JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF POSTGRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

GIS Based Annual Average Soil Loss Rate Estimation: The case of Sor River Watershed

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering

By: Elias Befkadu Abdisa

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Main Advisor: Dr. Eng. Fekadu Fufa
Co-Advisor: Mahmud Mustefa (MSc.)

DECLARATION

I, the undersigned, declare that this thesis entitled "**GIS Based Annual Average Soil Loss Rate Estimation: The case of Sor River Watershed**" has been carried out by me under the guidance and supervision of my Advisors Dr. Eng. Fekadu Fufa and Mr.Mahmud Mustefa (Msc). The thesis is my original work, and has not been presented by any other person for an award of master's degree in this or any other University.

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APPROVAL

As thesis research advisors, we hereby certify that we have read and evaluated this thesis, and prepared under our guidance, by Elias Befkadu entitled "**GIS Based Annual Average Soil Loss Rate Estimation: The case of Sor River Watershed**" and we recommend that it can be submitted as fulfilling the thesis requirement.

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

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

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ABSTRACT

Soil erosion is one among the most critical worldwide environmental challenges facing the world nowadays. Erosion by water can be dramatic during storm events resulting in washouts and gullies. Different studies show the occurrence and existence of soil erosion in different parts of the country. Almost all south west parts of Ethiopia have a rainfall throughout the year. Sor river watershed, which is one of the sub-basin of Baro Akobo river basin, is found in this rainy region. Hence, this study was undertaken to estimate the annual average soil loss rate from Sor watershed which shares the severity of the soil erosion problems using Revised Universal Soil Loss Equation (RUSLE) implemented for Ethiopian conditions with the integration of Geographic Information System (GIS) techniques. The RUSLE parameters; such as rainfall erosivity factor (R-factor), soil erodibility factor (K-factor), slope steepness and slope length factor (LS-factor), vegetative cover factor (C-factor) and conservation practice factor (P-factor), which consists of a set of logically related geographic features and related attribute data were used as data input for the analysis. Digital elevation model(DEM) of 30m spatial resolution, 27 years rainfall records of six stations, land use/land cover map of 2013 soil map of study area and field information were used for the analysis of RUSLES's soil loss parameters. The parameters were analyzed and integrated using raster calculator in Arc GIS 10.4.1 and the required spatially distributed annual average soil loss rate was obtained. Therefore, the result indicated that the annual soil loss of the watershed extends from none in the lower to 330 t ha^{-1} y^{-1} in the steeper slope part of the watershed with a mean annual soil loss 14.86 t ha^{-1} y^{-1}. The total annual soil loss from the entire watershed area of 2273km^2 was 3.38 M tons. To evaluate the effect of watershed management, particularly contour ploughing with terracing; if it is fully developed, and adjusting P-factor values for such conditions, the average annual soil loss rate would decrease from 14.86 to 8.57 t ha^{-1} yr^{-1}. Hence, applying the specified watershed management reduces the vulnerability of the watershed by 42.3 %. Thus, sustainable soil and water conservation mechanisms should be implemented in order to reduce soil erosion in the watershed.

***Key words**: GIS, RUSLE, Soil Erosion, Sor Watershed*

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LIST OF ABBREVIATIONS

ANSWERS	Areal non-point source watershed environmental response simulation
ARS	Agricultural research service
CREAMS	Chemical runoff and erosion from agricultural management system
DEM	Digital Elevation Model
EKWM	Erosion Kinematic Wave Model
EPA	Environmental protection agency
ETB	Ethiopian birr
EUROSEM	European soil erosion model
FAO	Food and agricultural organization
GDP	Gross domestic product
GIS	Geographic information system
GO	Governmental organization
IDW	Inverse distance weight
KM	Kilometer
LS	length and steepness factor
Mtons	Million tons
MUSLE	Modified universal soil erosion
SCRP	Soil conservation research project
SWAT	Soil and water assessment tool
USDA	United state development of agriculture
USGS	United state geographic survey
USLE	Universal soil loss equation
WEPP	Water erosion prediction project

1 INTRODUCTION

1.1 Background

Soils are an essential and non-renewable natural resource hosting goods and services vital to ecosystems and human life (FAO, 2017). Also Soil is a key component of the Earth System that control the bio-geo-chemical and hydrological cycles and also offers to the human societies many resources, goods and services (Keesstra *et al.,* 2012; Berendse *et al.*, 2015).

In addition, Soil is the basic resource for economic development and for maintaining sustainable productive landscapes and people's livelihoods especially for countries with agrarian economy like Ethiopia (FAO, 2017). However, soil degradation is a serious threat in agro-ecosystems and global environmental problems (Oldeman *et al.*, 1995; Angima *et al.*, 2003; Blanco-Canqui and Lal, 2008). Globally, one-third of agricultural soils were reported as being affected by soil degradation Hurni (2002), of which water and wind erosion account 56 and 28 percent of the observed damage, respectively (Blanco-Canqui and Lal, 2008).

In Africa and Asia, land degradation is severe, driven by high population pressure, land shortage and critical lack of resources for conservation by subsistence smallholder poor farmers (Blanco-Canqui and Lal, 2008). There are different interacting forces, which have been reasons and causing land degradation in Ethiopia (Berry, 2003). Soil erosion is one of land degradation components, which has a negative impact on agricultural production, water quality and in general quality of life.

Soil erosion is the deterioration of soil by the physical movement of soil particles from a given site. And also it's the major problem for a river basin as it removes nutrient that is essential for the growth of the plants and increases sedimentation of the river channel and reservoirs (Narayan and Babu, 1983).

Obviously, soil erosion by water is the most serious form of soil degradation and this problem is most significant in the tropics and sub-tropics compared to the rest of the regions on the Globe (Eaton, 1996 and Lal, 2001). There are variety of soil erosion types, rill and inter rill erosion are the recurrent types of water erosion, involving detachment, transport and accumulation of soil particles to a new deposition area (Fernandez, *et al.,* 2003). Soil erosion by water has been a challenging and continuous problem in Ethiopia for decades (Hurni 1988; Gete 2000; Bewket and Teferi 2009; Kebede *et al.,* 2015).

The average annual soil loss in Ethiopia is estimated to be 18 t ha^{-1} $year^{-1}$ (Hurni, 1985). The problem, however, is much more severe in the highlands where majority of the human and livestock population of the country are living and agriculture is intensive (Ayalew and Selassie, 2015). Soil erosion occurs as a result of changes in agricultural practices, agricultural intensification and global climate change (Yang *et al.*, 2003).

In Ethiopia, natural resources is the foundation of any economic development, food security and other basic necessities of its people. Smallholder agriculture is the dominant sector that provides over 85 percent of the total employment and foreign exchange earnings and approximately 55 percent of the Gross Domestic Product (GDP) (EPA, 2012). Therefore, the majority of the people are dependent on natural resources and it leads to land resource degradation (Paulos, 2001).

Different Studies indicate that splash, sheet and rill erosion by water are the major components of land degradation that affect land productivity in Ethiopia (Desta *et al.*, 2005; Haregeweyn *et al.*, 2015). These detached particles of soil are then transported ultimately to the river basin that enriches the suspended sediment yield, bed load of the river basin (Beskow *et al.*, 2009). The strictness of soil erosion in Ethiopia is due to most part of the country is being steep sloped, mountainous, and the existence of higher and frequent rainfall amount with higher intensities (especially in the study area). Beside to this; human activities, rapid population growth, poor cultivation system and poor land use practices, deforestation and overgrazing, have a great contribution to soil degradation in the country (Hurni, 1993; Kebede, 2012). In general, Soil erosion and transportation by water due to rain drop impact is the most common erosion agent in the country (Zeleke and Hurni, 2001).

In mid-1980's, 27 million ha or almost 50 percent the highland area was significantly eroded. Among this 14 million ha seriously eroded and over 2 million ha beyond reclamation. Recognizing the seriousness of the problem, the Ethiopian government launched a massive soil conservation program beginning the mid-1970s. However, most performance measures of soil and water conservation efforts of the country were failed. Conservation and regeneration of natural resources in the mountains and highlands, although a central issue, is just one of the factors for sustainable development (Hurni, 1988). So, it is very important to estimate the amount soil loss to address the problem of soil erosion.

The amount of soil erosion and sediment yield is measured quantitatively and consistently with the help of physical based models and empirical models. The physical based models illustrate the mechanism of the controlling of the erosion processes by solving corresponding various equations, while the empirical models are widely used for measuring of the surface soil loss and sediment yield from the catchment areas (for sediment yield estimation) (Bhattaraiand, 2007). Due to the limitation of data, only few are used to measure soil loss in Ethiopian conditions. One among these few empirical soil erosion prediction models, RUSLE is mostly used model because of its simplicity relative to other conceptual and process based models, relative data availability for this model and integration with GIS (Temesgen, 2017; Gelagay and Minale, 2016).

The Revised Universal Soil Loss Equation model can identify soil loss possibility on a pixel cell-by-cell method. According to Shinde, Tiwari and Singh (2010), it is effective as trying to recognize the spatial class of the soil erosion current time in a big area. It is the revised form of universal soil loss equation, which has been used at different geo-spatial scales by dividing a region of appeal keen into sub areas with similar parameters and connected with geographic information system framework (Renard *et al.,* 1997). These erosion models are presently included to put an environmental information system, which permits testing and evaluating of alternative management scenarios (Fistikoglu and Harman, 2002). The result of this model has been checked by different researcher and showed its efficiency in estimating rate of soil erosion and mapping of erosion risk areas throughout the world. For instance, Millward and Mersey (1999), show the potential of using a combination of remote sensing, GIS, and RUSLE in estimating soil erosion loss on a cell-by-cell basis.

The Sor River in the study area is one of the major tributaries of Baro Akobo. The Baro Akobo system from Ethiopia and Sobat from South Sudan, contributes 48 percent of the flow of the White Nile where these river systems join downstream of Malakal. In all studies RUSLE was revealed that the model shows conventional result. Hence, this research aimed to quantify the amount of annual soil loss rate from Sor River watershed using this most applicable model RUSLE, through the application of GIS technique and to identify the most vulnerable areas of the watershed.

1.2 Statement of the problem

Accelerated soil erosion by water, is a common problem affecting environmental quality, agricultural productivity and food security of the world (Lal, 2001). Moreover, it affects adversely the natural water-storage capacity of catchments, design-life of man-made reservoirs and dams causing enormous dredging costs, quality of surface water resources, aesthetic landscape beauty and ecological balance (Morgan, 2005; Bewket and Teferi, 2009).

Ethiopia is among the sub Saharan belt countries facing environmental degradation. The country is suffering land degradation in the form of soil erosion, resulting in gully formation, loss of soil fertility and severe soil erosion (Hurni, 1988). Soil erosion is one of the most serious environmental problems in Ethiopia and the strictness of the soil erosion in the country attributed by intense rainfall and also dissected nature of the topography which is nearly 70 percent of the highland having sloppy landscape (Semu, 2018).

According to Girma (2001), Ethiopia loses annually 1.5 billion metric tons of topsoil by erosion. Ethiopia whose economy mainly dependent up on agriculture, soil erosion affects the socio-economy of the country both directly and indirectly (Abate, 2011).

Among the natural factors, for example, topography plays a great importance. However, the alarming deforestation of natural forests and woodlands for agricultural land expansion, fuel and charcoal production in the study area aggravate the problem of soil degradation in the basin Desta (2014), has direct effect on irrigation and hydropower development, this two plays a significant role for the sustainable economic growth of the country, Ethiopia.

Sor watershed is one of the sub basin of Baro-Akobo basins, but the problem is that, there were no detail study conducted to address the estimation of annual average soil loss using any appropriate model in this specified catchment. Even though assessment of soil erosion, transport and deposition of sediments in reservoirs, irrigation and hydropower systems are considered essential for land and water management, these are not studied in-depth in the Sor river sub basin.

Even if it is difficult to assess the dimension of soil erosion in terms of extent, magnitude, rate and its economic and environmental consequences, estimation of the onsite effect of soil erosion with the help of soil erosion model is deemed necessary to formulate appropriate and integrated soil and water conservation measures.

Therefore, this study aimed to estimate the annual average soil loss rate and provides information about soil erosion both for the NGOs and GOs to plan appropriate soil conservation practice in the watershed, so that reducing fertile soil loss from cultivation lands and increasing crop production for farmers.

1.3 Objective of the study

1.3.1 General objective

The general objective of this study is GIS Based Annual Average Soil Loss Rate Estimation from Sor River Watershed.

1.3.2 Specific objectives

The specific objectives of the study includes:

1. To evaluate the effects of each RUSLE parameters on soil erosion
2. To determine the annual average soil loss rate for existing condition
3. To identify the most vulnerable and affected area at a district level and
4. To evaluate the effects of watershed management (contour ploughing with terracing) on soil erosion of the study area

1.4 Research questions

The research questions which were addressed in the study are:

1. How much is the effects of each RUSLE parameters on soil erosion?
2. How much is the quantity of annual average soil loss rate for the existing condition of the study area?
3. Which part of the watershed is highly affected by soil erosion at a district level?
4. If the watershed management (contour ploughing and terracing) were fully applied, by how much would be the erosion rate reduced?

1.5. Significance of the study

The result of the study will open the gate and gives information both for NGOs and GOs to plan appropriate soil conservation practice in the watershed and reduce fertile soil loss from lands and increasing crop production for farmers.

On the other hand, the result of this study would give clue for setting up preventive measures for sustainable agriculture development timely and cost effective for stakeholders, designers of different hydraulic structure and decision makers by providing the annual average soil erosion rate of the watershed. Furthermore, the outcome of the study may serve as the comparison of other models for the future study.

1.6. Scope of the study

The study was bounded only with general objective of estimation of annual average soil loss and specific objectives of evaluation of the effects each RUSLE parameters on soil erosion, determination of the annual average soil loss rate for the existing condition, identifying the most vulnerable and affected area and evaluation the effects of watershed management (terracing with contour ploughing) on soil erosion of the Sor watershed using RUSLE model with GIS techniques for the watershed area of 2273 km^2.

1.7 Limitations of the study

Even if, the study has a substantial role in providing the information about the status of soil erosion, in order to plan and implement an environmental protection programs by the concerned bodies, it has also some constraints. Among the constraints, the empirical soil erosion prediction model which was applied (RUSLE) applies only for water erosions; like sheet and rill erosions. The model also neglects certain interactions between RUSLE factors in order to distinguish more easily the individual effect of each. Getting the most recent Landsat image was also one of the difficulties.

1.8 Organization of the Thesis

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

2 LITERATURE REVIEW

2.1 Soil as a resource

Soil is one of the world's most valuable natural resources which is essential to all life forms on this planet, provides a physical matrix, chemical environment, and biological setting for water, nutrient, air, and heat exchange for organisms (Rosewell, 1999). It provides us with food, fodder, wood, and fiber. Almost 96 percent of human food is obtained from the soil (Pimental and Hall, 1989).

A great number of antibiotics are produced by soil microorganisms. Soil acts as a recycler of materials and as a purifier of water. Soils provide mechanical support for living organisms and hydrological processes, including infiltration, percolation, drainage, stream flow, and surface as well as underground water storage. Soils regulate exchange of material, energy, water, and gas within the lithosphere–hydrosphere–biosphere–atmosphere system. Soil is a source and sink of pollutants. Moreover, soil respiration and carbon sequestration may influence climate change. Soil is, without question, critical to the world, supplying virtually all the food and fiber that sustain the human population and providing ecosystem services that support life (Anderson, 2010).

It is a non-renewable natural resource in human life time frame (Lal, 2009). Soil is not land itself; it is a part of the land. According to Buringh (1989), between 11 and 12 percent of the land surface is generally suitable for food and fiber production, 24 percent is used for grazing, forests occupy about 31 percent and the remaining 33 percent has too many constraints for most uses. All agricultural soils are not fertile and productive, some soils are naturally unproductive; some are arid and saline; some are very sandy and dry; and some are wet and waterlogged for a part or most of the growing season. Advanced water management techniques including irrigation and drainage have enabled some use of the dry lands, wetlands, and peat lands.

There are sloping lands, sandy soils, and soils with low nutrient-holding capacity. Many soils in desert regions are irrigated, but these are considered unsustainable. Lal (1989), estimates that about 0.5 ha of cropland per capita is needed to sustain the human population at an acceptable level, but there are many countries where the per capita land is less than 0.07 percent. Mismanagement and misuse have degraded many productive lands worldwide.

Oldeman *et al.,* (1991), suggest that about 17 percent of the global land area is degraded by human interventions and soils of only about 3 percent of the total land area of the earth have a high level of productivity. The consequences of land degradation not only affect the performance of the land for food and fiber production but also have grave consequences for the environment. Formation of an inch top soil may need more than thousands of years; so it should not be allowed to degrade through our careless mismanagement.

Therefore, soil needs special attention by all stakeholders to be managed and protected sustainably in order to keep the ecosystem (both living and non-living things) safe and remain productive in future.

2.2 Soil degradation

Soil degradation is said to have taken place when the land within an ecosystem is no longer able to perform its environmental regulatory functions of accepting, storing, and recycling water, energy, and nutrients and when the potential productivity associated with a land-use system becomes non-sustainable (Oldeman *et al.,* 1991). Again, soil degradation is considered as the measurable loss or reduction of the current or potential capability of soils to produce plant materials of desired quantity and quality.

According to some authors (Blaikie and Brookfield, 1987), land degradation is a broader term than soil degradation. But for synonymous use of the terms land and soil in most soil management literature, land degradation and soil degradation will be used interchangeably in the following sections. Several physical, chemical, and biological processes are responsible for the degradation of soil (Lal 1994; Eswaran *et al.,* 2001). The physical processes include deterioration of soil structure, crusting, hard setting, compaction, erosion, and desertification. The chemical processes include leaching, fertility depletion, acidification, salinization, and pollution. The biological processes of soil degradation include reduction in carbon and decline in soil biodiversity. According to Beinroth *et al.,* (1994), land degradation results from a mismatch between land quality and land use.

2.3 Soil erosion

Soil erosion is a naturally occurring process on all land but the process could be accelerated because of mankind’s unwise actions that lead the soil to be non-renewable natural resource over the human time scale (Blanco and Lal, 2008). Soil erosion, which is one form of soil degradation, consists the process of detachment, transport and deposition of soil particles on land surface by the action of water, wind or other agents FAO (1986), the loss is measured as mass per unit area. Soil erosion has on-site and off-site effects. The on- site effects include loss of soil, loss of organic matter and nutrients, damage to growing crops, exposure of plant roots, and decline in soil fertility and productivity. The off-site effects are burrowing of crops and installations, siltation of reservoirs, eutrophication of ponds and lakes, pollution of water, etc. (Khan, 2014).

Soil erosion can be geological or natural soil erosion or accelerated or human induced. Natural erosion is considered as normal erosion and is usually of little concern from soil quality point of view because its rate is low and soil loss can be naturally compensated by soil formation. Geological or natural soil erosion takes place without human intervention and has been occurring for millions of years; the process could be slow or sometimes faster which occurs due to natural causes like flooding.

Human actions such as deforestation, overgrazing, over tilling, and shifting cultivation have accelerated soil erosion beyond the tolerance limit. A tolerance ranges of 5–11 t ha $^{-1}$year $^{-1}$ depending on soil types is accepted in the USA (Khan, 2014). There are places and situations where erosion rates are much higher than this limit, even as high as 100 t ha $^{-1}$year $^{-1}$. Accelerated or human induced soil erosion is sometimes 100 to 1000 times greater than geological erosion rate of 0.25 ton ha^{-1} year^{-1} (Julien, 2010). As it is mentioned; soil erosion has three main phases called detachment, transport and deposition. The first two processes (detachment and transport) require causing energy, while deposition takes place when energy is no longer available.

The severity of erosion depends on the quantity of soil being detached and the capacity of the eroding agents to transport it. If the agents have limited capacity to transport the detached one, the erosion is transport limited; if the agents have the capacity to transport more soil than supplied, the erosion is detachment limited (Morgan, 2005). After the soil absorbs raindrops and the pores are filled with water soil detachment can be occurred. The loosed up and fractured soil particles are transported in runoff and deposited at the down slope of the field. Due to transportation process, texture of the deposited soil is different from the original one (Blanco and Lal, 2008).

Table 2.1 Soil erosion losses on 5 SCRP sites in various parts of Ethiopia (SCRP, 1985)

Site	Ton ha^{-1} $year^{-1}$
Sidamo	41.2–49.5
Harar	25.5–27.8
North Showa	152.4–214.8
Gojjam	40.2–199.2
South Wollo	36.5–53.8
Iluababor	

There are various causative agents for Soil erosion and degradation to occur. Among these causative agents Water, wind, chemical degradation and physical degradation are common. Each form of land and soil degradation occurs both individually and in combination with each other. According to Stringer (2012), physical degradation includes disintegration of soil fragments and chemical degradation consists; the loss of nutrient and organic matter, salinization and acidification water and wind are the main contributor for soil erosion and transportation. For environmental and pedogenic reasons, soils of the arid and semiarid regions are usually dry, loose, low organic matter containing sandy soils susceptible to severe damage by wind erosion, while in our country which the most part is hillsides, soil degradation due to water erosion remains a major problem to continued agricultural production (Solomon et al., 2010). Therefore, this study were conducted to evaluate the susceptibility of soil erosion that caused by water.

2.4 Soil erosion by water

Detachment of soil particles from aggregates primarily by raindrops and flowing water and their transport by runoff water are involved in soil erosion by water (Khan, 2014). According to Dereje (2005), Soil erosion by water is the principal cause of land degradation, and it is a major constraint to agricultural development in many countries. One important feature of soil erosion by water is the selective removal of the finer and more fertile fraction of the soil.

2.4.1 Splash erosion

Splash erosion is the first stage of erosion process. It occurs when raindrops hit bare soil. The explosive impact breaks up soil aggregates so that individual soil particles are splashed onto the soil surface. The soil particles can move several meters from their original place through the air (Mitiku *et al.*, 2006). These particles will be ready to be washed away by sheet erosion, thus, raindrops initiate water erosion. By the time raindrops falling on exposed or bare soil, displacement of soil particles and destruction of soil structure will occur (Dereje, 2015). To prevent such destruction, the bare soil needs to be covered by vegetation.

2.4.2 Sheet erosion

It is the uniform removal of soil in thin layers by the forces of raindrops and overland flow. It can be a very effective erosive process because it can cover large areas of sloping land and go unnoticed for quite some time. Soil particles are detached primarily by raindrops and secondarily by frost, hooves of farm animals, tillage, and mechanical action of farm machines and detached particles are transported by runoff water as overland flow (Khan, 2014). Sheet erosion is more uniform and gradual, as the surface becomes smoother. However, water may still accumulate even on the smoothest slope. Sometimes, splash and sheet erosion are combined and known as inter-rill erosion which makes up about 70 percent of total soil erosion (Blanco and Lal, 2008).

2.4.3 Rill erosion

It is the removal of soil by concentration water running through little streamlets, or head cuts. Detachment in rill erosion occurs if the sediment in the flow is below the amount of the load can transport and if the flow exceeds the soils resistance to detachment. Rill erosion is largely caused as a result of large amounts of material that are released and transported for variable distances in concentrated areas. On the other hand, the flow of water over the surface has a smaller effect on soil detachment, but a larger transportation effect (Khan, 2014). Rill erosion is often described as the transition stage between sheet erosion and gully erosion.

2.4.4 Gully erosion

It is the removal of soil along drainage lines by surface water runoff. Once started, gullies will continue to move by head ward erosion or by slumping of the side walls unless steps are taken to stabilize the disturbance. Gullies may also develop by the gradual deepening on rills and it can be ephemeral and permanent. Ephemeral gullies form shallow channels that can be readily corrected by routine tillage operations. On the other hand, permanent gullies are very large and cannot be smoothed by regular tillage (Blanco and Lal 2008).

2.5 Factors affecting soil erosion

There are several factors that influence soil erosion. Such as: climate, soil, topography, vegetation and management practices.

2.5.1 Climate

Precipitation, humidity, temperature, evapo-transpiration, solar radiation and wind velocity are common climatic factors which affect the magnitude and rate of soil erosion (Blanco and Lal, 2008). Precipitation takes the lead in soil erosion by water. 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. 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 (Toy *et al.,* 2002).

In general, the rainfall erosivity is the function of its intensity and duration, and the raindrops' mass, diameter and velocity (Morgan, 2005). 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.

2.5.2 Soil properties

The susceptibility of soil is dependent on the soil's texture, content of organic matter, surface roughness, moisture and depth to be eroded by erosion agents (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. Organic materials stabilize soil structure and coagulate soil colloids so; it is possible to decrease soil erosion (Blanco and Lal, 2008). 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.

2.5.3 Topography

The earth feature is known as topography. The slope steepness and slope length 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). 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).

According to Stern (1990), put when the slope gradient increases, the ability of overland to erode and transport sediments rapidly until the erosion by the surface flow becomes the dominant mechanism contributing to the sediment transport. Runoff velocity and effective depth of interaction between surface soil and runoff increases with the increment of slope. Some researchers, for instance Bobe (2004), indicated that soil erosion increases exponentially with increase in slope gradient.

2.5.4 Soil

Soils differ in their resistance to erosion, which is a function of a range of soil properties such as soil texture, structure, soil moisture, roughness, and organic matter content (Vrieling, 2007). The susceptibility of soil to erosion agents is generally referred to as soil erodibility (Lal, 2001). Soil classifications are often used to account for spatial differences in erodibility.

Important factors on the basis on which soils can be classified including soil properties, climate, vegetation, topography, and lithology. Especially optical satellite imagery has been used for soil mapping, mainly through visual delineation of soil patterns (Lal, 2001). To use visual interpretation techniques, detailed knowledge on the relationship between observable and the occurrence of soil units is required. Soil classification by visual interpretation of optical satellite imagery has been used to assess differences in soil erodibility (Reusing *et al.,* 2000; Sharma and Singh, 1995). The relation between soil classes and erodibility was determined using equations of (Wischmeier and Smith, 1978).

2.5.5 Vegetation cover

Cover includes plant canopy, mulches, plant residues, or densely growing plants in direct contact with the soil surface. It has a greater impact on erosion than any other single factor. The canopy intercepts raindrops, and if it is close to the ground, water dripping off the leaves has much less energy than unhindered raindrops (Wischmeier and Smith, 1978). Materials in contact with the soil surface reduce erosion more effective than a canopy. No detachment occurs by raindrop impact where the soil surface is covered because there is no fall distance for drops to regain energy. Besides, such materials slow the runoff, which increases the flow depth. According to Morgan (2005), vegetation 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. Vegetation decreases the volume of run-off by increasing transpiration and evaporation; therefore, reduces soil moisture and increases soil organic content, which also increases soil's water absorptive capacity (FAO, 1986).

2.5.6 Land use land cover factor

Now a day, land use land cover change is a significant driving agent of global environmental change. Land cover and human activities on the land use, are the most crucial factors in reducing or increasing soil erosion (Wijitkosum, 2012). Such large scale land use changes through deforestation, expansion of agricultural land as well as other human activities, are inducing changes in global systems and cycles. But the major change in land use, historically, has been observed to increase worldwide in agricultural lands (Houghton, 1994). Therefore, in soil erosion calculation, land use land cover factor has been included in the RUSLE equations as it is one of the factor affecting soil erosion and represented by C-factor (Renard *et al.*, 1997).

2.5.7 Watershed management practice factor

Land protection 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. Crop residues, like straw, stubble and maize stalks can reduce soil losses by one halve or more depending on other factors (FAO, 1965). Terraces reduce slope length and velocity of running water. Agro forestry or intercropping is also another method for the reduction of soil erosion; the system evolves into more complex production systems that can provide different benefits than annual crop production system (Winter *et al.*, 2013). Integrated woody perennial plants protect the soil from erosion after the crops being harvested. The influence of such activities on soil erosion of a given watershed has been considered and included in RUSLE equation as P-factor (Renard *et al.*, 1997).

2.5.7.1 Types of watershed management

There are different practical solutions for soil and water conservations in different parts of the world. Among these practical solutions terracing, trench excavation, contour ploughing, strip cropping, stone buds, mulches and crop rotations are widely used.

Terracing refers to the building of a mechanical structure, a channel and a bank or an earthen ridge or a stone wall on the land to reduce steepness of slope and divide the slope into short gently sloping sections (Morgan, 1986). Are created to encourage infiltration, to intercept surface runoff, or divert toward a predetermined and protected safe outlet at a controlled velocity to avoid soil erosion (USDA Soil Conservation Service, 1980; FAO, 2000). The critical runoff velocity, at which soil particles that have been detached from soil aggregates begin to be transported over the surface, is 5 m s^{-1} in sandy soils and 8 m s^{-1} in clay soils (FAO, 2000). Terracing reduces runoff velocity below this threshold values.

Contour cropping or contour farming.is plowing and planting crop in the contour that is across the slope. So, contour farming is a cross-slope farming system. Contours reduce velocity of runoff, give accumulated water more time to infiltrate, and deposit detached soil particles along the contour lines. It retains sediments in the field. In contour farming, ridges and furrows are formed by tillage, planting, and other farming operations to change the direction of runoff from directly downslope to around the hill slope. Contour farming is most effective on slopes between 2 and 10 percent (Khan, 2014). In contour ploughing the ruts made by the plow run perpendicular rather than parallel to slope and allows more time for water to settle in to the soil (Vanost *et al.*, 2006).

Strip cropping refers to growing two or more crops in alternate strips. Crops of different strips vary in their root/shoot characteristics and cultural requirements. Crop strips break sloping landscapes in wide segments with diverse vegetative cover which intercepts runoff and promotes water infiltration, thereby reducing runoff and soil erosion. Sod-forming crops may be alternated with cereals, legumes with non-legumes, and root crops with vegetables. Strip cropping gives yields as good as mono cropping (Khan, 2014). The width of the strips depends on soil slope, erosion potential, crop type, and equipment size. Narrow strips reduce flow lengths more effectively than wide strips. The width of strips must match the equipment turn or width for cultivation. On gentle slopes of up to 5 percent, a strip width of about 30 m is recommended while on steeper slopes the width must be less than 20 m. Strip cropping may be successfully combined with contour farming.

2.5.7.2 Watershed management practice in Ethiopia

Ethiopia is among the sub Saharan belt countries facing environmental degradation. The country is suffering land degradation in the form of soil erosion, resulting in gully formation, loss of soil fertility and severe soil erosion (Hurni, 1988). Dating back to 1970s, Ethiopia has a history of watershed management initiatives. And the government has recognized the existence of serious soil degradation and as a result, large national program were implemented for long period of time to mitigate the degradation in the 1970s and 1980s. But, the efforts of these initiatives were seen to be inadequate in managing the rapid rate of population growth within the country (MoARD, 2005). Therefore, the basic approach has shifted from top to down infrastructural solution to community-based approach (AgWATER, 2012). Accordingly, there is now a supportive policy and legal framework in the form of policies that facilitate decentralized and participatory development, institutional arrangements that allow and encourage public agencies at all levels to work together.

Recently, the government of Ethiopia has adopted a 15 years strategy to protect the country from adverse effects of land degradation and build climate-resilient green economy by 2025 (FDRE, 2011). As a strategy, the government has planned two-phases of five years (2010-2015, 2015- 2020) Growth and Transformation Plan (GTP). The soil and water conservation plane was also included in this strategic plan to implement through community participation. Related to this plan, practical solutions for soil and water conservation implemented in some parts of the country includes soil and stone bunds, hillside terraces, deep trenches, check dams, diversions ditches and sediment storage dams (Paulos, 2001). Specifically in the study area, afforestation were implemented on certain area. In addition to this, traditionally most common land management technologies that have been practiced in the study area were contour ploughing (Adugna *et al.*, 2015).

2.6 Consequences of soil erosion

The effect of soil erosion goes beyond the loss of fertile land. It has led to increased pollution and sedimentation in streams and rivers, clogging, these waterways and causing declines in fish and other species. And degraded lands are also often less able to hold onto water, which can worsen flooding. The difficult is frightening ecosystems and human wellbeing throughout the world Toy *et al.,* (2002), because it results in significant reduction in economic, social and ecological benefits of land for crop and other environmental services. Soil erosion affects about one billion people globally; around 50 percent of them found in Africa, but, more attention is given to other agricultural topics than to soil erosion and its consequences (Blanco and Lal, 2008).

2.6.1 On-site effect of soil erosion

The main on-site impact is the reduction in soil quality which results from the loss of the nutrient rich upper layers of the soil, and the reduced water-holding capacity of many eroded soils. The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the structure and even change the texture.

According to Balasubramanian (2017), textural changes can in turn affect the water holding capacity of the soil, making it more susceptible to extreme conditions such as drought. Crop emergence, growth and yield are directly affected by the loss of natural nutrients and applied fertilizers. Seeds and plants can be disturbed or completely removed by the erosion. Organic matter from the soil, residues and any applied manure, is relatively lightweight and can be readily transported off the field, particularly during spring thaw conditions. Pesticides may also be carried off the site with the eroded soil. Soil quality, structure, stability and texture can be affected by the loss of soil. The reduction of soil productivity over extended period is the main onsite effect of soil erosion. In Ethiopia, the active soil erosion is turning many of the once fertile and surplus production areas in to badlands (Gete *et al.*, 2014). Highlands of the country are considered as the most seriously degraded parts of the world and in general, it is estimated that the country loses 1.9 to 7.8 billion tons a year and this cost the country close to 1 Billion ETB (Gete *et al.,* 2014).

2.6.2 Off-site effect of soil erosion

In addition to its on-site effects, the soil that is detached by accelerated water or wind erosion may be transported considerable distances. This gives rise to 'off-site problems'. Water erosion’s main off-site effect is the movement of sediment and agricultural pollutants into watercourses. This can lead to the silting-up of dams, disruption of the ecosystems of lakes, and contamination of drinking water. In some cases, increased downstream flooding may also occur due to the reduced capacity of eroded soil to absorb water. Sediment can accumulate on down-slope and contribute to road damage. Sediment that reaches streams or watercourses can accelerate bank erosion, obstruct stream and drainage channels, fill in reservoirs, damage fish habitat and degrade downstream water quality.

Pesticides and fertilizers, frequently transported along with the eroding soil, contaminate or pollute downstream water sources, wetlands and lakes. Rapid bank erosion leads to loss of valuable land, reduced water quality as sediment and nutrients enter the stream, as well as threatening infrastructure such as roads, bridges and buildings. Stream bank erosion is the dominant source of sediment in many river systems. For the conservation, development and utilization of our soil and water resources, sedimentation should be the main concern (Julien, 2010). Sediment is the product of erosion and it decreases the storage capacity and life expectancy of reservoirs, increases flood damage and water treatment cost (Toy *et al.,* 2002).

2.7 Soil erosion models

Now a day, field studies for prediction and assessment of soil erosion are expensive, time consuming and need to be collected over many years. Though providing detailed understanding of the erosion processes, field studies have limitations because of complexity of interactions and the difficulty of generalizing from the results. Soil erosion models can simulate erosion processes in the watershed and may be able to take into account many of the complex interactions that affect rates of erosion (Temesgen, 2017).

2.7.1 Physical model

Represent a synthesis of the individual components which affect erosion, including the complex interactions between various factors and their spatial and temporal variability (Lal, 1994). Such a model helps to identify which part of the system are the most important to the overall soil erosion process.

According to Morgan (1995), these models are developed to predict the spatial distribution of runoff and sediment over the land surface during the individual storms in addition to total runoff and soil loss. The common physically based models used in water quality erosion studies include: The Areal Non-Point Source Water Shed Environment Response Simulation (ANSWERS), Water Erosion Prediction Project (WEPP) and European Soil Erosion Model (EUROSEM).

Table 2.2 Physical based soil erosion models (Wells *et al.,* 1999)

Model	References
SWAT	Arnold *et al.,* (1990)
EKWM	Hjelmfelt, *et al.,* (1975)
ANSWERS	Beasley *et al.,* (1980)
CREAMS	Knisel (1980)
WEPP	Laflen *et al.,* (1991)
EUROSEM	Morgan (1998)

2.7.2 Conceptual models

Conceptual models play an intermediate role between empirical and physically based models. These models are general description of catchment processes, without including the specific details of process interactions, which would require detail catchment information (Merritt *et al.,* 2003). The common conceptual based models used in water quality erosion studies includes: ACRU, MMMF (Modified Morgan- Morgan- Finney), (Rapidel *et al.*, 2011).

Table 2.3 Conceptual based soil erosion models (Merritt *et al.*, 2003)

Model	References
Unit Sediment Graph	Rendon (1978)
MMMF	Rapidel *et al.*, (2011
Agricultural Catchment Research Unit	Schulze (1995)
Discrete Dynamic Models	Sharma and Dickinson (1979)
Sediment Routing Model	Williams and Hann (1978)

2.7.3 Empirical models

These models describe the erosion primarily based on observations and are statistical in nature signifying relationships between assumed important variables where a reasonable database exists (Morgan, 1995). They are generally based on the assumption of stationeries that is, it is assumed that the underlying conditions remain unchanged for the duration of the study period (Bobe, 2004). These models relate input to output through some transformation function. And it includes: Revised Universal Soil Loss Equation (RUSLE), MUSLE, and the Soil Loss Estimation Model for South Africa (SLEMSA) which all are based on USLE. Most models used in soil erosion studies are empirical models; this is because the data requirements for such models are usually less as compared to conceptual and physical based models**.**

Table 2.4 Empirical based soil erosion models (Merritt *et al.*, 2003)

Models	References
USLE	Wischmeier and Smith (1978)
MUSLE	Renfro (1975)
PSIAC	Pacific Southwest Inter-agency Committee (1968)
RUSLE	Renard *et al.*, (1991)
SLEMSA	Elwell (1978)

2.8 The Revised Universal Soil Loss Equation (RUSLE)

Development of equations to calculate soil loss from fields began about 1940 in the Corn Belt States and the field experience proved the value of such equations as a tool to help guide conservation farm planning (Wischmeier and Smith, 1965). As a result, the RUSLE model has been developed. The United State Departments of Agriculture developed the model RUSLE which was an improved version of USLE incorporating new approaches and correction of USLE limitations later in 1980s. The RUSLE has computer routines for many tillage operations and crops. In other instances, the user must input new data reflecting the amount of residue incorporated by a tillage operation and the roughness residual following tillage (Khan, 2014).

RUSLE, previously the Universal Soil Loss Equation (USLE), was developed to predict the long time average annual soil loss resulting from rain drop splash and runoff from specific field slopes in specified cropping and management systems and from range land (Renard *et al.,* 1997). The RUSLE model is advantages, because, its data requirements are attainable, relatively easy to understand and compatible with GIS.

It is also useful for construction sites and other nonagricultural conditions, but it does not predict deposition and does not compute sediment yields from gully, stream bank, and streambed erosion (Wischmeier and Smith, 1978). The equation of RUSLE as it is mentioned by Renard *et al*., (1997) is as follows:

$$A = R * K * LS * C * P \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. 2.1$$

A= estimated average annual soil loss (ton h^{-1} $year^{-1}$), R= rainfall erosivity factor (J mm ha^{-1} h^{-1} $year^{-1}$), K= soil erodibility factor (T h J^{-1} mm^{-1}), L= slope length factor (dimensionless), S= slope steepness factor (dimensionless), C= cover management factor (dimensionless), P= support practice factor (dimensionless). With appropriate selection of its factors values, RUSLE can compute the average soil loss "A" for a multi-crop system, for a particular crop year in a rotation or for a particular crop stage period within a crop (Renard *et al*., 1997).

Depending up on the recommendations of the Soil Conservation Research Project (SCRP) by Hurni, (1985), RUSLE model was customized and modified to Ethiopian conditions and the numerical values for each of the six factors in the study are derived from this modification by Hurni. The procedure for the soil loss prediction is more valuable as a guide for selection of practices if the user has a general knowledge of the principles and factor interrelations on which the equation is based.

In Ethiopia different, researchers had applied RUSLE to quantify the amount of soil loss in different parts of the country. For instance, Mestawot (2015), applied the model and found that soil erosion by water in Gerbi River Watershed about 158,830 tons of soil, with the rate of 22.69 t $ha^{-1}yr^{-1}$, was eroded from the total area of 70 km^2 annually, Tesfaye (2015), also applied the model and found that the mean annual soil loss rate from the Cheraqe Watershed, Bilate River Sub-Basin is about 68.7 ton $ha^{-1}yr^{-1}$ and Tsegaye (2007), in Bishan Guracha River sub-catchment found the mean annual soil loss rate as 30 t $ha^{-1}yr^{-1}$. All the founded result shown as how much the modeling of soil erosion is prominent in the country in order manage and conserve soil.

2.9 Significance of GIS and RS in Soil Erosion Modeling

The analytical capacity of empirical and process-based soil erosion models at different temporal and spatial scales has enhanced when they are combined with radical GIS and RS tools. Soil erosion models only calculate the amount of soil erosion based on the relationships between various erosion factors, but when they are assimilated with RS and GIS, it is possible to map the spatial distribution of soil erosion threat and then to develop suitable erosion preclusion techniques. In the process of soil erosion modeling, the GIS stores the necessary database needed as input for the modeling and elaboration of maps of erosion affected areas and display the outputs Blanco and Lal (2008), and there is nothing as practical and cost effective for obtaining a timely overview of land cover than remote sensing technique.

3 METHODOLOGY

3.1 Study area

3.1.1 Location

The study area is Sor River watershed, which is located in South West part Oromiya National Regional State, Ethiopia. Taking the outlet near the confluence points of Geba River, the study area covers an area of 2273 km^2. The geographical location of the study area extends from 35^0 20’0” to 36^0 0’0” E longitude and 7^0 30’0” to 8^0 20’0” N Latitude. Sor River is one of the largest tributaries of Baro akobo River which emerges from near Sigmo district and flows towards South-West direction to join Baro River.

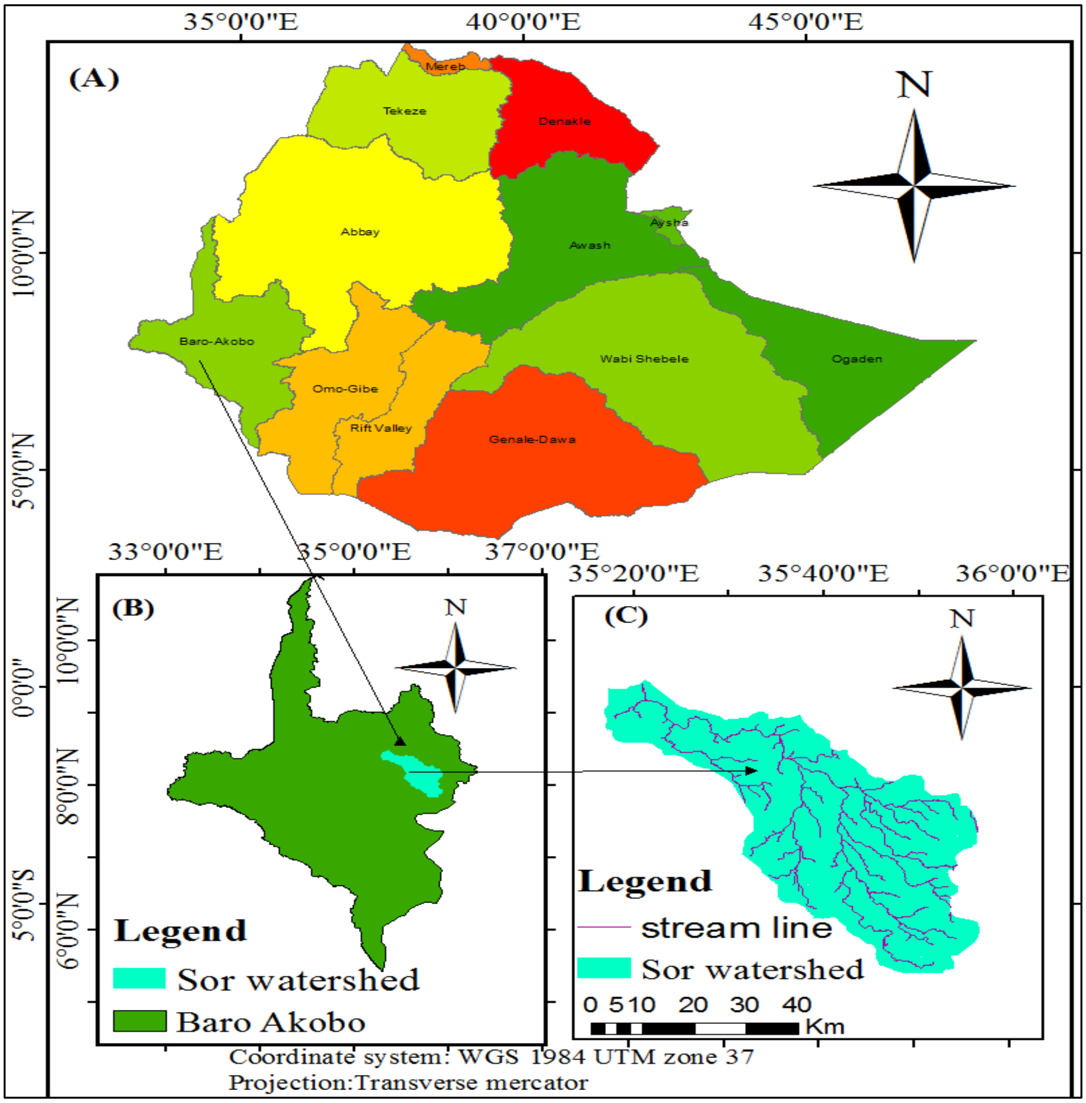


Figure 3.1 Location map of Ethiopian River Basins (A) Baro Akobo (B) and Sor River watershed (C)

3.1.2 Climate, Topography and Temperature

The study area which is a sub basin of Baro River basin contains of diversity of landscape with various topographical features (flat to hilly) with elevation variation from 977 to 2655 m above mean sea level (Figure 3.2). The climate of Ethiopia can be classified in different ways based on altitude and temperature. The most common classification systems are the traditional and the agro-ecological zones. According to the traditional classification system, this mainly relies on altitude and temperature; there are five climatic zones namely: Wurch (cold climate at more than 3000 m. altitude), Dega (temperate like climate-highlands with 2500-3000 m altitude), Woina Dega (warm at 1500-2500 m. altitude), Kola (hot and arid type, less than 1500 m in altitude), and Berha (hot and hyper-arid type) climate (NMSA, 2001). The study area has a tropical climate. In winter there is much less rainfall than summer. Most of the annual rainfall occurs in the wet season called Kiremt (June-September) (Conway, 2000). The driest month is January, with 25 mm of rainfall and the most precipitation falls in the form of rain in August with an average of 292 mm. The warmest month of the year is March and the lowest average temperature of the year in August with 22.7°C and 18.6°C respectively. The average temperature of the sub basin in the summer season locally known as Kiremt is lower but it rises in the winter season locally known as Bega (Kim *et al.*, 2008).

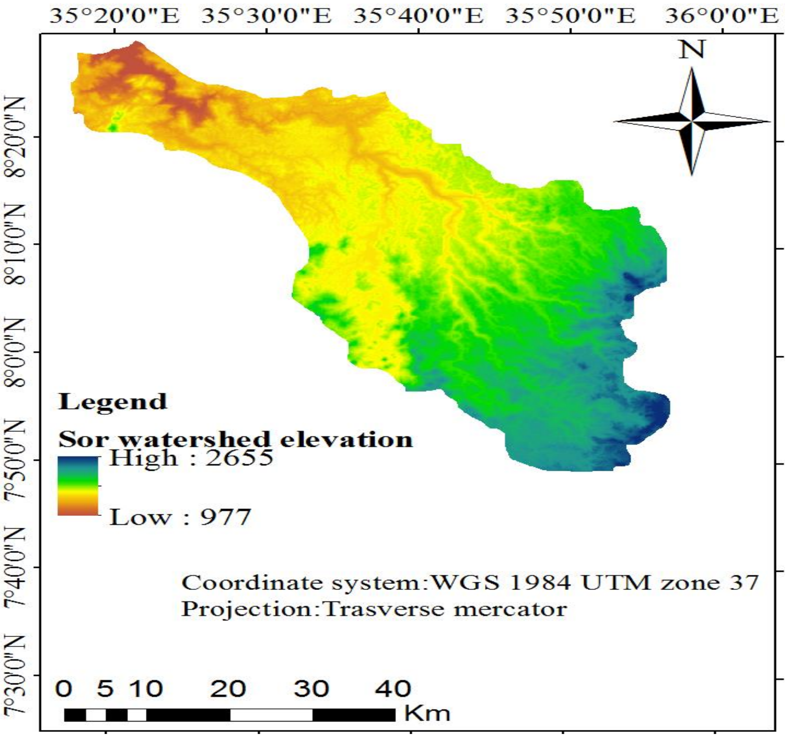


Figure 3.2 Map of elevation of study area

Table 3.1 Average monthly temperature and rainfall of study area

Month	Avg. Temp(℃)	Rainfall (mm)
January	19.7	25
February	21.8	31
March	22.7	54
April	22.6	87
May	21.5	196
June	19.5	234
July	18.8	253
August	18.6	292
September	19.2	252
October	19.4	115
November	19.2	45
December	19.5	27

The area receives its maximum rainfall from May to September.

3.1.3 Soil and Geology

The soil types in the study area as per from FAO (1998) soil map, was identified as Chromic Cambisols, Chromic Luvisols, Eutric Fluvisols, Eutric Gleysols, Eutric Leptosols, Haplic Lixisols, Haplic Nitosols and Rhodic Nitisols. From these Eutric Gleysols covers the largest area (62.5%). The geology of the sub basin is underlain primarily by basalt, although the basement complex is exposed in the North and West (Desta, 2014). From this parent material nitosol and lixisol soils have developed. The eastern highlands are volcanic and Precambrian Basement Complex rocks, mainly basalts origin; while the lowlands are mainly covered by Basement Complex and metamorphic rocks, such as Clastics, Alluvium, Colluvium and marble deposits (Desta, 2014).

3.2 Materials

For this particular study, different materials and tools were used. The materials and tools used in this study are listed in Table 3.2.

Table 3.2 software and model used for the study

Software and model	Purposes
ArcGIS 10.4.1	Analyzing, Displaying and viewing Spatial data
Arc Hydro extension	Watershed delineation
RUSLE	To quantify the soil loss rate

3.3 Data collection

To estimate the soil loss in the study area, different data were used as an input. These data were collected from different governmental and non-governmental organizations. The input data for RUSLE model were prepared after the data collection and analysis. Data that are used for this study were gathered from different sources such as National Mapping Agency, National Meteorological Agency, Ministry of Water, Irrigation, and Electricity of Ethiopia.

The following data were used for the research:

3.3.1 Rainfall data

The rainfall data for selected representative rainfall stations around the study area were collected from National Meteorological Agency (NMA) of Ethiopia. These rainfall stations were Alge, Darimu, Gore, Hurumu, Metu and Yayo stations. The data was 27 years (1990 to 2017) daily recorded data from each metrological station. Table 3.3 shows the locations and average rainfall for each station.

Table 3.3 Stations and mean annual precipitation of study area

Station	Location			Mean annual precipitation
	Longitude	Latitude	Altitude	
Alge	35.66667	8.533333	1880	2206.471
Darimu	35.50152	8.63443	1693	2530.680
Gore	35.53333	8.1333	2033	1891.758
Hurumu	35.667	8.33	1717	2112.907
Metu (Sor)	35.56667	8.283333	1711	1360.102
Yayo	35.71667	8.333333	1700	2018.361

3.3.2 Digital elevation model (DEM) data

The digital elevation model (DEM) data for this study were collected from Ministry of Water, Irrigation and Electricity. The DEM having 30 x30 meter resolution was used for the analysis.

3.3.3 Land use land cover (LU/LC) data

The land use land cover classification map of 2013 was used for this study which is collected from Ethiopian Mapping agency (EMA). It shows detailed classification of the LU/LC in the specified year for the whole country (Ethiopia). From The LU/LC map of the study area, about four different land use and land cover types were identified (Figure 3.7). These were Grass Land, agricultural lands, Open Forest and woodland.

3.3.4 Soil data

For this study, the soil data as per FAO (1998) soil group were collected from Ministry of Water resource Irrigation and Electricity (MoWIE) GIS department. The clipped map of soil types from FAO (1998) soil map for the study area was identified as Chromic Cambisoils, Chromic Luvisoils, Eutric Fluvisoils, Eutric Gleysoils, Eutric Leptosoils, Haplic Lixisoils, Haplic Nitosoils and Rhodic Nitisoils. Table 3.4 General Description of the soil types and detailed characteristics of the soil units (*Sources: Major Soils of the World, 2001; Mengistu et al., 2015; Molla and Sisheber, 2017).*

Table 3.4 Major soil group, types, color and their characteristics of the study area

Soil group	Soil type	Color	Characteristics
Be	Chromic Cambisoils	Brown	Are characterized by the absence of a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides.
RxLv	Chromic Luvisoils	Grey	Excessive to Very Excessive Drained, low structure stability, devastating surface erosion
ReVr	Eutric Fluvisoils	Brown	Imperfectly Drained to well drained, moderately well-structured surface horizons and show sub angular blocky structures
Ge	Eutric Gleysoils	Grey	Seasonally cracking soil, very poorly drained, very dark cracking heavy clay
V/SeLp	Eutric Leptosoils	Grey to yellow	Are soils with very shallow profile depth and they often contain large amount of gravel
Rh/Lx	Haplic Lixisoils	Yellow	Very acidic soils with a clay enriched subsoil and high nutrient-holding capacity.
RhNT	Haplic Nitosoils	Red	Deep, well-drained, tropical soils with moderate to strong angular blocky structure with shiny nutty elements.
S/RrNt	Rhodic Nitisoils	Red	Imperfectly Drained to well drained, moderately well-structured surface horizons and show sub angular blocky structures

Table 3.5 Summary of data types, source and purpose

Data types	Source	Purpose
Meteorological data (rainfall)	National Meteorological Agency, Ethiopia	To extract R-factor
DEM(30x30)m	Ministry of Water, Irrigation and Electricity, Ethiopia	Watershed delineation, slope map generation and LS -factor generation
Soil data	Ministry of water Resources Irrigation and Electricity	To extract K-factor
Land use land cover data	Ethiopian Mapping Agency	To extract C- factor
Land use information practices	Zone Environmental and natural resource conservation authority	To extract P-factor

3.4 Study design or procedure

In order to analyze the soil erosion vulnerability condition in the study area, RUSLE in GIS environment with factors obtained from metrological data, soil data, topographic map, satellite image (from Ethiopian mapping agency) and digital elevation model were used. Corresponding individual RUSLE factors such as R, K, LS, C and P were generated in GIS database and combined together cell by cell grid to predict soil loss rate for the study area.

To estimate the required spatially distributed annual average soil loss rate, mostly secondary data such as satellite image, DEM, meteorological data and soil data were collected from Ethiopian mapping agency, National meteorological and Ministry of water resources irrigation and electricity respectively. Besides to this, field observation were carried out to collect the primary data which were a key information regarding the current land management practice exercised in the study area.

So, as to estimate the total rate of soil erosion, the data layers or maps of R, K, LS, C, and P factors of RUSLE model which were extracted from the collected data were integrated through multiplication algorithm within the raster calculator in ArcGIS database. According to Renard *et al.*, (1997), the empirical equation of RUSLE model is given by Eq. (1).

$$A = R * K * LS * C * P \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .3.1$$

Where, A = Computed annual soil loss per unit area in [t ha^{-1} yr^{-1}], R = rainfall erosivity factor in [MJ mm ha^{-1} hr^{-1} yr^{-1}], K = soil erodibility factor (soil loss per erosion index unit for a specified soil measured on a standard plot of 22.1 m long, with uniform 9 % slope, in continuous tilled fallow) in [t hr MJ^{-1} mm^{-1}], LS = slope length and steepness factor (the ratio of soil loss from the field's slope length and steepness to standard slope length of 22.1 m and steepness of 9 % slope) (dimensionless), C = land use and land cover factor (ratio of soil loss from a specified area with specified cover and management to that from the same area in tilled continuous fallow) (dimension less), and P = support practice factor (ratio of soil loss with a support practice like; contour tillage, strip-cropping, terracing to soil loss with row tillage parallel to the slope (dimensionless).

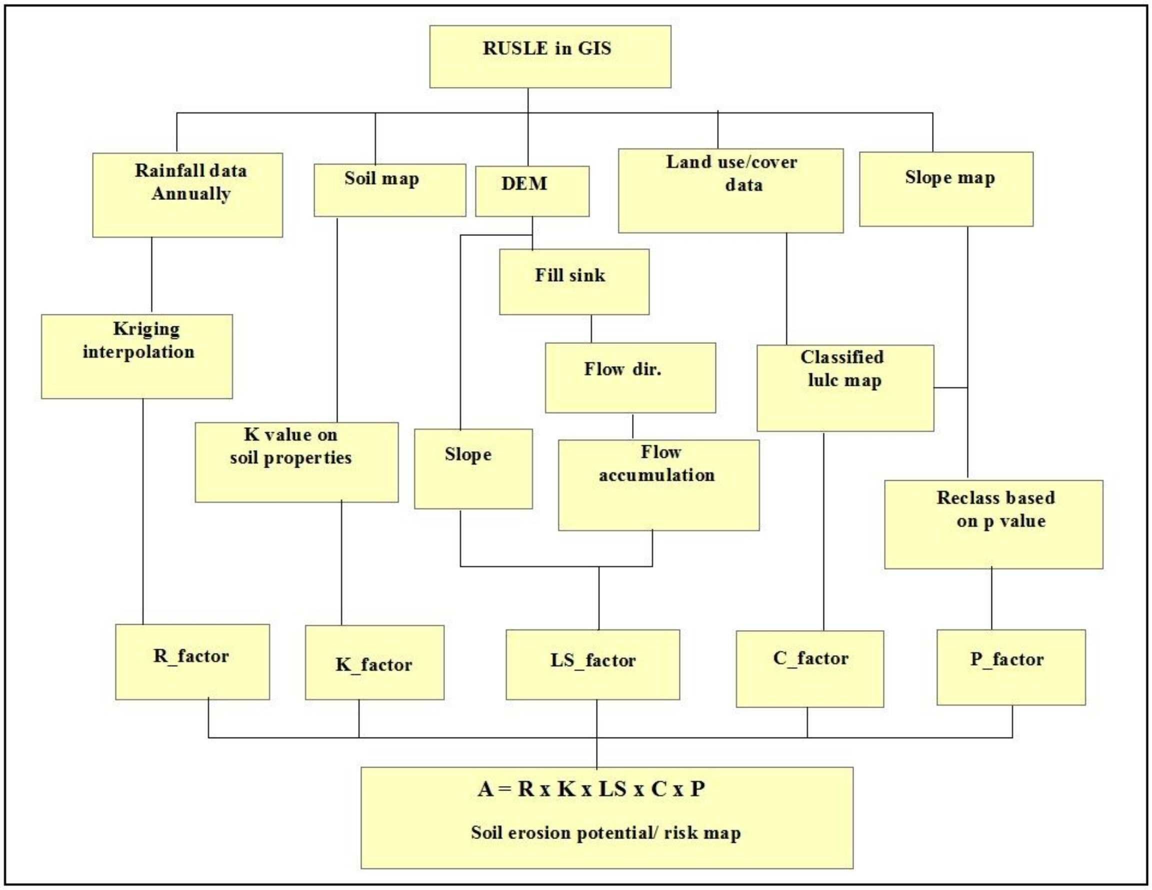


Figure 3.3 Flow chart of the methodologies

3.5 Data processing and analysis

Due to failures of measuring devices or recorder, the different data inputs which were collected from different data sources contain errors. Therefore, before using the data for specific purpose, the data's were to be checked and error had to be removed. The analysis was extended to all the data collected, to prepare them for the required accuracy.

3.5.1 Filling missing data

Filling the missed rainfall data was conducted for each station to fill the missed recorded rainfall data's from the neighboring rain gauge stations which have a complete data set. In order to fill the missed recorded rainfall data, normal ratio method which was recommended by Norazian (2013), to estimate missing data in the region where annual rainfall among stations differed by more than 10%.

3.5.2 Checking consistency of data

Consistencies of rainfall data's were checked by the method of double mass curve analysis. A plot of accumulated rainfall data at a station of interest against the accumulated average at the surrounding stations was generally used to check consistency of rainfall data. Therefore, for this study each of the station was checked for consistency of rain fall series by using double mass curve (appendix 1-6).

3.6 RUSLE Parameters Estimation

The estimation procedures for the different parameters working in RUSLE model are described in the following sections.

3.6.1 Rainfall erosivity

Wischmeier and Smith introduced the concept of rainfall erosivity in 1958 to encapsulate the climatic influence on soil erosion in such a way that, when other variables are held constant, rate of soil loss is directly proportional to the level of rainfall erosivity. Since then several measures of rainfall erosivity have been proposed, including the R-factor in the USLE model and its successor, the Revised USLE (Renard *et al.*, 1997); Foumier's index (Fournier 1960) and the modified Fournier's index (Arnoldus, 1977); Aim index (Lal, 1976); Kinetic Energy (KE) > 1 Index (Hudson, 1976); and Universal Erosivity Index (Onchev, 1985). Of these, the R-factor is the mean annual storm EI_{30}. For an individual storm EI_{30} is the product of the total Kinetic energy and maximum 30-minute intensity for the storm. Then, the R-value corresponds to the mean annual rainfall of the watershed was found using the R correlation established by Hurni in 1985 to Ethiopia condition.

To generate the parameter R-factor, rainfall erosivity map of the study area is needed. In other ways this factor can be determined from rainfall kinetic energy and 30 min intensity of rainfall which can be derived from a measurement of rainfall intensity with autographic recorders (Wischmeier and Smith, 1978; Bewket and Teferi, 2009). For the areas where there is no such map (rainfall intensity map), a different soil scientists develop different empirical equations with the function of average annual rainfall (Table 3.6). These empirical formulas were formulated and applied in different parts of the world.

For instance, the first equation is given in table 3.6 was developed by Hurni (1985), for Ethiopian condition, second equation in works well for Malaysia and the third equation was developed for Jordan. Application of these equations for other countries has less satisfactory. Morgan (1994), states that the equations give satisfactory results for the area which they developed based on the rainfall amount, duration and type. In line with this the fourth equation is used for rainfall of above 900 mm and it needs the recorded value of I30 (max 30 min rainfall intensity) to calculate R-factor values, which is difficult to get in the context of the study area.

Therefore, in this study Eq. (3.2) was used to determine R-factor values from annual average rainfall and presented in Table 3.7. This empirical equation was developed by Hurni (1985), from a spatial regression analysis for Ethiopian conditions. The equation is based on the readily available mean annual rainfall data and used by other similar studies in Ethiopia (Bewket and Teferi, 2009; Tadesse and Abebe, 2014; Kebede *et al.,* 2015; Gelagay and Minale, 2016: Mahmud, 2018).

Table 3.6 Summary of empirical equations for determination of R- factor

Rainfall Erosivity Formulas	Applicable Area	Sources
$R= -0.812 + (0.562*p)$	Ethiopia	Hurni (1985)
$R = 9.28*p-8838$	Malaysia	Morgan (1974)
$R = 23.61* e^{(0.0048p)}$	Jordan	Eltaif *et al*. (2010)
$R = 0.276*p*I_{30}$	Rainfall of above 900mm	Foster *et al*. (1981)
$R = -3172+7.562*p$	Honduras	Mikhailova *et al*.(1997)
$R= 0.0438*p^{1.61}$	Australia	Rosewell (1996)

$$R = -0.812 + 0.562 * P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

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

Table 3.7 Stations name with their respective average rainfall

Stations Name	Av. Rainfall (mm)
Alge	2206.471
Darimu	2530.68
Gore	1891.758
Hurumu	2112.907
Metu (sor)	1360.102
Yayo	2018.361

Interpolation of point data of rainfall was made by ArcGIS 10.4.1 Inverse Distance Weighted (IDW) method in order to form a surface of data from the scattered set of point data as given in Figure 3.4. Finally, the R-factor values were interpolated to generate erosivity map and clipped in GIS database (Section 4.1.1).

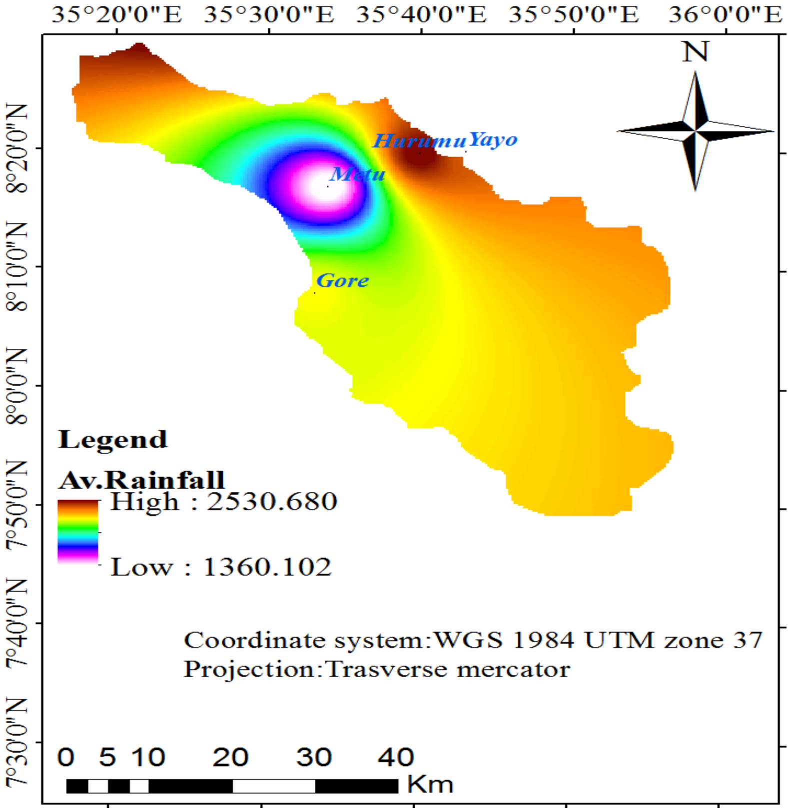


Figure 3.4 Interpolated map of average annual rainfall of the study area

3.6.2 Soil erodibility

The soil erodibility (K) factor represents both susceptibility of soil to erosion and the amount and rate of runoff. It is related to the integrated effects of rainfall, runoff, and infiltration on soil loss, accounting for the influences of soil properties on soil loss during storm events on upland areas (Lu, *et al.*, 2004). Soil texture, organic matter, structure and permeability determine the erodibility of a particular soil (Efe, *et al*, 2008). However, Soil data in Ethiopia often doesn't contain detailed information about such soil parameters (Bewket and Teferi, 2009). As Helden (1987), indicate for recognized soil color of black, brown, red, yellow, grey and white the recommended K-factor values are 0.15, 0.2, 0.25, 0.3, 0.35 and 0.4 in order of sequence.

Therefore, the K- factor values for the study area was assigned based on a qualitative index of soil that adapted by Helden (1987), based on the color of the soil which is believed to be a reflection of soil properties. He has suggested calibration-based values of K-factor, based on soil color for Ethiopian soil conditions. Experiment-based suggestion also given by others (Kaltenrieder, 2007), to determine K-factor values based on the soil color. To assign the K-factor values for the same model, this method (based on soil color) was used by (Bewket and Teferi, 2009; Gelagya, 2016; Haregeweyn *et al.,* 2017).

Table 3.8 Soil color and respective k-factor values (Hellden, 1987; Hurni et al., 2015)

Soil color	Black	Brown	Grey	Red	Yellow	White
K-factor values	0.15	0.2	0.25	0.25	0.35	0.4

Based on the existed soils on the study area and respective colors, the K-factor for the study area is rated on a scale from 0.2 to 0.35. The smaller value (0.2) refers to soils with least susceptibility to erosion whereas larger value (0.35) refers to soils which are highly susceptible to erosion by water. The soil types of the study area with their respective color types were collected from different literature which was shown in table 3.8.

Finally, the clipped soil map (Figure 3.5) and the resulting shape file attribute table was edited and K-factor values were added. Then the map changed to grid file or raster format with cell size of 30 x 30 m resolution in ArcGIS to generate erodibility factor map as shown in Figure 4.2 (B).

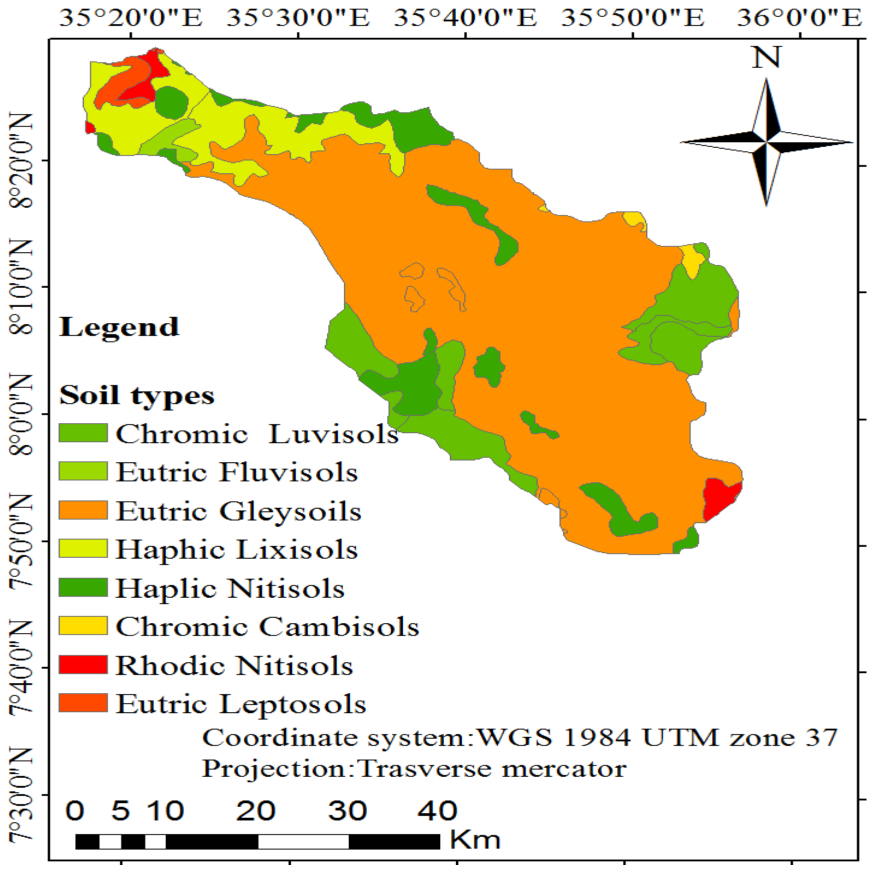


Figure 3.5 Map of major soil types in the study area

3.6.3 Slope length and steepness factor (LS)

The L and S factors in RUSLE reflect the effect of topography on erosion. It has been demonstrated that increases in slope length and slope steepness can produce higher overland flow velocities and correspondingly higher erosion (Lal, 1991). Moreover, gross soil loss is considerably more sensitive to changes in slope steepness than to changes in slope length (Wischmeier and Smith, 1978).

Slope length has been broadly defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough where deposition begins or the flow is concentrated in a defined channel (Wischmeier and Smith, 1978).

The specific effects of topography on soil erosion are estimated by the dimension less LS factor as the product of the slope length (L) and slope steepness (S) constituents converging onto a point of interest, such as a farm field or a cell on a GIS raster grid. In RUSLE, the LS factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22 m plot (Robert and Hilborn, 2000).

The steeper and longer the slope, the higher is the erosion. For this study, the LS -factor was generated from digital elevation model (DEM) data with 30 x 30 m resolution of the study area. The used DEM data was developed by United State geological survey (USGS) and freely available from the internet, but for this study it was collected from Ethiopian ministry of water, irrigation and electricity.

The spatial analysis tool of ArcGIS was used to generate raster layer of slope from DEM data. Flow direction and Flow accumulation map were also processed and generated from DEM after fill operation in ArcHydro tools of ArcGIS extension to use as an impute for the calculation of LS-factor.

To generate LS-factor map, the following equation Eq. (3.3) which was developed by Moore and Burch, 1986; Engel, (2005), was used in raster calculator of Arc GIS

$$\mathrm{LS} = \mathrm{Pow}\left(''\mathrm{flowacc}'' * \frac{[\mathrm{cellres}]}{22.1}, .4 \right) * \mathrm{pow}(\sin(''\mathrm{slope})'' * 0.01745))/0.09{,}1.4) * 1.4 \ldots\ldots (3.3)$$

Where, FA (flow Accumulation) is a raster-based total of the accumulated flow to each cell, and resolution is cell size or length and width of pixels side (Figure 3.6). The resulting LS-factor map is shown in Figure 4.3.

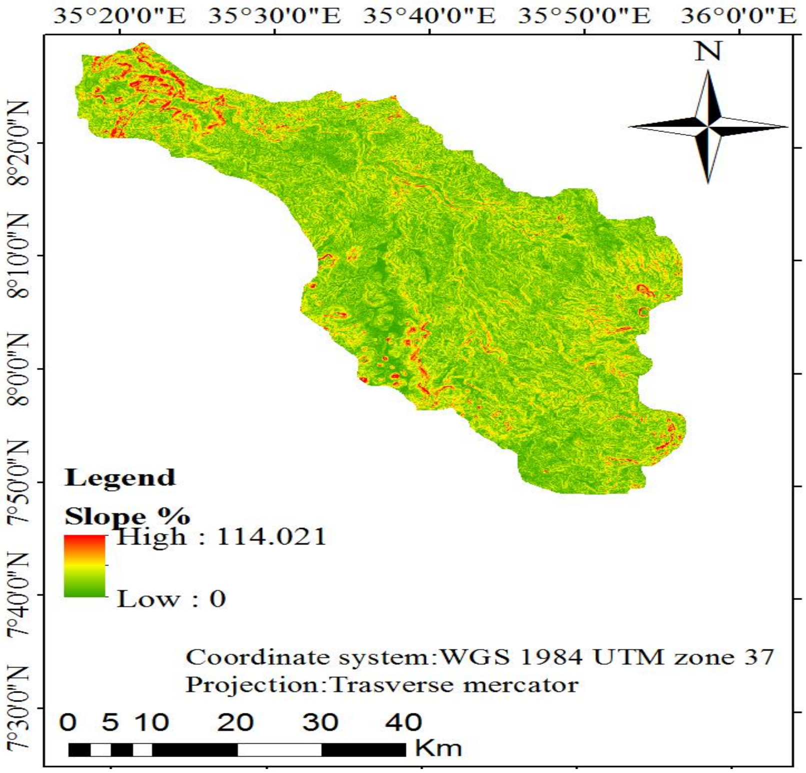


Figure 3.6 Map of slope in percent

3.6.4 Cover management factor (C)

The vegetation cover and management factor C 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. According to Biesemans *et al*., (2000), the vegetation cover factor together with slope steepness and length factors is most sensitive to soil loss. The value of C-factor is defined as the ratio of soil loss from a certain kinds of land surface cover conditions (Wischmeier and Smith, 1978). Deforestation due to cropland expansion has the highest impact on the C-factor. This land use change may have resulted in a significant increase in the C-factor, and consequently an increase in soil loss. The value of C-factor varies from 1 in completely bare land (no cover) to 0 in water body or completely covered land surface (Mengistu *et al.*, 2015).

The C factor combines plant cover, the level of its production, and the associated cropping techniques. As much as available, recent land use land cover (LU/LC) data which can show the current condition of the study area is needed to determine this factor. Therefore, for this study, the land use land cover classification map of 2013 was used. The study area was clipped form this LU/LC map and identified about four different land use and land cover types (Figure 3.7). From the classified map, 34.3% of the total area was found to be covered by agricultural lands (state farms, perennial crops and annual crops). Open forest and grass land have the area coverage with 48.4% and 12.07% respectively and the remaining area has been covered by woodland.

Hence, the corresponding C-factor values for different LU/LC class was assigned after having the classified map. These values were collected from previous studies and assigned for corresponding LU/LC types. Finally, the C-factor map was generated in ArcGIS database after adding these values in the attribute table of the LU/LC map. Converting this map to raster format, results C-factor map shown in Figure 4.4. Table 3.9 briefly indicates the type of LU/LC class with corresponding C-factor values.

Table 3.9 LU/LC types and corresponding C-factor values (Bewket and Tefri, 2009; Gelagay, 2016).

Land use land cover types	C-factor values	Sources
Bare soil	0.6	BCEOM (1998)
Agriculture land	0.15	HURNI (1985)
Open forest	0.01	HURNI (1985)
Dense forest	0.01	HURNI (1985)
Shrub forest	0.014	CGIP (1996)
Grassland	0.01	Van Lammeren (1996)
Water body	0	HURNI (1985)
Wood land	0.05	HURNI (1985)

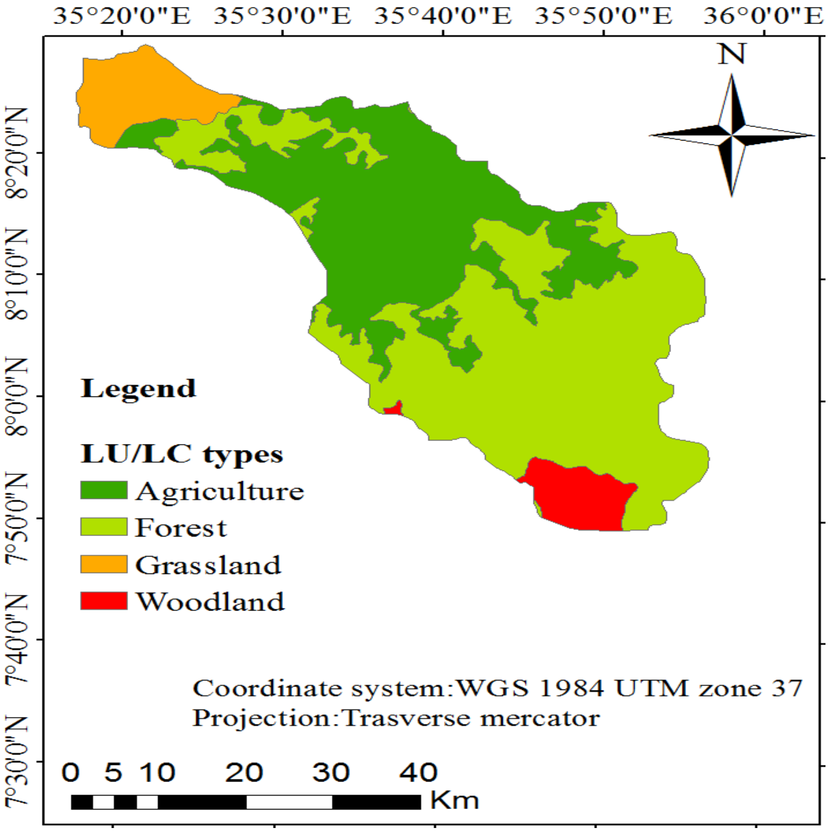


Figure 3.7 Map of dominant LU/LC types in the study area

3.6.5 Conservation practice factor (P)

The conservation practice factor (P) is also called as support factor. It represents the soil-loss ratio after performing a specific support practice to the corresponding soil loss, which can be treated as the factor to represent the effect of soil and water conservation practices (Omuto, 2008; Renard *et al.*, 1997). The range of P factor varies from zero to one. The lower the value is the more effective the conservation practices are. Therefore, the effects of this factor is depends on the actual agricultural activity held on the given area by the stake holders or farmers. The major erosion control practice such as contouring, strip cropping and terracing which reduces the eroding power of rainfall-runoff and increase infiltration by reducing slope steepness and slope length are the main controlling factors. In the study area, the entire basin is not treated with improved soil and water conservation measures. The widely used traditional conservation practice is the contouring, which is meant to safely drain excess runoff from croplands during rainstorms. Hence, P-factor values suggested by Shinn (1999) was used for the study. Table 3.10 represents the value of support practice factor according to the cultivation method and slope (shinn, 1999).

Table 3.10 Support practice factor

Slope (%)	P-Factor values	
	Contouring	Contour ploughing with terracing
0-7	0.55	0.1
7-11.3	0.6	0.12
11.3-17.6	0.8	0.16
17.6-26.8	0.9	0.18
> 26.8	1	0.2

Based on the information gathered at the time of site visit, contour ploughing was found to be the common soil and water conservation measure followed by a construction of a little bit soil and stone bunds in the study area. The specified method of soil conservation has been the dominant soil erosion control practice among the farmers in the cultivated lands for a long period of time. The entire watershed area was therefore, not treated with improved soil and water conservation measures. Hence, for this research, the P-factor values suggested by Shinn (1999), was used considering only the contour ploughing as dominant soil conservation practice for current soil erosion status of the study area (Table 3.10). Hence, the conservation practice factor values were given within the ranges of slope gradient of the study area. As shown in Table 3.10, the study area was classified in to five slope gradient ranges with corresponding P-factor values. After the classification in slope has been made (Figure 3.8), the corresponding P-factor values were added to the shape file of the reclassed slope map and using conversion tool in ArcGIS, conversion to raster has been executed and P-factor map was generated as shown in Figure 4.5 (Section 4.1.5).

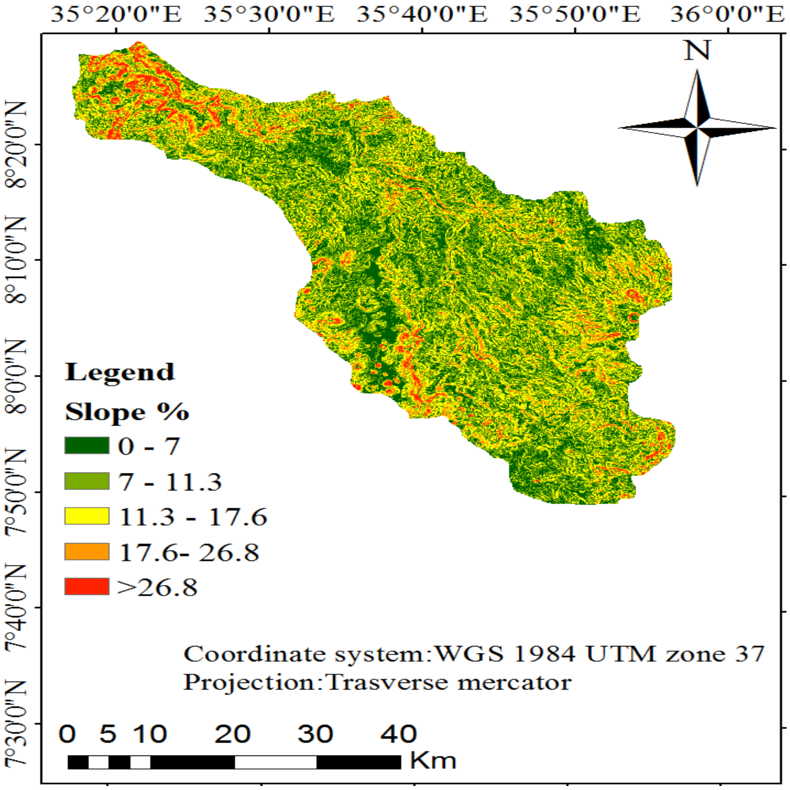


Figure 3.8 Map of slope gradient in percent

3.7 Digital elevation model (DEM)

The digital elevation model (DEM) is one of the inputs for RUSLE model to delineate the sub-watersheds in the ArcGIS interface. It is point elevation data stored in digital computer files. The DEM 30*30m found from Ministry of Water, Irrigation and Energy was used to delineate and developed according to the site of the study area. This data was projected into projected coordinate system. The projection of the DEM data was prepared using the Arc tool box operation in ArcGIS. The projected coordinate system parameters of study area are: UTM other GCS-Adindan UTM zone 37 N. projected to Transverse Mercator (UTM) on adenine of WGS1984 and it was in raster format to fit in to the model necessity. In this study, the DEM data was used to delineate the watershed making the outlet near the confluence point with Geba River, to classify the Agro-climatic zone of the catchment and to generate the very important RUSLE factors, such as LS and P-factors.

4 RESULTS AND DISCUSSION

4.1 RUSLE Model Parameters

4.1.1 Rainfall Erosivity (R) Factor

The rainfall erosivity (R-factor) is a property of rainfall that can quantitatively evaluate the potential capacity of rain to cause erosion in a given circumstances. After having the averaged 27 years rainfall data for each metrological station, interpolation by ArcGIS 10.4.1 was done to generate an estimated surface from these scattered set of point data into surface. Due to the variation in mean annual rainfall amount within the study area, variation in rainfall erosivity was observed. Hence, the rainfall erosivity values estimated from mean annual rainfall of the selected rainfall stations, varied from 763.617 MJ mm ha^{-1} hr^{-1} yr^{-1} at Metu to 1186.62 MJ mm ha^{-1} hr^{-1} yr^{-1} at Hurumu. Following this, the rainfall erosivity is high at the Northeast including Hurumu, Alge and Yayo, but low to the center towards Metu (Figure 3.4).

According to Hudson (1981), high rainfall may have high erosive power but the total erosivity is not directly proportional to the total amount of rainfall. Therefore, based on this the Northeastern part of the study area receives relatively higher rainfall that have high erosive power. The map of rainfall erosivity gives a spatial overview of the erosive energy of rain. The higher the erosivity value, the more powerful the rainfall to erode the soil from the surface.

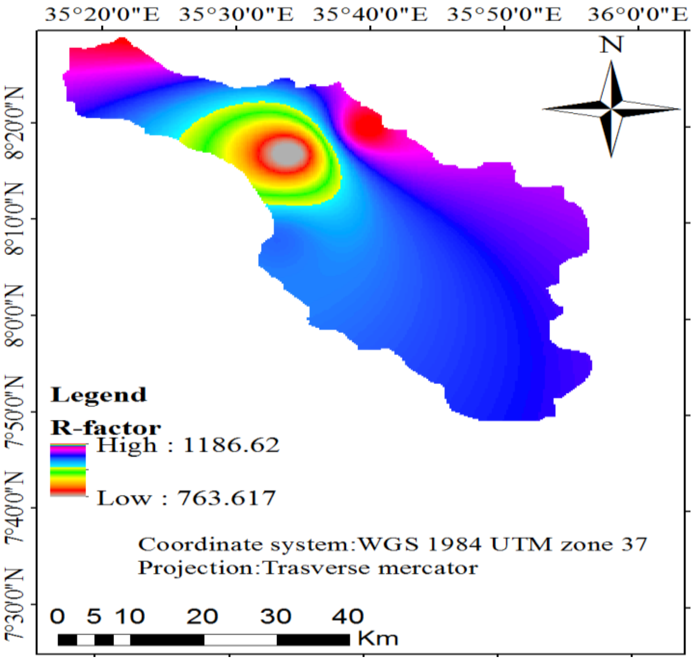


Figure 4.1 R-factor map of the study area

4.1.2 Soil erodibility (K) factor

Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called the soil erodibility factor (K). Soil erodibility factor (K) in RUSLE accounts for the influence of soil properties on soil loss during storm events on upland areas.

From the digital soil map of the study area, eight different soil types with different characteristics were identified. The dominant soil type, Eutric Gleysols covers the largest area which accounts about 62.5% of the total area. Mostly this soil type exists in the North-Western, North-Eastern, central parts and Southern boundary of the catchment (Figure 4.2A). Chromic Luvisols, which is the second largest coverage area (about 22.86%) is found at South-Western and Eastern part of the study area. Chromic cambisoils and Eutric Fluvisols which are highly resistance to erosion is found at the Eastern and Northern parts of the catchment with small areas coverage respectively. The erodibility characteristics of the existed soils in the study area were varied with the range of K-factor value of 0.2 to 0.35 t hr MJ^{-1} mm^{-1}.

Table 4. 1 Soil types, soil color and K-factor values (FAO, 2017)

Soil types	Soil color	K-factor (t hr MJ^{-1} mm^{-1})
Chromic Cambisoils	Brown	0.2
Chromic Luvisoils	Grey	0.35
Eutric Fluvisoils	Brown	0.2
Eutric Gleysoils	Grey	0.35
Eutric Leptosoils	Grey to Yellow	0.35
Haplic Lixisoils	Yellow	0.3
Haplic Nitisoils	Red	0.25
Rhodic Nitisoils	Red	0.25

Accordingly, Chromic Cambisoils and Eutric Fluvisoils have lower erodibility, while Chromic Luvisoils, Eutric Gleysoils, Eutric Leptosoils have relatively higher erodibility. This implies that Chromic Cambisoils and Eutric Fluvisoils are more resistant to erosion because of their low detachability, while Chromic Luvisols, Eutric Gleysols, Eutric Leptosols are more susceptible to erosion under similar conditions that affect soil loss. Generally, Figure 4.2(B) k-factor shows that > 62% of the total area of the catchment was covered with soils which have lower to moderate K-factor values of 0.2 and 0.3 t hr MJ^{-1} mm^{-1}. Such soil. Therefore, in terms of soil erodibility condition, the catchment characterizes with moderately vulnerable to erosion.

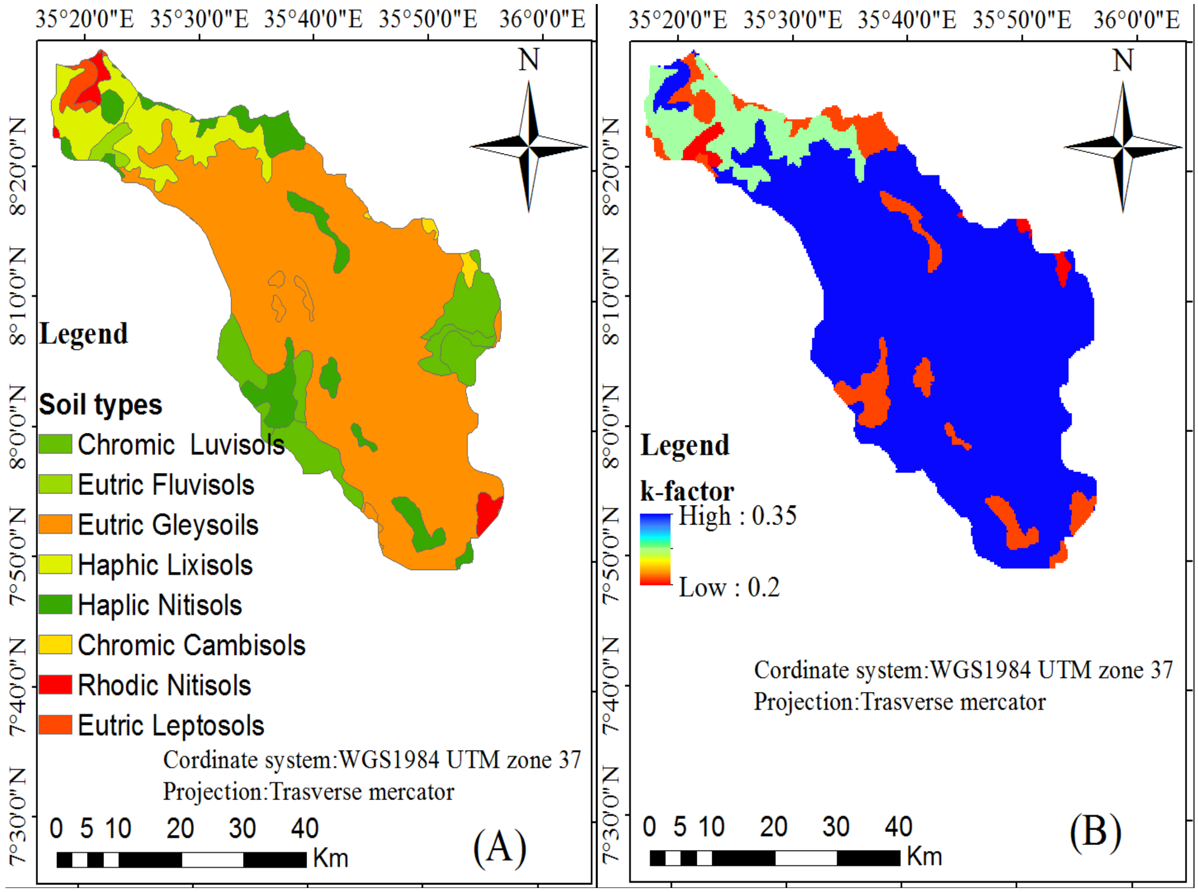


Figure 4.2 Major soil types in the study area and respective k-factor

4.1.3 Length and slope steepness factor

The LS-factor is the important features of topography used in modeling soil erosion. It represents the influence of slope length and steepness on erosion process. The combined LS-factor value was calculated for every segment by considering the flow accumulation and slope in percentage as an input and the result varies from 0 (flatter and lower part) to 48 (steeper and upper part) (Fig.4.3). Majority of the study area have relatively lower LS-factor (0 - 4.77) and were observed to occur in all part of the study area. In this study, high LS values (4.77- 48) were mostly determined in the southern, northeastern and the mountainous region of the sub basin. This is because, as the slope gradient increases, the value of LS-factor also increases.

Therefore, the higher the value of LS-factor, the higher would be the susceptibility of the area to soil erosion by water and vice versa.

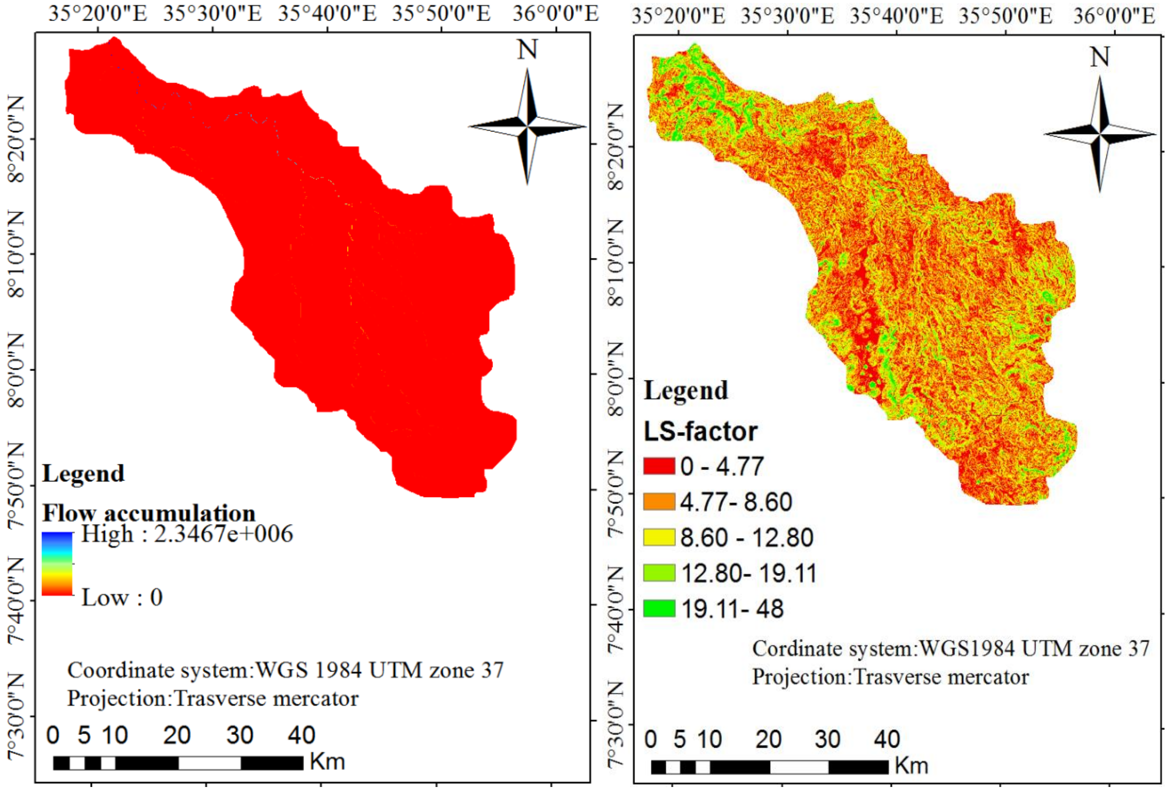


Figure 4.3 Flow accumulation and LS- factor map of the study area

4.1.4 Cover Management Factor(C-Factor)

Land use land cover information permits a better understanding of the land utilization aspects which are vital for developmental planning. The C-factor represents the effect of plants, crop sequence and other soil cover surface on soil erosion. The C-factor is dimensionless with values between 0 and 1.

As shown in Figure 3.7 and Table 3.9 four land cover classes were recognized in the study area that were mainly consists of forest (48.4%), agriculture (34.3%), woodland (12.07%) and the remaining catchment area was covered with grass land. These land cover class were used to determine the C-factor value as given in Table 3.9. The C values for the study area ranges from 0.01 to 0.15. As per the reference given in Table 3.9, C-factor value was assigned to each land cover class where the highest C-factor value (0.15) was given to dominantly agricultural land and the lower value (0.01) was given to grass land. As it is seen from the map (Figure 4.4) the cultivated land covers most of the central parts with some scattered distribution at Southern and Northern part of the study area. Hence, the contribution of this factor for erosion at the Central and South-Western part is high and the contribution at the Western and at the highland areas of the watershed is less. This can be seen on the C-factor map of the basin presented in Figure 4.4.

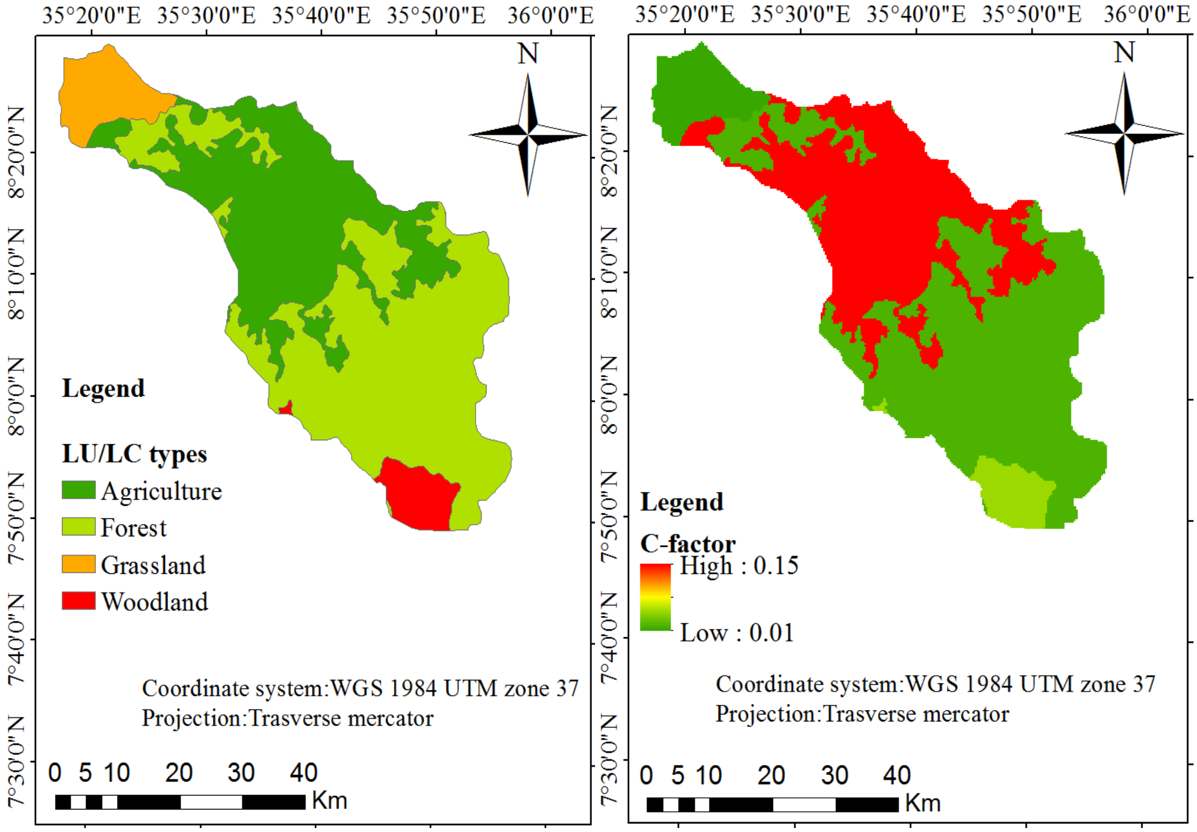


Figure 4.4 Map LU/LC and cover management factor (C-factor)

4.1.5 The support practice factor (P)

The P factor refers effectiveness of support practices that will diminish the amount and rate of soil erosion. In this perspective, soil erosion can be reduced by adjusting the flow pattern, grade, or direction of surface runoff and "P" also supports the C factor in land management system. The P-factor also reflects the impact of specific erosion management practices on the corresponding erosion rate with values between 0.55 and 1. There were no management practices applied to the study area, except contouring and ditch to safely remove excess runoff during rainy season from agricultural land. Considering an implementation of watershed management practice such as contouring with terracing fully developed, the P-factor values ranges from 0.1 to 0.2. In this condition also, the lower values of P-factor was concentrated at the Southeastern part of the study area and the higher values of P-factor was shown at upper and outer parts of the study area. Therefore, from the Southeastern parts of the study area, the expected soil erosion would be lesser due to the lesser LS-factor values in this particular area and the outer upper sloppy part of the study area contributes larger erosion due to larger LS-factor values in this area. Hence, the P-factor values were assigned according to the suggestion by Shin (1999) that is given under section 3.6.5 table 3.10.

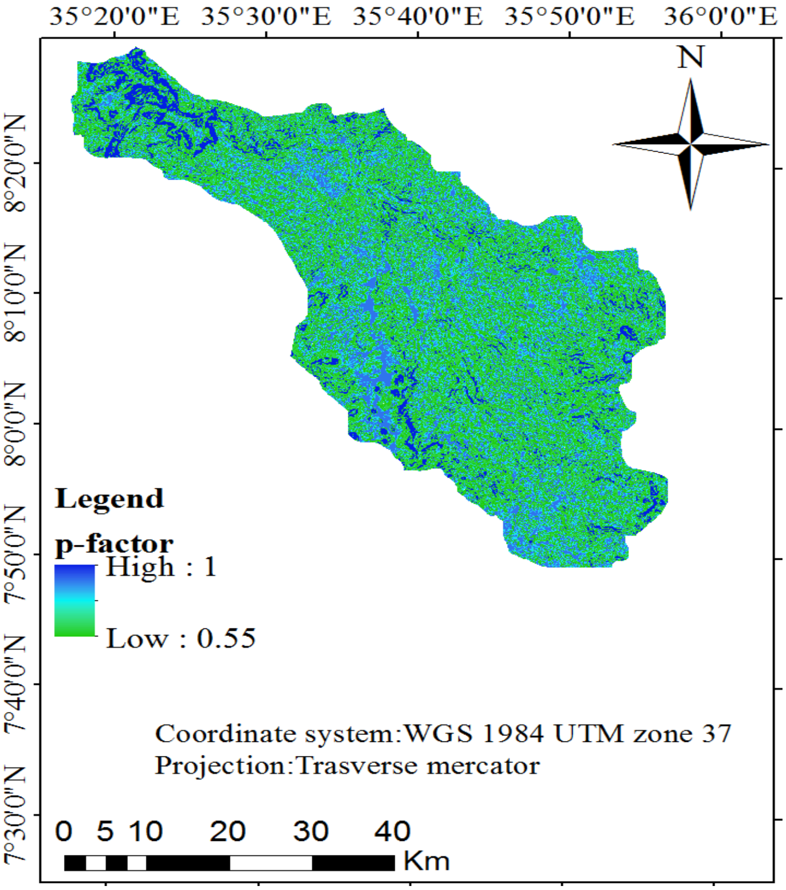


Figure 4.5 Map of support practice (p-factor)

4.2 Average annual soil loss estimation for the existing conditions of study area

The annual soil loss rate of the study area was determined by multiplying the respective RUSLE factor (erosivity (R-factor), erodibility (K-factor), topographic (LS-factor), cover management (C-factor) and conservation support practice (P-factor) values interactively in ArcGIS 10.4.1 using Eq. (3.1).

The RUSLE model result show that the spatial distribution of the annual soil loss rate varied from 0 t ha^{-1} yr^{-1} in low land and flat area to 330 t ha^{-1} yr^{-1} in degraded sloppy area with average annual soil loss rate of 14.86 t ha^{-1} yr^{-1} for the entire study area (Figure 4.6). On annual basis, the total soil loss of the watershed was found to be 3.38 M tons of sediment from 2273Km^2 of land per year. This indicates that the study area has a larger spatial variation of soil loss. The spatial variation is caused due to the difference in RUSLE parameters (soil erodibility, rainfall erosivity, slope steepness, poor land cover and improper land management). The potential soil loss in the study area has been categorized into six types (Table 4.2) as low, moderate, high, very high, severe and very severe erosion based on the rate of erosion according to (Bewket and Teferi 2009; Ayalew and Selassie, 2015). High erosion rate corresponds to very severe erosion and low rate of erosion corresponds to low erosion.

The other four categories fall in between moderate and severe erosion. The basis for the categorization of the severity classes was based on the Soil Loss Tolerance (SLT) which denotes the maximum allowable soil loss that will sustain an economic and a high level of productivity (Wischmeier and Smith, 1978; Renard *et al.,* 1996). About 74.71% (1698.16 km^2) of the sub basin was categorized as low class which falls below the normal soil loss tolerable values ranging from 5 to 11 tons ha^{-1} year^{-1} according to (Renard *et al.,* 1996). The remaining 25.26% (574.26 km^2) of the study area was classified under moderate to very severe class of which 15.85% (360.26 km^2) were above the maximum tolerable soil loss of 11 ton ha^{-1} year^{-1}.

Therefore, it is observed that from figure 4.6, most part of the study area comes under lower erosion category, which could be found in almost all areas, and very high erosion occurs only in a few regions where the steep slope exists and cultivation is concentrated.

Table 4.2 Annual soil erosion rates, percent of total area and corresponding severity classes

Soil loss (t ha^{-1} y^{-1})	Area (km^2)	Percent of total area	Severity classes
< 5	1698.16	74.71	None to low
5 – 12	214	9.44	Moderate
12 – 25	185.97	8.18	High
25 – 50	103.29	4.54	Very high
50 – 100	45.98	2.02	Severe
> 100	25.29	1.11	Very severe

The result of this study has the same pattern as previous researches conducted on different places in Ethiopia, even though there is a difference in value. For instance, in the Ethiopian highlands soil losses are extremely high with an estimated average of 20 t ha^{-1} yr^{-1} and measured amounts of more than 300 t ha^{-1} yr^{-1} on specific plots (Hurni, 1985). Using RUSLE model Molla and Sisheber (2017), estimated annual soil loss rate for Koga watershed and its value ranges from 12 to 456 t ha^{-1} yr^{-1}. Ayalew and Selassie (2015), estimated the mean annual soil loss potential for Guang watershed in Blue Nile Basin and was 24.95t ha^{-1} yr^{-1} for entire watershed. In North-East Wollega, Adugna *et al.*, (2015), indicates the soil losses have shown spatio-temporal variations that range from 4.5 t ha^{-1} yr^{-1} in forest to 65.9 t ha^{-1} yr^{-1} in cropland. Shiferaw (2011), estimated an average annual soil loss of 30.88 t ha^{-1} yr^{-1} for the Legemara watershed in Borena woreda (district), Mekonnen and Melesse (2011), estimated annual soil loss of 18 t ha^{-1} yr^{-1} for Debremawi watershed, North Gojjam sub-basin.

Hence, the extent and magnitude of soil erosion in the basin are spatially variable. Severe to very severe soil erosion were observed in the study area. The spatial variations of the soil erosion rates are normally due to the actual existing condition of the areas. A larger part of the study area was being flat possessing gently slope and covered by forest. Therefore, sedimentation of eroded soil from upstream area will be the major problem in the study area.

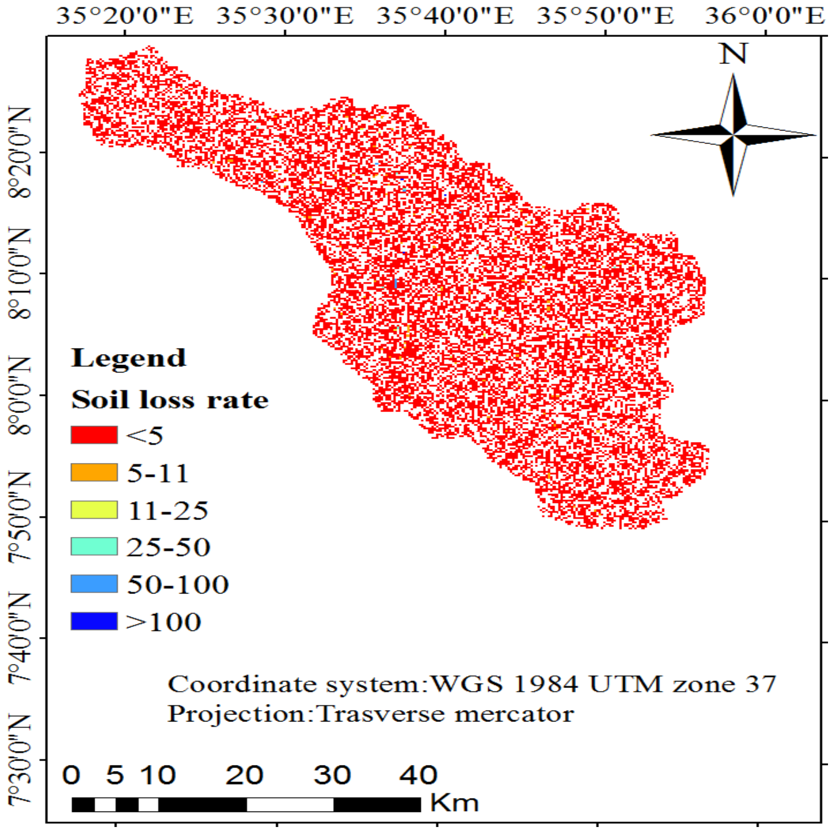


Figure 4.6 Map of annual soil loss rate of the study area

4.3 Prioritization of soil erosion vulnerable area

The areas with high to very severe soil erosion classes demand special priority for the implementation of soil erosion control measures. Even the whole area requires conservation measure; resource considerations may limit implementation of soil and water conservation technologies to a few priority areas only. Implementing conservation measures in only selected areas that are hotspots of erosion can significantly reduce total sediment yield of the area (Bewket and Teferi, 2009). Hence, prioritizing erosion hotspot areas for treatment with suitable conservation measures is necessary and strategic.

The minimum, maximum and average annual soil loss rate for each of the district in the study area were analyzed and presented in Table 4.3. Figure 4.7 shows the boundary of the districts and severity class of soil erosion for each district in the Sor River watershed. Based on the result, Darimu district was identified to be a sever soil erosion prone area. From this district, the rate of erosion was found to be minimum of 0 and maximum of 330 t ha^{-1} yr^{-1} with annual average of 37.8 t ha^{-1} yr^{-1} which is the maximum rate of the entire study area. Saylem was identified to be the least prone area with an average soil loss rate 4.56 t ha^{-1} yr^{-1} Thus, some parts of the study area, were affected by sever soil erosion than other regions due to various reasons. One of the major reasons was the variation of existed physical condition of the areas.

Table 4.3 Spatial distribution of soil loss at district level in Sor sub basin

District	Area (Km^2)	Area in percent	Soil loss (t ha^{-1} yr^{-1})		
			Minimum	Maximum	Annual Average
Ale	500.4	22.014	0	78	8.33
Darimu	100.58	4.424	0	330	37.8
Metu	733.4	32.265	0	167	14.43
Saylem	157.32	6.921	0	27	4.56
Sigmo	123.7	5.442	0	33	32.1
Yayo	657.6	28.931	0	109	28.7

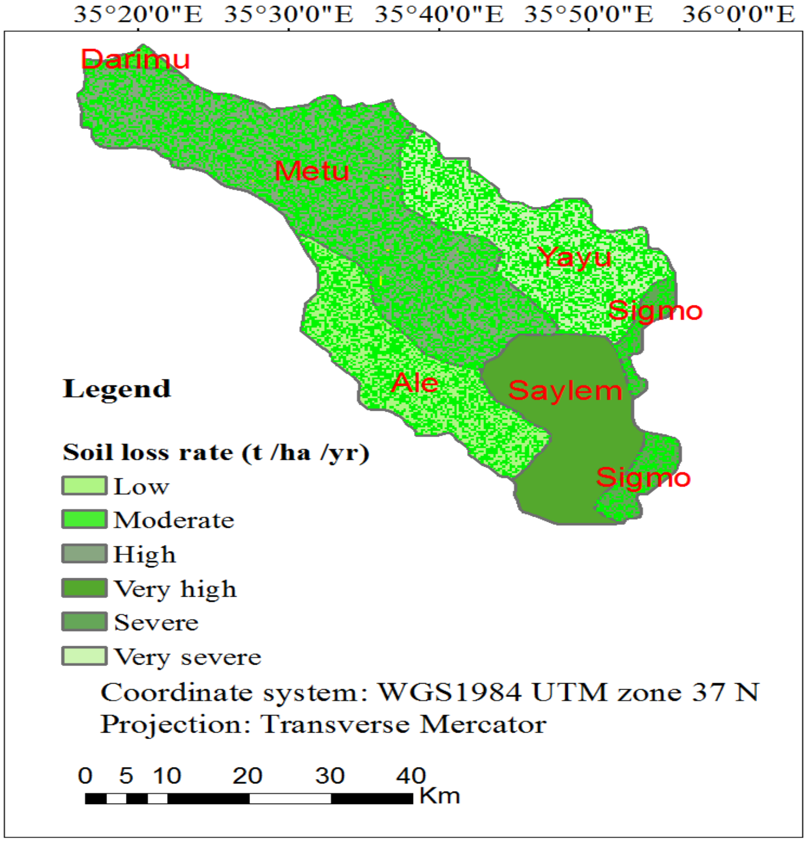


Figure 4.7 Boundaries of districts in the study area and severity class map

4.4 Impacts of proposed interventions measures

In order to check the effect of watershed management on soil erosion rate, p-factor values were tested for two conditions. The first condition was contour ploughing for the existed condition and the second was what if there was an implementation of effective terracing with contour ploughing of agricultural lands in the study area? For the second condition, the result shows that, the annual average soil loss rate was reduced from 14.86 to 8.57 t ha^{-1} yr^{-1}, which means it was reduced the annual soil loss rate by 42.3%. This was checked by taking the recommended values of P-factor for both contour ploughing with terracing and considering only contour ploughing, activities separately and comparing the result of the two conditions showed in Figure 4.8. After the application of this conservation method, the area with soil erosion rate existed in the limit of soil loss tolerance (between 5-11 t ha^{-1} yr^{-1}). Hence, the result of this section shows that the implementation of integrated watershed managements specifically terracing with contour ploughing, significantly reduces the susceptibility of soil erosion in the watershed. The comparison of these two conditions (current existed condition and imagined contour ploughing with terracing) is shown in figure 4.8.

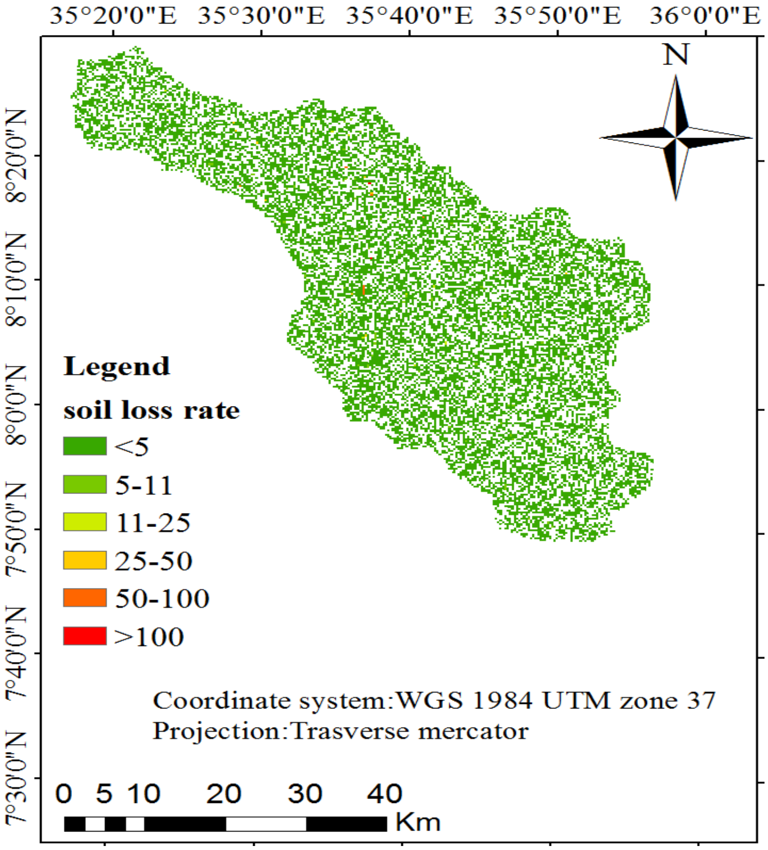


Figure 4.8 Considering the imagined management practice

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study was designed to estimate average annual soil loss rate in sor watershed, south west of Ethiopia, by employing the Revised Universal Soil Loss Equation along with GIS techniques. This study also endeavored to present an inclusive over view of the status of erosion and its distribution in the watershed under present watershed condition and with proposed watershed management practices. The result of this study specifies that the annual soil loss rate for existed conditions ranges from 0 to 330 t ha^{-1} yr^{-1} with average annual soil loss of 14.86 t ha^{-1} yr^{-1}. Such losses could threaten the sustainability of land productivity in the study area.

Applying conservation practice such as contour ploughing with terracing effectively could reduce the annual average soil loss by 42.3% (from 14.86 to 8.57 t ha^{-1} yr^{-1}). Results of the annual soil loss rates and the severity classes showed that almost the entire study area (74.71%) is classified under none to low and about 25.29% is classified under moderate to very severe soil erosion class. Depending up the model result, among the RUSLE parameters rainfall erosivity (R-factor) and slope-length (LS-factor) were the main causes for soil erosion rate in the study area.

The computed soil erosion rate was compared with previous estimates and reports of nearby areas in order to validate the result of this study, and found to be reasonable. The Darimu district was identified as a prioritization area for conservation. Therefore, predicted amount of soil loss and its spatial distribution could facilitate to implement a comprehensive and sustainable land management through conservation planning for the soil erosion risk areas in the study area.

Finally, the study demonstrates that the RUSLE together with geographic information system techniques provide useful tools to estimate erosion hazard over watershed and facilitate sustainable land management. It has given fairly reliable estimated soil loss rates. The method can thus be applied in other watershed for the estimation of average annual soil loss rates for the conservation and enabling efficient uses of limited resources.

5.2 Recommendations

Depending on the findings of this study, the following recommendations are forwarded.

- Further studies should be done to determine what conservation structure will be required for each severity classes to break the situation.
- A dedicated policy has to be developed by local authorities regarding the management of identified vulnerable micro-watersheds.
- Areas characterized by high to very sever soil loss should be given special attention before changed in to irremediable land degradation.
- Alternative income generating strategies should be applied for the farmers to increase the non-farm employment in order to decrease the need for additional farm land.

REFERENCES

Abate Shiferaw, (2011). Estimating soil loss rates for soil conservation planning in the Borena woreda of south Wollo highlands, Ethiopia. Journal of Sustainable Development in Africa Vol. 13, No.3, Clarion, Pennsylvania.

Adugna, A. and A. Cerda (2015) Soil erosion assessment and control in North-East Wollega, Ethiopia. Solid Earth Discuss, 7: 3511-3540.

AgWATER, (2012) Agricultural Water Management Learning and Discussion Brief, watershed management in Ethiopia,

Anderson, L. (2010), Soil Loss Estimation Based on the USLE/GIS Approach through Small Catchments - A minor field study in Tunisia. PhD Dissertation, Division of Water Resources Engineering, Department of building and environmental Technology, Lund University, Sweden.

Angima S, Stott, D, O'Neill, M, Ong, C, Weesies, G. (2003). Soil erosion prediction using RUSLE for central Kenyan highland conditions. Agricultural Ecosystem Environment. 97:295-308.

Arnoldus, HMJ., (1997): Methodology used to determine the maximum potential average annual soil loss due to sheet & rill erosion in Morocco, FAO, soil bulletin 34:39-48.

Ayalew, G and Selassie, Y. (2015), Soil Loss Estimation for Soil Conservation Planning using Geographic Information System in Guang Watershed, Blue Nile Basin. Journal of Environment and Earth Science.5 (1): 126 – 134.

Balasubramanian (2017), soil erosion cause and effect. Technical report

Beinroth,F.H., Eswaran,H., Reich,P.F. and Van Denberg,E, (1994): Land related stresses in agroecosystems. In stressed ecosystems and Sustainable Agricultural,eds. S.M. Virmani.J.C.Katyal,H. Eswaran, and I.P. Abrol.New Delhi:Oxford and IBH.

Berendse, F., van Ruijven, J., Jongejans, E., and Keesstra, S. (2012), Loss of plant species diversity reduces soil erosion resistance of embankments that are crucial for the safety of human20 societies in low-lying areas, Ecosystems, 18, 881–888, doi:10.1007/s10021-015-9869-6, 2015.

Beskow, S., Mello, CR., Norton, L, (2009), Soil erosion prediction in the Grande River Basin, Brazil using distributed modeling. Catena 79:49-59.

Bewket, E. and Teferi, E (2009), Assessment of Soil Erosion Hazard and Prioritization for treatment at the watershed level: Case Study in the Chemoga Watershed, Blue Nile Basin, Ethiopia. Land degradation & development, 20: 609-622.

Biesemans J, Meirvenne V., Gabriels D. (2000). Extending the RUSLE with the Monte Carlo error propagation technique to predict long-term average off-site sediment accumulation. Soil and Water Conservation. 55:35-42.

Blaikie, P and Brookfield, H. (1987), Land degradation and Society. London, 296

Blanco, H and Lal, R. (2008), Principles of Soil Conservation and Management. Springer, 1240.

Bobe Bedadi, (2004), Evaluation of soil erosion in the Hararge Region of Ethiopia using soil loss models, rainfall simulation and field trials, unpublished PhD, University of Pretoria, South Africa.

Buringh,P.(1989). Availability of agricultural land for crop and livestock production. Acadamic press, pp, 69-83

Conway, D. (2000), the climate and hydrology of the Upper Blue Nile. Geogr J. 166:49–62.

Dereje,T.(2005): potential soil erosion estimation and area prioritization for better conservation planning in Gumera watershed using RUSLE and GIS techniques. Research review

Dereje, T. (2015): Soil erosion and conservation in Ethiopia. Research review

Desta, S.B. (2014), Deforestation and a Strategy for Rehabilitation in Beles Sub Basin, Ethiopia. *Journal of Economics and Sustainable Development*. 5(15): 285-295.

Efe, R., Ekinci, D. and Curebal, I. (2008). Erosion Analysis of Sahin Creek Watershed (NW of Turkey) using GIS Based on RUSLE (3d) Method. Journal of Applied Science. 8 (1): 49-58.

El-Swaify, S.A and Hurni, H. (1996), Trans-boundary effects of soil erosion and conservation in the Nile basin. Land Husbandry 1: 6-21.

Eswaran, H., Lal, R. and Reich, P. F. (2001), Land degradation: an overview. Responses to Land Degradation. Proc. 2nd.International Conference on Land Degradation and Desertification. Oxford Press, New Delhi, India.

FAO, 2017, Voluntary Guidelines for Sustainable Soil Management Food and Agriculture Organization of the United Nations , Rome.

FAO (1965), Soil Erosion by Water: Some Measures for Its Control on Cultivated Lands. Rome.

FAO (1986), Ethiopian Highlands Reclamation Study. Final Report, Volume 1. FAO, Rome, 1-290.

FAO (1986), Highlands's reclamation study: Ethiopia. Final Report. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, (1996), Land husbandry - Components and strategy: FAO Soils Bulletin. Food and Agriculture Organization of the United Nations, Rome, Italy.

FDRE, Federal Democratic Republic of Ethiopia (2011). Ethiopia's climate-resilient green economy green economy strategy document. 22. Addis Ababa, November 2011. Retrieved 21July 2016, fromhttp://www.undp.org/content/dam/ethiopia/docs/Ethiopia % 20 CRGE.pdf.

Fistikoglu and Harman, (2002): Estimation of the rate of Soil erosion in the Tasik Chini catchment, Malaysia using the RUSLE model integrated with GIS. Australian Journal of Basic and Applied sciences 6(12):286-296

Fourenier's, (1960): Climate Erosion and Atmospheric precipitation. Press University, France,Paris.

Gelagay, H. Minale A. (2016), Soil loss estimation using GIS and Remote sensing techniques: a case of Koga watershed, North-Western Ethiopia. International Soil Water Conservation, 10.1016/j.iswcr.2016.01.002.

Gete Zeleke, Ahmed Amdihun, Ephraim Gebremariam, & Rebelo, L. (2014), Modeling Soil Erosion Dynamics in the Blue Nile (Abbay) Basin: A Land Scape Approach. Research Journal of Environmental Science, 8, 243-258.

Girma T, (2001): Land degradation: A challenge to Ethiopia. Environmental Management 27(6): 815-24

Haregeweyn, N., Nyssen, J., Meshesha, D.T., *et al.* (2015), Soil erosion and conservation in Ethiopia: A review. Progress in Physical Geography.1-25.

Haregeweyn, N., Tsunekawa, A. Poesen, J., *et al.*, (2017), Comprehensive assessment of soil erosion risk for better land use planning in river basins: Case study of the Upper Blue Nile River. Science of the Total Environment. 574:95-108.

Hurni, H. (1985), Soil Conservation Manual for Ethiopia. Ministry of Agriculture, Addis Ababa.

Hurni, H. (1988), Degradation and conservation of the resources in the Ethiopian highlands. Mountain Research and Development, 8 (2/3): 123-130.

Hurni H (1987), Erosion productivity conservation system in Ethiopia. In I placentae (Ed), soil conservation and productivity. Proc. Of the 4th Int. soil conservation conference. PP654-674.

Hellden, U. (1987), An assessment of woody biomass, community forests, land use and soil erosion in Ethiopia: A feasibility study on the use of remote sensing and GIS [geographical information system]-analysis for planning purposes in developing countries. Lund University Press.

Houghton, R. A. (1994). The Worldwide Extent of Land-Use Change. Global Impact of Land Cover Change, BioScience, 44 (5): 305-313.

Hudson, N. (1986), Soil conservation (Second Ed.). London: B.T. Batsford.

Julien, P.Y. (2010), Erosion and Sedimentation (2nd Ed.). Cambridge University Press.

Julien, A., Valentin, K. & Brice, S., (2011), Farmers' Perception and Response to Soil Erosion While Abiotic factors are the driving forces in Sudanian Zone of Benin. 1(2), Pp.20–30.

Kaltenrieder, J. (2007). Adaptation and validation of the Universal Soil Loss Equation (USLE) for the Ethiopian-Eritrean Highlands. Unpublished MSc. thesis. University of Bern, Switzerland.

Kebede, W. (2012b), Watershed management: An option to sustain Dam and Reservoir functions in Ethiopia. Journal of Environmental science and technology, ISSN: 1994-7887.

Keesstra, S. D., Geissen, V., van Schaik, L., Mosse. K., and Piiranen, S.: Soil as a filter for groundwater quality, Current Opinions in Environmental Sustainability, 4, 507–516, doi:10.1016/j.cosust.2012.10.007, 2012.

Kenneth G. Renard, George R. Foster, Glenn A. Weesies, and Jeffrey Porter (1991), Soil and water conservation 46(1):30-33 Journal of Soil and Water Conservation.

Khan (2014), soil degradation, conservation and remedies. University of chittagong.

Kim. U., Kaluarachchi, J., Smakhtin, V. (2008), Climate change impacts on hydrology and water resources of the Upper Blue Nile River Basin, Ethiopia. International Water Management Institute (IWMI) Research Report 126.

Lal, R. (Ed.). (1994), Soil Erosion Research Methods (2nd Ed.). St. Lucie Press.

Lal, R. (2001), Soil degradation by erosion. Land degradation Dev. 12:519-539.

Lal, R. (1995), Erosion-crop productivity relationship for soils in Africa. *American Journal of Social Science Society*.*59*:661-667.

Lu, D., Li G., Valladares, G. S., & Batistella, M. (2004). Mapping Soil Erosion Risk in Rondoˆ Nia, Brazilian Amazonia: Using RUSLE, Remote Sensing and GIS. Land Degradation and Development, 15, 499–512.

Mengistu, D. Bewket, W. and Lal, R. (2015), Soil Erosion Hazard under the Current and Potential Climate Change Induced Loss of Soil Organic Matter in the Upper Blue Nile (Abay) River Basin, Ethiopia. Reaearch Gate.137-163.

Merritt, W. S., Letcher, R. A. and Jakeman, A. J. (2003), A review of erosion and sediment transport models. Environmental Modelling & Software, 18: 761-799.

Millward, A. A. and Mersey, J. E. (1999), adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena, 38: 109-129.

Mitiku (2006), Sustainable Land Management: A New Approach to Soil and Water Conservation in Ethiopia. Article.

MoARD, (2005) Ministry of Agriculture and Rural Development, Ethiopia's Agricultural Sector Policy and Investment Framework (PIF) 2010–2020. Draft Final Report: 39.

Moore, I.D., Burch, G.J. (1986), Physical basis of the length-slope factor in the universal soil loss equation. Soil Sci. Soc. Am. J. 50: 1294-1298.

Morgan, R. P. C. (2005), Soil erosion and conservation book, Third edition. Blackwell: Malden.

Morgan, R. P. C., 1995 (1995), Soil Erosion and Conservation. Edinburgh: Addison-Wesley Longman. Earth Surface Processes and Landforms, Vol. 23, 1998, pp. 527-544.

Norazian, M. (2013): Roles of imputation methods for filling the missing values. Advances in environmental Biology 7(12): 3861-3869.

Oldeman, L.R. (1992), Global Extent of Soil Degradation. International Soil Reference and Information Centre.

Oldeman, L. R. (1998), Soil Degradation: A Threat to food Security International soil reference and information center, Wageningen, Report: 98-01.

Omuto,(2008): Assessment of soil physical degradation in Eastern Kenya by use of sequential soil testing protocol. Agricultural ecosystem & environment 128(4): 199-211.

Paulos, D. (2001), Soil and Water Resources and Degradation Factors Affecting their Productivity in the Ethiopia Highland Agro-ecosystems, International Conference on African Development Archives, Western Michigan University.

Pimentel D. (2006), Soil Erosion: A Food and Environmental Threat. Environment, Development and Sustainability, 8,119-137.

Rapidel, B., DeClerck, F., Le Coq, J.F. & Beer, J. (2011), Ecosystem Services from Agriculture and Agroforestry: Measurement and Payment. Earth scan.

Renard, K.G., Foster, G. R., Weesies, G.A., McCool, D.K. & Yoder, D.C. (1997), Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Research Service Handbook 703, 1-384.

Reusing M,Schnieder T, & Ammer U,(2000).Modeling soil erosion rates in the Ethiopian high lands by integration of high resolution MOMs-02/02-streao-data in GIS, international journal of remote sensing,21(9).

Robert, P and Hilborn, D. (2000). Factsheet: Universal Soil Loss Equation (USLE).Index No-572/751, Queen’s printer for Ontario.

RosewellCJ,(1999). Soil conserved water quality; an agenda for agriculture. National academy press, Washington DC.

Semu A. The impact of soil and water conservation for improved agricultural production in Ethiopia. Agri. 2018; 1(1):9-12. Review article.

V. Shinde, K.N. Tiwari, M. Singh, (2010): Quantitative Determination of Soil Erosion and Prioritization of Micro-watersheds using Remote Sensing and GIS. Journal of the Indian society of Remote sensing 39(2): 181-192.

Shinn, G.J.(1999). “The analysis of soil erosion analysis in watershed using GIS’’. PHD.Dissertation, department of civil engineering, Gang-Won National University.

Simms, A. Woodroffe, C. D and Jones, B. G. (2003), Application of RUSLE for Erosion Management in a coastal catchment, Southern NSW, Proceedings of MODSIM, International Congress on Modelling and Simulation, volume 2, pp. 678-683.

Solomon, A. Bantider,Berhanu Debele,Ludi,E.,Portner,B.,Birru Yitaferu, Gete Zeleke and Hurni (2010), Land degradation and sustainable land management in the highlands of Ethiopia:. Global change and sustainable development: A synthesis of regional experience from research partnership. Perspectives of the Swiss National Center of Competence in Research (NCCR) North South, University of Bern, Bern, Switzerland, Geographic Bernensia, 5: 187-207.

Stringer, L. C. (2012) Global land and soil degradation challenges to soil. Article.

Tadesse, A. Abebe M (2014), GIS based soil loss estimation using RUSLE odel: the case of Jabi Tehinan Woreda, ANRS. Ethiopia. Natural Resource 5: 616-626.

Temesgen, G. Taffa T. and Mekuria A. (2017), Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia, Environmental systems research, 6:1.

Toy, T.J., Foster, G.R. & Renard, K.G. (2002), Soil Erosion: Processes, Prediction, Measurement and Control. John Wiley & Sons.

Vanost, K. K.,Govers, G. G.,de alba, S. S., Quine, T. A. (2006). "Tillage erosion: a review of controlling factors and implications for soil quality". Progress in Physical Geography, 30 (4): 443-466.

Vrieling, A. (2007), Mapping Erosion from Space. Doctoral Thesis Wageningen University – with ref. – with Summaries in English and Dutch. ISBN:, 978-90-8504-587-8.

Wijitkosum, S., (2012).Impacts of Land Use Changes on Soil Erosion in Pa Deng Sub-district, Adjacent Area of KaengKrachan National Park, Thailand.Soil & Water Res., (1): 10-17.

Winterbottom, R., Reij, C., Garrity, D., Glover, J., Hellums, D., Mcgahuey, M. & Scherer, S. (2013), Improving Land and Water Management. World Resources Institute Working Paper, 1-43.

Wischmeier, W.H. & Smith, D.D. (1965), Predicting Rainfall- Erosion Losses from Cropland East of the Rocky Mountains: Guide for Selection of Practices for Soil and Water Conservation. USDA Agriculture Research Service Handbook 282, 1-47.

Wischmeier, W.H., and Smith, D.D. (1978), Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. USDA Agriculture Research Service Handbook 53, 1-58.

Wischmeier W and D.D. Smith, (1965), Predicting rainfall-erosion losses from crop land east of the Roc and Mountains-a guide for selection of practices for soil and water conservation. Agricultural Handbook 287, pp. 47-53

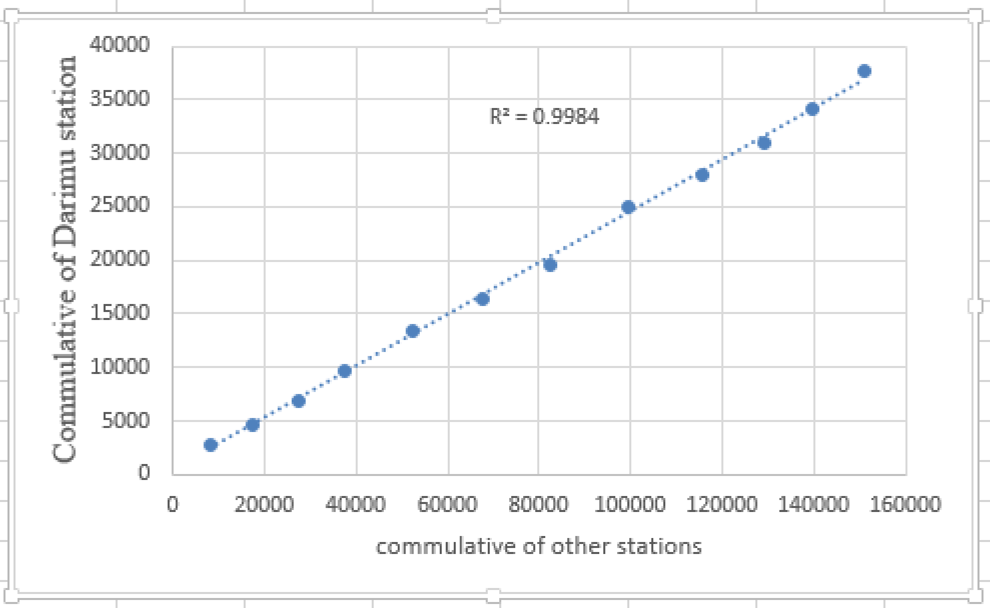
Wischmeier. W. H., and Smith, D. D., (1978), Predicting Rainfall Erosion Losses: A Guide to Conservation planning, agriculture Handbook 537, Washington D.C: US, Department of Agriculture, P-58.

Woldeamlak and Bewket (2003), Land degradation and farmers' acceptance and adoption of conservation technologies in the Digil watershed, northwestern highlands of Ethiopia. Social Science Research Report Series no. 29, OSSREA, Addis Ababa, Ethiopia.

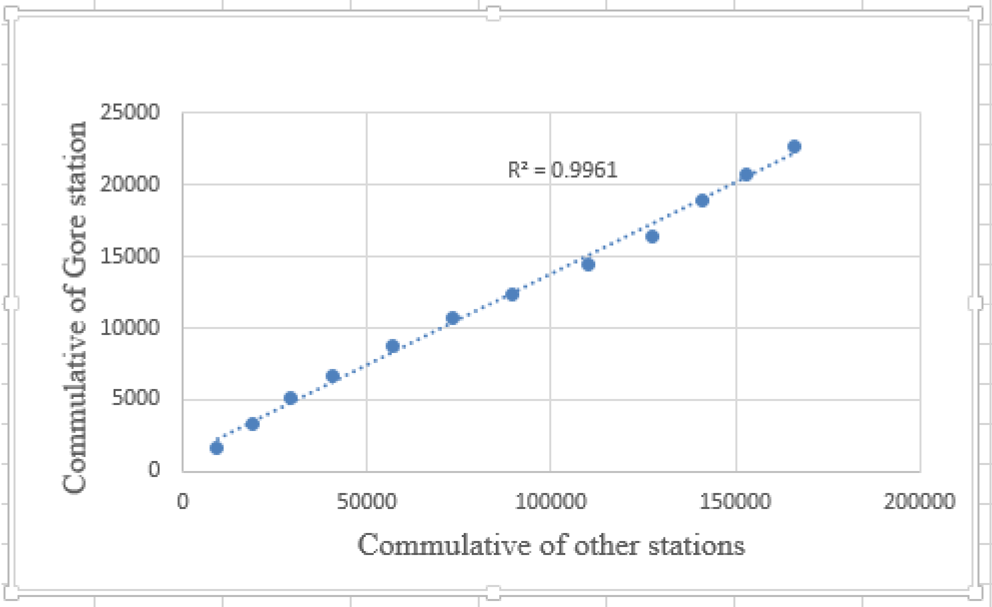
Zeleke and Hurni, H. (2001), Implications of land use and land cover dynamics for Mountain Resource Degradation in the Northwestern Ethiopian highlands. Mountain Research and Development, 21(2), 184-191.

APPENDIX

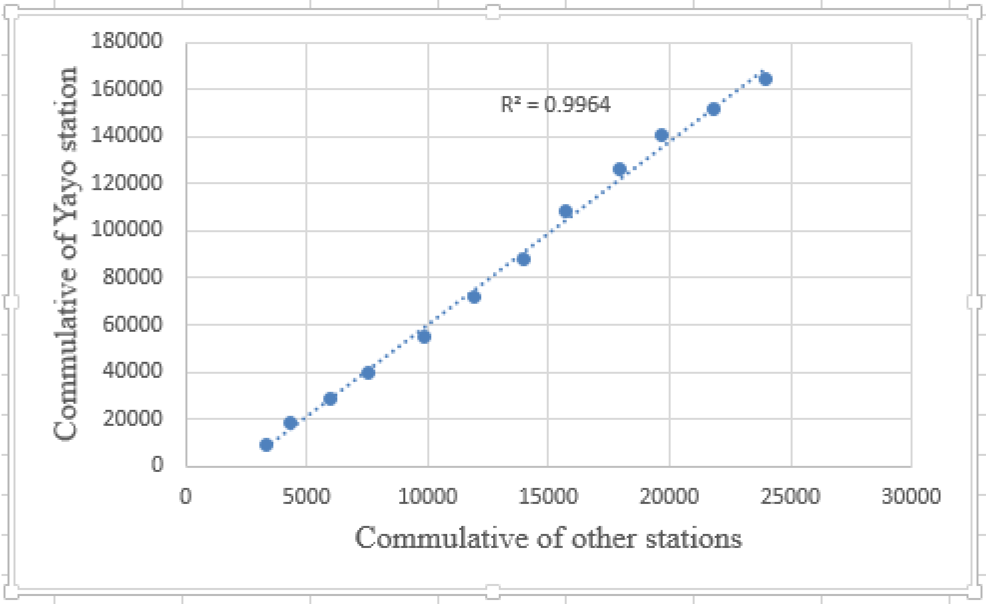
Appendix 1: Graph showing consistency of rainfall data of Darimu station



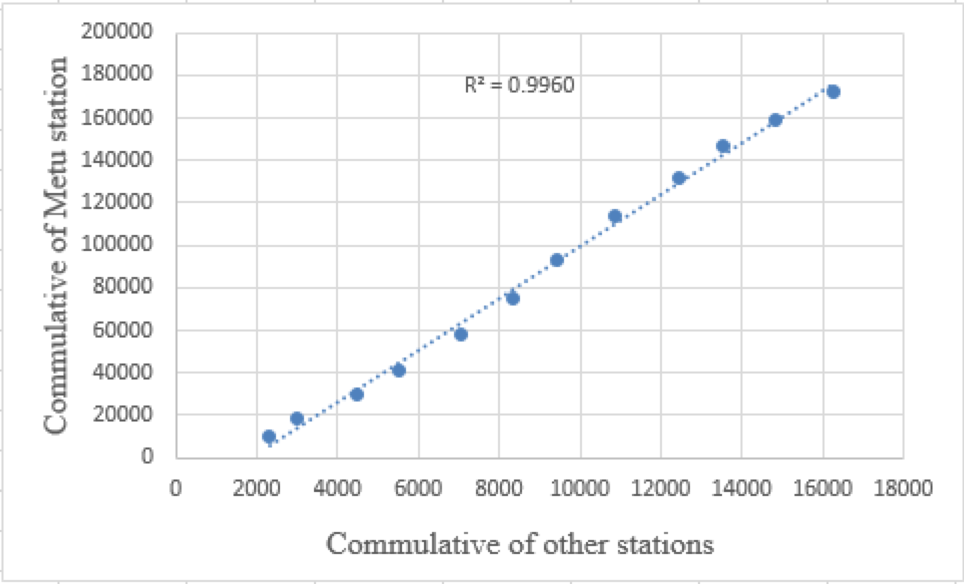
Appendix 2: Graph showing consistency of rainfall data of Gore station



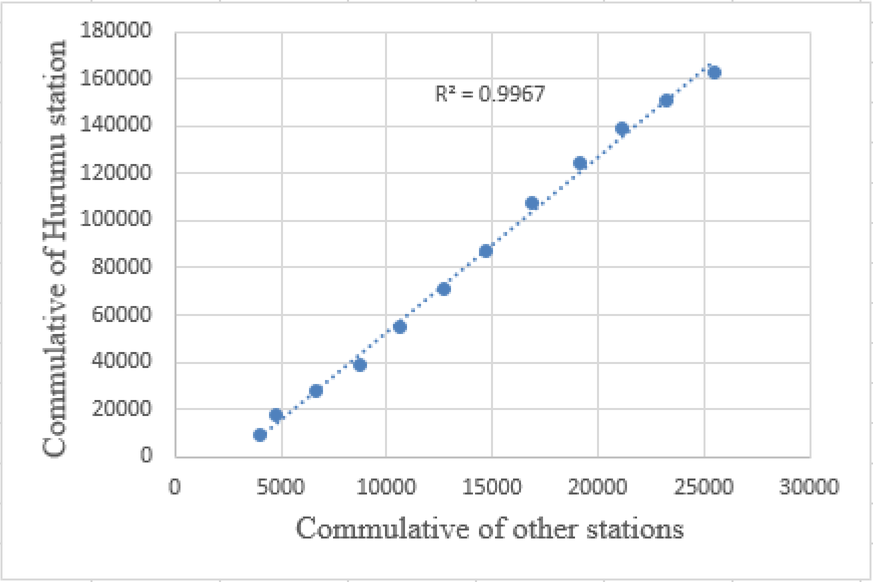
Appendix 3: Graph showing the consistence of rainfall data of Yayo station



Appendix 4: Graph showing the consistence of rainfall data of Metu station



Appendix 5: Graph showing the consistence of rainfall data of Hurumu station



Appendix 6: Graph showing the consistence of rainfall of Alge station