---|
| Farm land | 0-5 | 0.11 |
| | 10-20 | 0.12 |
| | 20-30 | 0.14 |
| | 30-40 | 0.12 |
| | 40-50 | 0.31 |
| | 50-100 | 0.43 |
| Other land | All | `1 |

Source: Adapted from Wischmeier& Smith (1978); Gelagay et al, (2016).

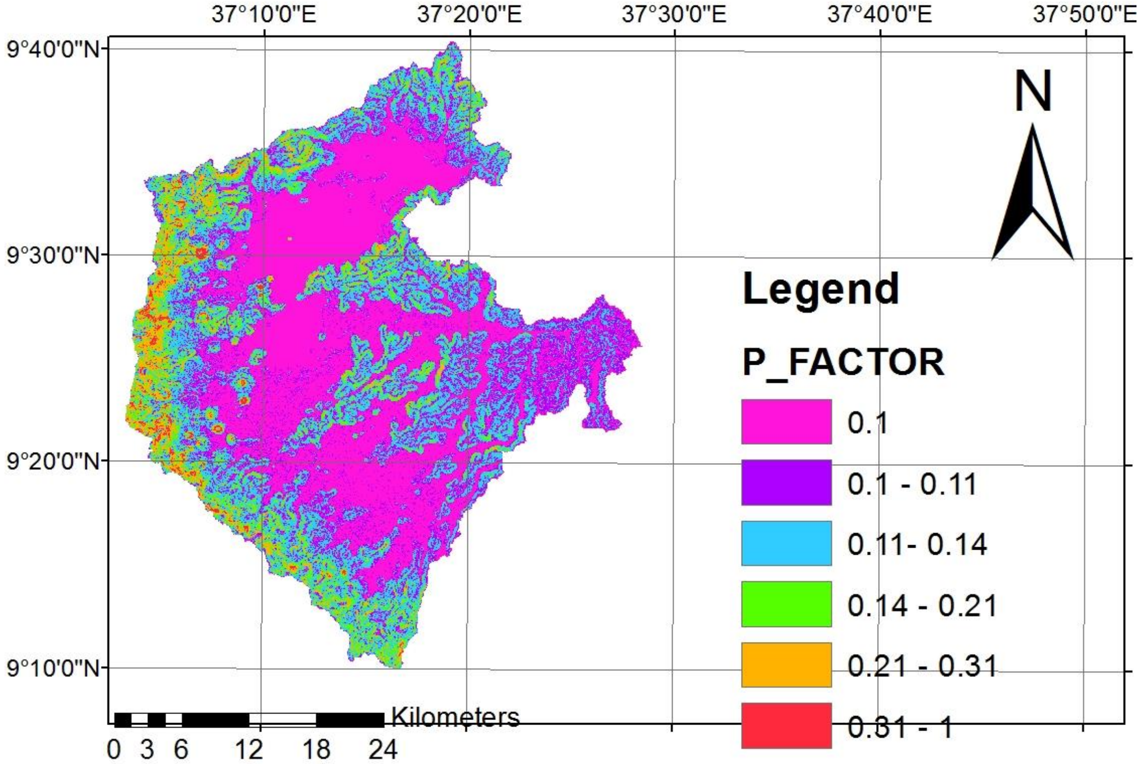

Figure 4.6 Support Practice Factor map (p)

## 4.6. Estimated average annual soil loss

The pixel-based modeling results show that the spatial distribution of the annual soil loss rate varied from 0 to 375 ton/ha/yr in flat area and in degraded sloppy area respectively. The average annual soil loss rate was found to be 31 ton/ha/yr (Figure 4.7). The total soil loss of the watershed was found to be 4.08 million tons per year of sediment from 1318 square kilometer of land.

The result showed that the catchment is experiencing quit large spatial variation of soil loss due to quit large difference in topographical condition, land use land cover variation and higher rainfall variation. It is because; these factors are the major factor affecting soil erosion in the study area. Accordingly, the watershed was classified in to six severity classes to identify the most prone area to erosion, moderately affected area, list affected area and other respective trends of erosion conditions. In terms of exposure to the risk of erosion, about 46 % of the watershed was characterized by low to moderate soil erosion problem, which was from 1 to 11 ton/ha/yr and such area can be considered as areas with tolerable soil erosion risk area. The remaining percentage area was categorized under, high, very high, sever and very sever soil erosion risk areas of 4, 3, 1 and 46 % of the study area respectively (Table 4.1).

According to Girmay, G., Moges, A. & Muluneh, A. (2020),the estimated soil loss rate was classified into six severity class, which were adapted from like low (0 - 5 ton/ha/yr), moderate (5 – 11 ton/ha/yr), high (11 – 25 ton/ha/yr), very high (25 - 50 ton/ha/ yr), severe (50-100 ton/ha/yr), very severe (>100 ton/ha/yr ).

In the Ethiopian highland case erosion rate ranging between 2 and 18 ton/ha/yr is believed to be tolerable (Hurni 1985).Soil loss tolerance refers to the maximum soil loss that can occur from a given land without leading to degradation of the soil (Renard et al., 1996) and this is estimated to be 5- 11 ton/ha/yr. In line with this, the central parts of the study area which covered about 46 % of the total area, could be considered as low soil erosion risk area .This is because; the result of soil erosion rate in this area was found to be in a range of maximum tolerable erosion limit of 11 ton/ha/yr, the area covered by sparse forest and cropland as shown from results. As it has been stated by Yahya (2013), LS-factor, R-factor and K-factor, have a significant effect on the process of erosion in decreasing order. Therefore, the lower values of soil loss vulnerability was because of the central parts of the study area is characterized with relatively flat and gentle slope having lower LS-factor and the lower rainfall erosivity as well as the lower K-factor values shown in (Figures 4.1, 4.2 and 4.3).

Based on the result found, about 54 % of the study area was identified to be highly suffered in soil erosion. This part of the area is found mostly at the northwest of the catchment due to LS factor and northeastern due to rainfall part of the catchment ( Figures 4.3 and 4.4). This is due to the higher erosive power of rainfall that comes from higher rainfall intensity around the specified area, due low cover management factor, due to low value of k factor and the higher LS-factor values which resulted from cultivation on steep slope lands (Figures 4.3 and 4.4). Table 4.1 clearly indicates the area coverage and relative percentage of each soil erosion severity class for current condition of the study area.

The estimated soil loss rate and the spatial patterns are generally realistic, compared to previous studies on some of Ethiopian basins and watersheds. For instance, soil loss rate estimated by Hurni (1985) for Ethiopian highlands ranges from 0.0 to 300 ton/ha/yr. Temesgen (2017) also reveals that the soil loss rate ranges from 0 to 237 ton/ha/yr. A recent comprehensive study by Haregeweyn *et al*. (2017) in the upper Blue Nile basin also found a comparable result ranging from zero to 200 ton/ha/yr.

Unlike the findings of this study, some studies however, report a rather higher rate of erosion in different parts of Ethiopian watersheds. The result in this study is somehow lower than the estimates for Chemoga watershed with 93 ton/ha/yr Zerihun et al. (2018) for Dembecha district 49 ton/ha/yr , Gelagay and Minale (2016) for Koga watershed 47 ton/ha/yr.

On the contrary relatively lower soil loss results were reported by Gashaw et al. (2017) 23.7 ton/ha/yr for Geleda watershed and Miheretu and Yimer (2018) 24.3 ton/ha/yr for Gelana sub-watershed and Haregeweyn et al. (2017) 27.5 ton/ha/yr for Upper Blue Nile Basin. This could be attributed to highland mountainous and steep slope conditions to gather with relatively higher rainfall in upper Fincha'a watershed. This variation of results comes from the actual existing condition of the watersheds. According to Beskow et al.,(2009) Soil erosion severity class was categorized as shown table below.

Table 4.5 Soil erosion severity class and corresponding percent coverage area.

| Current soil erosion status of the study area | | | |
|---|---|---|---|
| Soil-loss rate ton/ha/yr | Area (km$^2$) | Area coverage (%) | Severity Class |
| < 5 | 47423.6 | 36 | Low |
| 5-11 | 12944.1 | 10 | moderate |
| 11-25 | 4968.3 | 4 | high |
| 25-50 | 3494.7 | 3 | very high |
| 50-100 | 1777.3 | 1 | Sever |
| > 100 | 61192.1 | 46 | Very Sever |
| total | 131800 | 100 | |

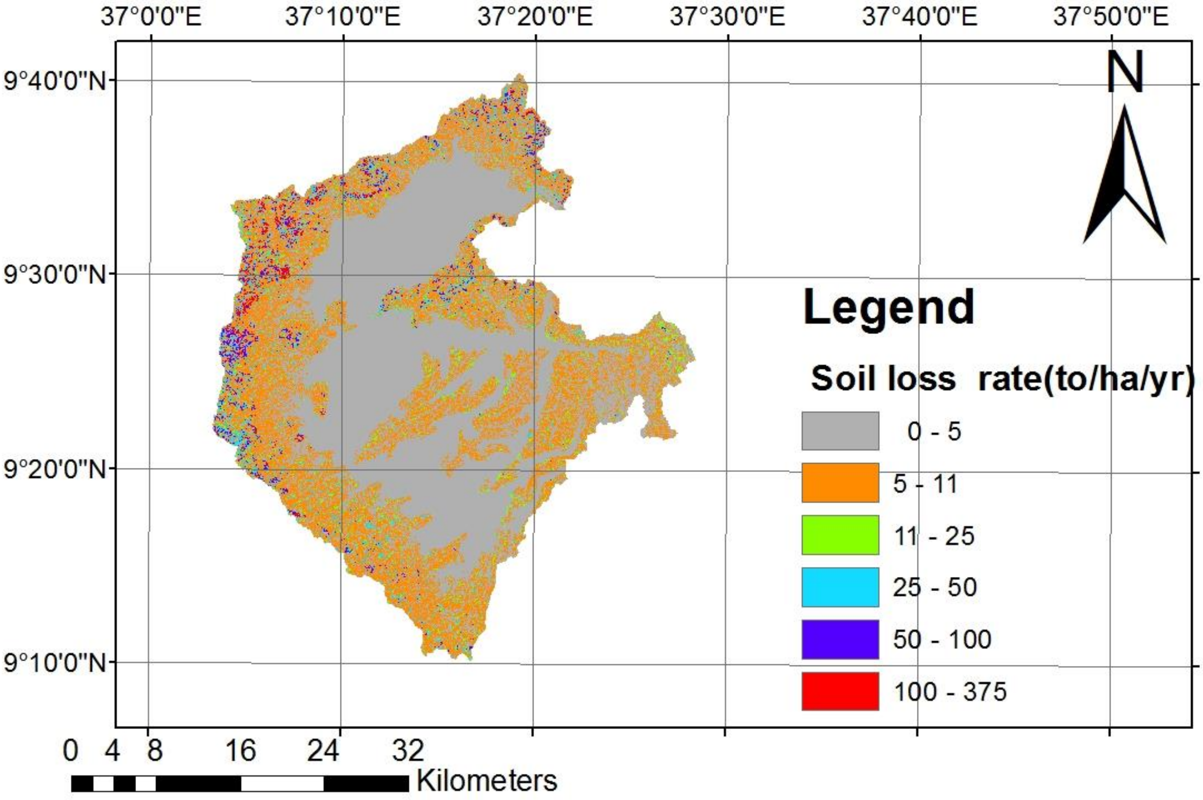

Figure 4.7 Map of soil loss rate in study area

## 4.7. Estimation of Sediment Yield

The sediment delivery ratio (SDR) denotes the ratio of the sediment yield at a given stream cross section to the gross erosion from the watershed upstream from the measuring point (Julien and Frenette 1998). Using the empirical equations, the sediment yield at the watershed outlet was calculated as follows

$SDR = A^{-0.2}$ ----------------------------------------------------------------------------------------------------------------------(4)

Where, SDR denotes the sediment delivery ratio and A area of the watershed. The SDR physically means the ratio of the sediment routed to the outlet over the watershed, both overland and channel. It is a measure of sediment transport efficiency which accounts for the amount of sediment that is actually transported from the eroding sources to a catchment outlet compared to the total amount of soil that is detached over the same area above that point. The sediment delivery ratio value in a given watershed indicates the integrated capability of a catchment for storing and transporting the eroded soil. SDR compensates for areas of sediment deposition that become increasingly important with increasing catchment area and therefore, determines the relative significance of sediment sources and their delivery.

Sediment yield is important for tells us how our top soils are being eroded by running water. Sediment yields are also very high at the out let of the watershed. To generate the sediment yield at the outlet, empirical equations were carried out.

$SDR = A^{-0.2}$

$SDR = (131800)^{-0.2}$

$SDR = 0.237$

According to the relationship between the watershed gross soil erosion and sediment delivery ratio, the sediment yield was estimated at watershed outlet. The result reveals that from the gross 4085800 ton/year soil erosion, 386628.64 ton/year were estimated at watershed outlet and estimated by the following empirical formula:

$SY=E*(1/A^{0.2})$ --------------------------------------------------------------------------------------------(5)

Where, Sy= Sediment yield (ton) at the watershed out let, E = total erosion (ton), A = Watershed area (ha), $Sy = 4085800 *(1/131800^{0.2})$ and Sy = 386628.64 tons per year.

The transporting ability of the runoff to move all the eroded sediments is insufficient. As a result deposition occurs in reservoirs, depressions, at the toe of the hills where changes slope. Thus the amount of erosion in the watershed is generally more than the amount of sediment leaving the watershed at the outlet point. Sediment yield estimation in this study therefore plays a vital role for upper Fincha’a catchment as a whole in identifying critical sediment source areas and to take site specific measures such as different drainage and water harvesting structures. An accurate prediction of SDR is also important in controlling sediments for sustainable natural resources development and environmental protection.

### 4.8 Soil erosion vulnerability

Overall, the soil loss vulnerability in the study area can be associated with the LS factor, erosivity factor, soil type and LULC of the area. This study made it possible to observe that high to very high soil erosion vulnerability occurs in the Haplic Alisols whenever it is associated with bare soil and sever to very sever vulnerability coincides with high LS values.

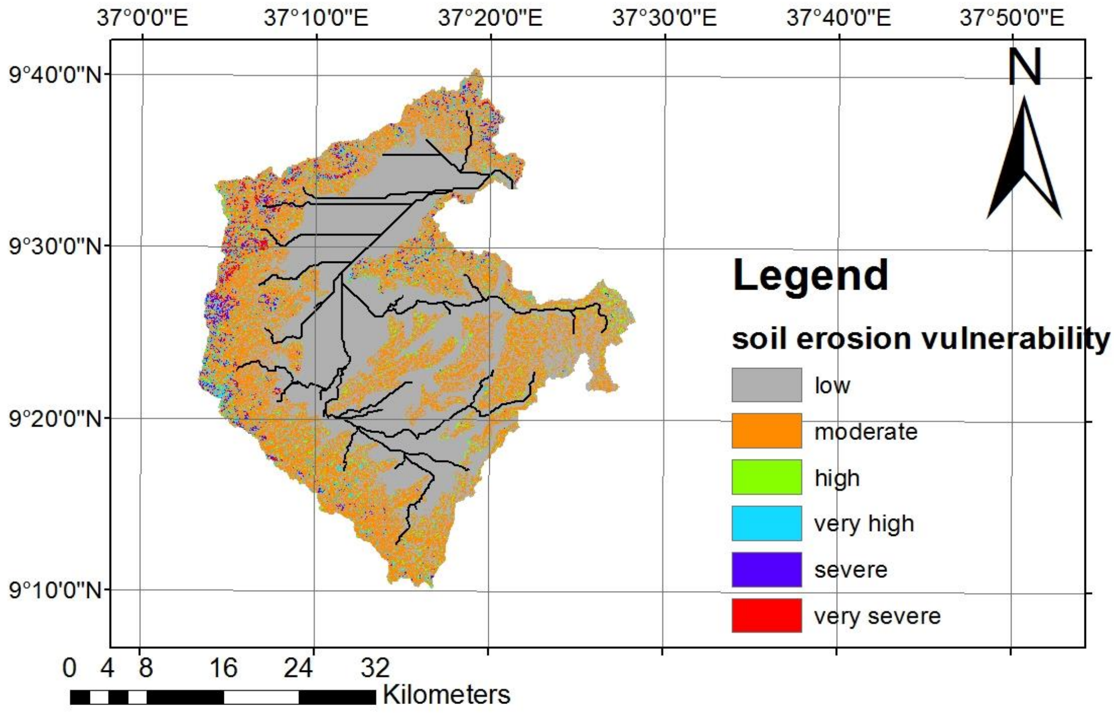

Figure 4.8 Map of soil erosion qualitative vulnerability for Fincha'a watershed.

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1. Conclusions

The upper Fincha'a watershed is located between 9°10'30''and 9°46'45'N latitude and 37°03'00" and 37°28'300''Elongitudes in Horo Guduru Wollega Zone of Abbay Chomen and Hareto District. The study demonstrate that an empirically based erosion assessment model, the RUSLE, integrated with satellite remote sensing and geographical information systems can provide useful information for conservation decision-making. It is also apparent that GIS provides a great advantage to analyze multi-layer of data spatially and quantitatively within the watershed. The estimation of soil loss in the watershed using GIS is also in the ranges of other studies. Basic data sets were organized and analyzed for estimating annual soil loss, sediment yield at outlet and to identify vulnerable area with soil erosion. The result revealed that the spatial data-processing efficiency GIS integrating with RUSLE is capable of quantifying soil loss, and sediment yield of the fincha'a watershed. The study generated a 30 × 30 m resolution soil erosion layer by employing RUSLE which is integrated with a GIS analysis for the Fincha'a watershed. The result of this study provides an understanding of the risks of soil erosion and the main factors that are contributing to the vulnerability of the watershed to erosion.

It can be concluded that the dominant contributors to erosion in the watershed are R-factor and LS-factor. The result discovered that the slope and LS-factor were highly matched with the soil loss layer of the watershed and played a larger role in its soil erosion. The soil loss of the watershed is comparable to similar studies in the nearby Ethiopia Highlands in particular and countrywide erosion levels in general. The estimated soil loss rate of watershed was classified into six severity classes of erosion, which were adapted from like low (0 -5 ton/ha/yr), moderate (5–11 ton/ha/yr), high (11–25 ton/ha/yr), very high (25-50 ton/ha/ yr), severe (50-100 ton/ha/yr), very severe (>100 ton/ha/yr ).The pixel-based modeling results show that the spatial distribution of the annual soil loss rate varied from 0 to ton/ha/yr in flat area to 375 ton/ha/yr in degraded sloppy area with average annual soil loss rate of 31 ton/ha/yr. The estimated of sediment yields at watershed outlet was 386628.64 ton/yr from 1318 square kilometer by using SDR and the total soil erosion. The result also reveals that most of the watershed erosion severity evaluated under low and moderate soil erosion severity classes covering 46 % of the watershed areas which is due to the effect of Cropland and Sparse Forest which shows less vulnerable to soil erosion and about 54 % of the study area was identified to be highly suffered in soil erosion .This is because; the result of soil erosion rate in this area was found to be above the range of maximum tolerable erosion limit previous stated in Ethiopia high lands based on study area. The estimated soil loss rate and the spatial patterns are generally realistic, compared to previous studies on some of Ethiopian basins and watersheds. Nevertheless, it is imperative to remind that the estimated soil loss values might not be completely free from errors because of the inherent limitations of the RUSLE model. The soil erosion-prone areas map generated in this catchment provides necessary information for soil and land resources management practices for the implementation of either structural or nonstructural soil conservation measures. From this study, it was found that the upper and the low-lying areas are highly vulnerable to soil erosion and a soil conservation strategy should be implemented to control the loss of top fertile soil in the catchment. Additionally, capacity building training should be given for the farmers and soil conservation experts to minimize the man-made soil loss driving factors such as deforestation and traditional way of farming practices. Finally, it was concluded that having information about the spatial variability of soil loss severity map generated in the RUSLE model has a paramount role to alert land resources managers and all stakeholders in controlling the effects via the implementation of both structural and non-structural mitigations. The results of the RUSLE model can also be further considered along with the catchment for practical soil loss quantification that can help for protection practices. Because of lack of decision support studies for watershed- level resource management in the area, the Fincha'a reservoir which has been designed to serve for 50 years is currently reducing in its size due to sediment accumulation from its upstream. Therefore, the result of this study is important to design and implement conservation measures to reduce soil loss in the watershed and sediment accumulation to the reservoir. The limitation of the study is that the results were not validated with measured values because of a lack of ground measurements since I encountered limited resources and time to undertake ground verifications. Based on my study, I recommend researchers incorporate more soil erosion models for comparison to find out the best results and to validate the estimations with measurements. I also recommend local land managers to design and construct conservation measures suitable for the land use and adaptable to the slope to reduce soil loss in the watershed. The model could be adapted to similar studies in the area following appropriate adjustments, and this study could be a source of information for related researches that will be conducted in the area.

## 5.2. Recommendations

Even though the success of conservation and management practice depends on the integrated factors of money, time, technical skills, appropriate policies and cultural perceptions of the communities, the research recommends the following important points on the basis of the result of the study.

- In the soil loss rate map, areas which were identified as extensive soil loss should be given a serious attention and priorities when implementing soil conservation and management activities before the area jumps to recover soil degradations.
- For long-term soil resource conservation and erosion preventions especially in steeper slopes, protection and conservation of existing vegetation cover and/or replanting forest in cultivated lands is deemed necessary for the sustainability of soil and other natural resources in the study area.
- Although, GIS, RS and Multi-Criteria Evaluation model is a valuable tool for the quantifications and mapping of an estimated value of soil loss at various locations, further studies in limited spatial scale using high resolution data is recommended to monitor and mitigate the areas appropriately.
- Also, for effective conservation of watershed resources, the study recommends that there is a need to plan for sustainable watershed management through effective soil and water conservation activities with the active participation of the local people.

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