JIMMA UNIVERSITY

SCHOOL OF POSTGRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Estimation of Annual Soil Loss Rate from Hangar River Watershed Using RUSLE through the Application of GIS Technique

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

By: Mahmud Mustefa

January, 2018

Jimma, Ethiopia

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By: Mahmud Mustefa

Main Advisor: Dr. Eng. Fekadu Fufa

Co-Advisor: Mr. Wakjira Takala

DECLARATION

I hereby declare that this thesis titled "Estimation of Annual Soil Loss Rate from Hangar River Watershed Using RUSLE through the Application of GIS Technique" has been carried out by me under the guidance and supervision of my Advisors Dr. Eng. Fekadu Fufa and Mr.Wakjira Takala. The thesis is original and has not been submitted by others and for any university or institutions.

Researcher's Name	Signature	Date
Mahmud Mustefa	______________________	January, 2018

Advisors' Name	Signature	Date
Dr. Eng. Fekadu Fufa	______________________	January, 2018
Mr. Wakjira Takala	______________________	January, 2018

As thesis research advisors, we hereby certify that we have read and evaluated this thesis, and prepared under our guidance, by Mahmud Mustefa, entitled "Estimation of Annual Soil Loss Rate from Hangar River Watershed Using RUSLE through the Application of GIS Technique" and we recommend that it can be submitted as fulfilling the thesis requirement.

Advisors' Name	Signature	Date
Main Advisor		
Dr. Eng. Fekadu Fufa	______________________	November, 2017
Co-Advisor		
Mr. Wakjira Takala	______________________	November, 2017

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 Mahmud Mustefa 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.

ACKNOWLEDGMENT

First of all, I would like to thank the almighty God, for the accomplishments of this work and all good and bad things in my life. Then, I wish to express my deepest gratitude to my main advisor Dr. Eng. Fekadu Fufa and co- advisor Mr. Wakjira Takala for their guidance, advice, criticism, encouragements and motivation during this study. My sincere appreciation also goes to the Ministry of Water and Energy, National Meteorological Authority and to all my instructors and staff members of the department of Hydraulic and water resource engineering for sharing their experience, materials and valuable cooperation throughout my study. All of my friends, I will never forget your support and love during the study time and my entire life. Finally, my grateful thanks belong to my families, for their moral support and belongingness throughout the study.

ABSTRACT

Ethiopia has been described as one of the most seriously affected nation in the world by soil erosion. Several studies indicate the existence of sever soil erosion problem in different parts of the country. This erosion problem has on-site and off-site effects. The study area, Hangar River watershed, which is a sub catchment of Didesa River Basin, shares this sever erosion problems. Hence, the aim of this study is to estimate the spatially distributed mean annual soil loss rate and mapping of the vulnerable areas in the watershed using the Revised Universal Soil Loss Equation (RUSLE) adopted for Ethiopian conditions with the aid of Geographical 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. In order to quantify the soil loss rate in the study area, spatial and non-spatial source of data were used as an input. A digital elevation model (DEM) with 30 x 30 meter resolution was implemented for catchment delineation and analysis of the LS-factor of the study area. The land use/ land cover map of 2013 was used for the analysis of C-factor and the Soil map of the study area was also used for the analysis of the K-factor. The analysis of R-factor was derived from mean annual rainfall data of the nearby rain gauge stations. Eventually, each of the RUSLE factors, with associated attribute data were digitally encoded in a GIS database to create five thematic map layers of each factor. By integrating these five map layers in GIS raster calculator, the required spatially distributed annual average soil loss rate was determined. Accordingly, the result of the analysis for the existed conditions depicted that the amount of soil loss from the study area ranges from 1 to 500 t ha^{-1} yr^{-1} *with average annual soil loss rate of 32* t ha^{-1} yr^{-1} *from the whole catchment. About 84.2 % of the total area experienced soil loss above tolerable limit of 11* t ha^{-1} yr^{-1}. *The total annual soil loss from the entire watershed area of* 7790 km^2, *was about* 24.93 Mtons. *It shows that, it could be difficult to maintain the sustainability of the soil productivity if the specified amount of soil is removed annually. 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 32 to 19.2 t* ha^{-1} yr^{-1}. *Hence, applying the specified watershed management reduces the vulnerability of the watershed by 40 %. Based on the result, most critical soil erosion areas were situated in the steepest upper part of the watershed due to intensive agricultural activities on the specified part of the watershed. Hence, this area needs immediate and appropriate intervention of soil conservation measures.*

Key words, G Annual soil loss rate; GIS; Hangar River watershed; RUSLE; Soil erosion

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ACRONYMS

CREAMS	Chemical Runoff and Erosion from Agricultural Management Systems
DEM	Digital Elevation Model
DUSLE	Differentiated universal soil loss equation
EMA	Ethiopian mapping agency
EUROSEM	European Soil Erosion Model
FA	Flow accumulation
FAO	Food and Agricultural Organization
FD	Flow direction
FDRE	Federal democratic republic of Ethiopian
GIS	Geographic Information System.
IDW	Invers distance weight
KINEROS	Kinematic Erosion Simulation
LISEM	Limburg Soil Erosion Model
LS	Slope Steepness and Slope Length Factor
Mha	Million hectare
Mtons	Million tons
Mm	Millimeter
MoWIE	Ministry of Water, Irrigation and Energy
MoARD	Ministry of Agriculture and Rural Development
MW	Megawatt
OWWDSE	Oromia water woks design and supervision enterprise
RUSLE	Revised universal soil los equation
$t\ ha^{-1}\ yr^{-1}$	Ton/ hectare/ year
USGS	United States geological survey
WEAP	Water Evaluation and Planning

1. INTRODUCTION

1.1. Background

Soil erosion is a natural process resulting from the removal of soil particles from the surface of the earth by water and wind, transporting and depositing elsewhere (Hurni, 1988). And it is one of the reasons of soil degradation which leads to the deteriorations of physical, chemical and biophysical properties of the soil (FAO, 1978).

The action of soil erosion is triggered by a combination of factors such as steeply slopes, heavy rainfall after long dry period, inappropriate use of land cover patterns and ecological disasters (Oldeman, 1998). Moreover, some intrinsic features of a soil can also make it more prone to erosion. such intrinsic features are a thin layer of topsoil being silty textured and low organic matter content (Kosmas, 1997).

Soil erosion is one of the biggest global environmental problems resulting both on-site effects such as; loss of top fertile soil, minimize water holding capacity of the soil, nutrients and minerals carried off by water and off-site effects such as; silting up of reservoirs, disruption of lake ecosystems, contamination of drinking water and increased downstream flooding (Tamene and Vlek, 2008). Even though these effects have been identified as a global problem in the 20th century, the trend of Soil erosion has continued to increase throughout the whole nation (Adugna *et al*., 2015). Studies show that in the whole globe, about 80 % of agricultural lands suffered from moderate to severe soil erosion which is a cause of loss of productivity of agricultural lands (Hurni, 1998; Gete, 2000). Pimentel *et al.* (2009) and Jahun (2015), also reveal a shocking figures about the erosion phenomenon, that is, most of the soil from farmlands is washed away about 10 to 40 times faster than it is being replaced, citing examples that in some parts of United States was losing a soil of 10 times faster than the regular replacement rate. On the other hand, Pimentel *et al.* (2009) and Jahun (2015) present that, China and India are also said to be losing soil of 30 to 40 times faster than its formation.

In Ethiopia, a number of studies indicate the existence of sever soil erosion in the highland areas and sedimentation in the low land areas of the country (Bewket and Teferi, 2009; Kebede *et al*., 2015). For instance some of the evidence research shows that an average annual soil loss rate of 35 t ha^{-1} yr^{-1} (FAO, 1986); 42 t ha^{-1} yr^{-1} (Hurni, 1993) and 57t ha^{-1} yr^{-1} (Girmay, 2009) were reported. In addition to this, other researches also show that soil erosion rate ranges from 16 to

300 t ha^{-1} yr^{-1} (Hurni, 1986) and 130 to 170 t ha^{-1} yr^{-1} (Gete, 2000) in the highland areas of the country. Related study also indicates the existence of sever problems on agricultural lands due to removal of fertile soil and sedimentations on the water bodies and reservoirs in Ethiopia (Kebede, 2012). The study area, Hangar River Watershed, is one of the catchments suffering with this sever soil erosion problem as well (Jemal, 2010).

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). 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).

The severity of soil erosion in Ethiopia is due to most part of the country is being steep sloped and mountainous, and the existence of higher and frequent rainfall amount with higher intensities. In addition 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). Loss of fertile soil, rapid degradation of natural systems, significant sediment depositions in the lakes and reservoirs and sedimentation of irrigation infrastructures are generally, due to poor watershed management system in the country (Akalu *et al*., 2009).

The main River in the study area (Hangar River) is one of the major tributaries of Didesa River, which finally joins to Blue Nile River. This River has a length of more than 200 km and has its own medium scale tributary rivers, which consists of 11sub-catchments larger than 500 km^2 each. The exposure to erosion and Sediment contribution from those tributary Rivers varies depending up on the existed situation of the sub-catchments. Therefore, conducting this research contributes to identify the most sever soil erosion areas in the specified catchment. Knowing and identifying the most prone area, is very important to take interventions measures in line with the identified erosion vulnerable area.

In order to predict and evaluate soil erosion quantitatively, different prediction models have been efficiently developed and employed by different soil scientists in the last few decades (Gelagay and Minale, 2016). Using these models now a day different researches are undertaken in different parts of the world to estimate the rate of soil erosion and mapping of erosion risk areas.

One of the most widely used empirical models is universal soil loss equation (RUSLE), with remotely sensed data and GIS software (Renard *et al*., 1997). 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.

Among the soil loss estimation models, only few are used to measure soil loss in Ethiopian conditions, because of data limitations. One of these few 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). Even though, this model has been developed after the parameters are tested and validated under diverse soil, climate and management conditions of United State of America, several efforts have been made to calibrate and validate the use of RUSLE model for other countries including Ethiopia. Among those studies for instance (Hurni, 1988; Helden, 1998; in Ethiopia; Angima *et al.*, 2003 in Kenya; Prasannakumar *et al.*, 2012 in India). Specifically as sited by Alemayehu (2012), Mulugeta, 2004 has calibrated RUSLE for Andit Tid watershed while Serkalem (2005) for Mayebar and Mesfin (2008) for Anjeni watersheds in Ethiopia. In all these studies RUSLE was publicized that the model shows satisfactory result. Therefore, this research aimed to quantify the amount of annual soil loss rate from Hagar 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. Statements of the problems

Ethiopia has been described as one of the most seriously affected nation in the world by soil erosion (Hurni, 1988; Mitiku *et al*., 2002; Gizachew, 2015). Soil erosion and sediment yield from catchments are therefore key limitations to achieve sustainable land use and maintaining water quality in rivers, lakes and other water bodies (Benedict and Andreas, 2006).

Many of Ethiopia's hydroelectric power and irrigation reservoirs such as Aba-Samuel, Koka, Angereb, Melka Wakena, Borkena, Adarko and Legedadi have been threatened by the heavy sedimentation. Therefore, these dams have been suffered from reduction in their capacity and life span, quality of water and require costly operation for removal and operation and thus these dams loss their intended services (Kebede, 2012; Gelagay, 2016).

The degradation of large part of the Ethiopian highlands has reached a scale where it has become increasingly difficult even to maintain the current level of production of basic food which is already insufficient in many regions of the country (Bekele, 1998). Hence, Soil erosion affects the socio-economic condition of a country directly or indirectly; especially countries like Ethiopia whose economy is extremely dependent on agriculture (Angima *et al*., 2003; Abate, 2011). Therefore, the economic implication of soil erosion is more serious in such countries because of the capacity to cope with it and also to replace the lost nutrients. As sited in Gashaw *et al*. (2017), Sonneveld and Keyzer (2003) estimates through modeling work and suggests that soil erosion in Ethiopia will reduce the potential production of the land by 10% in 2010 and by 30% in 2030. As a result, the value added per capita per annum in the agricultural sector goes down from US$372 in 2010 to US$162 in 2030.

The top fertile soil which is naturally abundant resource plays a vital role for the agricultural productivity. But, the removal of this top fertile soil leads to reduction in crop production. This reduction of crop production results in poverty on the major population in the country. At the same time, sedimentation problems occur in the water bodies and reservoirs and minimize the life span of reservoirs (MoARD, 2010).

Studies conducted by using Water Evaluation and Planning (WEAP) model, and assessed the future potential of irrigation and hydropower in Blue Nile River Basins shows that, Hangar River has a potential of developing more than 14000 ha of irrigation and 1.8 to 9.6 MW of hydroelectric power (Matthew *et al*, 2005). Accordingly, Federal Government of Ethiopia (FDRE) has a plan of implementing this project. However, the large part of this area is degraded due to deforestation for intensive agricultural activities like; farm expansion, extraction of fuel, constructional wood, overgrazing and for other related purpose which are the consequences of population growth and expansion over the area, as other parts of the country. Now a day agricultural lands in the study area is less productive due to soil degradations. Farmers use different fertilizers for agricultural lands in order to compensate some of the lost nutrients in the soil due to soil erosion, which is costly. This condition was seen during site visit. According to FAO (1986), Rapid population growth, cultivation on steep slopes, clearing of vegetation, and overgrazing are the main factors that accelerate soil erosion in Ethiopia. These, the damages associated with excessive soil erosion problem thought to be severe in this area as there are intensive agricultural activities, rapid population growth, cultivation on steep slope and related activities mentioned by FAO (1986) are common on the study area. Therefore, this study was done to estimate the annual soil erosion rate and add the soil erosion information for the decision makers to plan appropriate soil Conservation practice in the watershed so that reducing fertile soil loss from farm lands and sedimentation in the proposed multi-purpose hydraulic structure on Hangar River.

1.3. Objective of the study

1.3.1. General objective

The general objective of this study is to predict the annual soil loss rate from Hangar River watershed using RUSLE through the application of GIS techniques.

1.3.2. Specific objectives

The specific objectives of this study are:

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

1.4. Research questions

The research questions which were addressed in this particular study were:-

1. At which part of the study area, each RUSLE factor has significant contribution to soil erosion?
2. How much is the annual average soil loss rate of the study area in existing condition?
3. If the watershed management (terracing and contour ploughing) were fully developed, by how much would be the erosion rate reduced?
4. Which part of the watershed is highly affected by soil erosion?

1.5. Significance of the study

The result of this study makes the intervention measure timely and cost effective for stakeholders by providing the annual average soil erosion rate at district level. On the other hand, the result of this study, would also add for annual soil loss rate literature of North West region of Ethiopia, specifically to Blue Nile River Basin.

Modeling the annual soil loss rate of this catchment has also irreplaceable assist for designers of the hydraulic structure and decision makers. Moreover, figuring out of the amount of soil being eroded from the catchment is a crucial issue for designing and implementations of appropriate soil and water conservation practices and technology interventions in the catchment. Besides, the outcome of the study may serve as the comparison of other methods or approaches of modeling soil loss rate other than RUSLE/GIS technique.

1.6. Scope of the study

This study was a watershed level study and focuses mainly on the estimation of annual average soil loss rate due to water erosion, identification of the most vulnerable region in the watershed. The study watershed covers an area of 7740 km^2. In this study, the effects of fully developed terracing with contour ploughing on soil erosion rate were also evaluated. This task was done by the use of RULE model with GIS technique.

1.7. Organization of the research

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

1.8. Limitations of the study

Though, the study has a significant role in providing the information about the status of soil erosion of the study area in order to plan and implement an environmental protection programs on time, it has also some limitations. Among the limitations, the soil erosion prediction model

(RUSLE) applies only for water erosions; like sheet and reel erosions. Hence, it doesn’t consider soil erosion due to land slide and mass movements of soil. The model also neglects certain interactions between RUSLE factors in order to distinguish more easily the individual effect of each. Among the significant constraints, getting the most recent Landsat image was also one of the difficulties.

2. LITERATURE REVIEW

2.1. Soil erosion

Soil is a very complex medium which displays a great diversity in physical appearance, in chemical process and formations (Hurni, 199). It is vital resource to maintain healthy environment. But this resource is a non- renewable natural resource in which it couldn't replace in short period of time and very expensive either to reclaim or to improve the fertility and composition once it is physically degraded or chemically depleted (Oldeman, 1998).

Soil erosion is a natural process in which mainly consists of two-phases. These, the detachment of individual soil particles from the earth surface by erosive agent such as rain drop impact and overflow impact and transports of the soil particle by transporting agent such as running water and wind (Pimentel, 2006). When sufficient moving energy is no longer exists to transport the soil particles, a third phase, deposition occurs (Morgan, 2005). Resulting this, the effect of soil erosion has two significant effects on a given area; on-site and off-site effects. On-site effects are directly related to land resource degradation including loss of fertile soil, losses of organic matter, soil structure degradation, losses of nutrient, soil surface compaction, reduction of water infiltration, increase of coarse soil fraction, plant uprooting. whereas, the off-sit effects including; silting up of dams, disruption of lake ecosystems, contamination of drinking water and increased downstream flooding (Casanovas *et al*, 2006).

Water, wind, chemical degradation and physical degradation are causative agents for Soil erosion and degradation to takes place. Each form of land and soil degradation occurs both individually and in combination with each other. Loss of chemical encompasses the loss of nutrient and organic matter, salinization and acidification while physical degradation includes disintegration of soil fragments (Stringer, 2012). But the main contributor for soil erosion and transportation are water and wind. Out of these, wind erosion is a widespread phenomenon of arid and semi-arid climatic zone (Oldeman, 1998). In case of Ethiopia, in which the most part is mountains, soil degradation due to water erosion remains a major threat to sustained agricultural production (Solomon *et al*., 2010). Therefore, considering this fact, the research was conducted to assess the vulnerability of soil erosion that caused by water.

Research on soil erosion and degradation topic has a long scientific history and the underlying fundamentals of soil erosion processes have been investigated for many decades. But the research is still increasingly ongoing and focuses on very detailed topics of soil erosion processes as well as its modeling. Parallel to the detailed modeling of physical processes, such as the splash effects of water, strong efforts were undertaken to develop universally applicable soil erosion models. Among these erosion prediction models, RUSLE is the most widely used empirical model (Farhan *et al*., 2013; Adugna e*t al*., 2015).

2.2. Types of Soil erosion by water

The process of Soil erosion by water starts from detachment of soil particles by raindrop impact then transportation by the force of flowing water (Wischmeier and Smith, 1978). And when the flowing water losses its transportation energy, deposition occurs (Morgan, 2005). Depending on the stage of progress in the erosion process and the position in the landscape, there are various forms of soil erosion by water. Splash erosion, sheet erosion, rill erosion and gully erosions are the major ones (Mitiku, 2006).

Rain splash erosion is the first stage of erosion process. It occurs when rain falling directly on to the ground during rainstorms or intercepted by the canopy and make contact with the ground. Some of the water infiltrates into the soil, while some water stays on the surface, saturating it and weakens the natural soil aggregates and breaks them down so that facilitated to move with flowing water (Morgan, 1995).

Sheet erosion is characterized by removal of thin uniform uppermost surface layer of soil particle by surface runoff (sheet flow of water). This Surface runoff forms when the rainfall intensity of a storm exceeds the infiltration capacity of the soil (Morgan, 1995). During sheet erosion, the entire surface of the field is gradually eroded uniformly. According to Hurni (1983), sheet and rill erosions are the most hazardous forms of soil erosion in which resulting steady degradation of large areas under cultivation. When the sheet flow of water becomes more and more, it starts to concentrate and forms a rill flow.

Rills are micro-channels which will develop when surface water concentrates in a depression (Nyssen, 2006). Thus, rill erosion is the removal of soil particle by this concentrated flow of water along the formed small channels. It is more common in bare agricultural land, particularly overgrazed land, newly cultivated soil; where the soil structure has been loosen. The rills are shallow drainage line less than 30 cm deep and can usually be removed with farm machineries and tools (Nyssen, 2006). Rill erosion can be reduced by reducing the volume and speed of surface water with grassed waterways and filter strips, ripped mulch lines, and contour drains. Such erosion is often described as the intermediate stage between sheet erosion and gully erosion (Jenkins, 2002).

Gully erosion is formed when runoff water accumulates and often recurs in narrow channels and removes the soil from this narrow area to considerable depth (larger than 50 cm). It can be formed from rill erosion through gradual deepening and expansion (Nyssen, 2006).

2.3. Factors affecting soil erosion

The magnitude of rate of soil erosion is affected or controlled by different factors. Broadly these factors are two types, human induced factors and natural factors. Climatic factor, topographic factors and soil properties factors are categorized under natural factor affecting soil erosion. Vegetative cover factor and watershed management practice factors are categorized under human activities factors (Costick, 1996a). However, these factors are dependent on each other, as geology affects topography, which can influence the climate as well (Costick, 1996b).

2.3.1. Climatic factor

Different climatic variables including rainfall, wind and temperature have influence on soil degradation. From these variables, rain fall amount and intensity is one of the major climatic factors that contribute for soil degradation (Nill *et al*., 1996).When raindrops act upon the soil particles, the soil particle will detached from the parent granular surface of the earth and starts to move with over land flowing water. Therefore, as the intensity of rain drop increase, the resulting soil loss will increase by the detaching power (kinetic energy) of raindrops striking the soil surface and through the contribution of rainfall to runoff (Abiy, 2010). Thus, Erosivity is the capacity or capability of rain drops to produce detachment and movement of soil particle, due to kinetic energy of the rain drops on the soil surface (Renard *et al.,* 1997).

This phenomenon is included in the RUSLE equation as it is one of the causative agents of soil erosion and known as R-factor. A period of above 20 years average rainfall data of more than five selected rainfall stations in the catchment is recommended to compute the average erosivity factor (Farhan, 2013). Difference in the R-factor values reflects difference in rain fall intensity patterns between different regions. Different research has been attempted to conduct on rain fall intensities and erosivity for Ethiopian Highlands. For instance, the study by Nyssen *et al*, (2005) shows the relations between the rain fall intensities and erosivity for Northern Ethiopian Highlands.

2.3.2. Soil properties factor

Due to naturally inherent property of soil, different soil types affected by erosion differently.
Thus, Soil properties such as soil texture, structure, soil roughness, organic matter content and chemical and biological characteristics of soils make differ in erosion resistance capacity (Vrieling, 2007). Hence, this capacity is termed as soil erodibility factor (K-factor) which refers to the resistance or capability of the soil against erosion by different erosion agents (Morgan, 1995). According to Saaverda (2005), soils having faster infiltration rates, higher levels of organic matter and improved soil structure, have a greater resistance to erosion. It means, such soil characterize with low K-factor values. Generally, Soils with high clay content have low K-factor values, because they are resistant to detachment. And Soils which are coarse textured, such as sandy soils also have low K-factor values, this is because of low transportability even though these soils are easily detachable. Medium textured soils, such as silty-loam soils, have moderate K-factor values, because they are moderately susceptible to detachment and transport. Soils having high silt content are the most erodible of all soils as they are easy to detach the particle and cause a decrease in infiltration and easy to transport (Petter, 1992). Generally, soil erodibility (K-factor) values rated from 0 to 1. Zero refers to soils with least susceptible to erosion, whereas 1 refers to soils which are highly susceptible to erosion by water (Helden, 1987). The erodibility factor is included in RUSLE equation as one of the factor affecting the soil erosion condition (Renard *et al.*, 1997).

2.3.3. Topographic factor

Topographic factor that influence soil erosions are slope length, slope steepness and shape (concavity and convexity) (Morgan, 2005). Erosion would normally be expected to increase with increase in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff (Deore, 2005). Accordingly, Steeper surface slope causes higher runoff velocities, more splashes downhill and faster flow and therefore, contributes greater soil erosion.

The topographic factors or slope length and slope steepness factor have been considered as one of the major erosion contributing factor in RUSLE model and represented as LS-factor (Renard *et al*., 1997).

2.3.4. Land use land cover factor

Land cover and human activities on the land cover, is one of the most crucial factors in reducing or increasing soil erosion (Wijitkosum, 2012). The vegetation cover reduces soil erosion by protecting the soil against the action of direct falling and contact of raindrops, increasing the degree of infiltration of water into the soil, reducing the speed of the surface runoff, binding the soil particles by the roots of the cover plants and maintaining the roughness of the soil surface, and improving the physical; chemical and biological properties of the soil (De Asis and Omasa, 2007). To consider this ground cover effect 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).

2.3.4.1. Land use land cover change

Land use land cover changes takes two forms; conversion from one category of land use to other type of land use and modification of condition within a category (Meyer and turner, 1992). Hence, changes in land use reflect the history of humankind and linked with economic development, population growth, technology, and environmental condition of society (Houghton, 1994). Now a day, land use land cover change is a significant driving agent of global environmental change. 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). Thus, the increase in human population and distribution is the major cause of land cover change through time, rendering the soil to be left bare and more susceptible to erosion (Da Silva, 2008).

2.3.5. Watershed management practice factor

Watershed management practice, especially in agricultural areas, such as contouring, strip cropping, stone and earthen bunds and terracing, highly reduce soil degradation by reducing slope length (Oldeman, 1992). For instance, in the areas where there is terracing, runoff speed could be ultimately reduced with increased infiltration, resulting in lower soil loss and sediment delivery. The effect 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).

2.3.5.1. Types of watershed management

Most common standard technical solutions for soil and water conservations adopted in different parts of the world can be terracing, contour ploughing, trench excavation, strip cropping, stone buds, mulches and crop rotations.

Terracing is a piece of sloped plane that has been cut into a series of successively receding flat surface, which resemble steps for the purpose of more effective farming. Such graduated terrace stapes are commonly used to farm on hilly or mountainous terrain. A terraced field decreases both erosion and surface runoff (UNESCO, 2012).

Contour ploughing is a farming practice of ploughing and planting across a slope following its elevations contour line. These contour lines create a water break which reduces the formations of rills and gullies during times of heavy water runoff which a major cause of soil erosion. 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).

Bunds are among the most common techniques used in agriculture to collect surface run off, increase water infiltration and prevents soil erosion. The principle is comparably simple; by building bunds along the contour lines, so that water runoff is slow down, which leads to increased water infiltrations and enhancing soil moisture. Contour bunds can either be made of stones or soil (sometimes with crop remains).

Strip cropping is a method of farming which involves cultivating a field into long, narrow strips which are alternated in a crop rotation system. It is used when a slope is too steep and or when ether is no alternative method of preventing soil erosion. The most common crop choices for strip cropping are closely sown crops such as wheat, corn soybeans cottons and others. In certain systems, strips in particularly eroded areas are used to grow permanent protective vegetation; in most systems, however, all strips are alternated on an annual basis (Frederick, 2003).

Crop rotation is the practice of growing a series of dissimilar or different types of crops in the same area in sequenced seasons. It is done so that the soil of farms is not used for only one set of nutrient. It helps also in reducing soil erosion and increases soil fertility and crop yield

(Frederick, 2003). Among this all, the P-factor values were determined for only terracing, stone bunds and reforestation for Blue Nile River Basin (Betrie *et al*., 2011). In their study on sub basin level, they evaluate the effects of stone bunds and re forestation, and thy found 4 and 10 t ha^{-1} yr^{-1} erosion reductions on average respectively on Hanger River watershed.

2.3.5.2. Watershed management practice in Ethiopia

Ethiopia has a history of watershed management initiatives dating back to 1970s. 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. However, 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, standard technical 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, deep trenches excavation and afforestation were implemented on insignificantly small 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).

2.4. Impacts of soil erosion

Soil erosion problem has various effects on the environment. The effects are broadly of tow type; on-site effect and off-site effect. Some of on-site effects of soil erosions are; removal of top fertile soil, minimizing infiltration and water holding capacity of the soil, and loss of chemicals and fertilizers. Off-site effect of soil erosions includes; water resource disturbance, river sedimentation, siltation of water storage structures like dams and weirs, disruption of lake ecosystems, contamination of drinking water and increased downstream flooding (Tamene and Vlek, 2008).

Removal of top fertile soil leads to nutrient depletion such as Nitrogen, Phosphorus, Potassium and Calcium and organic matter which are vital for plant growth. When the top soil is removed crop roots are exposed to soil with low organic matter, phosphorous and nitrogen, and high pH contents. On the other hand soil moisture (water) is crucial for plant growth and if the top soil is eroded the infiltration and water holding capacity will decrease and loses its moisture (Morgan, 2005; Pal and Samanta, 2011). Consequently, the plant struggle to obtain the required water and nutrients in soils with low nitrogen and phosphorous availability and all this leads to inhibited plant growth and overall productivity declines.

Sedimentation is the end product of soil erosion (Sheikh *et al*., 2011). The eroded soil particles transported through the processes of sheet, rill, and gully erosion and joins streams and rivers. Once transported by these streams, sediment particles are transported through a river system and are eventually deposited in water bodies such as reservoirs and lakes. This portion of the eroded material that transported through the stream network to some point of interest is referred to as the sediment yield and subsequent sedimentation leads to decrease the carrying capacity of water bodies (Sheikh *et al*., 2011). According to FAO (1978), one-fourth of the soil lost through erosion in a watershed actually reaches to ocean as sediment. The remaining three-fourths are deposited on foothill slopes, in reservoirs, in river plains and other low-lying areas or in the river-bed which often causes channel shifts.

2.4.1. Impacts of soil erosion and siltation in Ethiopia

The impact of soil erosion is the most serious problem in the developing countries like Ethiopia, where farmers are highly dependent on intrinsic land properties and are unable to improve soil fertility through application of purchased imputes which can improve soil fertility (Lulseged *et al.*, 2006).

According to FAO (1984) and Hurni (1993), Ethiopia loses 200-300 t ha^{-1} $yr^{-1}$from the highland areas annually due to erosion. Gizachew and Yihenew (2015) also estimate annual average soil loss for Zingin watershed of Awi zone to be 57750.7 tons yr^{-1}. According to their result, about

21.69 % of the watershed area is highly affected by soil erosion. On the other hand, from Erer Guda catchment of Babile District, the soil is degraded with an average annual soil loss rate of 17.5 t ha^{-1} yr^{-1} (Lindi, 2014). And other related research on East Wollega Zone, the soil losses has shown patio-temporal variations that range from 4.5 t ha^{-1} yr^{-1} in forest area to 65.9 t ha^{-1} yr^{-1} in cropland (Adugna *et al*., 2015). Molla and Sisheber (2016) on their side have done a research on Koga watershed and found the soil loss rate to be 42 t ha^{-1} yr^{-1}. The impact of this loss of fertile soil in Ethiopia is multifaceted. Study conducted by Tadesse (2001), indicates that Ethiopia loses over 1.5×10^6 Mtons of soil each year from the highland areas by erosion resulting in a significant loss of grain from the country's annual harvest. It affects 50 % of the agricultural area and 88 percent of the total population of the country (Sonneveld *et al*., 1999).

The average crop yield from a piece of land in Ethiopia is very low by international standards mainly due to the decline of soil fertility associated with removal of topsoil by erosion (Sertu, 2000). In relation to this, Belay (1992) observes a very high correlation (r = 0.96) between soil productivity and erosion in southern Ethiopia Gununo watershed. Now a day, agricultural lands in Ethiopia gives agricultural products by providing synthetic fertilizer to the soil to compensate some of the lost nutrients due to erosion which is costly.

Much of the eroded sediment deposits along the river course. However, a certain portion of the eroded sediment particles will ultimately be transported to a reservoirs (Awulachew, 2008). In the process of its transportation, to a certain extent, it contributes for meandering of Rivers (Javaheri *et al*., 2008), by rising stream beds and reducing depth and capacity of channels. Ultimately, sediments in a reservoir greatly reduce the water velocity and turbulence resulting in deposition of soil particle at the base of the dam (Amare, 2005). Related studies done by Haregeweyen *et al*. (2014) on upper Blue Nile River basin, and presents to be 473 Mtons yr^{-1}. Out of the specified metric tons of eroded top soil, 26.7 % leaves Ethiopian boundary.

The consequence of this soil erosion and transportation through River system also creates a serious problem on Ethiopian dams and water retaining structures that increased sedimentation of reservoirs and lakes (Kebede, 2012). For instance, Koka dam has accumulated about 3.5 Mm^3 of silt in just 23 years (Gizaw *et al*., 2004). In 1993, Addis Ababa suffers due to power outage; even rainy season, after the turbine at the Koka Dam become clogged with sediment (Hathaway, 2008). According to Mekonnen *et al*. (2005) and Deivi *et al*. (2008) Estimation, sedimentation of

Koka Dam was found to be 17 Mm^3yr^{-1} and 23.02 t ha^{-1} yr^{-1} respectively. Elyas (2003), in his side, shows the economic impacts of the sediment in Koka Dam reservoir. He states that, in Koka Dam, 481 Mm^3sediment has accumulated displacing an equivalent volume of water with an estimated economic loss of 60 million birr which is due to an energy loss of 128 KWh. According to Haregeweyn *et al*. (2008), 50 % of studied reservoirs in Tigray, will lose their economic life before half of the design period because of siltation. Similar study done by Sileshi (2001) indicates that the existence of sediment concentration of 1. 67 t m^{-3} in Bilate River. Therefore, researches on sedimentation and its effect on huge dams of Ethiopia, the existing and the newly constructed one, are under threat of several problems mainly siltation. Therefore, the life span of dams in Ethiopia is mainly depends on the condition of land management and soil erosion conditions of the catchment (Kebede, 2012). Table 2.1 summarizes the trend of soil erosion and sedimentation condition done by different researchers.

Soil erosion rate and related problems for the study area of Hangar River watershed, was done by Jemal, (2010). He uses a multiple regression model and reports that the rate of soil loss in the watershed is 6.5 t ha^{-1} yr^{-1}. But the method that he used and the parameters of the model were not includes the effects of watershed management on the soil erosion rate. In addition to this, the recorded sediment concentration data he used to determine the constant parameters of the model were too poor. The result of his study was simply quantification of rate of soil loss but couldn’t indicate the vulnerability and its distribution over the study area.

Table 2.1 Summary of effects of sedimentation on some of reservoirs in Ethiopia (Kebede, 2012)

Reservoirs	Estimated capacity reduction	sources
Koka	23. 02 t ha^{-1} yr^{-1}	Devi *et al*. (2007)
koka	17 Mm^3 yr^{-1}	Amare (2005)
Aba-Samuel	50 % lost	Devi *et al*. (2007)
Abasamuel	0.67 Mtons yr^{-1}	Amare (2005)
Gilgel Gibe I	Design for 70 years but will function for 24 years	Devi *et al*. (2007)
Melka Wakena	Greatly reduced	Hathaway (2008)
Angereb	Annual siltation 12 t ha^{-1} yr^{-1}, 50 % will be lost after 2010.	Musa *et al*. (2005)
Borkena and Adrako	Silted up before their construction ended.	Haregeweny *et al*. (2006)
Legedadi	0.26 Mm^3 yr^{-1}.	Gessese (2008)
Gilgel Gibe III	1/3 reserved for sediment	Hathaway (2008)
Tekeze	30 Mm^3 yr^{-1} is expected	www.eepc .gov.et

2.5. Soil erosion prediction models

Erosion prediction models can be used as predictive tools for soil loss assessment, conservation planning, soil erosion inventories and project planning. Moreover, the models can be used as a tool for understanding erosion process and their impacts (Nearing *et al*., 1994).

Soil erosion prediction models which are the simplification of reality, have been effectively developed and employed in the last few decades utilizing different scientific method and modeling approach (Nearing *et al*., 1994). According to Saavedra (2005), generally, there are three main types of soil erosion prediction models.

2.5.1. Physical models

Physical based models represent a natural process by describing each individual physical process of the system and combining them in to a complex model. Physical based process hereby describe as a natural process, such as stream flow or sediment transport (Merritt *et al*., 2003). This complex approach requires high resolution spatial and temporal impute data. Physically based models are therefore often developed for specific applications, and are typically not intended for universal utilization. Physically based models (Table 2.2) are able to explain the spatial variability of most important land surface characteristics such as topography, slope, aspect, vegetation, soil, as well as climate parameters including precipitation, temperature and evaporation (Gebremichael, 2003).

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

Model	Reference
Soil and Water Assessment tool (SWAT)	Arnold *et al*. (1990)
Erosion Kinematic Wave Models	Hjelmfelt, *et al.* (1975)
Quasi-Steady State	Foster and Onstad (1977)
Areal Non-point Source WatershedEnvironment Response Simulation (ANSWERS)	Beasley *et al*. (1980)
Management Systems (CREAMS)	Knisel (1980)
Water Erosion Prediction Project (WEPP)	Laflen *et al*. (1991)
European Soil Erosion Model (EUROSEM)	Morgan (1998)

2.5.2. Conceptual models

Conceptual model are a mixture of empirical and physical based models. Their application is therefore to answer general question about soil erosion (Beck, 1987). The models are usually incorporated general description of catchment process without specifying process interaction that would require very detailed catchment information (Merritt *et al.*, 2003). Table 2.3 shows the commonly used conceptual models.

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

Models	References
Sediment Concentration Graph	Johnson (1943)
Renard-Laursen Model	Renard and Laursen (1975)
Unit Sediment Graph	Rendon (1978)
Instantaneous Unit Sediment Graph	Williams (1978)
Sediment Routing Model	Williams and Hann (1978)
Discrete Dynamic Models	Sharma and Dickinson (1979)
Agricultural Catchment Research Unit (ACRU)	Schulze (1995)
Hydrologic Simulation Program, Fortran	Walton and Hunter (1996)

2.5.3. Empirical models

Empirical models are a simplified representation of natural process based on observations and experiments. It refers to a simplified representation of a system or phenomenon which is based on experience or experimentation result. These models are based on defining important factors through field observation, measurement, experimentations and statistical technique relating erosion factors to soil loss (Nearing *et al*., 1994). Empirical models describe erosion using statistically significant relationships between assumed important variables where a reasonable database exists (Kadupitiya, 2002).

In empirical models, the inherent processes involved are not used and the model can be operated in the designed direction where inputs go in to one side of the equation and the output on the other side. These models are quick in predicting erosion, but are site specific and require long-term data (Elirehema, 2001). Empirical models are frequently utilized for modeling complex process and in the context of soil erosion, particularly useful for identifying the source of sediments (Merritt *et al*., 2003).

Most models used in soil erosion studies are empirical models. The most widely used empirical model is USLE. Others include RUSLE, SLEMSA, and MUSLE, which are based on modifications made on USLE.

Table 2.4 List of some common empirical models and their sources (Merritt *et al.,* 2003)

Models	References
Musgrave Equation	Musgrave (1947)
Revised Universal Equation (RUSLE)	Renard *et al*. (1991)
Equation (MUSLE) Sediment	Renfro (1975)
Delivery Ratio Method	Dendy and Boltan (1976)
Universal Soil Loss Equation (USLE)	Wischmeier and Smith (1978)
Soil Loss Estimation Model for South Africa (SLEMSA)	Elwell (1978)
Dendy-Boltan Method Flaxman Method	Flaxman (1972)
Pacific Southwest Interagency Committee (PSIAC)Method	Pacific Southwest Inter-agency Committee (1968)

Table 2.5 List of most commonly used soil erosion models

Models	Description	References
USLE	Universal Soil Loss Equation	Wischmeier and Smith (1978)
RUSLE	Revised USLE	Renard *et al*. (1991)
dUSLE	Differentiated USLE	Flacke *et al*. (1990)
CREAMS	Chemical runoff and erosion from agriculture management systems	Knisel (1980)
ANSWERS	Areal Nonpoint Source Watershed Environment Response System	Beasley and Huggins (1982)
WEPP	Water Erosion Prediction Project	Lane and Nearing (1989)
OPUS	Advanced simulation model for nonpointsource pollution transport	Ferreira and Smith (1992)
EROSION2D	Erosion- 2D	Schmidt (1991)
PEPP	Process-oriented erosion prognosis program	Schramm (1994)
KINEROS	Kinematic Erosion Simulation	Woolhiser *et al*. (1990)
EUROSEM	European Soil Erosion Model	Morgan *et al*. (1991)
LISEM	Limburg Soil Erosion Model	De Roo *et al*. (1994)

2.6. RUSLE model

The universal soil loss equation (USLE), which is an empirical equation was developed by (Wischmeier and Smith, 1978) to assess the vulnerability of soil erosion from agricultural lands in United State of America. Even though the equation was originally developed to predict soil erosion at field level, its use in large areas in a GIS platform has produced satisfactory result (Renard *et al.,* 1994; Mellerowicz *et al*., 2003).

The scientists develop this model after taking 10 thousands of test plots for a decade. It was developed and tested by experienced and nationally-recognized erosion scientists and environmentalists of USA. The length of these test plots typically was about 25 m length and width ranged from 2 m to about 13 m wide plots at one location. Thus, USLE can estimate soil loss for rills up to 375 mm deep on sides of hill slopes because these rill would be in plots placed on this part of the landscape. Deep ephemeral gullies or more than 3m deep classical gully in a concentrated flow area is not considered in USLE, because taste plots were not placed in such condition when the parameters of USLE were developed (Terrence, 1998).

Later in 1980s 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. This improvement was on the way of computations of RUSLE parameters (R,K,LS,C and P factors).This was done by Renard *et al*. (1991). Thus, the RUSLE model is given by a product of the five parameters or factors such as R, K, LS, C and P-factors. In examining RUSLE variables, the equation can be broken down into two parts; the first three parameters (R, K and LS) are environmental variables, which are a variable remains relatively constant over a time. While the last two parameters (P and C), are watershed management variables and they may change by human induced activities on (Breiby, 2006).

The model is used throughout the world in education and research as it can indicates the starting point of soil erosion, understanding of erosion hazard and prediction of the soil loss rate, because of its simplicity and data usage (Hagos, 1998). Many scientists have proposed changes, but all are woven around the same concept that; rainfall erosivity, soil erodibility, slope length and steepness, land cover and management factors are taken as directly proportional to the rate of soil erosion (Sohan *et al*., 2001).

The development of Remote Sensing (RS) techniques and availability of spatial datas with an integration of GIS makes it to be highly useful model to estimate long term average annual soil loss of large areas. In GIS environment, it can predict erosion potential on a cell-by-cell basis, which is successful in attempting to identify the spatial pattern of soil loss present within a watershed (Shi *et al*., 2003).Therefore, the advantage of GIS technology has allowed the equation to be used in a spatially distributed manner because each cell in a raster image comes to represent a field level unit.

2.6.1. The applications of RUSLE in Ethiopia

In Ethiopia, among the empirical and other type of soil erosion models, RUSLE is of higher importance. Sonneveld *et al.* (1999) argues that the applications of the process based models are not practically applicable due to their large data requirement. Even though, some detailed testing, calibration and validation trials need for further accuracy estimation of parameters of RUSLE, it is still applicable in case of Ethiopia.

Several efforts have been made to calibrate and validate the use of RUSLE models for Ethiopian conditions. Among those, Mulugeta (2004) has calibrated RUSLE for Andit Tid watershed while Serkalem (2005) for Mayebar and Mesfin (2008) for Anjeni. Alemayehu (2012), has tested and calibrated RUSLE for the case of twin catchment of Gununo watershed found in the South Nations, Nationalities and Peoples Region (SNNPR). In his result, he got correlation coefficient (r) of 0.889 between the measured and the predicted value of soil loss with model efficiency of 86%. In other hand, Habtamu *et al*. (2013), attempted to check the efficiency of USLE model on the selected field in East Gojam, Amhara Region. They tried to measure the run off and the resulted sediment from 38 storm events. Finally they have got a result of a model efficiency of 53.5 %. They conclude that this model is better and efficient for long term rainfall data and to estimate annual average soil loss rate.

Some researchers also tried to calibrate the model parameters by taking other parameters constant, and checking the parameters value for different conditions. Among those, Nyssen *et al.* (2009) has conducted runoff plot experiments in the semi-arid north Ethiopian Tigray highlands to examine the application of RUSLE to the Ethiopian highlands. According to his findings RUSLE works well in the area except the under estimation for the C- factor. Other study was made by Yohannes (2005) in order to estimate K- factor using input parameters such as soil texture, bulk density, and permeability. According to his result RUSLE has made a sound estimate of K- factor values.

Gebeyehu *et al*. (2017) have been attempted to determine RUSLE’s P-factor for stone bunds and trenches in range land and crop land in Northern Ethiopia. And also they have checked the C-factor values in the specified areas. For this study, 21 run off plots of 600 to 1000 m^2 were prepared and monitored during 2010, 2011 and 2012. The result of their study shows that the C-factor for range land ranges from 0.31 to 0.98 and for crop land range from 0.06 to 0.39. The calculated result of P-factor ranges from 0.3 to 0.74 for stone bunds and 0.07 to 0.66 for trenches. For the combination of trenches and stone bunds, the P-factor ranges from 0.03 to 0.22 (Gebeyehu *et al*., 2017).

2.7. Geographic information system (GIS) and remote sensing (RS)

GIS is a computer-based system which has a capability of handling geo-referenced data for data capturing and preparation, data management and manipulation, analysis and presentation (Aronoff, 1989). It is noted to be a useful tool in approach to integrate social, economic physical and environmental information for developments, planning and implementation. In the term, "Geographical Information System", "Geographic" represents the activities to be location based, spatial and geo-referenced, "Information" represents additional non spatial data or attribute data in the form of spread sheets, and "System" represents processes in the software (Saha *et al*., 1991).

The most complex use of a GIS involves tying the GIS to a known set of relationships, scientific laws, etc., to model real-world phenomena like, Hydrology, soil loss, and habitat qualities (Aronoff, 1989). These are all examples of geographic phenomena often modeled in a GIS environment. Modeling is a powerful tool, as it often opens the door for both trend and predictive analysis, which can prove quite useful in planning and operations. In this particular study, this powerful software was used to analyze the soil loss from the catchment based on the pre-determined empirical model (RUSLE).

Remote sensing is a science acquiring information about the earth's surface without actually being in contact with it (Saxena *et al.,* 2000). This is done by sensing and recording reflected or emitted energy and processing, analyzing and applying that information. For the assessment of erosion vulnerable area, remote sensing becomes very important in detecting the land features and obtaining information about physical cover of the watershed (Petter *et al.,* 2004).With the appropriate use of multispectral data, it is possible to differentiate different ground features from each other and prepare a thematic map depicting land use/ land cover (Saxena *et al.,* 2000).

2.8. Use of GIS in soil erosion risk assessment

For nearly 40 years the use of USLE (Wischmeier and Smith, 1978) and its predecessor RUSLE (Renard, 1997), have been used throughout the world to estimate the annual average soil loss per unit area (field-based) resulting from rill and sheet erosion by water. Due to the improvement and applicability of GIS and Remote Sensing technology with geo-referenced data, Recently, use of RUSLE has been extended as a useful tool predicting soil loss and planning control practice from small to large area of watershed in different conditions by effective integration with GIS-based procedure and techniques, to estimate the values of factors in a grid cell basis (Mongkoisawat *et al*., 1994).

The advantages of using GIS in assessing the environmental conditions were reported by Hinton (1996), and introduced the principles of GIS tools for collecting, preparing storing, manipulating, and displaying spatial data. The data required for the USLE calculations might be available in a GIS platform so that GIS-based procedures can be employed to determine the factor values for predicting erosion in a grid cell via the USLE/RUSLE (Kinnell, 2001).Thus, estimation of soil loss and it spatial distribution using remote sensing and GIS techniques could be performed with reasonable costs and better accuracy in larger areas (Millward and Mersey, 1999). Also it is recommended that the GIS/USLE modeling approach would offer quick and inexpensive tool for estimating sheet erosion within watersheds using publicly available information and data.

3. MATERIALS AND METHODS

3.1. The study area

3.1.1. Location

The study area was Hangar River watershed, which is located in North West part of Ethiopia. The major part of the catchment is found in East Wollega Zone Oromia National Regional State and some part of the catchment is located in Benishangul Gumuz National Regional state, Ethiopia. Taking the outlet near the confluence points of Didesa River, the study area covers an area of 7790 km^2. The geographical location of the study area extends from 36^O 02’ 21” to 37^O 58’ 50” E longitude and 9^O 01’26” to 9^o 59’ 50” N Latitude. Hangar River is one of the largest tributaries of Didesa River which emerges from near Horo district and flows towards South-West direction to join with Didesa River.

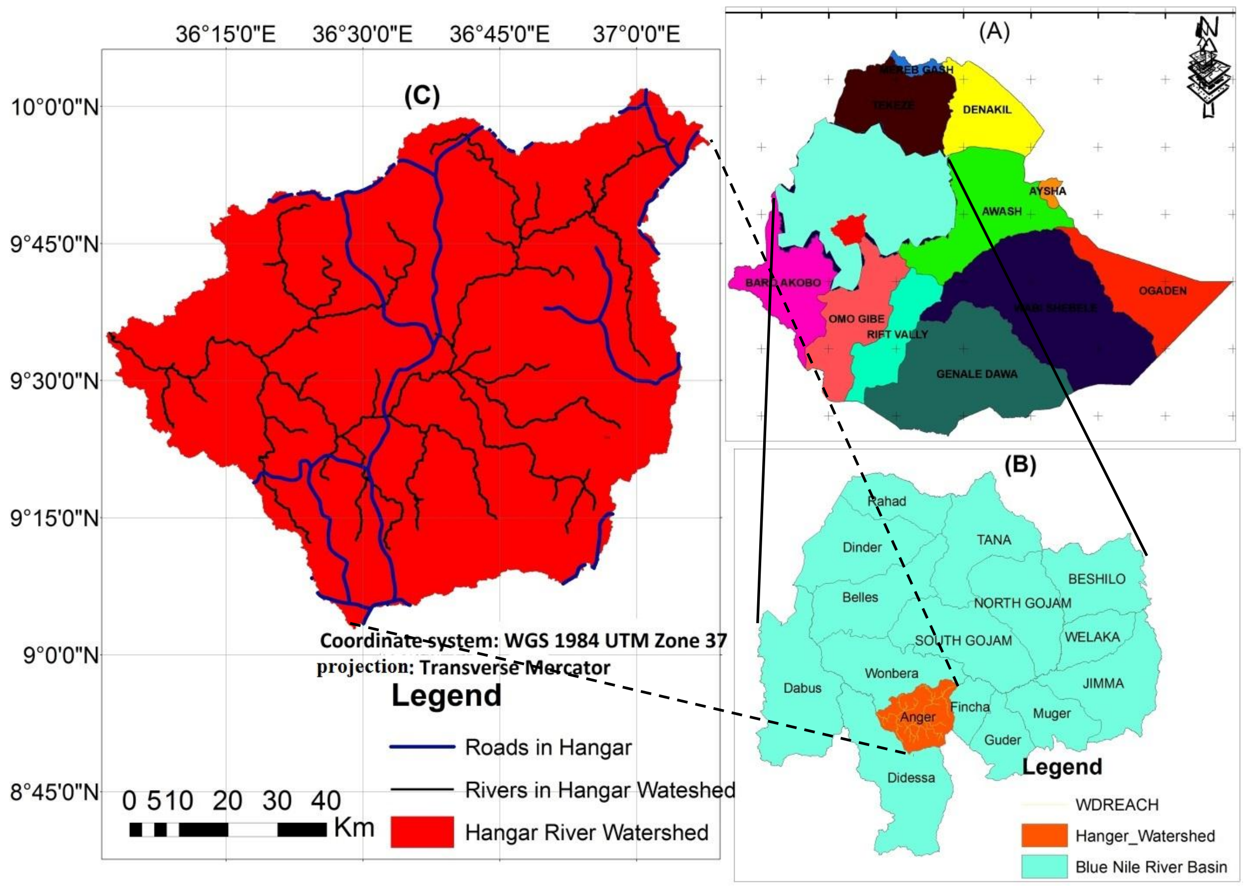

Figure 3.1 Location map of the study area Ethiopian River Basins (A) Blue Nile River Basin (B) Hangar River Watershed (C)

3.1.2. Climate and Topography

The study area which is a sub basin of Didesa River basin consists of variety of landscape with various topographical features (flat to mountainous) with elevation variation from 849 to 3215 m above mean sea level (Figure 3.3 A). The climatic condition varies depending up on the variation in elevation. According to Hurni (1986) description of Agro climatic zones of Ethiopia, the catchment consists of three agro-climatic zones "*kola*, *weynadega* and *dega*" with elevation variation of 500-1500, 1500-2300 and above 2300 m, respectively. The maximum and minimum temperature at higher elevation "*dega*" of the study area is about 27.9 and 12.2 ^{0}c respectively. And maximum and minimum temperature at lower elevation (kola) of study area is 30.3 and 14.7 ^{0}c respectively (OWWDSE, 2015). Table 3.1 shows the selected observed maximum and minimum temperatures from the higher and lower parts of the study area.

Table 3.1 maximum and minimum temperature of selected stations in the study area

Average Monthly temperature (^{0} c) of Nakamte station													
Maximum	26.0	27.8	27.9	26.9	25.1	22.5	21.0	21.0	22.5	24.0	24.5	25.0	24.5
Minimum	12.2	13.5	14.3	14.4	13.9	12.8	12.7	12.9	12.8	12.8	12.7	12.2	13.1
Average Monthly temperature (^{0} c) of Hanger Gute station													
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Maximum	28.3	30.0	30.3	28.6	25.5	25.1	24.2	24.9	24.5	24.9	27.1	28.6	26.8
Minimum	6.4	7.1	9.3	7.3	12.1	10.8	9.7	10.0	10.8	10.4	9.3	6.8	9.2

The rainfall distribution and intensity also varies across the elevation variation. The area receives its maximum rainfall from May to September (Figure 3.2).

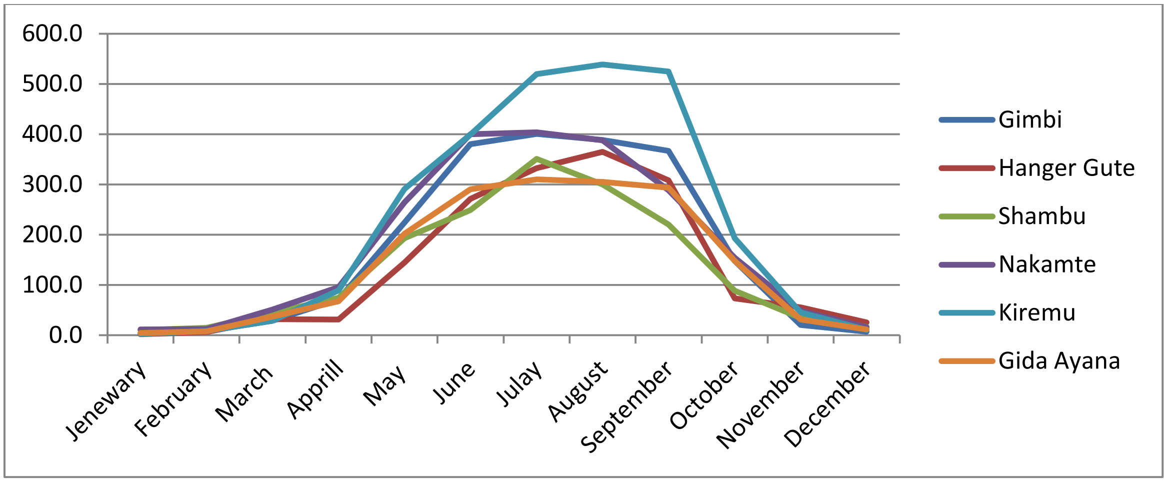

Figure 3.2 Mean monthly rainfall of the study area for the year 1990 to 2016

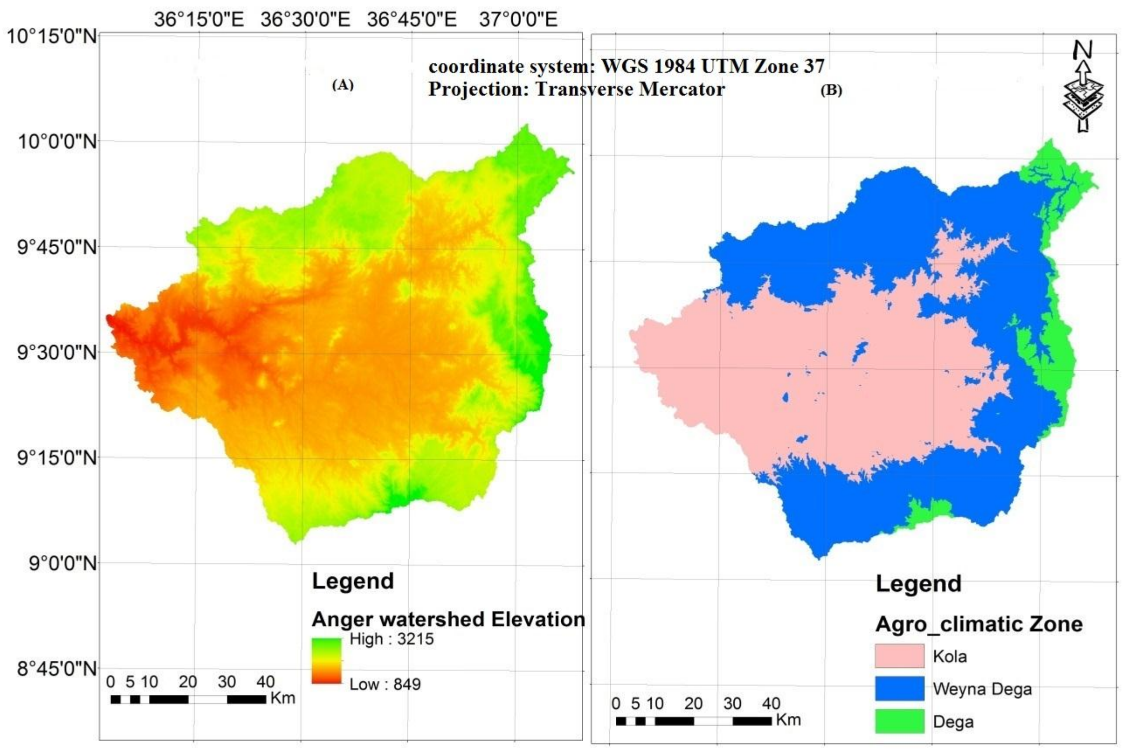

Figure 3.3 Map of elevation (A) and agro- climatic zone (B) of the study area

3.1.3. Soil and Geology

The soil types in the study area as per from FAO (1998) soil map, was identified as Haplic Alisols, Haplic Arenosols, Haplic Acrisols, Rhodic Nitosols, Eutric Vertisols, Haplic Nitosols, Eutric Leptosols and Dystric Leptosols. From these Haplic Alisols covers the largest area (38.2

%) and Haplic Arenosols covers the smallest area (0.004 %). Table 3.4shows the detail soil type, characteristics and coverage area.

The regional geology of the study area was developed from three types of geological terrains. These are Quaternary sediments, Paleozoic to Mesozoic rock, Precambrian rock (from youngest to oldest). Most of the study area is covered with intrusive Precambrian rocks mainly granite with coarse grained texture and massive in nature which is overlaid by thick black to brownish cotton soil (OWWDSE, 2015).

3.2. Materials used

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

Table 3.2 Software and model used for this study

Software and model used	Purposes
Arc GIS 10.3	Analyzing, Displaying and viewing Spatial data
Arc Hydro extension	Watershed delineation
RUSLE	To quantify the soil loss rate

3.3. Data collection

To analyze the soil loss in the study area, different data were used as an impute. These data were collected from different governmental and non- governmental organizations. The input data for RUSLE were prepared after the data collection and analysis.

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 Nakamte, Shambu, Gimbi, Hanger Gute, Gida Ayana and Kiremu stations. The data was 27 years (1980 to 2016) monthly recorded data from each metrological station. Table 3.3 shows the locations and average rainfall for each station.

Table 3.3 Rain gauge stations with respective annual average rainfall (mm)

Stations Name	Locations		Altitude (m)	Av.Rainfall (mm)
	Lati (N)	Long (E)		
Hanger Gute	9.5645	36.6317	1390	1604
Kiremu	9.9586	36.8605	2144	1892
Gida Ayana	9.8781	36.6272	2098	1708
Shambu	9.5655	37.0997	2582	1570
Nakamte	9.0909	36.5454	2133	2130
Gimbi	9.1667	35.7833	2031	1675

3.3.2. Soil data

For this study, the soil data as per FAO (1998) soil group were collected from Ministry of Water resource Irrigation and Energy (MoWIE) GIS department. The clipped map of soil types from FAO (1998) soil map for the study area was identified as Haplic Alisols, Haplic Arenosols, Haplic Acrisols, Rhodic Nitosols, Eutric Vertisols, Haplic Nitosols, Eutric Leptosols and Dystric Leptosols. Table 3.4 shows detail soil type, characteristics and coverage area.

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

Group Name	Soil Unit Map	Soil Type	Soil Characteristics	Area (Km^2)	% Area Coverage
RdLP	Dystric Leptosols	silty clay loam to silty clay	Shallow over hard rock and comprise of very gravelly material. They are found mainly in mountainous regions.	1169.1	15.1
VeVr	Eutric Vertisols	heavy clay	Seasonally cracking soil, very poorly drained, very dark cracking heavy clay	8.4.5	0.1
S/RhAc	Haplic Acrisols	Rocky to sandy soil	Strongly acidic soils with a clay-enriched subsoil and low nutrient-holding capacity, associated with acidic bed rock, deficient in nutrients.	2074.7	26.8
RhAI	Haplic Alisols	Very friable to friable clay loam to clay	Very acidic soils with a clay-enriched subsoil and high nutrient-holding capacity.	2990.0	38.2
RhaR	Haplic Arenosols	Sandy to silty soil	Easily erodible sandy soil with slow weathering rate, low water and nutrient holding capacity and low base saturation.	0.3	0.004
S/RrNt	Rhodic Nitisols		have deep profiles in relatively rich parent material	1547	19.8

3.3.3. Digital elevation model (DEM) data

The DEM data for this study were extracted from United State Geological Survey (USGS) which is available freely from the internet. The DEM having 30 x30 meter resolution was used for the analysis.

3.3.4. Land use land cover (LU/LC) data

For this study, the land use land cover classification map of 2013 was used. The classified map was collected from Ethiopian Mapping agency (EMA). It shows detailed classification of the LU/LC in the specified year for the whole Ethiopia. From The LU/LC map of the study area, about eight different land use and land cover types were identified (Figure 3.8). These were

Grazing Land, agricultural lands, Dense Forest, Grass Land, Open Forest, Shrub Land and bare soil.

Table 3.5 Summary of data type, source and the purpose of the data

Type of data	Source	Description	Purpose
Rainfall data	National Meteorological Agency, Ethiopia	27 years data from six rain fall stations near the study area (1980-2016)	To extract R-factor
Soil data	Ministry Of Water Resources irrigation and electricity	FAO (1998) Digital soil map	To extract K-factor
Land use land cover data	Ethiopian mapping agency	2013 land use land cover map	To extract C-factor map
DEM data	USGS	30x30 m resolution	Watershed delineation, slope map generation and LS- factor generation
Land use practice information	Natural resource responsible bodies in the study area		To extract P-factor

3.4. Soil erosion prediction procedure

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, digital elevation model and other relevant studies were used. Respective individual RUSLE factors such as R, K, LS, C and P were generated in GIS database and combined cell by cell grid to predict soil loss rate in a spatial domain.

In order to generate 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 different governmental and non-governmental organizations. In addition 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.

In order 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).

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

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 ha hr ha^{-1} 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).

RUSLE model analysis in GIS from the data source to the result is given in Figure 3.4.

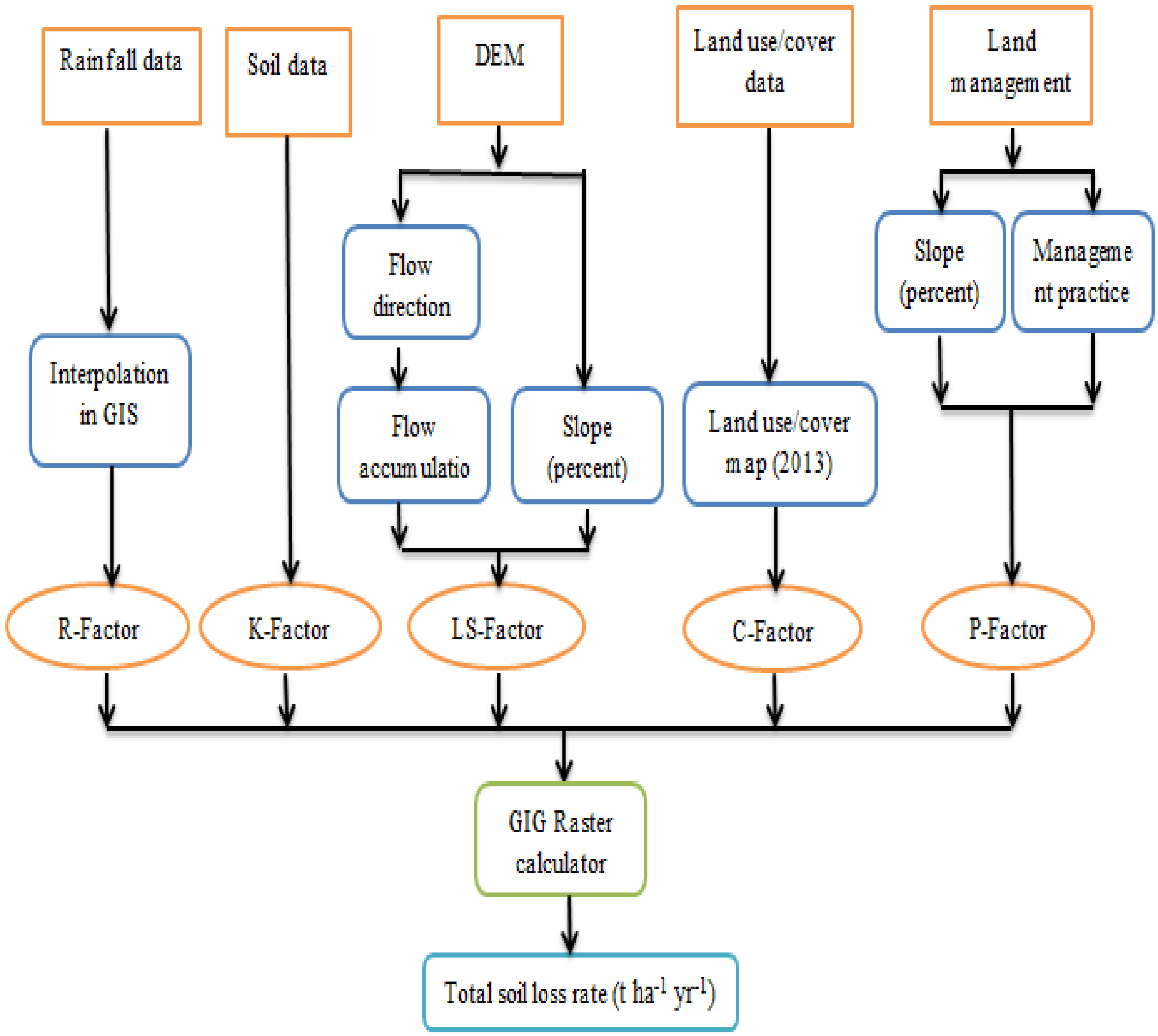

Figure 3.4 Flow chart of the determinations of soil loss using RUSLE in Arc GIS.

3.5. Data processing and analysis

The different data inputs which were collected from different data sources contain errors due to failures of measuring devices or recorder. So, 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 Dingman (2002) 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 2).

3.5.3. RUSLE factors estimation

The assessment procedures for the different factors employed in RUSLE model are described in the following sections.

3.5.3.1. R-Factor estimation

R-factor is the quantitative expression of the erosive power of local average annual precipitation and runoff causing soil erosion (Farhan, 2013). It is a measure of erosive force of specific rainfall. RUSLE and its predecessor USLE was designed to account for the effects of raindrop impacts and subsequent overland flow on soil erosion. Therefore, the rate of soil loss is closely related to rainfall intensity, duration and patterns of rainfall of a series of storm and by rate and amount of its runoff. It is due to the detaching power of raindrop striking the soil surface and through the contribution of rainfall to runoff (Tadesse and Abebe, 2014).

To generate the parameter R-factor, isoerodent map (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 in Table 3.6, works well for Malaysia and the second 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 third equation is used for rainfall of above 900 mm and it needs the recorded value of I_{30} (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. (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).

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

Rainfall Erosivity Formulas	Applicable Area	Sources
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)	Ethiopia	Hurni (1985)

Where; R is erosivity factor (MJ mm ha^{-1} hr^{-1} yr^{-1}), P is mean annual precipitation (mm); I_{30} is maximum 30 minute rainfall intensity (mm hr^{-1}).

$$R = -0.812 + (0.562 \times P) \qquad (2)$$

Where; R is erosivity factor (MJ mm ha^{-1} hr^{-1} yr^{-1}), P is mean annual precipitation (mm).

Table 3.7 Rain gauge stations with respective average rainfall and erosivity values

Stations Name	Av. Rainfall (mm)	R-Factor values (MJ mm $ha^{-1}.hr^{-1}.yr^{-1}$)
Hanger Gute		
Kiremu	1892	1063
Gida Ayana	1708	959
Shambu	1570	881
Nakamte	2130	1196
Gimbi	1675	941

Interpolation of point data of rainfall was made by Arc GIS 10.3 Inverse Distance Weighted (IDW) method in order to form a surface of data from the scattered set of point data as given in Figure 3.5. Finally, the R-factor values were interpolated to generate erosivity map and clipped in GIS database (*Section 4.1.1*).

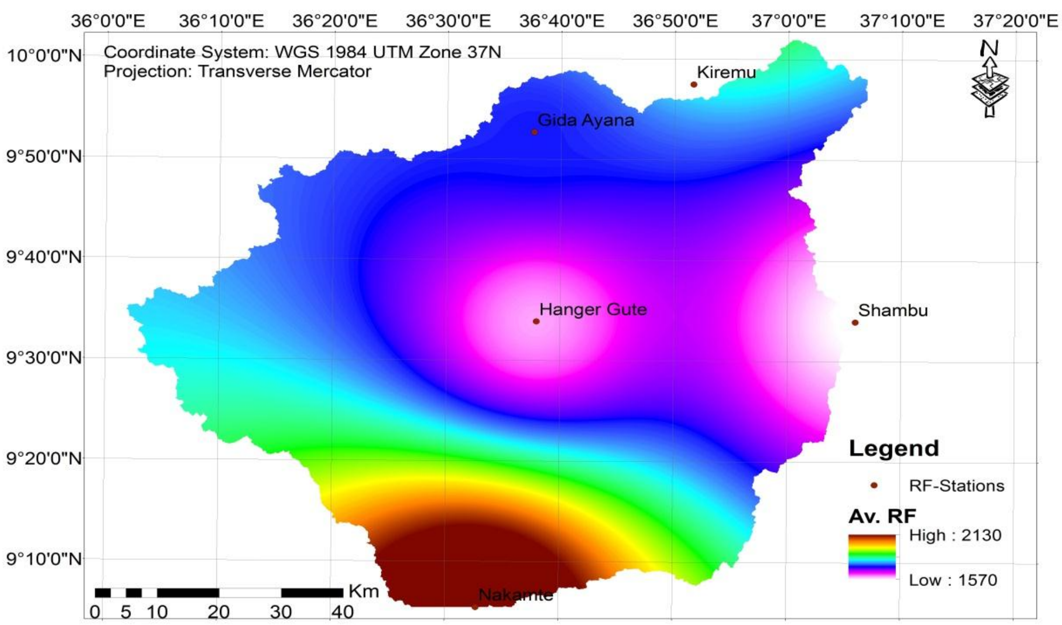

Figure 3.5 Map of annual rainfall of the study area

3.5.3.2. K-Factor estimation

K-factor express the soil susceptibility to detachment and transportation of soil particle under an amount and rate of runoff for a specific rainfall measured under standard plots of 9 % and 22.1 m length (Morgan, 1995). It reflects the combined effect of soil properties, showing the general proneness of a particular soil type to erosion (Tegegne, 2017).

According to Morgan (1995) explanations, soils which have different characteristics have different resistance to erosion. Hence, Erodibility varies with physical and bio-chemical properties of soil such as; soil texture and structure, aggregate stability, shear strength, infiltration capacity organic matter and chemical content. Therefore, K-factor value is influenced by those intrinsic soil properties, related to soil profile parameters such as percent silt, percent sand, percent organic matter, soil structure and permeability (Morgan, 1995). However, Soil data in Ethiopia often doesn't contain detailed information about such soil parameters (Bewket and Teferi, 2009). Therefore, the K- factor values for the study area was assigned based on a qualitative index of soil that adapted by Hellden (1987) and Hurni *et al*. (2015) based on the color of the soil which is believed to be a reflection of soil properties. They have suggested calibration-based values of K-factor, based on soil color for Ethiopian soil conditions. Experiment-based suggestion also given by others (Bono and Seiler, 1984; 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 Tefreri (2009); Gelagya (2016) and Haregeweyn *et al*. (2017). Table 3.8 shows the suggested values of K- factor with their respective soil colors.

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

Soil colors	Black	Brown	Red	Yellow	Grey	White
K-factor values	0.15	0.2	0.25	0.3	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 0.15 to 0.35. The smaller value (0.15) 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 identified soil type in the study area were; Haplic Arenosols, Haplic Acrisols, Haplic Alisols, Rhodic Nitosols, Dystric Leptosols Eutric Vertisols, Haplic Nitosols and Eutric Leptosols (Figure 3.6). The colors of those soil types were collected from different literatures and given in the Table 3.9.

Table 3.9 Soil type of the study area with physical color and corresponding K- factor values

Soil types	Soil color	K-factor (t ha hr ha^{-1} MJ^{-1} mm^{-1})
Dystric Leptosols	Grey	0.35
Eutric Leptosols	Grey to yellow	0.35
Eutric Vertisols	Black	0.15
Haplic Acrisols	Yellow	0.3
Haplic Alisols	Brown	0.2
Haplic Arenosols	Grey	0.35
Haplic Nitisols	Red	0.25
Rhodic Nitisols	Red	0.25

Finally, the clipped soil map (Figure 3.6) 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 Arc GIS to generate erodibility factor map as shown in Figure 4.2 (*Section 4.1.2*).

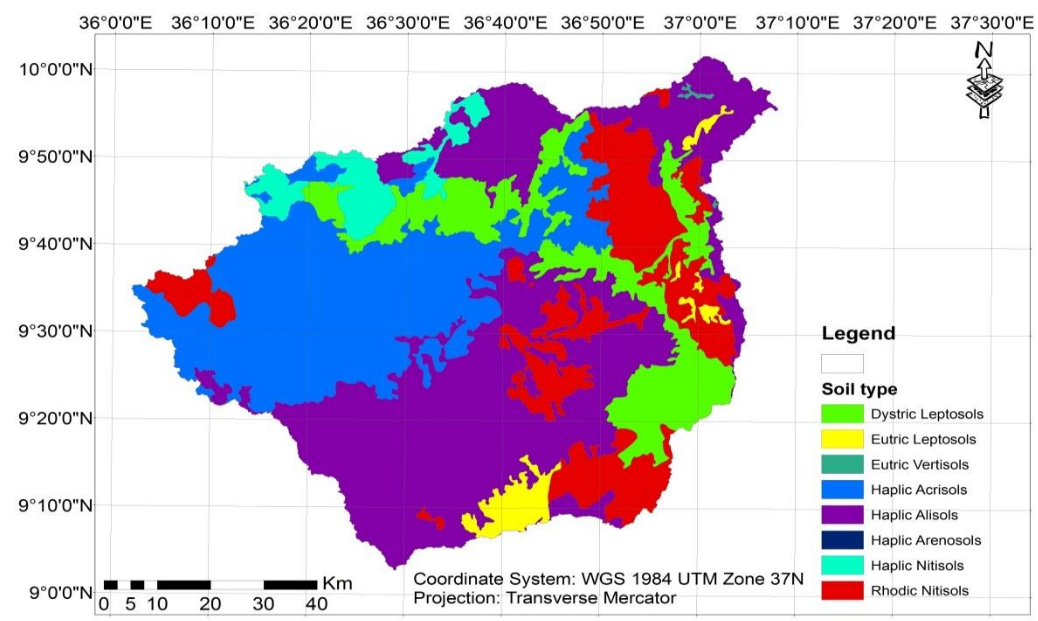

Figure 3.6 Map of major soil types in the study area

3.5.3.3. LS-Factor estimation

Slope length is the distance from the point of origin of overland flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well-defined channel (Wischmeier and Smith, 1978). Generally, the greater the slope length, the greater the velocity of runoff water as a result of progressive accumulation of runoff in the down slope. Consequently, the greater erosion expected.

On the other hand, slope steepness is the gradient from point of origin of flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well-defined channel (Wischmeier and Smith, 1978). Generally, slope steepness has been considered as one of the main factor affecting soil erosion in RUSLE model parameters due to the fact that the steeper the slope of the field, the more it is pushed down the hill, the faster the water runs and the greater will be the amount of soil loss from erosion by water (Doere (2005). The effect of these two factors can be considered in a single index as LS-factor. The effects of this combined factor is expressed as 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 (Wischmeier and Smith, 1978). This factor is the major contributing factor for soil erosion as the slope length and steepness increase, the resulted concentrated flow velocity and an instability of soil particle increases (Renard, 1997).

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.

The spatial analysis tool of Arc GIS 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 Arc Hydro tools of Arc GIS extension to use as an impute for the calculation of LS-factor. To generate LS-factor map, the following equation Eq. (3) which was developed by Mitas and Mitasova (1996), was used in raster calculator of Arc GIS.

$$\mathrm{LS} = \mathrm{Power}\left[(\mathrm{FA}) * \frac{\mathrm{Resolution}}{22.1}\right), 0.6] * \mathrm{power}[(\sin(\mathrm{slope}) * 0.01475)/0.09, 1.3] \ldots\ldots\ldots (3)$$

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 3.7). The resulting LS-factor map is shown in Figure 4.3 (*Section 4.1.3*).

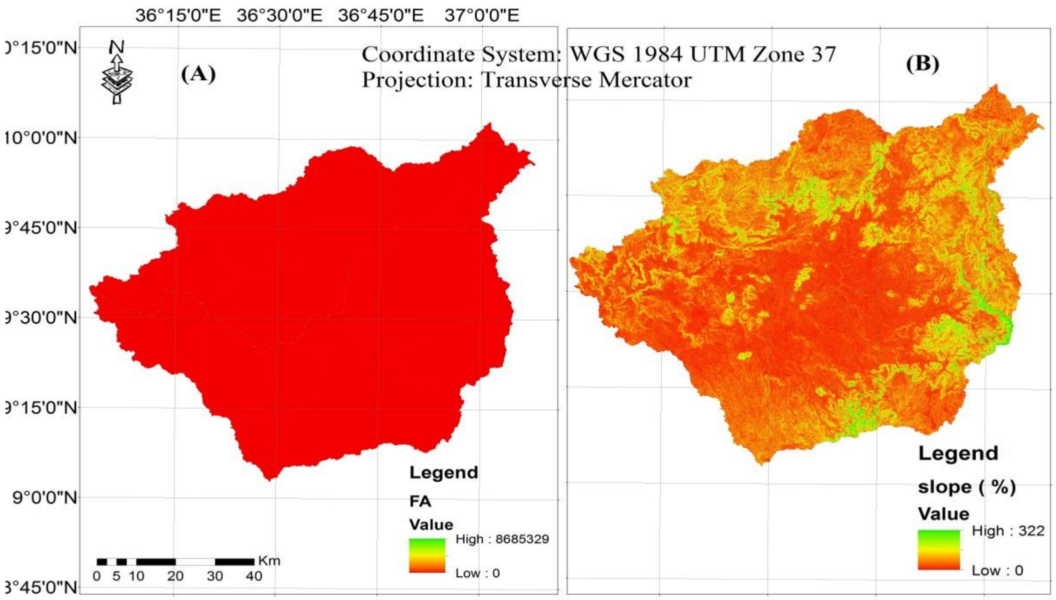

Figure 3.7 Map of flow accumulation (A) and slope in percent (B)

3.5.3.4. C-Factor estimation

The Land use land cover (LU/LC) factor express the effect of land cover and its management on soil erosion rate (Renard, 1997) and is considered the second major factor (after topography) controlling soil erosion (Farhan, 2013). It is the ratio of soil loss from land with specific vegetation cover to the corresponding soil loss from continuous fallow with the same rainfall (Wischmeier and Smith, 1978). The type of land cover (crop type) and type of tillage makes great difference in the amount of erosion that occurs in a given catchment. Surface cover, such as vegetation or plant residue may intercept and reduce raindrop impact, increase infiltration, slow down runoff and reduce transporting capacity of flowing water (Wischmeier and Smith, 1978).

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 eight different land use and land cover types (Figure 3.8). From the classified map, 59.5 % 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 second and third percent area coverage with 14 % and 12 % respectively (Table 3.8).

After having the classified map, the corresponding C-factor values for different LU/LC class was assigned. These values were collected from previous studies and assigned for corresponding LU/LC types. Finally, the C-factor map was generated in Arc GIS 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 (*Section 4.1.4*). Table 3.10 briefly indicates the type of LU/LC class with corresponding C-factor values.

Table 3.10 LU/LC types and corresponding C-factor values (Bewket and Tefri, 2009; Gelagay, 2016).

Land Use Land Cover Types	Area (km^2)	Percent Area coverage	C-factor values	Sources
Grazing Land	65	0.83	0.05	CGIP (1996)
Bare soil	2	0.03	0.6	BCEOM (1998)
Agricultural land	4632	59.5	0.15	HURNI (1985)
Dense Forest	348	4.5	0.01	HURNI (1985)
Grass Land	928	12.0	0.01	Van Lammeren (1996)
Open Forest	1092	14.0	0.05	HURNI (1985)
Shrub Land	717	9.2	0.014	CGIP (1996)
Water Body	6	0.08	0	HURNI (1985)

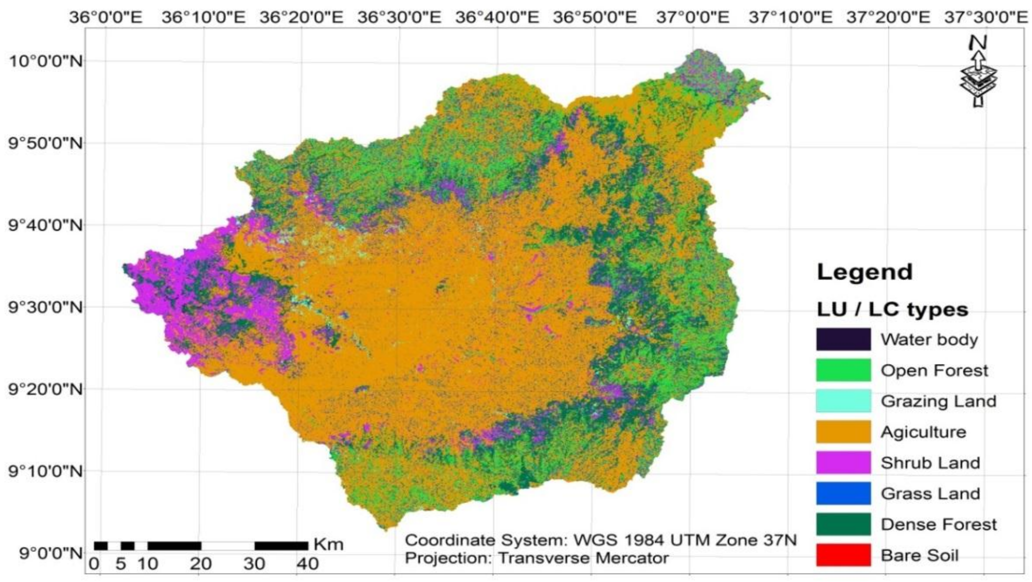

Figure 3.8 Map of major LU/LC types in the study area

3.5.3.5. P-Factor estimation

The conservation practice factor expresses the effects of soil conservation practices that reduce the amount and rate of water runoff, increase infiltration and subsequent reduction of the amount of erosion. In RUSLE model, the P-factor is considered as the ratio of soil loss with a specific conservation practice to the corresponding loss with up and down slope cultivation or zero management (Wischmeier and Smith, 1978). 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. These activities have a great advantage against erosion by letting the surface runoff to be not concentrated in a channel and to have less flow velocity. Different management practice shows different capability of soil erosion reduction. Related to this, different researcher attempts to evaluate the most common physical management practice like; contouring during farming and contouring with terracing both at a time.

Table 3.11 shows the P- factor values for corresponding conservation practice for two cases (if only contouring practice is commonly practiced and if both contouring and terracing practice was fully developed), with in a given range of slope gradient in percent.

Table 3.11 LU/LC types and corresponding C-factor values (Bewket and Tefri, 2009; Gelagay, 2016).

Slope in percent	P-factor values	
	For only contouring	For Contouring with terracing
< 2	0.4	0.1
2 - 5	0.5	0.11
5 - 8	0.55	0.11
8 - 12	0.6	0.12
12 - 16	0.7	0.14
16 - 20	0.8	0.16
> 20	0.9	0.18

The soil conservation and management practice Information which has been practiced in the study area were collected during the time of site visit. Based on the information gathered at the time of site visit, contour ploughing was found to be the common soil and water conservation measure. On the other hand, Adugna *et al.* (2015) reveal that in the study area, contour ploughing is the dominant soil erosion control practice followed by a construction of a little bit soil and stone bunds. 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.

Following the GTP plan of FDRE building climate-resilient green economy, attempts for applications of management practice has been made for the last 6 years in the country as well as in the study area. Based on this plan, some insignificant trench excavation and afforestation activities have been also observed in small area of the study area. On their discussion, Gebeyehu *et al*. (2017) indicate that, excavated trenches show a very significant decline of effectiveness over time, which is attributable to the reduction of static storage capacity of the trenches as a result of sediment deposition.

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 Doer (2005) and Kebede (2014) was used considering only the contour ploughing as dominant soil conservation practice for current soil erosion status of the study area (Table 3.11). This research also, shows the comparison of the soil erosion rate under the current soil management practice (only contour ploughing) with the expected or imagined fully developed application of standard technical solutions like; terracing with contour ploughing in the study area. Since the expected amount of soil erosion from steep slope and gentle slope with the same management practice would not be equal, and conservation activities were highly dependent on the topographic condition (slope) of the land. Hence, the conservation practice factor values were given within the ranges of slope gradient of the study area. As shown in Table 3.11, the study area was classified in to seven slope gradient ranges with corresponding P-factor values. After the classification in slope has been made (Figure 3.9), the corresponding P-factor values were added to the shape file of the re-classed slope map and using conversion tool in Arc GIS, conversion to raster has been executed and P-factor map was generated as shown in Figure 4.5 (*Section 4.1.5*).

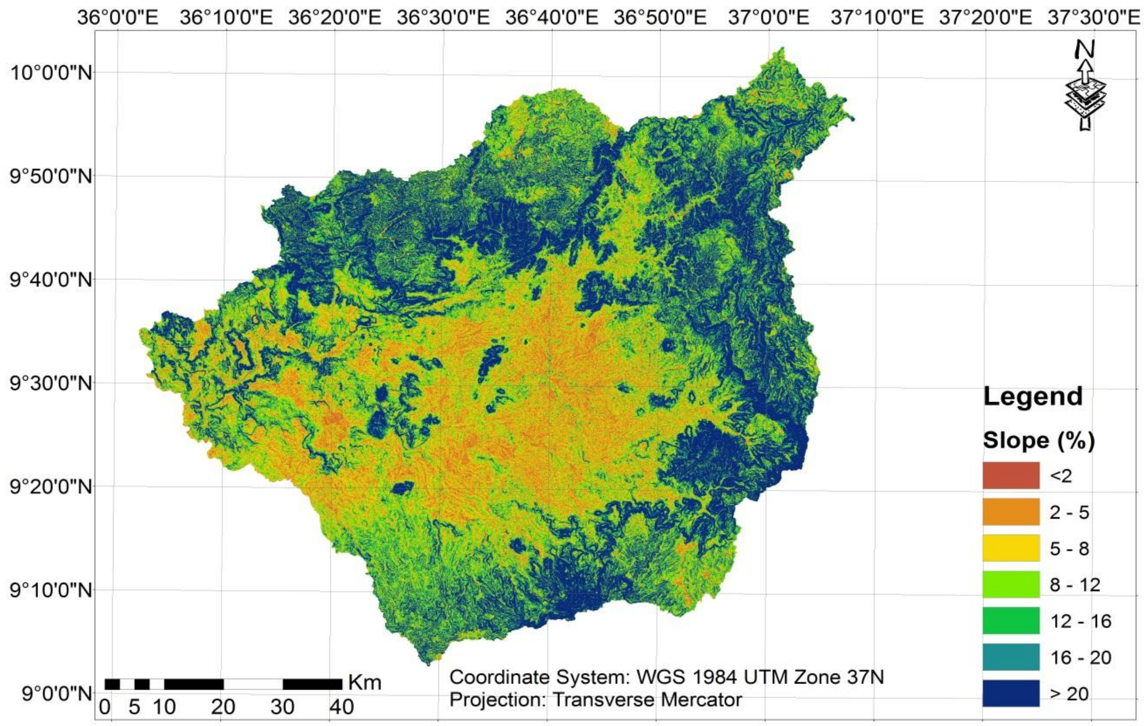

Figure 3.9 Map of slope gradient in percent

3.5.4. Digital elevation model (DEM)

Digital elevation models (DEMs) are point elevation data stored in digital computer files and can freely download from internet. These data consists of x, y grid locations and point elevation or z values. It is a raster data set generated in a variety of ways for a different map resolutions or scales (Li *et al*., 2005). It is also commonly used digital elevation data source and an important part for watershed characterization. Many agencies provide DEM data with 200, 90, 30 and 10 m resolutions. But for this specific study resolution or pixel size of 30 by 30 m resolution was used. The point elevation data are very useful to use as an input to the GIS to yield important derivative products such as slope, flow accumulation and flow direction in the process of watershed delineation.

In this study, the DEM data was used to delineate the watershed making the outlet near the confluence point with Didesa River, to classify the Agro-climatic zone of the catchment and to generate the very important RUSLE factors, such as LS and P-factors.

3.6. Dissemination plan

The thesis will be given to concerned bodies for the considerations of the recommendations given to reduce the erosion problem in the study area. In addition, it will be submitted to international peer reviewed journal for the considerations of publication.

4. RESULTS AND DISCUSSIONS

4.1. RUSLE Model Parameters

4.1.1. R - Factor

In the study area, the long-term mean annual rainfall amount was varied between 1570 to 2130 mm. Owing to this variation in mean annual rainfall amount within the study area, variation in rainfall erosivity was observed. Accordingly, the rainfall erosivity values estimated from mean annual rainfall of the selected rainfall stations ,varied from 882 MJ mm ha^{-1} hr^{-1} yr^{-1} at Shambu to 1196 MJ mm ha^{-1} hr^{-1} yr^{-1} at Nakamte. The calculated values in (Table 3.4.1.1, *Section 3.4.1.1*) show that as the mean annual rainfall increases, the rainfall erosivity also increases. Following this, the study area faces highly erosive rainfall at Southern part of the study area Around Nakamte and gradually decreases towards the central and eastern parts of the study area around Hanger Gute and Shambu respectively. The areas in between the two extremes (Shambu and Nakamte), shares the values of erosivity in between the maximum and minimum erosivity value distributed spatially. Figure 4.1 shows the spatial variation of erosive power of rainfall in the study area.

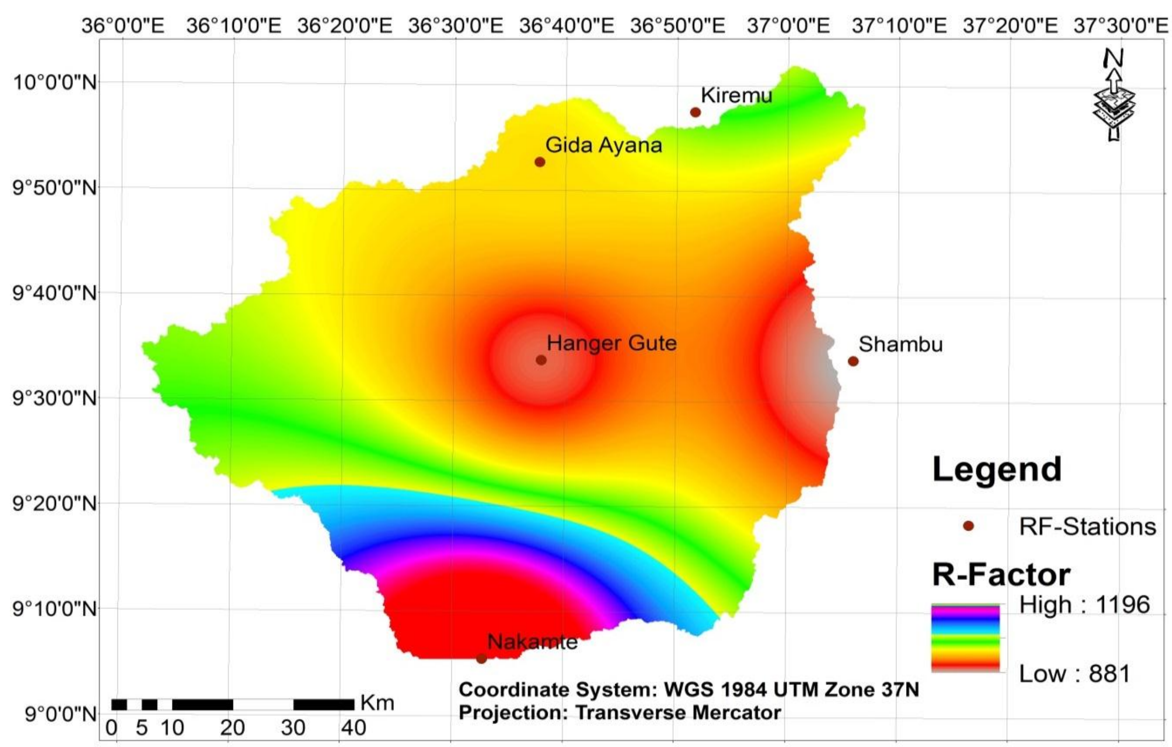

Figure 4.1 R-factor map of the study area

4.1.2. K-Factor

From the digital soil map of the study area, eight different soil types with different characteristics were identified (Table 3.7, *Section 3.4.1.2*). The dominant soil type, Haplic Alisols covers the larger area which accounts about 38.2 % of the total area. Mostly this soil type exists in the Southern, central parts and northern boundary of the catchment (Figure 4.2 A). Haplic Acrisols, which is the second largest coverage area, is found at central to West and North-Western parts of the catchment. Haplic Arenosols which is highly resistance to erosion is found at the northern parts of the catchment and covers too small areas, about 0.004 % which is even invisible on the soil map unless zoomed in it in the GIS windows.

The erodibility characteristics of the existed soils in the study area were varied with the range of K-factor value of 0.15 to 0.35 t ha hr ha^{-1} MJ^{-1} mm^{-1}. As the K-factor values approaches to 1, it indicates the susceptibility of the soil to erosion and as the K- factor values close to 0, it indicates the soil having good erosion resistance capacity. Hence, Dystric Leptosols, Eutric Leptosols and Haplic Arenosols which accounts about 12.8, 2.3 and 0.004 % of the total area respectively, have highest K-factor values of 0.35. Eutric Vertisols, which covers smaller area about 0.1 %, has the lowest K-factor values of 0.15, which indicates that the soil is less susceptible to erosion (Table 3.7).

Generally, Figure 4.2 (B) shows that > 60 % 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 ha hr ha^{-1} MJ^{-1} mm^{-1}. Such soil types were found mostly at the central and South-Western parts of the catchment with some coverage at Northern part as well. Therefore, in terms of soil erodibility condition, the catchment characterizes with moderately vulnerable to erosion.

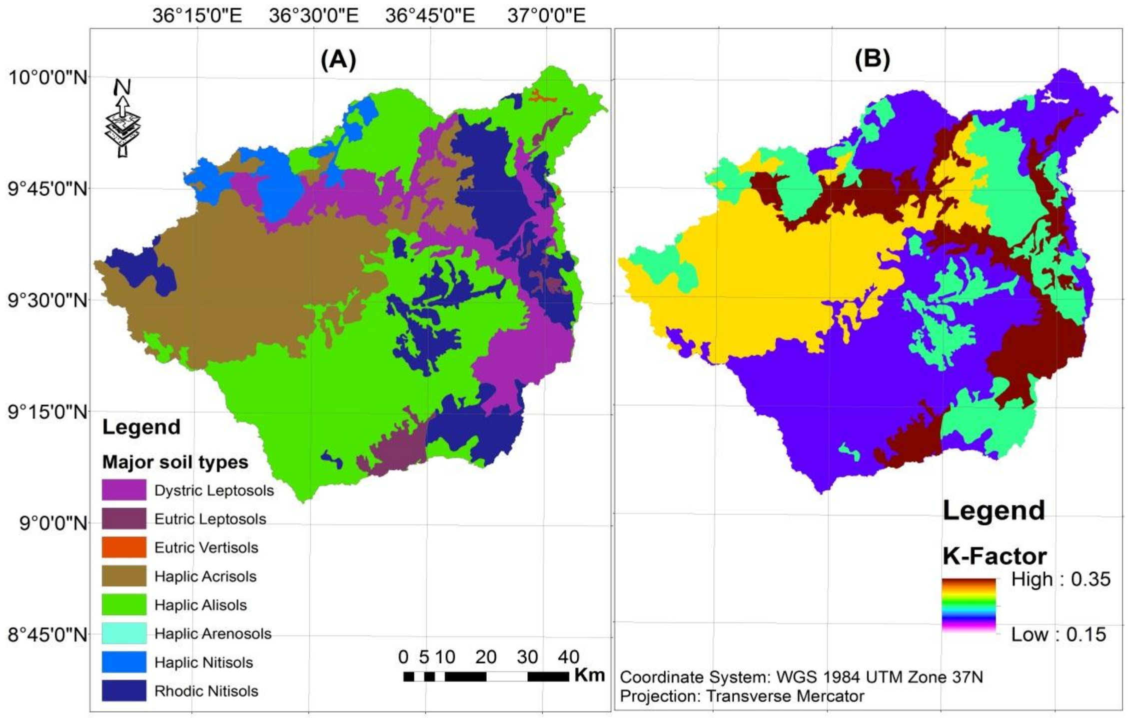

Figure 4.2 Major Soil types in the study area (A) respective K-factor map (B)

4.1.3. LS-Factor

The values of LS-factor in the study area varies between 0 (flatter and lower part) to 61(steeper and upper part). As illustrated in Figure 4.3, most of the central and South-Western parts of the study area show a lower LS-factor value of 0 to 0.05. The higher LS- factor values of 10 to 61 were mostly observed at the mountainous and hilly region of the study area and along the side (bank) of the rivers. This is because, as the slope gradient increases, the value of LS-factor also increases. Consequently, soil erosion also increases. Therefore, at the area, where smaller LS-factor values existed, the expected soil erosion due to this factor would be less and at the area where, larger LS-factor values existed, the expected soil erosion would be more.

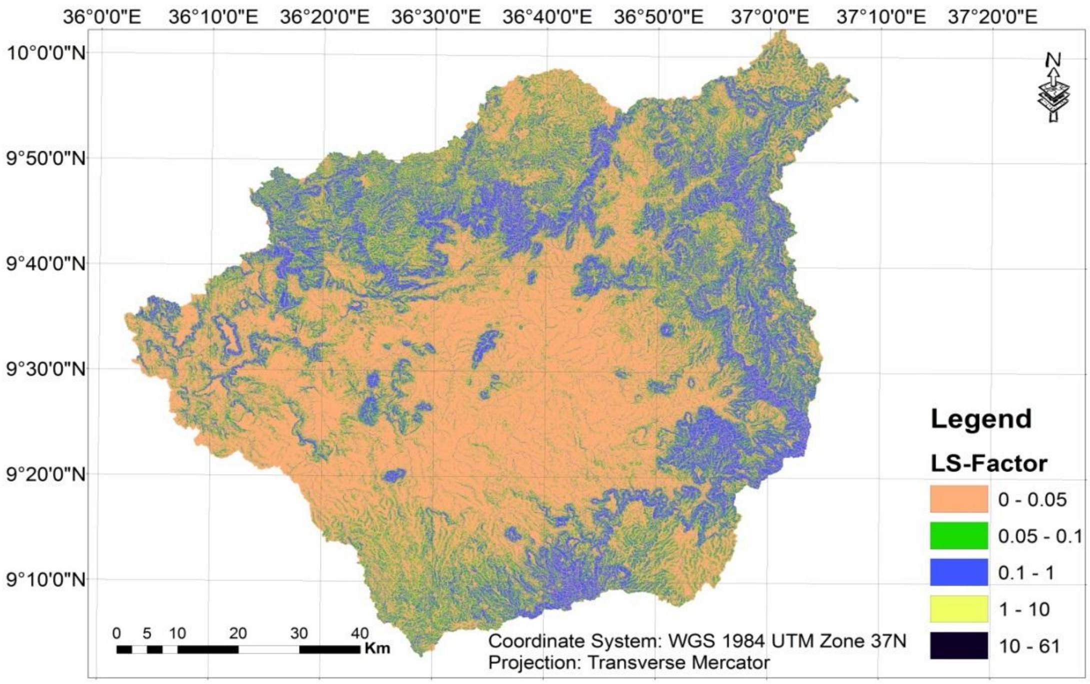

Figure 4.3 LS- factor map of the study area

4.1.4. C-Factor

From the classified LU/LC image, the area of each LU/LC class was calculated and presented in (*section 3.4.1.4*, Table 3.8). Based on the calculation, it was observed that the highland area was covered with open forest about 14 %, grazing land about 0.83%, grass lands about 12% and dense forest of 4.5% which corresponds with lower C-factor values. Over the study area, dense forest and grass land which have C-factor values of 0.01, collectively covers an area of only 16.5 % and about 59.5 % of the study area was covered with agricultural land which exposes to direct rainfall during the time of farm preparation. Soil erosion from this area was expected to be high because of the soil is exposed to the first rainfall events without any cover. For this area, the maximum C-factor value of 0.15 was assigned for agricultural lands next to bare soil with C-factor values of 0.6. As it is seen from the map (Figure 4.4 A) the cultivated land covers most of the central parts with some scattered distribution at Southern and Northern part of the study area. Therefore, 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 clearly on C-factor map for respective land use and land cover class (Figure 4.4B).

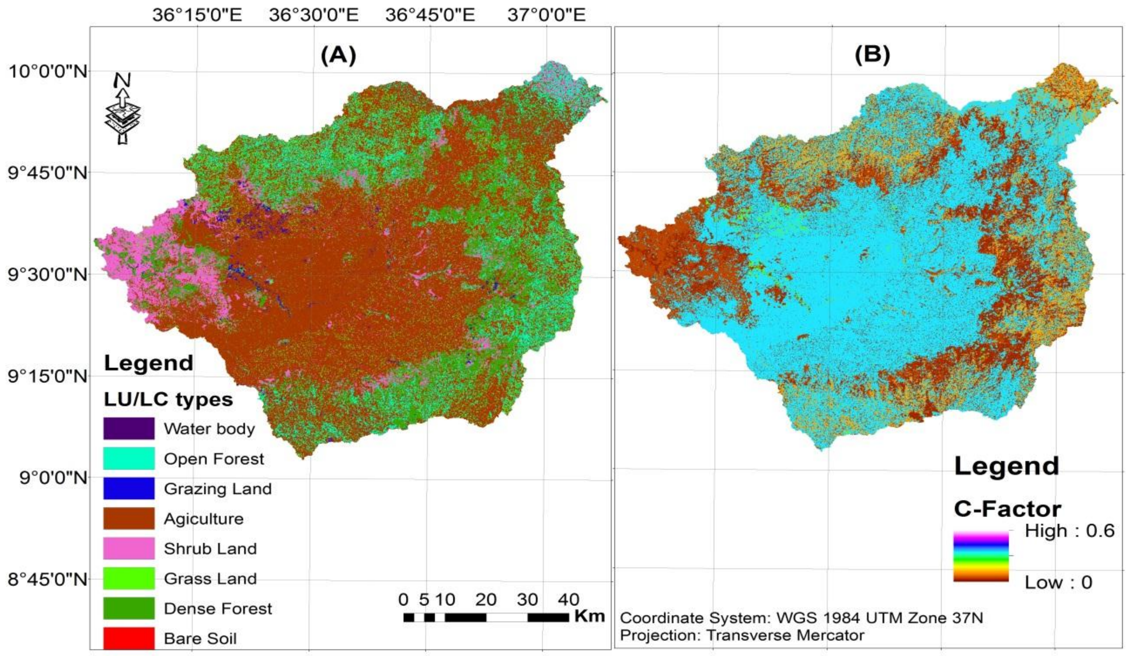

Figure 4.4 Maps of LU/LC (A) and corresponding map of C- factor (B)

4.1.5. P-Factor

Depending on the land management practice employed in the study area currently on varied slope gradient, the value of P-factor ranges from 0.4 to 0.9 (Figure 4.5 A). Based on the result, the central part of the study area characterizes with lower P-factor values and the whole other part of the study area shows the higher P-factor values. As shown in slope map of the study area (*Section 3.4.1.4*, Figure 3.9), the central part of the study area is highly flat and gentle slope from 2 to 16 % and the Southern, Eastern and Northern parts of the study area is steeper slope which is more than 16 % slope. Because of the P-factor values are highly influenced by slope steepness conditions, this upper part of the study area was characterizes with higher value of P-factor. Figure 4.5 shows P-factor values for existed conditions (A) and for imagined watershed management practice (B). Considering an implementation of watershed management practice such as contouring with terracing fully developed, the P-factor values ranges from 0.1 to 0.18 (Figure 4.5 B). In this condition also, the lower values of P-factor was concentrated at the central 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 central 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.

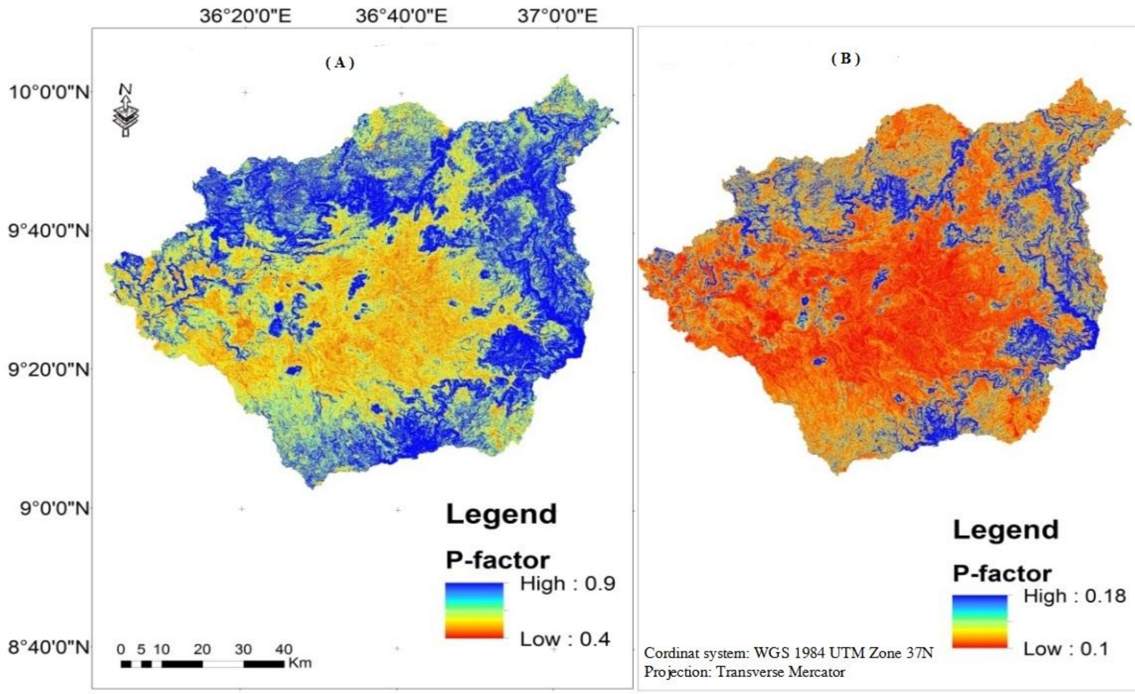

Figure 4.5 Map of P-factor for existing condition (A) for the imaged conditions (B)

4.2.Estimated average annual soil loss for existing condition

The pixel-based modeling results show that the spatial distribution of the annual soil loss rate varied from 1 t ha^{-1} yr^{-1} in low land and flat area to 500 t ha^{-1} yr^{-1} in degraded sloppy area with average annual soil loss rate of 32 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 24.93 Mtons of sediment from 7790 Km^2 of land.

The result showed that the catchment is experiencing quit large spatial variation of soil loss due to quit large difference in topographical condition, land use land cover variation and higher rainfall variation. It is because; these factors are the major factor affecting soil erosion in the study area. Accordingly, the watershed was classified in to six severity classes to identify the most prone area to erosion, moderately affected area, list affected area and other respective trends of erosion conditions. In terms of exposure to the risk of erosion, about 15.8 % of the watershed was characterized by low to moderate soil erosion problem, which was from 1 to 11 t ha^{-1} yr^{-1} and such area can be considered as areas with tolerable soil erosion risk area. The remaining percentage area was categorized under, high, very high, sever and very sever soil erosion risk areas of 39.3, 31.8, 12.1 and 1% of the study area respectively (Table 4.1).

According to FAO (1985) and Renard *et al.* (1996), soil loss tolerance refers to the maximum soil loss that can occur from a given land without leading to degradation of the soil, and this is estimated to be 5- 11 t ha^{-1} yr^{-1}. In line with this, the central parts of the study area which covered about 15.8% of the total area, could be considered as low soil erosion risk area. This is because; the result of soil erosion rate in this area was found to be in a range of maximum tolerable erosion limit of 11 t ha^{-1} yr^{-1}. As it has been clarified by Yahya (2013), LS-factor, R-factor and K-factor, have a significant effect on the process of erosion in decreasing order. Therefore, the lower values of soil loss vulnerability was because of the central parts of the study area is characterized with relatively flat and gentle slope having lower LS-factor of 0 to 0.1 and the lower rainfall erosivity values of 882-973 MJ mm ha^{-1} hr^{-1} yr^{-1} as well as the lower K-factor values shown in (Figures 4.1, 4.2 and 4.3).

Based on the result found, about 84.2% (> 4480 km^2) of the study area was identified to be highly suffered in soil erosion. The severity of erosion ranges from high (12-25 t ha^{-1} yr^{-1}), very high (25-50 t ha^{-1} yr^{-1}) and sever soil erosion class (50-100 t ha^{-1} yr^{-1}) (Table 4.2). About 1% of the total area (77.9 ha) was exposed to very sever soil erosion risk (>100 t ha^{-1} yr^{-1}). This part of the area is found mostly at the South corner of the catchment and some parts to Western part as well as Eastern part of the catchment. This is due to the higher erosive power of rainfall that comes from higher rainfall intensity around the specified area and the higher LS- factor values of 10 to 60, resulted from cultivation on steep slope lands (Figures 4.3 and 4.4). Table 4.1clearly indicates the area coverage and relative percentage of each soil erosion severity class for current condition of the study area.

The estimated soil loss rate and the spatial patterns are generally realistic, compared to previous studies on some of Ethiopian basins and watersheds. For instance, soil loss rate estimated by Hurni (1985) for Ethiopian highlands ranges from 0.0 to 300 t ha^{-1} yr^{-1}. Temesgen (2017) also reveals that the soil loss rate ranges from 0 to 237 t ha^{-1} yr^{-1}. Other related study conducted by Kebede (2014) shows that the soil loss rate ranges between 0 and 203 t ha^{-1} yr^{-1} from neighboring catchment of the study area, using the same model and from 0 to 150 t ha^{-1} yr^{-1} was presented by Betrie (2011) for the whole Blue Nile Basin.

In line with this, the average soil loss rate of the whole watershed in this study (32 t ha^{-1} yr^{-1}) is comparable with similar findings reported in Amare *et al.* (2014) for Wondo Genet watershed about 26 t ha^{-1} yr^{-1}, in Tadesse (2014) for the Jabi Tehinan watershed in the North-Western highlands about 30.6 t ha^{-1} yr^{-1} and Haregeweyn *et al.* (2017), also for the whole Upper Blue Nile Basin, reports to an average of 27.5 t ha^{-1} yr^{-1} with the same prediction model.

Table 4.1 Soil erosion severity class and corresponding percent coverage area.

	Current soil erosion status of the study area		
Soil-lossrate (t ha^{-1} yr^{-1})	Area (km^2)	Area coverage (%)	Severity Class
<5	315	4.0	Low
5-11	915	11.8	Moderate
11-25	3063	39.3	High
25-50	2475	31.8	Very High
50-100	941	12.1	Sever
>100	80	1.0	Very Sever
Total	7790	100	

Unlike the findings of this study, some studies however, report a rather higher rate of erosion in different parts of Ethiopian watersheds. For instance, Bewket and Teferi (2009) report high rate of erosion with an average soil rate of 93t ha^{-1} yr^{-1} for Chemoga watershed of Blue Nile Basin in North-Western highland. Gelagay and Minale (2016) also report for Koga watershed of Blue Nile basin, the average soil loss rate to be 47.4 t ha^{-1} yr^{-1}. In Contrary to the current and other studies in the highlands, few other studies report very low average soil erosion rate. For instance, in Medego watershed in the northern highlands with a rate of 9.63 t ha^{-1} yr^{-1} is observed by Gebreyesus and Kirubel (2009) and in Zingin watershed with a rate of 9.10 t ha^{-1} yr^{-1} is reported by Gizachew (2015). This variation of results comes from the actual existing condition of the watersheds. The lower results were due to the large portion of their study area being flat and gentle slope. For instance, about 49.77% of Medego watershed was covered with a slope less than 15% (Gebreyesus and Kirubel, 2009). Figure 4.6 shows total soil loss rate and its distribution over the study area.

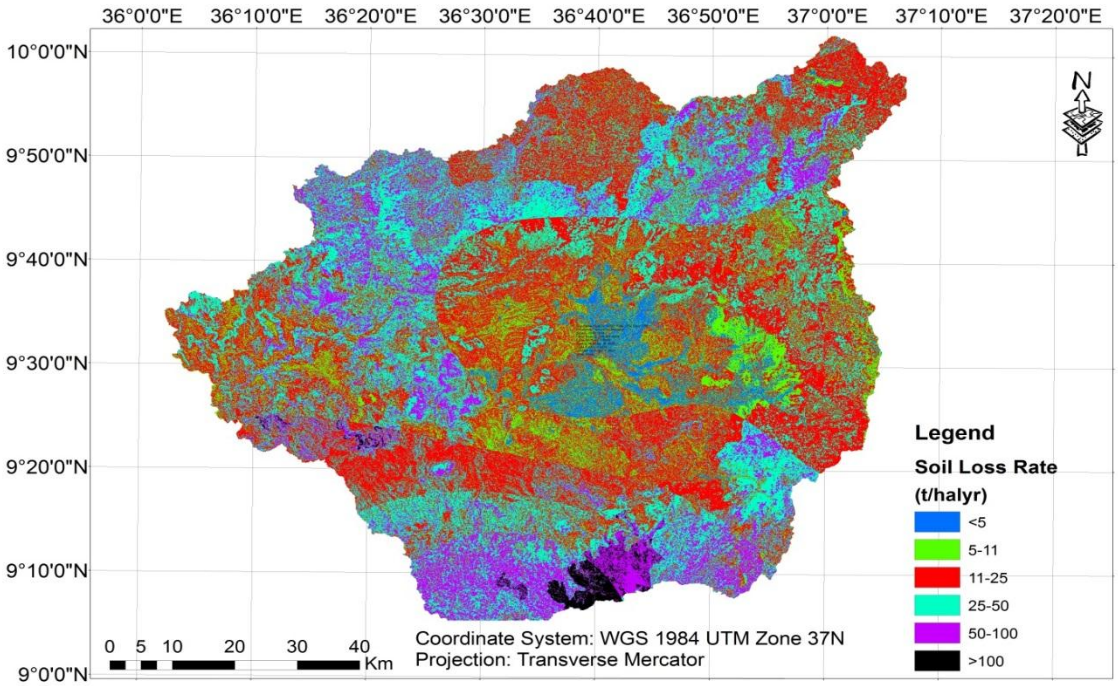

Figure 4.6 Total soil loss rate map of the study area

4.3. Impacts of proposed interventions measures

In this study, two cases of P-factor values were tasted to check the effects of watershed management on soil erosion rate. The first case, when P-factor values are taken for existed condition of the study area, discussed in Section 4.2. And the second case was what if there was an implementation of effective terracing with contour ploughing of farm lands in the study area? For this case, the result shows that, the annual average soil loss rate was reduced from 32 to 19.2 t ha^{-1} yr^{-1}, which means it was reduced the annual soil loss rate by 40%. 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 (Figure 4.7). Due to this physical intervention, the area, with soil erosion rate existed in the limit of soil loss tolerance of 11 t ha^{-1} yr^{-1}, increases from 15.80 to 41.81 % of the total area. On the other hand, the severely affected area, which shows a soil loss rate of >50 t ha^{-1} yr^{-1} would be reduced from 13.1 to 5.61 % of the total area, which indicates the reduction of severely affected area and the increment of least affected area by soil erosion.

Generally, the result of this section shows that the implementation of integrated watershed managements specifically terracing with contour ploughing, significantly reduces the vulnerability of soil erosion in the study area. The comparison of these two conditions (current existed condition and imagined contour ploughing and terracing) is presented on Table 4.2 and Figure 4.7 with the same color codding to easily understand the reduction of soil erosion rate due to this intervention.

Table 4.2 The comparisons of soil loss for current management practice and imagined management practice

	Current soil erosion status of the study area		Soil erosion status considering contour ploughing and terracing		
Soil-lossrate (t ha^{-1} yr^{-1})	Area (Km^2)	Area coverage (%)	Area (Km^2)	Area coverage (%)	Severity Class
<5	315	4.0	948	12.17	Low
5-11	915	11.8	2309	29.64	Moderate
11-25	3063	39.3	2949	37.86	High
25-50	2475	31.8	1133	14.62	Very High
50-100	941	12.1	398	5.11	Sever
>100	80	1.0	47	0.59	Very Sever
Total	7790	100%	7790	100%	

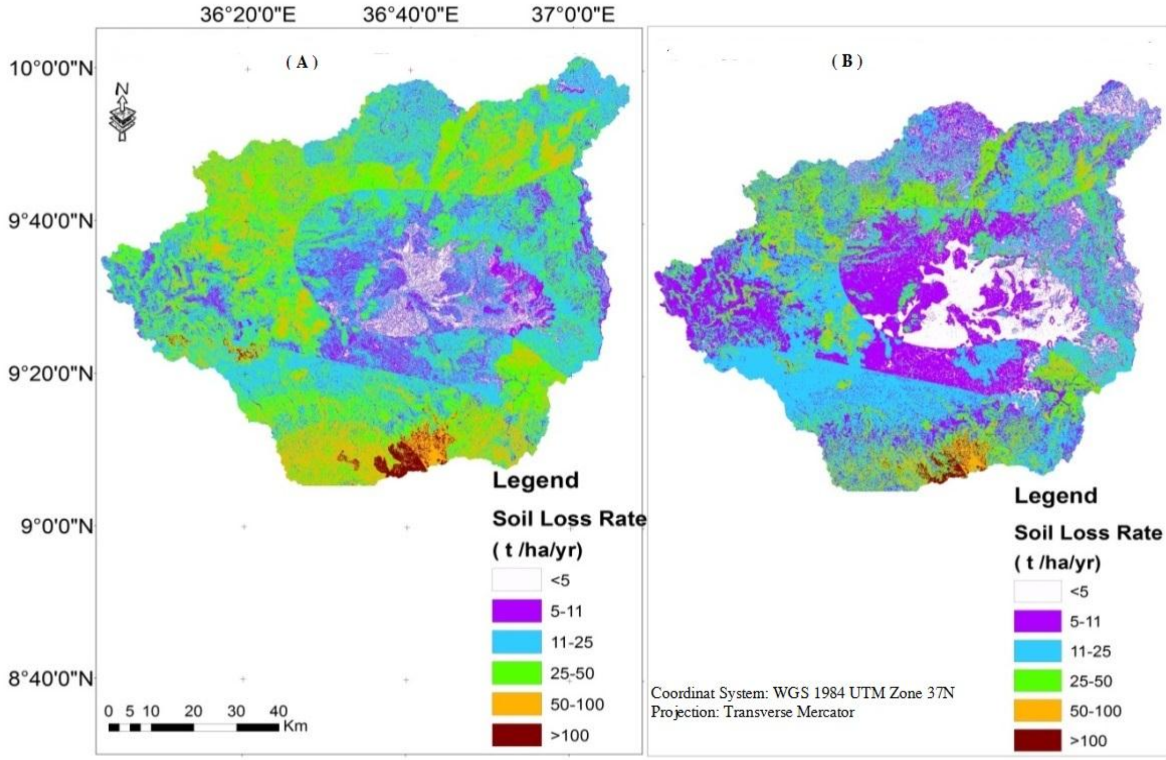

Figure 4.7 Map of total soil loss rate for current condition (A) considering the imagined management practice (B)

4.4. Prioritization of soil erosion vulnerable area

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 4.8 shows the boundary of the districts and the color coding severity class of soil erosion for each district in the Hangar River watershed. Based on the result, *Wayu* district was identified to be a sever soil erosion prone area. From this district, the rate of erosion was found to be minimum of 2 and maximum of 500 t ha^{-1} yr^{-1} with annual average of 47.2 t ha^{-1} yr^{-1} which is the maximum rate of the entire study area. *Seyo* and *Horo* districts show relatively a lesser vulnerability with an annual average soil loss of 23.8 and 21.2 t ha^{-1} yr^{-1}, respectively. 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 shows the minimum, maximum and annual average soil loss rate for each district.

Table 4.3Table shows the vulnerability of soil erosion at district level

Districts	Soil loss rate (t ha^{-1} yr^{-1})		
	Minimum	Maximum	Annual Average
Limu	4	320	39.2
Belew Jiganfoy	4	160	31.5
Sasiga	2	320	36.4
Wayu	2	500	47.2
Sire	2	250	27.7
Seyo	2	100	23.8
Horo	1	100	21.2
Dengoro	2	160	24.3
Jarte	2	300	30.3
Yaso	6	200	27.7
Gida Ayana	2	100	29.5

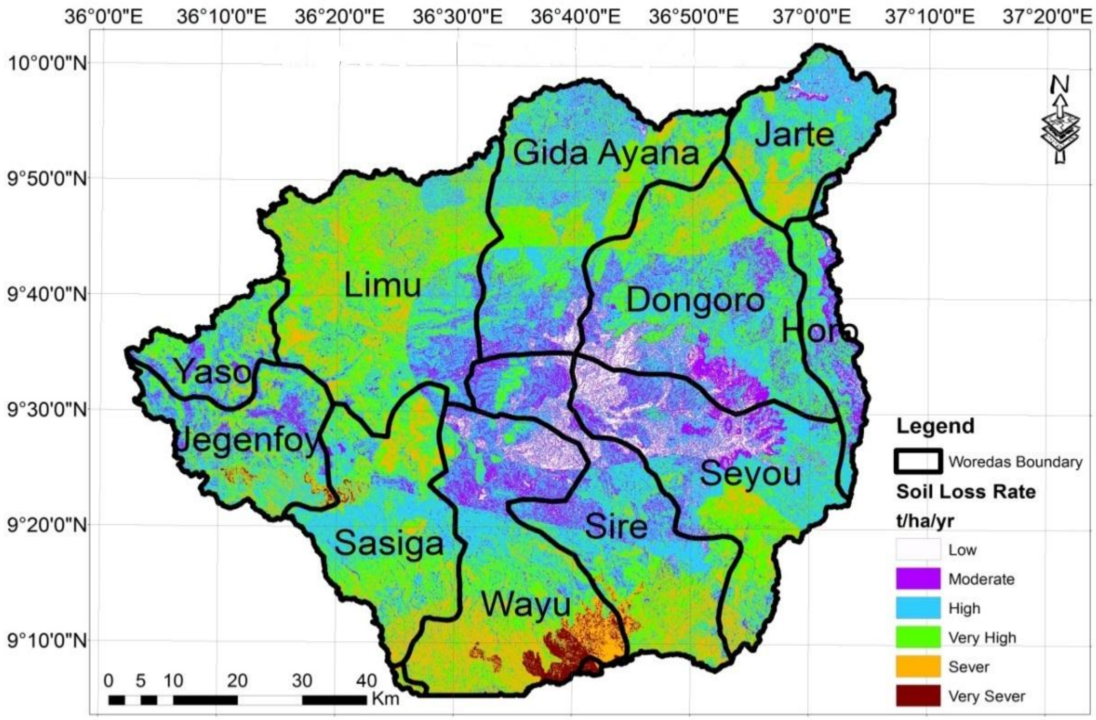

Figure 4.8 Boundaries of districts in the study area and severity class map

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study attempted to present a comprehensive over view of the status of erosion and its distribution in the watershed under present watershed condition and with proposed watershed management practices. The findings of this study reveal that the study area is currently experiencing severe soil erosion by water. The result of this study indicates that the annual soil loss rate for existed conditions ranges from 1 to 500 t ha^{-1} yr^{-1} with average annual soil loss of 32 t ha^{-1} yr^{-1}, which is far larger than the maximum tolerable soil loss of 11 t ha^{-1} yr^{-1}. Such losses could threaten the sustainability of land productivity in the study area and at the same time, excessive sedimentation and eutrophication problem at the downstream proposed reservoirs on Hangar River and also on Ethiopian Great Renaissance Dam.

Implementing conservation practice such as contour ploughing with terracing effectively could reduce the annual average soil loss from 32 to 19.8 t ha^{-1} yr^{-1}. Due to the imagined intervention, the area which was in a range of maximum soil los tolerance could be improved from 15.8 to 42.34% of total area.

In the steep slope areas of the watershed especially in wayu district, the rate of soil erosion extends up to 500 t ha^{-1} yr^{-1} with annual average soil loss of 47.2 t ha^{-1} yr^{-1}. Central and Eastern parts of the study area including Horo and Seyo districts, show a lesser rate of erosion of 21.2 and 23.8 t ha^{-1} yr^{-1} respectively which shows a lesser vulnerability to erosion.

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 predicted amount of soil loss and its spatial distribution could facilitate to implement a comprehensive and sustainable land management through conservation planning for the prioritized soil erosion risk areas in the study area.

5.2. Recommendations

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

- Intensive sustainable soil and water conservation practices should be carried out by taking each stream order and agricultural field as management unit especially in the upper part where most critical sediment source areas are situated.

- Areas characterized by high to very sever soil loss should be given special attention before the area is changed to irreversible land degradation.
- The watershed management for moderate soil erosion area should also be provided in order to protect them from further degradation and erosion.
- Local stake holders and decision makers should implement both long and short-term timely updated natural resource management systems.
- From the result, the effects of implementation of physical soil conservation measure terracing with contour ploughing reduces soil loss rate by 40% , therefore, other physical and biological indigenous means of soil conservation measures should be tested by how much it could be reduced if fully developed.

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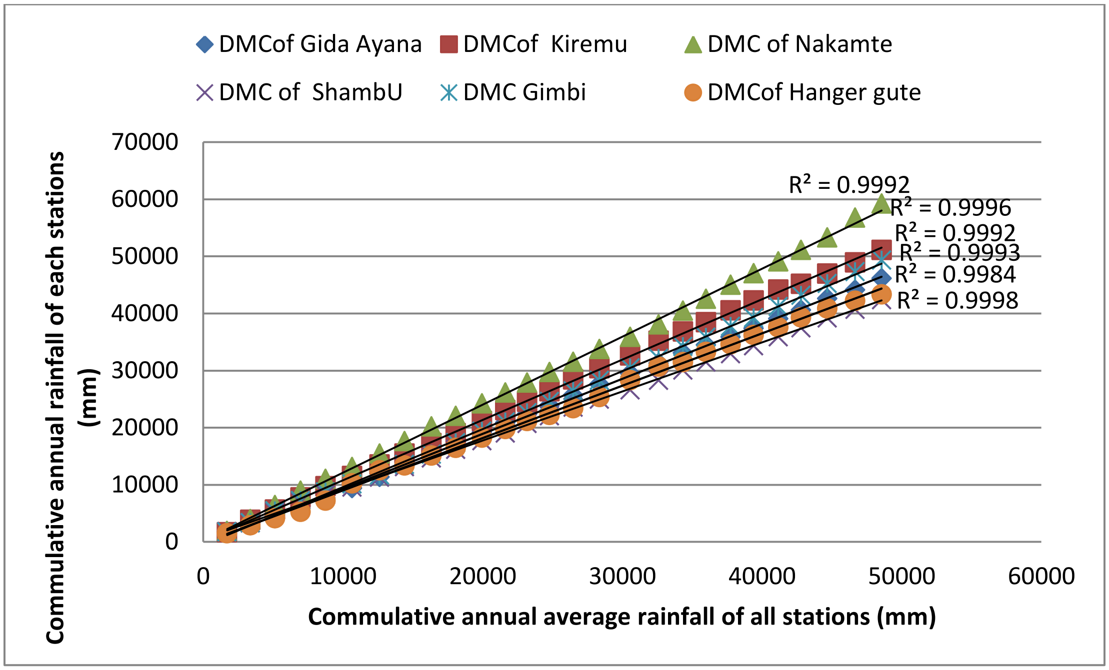
Appendixes

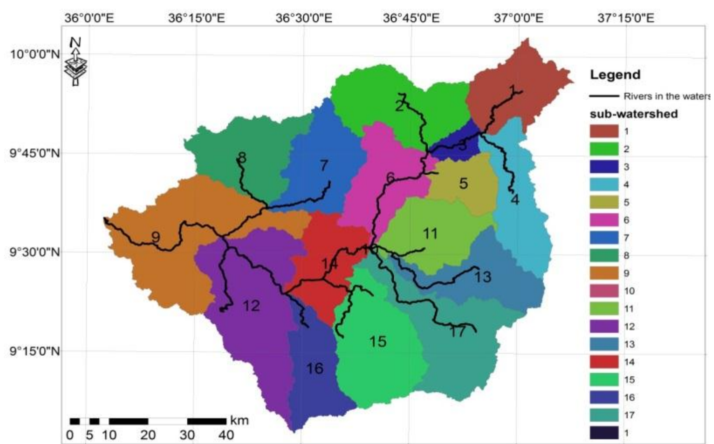
Appendix 1: Mean annual rainfall (mm) of selected stations (1990-2016)

Years	Gida Ayana	Kiremu	Nakamte	Shambu	Hanger Gute	Gimbi
1990	1733.3	1668.5	1889.7	1773.7	1513.9	1725.3
1991	1160.6	2165.9	2057.9	1501.6	1397.8	1645.0
1992	1215.9	1812.9	2479.1	1834.8	1196.1	2061.0
1993	1745.4	2101.7	2519.4	1807.6	1155.3	1756.8
1994	1780.8	1994.5	2090.0	1275.8	1950.2	1542.6
1995	1765.7	1792.9	2081.1	1376.2	2995.9	1375.8
1996	1936.1	1979.7	2320.9	1753.3	2332.6	1576.0
1997	2119.0	1946.0	2190.0	1809.3	812.1	1857.0
1998	2080.9	1815.2	2551.4	1498.5	1778.6	1817.2
1999	1909.8	1754.3	1894.8	1546.5	1323.2	1980.7
2000	1764.7	2104.3	2151.3	1509.0	1761.5	2028.7
2001	1680.0	1910.7	1942.2	1350.8	1533.9	1603.6
2002	1487.7	1455.1	1706.0	1686.4	1387.1	1651.0
2003	1499.6	1834.0	1837.5	1349.3	1095.0	1946.3
2004	1834.4	2085.6	1792.1	1489.3	1154.7	1873.3
2005	1856.2	1971.0	2248.7	1420.3	1948.9	1808.2
2006	1907.7	2260.8	2139.4	1619.8	2995.9	2191.0
2007	1822.8	2541.3	2173.0	1656.6	2332.6	1709.4
2008	1762.9	1631.7	2441.3	1789.6	812.1	2028.4
2009	1422.7	1643.5	2022.8	1423.3	1778.6	1629.7
2010	1397.5	2078.1	2482.1	1431.7	1323.2	1899.0
2011	1501.0	1715.5	2010.4	1421.9	1647.8	1550.1
2012	1715.9	1889.9	2109.3	1567.8	1314.0	1929.9
2013	1478.3	1039.0	1965.3	1543.4	1780.1	1990.9
2014	2016.8	1799.3	2196.6	1742.2	1533.9	2047.7
2015	1514.6	1967.8	3486.6	1525.8	1386.7	1675.0
2016	2022.0	2136.3	2447.4	1680.8	1067.5	1629.7
Total Av.	1708	1892	2130	1570	1604	1675

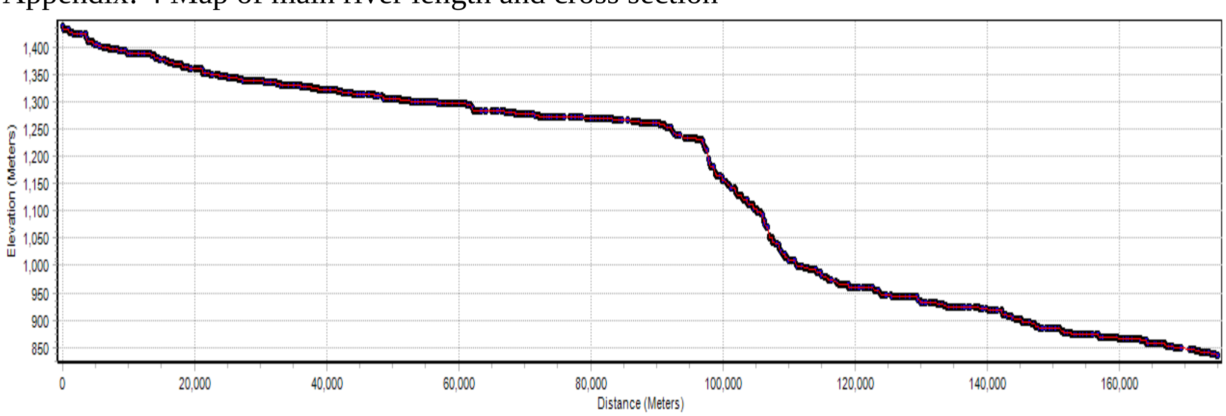
Appendix: 2 Graph showing consistency of rainfall data



Appendix: 3 Map showing sub-watersheds in the study area



Appendix: 4 Map of main river length and cross section



Appendix: 3 Image of grazing land (A) Hanger River (B) farm land (C) and degraded grazing land (D) in the study area.

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