Jimma University

College of Social Sciences and Humanities

Department of Geography and Environmental Studies

Watershed Based Spatial Modeling of Soil Loss Using RUSLE Model, GIS and Remote Sensing Techniques: The Case of Gulufa Watershed, Dabus River Basin, West Ethiopia

By

Abdeta Tolassa Fayisa

Thesis Submitted to the Department of Geography and Environmental Studies, School of Graduate Studies, Jimma University, in Partial Fulfillment of the Requirement for the Degree of Master of Sciences (M.Sc.) in Geographic Information System and Remote Sensing

Major Advisor: Dr. Ajay Babu

Co-Advisor: Mr. Wondafrash Geneti

June, 2019

Jimma, Ethiopia

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DEDICATION

This thesis work is dedicated to my father Tolassa Fayisa and my mother Damme Terfa those are passed away within a week 28 years ago before my age reach for school.

STATEMENT OF THE AUTHOR

First and foremost, I declare that this thesis is my legitimate work and all the material sources used have been duly acknowledged. This thesis had been submitted in partial fulfillments of the requirements for M.Sc. degree at Jimma University College of Social Sciences and Humanities (JUCSSH). I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate. It is made available at the Jimma University's library to borrowers as per the rules and regulations.

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Date of submission June, 2019

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LIST OF ACRONMYS

AGNPS	Agricultural Non-Point Source
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
EGS	Ethiopian Geological Survey
EPA	Environmental Program Authority
ERDAS	Earth Resource Data Analysis System
EUROSEM	European Soil Erosion Model
FAO	Food and Agriculture Organization
GIS	Geographic Information Systems
GPS	Global Positioning System
LULCC	Land Use Land Cover Classification
MoARD	Ministry of Agriculture and Rural Development
MSANRO	Mana Sibu Agriculture and Natural Resource Office
NMA	National Meteorological Agency
OWWDSE	Oromia Water Work Design and Supervision Enterprise
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SLM	Sustainable Land Management
SSA	Sub-Saharan Africa
SWAT	Soil and Water Analysis Tool
SWC	Soil and Water Conservation
UNDP	United Nations Development Programme
USDA	United State Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Traverse Mercator
WEPP	Water Erosion Prediction Project

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ABSTRACT

Soil erosion is a serious environmental and long lasting problem resulting in both on-site and off-site effects that has political, environmental, economic and societal implications in Ethiopia as a country and is a common challenge for agricultural production. The aim of this study was to estimate annual soil loss using Revised Universal Soil Loss Equation (RUSLE) model within Geographic Information Systems (GIS) environment to quantify the actual soil loss of Gulufa watershed. Accordingly, rainfall data from rainfall stations, soil data from Dabus River basin digital soil map, slope steepness and length from Digital Elevation Model and Sentinel-2 image were used as input datasets to generate factor maps. Raster calculator was used to interactively calculate actual soil loss of these factors. The results showed that the actual annual soil loss ranges from 0 to 439.22 ton/ ha/ year with the mean annual soil loss of 21.24 ton/ha/yr. Based on annual soil loss rates, the area suffers from a low to moderate annual soil loss covered about 73.39% (8986.32 ha) whereas high to very severe soil loss covered about 26.6% (3258.15 ha) of the study area. Among the 13 sub watersheds, five (35.1%) were experienced annual soil loss more than the watershed's mean (21.24 ton/ha/year) are given priority from 1-4 whereas eight sub watersheds soil loss (64.9%) were less than the mean which is given the last 5-6 ranks. The study demonstrates that Revised Universal Soil Loss Equation together with Geographic Information Systems and remote sensing are useful tools to estimate soil loss over small areas. Therefore, spatial modeling of soil loss and prioritization of proneness areas from high to very severe soil loss is recommended to be intervened soil and water conservation plan for the prioritized sub watersheds.

Keywords: Conservation, Land use land cover, Gulufa Watershed, RUSLE, Soil Loss

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Soil erosion by water is a severe environmental problem in many parts of the world especially in developing countries (Deniz *et al.,* 2008; Toros *et al.,* 2008). Degradation of agricultural land by soil erosion is a worldwide phenomenon leading to loss of agricultural lands, nutrient rich surface soil and decreased water availability to plants. Soil erosion as a result of uncontrolled land use, deforestation, over cultivation, over grazing, exploitation of biomass for firewood and family uses due to increasing population ultimately lead to intense soil erosion. Soil erosion rates are estimated that 85% of global land degradation is related to soil erosion (Piccarreta *et al.,* 2006). It is also estimated to be the highest in Asia, Africa and South America ranging on average between 30 and 40 tons per hectare per year. In Africa only estimated that the decrease in agricultural productivity due to soil loss is between 2 to 40% with an average of 8.2% for the whole continent and with average of 19% of reservoir storage volumes been silted (Andersson, 2010).

Soil erosion and land degradation are major problems of Ethiopian highlands. It is expected that 1.5 billion tons of soil is being eroded every year in Ethiopia. The average soil loss rates on croplands have been estimated at 42 ton/ ha/ year and also reach up to 300 ton/ ha/ year in individual fields (Hurni, 1993). FAO (1986) estimated that some 50% of the highlands are significantly eroded, of which 25% are seriously eroded and 4% have reached a point of no return. This shows the impacts of soil erosion on loss of fertile top soil, decline of soil productivity and reduction in water quality in river networks become severe as essential plant nutrients depleted. Therefore, the area at risk can be mapped using an appropriate model of soil erosion (Flugel *et al.,* 2003). Such processes of mapping or modeling of risk area is important to take appropriate onsite conservation practices or create societal awareness.

The most common empirical soil erosion prediction models integrating with Geographic Information System (GIS) and remote sensing (RS) are Universal Soil Loss Equation (USLE) later Revised Universal Soil Loss Equation (RUSLE), Water Erosion Prediction Project

(WEPP) and Coordination of Information on the Environment (CORINE). These models can effectively used for soil loss mapping. Among these, RUSLE was developed to estimate the annual soil loss per unit area based on erosion factors including rainfall, erodibility, topography, land use land cover and conservation practices (Yuksel *et al.,* 2008). The RUSLE model, due to its simple structure and empirical basis and integration with GIS and RS, is a frequently used tool in estimating average annual soil erosion rates at local, regional or global scales (Naipal *et al.,* 2015). It has also the capacity to estimate soil erosion by incorporating the environment having complex and varying gradients (Zhao *et al.,* 2009).

The use of GIS and RS techniques in soil erosion estimation and its spatial distribution have become feasible with reasonable costs and better accuracy in modeling larger areas (Lu *et al.,* 2004). There have been many studies on estimating soil erosion by utilizing GIS and RS technologies (Wischmeier and Smith, 1978; Hurni, 1993; Haregeweyn *et al.,* 2013). The capabilities of these technologies even increase when they are integrated with empirical erosion prediction models. While soil erosion models only calculate the amount of soil loss based on the relationships between various erosion factors, GIS and RS integrated erosion prediction models do not only estimate soil loss but also provide the spatial distributions of the erosion and identify the spatial patterns of soil loss within a watershed (Millward and Mersey, 1999). Especially, generating accurate and timely soil erosion risk maps in GIS environment is very important to locate the areas with high erosion risks and to develop adequate erosion prevention techniques (Yuksel *et al.,* 2008).

Gulufa watershed is one of the sub watersheds of Dabus River basin that finally flows to Abay (Blue Nile) River basin. If this watershed is managed properly, it reduces the amount of sediments that reaches Dabus River which in turn contributes to the reduction of sediment load at the downstream where there is ongoing construction of Grand Ethiopian Renaissance Dam (GERD) is underway. Hence, spatial estimation of soil loss and its spatial distribution in response to different factors have great importance for designing appropriate soil and water conservation (SWC) practices and monitoring of soil nutrient status to increase the production capability of lands in the study area accordingly. However, basic information on extent of soil loss its spatial distributions and soil nutrient status are remained poorly understood to give recommendations for optimal and sustainable utilizations of land resources. Therefore, the present study was conducted with an aim to assess the extent of soil loss and its spatial distribution in Gulufa watershed using RUSLE model, GIS and RS.

1.2. Statement of the problem

Soil erosion is a major global environmental problem having widespread and serious negative effects on agricultural production, infrastructure, water quality, biodiversity and promoting the emission of climate changing greenhouse gases (Pimental *et al.,* 1995 and Lal, 2004). Even though soil erosion can be caused by natural or geological processes, anthropological process of the landscape or accelerated erosion is the major triggering factor for the loss of soil and water resources. Erosion results in the degradation of soil productivity in a number of ways-it removes plant nutrients, reduces rooting depth due to loss of soil mass, and reduces the soil water-holding capacity, which in turn increases runoff (Lal, 2001). Erosion not only damages the immediate agricultural areas where it occurs but also negatively affects the surrounding (e.g. sedimentation and water pollution). The problem has far reaching economic, political, social and environmental implication due to both onsite and offsite damages it creates (Pandey *et al.,* 2007).

Ethiopia is one of the developing countries in Sub-Saharan Africa (SSA) depends on agriculture to satisfy demands for foods, fibers and other goods. The diminishing crop productivity, resulting from degradation of agricultural land induced by soil erosion has been and is still a major concern (Amare, 2005). As indicated by Tamene *et al.* (2006), some 50% of the highlands of Ethiopia were already significantly eroded, and erosion was causing an annual decline in land productivity of 2.2%. To estimate this soil loss many empirical models have been developed and highlighted for estimating soil loss. The USLE was originally developed for soil erosion estimation in crop lands on gently sloping topography (Wischmeier and Smith, 1978). The RUSLE has broadened its application to different situations including forest, rangeland, and other disturbed areas (Renard, 1997).

The traditional methods of quantifying soil loss based on erosion plots poses many limitations in terms of cost, representativeness and reliability of the resulting data. Such methods cannot provide spatial distribution of soil erosion loss due to the constraint of limited samples in complex and large areas environments (Lu *et al.,* 2004). The alternative solution is to use the

RUSLE as it has better technical capability and easily integrates with spatial data analysis in GIS and RS platforms. The assessment of soil loss as result of erosion factors can be very helpful to identify the increment and the degree of the soil loss to establish conservation plans and soil fertility management practices.

Meanwhile, the study area, Gulufa watershed, is characterized by having large population settlement, undulating topography, deforestation and severe termite infestation that might have made the area vulnerable to accelerated soil erosion. On the other hand, shortage of grazing lands and large cattle population in the area could have forced land use land cover conversion and the removal of crop residues from cultivated land for animal feed that might have caused the soil nutrient depletion in this study watershed. And also, many farmers have been subjected to continuous cultivation of lands without adequate SWC measures and soil fertility amendments.

Although the consequence of soil erosion results in soil nutrient depletion from time to time is serious in the study area in particular and Western Ethiopia in general, it has not received more research attention. Only few studies were done (e.g. on evaluation of soil acidity in agricultural soils of smallholder farmers (Abdenna, 2013) and the relationship of topsoil properties with coffee production (Likassa, 2014)). Dawit (2012) also conducted the assessment of farmers' adoption of land rehabilitation practices in the case of Mana Sibu district, West Ethiopia. Those studies have mainly concentrated on soil quality analysis and adoption of onsite land rehabilitation practices. Therefore, the study was focused on spatial modeling of soil loss by water erosion in order to obtain reliable data in terms of both scientific and applied for sustainable soil management. Thus, the aim of this study is to estimate soil annual soil loss by identifying erosion prone areas using RUSLE model within GIS and RS techniques.

1.3. Objective of the study

1.3.1. General objective

The General objective of study is to estimate soil loss by water erosion from sheet and rill erosion at Gulufa watershed through integration of RUSLE model within GIS and RS techniques.

1.3.2. Specific objectives

- To estimate mean annual soil loss from sheet and rill erosion over Gulufa watershed.
- To map spatial variation of soil erosion prone areas at Gulufa watershed.
- To identify sub watersheds priority areas for soil conservation planning.

1.4. Research questions

- How much a tone of soil is lost from the Gulufa watershed annually?
- Where is the erosion hotspot areas located for conservation prioritization?
- For which sub watersheds soil conservation priority is given?

1.5. Significance of the study

The dynamic nature of soil erosion, associated processes and its dependence on climatic, soil, topography, and land cover and conservation factor result in spatial and temporal variability. The information on the extent, severity and spatial distribution of eroded lands are of paramount importance for planning the reclamation strategies and setting up preventive measures for sustainable agricultural development. In addition, the soil loss estimated by different researchers could vary for the same environment. This implies that there is a need to have watershed specific information on soil erosion to support timely information. As different portions of the landscape vary in sensitivity to erosion through differences in their topography, soil and land cover attributes; it was necessary to estimate rates of soil loss and develop a soil loss intensity map of the study watershed using RUSLE within GIS environment to identify severity areas and prioritize for specific SWC plans. The results add value to scientific documentation that used by the farmers, decision makers, planners and

NGOs in design and implementing of SWC by providing information on soil loss and suggests some key issues for further redesign.

1.6. Scope of the study

This study is actually a watershed level study. Geographically, the study was undertaken in Gulufa watershed of Dabus sub River basin which is one of the tributary of the Nile river basin. The study was used rainfall, soil erodibility, topographic factor, land cover and conservation practices factor data. The study was also focused on soil loss by water erosion in Gulufa watershed by using RUSLE model integrating with ArcGIS 10.5 and earth resource data analysis system (ERDAS) IMAGINE 2015 in the LULC data analysis part.

1.7. Limitations of the study

The study has a significant role in the in the planning and implementation of soil and water conservation programs on time and in a cost effective way. The study has some the limitations of its own and attempts have been made to solve some of these limitations. Among these, the soil loss rate map using RUSLE model did not consider gully erosion. To maximize the representativeness of the result of the soil erosion rate map relatively dense metrological stations were required to spatially represent rainfall over the study area. Due to the unavailable rainfall stations inside the study watershed, the daily rainfall data for the stations located nearby the watershed were used. An attempt was made to fill the missed data in order to obtain the mean annual rainfall amount.

1.8. Organization of the thesis

This study is organized into five main chapters. Under Chapter one; Introduction of the study including statement of the problem, objective, significance, scope, limitations and organization of the study were described. Chapter two is deals with literature review part; Chapter three describes about materials and methods starting with description of the study area to methods of data analysis and ethical consideration; in chapter four the results and discussion of the study were presented in detail including the RUSLE factors and sub watershed prioritization. Finally, chapter five deals with conclusion which is drawn from the study and recommendations that were forwarded for further study.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Related concepts and definitions of soil erosion

Soil erosion: Soil erosion is a naturally occurring environmental process by which soil materials or particles are displaced, transported and deposited in downstream areas primarily due to forces of water, wind or gravitational (Gitas *et al.,* 2009; FAO, 2010; Amdemariam *et al.,* 2011). The three main phases of soil erosion are detachment, transport and deposition.

There are two main types of erosion: geologic and accelerated erosion. Geologic erosion is 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. The wearing a way of rocks and formation of soil profiles are processes affected by the slow but continuous geologic erosion. Indeed, low rates of erosion are essential to the formation of soil. In contrast, soil erosion becomes a major concern when the rate of erosion exceeds a certain threshold level and becomes rapid, known as accelerated erosion. It has adverse economic and environmental impacts. Worldwide, each year, about 75 billion tons of soil is eroded from the land a rate that is about 1340 times as fast as the natural rate of erosion (Surjit *et al.,* 2015).

Soil erosion is one of the major factors affecting sustainability of agricultural production. In developing countries, like Ethiopia, anthropological or accelerated erosion, which is mainly favored by human activities, is the major trigger factor for the loss of soil and water resources. To facilitate the urgent policy intervention that targeted soil degradation, study the amount of soil loss is inevitable. Although water and wind are both agents of soil erosion, wind erosion is not generally a problem of any significance in the humid areas (Feyissa, 2009). The level of soil erosion reflects its impact on soil resources. As investigated from studies made by Morgan (1996), soil's inherent property, climatic factors, terrain characteristics and the land cover were determined as significant factors and indicate the level of soil erosion.

2.2. Land degradation

Land degradation has wide and broader concept which comprises the degradation of soil, water, climate, fauna and flora (Ofori, 1993) but, this study focusing on degradation of land or removal of soil in terms of the soil erosion by water. Generally, land degradation due to water erosion is one of the most serious that globally and locally concerned today as threatens of agricultural and natural environment (Vrieling, 2006). Land degradation is a serious problem in worldwide with its most severe negative implication on the rural communities annually $42 billion income and 6 million hectare of land are lost globally due to land degradation and decline in agricultural production. The degradation is caused by soil erosion, loss of soil fertility and soil cover and chemical pollution. Furthermore, over cultivation, overgrazing and deforestation are the underlying causes of land degradation in rural areas (Samuel and Uttama, 2014; Adugna *et al.,* 2015).

2.3. Soil erosion

Mitchell and Bubnezer (1980) also defined soil erosion and soil loss as: Soil erosion is the gross amount of soil moved by drop detachment or runoff and soil loss is the soil moved off a particular slope or field. The soil loss rate is various from state to state and globally and regionally. About 80% of the world's agricultural land suffers moderate to severe erosion and 10% suffers slight to moderate erosion. Crop lands are the most susceptible to erosion because their soil is repeatedly tilled and left without a protective cover of vegetation (Pimentel, 2006). The study on global soil loss, indicate worldwide around 1.96 billion ha are affected by human-induced soil degradation mainly caused by water and wind erosion, 1094 million ha and 548 million ha respectively. Chemical degradation accounted for 240 million hectares, mainly nutrient decline, 136 million ha and secondary salinization 77 million hectares. Physical degradation occurred on 83 million hectares, mainly as a result of compaction, sealing, and crusting (Oldeman, 2000). According to (Pimental and Kounang, 1998), approximately 75 billion tons of fertile soil is lost annually from the world agricultural system.

According to the Ethiopian highland reclamation study (EHRS) (FAO, 1984), in mid-1980's 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. In general, soil erosion is the major factor causing for land degradation problem in Ethiopia, which in turn is threatening the agricultural productivity. A study by EHRS indicated that about 80% of the highlands of Ethiopia occur on crop lands whereas the remaining 20% were occurred on overgrazing grass lands, waste lands and deforested areas. This study estimated the annual soil loss from crop land in the Ethiopian highlands was to be 130 ton/ha and this was expected to result in a loss of 7.6 million ha of crop land to productive use in Ethiopia by the year 2010. According to Bobe *et al.* (2004) showed that the major cause of land degradation which needs further study in Ethiopia is soil erosion that leading to formulate appropriate strategies and policy for soil conservation measures for rehabilitation of degraded area for providing maximum benefits.

2.4. Soil erosion types

According to Mitiku *et al.* (2006) based on the stage of progress in the erosion cycle and the position in the landscape, various forms of soil erosion by water are there. From these: splash, sheet, rill and gullies erosion are the major ones and yields many varied impacts. The gradual development of erosion from the very subtle splash erosion in to gullies that almost always associated with accelerated erosion indicates the severity of soil erosion (Fernandes and Burcroff, 2006).

2.4.1. Rain splash/splash erosion

Rain splash is occurs when water falling directly on to the ground during rainstorms or when it is intercepted by the canopy and finds its way through the ground (Morgan, 1995). Some of the water infiltrates into the soil while some water stays on the surface saturating it and weakening natural soil aggregates so that the impact of subsequent raindrops breaks them down. According to Morgan (1995) it is the first stage of erosion process and its particles can rise as high 60 cm above the ground and move up to 1.5 meters from the point of impact.

Splash erosion; raindrops impacting the soil surface disperse and splash the soil, displacing particles from their original position. Splash erosion is caused by the bombardment of soil surface by impacting raindrops. Processes of splash erosion involve raindrop impact, splash of soil particles and formation of craters (Morgan, 2005). Raindrops striking the soil surface develop a raindrop-soil particle momentum before releasing their energy in the form of splash.

These raindrops strike the soil like small bombs forming craters or cavities of contrasting shapes and sizes. The depth of craters which is equal to the depth of raindrop energy penetration is a function of raindrop velocity, size and shape.

2.4.2. Sheet erosion

Sheet erosion occurs in the form of a shallow sheet of water flowing over the ground surface, resulting in the removal of a thin layer of soil from the soil surface. Surfaces run off formed when the rainfall intensity of a storm exceeds the infiltration capacity of the soil. Hurni (1983), describe that sheet and rill erosion are the most dangerous form of soil erosion in which resulting in an almost invisible but steady degradation of large areas under cultivation. The surface water flows that cause sheet erosion rarely flow for more than a few meters before concentrating into rills. During sheet erosion the entire surface of a field is gradually eroded in more or less uniform way (Robert and Hilborn, 2000). Sheet erosion is a gradual process and it is not immediately obvious that soil is being lost (Morgan, 2005). Sheet, splash, or inter rill erosion is the removal of a fairly uniform layer of soil from the land surface by raindrop splash or runoff water.

2.4.3. Rill erosion

Rill erosion is the detachment and transport of soil by concentrated flow of water resulted from intensive rainstorms produces more observable features of linear erosion often on steep slopes and in depressions. This feature forms channels up to 50 cm deep (Nyssen *et al.,* 2006). It is the predominant form of surface erosion and initiated at a critical distance down slope where surface runoff concentrates and becomes channeled. The water in a rill has sufficient depth for turbulence to develop in it and therefore entrain large particles (Morgan, 1995). Rill erosion happens as a result of concentrated overland flow that creates small channels up to a few inches in depth. The width and spacing of these channels will depend on soil properties (e.g., texture and structure) and management practices (e.g., tillage, roads, or trails).

2.4.4. Gully and stream bank erosion

Gully erosion produces channels larger than rills. Gullies are associated with accelerated erosion and carry larger sediment loads and display very erratic behavior. Gully erosion over

30 cm (one foot) deep is usually referred to as gullies. These ephemeral channels carry water during and immediately after rains. Gullies are distinguished from rills in that gullies cannot be obliterated by tillage. The amount of sediment from gully erosion is usually less than from upland areas, but the nuisance from having fields or developed areas divided by large gullies is often a greater problem (Fangmeier *et al*., 2006).

Gully erosion has a cross-sectional area/depth greater than 1 m^2 and smaller width than stable channels. They cannot be simply tilled out like a rill (Morgan, 2005). As more and more flow concentrates in rills, they deepen, speed up runoff, and lower the water table of alluvial lands. As the number of channels increase, peak flow increase and productive lands are lost. Stream bank erosion is the removal of the soil mass along the banks of rivers and streams. It is often causes damage to more productive bottom land soils and destroys the approaches to bridges and culverts. Stream bank erosion also causes bridge failure by removing materials that serve as footings.

2.5. Factors of soil erosion

Soil erosion is a complex process that physically takes place by the movement of soil particles from a given site. Erosion is triggered by a combination of factors such as steep slopes, climate (e.g. long dry periods followed by heavy rainfall), in appropriate land use, land cover patterns (e.g. sparse vegetation) and ecological disasters. Moreover, some intrinsic features of a soil can make it more prone to erosion (e.g. a thin layer of topsoil, silt texture or low organic matter content) (Gitas *et al.,* 2009). This indicates that the rainfall intensity, slope length and slope steepness and land use land cover are the major factors affecting soil erosion. Water erosion causes soil degradation, which is closely related to nutrient losses either in, the soluble form or adsorbed to soil particles, depending mainly on the adopted soil management system (Bertol *et al*., 2003). Understanding soil erosion controlling factors is vital to assess the amount of soil loss in a watershed (Mwawasi, 2013; Sharma and Goyal, 2016).

Generally there are five primary types of factors that affected soil erosion. These are Climatic factor, Soil (its properties like structure, texture, organic matter and permeability), slope length and slope steepness, land use land cover and conservation practices. These factors are interdependent to each other, as geology affects topography, which can influence climate and the like. Different soil erosion types and the formation of these erosions, there are several factors principally concerned which are climates, soil characteristic or soil type, slope length and slope steepness and land use land cover, including the crop management (Wischmeier and Smith, 1978; Hurni, 1993). All factors are related together directly and indirectly.

On the other hand, socio-economic and institutional factors are the underlying causes that affect surface runoff and soil erosion through their impacts on farmers' decisions with respect to land use land management practices. These factors include population pressure, poverty, limited access to agricultural inputs, credit facilities and the absence of comprehensive land use and disposal policies and land tenure systems (Tefera *et al.,* 2002; Kidane and Alemu, 2015). These five factors are mainly composed in models of USLE, RUSLE and as well as in other soil loss models.

2.5.1. Climatic factor

Climatic factors affect the magnitude and rate of soil erosion are; precipitation, humidity, temperature, evapotranspiration, solar radiation and wind velocity (Blanco and Lal, 2008). From these agents precipitation (amount and intensity) is one of the affecting driving forces and leading for water erosion. The effect of precipitation on soil loss is partly through the detaching power of raindrops striking the soil surface and partly through the contribution of runoff. Potential ability of rain to cause erosion is known as erosivity (R) factor (Renard *et al*., 1997). Raindrops while falling acquire kinetic energy and on impact, the kinetic energy is used up in detaching the soil particles. Energy is required to break the soil aggregates, splashing them and subsequently carrying them with runoff (Saavedra, 2005).

The raindrops which pound on the soil surface either infiltrate into the soil or leave the field as surface runoff. Runoff occurs when the precipitation rate exceeds the infiltration capacity of the soil, and then it collects and flows across the land surface. As the rainfall intensity and the mass, diameter and velocity of raindrops increases, the soil would be ready to be washed away from the ground through storm runoff (Bewket and Teferi, 2009). Soil loss is closely related to rainfall partly through the detaching power of raindrop striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1996). The most suitable expression of the erosivity of rainfall is an index based on kinetic energy of the rain. Different researchers mentioned different approaches of analyzing the R factor. For instance,

(i) $R = 9.28 * P - 8838$, mean annual erosivity (KE > 25) where P is mean annual precipitation (Morgan, 1984).
(ii) $R = 0.276 * P * I30$. Mean annual EI30, where P is mean annual precipitation
(iii) $R = -8.12 + 0.562 * P$

Most of the above formulas are location specific. The application of the formulas to other location depends on the relative similarity to the original area and the available data. The first equation appears to work well for Peninsular Malaysia, whereas the application for other countries is less satisfactory. Especially with the annual rainfall below 900 mm, the equation yields estimates of erosivity, which are obviously meaningless (Morgan, 1984). In line with this, the second equation needs the value of I30 for calculating erosivity factor, which is difficult to get in the context of the study area. Therefore, although there are many methods of calculating rainfall erosivity the values for the R factor in the present study was computed using the equation number (iii) which is $R = -8.12 + 0.562 * P$ proposed by Hurni (1985). Where: R= Rainfall erosivity P= mean annual precipitation (mm/year).

2.5.2. Soil erodibility factor

Soil erodibility defines the resistance of the soil to both detachment and transport (Morgan, 1995). Due to a different of soil properties function like soil texture, structure, soil moisture, roughness, organic matter content, chemical and biological characteristics, soils have different capacity of resistance to erosion (Mitiku *et al.*, 2006). Soil texture refers to the relative proportion of clay, silt and sand. Fine particles have cohesive property, as a result, they can resist detachment but easy to be transported whereas large particles are resistant to transport because they need greater energy to be transported (Morgan, 2005). Silts and sands are the least detachment resistant particles. Roughness of the soil surface provides storage of rainwater, that helps the water to soaks into the soil slowly and if the depth and porosity of the soil is high, runoff will decrease through the increment of infiltration volume.

In addition as greater force is required to move, larger particles are more resistant to transportation and the erodibility of soil with particle size less than 0.06 are low due to cohesiveness properties. Therefore silt and fine sand are the particles that are less resistant to erosion (Petter, 1992). The susceptibility of soil to erosion agents is generally referred to as soil erodibility (Renard *et al*., 1997). Soil erodibility increased with an increase in silt, due to their weak structural stability comparing to clay and sand (Nill *et al*., 1996). Soils with coarse texture, high organic matter content and strong structural development are less susceptible to soil erosion. Soil organic matter content decreased linearly with increase in soil erosion. On the other hand shallow soils with less fertility and vegetative cover are more susceptible to erosion, their water retention and holding capacity decreasing with decreasing soil depth (Pimentel, 2006).

2.5.3. Slope length and steepness factor

The slope length and slope steepness of an area has greater impact on soil erosion rate; as slope steepness and length increases, the velocity and volume of surface runoff increases (Morgan, 2005). Naturally, the steeper slope of a field, the greater the amount of soil loss due to erosion by water. Soil erosion by water also increases as the slope length increasing due to the greater accumulation of runoff. Sloping watersheds are known by rill, gully, and stream channel erosion and steeper surfaces of the earth are prone to mudflow erosion and landslides (Blanco and Lal, 2008).

2.5.4. Land cover factors

A land cover (C) factor is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding tilled continuous fallow (Wischmeier and Smith, 1978). According to FAO (2010) land cover is defined as the observed biophysical cover on the earth’s surface and land use as the arrangements, activities and inputs that people undertake on a certain land cover type.

Vegetation cover is one of the most crucial land cover type that contributes in reducing soil erosion. Vegetation cover determines the soil erosion in so many different ways; leaves and stems which are called the above ground components, absorb some of the energy of falling raindrops, running water and wind, so there would be less contact with the soil, while the below ground components which contain the root system help the soil to get mechanical strength (Morgan, 2005). Vegetation decreases volume of runoff by increasing transpiration and evaporation, therefore reduces soil moisture and increases soil organic content which also increases soil's water absorptive capacity (FAO, 1986). The effectiveness of vegetative cover to protect soil erosion depends on plant species, density, age, and root patterns (Blanco and Lal, 2008). Dense and short growing vegetation is more effective to decrease soil erosion by detachment and runoff than tall and sparsely growing plants.

The vegetation covers and land 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. As the vegetation cover increases, the soil loss decreases (Tesfaye, 2015). Strips of dense mulch and grasses can induce deposition and filter sediment from the runoff (Mekonnen, 2005). Recent studies suggest that once vegetative cover is reduced by 30%, the acceleration of erosion is rapid. Cropland usually provide less than 30% cover at critical times (i.e., when the most erosive rains fall). The greatest erosion hazard on croplands occurs when soils are exposed prior to planting and during early plant growth (Tesfaye, 2015).

2.5.5. Conservation practice factor

This conservation practice (P) factor refers the practice of farmers to protect soil detachment, transportation and deposition. Soil which is covered by crop plants, cover crops, mulches or residues would be protected from water and wind erosion. Conservation practices like contouring strip cropping, terraces, crop rotations, reduced tillage and leaving crop residue on the land helps to reduce soil erosion directly or indirectly (Nyssen *et al.,* 2010). Crop residues, like straw, stubble and maize stalks can reduce soil losses by one half or more depending on other factors (FAO, 1965). Terraces reduce slope length and velocity of running water. About 24% of soil erosion by water is caused by agricultural mismanagement (Oldeman, 1992).

As Israel (2011) especially in agricultural areas, conservation practices such as contouring, strip cropping, or terracing reduce soil losses. For instance, in areas where there is terracing, runoff speed could be reduced with increased infiltration, ultimately resulting in lower soil loss and sediment delivery. The effectiveness of such practices is often analyzed with a conservation practice (P) factor which is defined as the ratio of soil loss with the practice applied and up and down slope cultivation (Wischmeier and Smith, 1978; Renard *et al*., 1997). P values have been assigned to land use land cover classes using literatures values and ranges from 0 to 1 (Kaltenrieder, 2007). The lower the value is the more effective the conservation practices are (Tesfaye, 2015). For Ethiopia, P value is based on the conservation practice applied at area in order to reduce soil erosion. Hurni (1985) adopted different P values for different supportive management practices.

2.6. Sub watersheds vulnerability prioritization

A watershed is a surface area from which runoff which is resulting from rainfall is collected and drained through a common outlet. It is an area from which the runoff drains through a particular point in the drainage system. It is made up of the natural resources in a basin, especially water, soil and vegetative factors. Socioeconomically a watershed includes people, their farming system and interactions with land resources, cropping strategies, social and economic activities and cultural aspects (MoARD, 2005). All parts of sub watershed cannot be eroded at the same extent because of their differences in environmental attributes across landscapes (Tamene and Vlec, 2007; Tripathi *et al.,* 2003). Those it is very important to identify the most erosion vulnerable sub watershed and give priority for soil and water conservation activities. Based on that, it is possible to implement effective and efficient watershed management programs. It is important to consider various factors to identify the most erosion vulnerable area because in the watershed there is an integration of different variables such as precipitation, runoff, erosion and sediment discharge as they relate to input and output in an open hydrological system (Deore, 2005; Pimental, 2006).

2.7. Consequences of soil erosion

Water induced soil erosion has adverse economic and environmental impacts. The extent of soil degradation is estimated to be between 5 and 7 million ha/year, which means that 0.3 to 0.5% of the world's arable land area, is being lost every year through soil degradation (FAO, 1983). About 87% of the world’s degraded soils are caused by erosion (Oldeman *et al.,* 1991; UNEP, 1992; Katyal and Vlek, 2000). Land degradation due to soil erosion is a global problem and Ethiopia is changing into desert mainly due to intense water erosion. Over the recent decades the country's forest coverage level has reduced to 3% and consequently 97% of the total landmass remains highly exposed to erosion by water and wind (Terefe, 2010).

The consequences of soil erosion and sediment deposition occurs both on-site and off-site (Anton *et al.,* 2003; Rompaey *et al.,* 2003). On-site effects are directly related to land resources include loss of OM, soil structure degradation, soil surface compaction, reduce water infiltration, reduce supply of water to the water table, nutrient removal, increase of the coarse fraction of soils, rill and gully generation, plant uprooting and reduction of soil productivity (Arrow *et al*., 1996; Casanovas and Ramos, 2006; Pimentel, 2006). Tackling the onsite effects of soil erosion requires understanding of the rates of erosion processes as well as identification of the major controlling factors that enhance or retard this processes (Gebreyesus, 2011).

Although offsite effects may not be always immediate harmful, water pollution, eutrophication, flooding, burial of infrastructure, carbon stock reduction, reduction in hydropower supply and irrigated land productivity are some of the major downstream effects of soil erosion (Blanco and Lal, 2008; Bahadur, 2013; Haregeweyn *et al.,* 2013). Off-site effects of erosion usually more costly and severe than the on-site effects (Figure 1), therefore, proper management of on-site effect of soil erosion could reduce the risks and negative impacts of indirect effects. Sediment decreases the storage capacity and life expectancy of reservoirs, increases flood damage and water treatment cost (Toy *et al.,* 2002).

In Ethiopia, most of the reservoirs built for different purpose are filled with sediment with in less than 50% of their projected service lives (Braimoh *et al.,* 2008). Soil erosion and nutrient depletion has been one of the most important environmental problems (Bekele and Drake, 2003; Nyssen *et al.,* 2010; Csafordi *et al.,* 2012).

Removing vegetative cover on steep slopes for agricultural expansion, firewood and other wood requirements as well as for grazing space has paved the way to massive soil erosion. It is estimated that more than 1.9 billion tons of soils are lost from highlands of Ethiopia as a causes of these annually. Therefore, it is concluded that about half of the highland's land area (around 27 million hectares) is significantly eroded and over one fourth (14 million hectares) are seriously eroded. Moreover, 2 million ha of land is permanently degraded that the land is no longer able to support cultivation and particularly by destroying topsoil structure, reducing soil volume, water holding capacity, reducing infiltration, increasing run off, and washing away plant nutrients, such as nitrogen, phosphorous and organic matter (Amdemariam *et al.,* 2011).

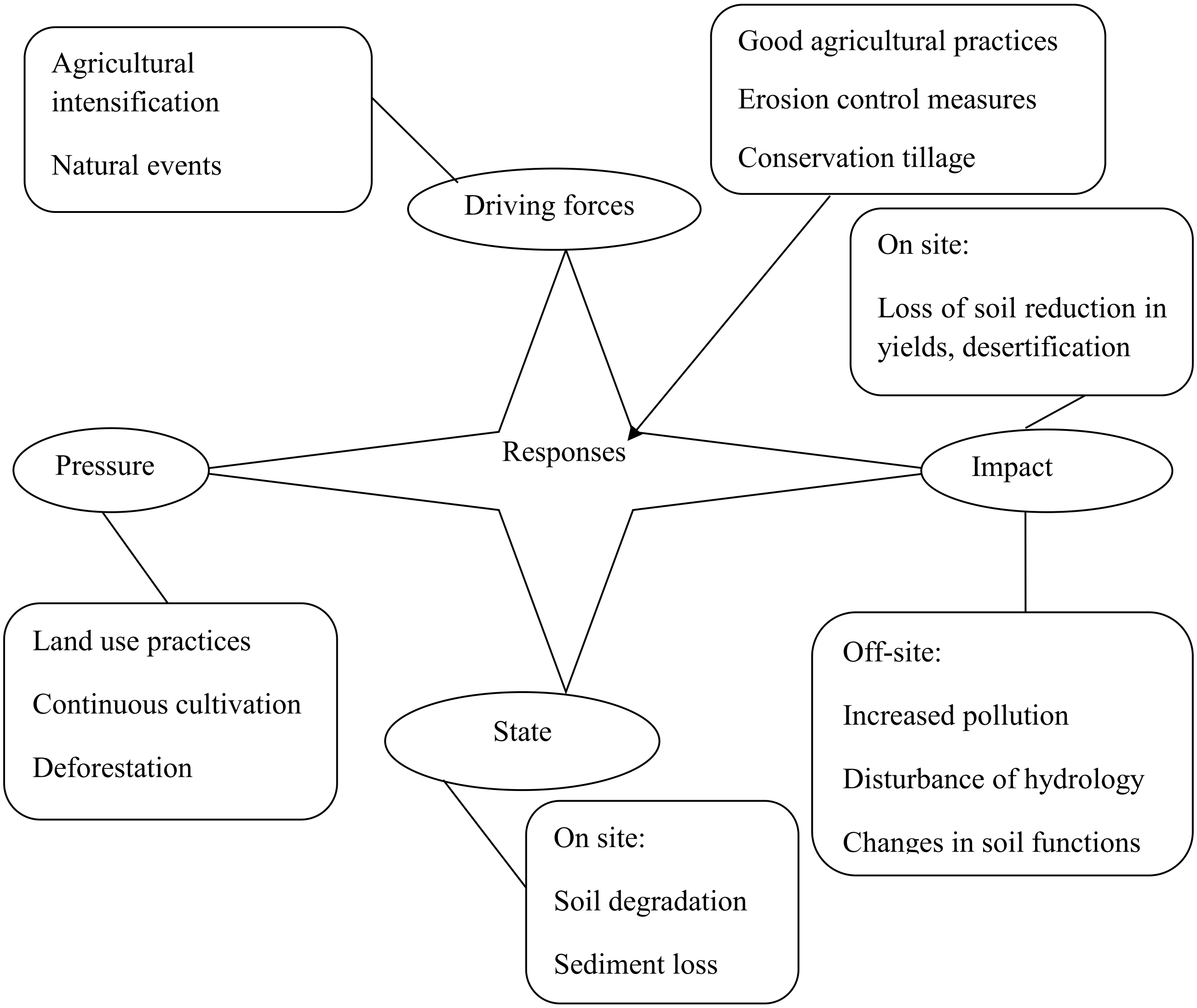

Figure 1: Causes and consequences of soil erosion (Source: Anton, 2003)

2.8. Soil loss tolerance

Soil tolerance refers to the maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically (Wischmeier and Smith, 1978). It reflects the loss of productivity due to erosion and considers the rate of soil formation from parent materials. Hurni (1983) also defined SLT as the maximum soil loss that can occur from a given land without leading to degradation of the soil. Soil loss tolerance indicates the maximum allowable soil loss that will sustain an economic and a high level of productivity (Wischmeier and Smith *et al*., 1978). According to Nill *et al*., (1996) on very deep and homogenous soils, the effects of erosion were less pronounced than on shallow soils encountered on highlands of semiarid zones or highly weathered soils whose nutrient storage and availability depend largely on the organic matter of the surface layer. The determination of soil tolerance is intended to compare the expected soil loss with the soil loss tolerance. If the soil loss is less than or equal to the soil loss tolerance, the soil loss can be still accepted. However, if the soil loss is more than soil loss tolerance, measurement to reduce soil erosion should be taken into consideration until a level of equal or less than the soil loss tolerance has been reached.

Hudson (1986) stated factors that govern soil tolerance are soil depth, physical properties and other characteristics affecting root development, gully prevention, filed sediment problems, seeding losses, reduction of soil organic matter and loss of plant nutrients. According to Ringo (1999), the maximum soil loss tolerance for tropical region is 25 tons /ha/year. But, Hurni (1980) and Lal (1998) established annual soil loss tolerance limits that vary between 0.2 and 11 ton/ha/year. Tolerable soil loss rate is 11 tons /ha/year (Morgan, 2005). Different types of soils have different tolerance to be totally erodible even when they are excessively exposed to soil erosion. Selecting and implementing the soil conservation measures for different sub watersheds is based on the concept of soil loss tolerance (SLT). Different literatures indicated as the normal SLT values range from 5 to 11 tons ha^{-1} year^{-1} (Renard *et al*., 1996). According to Hurni (1983) the maximum tolerable soil loss rates range for medium soils in the various agro-ecological zones of Ethiopia was found from 1 ton/ha/year for Berha agro-climatic zone to 16 ton/ha/year for Wet Weyna Dega agro-ecological zones.

2.9. Soil erosion assessment models

Most of the models used in soil erosion assessment are of the empirical grey-box type. They are based on defining the input factors and through the use of observation, measurement, experiment and statistical techniques relating them to soil loss. Although this approach was found to be unsatisfactory in meeting the model objectives in assessing spatial variability of soil erosion, the advancement in knowledge of how erosion system functions and responds to changes in controlling factors have made significant progress in stratification of factors for landscapes and geographical areas. Soil erosion prediction and assessment has been a challenge to researchers since the 1930s' and several models have been developed (Lal, 2001). Two different methods were used in order to estimate the potential erosion risk areas. The first one was the USLE developed by Wischmeier and Smith (1978). The second one was the SWAT model which is a continuation of nearly 30 years of modeling efforts conducted by the United State Department of Agriculture (USDA) of agricultural research service.

Many models are based on equations for calculating soil erosion, such as the Universal Soil Loss Equation (USLE) and its revised versions, Revised USLE (RUSLE) and Modified USLE (MUSLE). The USLE estimates average soil loss over time as a product of five factors: rainfall erosivity index, soil erodibility, slope length and steepness, land cover management, and support practice factor (Wischmeier and Smith 1978). These factors can be computed in a GIS using widely available spatial data such as climate, soil, geology, topography, hydrology, land use, and land cover data.

Although USLE was designed for, and used most widely, in estimating erosion from agricultural lands, efforts to modify USLE for use in watersheds that are more topographically complex and with a higher diversity of land uses have led to the development of erosion models such as the Automated Geospatial Watershed Assessment (AGWA) and the RUSLE model. Some models not only calculate soil erosion, but they also simulate the transport of eroding soil downhill-slopes and into stream channels by incorporating hydrological modeling, such as the SWAT and the WEPP (David *et al.,* 2012).

Assessing and prediction of soil erosion using field studies was very expensive, time consuming and it also needs to be collect many years of data. Soil loss assessment using field study is complex and difficult to generalize from the result numbers spatially. With limited resources, an effective way of determining the process of soil erosion is the use of models. A model is a mathematical expression of the relationship and interrelationship of major governing factors of a system including describing soil particle detachment, transport, and depositions on land surfaces (Moldenhauer and Foster, 1981). There are at least three reasons or motives for modeling erosion: (a) erosion models can be used as predictive tools for assessing soil loss for conservation planning, project planning, soil erosion inventories, and for regulation; (b) physically based mathematical models can predict where and when erosion is occurring, for this reason assisting the conservation planner target efforts to reduce erosion; (c) models can be used as tools for understanding erosion processes and their interactions and for setting research priorities (Nearing *et al.,* 1990).

A wide variety of models are available for assessing soil erosion risk based on different ways. The emergence of soil erosion models has enabled the study of soil erosion especially for conservation purposes, in effective and acceptable level of accuracy. To estimate soil erosion and develop optimal soil erosion management plans, many erosion models, such as USLE/RUSLE, WEPP, ANSWERS, EUROSEM, SWAT, AGNPS, etc. were used in regional scale assessment. Each model has its own characteristics and application scopes (Lu *et al*., 2004; Dabral *et al.,* 2008).

The dominant model applied worldwide to soil loss prediction is RUSLE, developed by Wischmeier and Smith (1978) because of its convenience in application and compatibility with GIS. Input data for RUSLE: satellite image, DEM data, land cover data, aerial photo, soil data, topographic map, meteorological data and agricultural management. The choice for a particular model largely depends on the purpose for which it is intended and the available data, time and money (Lal, 2001). Generally, the models fall into three main categories which are available these days: conceptual (semi-empirical), empirical (statistical) and physical based (deterministic) depending on the physical processes simulated by the model, the model algorithms describing these processes and the data dependence of the models (Saavedra, 2005).

All groups of models have merits and demerits, and are developed for application in certain locations under certain conditions. Models are acceptable if they meet their objectives or design requirements. Generally, models are selected based on reliability, universal applicability, easy use with a minimum of data, comprehensiveness in terms of the factors and erosion processes included and the ability to take account of changes in land use and conservation practice (Morgan, 2005). Under Ethiopian conditions, most of the models can’t simply be applied because of data gaps and applicability issues. However, RUSLE application to the Ethiopian environment has a better ground and substantiated through empirical research conducted during 1980s by the Soil Conservation Research Project of the then Community Forests and Soil Conservation Development Department (Hurni, 1985).

2.9.1. Empirical models

These are the simplest model types and primarily based on defining important factors through field observation, measurement, experimentation and statistical techniques relating erosion factors to soil loss (Petter, 1992). The models are based on mathematical calculations which consists relatively simple responses functions calibrated to fit limited numbers of statistical observations (Abate, 2011). The models also require less data and thus that best fit with available resource and if they integrated with GIS environment conveniently be used to estimate soil loss and stimulate conservation options. The most widely applicable ones are USLE (Wischmeier and Smith, 1978) and its variants; RUSLE (Renard *et al*., 1996) and MUSLE (Modified Universal Soil Loss Equation) (Williams, 1975), PESERA (Pan-European Soil Erosion Risk Assessment) approach (Gobin *et al*., 2003).

Empirical models are based on identifying statistically significant relationships between assumed important variables where a reasonable database exists. The most commonly and widely used empirical model is the USLE (Wischmeier and Smith, 1978). It is derived from the theory of erosion processes, more than 10,000 plot years of data from natural rainfall plots, and numerous rainfall simulation plots.

2.9.2. Physically based models

Physically based mathematical model can predict where and when erosion is occurring, thus helping the conservation planner target efforts to reduce erosion and providing detailed understanding of the erosion processes. It can allow users to ascertain temporal trends, examine spatial variations, identify critical processes and explore the possible impacts of remedial measures and the relative effectiveness of implementations strategies for erosion and sedimentation controls (Baigorria and Romero, 2007). Generally, it can be used as tools for understanding erosion processes and their interaction and for setting research priorities.

They predict the spatial distribution of runoff and sediment over the land surface during individual storm in addition to total runoff and soil loss and mainly applicable to small farm fields to small catchments. Some of the variants of physical based models are CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems)-developed to assess non-point source pollution and to investigate quantitatively the environmental consequences of different agricultural practices. WEPP-developed based on modern hydrological and erosion science and designed to replace Universal Soil Loss Equation for the routine assessment of soil erosion by organizations involved in soil and water conservation planning and assessment is mainly developed to simulate the process of erosion and deposition along the hill slope (Rose*,* 1998). Other examples of these models are SWAT, ANSWERS, EUROSEM and AGNPS etc.

2.9.3. Conceptual models

Conceptual models play an intermediary role between empirical and physical based models and are based on spatially lumped forms of water and sediment continuity equation (Beck, 1987). It includes only a general description of catchment processes without including the details occurring in the complex process of interactions (Renschler, 1996). This model allows providing an indication of the qualitative and quantitative effects of land use changes without requiring large amount of spatially and temporally distributed input data (Merritt *et al.,* 2003). It reflects the hypotheses about the process governing system behavior.

2.10. Revised universal soil loss equation model

Several empirical soil erosion models were developed. The USLE model at the beginning was specifically developed for USA with the natural conditions of temperate zones as a design tool for conservation planning. Due to its good predictive ability and comprehensiveness by allowing more detailed consideration of farming practices, topography and its simplicity, the equation has been applied to conditions beyond USA through modification of some of its factors (Morgan, 1996). RUSLE uses the same empirical principles as USLE, but includes numerous improvements in computation of various factors.

RUSLE method is most widely and frequently used around the world to predict long term rates of inter-rill and rill erosion from field or farm size units subject to different management practices. It is used to predict long term mean values of soil erosion that would generally result from sheet and rill erosion on agricultural plots to watershed level. It has been considered as a good predictive tool by different researchers, planners and consultants since it considers ranges of parameters that significantly influence soil erosion (FAO, 2010). The RUSLE assumes that detachment and deposition are controlled by the sediment content of the flow. The RUSLE model in GIS environment predict erosion potential based on a cell-by-cell, which is effective when attempting to identify the spatial pattern of soil loss present within a large watershed area (Shi *et al.*, 2003).

The application of RUSLE in a GIS framework has been employed in various circumstances such as mountainous tropical watersheds, large scale watersheds, in agricultural dominant watersheds, in areas with distinct wet and dry seasons, and also in areas with dynamic changes such as in land cover patterns, agricultural farmlands and developments. The RUSLE model consists of three main databases: 1) Climatic and survey database which contain information such as monthly temperature and precipitation and contours that is required for the calculating the erosivity factor (R) as well as slope length and steepness factors (LS). 2) Crop database contains information necessary for determining the land cover factor (C). 3) Soil data contains soil survey and soil characterization data which is responsible determining the soil erodibility factor (K) (Jahun *et al.,* 2015).

2.11. Strength and limitations of RUSLE model

2.11.1. Strength of RUSLE model

RUSLE is a well-tested model that has gone through various improvements since its inception as the USLE in 1978 (Wischmeier and Smith, 1978). RUSLE is a science based tool that has been improved over the last several years before recognized as a world used model. 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 (Rahaman *et al.,* 2015).

Empirical soil erosion models, like RUSLE are easy to interpret physically, require minimal resources and can be worked out with readily available inputs to precisely the areas exposed to high erosion risk. The method is universally recognized as a standard method for soil loss monitoring. It is relevant for ecosystem services related to soil erosion and protection. RUSLE provides international applicability and comparability of the results and methods, as the method has been adapted to and applied in many world regions. The results are plausible in terms of assessing risks of water erosion. The algorithms can be implemented based on literature values or adapted to empirical/statistical data by using standard GIS software. Required input data are usually available and easy to obtain (Wischmeier and Smith, 1978).

2.11.2. Limitations of RUSLE model

RUSLE model was designed primarily for agricultural regions. Soil erosion potential as identified in non-agricultural regions may be inconsistent. The environmental variables used in RUSLE are relatively constant over the timescale of tens of years (at a minimum), while the management variables may change over the course of a year or less. Consequently, it is difficult to obtain current and accurate management variable coverage. Several algorithms are required when processing data for input into RUSLE. Each of those algorithms may accentuate existing errors in data. Because RUSLE requires five input data layers to be multiplied together, the errors inherent in each layer are similarly multiplied, contributing to an even greater error in the derived soil loss values (Shi *et al.,* 2002).

RUSLE only accounts for sheet erosion; it does not estimate wind, ephemeral gully, or stream bank erosion, each of which can be severe depending on the region. RUSLE is used to estimate the average long term risk of erosion on arable land. It is not designed for modeling soil erosion and sediment transport under individual rainfall events (Saha, 2003). Due to the relatively simple empirical approach, the typical erosion processes such as splash erosion, soil transport and soil deposition are not considered as a dynamic process. Antecedent soil moisture and soil stratification are not considered (Wischmeier and Smith 1978).

2.12. Application of GIS and remote sensing in soil erosion assessment

Nowadays**,** GIS and RS technique is a technology that widely applying in spatial related different studies as all factors on soil erosion can be extracted by spatial analysis (Mwawasi, 2013). The advent of technological tools such as GIS and remote sensing has significantly enhanced the usefulness of soil erosion models through their advance features of data storage, management, analysis and display (Blanco and Lal, 2008). Specially many of researchers used this technique for assessment of soil erosion risk for specific area with different models through tiding with GIS and RS (Saha *et al.*, 1991; Abate, 2011; Rahaman *et al.,* 2015). Theses researchers strongly indicated that GIS and RS technique is wisely recommended to spatial prediction of erosion risks for specific plot or watershed with RUSEL model.

The predictive capacity of empirical and process based soil erosion models at different temporal and spatial scales has improved when they are combined with GIS and RS tools. The potential utility of remotely sensed data in the form of aerial photographs and satellite sensors data has been well recognized in mapping and assessing landscape attributes controlling soil erosion such as soils, land cover, relief, soil erosion pattern (Pande *et al.*, 1992).

Soil erosion models only calculate the amount of soil erosion based on the relationships between various erosion factors, but when they are integrated with GIS and RS, it is possible to map the spatial distribution of soil erosion risk to develop adequate erosion prevention techniques (Shi *et al.*, 2003). The use of GIS and RS techniques makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas (Lu *et al.*, 2004; Gusta *et al.,* 2013). According to Mati and Veihe (2001) the application of GIS has increased in the last decade with the availability of digital data, cheaper and more user-friendly software and the need to handle large spatial databases. In a GIS environment, it is possible to link data generated from remote sensing with their spatial location (Beck, 1987).

In general the use of geo-information techniques offer the following advantages in erosion modeling: fast and cost effective estimates, possibilities to investigate larger areas, greater possibilities of continuous monitoring of these areas and possibilities to refine the soil erosion model depending on the required output scale i.e. rough global to more precise local scale. According to Yazidhi (2003) the use of digital elevation models and GIS offers possibilities to estimate topographical parameters that are useful in soil erosion modeling.

2.12.1. Geographic information system and soil erosion modeling

Soil loss by water erosion is most frequently assessed by USLE. Spanner *et al.* (1982) first demonstrated the potential of GIS for soil loss assessment using USLE. There is considerable potential for use of GIS technology to erosion modeling and hazard assessment. GIS is characterized by its capability to integrate layers of spatially oriented information. The number and type of applications and analysis that can be performed by GIS in a watershed are as large and diverse as the available geographic datasets (Deore, 2005). GIS has been widely used in characterization and assessment studies which require a watershed based approach (Khan *et al*., 2001). In addition, the modeling and visualization capabilities of modern GIS, offer fundamentally new tools to understand the processes and dynamics that shape the physical, biological and chemical environment of watersheds (Jain and Goel, 2002).

GIS are widely applied to predict soil erosion, as all factors on soil erosion can be extracted by spatial analysis. The time required for data collection and high cost of research, is the difficulty in identification of area sensitive to water induced soil erosion by conventional methods. However, these problems can be solved by the use of GIS based predictive models both at local and regional scale (Amsalu and Mengaw, 2014); Surjit *et al.,* 2015).

2.12.2. Remote Sensing and soil erosion modeling

The basic fundamentals in remote sensing are the properties of electromagnetic radiation and their interaction with matter. Remote sensing has opened a new era in the planning and development of watershed management, as satellites imagery provides a fast and economic way to analyze large watersheds by virtue of their synoptic and repetitive coverage (Jain and Goel 2002). Thus, by using multispectral data appropriately, different ground features can be differentiated from each other and a thematic map depicting land use land cover can be prepared. DEM one of the vital inputs required for soil erosion modeling can be created by analysis of stereoscopic optical and microwave remote sensing data (Pande *et al.*, 1992).

Satellite imagery has been well utilized for measuring qualitative and quantitative terrestrial land covers changes (Lu *et al.,* 2004) in a watershed. For soil erosion assessment in a watershed, remote sensing has been used for both detecting erosion features and obtaining erosion model input data (Petter, 1992; Vrieling, 2006). Remote sensing can facilitate studying the factors enhancing the process, such as soil type, slope gradient, drainage, geology and land cover. Multi temporal satellite images provide valuable information related to seasonal land use dynamics. With appropriate use of multispectral data, it is possible to differentiate different ground features from each other and prepare a thematic map depicting land use land cover. Now a day's different study utilize Satellite imagery for the characterization of watershed and management aims (Saxena *et al.,* 2000).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Location and accessibility

The study was conducted in Gulufa watershed of Dabus River sub basin with the total land area of 12,244.45 hectare and geographically located at 9º 39' 0'' - 9º 46' 0'' N latitude and 35º

07' 30" - 35 º 12’ 30’’ E longitudes. Administratively, it is situated in Mana Sibu district of Oromia region, West Ethiopia (Figure 2). The watershed is located 582 kilometers to the west of Addis Ababa and 150 kilometers from Gimbi, the Zonal town of West Wollega on the way to Assosa, the capital town of Benishangul Gumuz Regional State (MSANRO, 2019).

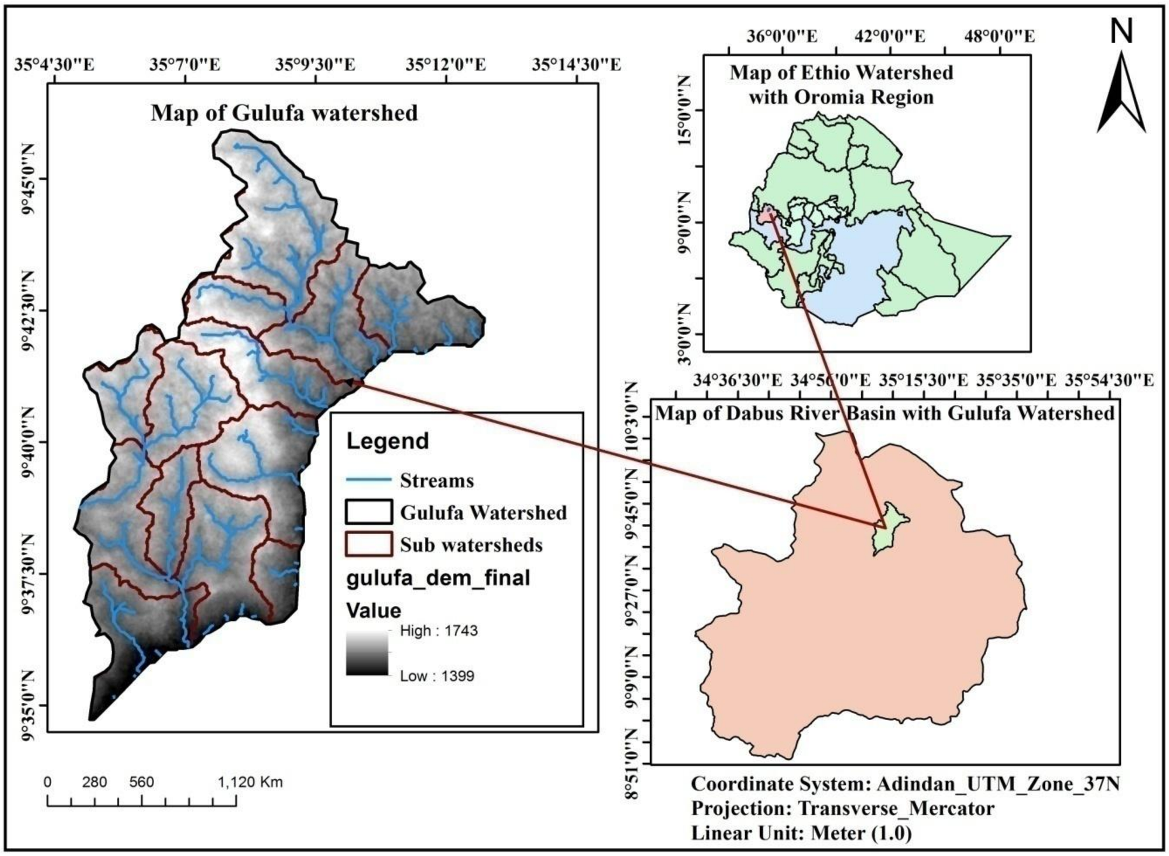

Figure 2: Location map of the study area (Source: Ethio GIS and SLM Project)

3.1.2. Agro-ecology and climate

Agro-climatically, the study area laid in Woyina Dega (mid altitude) agro-ecological zones.

The climatic data from National Meteorological Agency shows an average annual rainfall of

1200 mm and the temperature is moderate with an average of 25 ^{0}C. The rainy season usually starts in April and extends up to October, with the highest rainfall concentration between June and August. The dry season is from November to March (MSANRO, 2019).

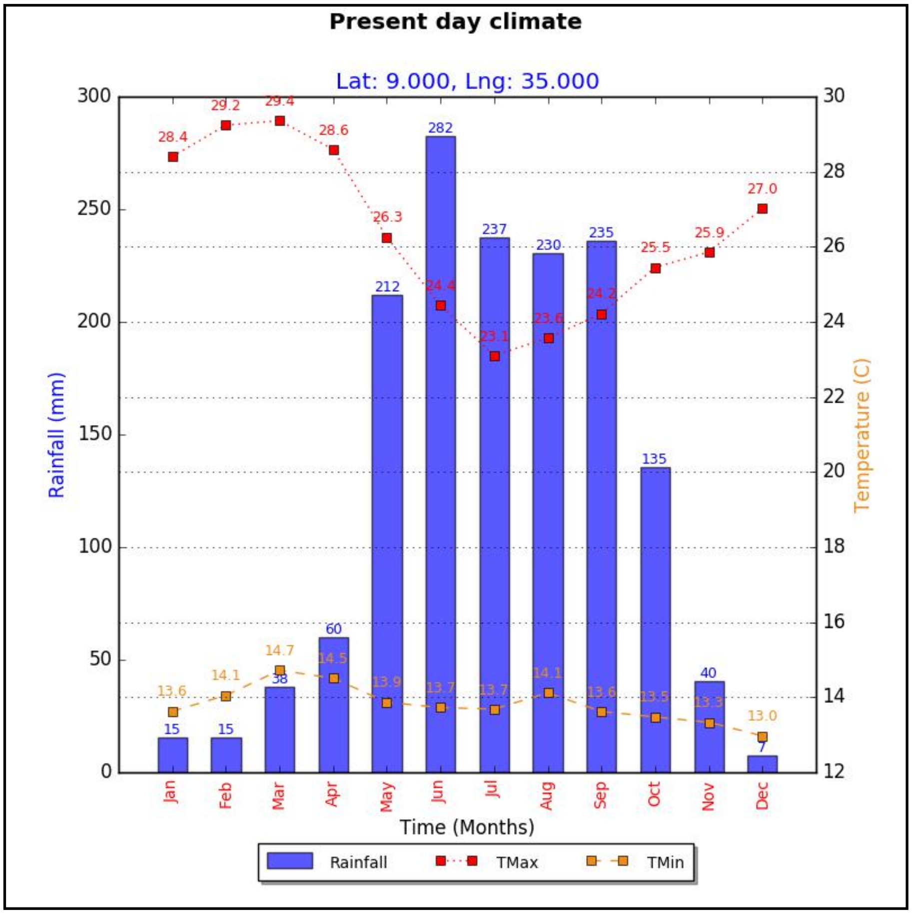

Figure 3: Mean monthly rainfall, monthly maximum and minimum temperatures of the area (Source: www. MarkSim® weather file generator, 2019)

3.1.3. Topography and drainage system

The watershed has varied landforms. The topography of the area is mainly characterized by gentle slopes (40%), undulating hills steeply slopes (25%) and moderate lowlands/plane (35%) with many small tributaries. The altitude of the study area varies in altitudinal ranges between 1399 m and 1743 m above sea level (MSANRO, 2019). Watershed is a natural topographical and hydrological entity which collects all the rainwater falling on it to a common outlet and hence forms an ideal unit for management and sustainable development of its natural resources like water, soil, land and vegetation. Watershed is also the boundary of the drainage basin. Socioeconomically a watershed includes people, their farming system and interactions with land resources, cropping strategies, social and economic activities and cultural aspects (MoARD, 2005). There are many major rivers that drain in this sub watershed those mostly used for small scale irrigation and drinking of animals. This sub watershed includes *Dembi, Sechi* that at the outlet side called Gulufa and *Kersa* rivers. And also there are around 13 sub watershed those are drained to these rivers and finally to Dabus river.

3.1.4. Major soil types

According to FAO (1990), the soil class of the study area is Nitisols with reddish brown color. Nitisols are soils having a well-structured surface feature with high base saturation and moderate to high organic matter contents. Acrisols are soils that have higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an argic subsoil horizons and widely distributed in this sub watershed. The Alisols of the study area are the most widely distributed in the lower topography of the sub watershed (Ahmed and Abraham, 2014). Cambisols are soils having high base saturation in the earth fraction. Fluvisols refers to soils having a well-structured, dark colored surface horizon with high base saturation and moderate to high organic matter contents. This soil type is severely affected by erosion and a landslide which is arises from intensive cultivation and mining of gold by local farmers (Likassa, 2014). Lixisols are soils that have higher clay content in the subsoil than in the topsoil. The Lixisols of the study area are distributed in some parts the areas of the watershed.

3.1.5. Land use land cover types

The study area major land use types include farmland/cultivated land (annual and perennial crops), forestland, plantation, grazing land (open grassland for all year round), shrubs land and bare land (degraded land) which is an area were continuous cultivation with less management has been practiced that may eventually affect soil properties (Dawit, 2014).

3.1.6. Population and major economic activity

According to the data obtained from MSANRO (2019), the population of the watershed is about 17,155 with total household of 2,040 (Female 252 and Male 1,988). The livelihoods of the rural communities of the study area depend mainly on crop production, animal husbandry and mixed farming systems.

The major cereal crops of the areas are maize (*Zea mays L.*), sorghum (*Sorghum biocolor L.*), teff (*Eragrostictef Zucc. Trotter*), finger millet (*Elevsine coracana*), barley (*Hordeum vulagare L.*), pulses such as haricot bean, faba bean (*Vicia faba*), field pea and Lima bean (Abdenna, 2013) and oil crops such as Niger (*Guizotia abyssinica*) and Sesame are also among the important crops in area. Coffee (*coffee arabica*) is the cash crop grown by some households (Dawit, 2014). On the other hand, livestock farming such as cattle, goats, sheep, and chickens are important livestock species reared by the farmers. According to the data obtained from the Livestock and Fishery Development Office of the district, the number of livestock available in the study area in the year 2019 is 97,188 heads of which cattle accounts for 24 % of the total livestock population.

3.2. Research design

The explanatory sequential approach of the mixed research design was implemented. According to Creswell (2005) explanatory sequential approach gives more priority for quantitative data than exploratory sequential approach that gives priority for qualitative data. Therefore, the study followed quantitative method of data collection and analysis. To attain the objectives of this study, research instruments such as personal observation and document reviewing were used to get reliable data. Different methods such as satellite images processing and RUSLE model analysis were also applied. Finally, the results were interpreted depending on the analyzed data following scientific ways.

3.3. Methods of data collection

3.3.1. Data sources and types

In order to answer the specific objectives, both primary and secondary data were used for this study. The major land use land cover classes in the area were checked during field observation. The primary data was obtained through field observation and ground control points (GCP) for soil loss vulnerability verification and accuracy assessment. Secondary data were also explained below: mean annual rainfall data of 20 years were obtained from NMA for erosivity factor. Dabus basin digital soil map was obtained from OWWDSE. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) for DEM and Sentinel-2 image for LULCC from USGS website (http://earthexplorer.usgs.gov). Secondary data such as human and livestock population were obtained from district Agriculture and Natural Resource office for description of study area.

3.3.2. Sampling techniques

The study area of Gulufa watershed was selected purposively based on prior knowledge of the area and severity of the soil erosion problems. In Mana Sibu district there are 141 sub watersheds and 4 macro watersheds (MSANRO, 2019). Among these Gulufa watershed is one of the watershed mainly affected by the erosion and where conservation activities were started in recent years. The amount of soil loss is not known as well when this conservation practices was started. And also as it appears at the upper side among the other watershed in the district gives the priority for conservation. For this study, all Gulufa sub watershed from *Laga Dembi* sub watersheds from upper side to *Fincha'a* from the lower or downstream side were selected based on their high rate of soil loss and deposition.

3.3.3. Description of RUSLE model

The RUSLE is one of the most widely used empirical overland flow or sheet rill erosion equation. This model is more efficient for small area, e.g., watershed level, because it does not have the capability for routing sediment through channels (Chen *et al*., 2011). RUSLE is an erosion prediction model designed to predict the long-term mean annual soil loss from specific field slopes in specified land uses and management system. It computes soil loss as a product of five major factors, representing rainfall runoff erosivity, soil erodibility, slope length and steepness, cover factor, and conservation practices (Morgan, 1996). The equation is represented by $A = R * K * LS * C * P$ Where: A is the amount of soil loss that is eroded within unit area during corresponding period; R is rainfall runoff erosivity factor; K is a soil erodibility factor; LS is the slope length and steepness of erosion; C is a land cover factor; and a conservation practice P factor.

Based up on soil and water conservation research plots data, a RUSLE was adopted to Ethiopian condition by Hurni (1985). The five factors of the RUSLE are estimated for each land mapping unit using the land resources data as an input. The equation was validated by comparison with the plot measurement in Ethiopia and showed a high correlation of 0.90, explaining 80% of the measured sample (Hurni, 1986). For the current study, RUSLE model as modified and adopted to Ethiopian conditions by Hurni (1985) was used to compute annual soil loss from sheet and rill erosion within the watershed.

3.3.4. Soil loss estimation

The mean annual rainfall data for a period of 20 (twenty) years (1999–2018) were obtained from the National Meteorological Agency (NMA) for R factor. Rainfall data taken at a single station and a year cannot provide a reliable estimate for the study area, to address this problem daily rainfall data recorded at many years (i.e. 20 years) and different stations (i.e. five stations) nearby the watershed was used. Dabus river basin soil map was used for erodibility factor map. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data was obtained from USGS website (http://earthexplorer.usgs.gov) for digital elevation model to generate slope length and steepness factor. Sentinel-2 image with spatial resolution of 10 m* 10 m was downloaded from USGS website (http://earthexplorer.usgs.gov) at cloud free season for land cover and conservation practice factors. ArcGIS was also used in vectorization, area calculation and thematic map preparation of the study area.

3.4. Methods of data analysis

3.4.1. Data processing and classification

Prior to image analysis, initial processing on the raw data was carried out to correct for any distortion due to the characteristics of the imaging system and conditions. Image files were firstly imported into ERDAS IMAGINE for image pre-processing and then image classification.

3.4.1.1. Satellite image pre-processing

Pre-processing is the preliminary step which transforms the data into a format that more easily and effectively processed including all correction of deficiencies and the removal of errors present in the data. In Pre-processing of image classification extraction and image staking were done using band combination in ERDAS IMAGINE to form different combination of Red, Green, Blue color composition. The basic bands 4, 3 and 2 were used prior to classification to improve visualization of the image for the prospected classification. The preprocessing activities were carried out to enhance the image readability and avoid wrong placement of reflectance signatures against the ground reality during classification. Pre-processing such as layer stacking (band composite) and sub setting of an image were carried out. After that an image of the study area was sub setted by using study area boundary obtained from Sustainable Land Management (SLM) project.

3.4.1.2. Image classification

Image classification is the process of assigning pixels into a finite number of individual classes, or categories of data, based on their data file values. Sentinel-2 image of 2019 with spatial resolution of 10 m*10 m was used for the land use land cover classification (LULCC) analysis. The preprocessed image was used to classify land use land cover types of the study area into different major classes and this was help to generate land use land cover maps.

Supervised classification was carried out for the purpose of identifying land use land cover types in the study area. In Supervised classification user selects area in image that represent each unique class and pixel values for each band were recorded for each class and groups according to the judgment of the operator who decides not only the required number of classes but also which classes should be grouped together. For this supervised image classification, training areas were established based on the GCP taken during field work. Intensive GPS based ground control points were used to reclassify the images and derive the LULC maps.

Among different algorithms in the supervised classification maximum likelihood which assumes that each spectral class can be described by a multivariate normal distribution was utilized. The image was classified in to six major land use land cover types (farm land, forest land, bare land, wet land, grazing land and built-up area) by using ERDAS IMAGINE software in that signature editor was created for defining the classes. The boundaries and number of pixels for each class was added into signature editor using area of interest (AIO) tools. A Land use land cover map of the year 2019 was prepared to determine quantitative information on spatial distribution of different land cover types.

3.4.1.3. Accuracy assessment

Accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true in order to determine the accuracy of the classification process. To assess the classification accuracy, confusion matrix was employed. The confusion/error matrix consists of rows and columns. The rows represent the classification values and the column represents facts from field. The diagonal line of the error matrix represents the number of pixels that are correctly classified. Accuracy of the classified LULC maps were assessed using a combination of overall accuracy, producer's accuracy, user's accuracy, errors of commission and omission (Jensen, 1995) and kappa coefficient (Cohen, 1960).

The overall accuracy index was produced by dividing all the pixels correctly classified by the total number of pixels in the matrix. Producer's accuracy corresponds to error of omission (exclusion). The producer accuracy index was produced by dividing the number of correctly classified pixels that belong to a class by the sum of the values of the column of the same class. User's accuracy corresponds to error of commission (inclusion). The user accuracy index was produced by dividing the total number of correctly classified pixels that belong to a class by the sum of the values of the rows of the same class.

The Kappa coefficient expresses the proportionate reduction in error generated by a classification process. It was compared with the error of a completely random classification (Congalton, 1991). The kappa coefficient lies typically on a scale between 0 and 1. The overall accuracy and kappa coefficient results were checked to be above the minimum and acceptable threshold level. The Kappa coefficient result values are 0 to 1 and are often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values are also grouped into three: a value greater than 0.80 (80%) represents strong agreement, a value of kappa coefficient between 0.40 and 0.80 (40 to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement (Rahman *et al.,* 2006).

3.4.2. Analysis of factors influencing soil loss estimation

The rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), land cover (C) and conservation practices (P) factors were multiplied by using the RUSLE model to obtain amount soil loss annually. RUSLE is an empirical model developed by Renard (1997), framed with GIS and remote sensing techniques was employed to compute the annual soil loss. Since the input model layers are acquired from various sources, and at varying scales, resampling procedures was provided in spatial analysis tools need to apply for the input datasets to be compatible with each other. Therefore, RUSLE is empirically expressed as:

$$A = R * K * LS * C * P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (1)}$$

Where A: the annual soil loss (tons/ha/year); R: the rainfall erosivity factor (MJmm/ha/year); K: the soil erodibility factor (tons/ha/MJmm); LS: the slope length-steepness factor; C: the cover management factor and P: the conservation practice factor. All the RUSLE factors layers were multiplied pixel by pixel using the equation (Eq.1) and raster calculator in ArcGIS to compute the annuals soil loss in Gulufa watershed and FAO soil loss severity classes were used for classification (Table 1).

Table 1: Annual soil loss rate and its severity classes

Soil loss (ton/ ha/year)	Severity classes
<12	Low
12–25	Moderate
25–50	High
50–80	Very high
80–125	Severe
>125	Very Severe

Source: FAO, 1986

3.4.2.1. Rainfall erosivity factor

The rainfall erosivity (R) index represents the energy that initiates the sheet and rill erosion (Wischmeier and Smith, 1978). Originally, it is computed as total storm energy (MJ m-2) times the maximum 30 minute intensity (El30 in mm/hr), being expressed as e.g. MJ mm ha/year (Renard and Freimund, 1994). The computation of R calls for detailed long-term information on number and depth of storm events; information which is only available for very few stations. The rainfall erosivity factor (R) quantifies the effects of raindrop impact and reflects the amount and rate of runoff likely to be associated with rain (Renard*,* 1997). The soil loss is closely related to rainfall partly through the detaching power of raindrop striking the soil surface and partly through the contribution of rain to runoff. There are a number of ways of analyzing the rainfall erosivity depending on the local conditions of the place (country), the values of R-factor for this study was estimated according to the equation adopted by Hurni (1985) for Ethiopian conditions. This is due to lack of rainfall intensity data.

Daily rainfall collected per months which has missed values was filled by XLSTAT software using its linear regression analysis. To fill missed data by using XLSTAT software, first list days of the data were listed vertically from start to end. The daily rainfalls data of two neighboring station are required. Then, daily rainfall data was converted to vertical by transposing data means the reference station. And also the station which have missed values are listed side by side until the vertically listed years or months are end and modeling by linear regression, select the rows of reference station first and select the stations of missed values rows secondly and then ok, the regression analysis result was presented. Through this process missed values were filled accordingly. After those missed values are filled, average mean monthly and annual rainfall were computed. The accumulation in the station with the surrounding neighboring stations was computed and plotted. Consistency of the rainfall data has been also tested using double mass curve method. Finally, the association between them was evaluated using their coefficient of determination (R^2). The R^2 was calculated for accumulation of rainfall in a given station with accumulation of mean rainfall in the surrounding stations.

Therefore, to compute R factor, mean annual rainfall of 20 years were collected from period of 1999 to 2018. The average annual rainfall distribution nearby the watershed was computed from the record of the last 20 years. Mean monthly rainfall data was analyzed from these meteorological stations. After calculating the average 20 years of rainfall for each station, the R factors were computed using the following equation. All observations in the stations were not all in all included in the study area. So, it was interpolated by using Inverse Distance Weight interpolation technique from observation points in ArcGIS by Geostatistical analyst tool. It predicts cell values at unknown locations based on the distance between the unknown cell and the known points (Krivoruchko, 2011) and converted into raster surface. Finally, the erosivity (R) factors were obtained using the raster calculator in raster calculator of spatial analysis toolbox (Hurni, 1985).

$$R = -8.12 + (0.562 * P) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. } (2)$$

Where: R= Rainfall erosivity P= mean annual precipitation (mm/yr). The mean annual rainfall data of 20 years (1999 to 2018) derived from 5 rainfall stations were considered to estimate R factor using the above formula. The calculated R factor for each station was converted to raster surface with 30 m grid cell using IDW interpolation techniques.

3.4.2.2. Soil erodibility factor

Soil erodibility is a measure of a soil’s resistance to the erosive powers of rainfall energy and runoff. K factor reflect the rate of soil loss per rainfall-runoff erosivity (R) index. For this study, the soil map of Dabus River basin obtained from OWWDSE was used as Gulufa watershed is one of the watersheds in this basin to develop the soil erodibility map. The soils of the study area contain their own distinctive erodibility values. The soil vector map of the study area was obtained by clipping the Dabus River basin soil map with the study watershed in the GIS environment. Then, K factor value is assigned for each of the soil textures (Loamy sand, Clay, Sandy loam, Sandy clay loam, Loam, Silt) as indicated by Tafa (2011) in RUSLE (Table 2). Finally, the resulting shape file was changed to raster with a cell size of 30 x 30 m. The soil map was reclassified based on K factor value of each map unit to generate soil erodibility map using ArcGIS. According to Farhan *et al.* (2013), the soil erodibility factor mostly ranges between 0 and 1, where 0 shows the soil class’s less susceptible to erosion while 1 is the high susceptibility of soil class to water erosion.

Table 2: Soil erodibility (K) factor

Textural class	**Soil Organic Matter Content**		
	<0.5%	**2%**	**4%**
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine Sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay	-	0.13-0.29	-

Source: Taffa, 2011

3.4.2.3. Slope length and steepness factor

DEM is an ordered array of numbers that represents the spatial distribution of elevation of the surface in digital format. DEM has become vital input for automated generation of terrain and hydrologic features. It is basic source for generation of such terrain features like slope, aspect, hill shade, and other relief features. DEM has also some hydrologic application for watersheds such as determining flow direction, flow accumulation, stream-order, stream length, watersheds, basins etc. DEM is also vital input for soil erosion modeling (Samuel, 2007). The specific effect of slope length and steepness on soil erosion was estimated by dimensionless LS factor as the product of the slope length and slope steepness (Jim *et al.,* 2012).

Several methods of LS factor determination is developed with different GIS professionals at different time period. Of which, the following is one for calculating LS using DEM after preparing the flow direction map and flow length map. In this two parameters were used to calculate the LS factor, flow length and slope. The modified equation for computing LS factor in GIS environment was employed by the following Israel (2011).

$$LS = (\text{Power (flow length}, 0.3)/22.1) * \text{Power (slope}/9, 1.3) \ldots\ldots \text{Equation (3)}$$

Two steps in raster calculator were determination of power (flow length, 0.3) * power (slope/9, 1.3) and finally division of the result of step one by 22.1. To calculate the LS factor for the RUSLE equation, first calculate flow length and slope in degree were required. A depressionless DEM which has no sinks was used to perform the subsequent steps in finding the LS factor. Therefore, simply using the fill tool can produce a sink free DEM, then the flow length and slope should be calculated respectively in order to generate LS factor map. The values in the cells of the flow direction grid indicate the direction of steepest descent from that cell. The LS factor was calculated from ASTER DEM of 30 m grid size with the study watershed and raster calculator tool of ArcGIS. Finally, the LS factor map was derived using the above formula in ArcGIS spatial analyst raster calculator function (Kim*,* 2014).

3.4.2.4. Land cover factor

Land cover has a profound impact on erosion and deposition. Surface cover, such as vegetation or plant may intercept and reduce raindrop erosivity, increase infiltration rates, slow down runoff and reduce transporting capacity of water flow. Different LULC types were identified and described for this study (Table 3).

Table 3: Descriptions of land cover categories of the study area

Land cover	General description
Farm land	Areas of land that is ploughed and/or prepared and currently under crops (rain-fed or irrigated crops) for growing crops. This class includes small inter-field cover types (e.g. hedges, grass strips, small windbreaks, etc.)
Bare land	Areas with degraded lands, bare ground, quarry and inundation areas
Built up area	Settlement areas of large communities as well as clustered and dense rural settlements
Forest land	An area made of a main layer of natural trees with a cover from 10 to 100 %.
Wetland	Wetland is that is plain land along river
Grazing land	Area with a main layer of natural herbaceous vegetation and closed one with a cover from 10 to 100% of grass types

Source: FAO, 2010

The value of C factor is defined as the ratio of soil loss from a certain kinds of land cover conditions (Wischmeier and Smith, 1978). The C factor is a dimensionless factor that ranges from 0 for a completely non-erodible condition in areas with high plant cover to 1 which corresponds to the greater magnitude of soil loss due to very extensive tillage, leaving a very smooth surface that produces much runoff and makes the soil susceptible to erosion (Renard, 1997). A field checking effort was made in order to collect GCP and used as a reference for supervised classification, accuracy assessment and validation of the results (Appendix VII).

Land use land cover map of the study area was prepared from cloud free Sentinel-2 image acquired on January, 2019 for the estimation of C factor. Landsat sentinel-2 with bands 2, 3, 4 and 8 with spatial resolution of 10 m were layer stacked using the tool in ERDAS IMAGINE 2015. In order to determine C factor, the study area was classified into different land use classes by supervised image classification methods using maximum likelihood classifier in ERDAS IMAGINE. The supervised image classification was used to produce land use land cover map. In supervised image classifications technique, land use land cover types were classified so as to use the classified images as inputs for generating C factor. The raster land use land cover map was converted to a vector format. Based on the land cover classification map, corresponding C factor obtained from Hurni (1985) were assigned in ArcGIS environment as shown in table 4 below. Finally, using reclassification and vector to raster conversion the LULC map was converted to C factor map.

Table 4: Land use lands cover factor value of the study area

Class name	C factor	References
Farm land	0.17	Hurni (1988)
Forest land	0.001	Hurni (1985)
Grazing land	0.01	Eweg and van Lammeren (1996)
Wetland	0.01	Bewket and Teferi (2009)
Bare land	0.05	Hurni (1985)
Built-up area	0.003	Hurni (1985)

3.4.2.5. Conservation practice factor

Conservation practices directly affect the overall soil erosion problem. The P factor accounts for conservation practices that reduces erosion potential of the runoff by influence on drainage patterns, rate of erosion, runoff concentration and runoff velocity on soil. In RUSLE, P factor is the ratio of soil loss with a specific conservation practice to the corresponding loss with up and down slope cultivation. In agricultural areas, conservation practices such as contouring, strip cropping or terracing can reduce soil losses by reducing runoff speed and increased infiltration. These management activities are highly dependent on the slope. For this study, field observation was made to assess and evaluate conservation practices and identify locations within study watershed where there are major conservation activities exist or not.

The P factor ranges between 0 and 1 depending on the soil conservation practices employed, where the value closer to 0 shows good conservation practices and the values close to 1 is showing little or poor conservation practices (Ganasri and Ramesha, 2016). Based on the estimated P values given for different land use land cover in the table 5, conservation practice factor map was generated by reclassifying land use type map by the help of ArcGIS.

Table 5: Conservation practice (P) factor values

Class name	**P factor**
Farm land	0.90
Forest land	0.50
Grazing land	0.70
Wetland	0.70
Bare land	0.73
Built-up area	0.63

Source: Hurni, 2019

3.4.3. Prioritization of sub watersheds

The watershed was divided into 13 sub watersheds on the bases of hydrological response unit generated and prioritized on the bases of mean annual soil loss rate of each sub watershed, and the sub watersheds with high soil loss are given first priority and with the least value of soil loss are given last priority (Gizaw and Degifie, 2018). The soil losses values for each of the sub watershed exist were extracted from the soil loss map of the watershed. Soil erosion severity classes were also done using mean annual soil loss recorded for sub watersheds. Sub watersheds of the watershed were categorized into 6 classes as shown in table 6 below. Finally, the overall methodological flow of the study was described to summarize and highlight the study methods (Figure 4).

Table 6: Annual soil loss rate and its severity classes of sub watershed

Soil loss (ton/ ha/year)	Severity classes
>20	Low
20-23	Moderate
23-26	High
26-29	Very high
29-32	Severe
>32	Very Severe

3.4.4. Ethical considerations

The main concern in scientific research, which incorporates human subjects in the study, is ethical considerations for the research subjects. The researcher is cognizant to recognize the ethical principles of scientific research declared in Belmont Report 1 (1979). These principles were shading light on issues like informed consent, beneficence, anonymity and respect for the respondents. Cognizant of this truth the researcher get the consent key informants. They informed about the objectives and outcomes of the research quite adequately. Beyond the ethics on human subjects, research ethics also considers acknowledgment of data generated by others and appropriate citations of scholarly research outputs, books, websites and any other related documents in order to assure intellectual and scientific integrity of the researcher. By recognizing this, the researcher cited and acknowledged all the information taken from scholarly literatures and data generated by other individuals or organizations.

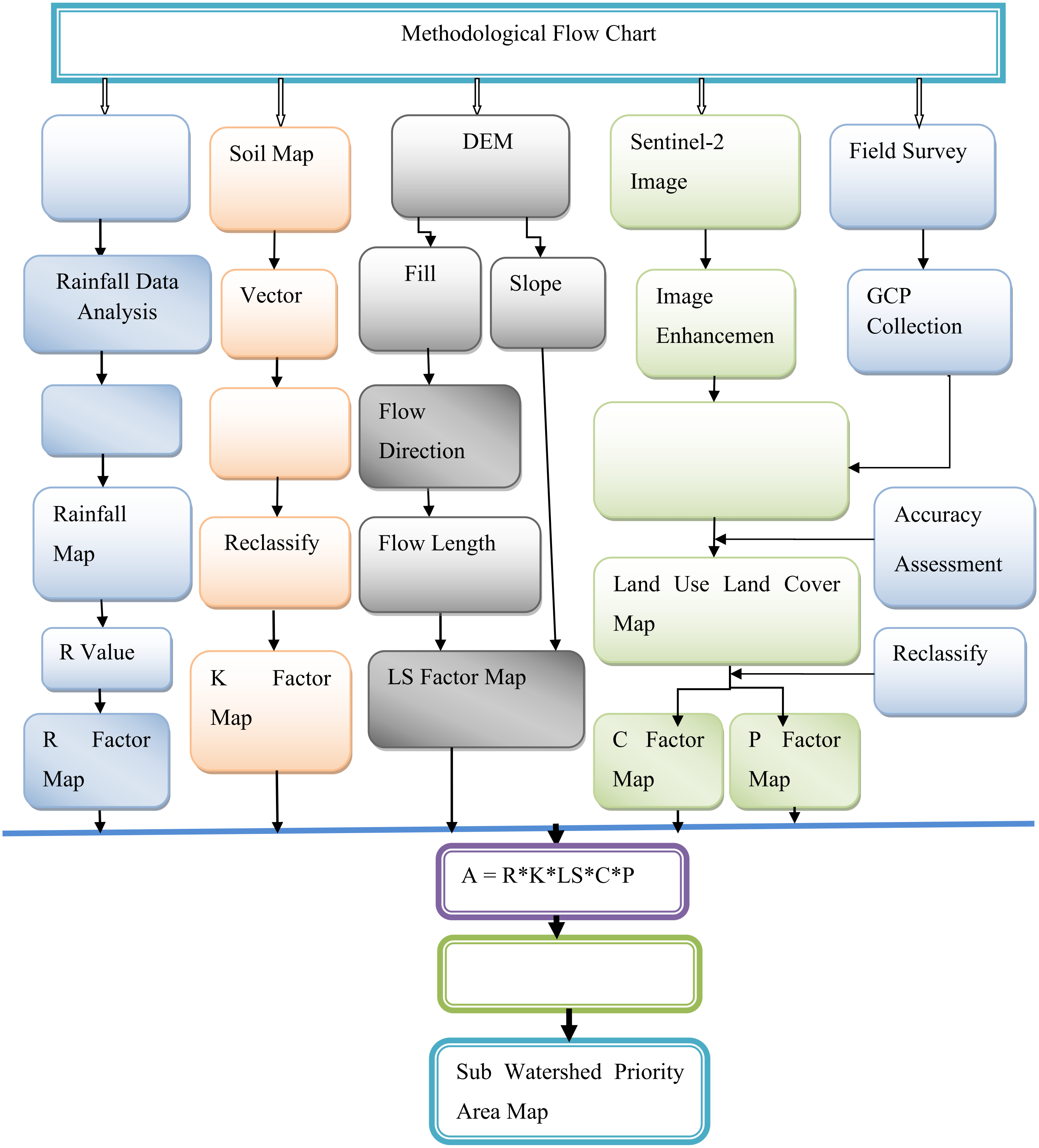

Figure 4: Methodological flow chart of the study

CHAPTER FOUR

4. RESULTS AND DISCUSSION

This chapter presents the results and discussion of all RUSLE factors that affect the mean annual soil losses and its spatial variation on soil loss prone areas of Gulufa watershed.

4.1. Factors influencing annual soil loss

4.1.1. Rainfall erosivity factor

Twenty years (1999–2018) of rainfall data was used for each selected local rainfall stations such as (Mendi, Jarso, Kiltu Kara, Bambasi and Begi) stations (Appendix I to V) which then interpolated using 30 m grid cells in ArcGIS 10.5 by following the methods used by Mengesha *et al.* (2018). The most commonly observed problem in rainfall data is related to incompleteness of data. Estimation of missed data values of station is often desirable to use the data before using for further analysis. Standard normal homogeneity test method is one which is recommended to estimate missing data in regions where annual rainfall among stations differ by more than 10%. The XLSTAT software with version 2018.7.55140 is used to fill in missing data on rainfall stations nearby the study area using the multiple imputation estimation method (Hailu and Biru, 2019) and the results were shown under Appendix I to V).

Homogeneity checking is very important before rainfall data used to continue for further analysis. Therefore, standard normal homogeneity test (SNHT) was used to test homogeneity of the rainfall data using the XLSTAT software (Appendix VI). Prior to consistency checking, the data were test for an outlier. Following the procedure of Hailu and Biru (2019), the accumulation in the station with the surrounding neighboring stations was computed and plotted. Although there is no station found within the study area boundary, erosivity factor was generated using mean annual rainfall from five relevant meteorological stations (Mendi, Jarso, Kiltu Kara, Bambasi and Begi) nearby the study area was obtained from NMA. However, the locations of the stations are not uniformly distributed around the study area and representative information could not be found for the area. As a result of this, interpolation was required. For this study area, five meteorological stations' rainfall data with 20 years span of (from 1999 to 2018) was used and its rainfall data were used for further analysis. Rainfall erosivity (R) factor was calculated from mean annual rainfall by using the formula stated in equation 2.

Table 7: Mean annual rainfall of stations and R factor of 20 years around the study area

Station name	Location			Mean annual rainfall (mm)	R factor
	Latitude (Y)	Longitude (X)	Elevation (Z)		
Mendi	9.78	35.1	1650.0	1916.27	1068.67
Jarso	9.45	35.32	1750.0	1712.18	954.13
Kiltu Kara	9.71	35.21	1850.0	3169.34	1772.86
Bambasi	9.75	34.73	1460.0	1307.59	726.74
Begi	9.33	34.53	1650.0	1271.84	706.66

Source: Computed from National Meteorological Agency (2019)

The total mean annual rainfall of the study area varied from 3169.34 mm to 1271.84 mm (Table 7) whereas the rainfall erosivity of the watershed was ranging from 1772.86 MJmm/ha/year to 706.66 MJmm/ha/year with a mean value of 1045.81 MJmm/ha/year. Similarly, the rainfall erosivity value estimated from the rainfall map using ArcGIS ranged from 1774.78 MJmm/ha/year to 1145.56 MJmm/ha/year with a mean value of 1431.32 MJmm/ha/year which is close to the erosivity values estimated using the mean annual rainfall (Table 7). As the value of mean annual rainfall increases the erosivity value also increases. As a result the rainfall erosivity is high at Kiltu Kara, Mendi and Jarso areas but low was observed in Bambasi and Begi areas. Rainfall stations having high rainfall had resulted in high rainfall runoff erosivity value which may cause high soil erosion.

It was observed that the higher value of rainfall erosivity which found in the upper or Eastern part of the study area indicated that this part of the watershed was more vulnerable to erosion; whereas the lower value of R factors which covers some area of the lower part of the study area implies that this is less vulnerable to erosion (Figure 5). According to Hudson (1981), high rainfall may have high erosive power. Therefore, based on this, the watershed area receives relatively higher rainfall that has high erosive power.

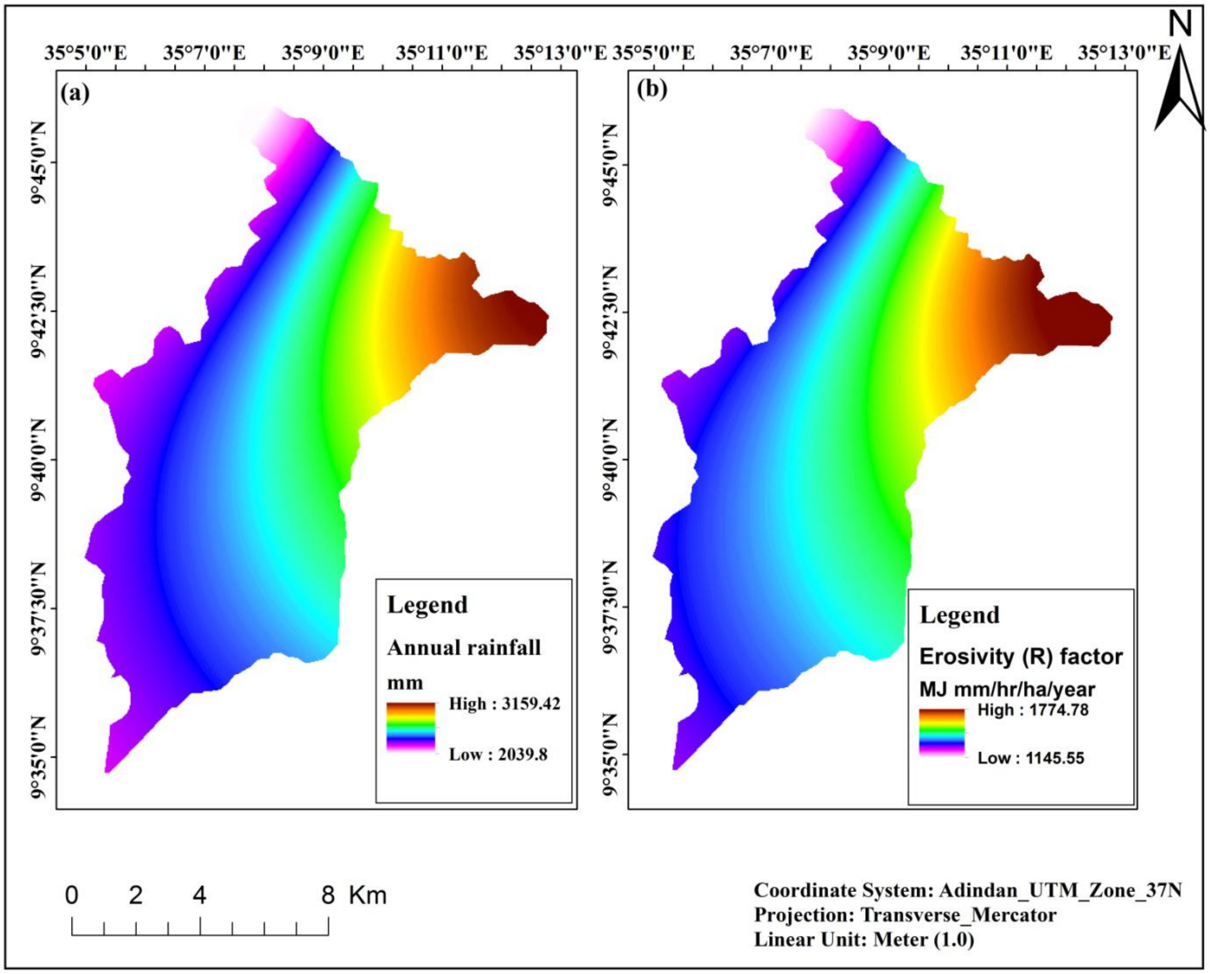

Figure 5: Mean annual rainfall and R factor map

4.1.2. Soil erodibility factor

The soil map data of the study area indicate Acrisols, Alisols, Cambisols, Fluvisols, Lixisols and Nitisols were major soils of the watershed and the K factor values of the soil types were assigned following the K values adopted by Taffa (2011) which is depends essentially on the amount of organic matter and texture in the soil (Table 2). Based on this, the K factor values for six soil texture (Clay, Silt, Sandy clay loam, Clay Loam, Loam, Sandy loam) of the study area was assigned (Table 2). The soil map was determined based on these soil texture classifications and soil organic matter content as shown in Figure 6. The output was reclassified to obtain the soil erodibility factor map.

The result shows that soil erodibility values of the watershed range from 0.12 to 0.42 (Figure 6). Higher erodibility (0.42) indicates, the soil is more susceptible to erosion as higher k value indicates a lower infiltration rate thus the soil is more prone to erosion while lower value (0.12) indicates resistant to erosion.

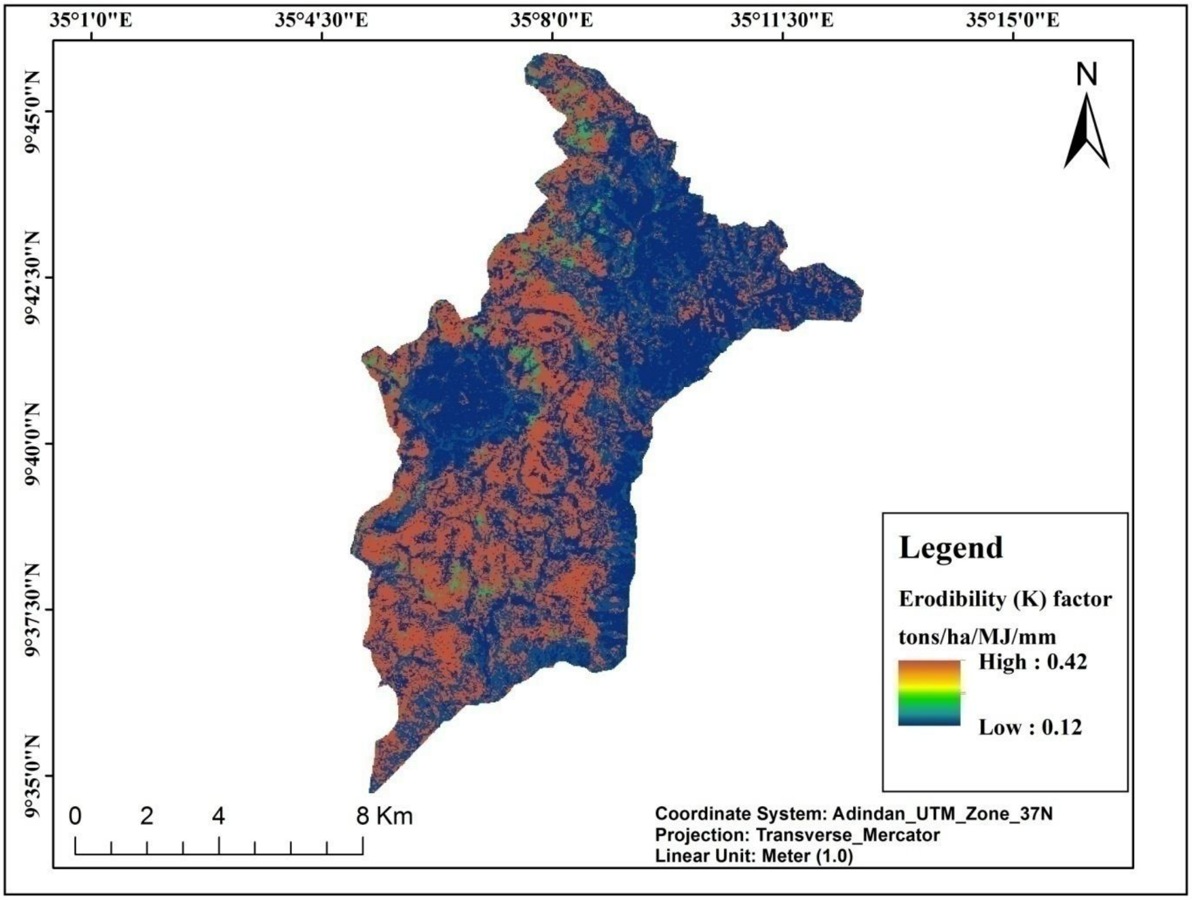

Figure 6: K factor map of the study area

In order to obtain a better view and understanding, be able to compare areas and percent resulted from figure 6 and grouped into six classes (Table 8).

Table 8: Soil erodibility values and their area coverage

Soil texture classes	K factor values	Area	
		Ha	%
Loamy sand	0.12	1803.80	14.70
Clay	0.13	71.00	0.60
Sandy loam	0.19	158.30	1.30
Sandy clay loam	0.21	9497.90	77.60
Loam	0.29	620.90	5.10
Silt	0.42	92.60	0.80
Total		**12244.45**	**100**

About 5.9% of the watershed soils were highly susceptible to soil erosion which covers (713.5 ha) and 78.9% of the area covers (9656.2 ha) relatively moderate and about 15.3% the area that covers (1874.3 ha) resistant to erosion. As the erodibility index was observed the values indicate that silt and loam has relatively higher erodibility while sand clay and clay soil have lower erodibility. This implies that the silt and loam more susceptible to erosion while clay and sandy clay have more resistant to erosion because of their low detachability under similar condition that affect soil loss.

4.1.3. Slope length and steepness factor

The slope steepness and slope length factors (LS) reflect the effect of the slope length and slope gradient in the soil erosion. The higher the slope length and slope gradient, the greater erosion will occur. Slope length and slope gradient (steepness) was generate from the DEM of the study area. The elevation of the study area ranges from 1743 to 1399 m above sea level. The highest value was observed at the northwest boundaries and in some central parts of the watershed which had high elevation and lowest near the river at the middle or bottom of the watershed. This shows the area has topographical variations that facilitate the soil erosion. This result was in line with Gizaw and Degefie (2018) who reported the highest LS value was observed at the boundaries of the catchment which had high soil erosion of Gilgel Gibe-I catchment.

Several methods of LS factor determination is developed with different GIS professionals at different time. Of which, the following is one for calculating LS using DEM after preparing the slope map and flow length map was used (Figure 7).

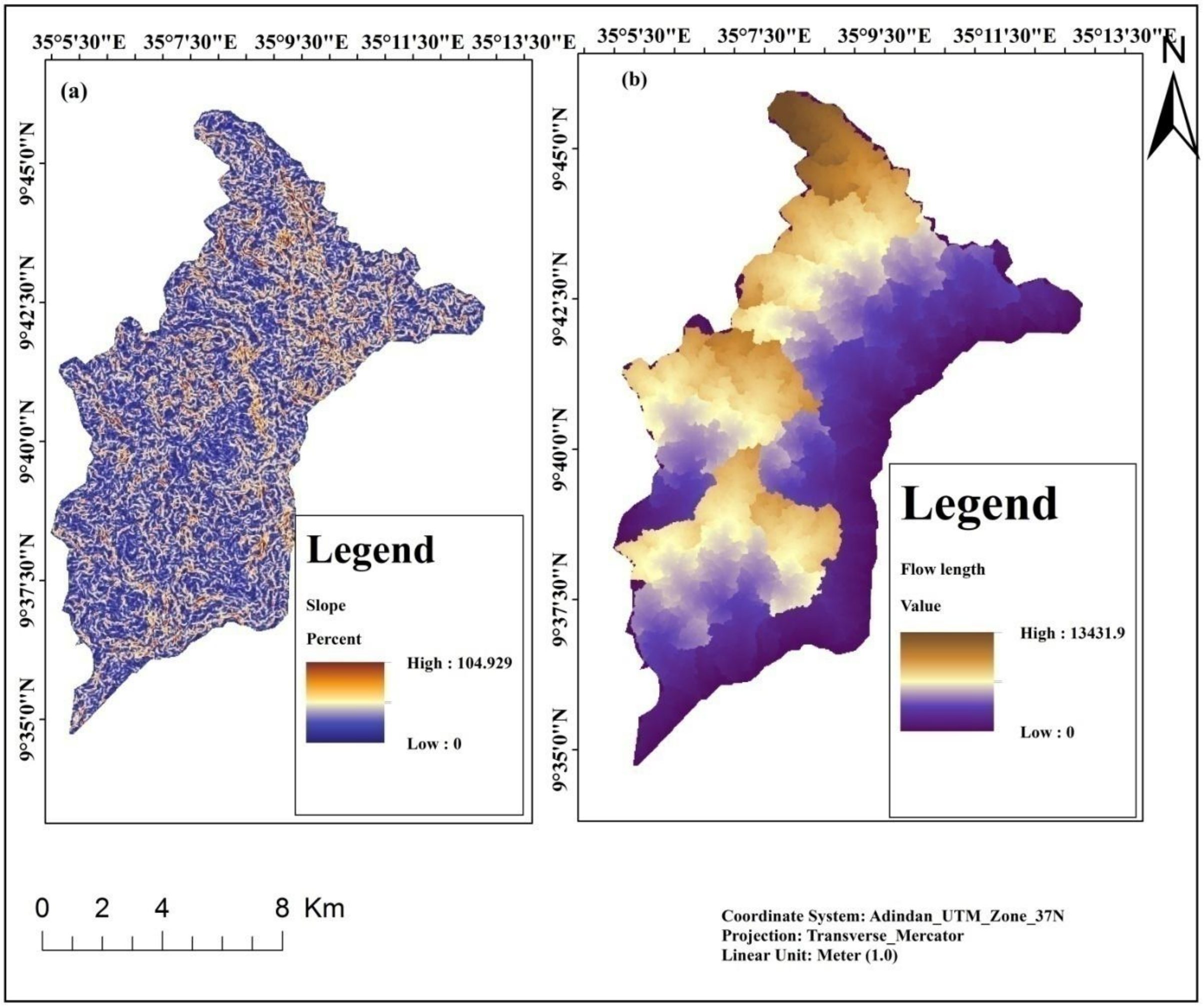

Figure 7: Gulufa slope (a) and flow length (b) map

The LS factor varies from 0 to 15.3453, the increase in LS factor increases the erosion because the runoff will be faster and then its energy will increase. As it is shown on (Figure 8), Northern and central part of study area which was assigned with high LS factors are as relatively high vulnerable to soil erosion. Dominant portion of the study area was assigned as medium LS factor. This indicated that this part is less vulnerable for soil erosion risk. According to Morgan (1995), soil erosion increase with the increase in slope steepness and slope length as a result of respective increase in velocity and volume of surface runoff.

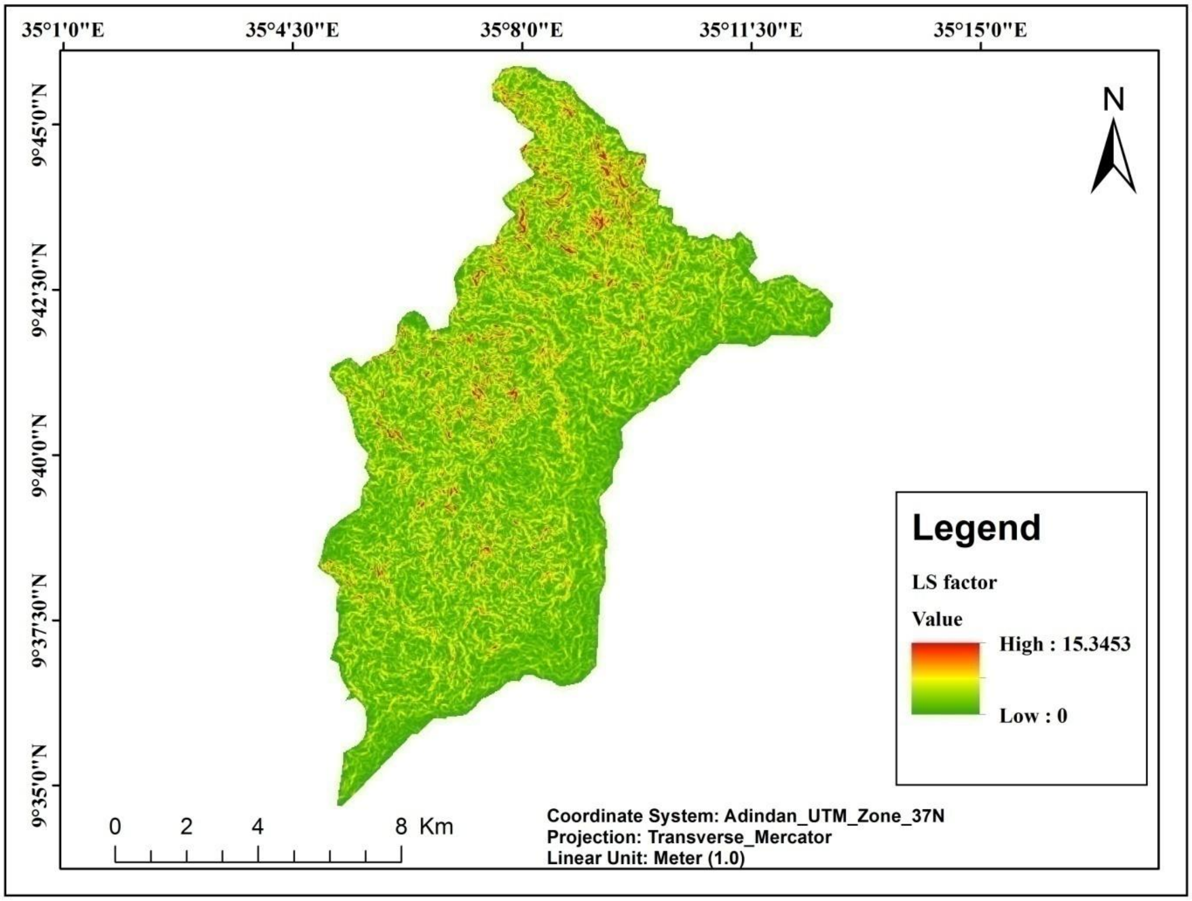

Figure 8: Slope steepness and slope length (LS) factor map

4.1.4. Land cover factor

In order to determine land cover factor (Figure 9), satellite images of sentinel-2 for the year 2019 was used. Among the Sentinel-2 image bands, band 2, 3, 4 and 8 were used for classification as these bands were used for vegetation classification with the same resolution of 10 m. In order to identify specific values for each land use cover types, the image was classified into six major land use land cover types as farm land, forest land, grazing land, wetland, bare land and built-up areas as indicated in figure 9 and Table 3.

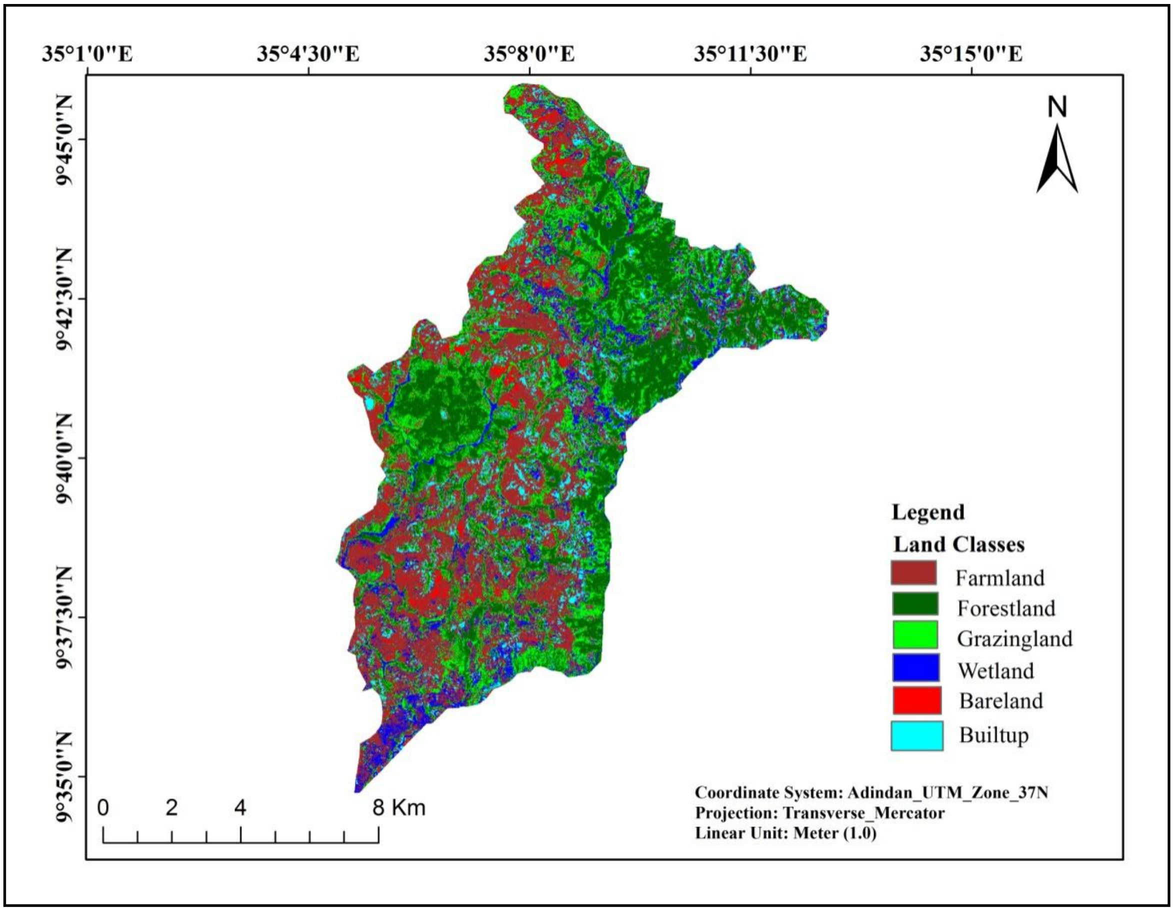

Figure 9: Land use land cover classification map of 2019

Table 9: LULC classification of Gulufa watershed for the of year 2019

Class name	**Area**	
	Ha	**%**
Farm land	4,760.79	38.88
Forest land	2,767.23	22.60
Grazing land	2,255.76	18.42
Wetland	1,603.51	13.10
Bare land	597.08	4.88
Built-up area	260.08	2.12
Total	**12,244.45**	**100**

The largest portion of the study area is dominated by farm land which covered about 38.88% (4,760.79 ha). Similarly, the study area was covered by forest land 22.60% (2,767.23 ha), grazing land 18.42% (2,255.76 ha), wetland 13.10% (1,603.51 ha), bare land 4.88% (597.08 ha) and built-up area with about 2.12% (260.08) from the next largest to smallest percent and coverage size respectively (Table 9). Generally, the farm land was the dominating land use type followed by forest land, while built-up area was the smallest land use land cover type in the watershed. In order to identify specific values for each land use land cover types, C factor values were assigned to each of the land use land cover classes recognized over the study area from different study (Table 4).

4.1.4.1. Accuracy assessment

Errors are inevitable in any digitally generated land cover maps obtained from remote sensing imagery. These errors may occur from the source itself because of errors during data acquisition or from classification techniques during image processing. As a result, assessment of classification accuracy is required in order to guarantee the reliability of the result (Congalton, 1991; Lillesand *et al*., 2004). After the preparation of LULCC; its accuracy assessment was done from 90 ground truth points 19, 17, 16, 14, 12 and 12 from farmland, forestland, grazing land, wetland, bare land and built-up area respectively (Appendix VII). These points were identified from each class of the land cover classification for the 2019 map. Each classified point was computed with these field data to ascertain the classification accuracy. Producer's accuracy is calculated as the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data.

This accuracy measure indicates the probability of a reference pixel being correctly classified. On the other hand, if the total number of correct pixels in a category is divided by the total number of pixels that are classified in that category, it is said to be user's accuracy is reliability. Kappa coefficient measures the agreement between the classifications on map and the reference or GCP data. Accordingly the overall classification accuracy in this study is 86.6% and its Kappa index agreement is 0.834. This implies that the classification process is avoiding 83% of the errors that a completely random classification generates. On the other hand, the accuracy of individual class varies from 80.95% to 90.91% for producer's accuracy and from 83.3% to 90.91% for user's accuracy (Table 10). With regard to producer’s accuracy, all classes are accurate by more than 80%. The result of the overall land classification reveals a good result which is feasible for further applications as shown below:

Table 10: The confusion matrix of LULCC map of the study watershed (2019)

Classified data	Reference data						Row total	Number of corrected classes	Producers accuracy	Users accuracy
	Built-up areas	Farm land	Forest land	Bare land	Wet land	Grazing land				
Built-up areas	10	1	0	0	0	0	11	10	90.91%	90.91%
Farm land	1	17	0	0	1	1	20	17	80.95%	89.47%
Forest land	0	1	15	0	0	1	17	15	93.75%	88.24%
Bare land	0	0	1	10	0	0	12	10	90.91%	83.33%
Wet land	0	0	0	1	12	1	14	12	85.71%	85.71%
Grazing land	0	1	0	0	1	14	16	14	82.35%	87.50%
Total	**11**	**20**	**16**	**11**	**14**	**17**	**90**	**78**	**86.67%**	

The C factor map of the watershed was generated by reclassifying land use land cover types, in spatial tool analysis (Figure 10). Accordingly, the mean C value of the watershed was resulted 0.066.

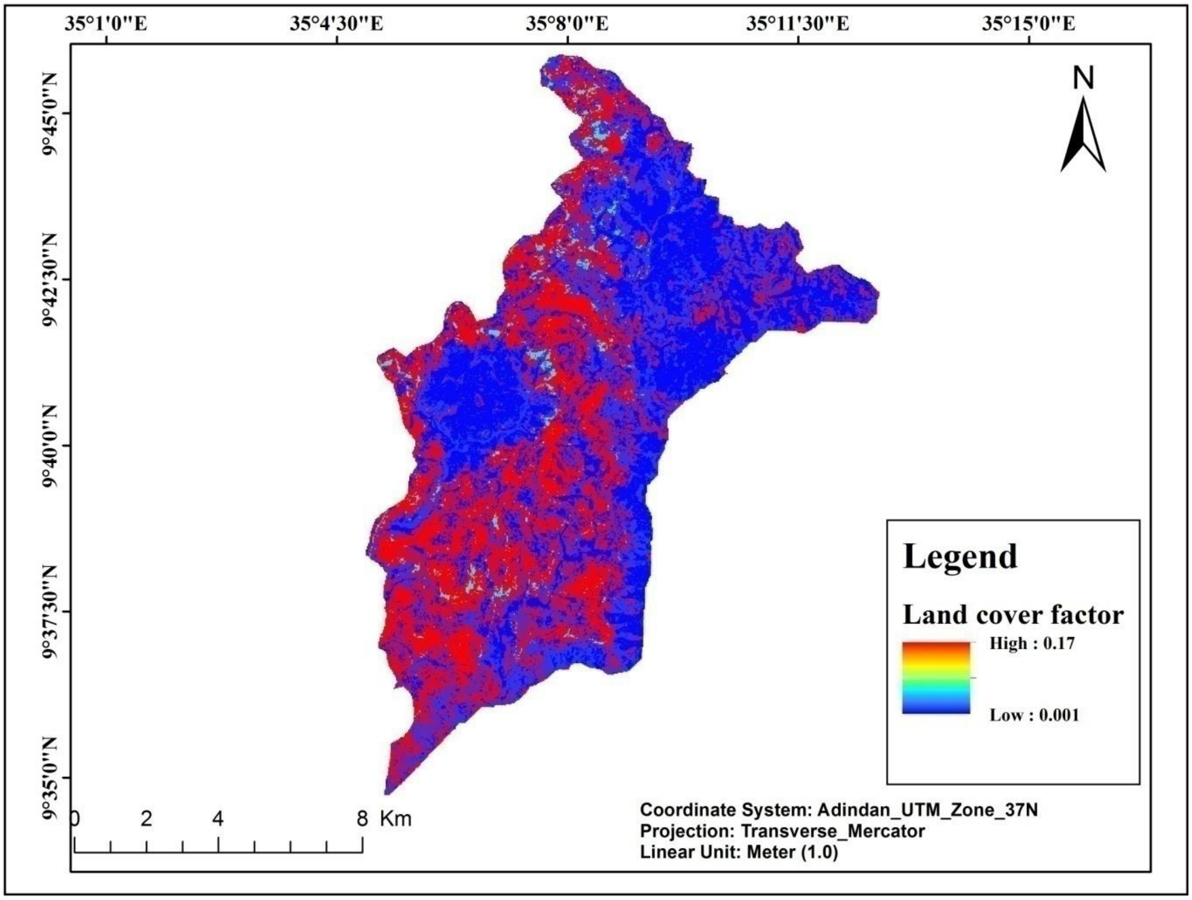

Figure 10: Land use land cover (C) factor map

Table 11: Land cover (C) factor values and their area coverage

Class name	Land cover (C) factor values	Area	
		Ha	%
Bare land	0.001	318.49	2.60
Built-up area	0.003	646.87	5.28
Farm land	0.17	4400.52	35.94
Forest land	0.01	3208.40	26.20
Grazing land	0.05	2361.65	19.29
Wetland	0.01	1308.52	10.69
Total		**12244.45**	**100**

As shown in figure 10 and Table 11, the land cover (C) factor of the study area shown that most parts of the land use land cover were covered by farm land which is about 35.94% (4,400.52 ha) or other land use land covers about 64.06 % (7,843.93 ha) of the total watershed. As a result, areas with high C factors are more susceptible to erosion than lower. The C values of the study are range from 0.001 to 0.17 (Figure 10). The C factor values were high in the farm land (0.17) whereas the low in other land use land cover classes which 0.05 to 0.001 (Table 11). This might be due to farm lands are the most susceptible to erosion because their soil is repeatedly tilled for different crops. This finding was in line with Pimentel (2006) who reported the farm lands left without a protective cover of vegetation is more vulnerable for soil erosion.

4.1.5. Conservation practice factor

For this study, the data related to conservation practices situations of the study watershed were collected during the field survey. During this, field observation by transect walk, interview of the local community and secondary information collected from Agricultural and Land Administration offices were used to identify the availability of conservation practices. Accordingly, conservation practices in the study area were taken as the value for similar to land use land cover types because there is lack data related to conservation practices. Therefore, from 2019 year Sentine-2 image (10 m*10 m) resolution were classified to identify land use land cover. Therefore, P values were assigned to each LULC types suggested in Hurni (1985) (Table 5). As a result the classified LULC map format has been converted into vector format and the corresponding P values were assigned to each LULC classes and the P factor map was produced (Figure 11).

On the bases of the study area of land use land cover types, the P value of the watershed was range from 0.5-0.9 and resulted with the mean of 0.72 (Figure 11).

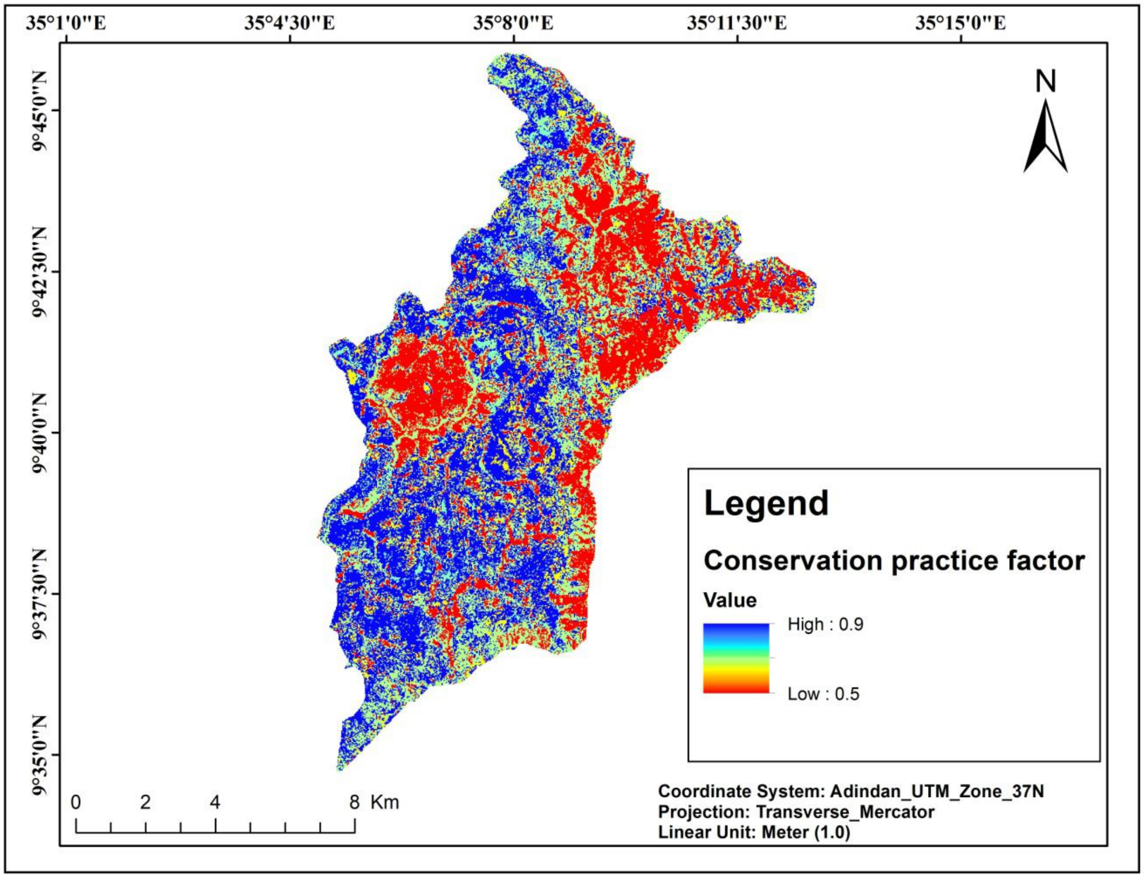

Figure 11: Conservation practice (P) factor map

Table 12: Conservation practice (P) values and their area coverage

Class name	Conservation practice (P) factor values	Area	
		Ha	**%**
Bare land	0.73	326.70	2.67
Built-up area	0.63	672.01	5.49
Farm land	0.90	4316.49	35.25
Forest land	0.50	3148.77	25.72
Grazing land	0.70	2423.02	19.79
Wetland	0.70	1357.48	11.09
Total		**12244.45**	**100**

As shown in figure 11 and table 12, the conservation practice (P) factor of the study area shown that most parts of the land use land cover types were covered by farm land which is about 35.94% (4,400.52 ha) of the total watershed area. As a result, areas with high P factors are more susceptible to erosion than lower P values. The P values (Figure 11) of the study area range from 0.5 to 0.90. The P factor values were high in the farm land (0.90) whereas the low in the forest land which 0.5 (Table 12 and Figure 11). This might be due to removal of crop residues, like straw, stubble and maize stalks for different purposes such as fuel wood and animals feed and forest land soil might be protected from the detachment and transportation of the soil. FAO (1965) and Tesfaye (2015) also reported that the lower the value is the more effective when the lands are covered by cover crops, mulches or residues would be protected from water and wind erosion.

4.2. Assessment of actual soil loss

The actual soil loss assessment is based on the principles of RUSLE model, which multiplies the five factors; rainfall erosivity, soil erodibility, slopes steepness and length, land cover and conservation practices. Annual soil loss of the study area was computed by multiplying these respective RUSLE factors map using raster calculator in ArcGIS. The soil loss map (Figure 12) of the area was generated by multiplication overlay cell to cell operation of the grids (raster) input factors. Accordingly, the quantitative output of estimated actual soil loss from Gulufa watershed varied from 0 - 439.22 tons/ha/year (Figure 12).

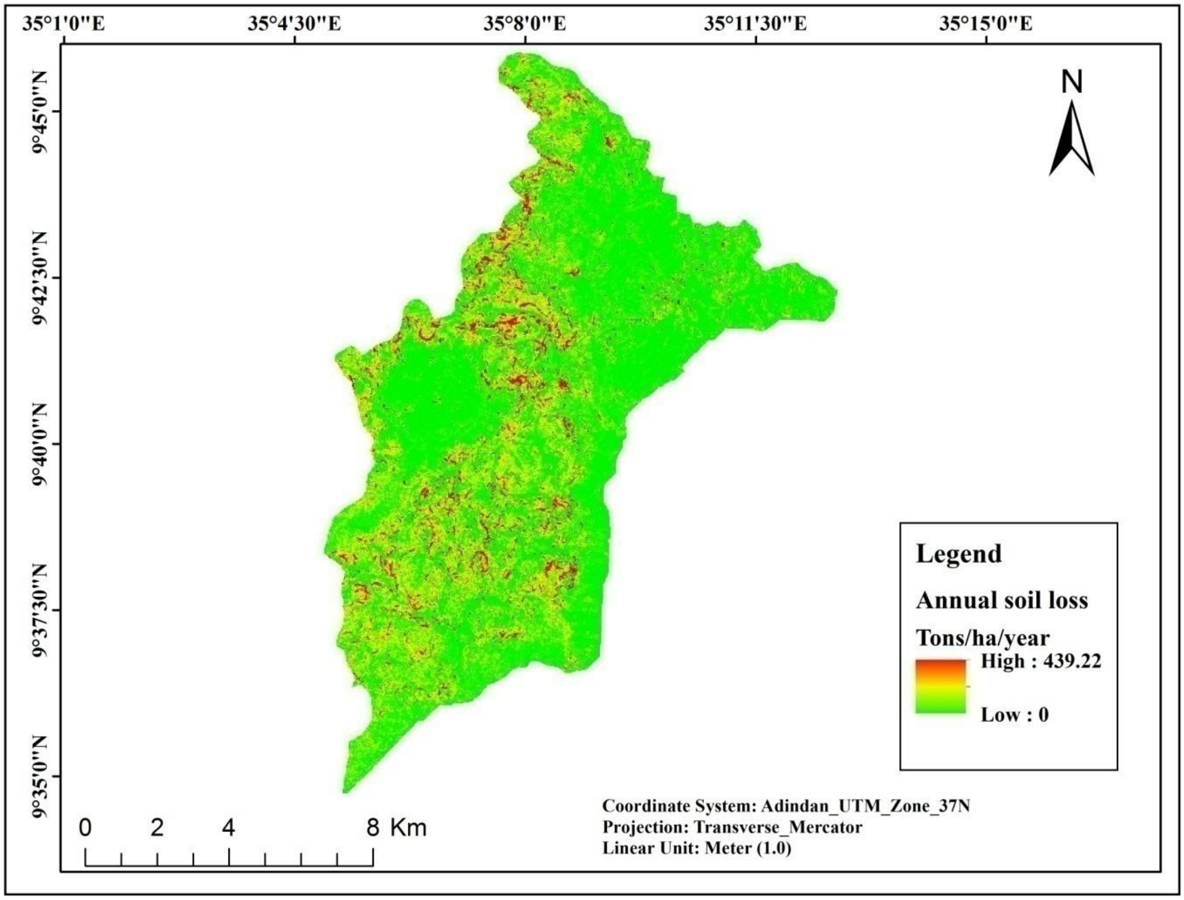

Figure 12: Annual soil loss map

For this study the soil erosion rate classified in to six erosion severity classes ranging from low soil loss (0-12) tons/ha/year to very severe soil loss (>125) tons/ha/year was used (Table 1). The first two classes are relatively considered in range of soil loss tolerance values. High and very high classes need conservation applications to maintain a sustainable productivity while the last two classes severe and very severe is very dangerous because it can be destructive in few years if no intervention are done and soil loss level is maintained constant in the future.

In order to compare areas and percent below, the quantitative output of soil erosion rate for Gulufa watershed resulted from these factors were computed and grouped into six ordinal classes (Table 1). The soil loss map also further classified into six severity classes in ArcGIS as shown in the Figure 13 below.

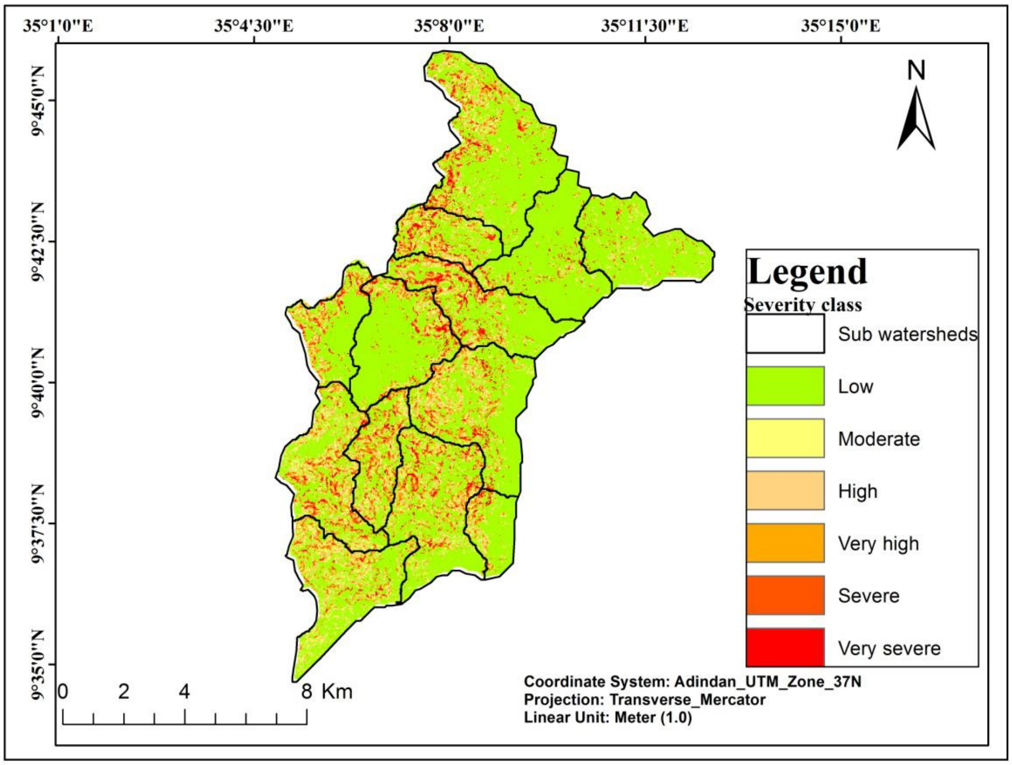

Figure 13: Gulufa annual soil loss severity map

Table 13: Annual soil loss rates and severity classes

Soil loss rate (tons/ha/year)	**Soil loss severity classes**	**Area**	
		Ha	**%**
0-12	Low	8186.62	66.86
12-25	Moderate	799.70	6.53
25-50	High	1265.40	10.33
50-80	Very high	987.97	8.07
80-125	Severe	655.60	5.35
>125	Very severe	349.18	2.85
Total		**12244.45**	**100.00**

According to the result of this study (Table 13), 73.39% (8986.32 ha) of the area is under low to moderate erosion rates, which is good in the current situation and 18.47% (2,253.37 ha) of the area is under high to very high erosion rates. An areas which are classified under severe to vey severe erosion classes (>125 ton/ha/year) covers about 8.2% (1,004.78 ha) of the study area. Generally low to moderate erosion risk classes (0 to 25 tons /ha/year) covers an area of 73.39% (8,986.32 ha) whereas high to very severe erosion severity classes (50 to >125 tons/ha/year) covers 26.6% (3,258.15 ha) of the total area coverage (Figure 13). Next to severe to very severe erosion risk classes, high to very high classes are concentrated around areas having higher LS factors and on the steep slope land of the study area. According to Morgan (1995), soil erosion increase with the increase in slope steepness and slope length as a result of respective increase in velocity and volume of surface runoff. This is mainly due to the high steep slopes and undulating features of the study area. Accordingly, area with high, very high, severe and very severe areas are require urgent soil and water conservation practices. Generally, high to very sever soil loss is evident on 33.14% of the area and almost a comparable coverage (73.39%) experiences moderate to low soil loss.

The annual soil loss analysis of the watershed revealed that, the total amount of soil loss in watershed was 439.22 tons/year from a total area of 12,244.45 ha with mean annual soil loss of 21.24 tons/ha/year which is much greater than the tolerable level 11 ton/ha/year (Hurni, 1983). Accordingly, the total annual soil loss of the watershed is 260072.12 tons/year. The estimated soil loss rate and the spatial patterns are generally realistic compared to what can be observed in the field and the results were more than the soil losses by different previous studies. For instance, the results of this study goes beyond the ranges of the soil loss estimated for Ethiopia, which was ranging from 0 to 300 ton/ha/year with an average of 12 ton/ha/year (Hurni, 1985). According to Gera (2014), averagely Ethiopia losses 12 tons/ha/year or an estimate of 1,493 million tons/year because water erosion but in this study averagely 21.24 tons/ha/year were lost due to water erosion in Gulufa watershed which is around two times more. This fact shows how much soil erosion is a serious and harmful in Gulufa watershed.

According to FAO (1986), the annual soil loss of the highlands of Ethiopia ranges from 1248–23400 million tons/year from 78 million of hectare (16 - 300 tons/ha/year) of pasture, ranges and cultivated fields throughout Ethiopia. The mean annual soil loss of 21.24 ton/ha/year is also greater than the tolerable level 2-18 tons/ha/year (Hurni, 1983). This indicates that study area is highly affected by soil loss comparative to this study. But less than the mean annual soil loss reported by Israel (2011) which is 33.66 tons/ha/year from Dire Dam watershed. The study results also indicate that some portions of study watershed were under high to very high prone of soil erosion status. This might be due to the rapid formation of rills and gully in the cultivated lands are witnessing for the alarming rate of soil loss in the Gulufa watershed. In addition stream bank erosion was observed in some parts of sub watershed and it destroyed coffee farm, grazing land, wetland and indigenous trees around the embankment of the river.

This study estimates is also annual soil loss greater than other estimates in upper part of Abay (Nile) river basin for Somodo watershed which is 131.21 tons/ha/year (Gizaw and Degifie, 2018) and 223.12 tons/ha/year estimated from Fincha'a watershed (Gamtessa and Birhanu, 2019). Other studies on the other hand estimated 983.14 tons/ha/year soil loss from Gilgel Gibe-1 Catchment by Gizaw and Degifie (2018) is much greater than the results of this study. This might be due to the variations in topographical settings of in Gilgel Gibe-1 Catchment as compared to Gulufa watershed. Comprehensive study in Upper Blue Nile Basin by Haregeweyn *et al.* (2017) estimated a mean annual soil loss of 27.5 tons/ha/ year which relatively similar with means annual soil loss of Gulufa watershed.

4.3. Prioritization of sub watersheds

Gulufa watershed is classified into 13 sub watersheds based on their drainage pattern (Figure 2). For this study prioritization of sub watersheds shows ranking of the sub watersheds found in study area according to their severity classes based on the mean annual soil loss (Figure 14). This helps to determine which areas of the sub watershed is at high risk of erosion for prioritization of interventions. Mean annual soil loss value for each sub watershed was recorded and identification of prone areas of sub watersheds on the basis of annual soil loss rate was ranked (Appendix VIII).

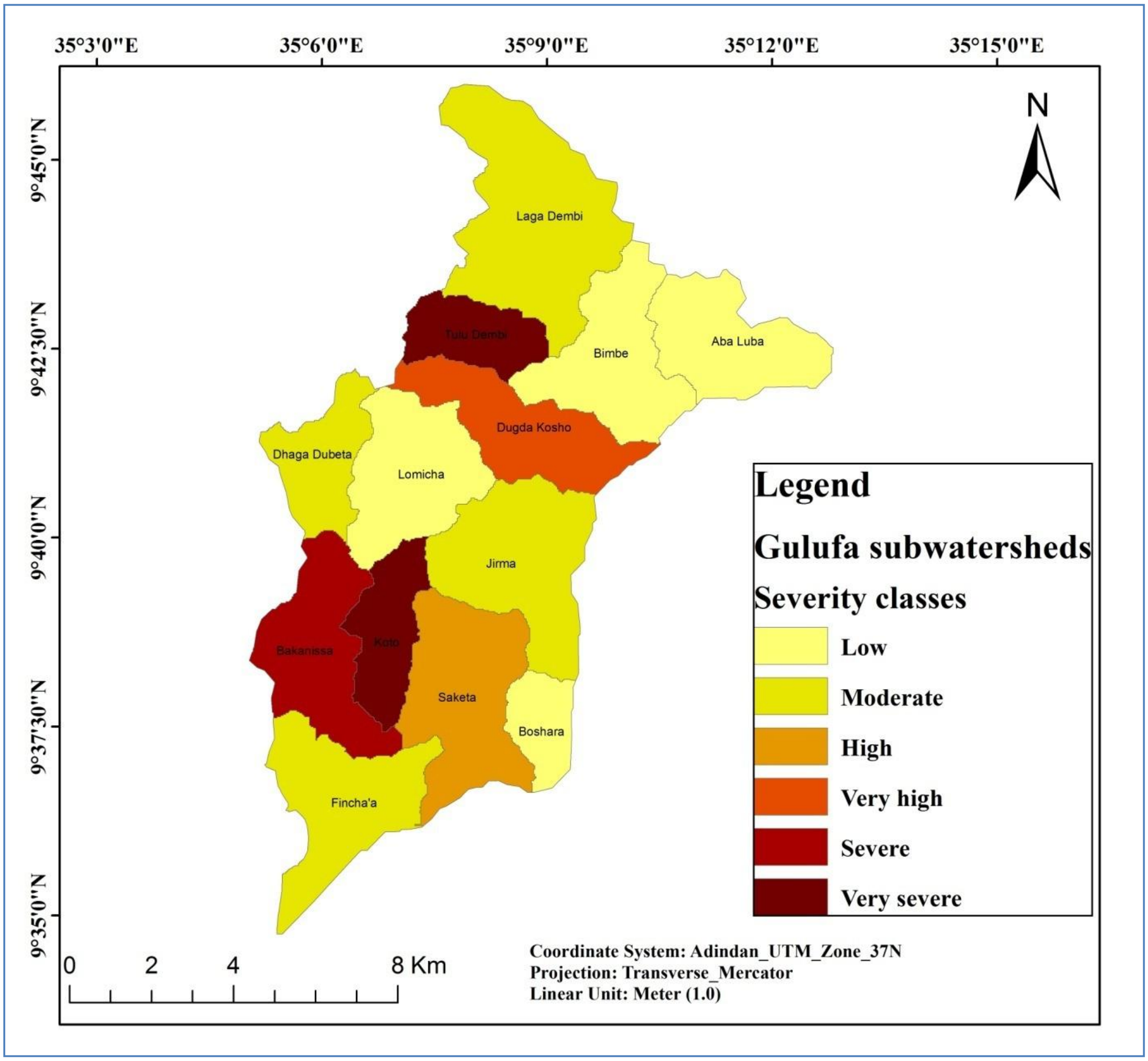

Figure 14: Severity class of sub watersheds by mean annual soil loss

Table 14: Soil loss and severity classes of sub watersheds

Sub watersheds	Area		Soil loss rates	Severity classes	Mean annual soil loss	Priority rank
	Ha	%				
Aba Luba, Bimbe, Boshara and Lomicha	3387.97	27.67	Low	<20	15.05	6
Laga Dembi, Jirma, Fincha'a and Dhaga Dubata	4558.25	37.23	Moderate	20-23	21.16	5
Saketa	1213.9	9.91	High	23-26	25.00	4
Dugda Kosho	957.55	7.82	Very high	26-29	27.30	3
Bakanissa	995.61	8.13	Severe	29-32	30.00	2
Tulu Dembi and Koto	1131.17	9.24	Very severe	>32	34.30	1

As shown in table 14, the some portions of the sub watersheds which represents about 27.67% (3387.97) was characterized by low soil loss severity class (<20 tons/ha/year). These sub watersheds (*Aba Luba, Bimbe, Boshara* and *Lomicha*) shows low soil loss rate among the sub watersheds that is less vulnerable to soil erosion. These values were observed in the eastern and central part of the watershed. *Laga Dembi, Jirma, Fincha'a* and *Dhaga Dubata* sub watersheds which covering 37.23% (4558.25 ha) are characterized by moderate soil erosion severity class (20-23 tons/ha/year). High soil loss severity class (23-26 tons/ha/year) include only *Saketa* sub watershed and it covers l9.91% (1213.9 ha) portions of the study area. The very high soil loss severity class (26-29 tons/ha/year) covers about 7.82% (957.55 ha). The severe soil loss severity class (29-32 tons/ha/year) include only *Bakanissa* sub watershed and covers 8.13% (995.61 ha) portions of the study area while the some portion of the sub watersheds which represents about 9.24% (1131.17 ha) was characterized by very severe soil loss. These two sub watersheds (*Tulu Dembi and Koto*) shows very severe soil loss rate (>32 ton/ha/year) (Table 6). This might be due to the area characterized by sloppy surface and used for crop cultivations that disturbs soil structures during ploughing.

Generally, the results showed that the western part of the study area is characterized by high amount of soil loss whereas relatively the eastern and lower part was less prone to soil loss. The sub watershed under this class is not critical area of action plan. Based on the mean annual soil losses, sub watersheds are identified and ranked in the order for prioritization (Appendix IX). The sub watershed that comes first is more erosion affected and priority is given for developing the conservation plan to reduce the soil and nutrient losses. Even if, the average annual soil loss of all sub watershed (Table 14 and Figure 14) clearly shows that nearly the entire watershed requires implementation of different types of soil and water conservation measures for a sustainable land use; it is important to plan the activities on priority basis for addressing prone areas to arrive at immediate solutions.

Finally, the watershed was classified based on mean annual soil loss of each sub watersheds as <20 tons/ha/year as a low, 20-23 tons/ha/year as moderate, 23-26 tons/ha/year as high, 26-29 tons/ha/year as very high, 29-32 as a severe and >32 tons/ha/year as very severe. Accordingly, sub watersheds with high mean annual soil loss were given priority and with the least value of mean annual soil loss were given last priority for SWC implementation. Based on this mean annual soil loss *Tulu Dembi and Koto* as first*, Bakanissa* as 2nd*, Dugda Kosho* as 3rd, *Saketa* as 4th*, Laga Dembi, Jirma, Fincha'a* and *Dhaga Dubata* as 5th*, Aba Luba, Bimbe, Boshara* and *Lomicha* as 6th priorities respectively (Table 14). Mean annual soil loss of sub watershed with first priority was 34.3 tons/ha/year and 15.05 tons/ha/year for the last priority. There was no big difference between priorities of sub watersheds based on mean annual soil loss as described in Table 14.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

The Gulufa watershed is affected by soil erosion by water. The soil loss estimation was undertaken through integration of RUSLE model, GIS and remote sensing techniques on soil loss modeling. This study shows the usefulness of these techniques in estimating and mapping of the watershed's annual soil loss, erosion prone areas identification and prioritization for sub watershed based on the mean annual soil loss results. The RUSLE model has been an easy tool to estimate the mean annual soil loss, especially in small areas such as watershed and sub watershed levels for effective planning of soil and water conservation measures.

This study estimates the soil loss in the Gulufa watershed and prioritizes sub watersheds based on mean annual soil loss. Modeling of annual soil loss rate of the watershed provided several insights on soil loss. It can be concluded that soil erosion is severe in the study area. The mean soil loss observed in the watershed was also above the tolerable soil loss rate. As a result, the study area is prone to soil erosion that can put under risk the sustainability of agriculture. Generally, the study demonstrates that RUSLE together with GIS and remote sensing are useful tools to estimate soil loss over areas and facilitate sustainable land management. The results of the study show that Gulufa watershed losses annual soil of 439.22 tons/ha/year with mean value of 21.24 tons/ha/year with different severity classes. Accordingly, the annual sol loss rate of 73.39% (8986.32 ha) of the study area is classified under low to moderate which is not worst in a current situation and 26.67 % (3258.13 ha) of the area is under high to very severe erosion classes of the study area. The soil loss map produced can be used as a decision support system to provide conservation practices for decision makers.

The result also showed that among 13 sub watersheds *Tulu Dembi* and *Koto* were under very severe soil loss severity class while *Bakanissa* and *Dugda Kosho* were under severe and very high soil loss severity class respectively. On the other hand *Saketa* was under high soil loss severity class. *Laga Dembi, Jirma, Fincha'a* and *Dhaga Dubeta* were under moderate severity class while *Aba Luba, Bimbe, Boshara and Lomicha* sub watersheds were under low severity class on the basis of mean annual soil loss. It was found that the RUSLE factors within GIS environment have significant effect on the erosion proneness identification in the sub watersheds by providing useful information on vulnerability of watershed. The method can also be adopted for other watersheds in the West Ethiopia to have information on the spatial variation and quantitative estimate of soil loss as a guide for planning of the strategy for SWC practices that minimize top soil removed from the area and siltation of Dabus River for healthy ecosystem.

5.2. Recommendations

The findings of the study showed that the study area is prone to soil loss that can put sustainability of agricultural land of the area at risk in a long run if trend is continued. In addition, the following points are forwarded as a recommendation:

- Based on the result of the study, the areas which have fallen under high to very severe severity classes of soil loss rates need immediate attention before the area jumps to irreversible soil degradations.
- Although, the current soil loss assessment is somehow indicative to annual soil loss from the watershed. Therefore, detail study including field measurements of sediment yield from gully and stream banks might be done to come up with a solution for mitigating the problem and amount of soil loss reach at the outlet of the watershed.
- Local communities need to adopt immediate soil conservation practices in their farm lands by applying different soil protective methods like mulching, strip cropping, terracing and contour plowing including their indigenous knowledge.
- Long-term soil erosion preventions especially in steeper slopes and conservation of existing vegetation cover and replanting or reforestation of forest remnants is necessary for the sustainability of soil and other natural resources in the study area.
- The results may needs some validations from field measurements or socio-economic study.

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APPENDICES

Appendix I: Rainfall station of Mendi and its mean average rainfall

Element: Monthly rainfall in millimeter

Region: Assosa

Station: Mendi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	0.00	0.00	0.00	47.50	337.30	649.60	274.90	623.90	646.10	255.80	0.00	0.00	2835.10
2000	0.00	0.00	0.00	115.20	202.00	527.70	562.10	428.40	455.00	559.40	58.70	0.00	2908.50
2001	22.13	0.00	0.00	0.00	0.00	254.74	493.80	718.30	383.30	188.60	0.00	0.00	2060.87
2002	0.00	0.00	0.00	54.40	76.20	247.80	542.20	703.20	292.30	272.60	191.20	52.00	2431.90
2003	0.00	22.50	0.00	0.00	0.00	291.17	270.70	646.30	571.20	197.90	153.40	0.00	2153.17
2004	0.00	0.00	0.00	99.30	204.10	162.70	418.70	644.00	340.20	119.00	0.00	0.00	1988.00
2005	0.00	3.04	0.00	40.70	0.00	0.00	355.27	613.50	351.05	177.90	44.25	15.30	1601.01
2006	0.00	0.00	0.00	0.00	208.40	328.50	236.10	237.00	235.60	358.60	0.00	0.00	1604.20
2007	0.00	0.00	4.60	70.10	54.90	434.80	320.00	410.50	319.60	63.80	8.60	0.00	1686.90
2008	4.00	0.00	0.00	153.10	269.00	300.70	464.90	446.80	268.30	128.30	0.00	0.00	2035.10
2009	0.00	0.00	8.50	21.40	36.00	369.90	354.80	449.00	436.10	260.70	28.38	0.00	1964.78
2010	0.00	10.30	0.00	8.00	199.80	406.50	543.00	499.50	369.20	66.70	0.00	1.40	2104.40
2011	0.00	0.00	27.50	41.40	208.30	242.40	381.80	336.00	482.30	0.00	0.00	0.00	1719.70
2012	0.00	0.00	0.00	0.90	85.47	377.00	291.80	451.60	335.30	249.10	23.91	0.00	1815.08
2013	0.00	0.00	0.00	0.00	124.80	236.50	424.80	398.20	480.40	251.80	76.20	0.00	1992.70
2014	0.00	0.00	50.30	48.60	204.40	228.10	295.90	330.30	328.60	78.90	0.00	0.00	1565.10
2015	0.00	7.01	0.00	16.43	143.83	375.83	394.32	353.74	449.60	194.81	71.77	2.91	2010.25
2016	0.00	0.00	0.00	142.50	164.70	215.50	246.30	311.30	385.00	178.90	32.10	0.00	1676.30
2017	4.25	2.58	0.38	57.91	146.75	372.95	396.74	476.13	373.53	204.25	36.15	9.70	2081.31
2018	9.17	5.31	4.90	52.77	144.51	301.88	371.22	491.57	348.05	227.32	12.26	6.09	1975.06
Mean	1.98	2.54	4.81	48.51	140.52	316.21	381.97	478.46	392.54	201.72	36.85	4.37	1916.27
St.Dev	5.28	5.51	12.44	47.35	93.30	136.57	100.38	138.38	100.35	120.52	52.93	11.92	824.94
CV	2.67	2.17	2.59	0.98	0.66	0.43	0.26	0.29	0.26	0.60	1.44	2.73	15.07

Appendix II: Rainfall station of Jarso and its mean average rainfall

Element: Monthly rainfall in millimeter

Region: Assosa

Station: Jarso

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	0.21	1.72	14.76	37.19	268.94	339.39	464.59	293.04	203.84	85.59	17.97	1.38	1728.60
2000	0.87	3.26	9.58	120.88	226.72	243.69	483.61	250.92	238.87	137.40	6.90	0.06	1722.75
2001	0.54	0.06	14.86	48.06	203.83	265.66	471.34	323.67	303.17	121.66	25.11	0.71	1778.67
2002	0.10	0.18	17.82	94.14	164.22	252.36	458.31	388.93	284.87	115.46	16.69	1.10	1794.17
2003	1.65	0.22	19.98	44.22	227.69	292.67	319.76	357.75	234.90	109.81	14.15	3.01	1625.82
2004	1.65	0.28	9.13	37.70	178.39	324.07	396.68	307.01	224.42	131.05	10.55	1.00	1621.90
2005	0.02	0.33	2.55	103.55	191.88	318.55	456.34	299.38	231.63	88.76	11.55	0.79	1705.33
2006	0.99	0.16	7.30	101.37	147.13	269.47	497.96	378.63	213.85	114.52	21.49	2.13	1754.99
2007	1.23	0.03	9.27	121.40	126.60	290.60	481.36	373.16	288.24	151.00	3.80	0.00	1846.69
2008	0.00	0.00	0.00	176.80	183.82	293.70	617.10	289.60	230.40	104.80	1.70	2.40	1900.32
2009	6.00	8.50	0.00	58.80	170.83	130.60	224.50	146.60	177.90	43.30	0.00	7.20	974.23
2010	0.00	0.00	0.00	7.20	7.20	290.30	337.90	260.70	136.70	105.70	17.00	0.50	1163.20
2011	0.00	0.00	28.40	5.60	119.60	315.90	309.60	311.10	276.00	174.00	19.08	0.00	1559.28
2012	0.00	0.00	31.20	8.00	248.70	324.00	563.00	557.20	347.30	74.90	21.80	0.00	2176.10
2013	0.84	0.49	0.00	0.00	260.90	183.90	511.50	364.70	254.30	311.70	35.90	0.00	1924.24
2014	0.00	0.00	18.80	227.40	345.50	378.80	456.30	448.40	286.60	208.50	15.20	0.00	2385.50
2015	0.00	0.17	13.51	36.33	170.98	230.19	477.05	257.41	211.57	115.77	3.38	0.30	1516.65
2016	0.00	0.00	20.40	130.05	201.50	345.30	358.20	282.60	278.96	106.51	13.09	0.58	1737.19
2017	1.94	1.10	13.93	58.48	217.91	259.47	464.41	303.42	276.36	111.32	13.31	0.46	1722.11
2018	0.19	0.52	4.25	98.84	117.12	245.05	372.61	347.55	259.76	143.95	15.49	0.62	1605.96
Mean	0.81	0.85	11.79	75.80	188.97	279.68	436.11	327.09	247.98	127.78	14.21	1.11	1712.18
St.Dev	1.38	1.97	9.30	60.42	70.28	57.51	92.94	83.74	47.70	55.81	8.63	1.67	491.35
CV	1.71	2.31	0.79	0.80	0.37	0.21	0.21	0.26	0.19	0.44	0.61	1.50	9.39

Appendix III: Rainfall station of Kiltu Kara and its mean average rainfall

Element: Monthly rainfall in millimeter

Region: Assosa

Station: Kiltu Kara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	6.00	0.70	0.00	0.00	150.00	509.60	541.30	763.00	325.00	180.00	0.00	0.00	2475.60
2000	0.00	0.00	0.00	6.20	200.00	532.70	638.70	780.00	315.00	213.60	12.00	0.00	2698.20
2001	0.00	0.00	1.00	10.00	183.00	597.80	539.90	657.20	298.30	113.50	0.00	0.50	2401.20
2002	0.00	0.00	0.00	8.00	175.10	816.40	702.80	748.50	270.00	125.40	1.80	0.00	2848.00
2003	0.00	0.00	2.60	5.20	119.60	581.50	845.30	760.50	210.00	195.20	2.37	0.00	2722.27
2004	4.30	0.00	0.00	7.80	176.20	308.80	571.10	556.80	245.10	251.30	5.30	0.00	2126.70
2005	0.00	0.00	25.10	7.70	200.00	300.50	516.90	567.20	310.00	203.70	0.00	0.00	2131.10
2006	0.00	0.70	0.00	0.00	165.20	278.30	639.40	764.50	133.00	243.96	7.00	0.00	2232.06
2007	0.00	3.00	8.54	0.00	130.00	612.12	771.25	613.35	254.00	190.20	6.30	0.00	2588.77
2008	7.80	0.00	0.00	23.00	200.00	459.40	539.90	572.90	281.00	87.00	0.00	0.00	2171.00
2009	0.00	1.80	24.80	8.70	60.80	626.60	544.70	657.00	265.80	260.80	0.00	0.00	2451.00
2010	4.00	0.20	0.00	0.00	167.00	742.00	700.80	828.80	205.00	395.90	7.00	3.10	3053.80
2011	0.00	0.00	15.70	0.00	200.00	546.00	795.00	610.90	306.00	131.00	0.00	0.20	2604.80
2012	0.00	0.00	0.00	0.00	181.00	663.00	862.20	810.00	201.00	91.60	0.00	0.00	2808.80
2013	0.00	0.00	0.00	0.00	143.70	350.30	830.50	508.90	195.00	517.20	0.00	0.00	2545.60
2014	0.00	7.00	0.00	9.70	230.00	665.54	270.50	534.30	174.60	412.70	0.00	0.00	2304.34
2015	2.00	0.24	6.00	8.23	20.00	599.00	774.89	633.05	302.00	184.26	9.00	0.10	2538.77
2016	0.00	0.00	7.40	11.80	240.00	684.60	584.64	679.29	307.30	109.00	1.79	1.10	2626.92
2017	1.98	0.67	7.00	0.00	121.00	517.99	680.32	783.18	264.00	91.00	4.00	5.00	2476.13
2018	3.68	11.66	1.72	8.00	279.78	426.98	538.40	694.51	231.00	236.37	5.52	2.12	2439.74
Mean	1.49	1.30	4.99	5.72	167.12	540.96	644.42	676.19	254.66	211.68	3.10	0.61	3169.34
St.Dev	2.39	2.95	8.00	5.92	59.13	149.79	145.97	99.25	53.85	115.75	3.68	1.32	240.64
CV	1.61	2.27	1.60	1.04	0.35	0.28	0.23	0.15	0.21	0.55	1.18	2.18	0.10

Appendix IV: Rainfall station of Bambasi and its mean average rainfall

Element: Monthly rainfall in millimeter

Region: Assosa

Station: Bambasi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	1.57	0.31	11.21	57.10	216.38	215.41	229.20	254.08	175.79	151.30	27.88	4.71	1344.93
2000	1.42	0.12	8.26	31.29	195.39	217.38	210.78	254.75	236.26	150.10	69.00	3.03	1377.80
2001	2.22	0.11	17.00	72.17	201.92	207.59	216.33	242.51	179.26	161.42	38.01	2.01	1340.53
2002	0.38	0.42	8.22	28.28	181.41	203.50	192.64	253.81	171.62	131.98	16.20	2.48	1190.94
2003	3.38	0.25	5.55	39.59	174.46	203.42	230.40	227.30	201.74	140.33	17.94	3.81	1248.16
2004	1.24	0.21	16.06	21.49	202.53	183.72	208.91	270.63	238.52	108.30	40.61	3.55	1295.77
2005	0.71	0.41	16.49	45.00	121.80	165.20	224.20	283.40	0.00	202.38	0.00	4.02	1063.60
2006	0.74	0.48	8.88	59.43	166.34	189.90	193.20	273.10	157.00	157.60	0.50	2.76	1209.94
2007	0.50	0.00	19.80	81.00	145.80	180.30	162.90	200.60	157.30	134.30	68.40	0.00	1150.90
2008	9.90	0.00	3.50	96.50	220.20	225.10	230.10	255.70	172.20	90.80	9.00	2.66	1315.66
2009	0.00	0.00	3.40	56.20	168.85	309.90	264.20	275.70	122.30	90.90	0.00	11.10	1302.55
2010	0.00	0.00	0.00	7.50	134.10	245.30	248.30	265.20	222.30	188.50	68.10	4.30	1383.60
2011	0.00	0.00	16.20	17.40	211.50	122.50	202.30	243.20	243.70	162.92	29.11	0.47	1249.31
2012	0.00	0.14	0.00	36.60	224.02	162.93	211.80	241.30	251.70	120.30	36.70	4.70	1290.18
2013	0.00	0.00	7.40	0.00	209.90	237.80	218.10	335.00	317.40	186.60	9.06	0.00	1521.26
2014	0.00	2.30	27.20	150.90	212.90	165.70	263.60	240.90	184.00	241.80	12.30	0.00	1501.60
2015	1.22	0.00	18.24	49.57	146.87	238.39	233.55	273.15	177.96	172.74	5.93	1.84	1319.48
2016	0.00	0.00	11.90	32.80	204.20	249.70	210.90	194.10	277.20	142.34	19.76	5.60	1348.50
2017	3.07	0.11	14.73	34.45	181.56	192.03	223.70	256.09	255.39	156.24	22.59	3.18	1343.13
2018	2.26	0.02	6.09	43.04	188.24	194.01	232.82	272.44	214.86	160.71	36.02	3.36	1353.89
Mean	1.43	0.24	11.01	48.01	185.42	205.49	220.40	255.65	197.82	152.58	26.36	3.18	1307.59
St.Dev	2.26	0.51	7.14	33.87	30.13	40.25	23.78	29.96	66.44	36.44	22.22	2.49	295.48
CV	1.58	2.09	0.65	0.71	0.16	0.20	0.11	0.12	0.34	0.24	0.84	0.78	7.80

Appendix V: Rainfall station of Begi and its mean average rainfall

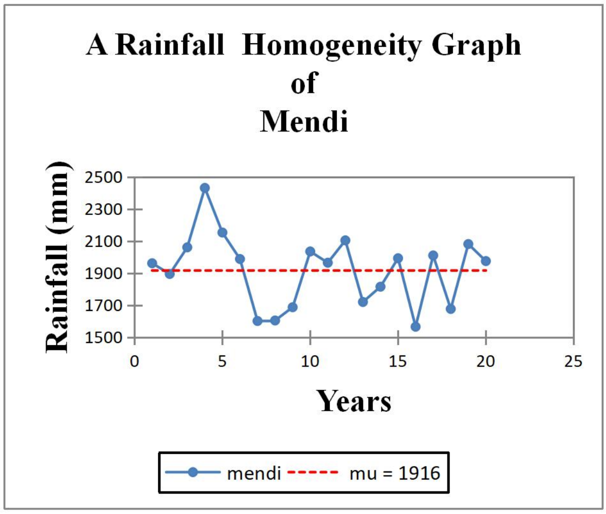
Element: Monthly rainfall in millimeter

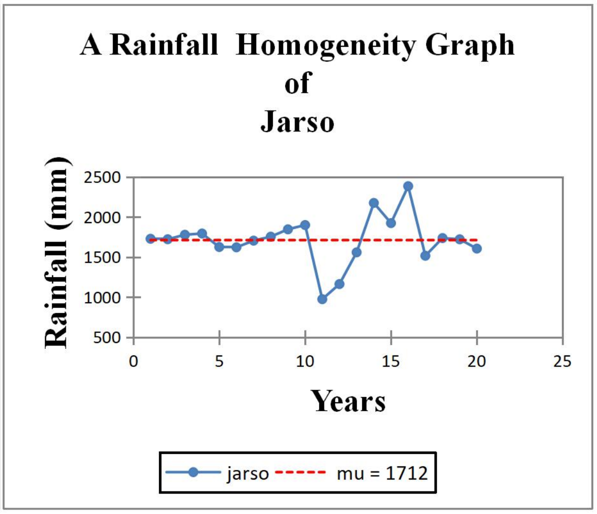
Region: Assosa

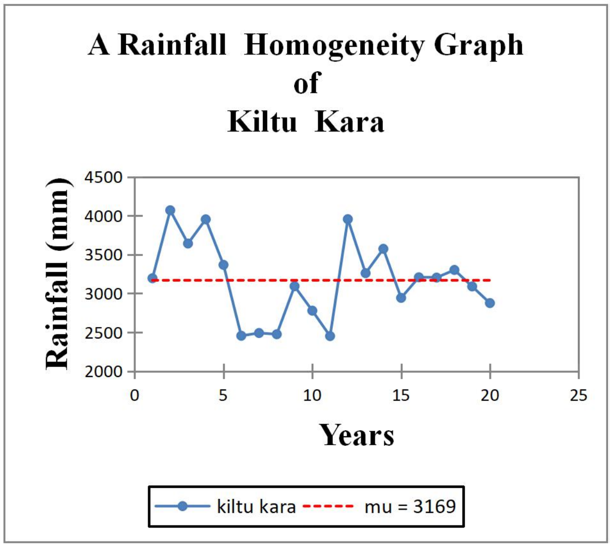
Station: Begi

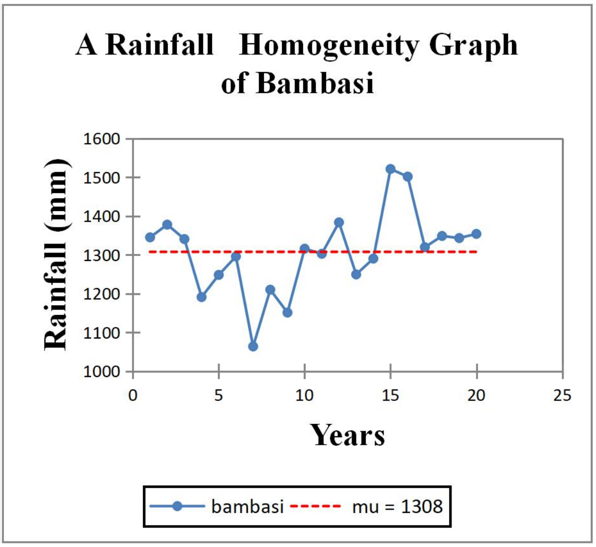
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	8.11	0.33	8.83	104.68	204.33	250.41	233.39	168.28	196.29	104.51	0.00	3.30	1282.46
2000	6.40	32.90	6.36	25.95	175.51	248.04	205.70	207.38	167.53	153.81	24.26	15.76	1269.61
2001	0.00	0.00	8.60	121.80	195.10	227.10	167.90	191.90	213.00	185.70	38.10	306.70	1655.90
2002	1.60	0.00	28.60	43.10	121.30	231.50	233.30	172.20	240.70	81.50	31.80	5.40	1191.00
2003	0.00	5.30	0.00	18.10	232.20	261.20	254.40	164.50	195.20	129.40	66.80	0.00	1327.10
2004	0.00	10.00	0.00	153.70	198.40	160.80	282.50	249.90	176.00	96.62	25.13	49.93	1402.99
2005	8.57	6.01	6.80	78.18	122.41	201.60	281.27	196.27	186.23	135.95	16.73	92.26	1332.27
2006	13.50	0.00	0.00	21.80	192.60	197.30	199.00	182.10	204.00	133.40	13.20	52.86	1209.76
2007	1.30	0.00	27.20	95.60	104.40	286.10	186.00	164.00	291.40	73.40	16.94	93.45	1339.79
2008	5.10	13.70	26.40	172.60	287.60	185.30	147.90	199.30	168.30	138.30	4.10	51.40	1400.00
2009	18.00	3.20	6.00	91.10	57.40	266.00	187.30	177.40	141.90	90.30	54.20	11.90	1104.70
2010	0.00	6.60	1.70	14.80	156.20	154.70	187.40	185.70	134.80	148.30	94.60	9.30	1094.10
2011	11.10	0.40	16.40	29.00	248.00	193.10	123.40	146.60	161.50	134.70	0.00	1.20	1065.40
2012	0.00	2.55	4.82	48.85	214.01	225.04	190.72	188.11	238.66	102.41	46.08	0.00	1261.25
2013	1.48	0.00	5.70	2.00	236.50	158.80	145.90	223.60	190.10	50.00	0.00	0.00	1014.08
2014	6.44	8.21	17.87	37.40	200.08	196.66	258.52	176.58	185.12	100.39	43.74	58.12	1289.13
2015	0.84	3.88	11.76	40.44	149.65	204.37	162.82	170.03	214.55	86.10	40.43	66.85	1151.71
2016	7.18	4.99	18.44	64.14	141.72	330.40	443.60	196.45	123.70	106.61	32.28	44.29	1513.81
2017	1.86	6.39	12.73	44.87	153.67	215.01	191.55	167.04	163.34	141.03	51.65	63.59	1212.73
2018	0.00	7.69	5.42	54.46	168.67	207.96	287.70	208.80	127.30	181.90	52.00	17.20	1319.10
Mean	4.57	5.61	10.68	63.13	177.99	220.07	218.51	186.81	185.98	118.72	32.60	47.18	1271.84
St.Dev	5.24	7.52	9.07	47.00	54.40	44.45	71.39	23.72	41.49	35.41	24.73	68.59	432.99
CV	1.14	1.34	0.85	0.74	0.31	0.20	0.33	0.13	0.22	0.30	0.76	1.45	7.77

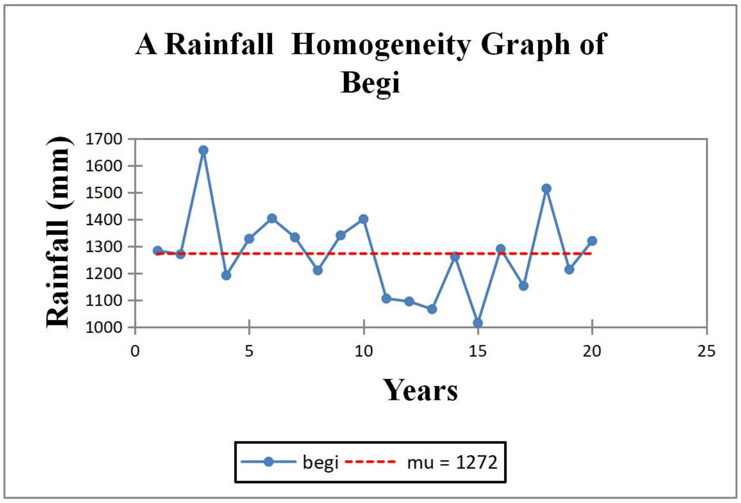
Appendix VI: Homogeneity test for rainfall data of the stations











Appendix VII: Ground control points collected by GPS for major LULC types

S. N.	Coordinates				Coordinates		Land Use
	Easting (X)	Northing(Y)	Land Use	S. N.	Easting (X)	Northing (Y)	
1	731395	1068595	Built-up	46	739175	1075585	Forestland
2	731585	1067915	Built-up	47	739215	1074155	Forestland
3	732405	1065845	Built-up	48	739995	1073245	Forestland
4	733135	1069015	Built-up	49	730085	1067825	Bare land
5	733505	1068065	Built-up	50	732765	1075035	Bare land
6	733855	1069015	Built-up	51	733135	1067395	Bare land
7	735805	1067025	Built-up	52	733225	1071975	Bare land
8	736225	1072495	Built-up	53	733305	1071855	Bare land
9	736705	1078565	Built-up	54	733615	1071645	Bare land
10	736965	1070785	Built-up	55	733795	1070885	Bare land
11	737105	1070695	Built-up	56	734675	1078045	Bare land
12	740665	1075405	Built-up	57	734785	1079235	Bare land
13	729545	1066765	Farmland	58	734935	1078435	Bare land
14	729585	1063635	Farmland	59	735045	1077955	Bare land
15	729965	1068495	Farmland	60	735715	1076455	Bare land
16	730615	1067075	Farmland	61	730255	1071205	Wetland
17	731055	1065905	Farmland	62	730885	1068795	Wetland
18	731275	1062475	Farmland	63	731255	1062125	Wetland
19	731585	1063415	Farmland	64	731465	1062055	Wetland
20	731835	1072425	Farmland	65	731635	1062555	Wetland
21	732095	1062575	Farmland	66	732185	1062615	Wetland

22	733435	1073995	Farmland	67	732315	1068575	Wetland
23	733515	1068175	Farmland	68	734525	1075195	Wetland
24	734045	1075355	Farmland	69	736125	1072555	Wetland
25	734355	1065535	Farmland	70	736475	1072855	Wetland
26	734705	1067375	Farmland	71	736625	1073355	Wetland
27	734705	1070165	Farmland	72	736675	1072885	Wetland
28	734845	1064495	Farmland	73	737805	1074285	Wetland
29	735085	1079845	Farmland	74	738495	1075985	Wetland
30	735895	1078715	Farmland	75	730265	1071625	Grazingland
31	738795	1075575	Farmland	76	730965	1071205	Grazingland
32	729675	1067345	Forestland	77	731885	1062155	Grazingland
33	731135	1071285	Forestland	78	732475	1069935	Grazingland
34	731235	1071545	Forestland	79	732965	1065445	Grazingland
35	731325	1068795	Forestland	80	733985	1064405	Grazingland
36	732015	1064115	Forestland	81	734975	1067675	Grazingland
37	732665	1064705	Forestland	82	735495	1076895	Grazingland
38	734045	1072595	Forestland	83	735575	1072875	Grazingland
39	735765	1068285	Forestland	84	735935	1069735	Grazingland
40	736115	1077565	Forestland	85	736435	1069435	Grazingland
41	736195	1067065	Forestland	86	736445	1073105	Grazingland
42	736225	1073305	Forestland	87	736485	1066895	Grazingland
43	737775	1072255	Forestland	88	737155	1071735	Grazingland
44	737775	1075575	Forestland	89	737255	1070775	Grazingland
45	738315	1076495	Forestland	90	737535	1071015	Grazingland

Appendix VIII: Sub watershed level soil loss severity classes

Sub watershed	**Severity classes**						
	Low	**Moderate**	**High**	**Very High**	**Severe**	**Very Severe**	**Total**
Laga Dembi	1216.01	100.21	144.04	113.51	81.95	48.82	1704.73
Tulu Dembi	266.71	48.81	74.28	65.40	45.47	30.90	531.37
Bimbe	954.82	20.43	34.83	26.47	20.05	13.15	1069.81
Aba Luba	778.50	32.39	42.69	26.73	16.84	8.17	905.29
Dugda Kosho	612.46	52.51	89.41	80.99	72.09	50.06	957.55
Lomicha	795.41	40.50	65.01	55.62	47.00	32.93	1036.12
Dhaga Dubeta	386.68	34.91	61.27	51.96	37.23	18.99	591.08
Jirma	831.49	77.31	141.45	111.36	63.89	30.12	1255.55
Saketa	745.35	85.84	145.76	117.16	78.06	41.80	1213.90
Boshara	259.37	24.78	37.94	27.30	16.92	10.49	376.75
Koto	267.72	58.43	98.98	87.46	63.50	23.65	599.80
Bakanissa	477.60	112.37	172.81	128.17	72.61	32.07	995.61
Fincha'a	576.62	112.38	158.88	99.89	45.31	13.83	1006.89
Total	**8168.80**	**800.86**	**1267.09**	**991.92**	**660.83**	**354.96**	**12244.45**

Appendix IX: Soil loss priority rank of sub watersheds based on severity rates

Sub watershed	Mean annual soil loss (ton/ha/year)	Priority given by mean annual soil loss
Laga Dembi	20.0	9
Tulu Dembi	33.5	2
Bimbe	17.2	12
Aba Luba	8.3	13
Dugda Kosho	27.3	4
Lomicha	17.4	10
Dhaga Dubeta	22.1	6
Jirma	20.9	8
Saketa	25.0	5
Boshara	17.3	11
Koto	35.1	1
Bakanissa	30.0	3
Fincha’a	21.7	7