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JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

ENVIRONMENTAL ENGINEERING CHAIR

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ASSESSMENT OF SOIL EROSION RISK USING RUSLE AND GIS: A CASE STUDY OF BELES SUB-BASIN, NORTH-WESTERN BLUE NILE, ETHIOPIA

BY: YADETA SAKETA KEBEDE

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

November, 2018

Jimma, Ethiopia

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Advisor: Dr.-Ing. Fekadu Fufa (PhD)
Co advisor: Wagari Mosisa (MSc.)

November, 2018
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DECLARATION

I, Yadeta Saketa, do hereby declare that this thesis titled “Assessment of soil erosion risk using RUSLE and GIS: a case study of Beles sub-basin” is entirely my original work. This thesis has not been submitted and presented for any academic degree award at any other University and all other materials used are duly acknowledged. The thesis has been carried out by me under the guidance and supervision of my advisors Dr.-ing. Fekadu Fufa and Mr. Wagari Mosisa (MSc.).

By Yadeta Saketa ______________ ____________

As this thesis advisors, we hereby certify that we have read and evaluated this thesis prepared under our guidance, entitled “Assessment of soil erosion risk using RUSLE and GIS: a case study of Beles sub-basin” and we recommended that it can be submitted as fulfilling the thesis requirement.

Advisors name	**Signature**	**Date**
Dr.-ing. Fekadu Fufa Main advisor	______________	_______________
Mr. Wagari Mosisa (MSc.) Co-dvisor	______________	_______________

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 Yadeta Saketa and examined the candidate. We recommended that the thesis be accepted as fulfilling the requirement for the degree of Master of Science in Environmental Engineering.

Approved by the Board of Examiners:	**Signature**	**Date**
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Internal Examiner		
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External Examiner		
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Chairman		

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ABSTRACT

Soil erosion by water is a serious environmental problem that affects environmental quality, agricultural productivity and sustainability of downstream structures and resources. The impacts of soil erosion could be worst in the developing countries including Ethiopia. Assessment of soil erosion is useful in planning and soil conservation works. The objective of this study was to assess soil erosion risk in the Beles sub basin located in the Metekel Zone of Benishangul-Gumuz and Awi Zone of Amhara National Regional State, north western part of Ethiopia. The study was conducted using the Revised Universal Soil Loss Equation (RUSLE) model with GIS. The model incorporate rainfall, soil, land cover and digital elevation model data to generate RUSLE parameters. The rainfall erosivity factor was derived from mean annual rainfall data of nearby rain gauge stations and the soil map data of the study area was used to generate soil erodibilty factor. A digital elevation model (30 m x 30 m resolution) was used to delineate the study area and analysis slope factor. The land use/cover map of 2013 was used to generate crop management factor and conservation practices factor. The five factors raster maps were multiplied in GIS raster calculator and the spatially distributed annual soil loss rate map was determined. The result shows that the amount of soil loss from the study area ranges from zero up to 370 ton ha^{-1} yr^{-1}. The average annual soil loss rate for the entirely area was estimated at 8.39 ton ha^{-1} yr^{-1} and the total annual soil loss potential was 11.91Million ton yr^{-1} for the whole area. Based on the results, about 15.85 % of the study area has soil loss that was above the maximum tolerable soil loss of 11 ton ha^{-1} yr^{-1}. The method (RUSLE) used as erosion assessment model has given up a fairly reliable estimation of soil loss rates in the study area that helps to delineate erosion-prone areas and prepare conservation plans for efficient use of resources. Therefore, the model could be applied in other watershed or basin for assessment, delineation and prioritization of erosion prone areas for conservation interventions. Those areas with high soil erosion rate needs immediate and appropriate intervention of soil conservation measures that needs the collaboration of all the stakeholders.

Key words: Beles sub basin, GIS, RUSLE, Soil erosion

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ACRONYMS

AGNPS	Agricultural Non-Point Source
ArcGIS	Architectural Geographic Information System
DEM	Digital Elevation Model
EMA	Ethiopia Mapping Agency
EUROSEM	European Soil Erosion Model
FAO	Food and Agriculture Organization
IDW	Inverse Distance Weight
KINEROS	Kinematic Erosion Simulation
MUSLE	Modified Universal Soil Loss Equation
Mt	Million ton
RUSLE	Revised Universal Soil Loss Equation
SCRP	Soil Conservation Research Project
SEDD	Sediment Delivery Distributed
SEMMED	Soil Model for Mediterranean Area
SLT	Soil Loss Tolerance
SWAT	Soil and Water Analysis Tool
UNEP	United Nations Environment Program
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WEPP	Water Erosion Prediction Project

1. INTRODUCTION

1.1. Background

The land degradation observed today is human-induced phenomenon resulted from population growth and the associated change in land use. Agreeing with Mitiku *et al.* (2006), utilizing natural resources such as soils basically implies the risk of overusing and degrading these resources. At the beginning of the 21^{st} century, about 19.65 percent of the terrestrial surfaces worldwide were defined as degraded land (Eswaran *et al.*, 2001).

Soil erosion by water is considered the most prominent form of soil degradation and one of the severe global challenges of the twenty-first century (Lal, 2001; Mitiku *et al.*, 2006; Pimentel, 2006). It is most significant problem in the tropics and sub-tropics compared to the rest of the regions on the Globe (Lal, 2001). Soil degradation is a change in the soil health status largely due to anthropogenic processes (FAO, 2014). It results in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries.

Without human influence, geological or natural erosion occurs at all times due to the interaction of climate, vegetation, parent material and topography (Mitiku *et al.*, 2006; Ganasri and Ramesh, 2016). But this natural process can be accelerated by human activities creating soil loss that exceeds the soil formation rate in a given area which is, therefore, referred to as accelerated or human induced soil erosion.

Accelerated soil erosion creates difficulty to sustainably use of agricultural land resulting in both on-site and off-site effects (Hurni *et al.*, 2008; Tamene and Vlek, 2008; Shiferaw, 2011; Molla and Sisheber, 2017). The on-site effect is the erosion damage on the plot or farm where it occurs. This effect is related to soil quality and loss of agricultural soil by runoff (Hurni *et al.*, 2008). The off-site effects of erosion is the consequences of erosion downstream such as sedimentation of dams, sediment load in rivers causing flood risk, non-point source of pollution causing eutrophication and turbidity (Lal, 2003; Hurni *et al.*, 2008; Bewket and Teferi, 2009).

Study shows that about 80 % of the world's agricultural land suffers from moderate to severe erosion (Ritchie *et al.*, 2003). About one billion people globally; around 50 % of them found in Africa are affected by soil erosion (Blanco and Lal, 2008). The risks of soil erosion to food security are severe in developing countries of Africa and Asia (Blanco and Lal, 2008; Shiferaw, 2011). This is largely due to high population pressure, land shortage, inappropriate agricultural practices and low adaptive capacity to restore degraded soils and replace depleted nutrients by subsistence smallholder poor farmers (Blanco and Lal, 2008; Mengistu *et al.*, 2015).

In Ethiopia, soil erosion by water constitutes a severe threat to the national economy (Hurni, 1993; Gete, 2000; Bewket and Teferi, 2009). According to Tekalign (2008), land degradation in Ethiopia accounts for 8 % of the global total. Since more than 80 % of the population depends on agriculture, physical losses of top soil and removal of plant nutrients exacerbate food insecurity (Hurni, 1993; Tamene and Vlek, 2008; Bewket and Teferi, 2009). The problem is much more severe in the highlands where majority of the human and livestock population of the country are living and agriculture is intensive (Ayalew and Selassie, 2015).

In the Ethiopian highlands, soil erosion ranges from 16-300 ton ha^{-1} yr^{-1} in cultivated lands (Hurni, 1988; Assegahegn and Zemadim, 2013). A study by Gete (2000) also estimates 130-170 ton ha^{-1} yr^{-1} soil loss on a similar land use in the northwestern highlands of Ethiopia. Even though the statistics are disagreeing, the magnitude of soil erosion problem is largely indubitable. The estimations of soil loss rates can give only an indication about an average order of magnitude. The maximum amount of soil erosion, called tolerable soil loss rate, that can occurs without any reduction in crop productivity (Hurni, 1983) can ranges from 5 to 11 ton ha^{-1} yr^{-1} according to Renard *et al. (*1996).

But, every year an estimated 1.9 to 7.8 billion tons of soil have been lost in Ethiopia (Gete *et al.*, 2014). As a result, more than 30,000 ha of the country's cropland become out of production annually due to severe soil erosion (Erkossa *et al.*, 2015). A national level study by FAO (2005) in Ethiopia also indicates that more than 2 million ha of Ethiopia's highlands have been degraded beyond rehabilitation. This is reflected in cereal yield reduction and renders highland cultivation unsustainable. Thus, in order to achieve food security, poverty reduction and environmental sustainability in the country reversing soil erosion is a high priority (Bewket and Teferi, 2009; Shiferaw, 2011). The study area, Beles sub basin, is one of the area suffering with soil degradation problems largely due to deforestation (Desta, 2014).

Various studies suggest that high rates of soil erosion in Ethiopia are mainly caused by extensive deforestation, overgrazing, changes in land cover, agricultural intensification and intense rainstorms, population growth, declining land productivity and climatic fluctuation (Amsalu *et al.,* 2007; Erkossa *et al.,* 2009; Shiferaw, 2011; Wolka *et al.*, 2015). In general, UNEP (2002) suggest five major human causative factors of soil degradation at the global level. These are overgrazing, deforestation, agricultural mismanagement, fuel wood consumption and urbanization.

In the Beles sub basin which is typical of the northwestern part of the Abbay basin, Gilgel Beles River and many small tributaries drained into the main Beles River contributing sediment to the main River at various rate and extent. Despite to the sediment contributed by this sub basin and the effects of soil erosion, little if any research has been done in the study area, specifically with regards to the estimation of annual soil erosion risk. The eroded soil in the study area results in sedimentation problem that seriously affect the storage capacity of dams especially the Grand Ethiopian Renaissance Dam, thereby jeopardizing its sustainability.

To tackle the on-site and off-site effects of soil erosion, appropriate erosion control and sediment management strategies are urgently needed. Most recently, watershed management is an approach followed by the government of Ethiopia to protect soil from erosion in particular and to reverse land degradation in general (Nigussie *et al.,* 2012). In order to plan and implement such strategies, understanding of the magnitude, factors responsible for and spatial pattern of soil erosion is crucial.

To predict soil erosion quantitatively, different prediction models have been efficiently developed. One of the most widely used empirical models is the RUSLE (Renard *et al*., 1997). Therefore, the objective of this study was to assess soil erosion risk in Beles sub basin using RUSLE and GIS.

1.2. Statement of the problem

Soil is the basic resource for economic development and for maintaining sustainable productive landscapes and people's livelihoods especially for countries with agrarian economy like Ethiopia (Gashaw *et al.,* 2017; Molla and Sisheber, 2017*)*. However, soil erosion by water is a widespread problem affecting environmental quality, agricultural productivity and food security of the world.

Moreover, soil erosion affects negatively the natural water-storage capacity of catchments, design-life of man-made reservoirs and dams causing enormous dredging costs, quality of surface water resources, aesthetic landscape beauty and ecological balance. Soil erosion causes a severe decline in land productivity and severe downstream sedimentation, which is a major threat to the existing and future water resources development. Accelerated soil erosion reduces the soil organic matter content by washing away the nutrient rich topsoil (Pimentel, 2006) which reduces water infiltration capacity of soils and increases water run-off and exacerbates soil erosion.

As study indicates, Ethiopia is described as one of the most soil erosion affected country in the world. In Beles sub basin, sedimentation on gentle slopes and erosion on sloped areas exists. But, previous studies conducted in the study area indicate that Beles sub basin is important nationally and regionally. It has immense potential for irrigation and hydroelectric power potential and is considered as the development corridor with that of Tana sub basin by Ethiopian government. Agriculture and hydropower generation plays a significant role for the sustainable economic growth of Ethiopia.

The study area is typical of the northwestern part of the Abbay basin known to be surplus producing basin, but presently threatened by resource degradation as indicated by Bewket and Teferi (2009). The site is characterized by degradation of soils due to extensive deforestation and soil erosion is a major problem with trans-boundary consequences. The existing land and water resources system of Beles is adversely affected due to the rapid growth of population, deforestation, surface erosion and sediment transport which needs provision of modeling expertise and tools to effectively manage the water resources of the sub basin. Unless sedimentation for the existing projects as well as for the future was not properly managed, problems like difficulties in irrigation systems management leading to water shortage will exist.

Hence, for proper utilization of the available soil and water resources of the area for development of irrigation and hydropower soil erosion risk have to be characterized by the aid of models. This has a great importance for designing and implementing of appropriate soil and water resources conservation planning. The focus of this research study was therefore to estimate the amount of soil loss and better understand the spatial distribution of erosion rate in Beles sub basin.

1.3. Objectives

1.3.1. General objective

- ☞ The general objective of this study was to assess soil erosion risk by estimating annual soil loss rate in Beles sub basin using RUSLE in GIS environment.

1.3.2. Specific objectives

The specific objectives of this study are:

- ☞ to assess the five RUSLE factors and their effect on the rate of soil erosion in the area;
- ☞ to estimate and analysis the mean annual soil loss rate and
- ☞ to delineate soil erosion probability areas/zones

1.4. Research questions

The research questions that were addressed in this particular study are:-

1. What is the effect of each of the RUSLE factors on soil erosion rate at different part of the study area?
2. How much is the predicted mean annual soil loss rate of the study area?
3. Which parts of the sub basin are vulnerable to erosion?

1.5. Significance of the study

The results of study could provide information on the spatial distribution of erosion and the highly soil erosion affected areas within the sub basin based on the estimated value of soil loss. On the other hand, the results of this study will be helpful to make the design, the intervention measure, such as implementation of soil conservations, planning for reclamation strategies and setting up preventive measures for sustainable agriculture development timely and cost effective for stakeholders, designers of the hydraulic structure and decision makers by providing the annual average soil erosion rate.

This study also provides an indication of soil erosion hazard on the sustainability of the reservoirs and dams including the Grand Ethiopian Renaissance Dam and the downstream countries. Overall, the findings of the study can be used as one of the additional source materials for the development of integrated watershed management in the study area and for farther related study.

1.6. Scope of the study

The research study area is geographically limited to Beles sub basin in Abbay River basin. The study area covers an area of about 14,200 km^2. The study mainly focuses on issues related to quantifying the amount of annual soil loss rate through characterizing five RUSLE parameters using GIS technique.

1.7. Limitations of the study

Some limitation was encountered during the study. Due to the unavailable rainfall stations at some parts of the area inside the sub basin, the monthly rainfall data for the stations located near the watershed were used. There is also missed rainfall data that were filled using the data of neighboring stations. This condition might influence the exact potential of rainfall erosive capacity. There was also difficulty to get very recent landsat images. The other limitation encountered was absence/difficulty of up to date classified soil map and absence of documented detail properties on soils of the study area. In addition to this, quantification of soil loss rate is a model-based approach which implies uncertainties in the calculation of each factor.

2. LITERATURE REVIEW

In the introduction section of this thesis, the general background of study, objectives, statements of the problem, scope and significance of the study have been described. In this section, basic understanding of the topic by review of different literatures and relevant research studies has been given. The soil erosion and its effects in general, types of soil erosion by water, principal soil erosion factors, soil erosion models, RUSLE and application of GIS in soil erosion modeling has been explained.

2.1. Soil erosion and its effects

Soil is being degraded at an unprecedented scale, both in its rate and geographical extent (Tamene and Vlek, 2008). But, deterioration of the soil resource is often recognized at an advanced stage of soil degradation only after it has already affected plants, animals and water (Hurni *et al.*, 2008). One of the major causes of soil degradation is soil erosion and is a serious mechanism of land degradation and soil fertility decline (Oldeman, 1994).

Soil erosion is a two-phase process consisting of the detachment of individual soil particles from the soil mass and then transport by erosive agents such as running water or wind (Morgan, 2005; Mitiku *et al.*, 2006; Pimentel, 2006; Ganasri and Ramesh, 2016). When sufficient energy is no longer available to transport the particles, a third phase, deposition, occurs (Morgan, 2005).

Soil erosion is the most serious environmental problem affecting the quality of soil, land and water resources upon which humans depend for their sustenance (Lal, 2001; Tamene and Vlek, 2008). About one-third of the land used for agriculture worldwide, has been affected by soil degradation in the historic past (Hurni *et al.*, 2008). Most of this damage was caused by water and wind erosion (Mitiku *et al.*, 2006; Hurni *et al.*, 2008). But, water erosion accounted for about 55% of the almost 2 billion ha of degraded soils in the world (El-Swaify, 1994).

Since the 1950s, pressure on agricultural land has increased considerably owing to population growth and agricultural modernization (Hurni *et al.*, 2008). As Hurni *et al.* (2008) state, small-scale farming is the largest occupation in the world, involving over 2.5 billion people, over 70 % of who live below the poverty line. Hence, soil erosion along with other environmental threats, particularly affects these farmers by diminishing yields that are primarily used for subsistence (Blanco and Lal, 2008; Hurni *et al.*, 2008; Mengistu *et al.*, 2015). Lal (1994) compiled worldwide data from different sources and show that the yield of rain fed agriculture may decrease by about 29 % over the next 25 years because of erosion.

On average, the soils of the world have lost 25.3, 300 and 760 million tons of humus per year over the last 10 thousand, 300 and 50 years ago, respectively (Rozanov *et al.*, 1990). As Rozanov *et al.* (1990) indicates the last 50 years have brought human-induced soil resources degradation to exceptionally high levels. Loss of the top fertile soil or humus leads to reduction of agricultural products. Regarding to this, Lal (1995) estimate crop yield reduction of 2-5 % per millimeter of soil loss and show that soil erosion in Africa has caused yield reductions of about 9 %. According to Lal (1995), if the present trend continues the yield reduction by 2020 may be about 16 %. But, Dregne (1990) identifies several regions of Africa where yield reduction due to erosion is as much as 50 %. Hence, soil erosion is a major challenge to sustainable agricultural practices, as it reduces on-farm soil productivity and causes food insecurity.

Generally, soil erosion is one of the biggest problems worldwide resulting in both on-site and off-site effects (Hurni *et al.,* 2008; Tamene and Vlek, 2008; Molla and Sisheber, 2017) and challenge sustainable agricultural practices. The direct on-site effect is often linked to loss of agricultural soil by runoff and can be expressed by the costs of replacing fertility loss through fertilizers (Hurni *et al.*, 2008). The off-site erosion effect is the consequences of erosion downstream that involves costs due to the consequences of sedimentation, deterioration of water quality and infrastructure damage due to landslides, mud flows, and flash floods (Lal, 2003; Hurni *et al.*, 2008; Bewket and Teferi, 2009).

In Ethiopia, the productivity of the agricultural sector of the economy is being seriously affected by soil productivity loss due to erosion and unsustainable land management practices (Hurni, 1993; FAO, 2005; Tamene and Vlek, 2008; Bewket and Teferi, 2009; Erkossa *et al.*, 2015). But, agriculture is the backbone of Ethiopia economy (Ayalew and Selassie, 2015), which supports more than 80 % of the country's workforce (Hurni, 1993;

Tamene and Vlek, 2008). Due to soil fertility decline associated with removal of topsoil by erosion the average crop yield from a piece of land in Ethiopia is very low (Sertsu, 2000) and Taddese (2001) indicates a reduction of about 1.5 million tons of grain from the country's annual harvest.

Similarly, various researchers such as (FAO, 2005; Assegahegn and Zemadim, 2013; Gete *et al.,* 2014; Erkossa *et al.,* 2015) estimates the average annual soil loss in Ethiopia. While there are some disagreements in their statistics, the magnitude of soil erosion problem is largely indubitable. The variation is because different authors use different sources for their estimates such as models, plot measurements on farms, sediment data obtained from rivers, etc (Hurni *et al.,* 2008). Consequently, the estimations and extrapolations of soil loss rates can give only an indication about an average order of magnitude. This is because erosion is a process with great variation both in time and space (Hurni *et al.,* 2008; Haregeweyn *et al.,* 2015).

2.2. Types of soil erosion by water

Basically, water erosion is a two-part-process; the loosening of soil particles caused largely by raindrop impact and the transporting of soil particles mostly by flowing water (Wischmeier and Smith, 1978; Goldman *et al.,* 1986; Mitiku *et al.*, 2006; Ganasri and Ramesh, 2016). Raindrops segregate the soil particles from the earth's mass. With the water flow, the segregated soil particles move following the flow and then finally sediment.

Sedimentation is the process whereby the detached particles generated by erosion, are deposited elsewhere on the land, in lakes or in rivers (Morgan, 2005). Together, the two processes; erosion and sedimentation, result in soil being detached, carried away and eventually deposited elsewhere (Morgan, 2005; Mitiku *et al.*, 2006). To erode the soil, the major types of water erosion are rain splash erosion, sheet erosion, rill erosion, gully erosion and channel erosion (Morgan, 2005; Mitiku *et al.*, 2006).

2.2.1. Rain-splash erosion

This is the first stage of the water erosion processes. Splash erosion occurs when the soil is directly exposed by raindrop impact. The soil aggregates are broken up and can rise as high 60 cm above the ground and move up to 1.5 meters from the point of impact (Morgan, 2005; Mitiku *et al.*, 2006). The particles block the spaces between soil aggregates, so that the soil forms a crust that reduces infiltration and increases runoff.

Soils with geometric mean particle size between 0.063 and 0.250mm are the most vulnerable to detachment (Morgan, 2005). Coarser soils are resistant to detachment because of the weight of the larger particles and finer soils are resistant because the raindrop energy has to overcome the adhesive or chemical bonding forces that link the minerals comprising the clay particles (Morgan, 2005).

2.2.2. Overland flow or sheet erosion

Sheet erosion occurs during a rainstorm when rainfall intensity becomes greater than the infiltration rate of the soil or when the infiltration capacity of the soil is exceeded (Morgan, 2005). This erosion type is caused by shallow sheets of water flowing over the soil surface (Goldman *et al.*, 1986; Mitiku *et al.*, 2006). Soils most vulnerable to sheet erosion are overgrazed and cultivated soils where there is little vegetation to protect and hold the soil.

Thin layers of the topsoil are moved by the force of the runoff water, leaving the surface uniformly eroded with no pronounced channels. This erosion type accounts for great volumes of soil. The flow can be broken up by stones and vegetation cover.

2.2.3. Rill erosion

Rill erosion is initiated at down slope, where overland flow concentrates and becomes channeled (Morgan, 2005). The energy of this concentrated flow is able to both detach and transport soil particles. The soil surface is cut to small channels or rills which results in rill erosion. Rill erosion is the detachment and transportation of soil particles by concentrated surface water flow (Beskow *et al.*, 2009). Both sheet and rill erosion occur on overland-flow areas and when erosion becomes increasingly severe, rill erosion is assumed to begin. It is often described as the intermediate stage between sheet erosion and gully erosion. Rill erosion can often progress to gully erosion (Mitiku *et al.*, 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.

2.2.4. Gully erosion

Gullies are relatively permanent steep-sided water courses that experience ephemeral flows during rainstorms (Morgan, 2005). Gully erosion occurs when water flows in narrow channels during or immediately after heavy rains or melting snow (Mitiku *et al.*, 2006). A gully is sufficiently deep that it would not be routinely recovered by tillage operations whereas rill erosion can be smoothed by ordinary farm tillage (Billi and Dramis, 2003). The gully formation is a complex process that is not fully understood (Goldman, *et al.*, 1986).

The gully erosion does not always develop from rill erosion (Morgan, 2005). Some gullies are formed when runoff cuts rills deeper and wider or when the flows from several rills come together and form a large channel. Gullies can enlarge in both uphill and downhill directions. Once it is established, gully erosion can be difficult to stop it from growing, and repair is costly.

In Ethiopia, Billi and Dramis (2003) identify two main types of gullies. These are discontinuous gullies that generally develop on low slope gradients (2-9 %) and continuous valley-bottom gullies (ephemeral river channels), formed by intense hydraulic erosion processes typically expanding upslope. As Haregeweyn *et al.* (2015) cite, human activities such as road construction that lead to a diversion of concentrated runoff to other catchments, disintegration of waterfall, land use changes are possible causes for gully erosion. He also states rates of gully erosion vary with the stage and management condition in the catchment.

2.2.5. Channel erosion

In addition to these four erosion types, channel erosion happens when the cover material or vegetation is disturbed or when the volume or velocity of flow in a stream increases. The equilibrium of a stream changes and it causes stream bank erosion, known as channel erosion (Goldman, *et al.*, 1986). Common points where channel erosion occurs are at stream bends and at construction points, for instance where a bridge crosses the river. Once more, eroded stream bank is not easy to recover from and is expensive.

2.3. Principal factors affecting soil erosion

Apart from land use activities that trigger soil erosion processes, there are a number of factors that directly influence or steer the soil erosion process. These factors are strongly interlinked together directly and indirectly (Mitiku *et al.*, 2006), which means they influence each other as well as the erosion processes. These factors are climate, soil properties, topography, vegetation cover and soil management (Goldman *et al.*, 1986; Morgan, 2005; Mitiku *et al.*, 2006; Ganasri and Ramesh, 2016).

2.3.1. Climate factor

The climatic factor includes the rainfall erosivity, wind and temperature of which the rain intensity and raindrop size play a major role in soil loss. Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff (Morgan, 2005; Abiy, 2010). Highly intense rainfall and large rain drops are significantly more erosive than short duration and small rain drops significantly.

Not only is the direct effect on soil erosion caused by the rain, but also climate effects soil erosion indirectly. The season effects vegetation growth covering which is one of the most important factors on soil erosion. In extreme climate for instance in deserts or in cold climate area, ground can be uncovered in long period which is more potential to erode than the mild climate. The erosivity of a rainstorm is a function of its intensity and duration, and of the mass, diameter and velocity of the raindrops (Morgan, 2005).

2.3.2. Soil properties

Soil properties is associated to erodibility, permeability, structure, organic matter content, texture of soil, chemical and biological characteristics of soils which make differ in erosion resistance capacity (Mitiku *et al.*, 2006; Vrieling, 2007). These properties represent how soil reacts to raindrops, runoffs and sediment transport. When soil is high in silt or fine sand and low in clay or organic matter, it is generally the most erodible, whereas, the more organic content in soil, the less soil erosion occurs and soils which are coarse textured, such as sandy soils are less erodible because of low transportability even though these soils are easily detachable (Morgan, 2005). Generally, soil erodibility is the resistance of the soil to both detachment and transport and its values rated from 0 (least susceptible) to 1(highly susceptible) to erosion by water (Helden, 1987; Bewket and Teferi, 2009).

2.3.3. Topography

Erosion would normally be expected to increase with slope steepness and slope length increments as a result of respective increases in velocity and volume of surface runoff (Deore, 2005; Morgan, 2005; Ganasri and Ramesh, 2016). A long and steep slope contributes large momentum, thus, the energy of flow or erosion potential is increased. High velocity runoff is prone to concentrate in narrow channels and produce rills and gullies (Goldman *et al.,* 1986).

In addition, the shape of the slope effects substantially on soil erosion. Relevant to the momentum, at the foot of a slope will obtain greater momentum. Therefore, a convex slope magnifies erosion, while a concave one reduces the momentum (Morgan, 2005). Likewise, in Goldman *et al.* (1986) and Ritter (2006) stated as well about outcomes of slope orientation. When slopes orientate or face more towards the sun, the soil surface tends to be warmer and drier than other orientations. The dry and warm soil surface yields sparser vegetation and so causes more soil erosion.

As Morgan (2005) cited, erosion may decrease with increasing slope length if the soil becomes less prone to crusting and infiltration rates remain higher than on the gentler-sloping land at the top of the slope. Similarly Morgan (2005) states the decreasing of soil loss with increase of slope length and decline of slope angle as a result of deposition.

2.3.4. Vegetation cover

Another important factor is vegetation cover which is greatly significant in soil erosion. Vegetation acts as a protective layer or buffer between the atmosphere and soil, and is associated with other factors especially farming, land use and climate (Morgan, 2005). These have several effects on soil erosion which almost all could be scaled down by vegetation cover. The vegetation absorbs the energy of rainfall, reduces the velocity of runoff, and helps to protect the land against mass movement. When the natural covering is disturbed, re-establishing vegetation can be a difficult and expensive process. Soils covered by dense vegetation are often characterized by higher occurrence of organic carbon, moisture and different soil structure or aggregates. These result in better growth conditions for other plants resulting in minimal soil erosion.

In addition to vegetation cover, land use type has considerable effects on soil loss. Regarding to land use, Taye *et al.* (2013) state that, soil loss rate from rangeland is higher as compared with soil loss from cropland. This higher soil loss in rangeland is due to increased runoff resulting from intensive grazing and soil compaction, whereas soil tillage supports infiltration and causes less runoff and soil loss in croplands. A change in vegetation cover has a significant contribution to soil erosion rate. Concerning to this, Meshesha *et al.* (2012) indicate a marked increase in soil erosion rates from 31 ton ha^{-1} in 1973 to 56 ton ha^{-1} in 2006 in the Central Rift Valley of Ethiopia due to conversion of forests or woodlands to croplands.

2.3.5. Soil management

It is an expression of the overall effects of soil conservation practices such as contour farming, strip cropping, stone and earthen bunds and terracing. Those practices principally affect water erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the volume and rate of runoff (Renard *et al.*, 1997). The conservation practices reduce the runoff speed which increase infiltration, resulting in lower soil loss.

2.4. Soil erosion models

In the 1930s and 1940s with the need to evaluate different soil conservation practices, the stimulation for developing soil erosion models has begun. According to Nearing *et al.* (2005), substantial efforts have been spent on the development of soil erosion models. This is because; it is impractical to measure soil loss across whole landscapes (Morgan, 2005). Directly measuring soil erosion by water across large areas using experimental plots or sampling river sediment load is technically and logistically difficult and financially expensive. Such a constraint can be solved by modeling. Modeling soil erosion is the process of mathematically describing soil loss. Effective modeling can provide information about current erosion, its trends and allow scenario analysis (Ganasri and Ramesh, 2016).

Soil erosion modeling can be used as predictive tools for assessing soil loss for conservation planning, project planning, soil erosion inventories, knowing spatial and temporal of erosion and for understanding erosion processes (Lal, 1994). Several models exist to predict soil erosion rates by water with varying degrees of complexity. The choice for a particular model largely depends on the purpose for which it is intended and the available data, time and money.

However, the main problem in relation to the erosion risk models is the validation, because of scarcely available data for comparing the estimates of the models with actual soil losses (Gitas *et al.,* 2009; Lazzari *et al.,* 2015). Generally, soil erosion models are classified into three main groups (Marino and Simonovic, 2001; Jha and Paudel, 2010). These are: - Empirical, Conceptual (partly empirical or mixed) and Physically-based models.

2.4.1. Empirical models

These are generally the simplest of all three model types. They are developed based on data from field observations or experiments and applicable to the conditions for which the parameters have been calibrated (Lal, 1994; Terranova *et al*., 2009). Moreover, the parameter values in empirical models may be obtained by calibration, but are more often transferred from calibration at experimental sites (Merritt *et al*., 2003). The data requirements for such models are usually less as compared to conceptual and physical based models.

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). The RUSLE (Renard *et al*., 1997), SEDD (Ferro and Porto, 2000) and USLE (Wischmer and Smith, 1978) are some of such models that are more often used.

2.4.2. Conceptual models

These models lie between the empirically based and the physically based models. They are based on the representation of physical erosion processes with empirical equations among the involved variables (Terranova *et al*., 2009). 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). The conceptually based models includes SWAT (Shen *et al*., 2009), AGNPS (Walling *et al*., 2003) and SEMMED (De Jong *et al*., 1999).

2.4.3. Physically based models

These are derived from mathematical equations to describe the process involved in the model, taking into account the laws of conservation of mass and energy (Morgan, 2005). They are based on synthesis of the individual components which affect erosion and helps to identify which part of the system are the most important to the overall soil erosion process (Lal, 1994). Furthermore, physics-based models in particular are often over-parameterized, marking an excessive number of parameters in a model (Meritt *et al.*, 2003). Some examples of physics-based models are WEPP (Flanagan and Nearing, 1995), EUROSEM (Quinton *et al.*, 2011) and KINEROS (Martínez-Carreras, 2007).

2.5. The Revised Universal Soil Loss Equation

The Revised Universal Soil Loss Equation (RUSLE) model is an update version of the Universal Soil Loss Equation model (Renard *et al.*, 1997). The USLE was designed by the United States Department of Agriculture in 1978 to predict longtime-average sheet and rill cropland soil losses by water under various effects such as land use, relief, soil and climate, croplands, rangelands, distributed forest lands and guide development of conservation plans to control erosion (Wischmeier and Smith, 1978).

The estimation of soil erosion risk is given by the product of both natural factors (rainfall erosivity, soil erodibility, slope length and slope steepness) and human induced factors (cover management and support practice factors) (Wischmeier and Smith, 1978; Renard *et al*., 1997). The natural factors are environmental variables, which remains relatively constant over a time whereas the human induced factors are watershed management variables that may change by human activities. With its revised (RUSLE) and modified (MUSLE) versions, USLE is still being used in a large number of studies on soil loss estimation.

Following the revision, the equation can be employed in variety of environments including agricultural site, rangeland, mine sites, construction sites etc (Wischmeier and Smith, 1978). RUSLE, which is largely accepted and has widely used is simple and easy to parameterize and requires less data and time to run than most of other models dealing with soil erosion (Fu *et al.*, 2005). The RUSLE takes into consideration all major components likely to affect sheet erosion; because of this it is the most widely used soil loss equation available. The model is applied to predict soil erosion rates by water in all the countries.

In case of Ethiopia, the RUSLE is among the empirical model that has greater importance than other type of soil erosion models. Various studies indicates it's applicability in different parts of Ethiopia, even though some detailed testing, calibration and validation trials still need for further accuracy estimation of RUSLE parameters. The main problem is the difficulty of obtaining the necessary data to determine the value of each RUSLE factors in its original equation. For example, due to unavailability of intensity data, Hurni (1985) developed empirical equation that estimates R-factor value from annual total rainfall.

Similarly, Helden (1987) suggested K-factor values for use in Ethiopia based on soil color to overcome unavailability of soil property data. Moreover, various researcher states the RUSLE model is better and efficient to estimate annual average soil loss rate using long term rainfall data and sound estimate of each factor values.

2.6. Application of GIS on soil erosion modeling

With the recent increases in computing power, there has been a rapid increase in the exploration of catchment erosion and sediment transport through the use of computer models. GIS has been a widely known tool for spatial analysis for decades. A GIS is a system that captures, stores, integrates, analyzes, manages and visualizes data that are linked to coordinates or locations.

GIS is a combination of statistical analysis, database and cartography that allows the user to identify geographic information, relationships, patterns and trends (Omar, 2010). Within GIS, data can be stored as either a raster or a vector. A raster is represented by a grid of pixels with unique data. Vectors are points, lines, and polygons (each with respective data). When combined with GIS, soil models can be a significantly simpler and less time consuming method for estimating soil loss (Kunta and Carosio, 2007). For this thesis, ArcGIS version 10.4.1 was used.

Mapping soil erosion using GIS can easily identify areas that are at potential risk of extensive soil erosion and provide information on the estimated value of soil loss at various locations. Hence, with the aid of GIS, erosion and sediment yield modeling can be performed on the individual subunits. The RUSLE is an ideal method for analyzing soil loss potential due to its compatibility with GIS.

When modeling erosion in GIS, specific soil erosion parameters in RUSLE can be investigated together or separately. For example, the slope length and slope steepness parameters are investigated together as LS- factor. Cells within a raster accurately define the variables of RUSLE for a given area. The combined use of GIS and RUSLE has been shown to be an effective approach to estimating the magnitude and spatial distribution of erosion (Jahun, 2015).

GIS has been a widely known tool for spatial analysis for decades. Researchers show that using GIS for estimation of soil loss and it spatial distribution could be performed with reasonable costs and better accuracy in larger areas. In addition to this, GIS and USLE modeling approach offer quick and inexpensive tool for estimating erosion within watersheds using publicly available data. All relevant erosion factors can be converted in different GIS data formats as they are spatial information. As a result, GIS is universally applied to soil erosion analysis as well as to other environmental problems.

3. MATERIALS AND METHODS

The previous section discussed the essential knowledge of soil erosion by water; the basic concepts of RUSLE and GIS in soil erosion modeling. In this section, the materials and methods for the study were presented. The first section describes the Beles sub basin. The second section describes the data needed by the model to estimate soil loss rate. In the third section, the methodology and parameter estimation have been described.

3.1. The study area

3.1.1. Location

The Beles sub basin is one of the major sub-basins of the upper Blue Nile (Abay in Ethiopia), covering an area of about 14,200 km^2 or 8.1 % of the total area of Abay basin (Figure 3.1). It is located on the plateau of the north-western highlands of Ethiopia. The Beles sub-basin falls within the two regional states and drains the Agew Awi Zone of the Amhara and Metekel Zone of the Benshangul Gumuz National Regional States. Geographically, it is located between 10°56’00” to 12° 00’00” N latitude and 35°15’00” to 37°00’00” E longitude.

3.1.2. Topography

The Beles sub basin is characterized typically by valley surrounded by high mountain ranges, hills with or without vegetation cover. It has also typical flat landform. The rolling to hilly terrain in the north and west separates it from the Dindir River drainage basin. The altitude in Beles sub basin ranges approximately between 458 and 2729 meter above sea level (Figure 3.2). The highlands in the eastern part of the sub basin are higher in altitude, greater than 1200 meters. The lowlands have lower altitude less than 800 meter above sea level in the western parts of the sub basin. The central part of this sub basin encloses wide gently undulating to flat plains.

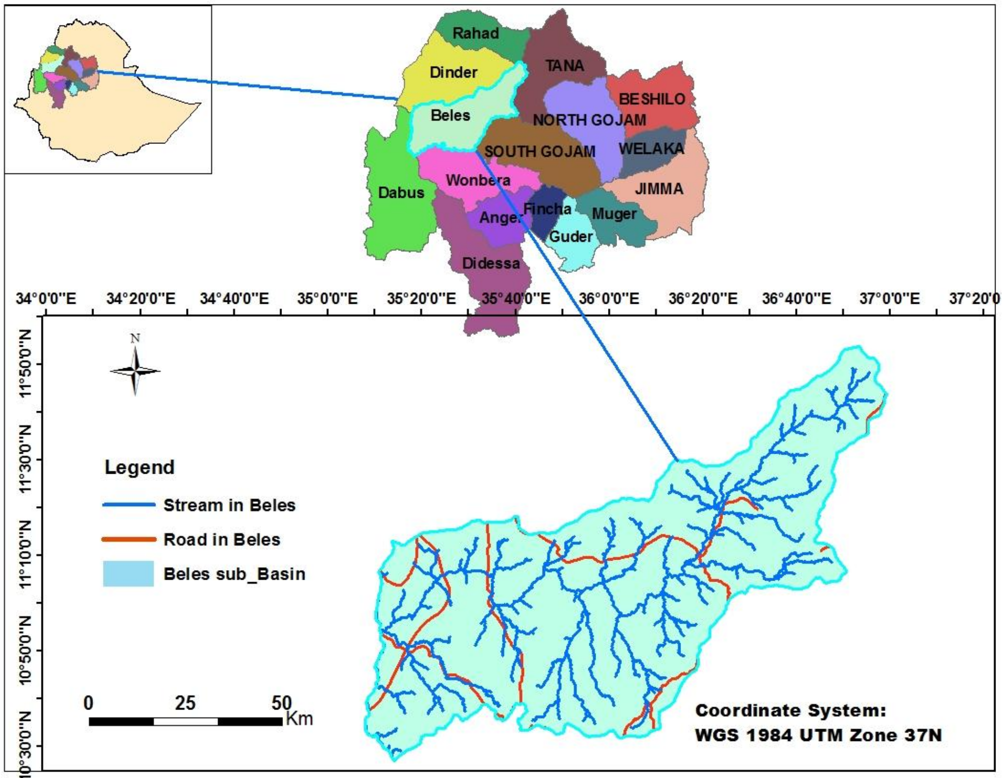

Figure 3.1 Location map of the study area

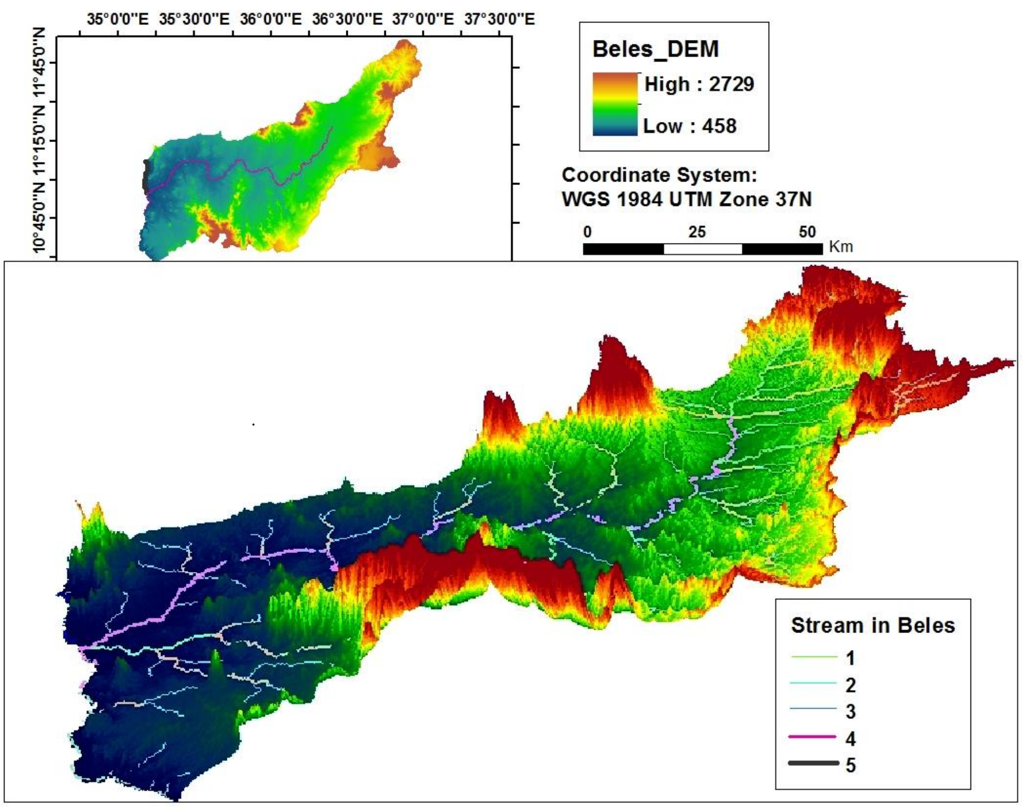

Figure 3.2 Elevation map of the study area

3.1.3. Metrological conditions

3.1.3.1. Temperature

The agro-ecological zones of the area is characterized by hot to warm moist and sub humid lowlands and warm to cool moist and sub humid mid highlands (Yilma and Awulachew, 2009). The annual maximum and minimum temperature in the sub basin varies between 21-35^{0}C and 7-20^{0}C respectively (Yilma and Awulachew, 2009). However, it varies in time and space. The average temperature of the area in the summer season locally known as Kiremt is lower but it rises in the winter season locally known as Bega (Kim *et al.*, 2008). The western lowlands has the highest temperature with a maximum value reaching 35^{0}C and minimum value reaching 20^{0}C (Yilma and Awulachew, 2009). The authors also states the mean annual potential evapo-transpiration in the sub basin is high, spatially variable and estimated to range from 1440 to 2088 mm per year.

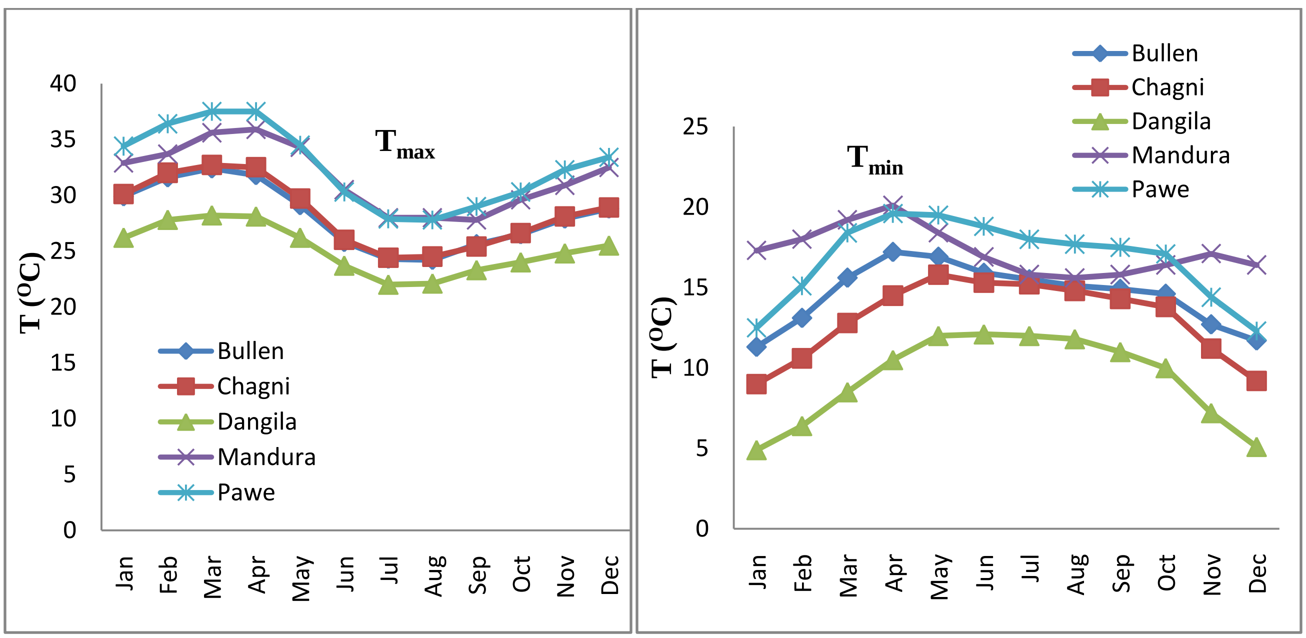

Figure 3.3 Mean maximum and minimum monthly temperature of selected stations in Beles sub basin (EMA from 1992-2016)

3.1.3.2. Rainfall

The area has a variable annual rainfall both in intensity and time. Most of the annual rainfall occurs in the wet season called Kiremt (June-September) (Conway, 2000). The south eastern highlands receive the highest annual rainfall greater than 1700 mm and the western parts of the sub basin receive the lower annual rainfall ranges from 1052 to 1300 mm (Yilma and Awulachew, 2009). Generally, rainfall increases with elevation and the annual rainfall ranges approximately between 1052 to 1957 mm.

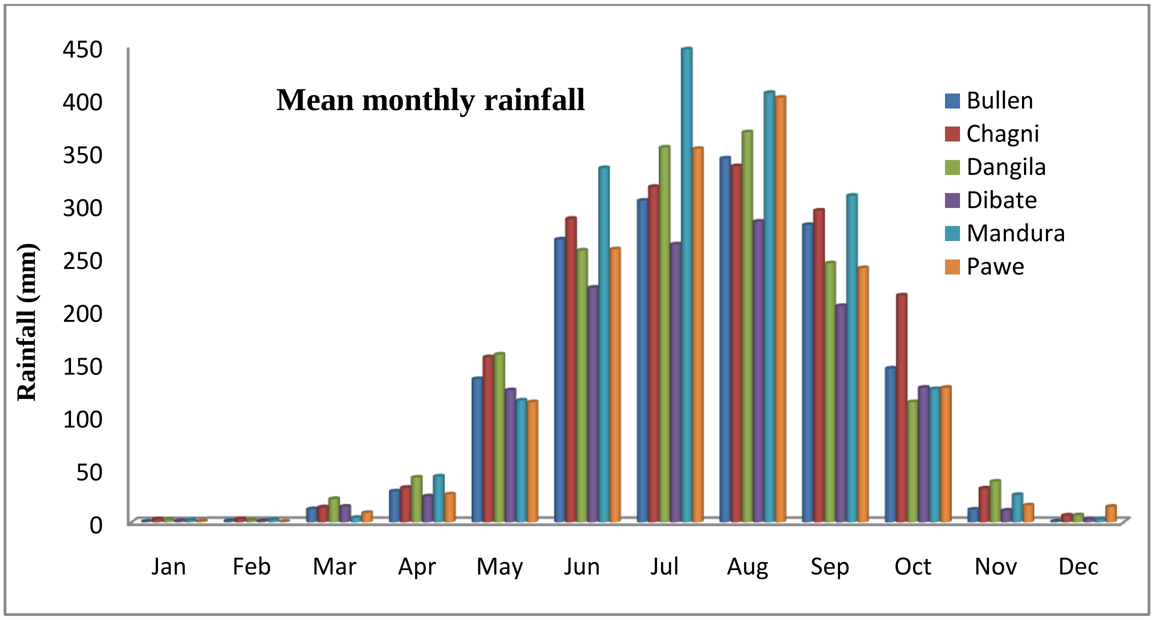

Figure 3.4 Mean monthly rainfalls of selected stations (EMA from 1992-2016)

3.1.4. Socio-economy

The Beles sub basin is one of the important sub basins of Abay river basin. In response to increasing demand for food and contrastingly declining agricultural production, the Ethiopian government is considering Beles sub basin as the development corridor with that of Tana sub basin (Awulachew *et al.*, 2009) and thus embarked on development of irrigation and hydropower development projects in the two sub basins. Some hydropower installations are currently under development.

The economy of the population living in the sub basin is mainly depends on rain fed agriculture and livestock production. Shifting cultivation systems is also practiced in the western and southern lowlands of the sub basin. The sub basin is also home to a large population that is growing rapidly. The total population in the sub basin is about 1.4 million (Yilma and Awulachew, 2009). A large majority of the population in the sub basin still lives in rural areas, but the rate of urbanization is very high. The large rural population depends directly on the natural resource base for its food security and livelihood. This is a major factor responsible for a severe environmental degradation in the Basin.

3.1.5. Land use land cover

According to the classified land use land cover map obtained from Ethiopia Mapping Authority (2013), the LULC of the study area was mainly categorized as agricultural, forest or woodland, bamboo, bushes and grassland. The western lowland is dominated by woodland. The eastern and southeastern highlands are dominated by agriculture. The north-western portion of the area is dominated by open grassland whereas the southern half of the basin is characterized by wood-land composed of various species of trees. The Upper Main Beles sub-basin is dominated by open grassland. Based on the classified LULC map (2013) of the study area cultivated lands, woodland dense, bush land and bamboo cover 29.82, 29.37, 12.07 and 10.89 % of the sub basin, respectively.

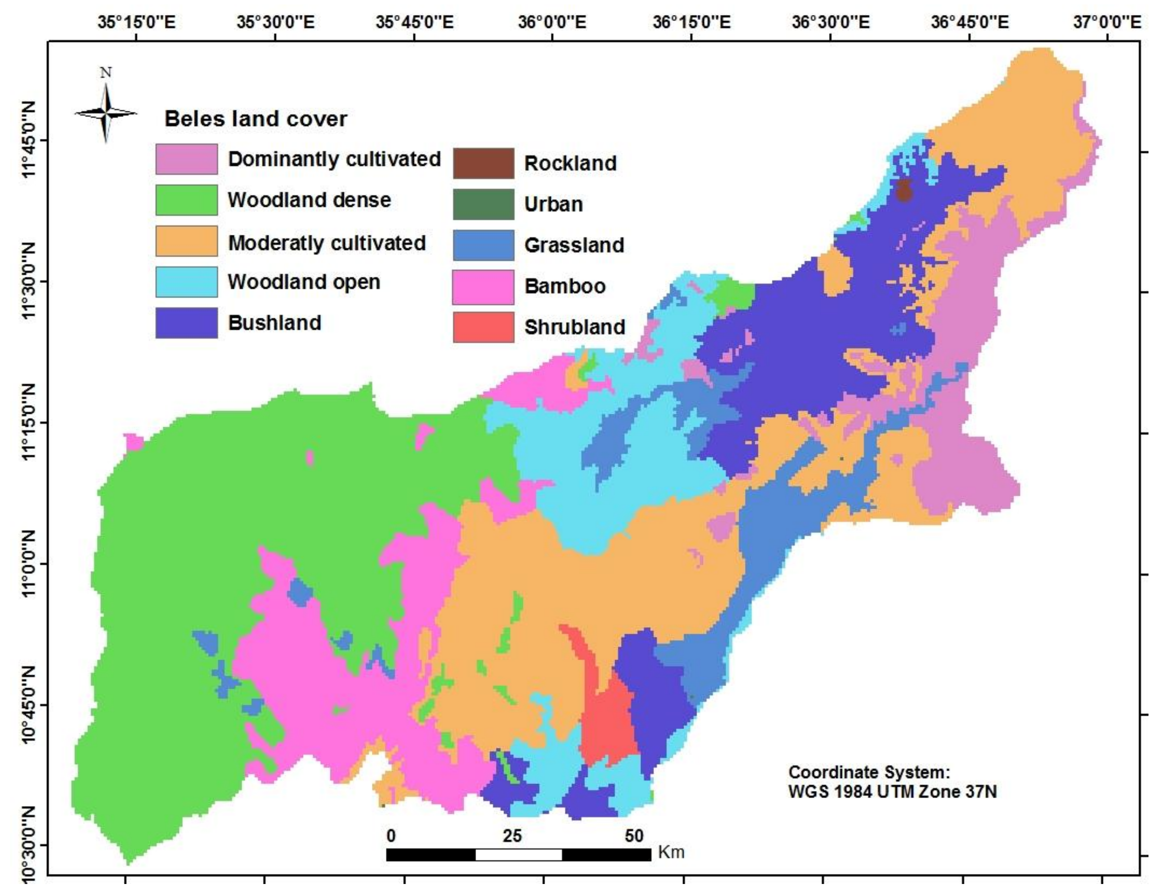

Figure 3.5 Land use land cover of the study area (EMA, 2013)

3.1.6. Vegetation cover

The natural vegetations grown in Beles sub basin include wood or forest including closed and open forest, shrubs, bushes and grasses. Wood areas occupy the lowland parts of the study area with various species of trees. Vegetation cover map could be used as one indicator of land degradation. Vegetation has a complex and diverse effect on erosion. It intercept rainfall and reduce the impact of the raindrop on soil particles, it act as a barrier and reduce the velocity of the running water and thereby increase the infiltration rate. It also adds soil organic matter which play important role in improving the soil physical conditions, especially soil structure.

Areas with low vegetation cover are vulnerable to land degradation and good vegetation cover conditions are less vulnerable to land degradation. Figure 3.6 shows the spatial patterns of vegetation cover in the Beles sub basin.

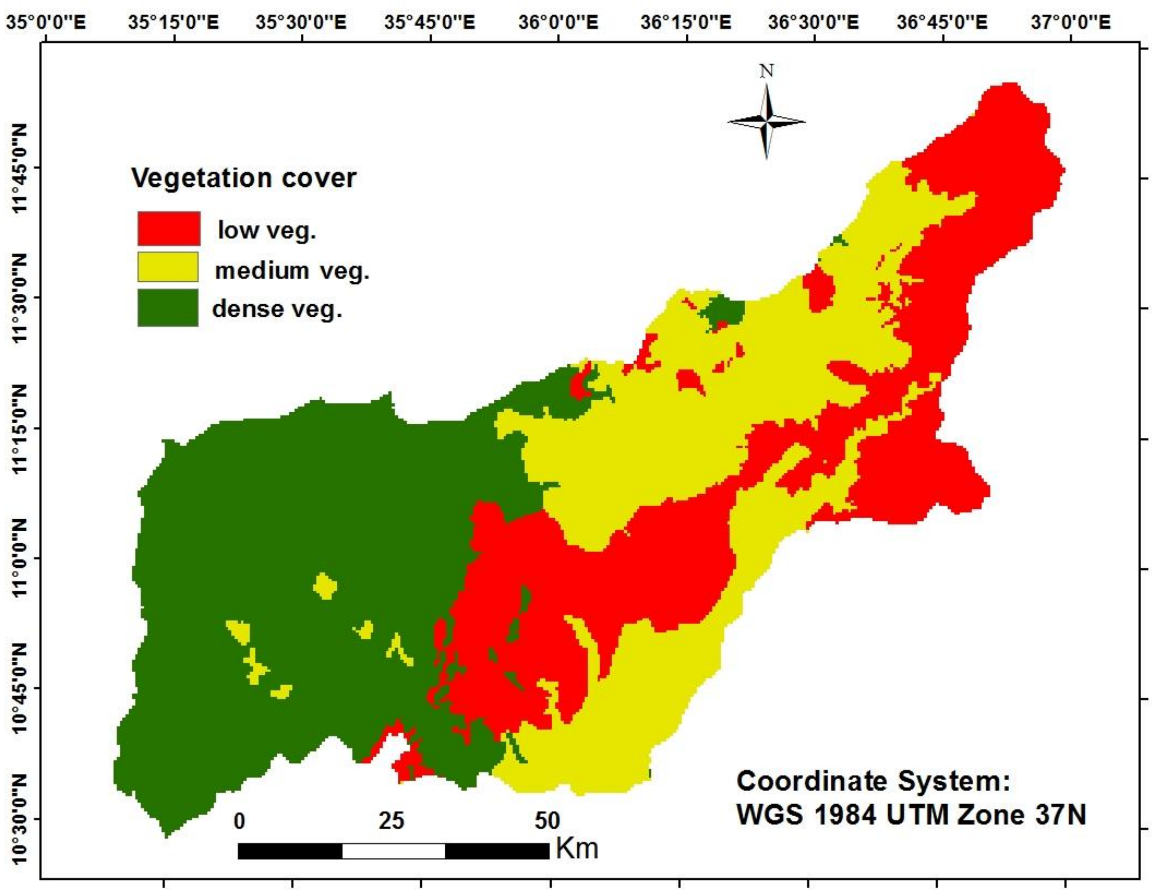

Figure 3.6 Vegetation cover map of the study area (EMA, 2013)

3.1.7. Geology and soils

The geology of the sub basin is mainly dominated by granite, diorites and granodiorites (Yilma and Awulachew, 2009). The eastern highlands are volcanic and precambrian basement complex rocks, mainly basalts origin; while the lowlands are mainly covered by basement complex and metamorphic rocks, such as clastics, alluvium, colluvium and marble deposits (Yilma and Awulachew, 2009).

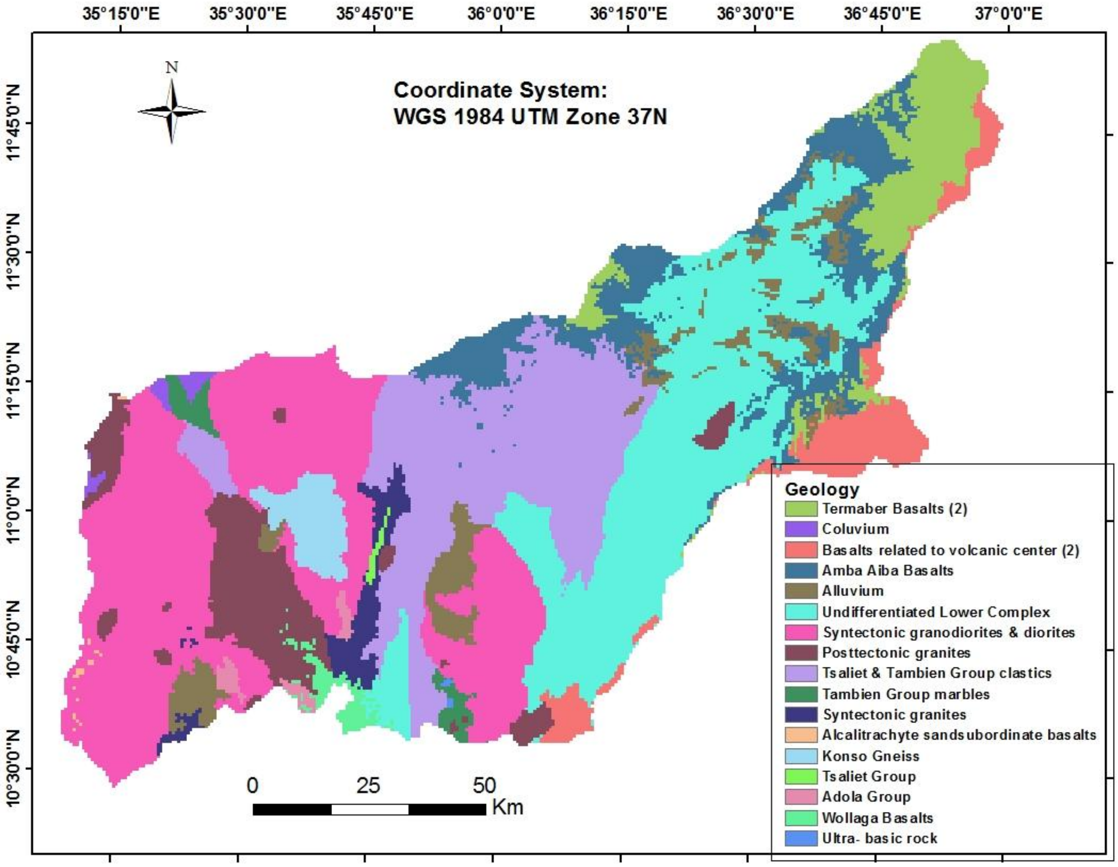

Figure 3.7 Geology map of Beles sub basin

The soils of the sub basin are variable. However, nine major soil types namely nitisols, leptosols, luvisols, vertisols, acrisols, cambisols, alisols, regrosols and fluvisols are dominant in the sub basin. The soil types of the study area were extracted from Abay basin soil map of the FAO (1998) soil classification map of Ethiopia. As the soil classification map of the area, nitisols are the dominant soils in the western and central part. The eastern part of the basin is dominantly covered with luvisols and fluvisols.

Cambisols are dominant in the southern part and the southeastern part is dominated by acrisols.

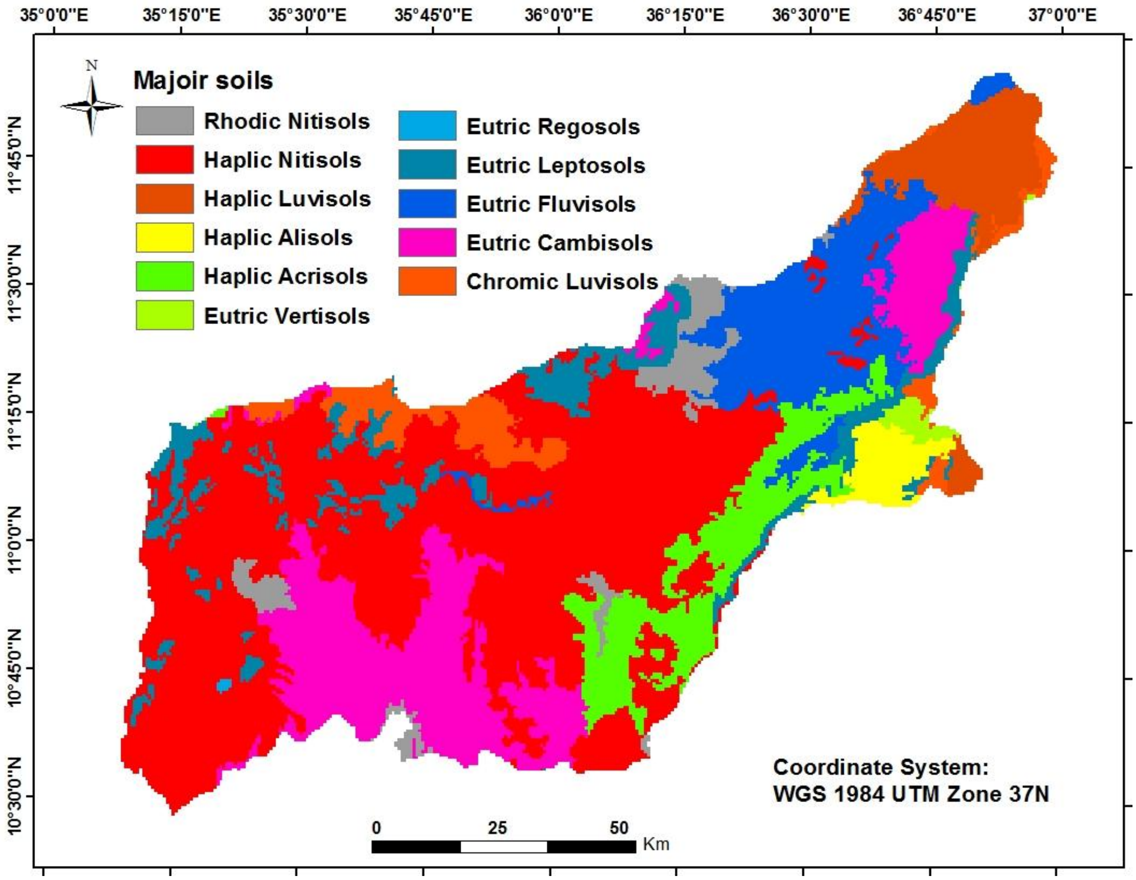

Figure 3.8 Soil map of Beles sub basin

3.1.8. Drainage networks

The courses of the rivers and streams follow the drainage pattern radiating from volcanic rocky peaks. The Beles sub-basin is comprised of two main rivers namely Main Beles and Gilgel Beles. A number of tributaries join the Main Beles River. The head water of Beles River starts from the area close to the western periphery of Lake Tana. Along its way it collects many major and minor tributaries, most of which are perennial though highly seasonal in their flow volumes. These include Babzenda, Yazbil, Aysika, Gulbak, Bunta, Rapids, Shar, Dukusi, Gorishi, Bajengi and many other small tributaries. The drainage network was shown in Figure 3.9. The Beles River that drains the Beles Sub-Basin is the largest right bank tributary of the Blue Nile and joins the main stream just before the Ethio-Sudanese border.

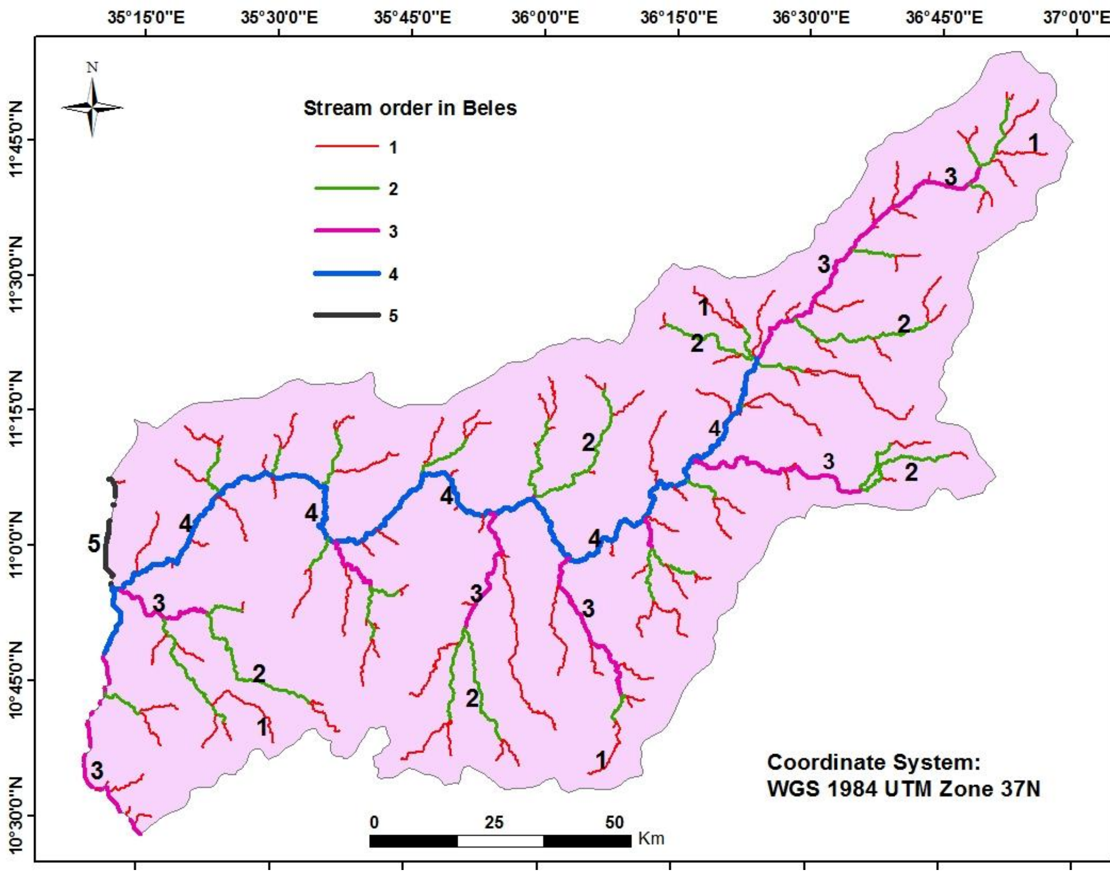

Figure 3.9 Drainage line map of the study area

3.2. Data

Soil erosion is influenced by a variety of factors such as rainfall intensity and distribution, soil types, topography of basin, land use types, etc. These factors are presented very well with the spatial type using GIS technique. GIS application is increasing more and more to predict soil erosion in the basin. For this particular study to predict the soil erosion risk of Beles sub basin, ArcGIS 10.4.1 (Esri. ArcGIS® and ArcMap™, Esri BeLux S.A., Belgium) software and the RUSLE model (Renard *et al*., 1997) were used. The ArcGIS software was used for data processing, storing, spatial data analysis, displaying and viewing the result. The RUSLE were used for quantifying the average annual soil loss rate of the study area. Moreover, different data set including rainfall data, soil data, DEM data and land use land cover data were used.

The rainfall data for 25 years for 1992 to 2016 were collected from the National Metrological Agency of Ethiopia for selected representative rainfall stations located within or around the study area. The data consists of monthly precipitation and the geographical coordinates of the locations of eleven weather stations (Bahir Dar, Bullen, Chagni, Dangila, Dibate, Enjabara, Mandura, Pawe, Sherekole, Sirba Abay and Worota). The rainfall data was used to estimate rainfall erosivity (R) factor. The soil data for the study area were clipped from Abay basin soil data as per FAO (1998) soil group classification of Ethiopia soil map. The data were collected from Ministry of Water resource, Irrigation and Electricity. The soil data were used to analyze the soil erodibility (K) factor.

Land use land cover map of the study area was obtained from Ethiopian Mapping Agency and used for quantification of C-factor. For the purpose of this study, a recently (2013) classified land use land cover map that shows detailed classification of the land use land cover in the specified year for the whole Ethiopia was used. The DEM data having 30x30 meter resolution that was extracted from United State Geological Survey (USGS) was used. The DEM data is used to determine inputs such as slope, flow direction, flow accumulation and sink route to delineate the study area and to generate the slope factor.

Table 3.1 Summary of the data type, source and description

Data type	Source	Description
Rainfall data	National Metrological Agency of Ethiopia	25 years (1992 - 2016) data from eleven rainfall stations used to extract R-factor
Soil data	Ministry of Water Resources Irrigation and Electricity	FAO (1998) soil map used to extract K-factor map
Land use land cover data	Ethiopian Mapping Agency	Land use land cover map (2013) used to extract C-factor map
DEM data	USGS	30x30 m resolution used to determine slope factor, flow direction, flow accumulation, sink route and delineate the study area
Conservation practices data	Concerned bodies in the study area	To determine P-factor value

3.3. Methodology and Parameter estimation

Potential soil loss in basin areas depends on the configuration of the basin, the soil characteristics, the local climate conditions and the land use and management practices implemented in the basin (Morgan, 2005; Mitiku *et al.*, 2006; Kamaludin *et al.*, 2013; Ganasri and Ramesh, 2016). Soil erosion rates within basins can be measured using RUSLE. According to Renard *et al.* (1997), RUSLE calculation can be presented based on climate, soil, topography and land use which influence the occurrences of stream and inter-rill soil erosion by direct rainfall impact and surface runoff. It has been used extensively to estimate soil loss, assess the risk of soil loss and also as a guide to development and conservation plan to control erosion (Kamaludin *et al.*, 2013). The RUSLE, originally developed by Wischmeier and Smith (1978) and revised by Renard *et al.* (1997), was used as shown in Equation (1).

$$A = R * K * LS * C * P \quad (1)$$

Where, A is the computed annual soil loss per unit area [t ha^{-1} yr^{-1}], R is rainfall erosivity factor [MJ mm ha^{-1} hr^{-1} yr^{-1}], K is soil erodibility factor [t hr MJ^{-1} mm^{-1}], LS is the slope length and steepness factor (unit less), C is cover management factor (unit less) and P is a dimensionless conservation practice factor.

In GIS environment, five types of analyses can be used to analyze potential soil loss (*A*) in connection to the RUSLE parameters. Annual soil loss (A) was computed by overlaying five raster layers over the sub basin using Equation (1). Rainfall factors are derived by Inverse distance weighted (IDW) interpolation estimators, soil erodibility factors are derived from soil properties, slope factors are estimated from DEM and land use is derived from classified land use/cover data. All layers produced were projected with UTM Zone 37N datum. The general flow chart of the research approach of this study was shown in Figure 3.10. The methods of generating the RUSLE parameters are almost the same and for this study the methods used by Ganasri and Ramesh (2016) was adopted as it is clearly indicated and fits with this study.

3.3.1. Filling missing rainfall data

Before using the rainfall records of a station, it is necessary to first check the data for continuity and consistency. The continuity of a record may be broken with missing data due to many reasons such as damage or fault in a rain gauge and absence of observer during a period. It is often necessary to estimate these missing records. The missing data can be estimated by using the data of the neighboring stations.

There are different methods of filling missing data such as arithmetic average method, normal ratio method or other approximation methods (Subramanya, 2008). Where annual rainfall among stations differed by more than 10 %, normal ratio method was recommended (Subramanya, 2008). Hence, for this study, normal ratio method was used. The consistencies of rainfall data's were also checked by the method of double mass curve analysis. Accumulated annual rainfall data at a station of interest against the accumulated average at the surrounding stations was plotted as shown in Appendix 4.

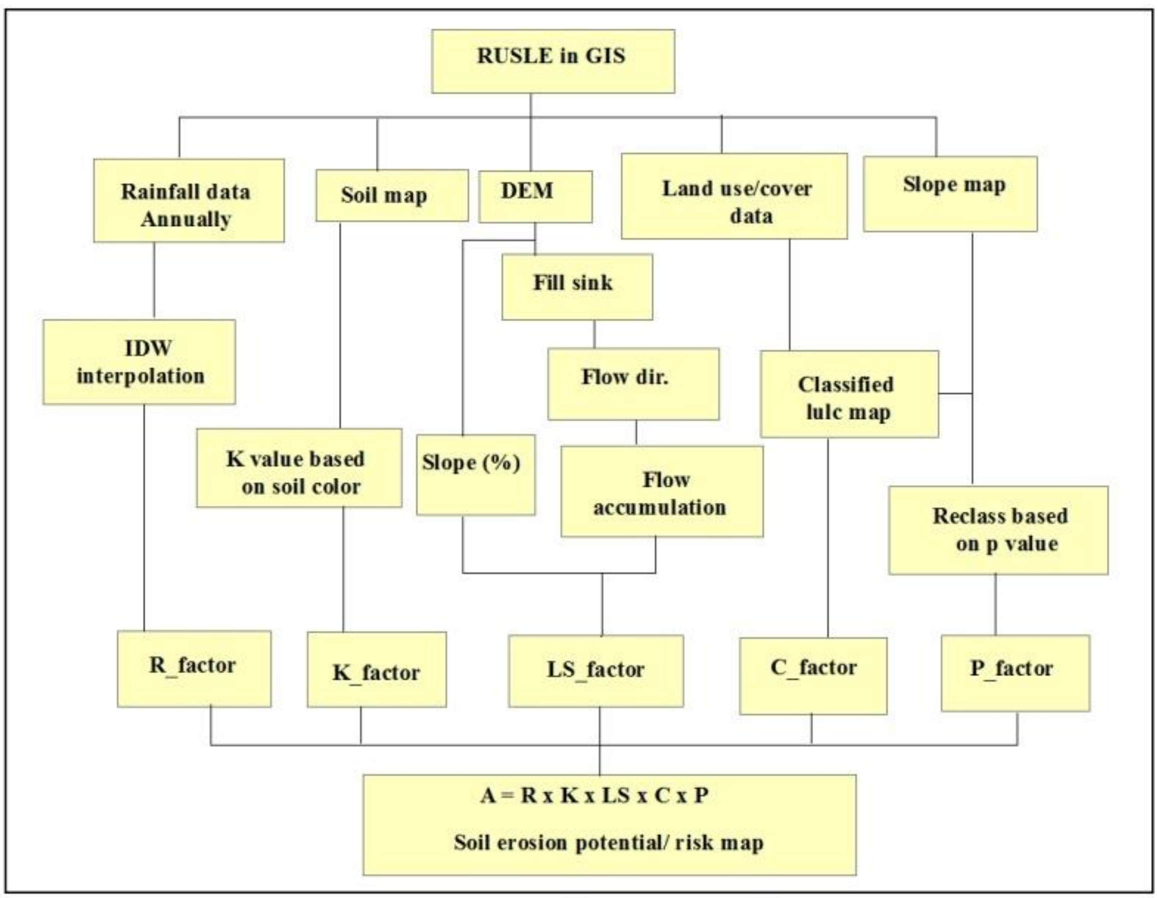

Figure 3.10 Flow chart of the methodology (adopted from Ganasri and Ramesh, 2016)

3.3.2. RUSLE parameters estimation

3.3.2.1. Rainfall erosivity (R) factor

Rainfall erosivity is a climatic factor, which is estimated from the rainfall data. It indicates the soil loss potential of a given storm event. Rainfall erosivity is defined as the potential ability of rain to cause erosion and given as the product of the total energy of rainstorm and the maximum 30-min intensity (Wischmeir and Smith 1978). The rainfall-runoff erosivity factor quantifies the effects of raindrop impact and reflects the amount and rate of runoff likely to be associated with rain (Renard *et al*. 1997). 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 (Morgan, 2005; Abiy, 2010).

In the original equation of RUSLE, the value for R-factor measures the kinetic energy of the rain and it requires measurements of rainfall intensity with autographic recorders (Wischmeir and Smith 1978; Bewket and Teferi, 2009). Computing kinetic energy of rain requires long-term continuous rainfall intensity data. However, rainfall intensity data are not available for the study area. Hence, in the area with absence of the rainfall intensities data the alternative methods used include empirical equations to estimate local erosivity values from the available average annual total rainfalls.

In Ethiopia, Hurni (1985) develop an empirical equation used to determine R-factor values from annual average rainfall while adapting the USLE model to Ethiopian highlands. The equation is based on the readily available mean annual rainfall data. Similarly, Kaltenrieder (2007) developed another equation to estimate R-factor from annual total rainfall amount. The equation of Kaltenrieder (2007) is given by R = 0.36 X + 47.6 where, X is mean annual rainfall in mm. As Mengistu *et al.* (2015) indicate, the regression model developed by Kaltenrieder (2007) estimates lowers R-factor than that by Hurni (1985). For the present study, the Hurni (1985) model Equation (2) was used.

$$R = -8.12 + (0.562xP) \quad (2)$$

Where R is the rainfall erosivity factor (MJ mm ha^{-1} hr^{-1} yr^{-1}) and P is the mean annual rainfall (mm). The general approach has been used by several researchers in different parts of Ethiopia for determining R-factor value from total annual rainfall (Bewket and

Teferi, 2009 in Chemoga catchment; Meshesha *et al.,* 2012 in Central Rift Valley of Ethiopia; Mengistu *et al.,* 2015 in Abay River Basin; Adugna *et al.,* 2015 in Northeast Wollega; Ayalew, 2015 in Zingin watershed; Ayalew and Selassie, 2015 in Guang Watershed; Shiferaw, 2011 in Borena Woreda).

The estimation of the R-factor involves two steps in addition to rainfall data collection. These are the calculation of the R-factor for each rainfall station and the spatial interpolation of R-factor point values. The rainfall erosivity thus computed was used to prepare rainfall erosivity map by using IDW interpolation method in spatial analyst tools of ArcGIS 10.4.1 software.

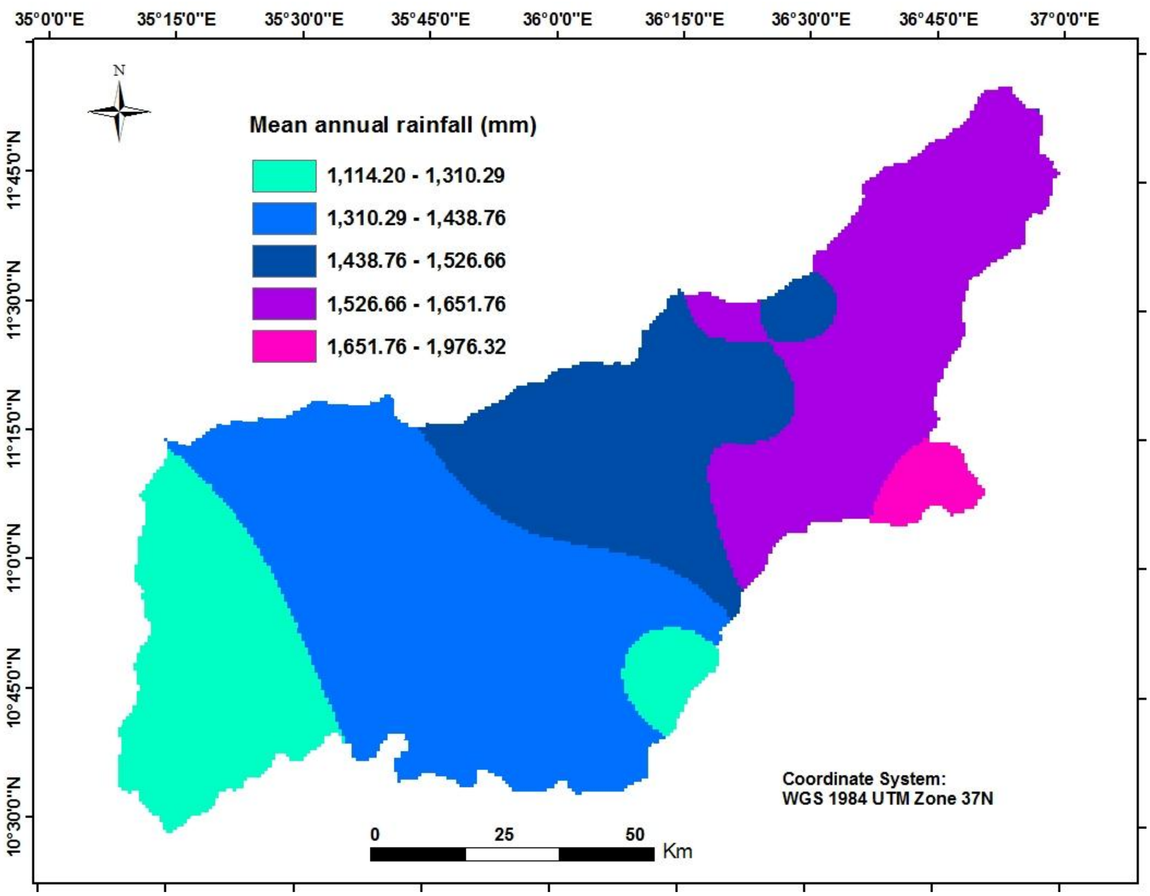

Figure 3.11 Average annual rainfall map

3.3.2.2. Soil erodibility (K) factor

Soils vary in their susceptibility to erosion. The erodibility of soil is an expression of its inherent resistance to particle detachment and transport by rainfall, which may vary depending on the presence or absence of plant cover, by the soil's moisture content and by the development of its structure (Wischmeier and Smith, 1978). K-factor represents both susceptibility of soil to erosion and the amount and rate of runoff, as measured under the standard unit plot of 9 percent and 22.1 m length (Morgan, 1995). Soil erodibility depends on the physical and bio-chemical properties of soil and ranges from 0 to 1 (Bewket and Teferi, 2009). The properties are soil texture and structure, aggregate stability, shear strength, infiltration capacity, organic matter and chemical content (Wischmeier and Smith, 1978; Robert and Hilborn, 2000; Efe *et al.,* 2008; Bewket and Teferi, 2009).

Various researchers suggest different methods of determining K-factor. But, soil erodibility is best estimated by carrying out direct measurements on field plots (Kinnell, 2010). However, direct measurements of K-factor on field plots are not economically sustainable at large scale. Hence, usually researchers investigate the relation between typical soil properties and soil erodibility to determine K value. The most commonly used method is soil erodibility nomograph (Wischmeier *et al.,* 1971). The nomograph yields K-values as a function of the percentages of silt and very fine sand as well as the permeability, structure, and organic matter content of the soil (Wischmeier *et al.,* 1971; Wischmeier and Smith, 1978; Renard *et al.,* 1997). However, the resulting values of K are satisfactory only in situations resembling those for which it was developed (Rejman *et al.,* 1999).

The lack of data on soil characteristics is a serious obstacle to soil erosion modeling at larger spatial scales in general and in the study area in particular. To overcome unavailability of such data, Hurni (1985); Helden (1987); SCRP (1996) suggested K-factor values for use in Ethiopia based on soil colour, which is believed to be a reflection of soil properties. Hence, for this study the soil color-type based determination of k value was used. As Helden (1987 indicate for recognized soil color of black, brown, red, yellow, grey and white the recommended K-factor values are 0.15, 0.2, 0.25, 0.3, 0.35 and 0.4 in order of sequence. In the study area, five types of soil colors namely black, brown, red, yellow and grey was identified depending on the soil unit characteristics. The detail characteristics of the soil units were indicated in Table 3.2 by referring various literatures.

Table 3.2 Description of soil types and detailed characteristics of the soil units (Major Soils of the World, 2001; Mengistu *et al.*, 2015; Molla and Sisheber, 2017)

Soil group	Soil unit name	Soil characteristic
RhNT	Haplic Nitisols	Dusky red or dark red clayey soils of high aggregate stability, deep, well-drained, tropical soils with moderate to strong angular blocky structure with shiny nutty elements.
ReCm	Eutric Cambisols	A reddish medium-textured, good structural stability, higher clay content, high porosity, good water holding capacity and good internal drainage
ReVr	Eutric Fluvisols	A black silt clay to clay, imperfectly drained to well drained, moderately well-structured surface horizons and show sub angular blocky structures
S/RhAc	Haplic Acrisols	A grey medium to coarse sub angular blocky or massive soils, weakly developed structures, low amount of organic matter, often found on slopes and on surfaces subject to erosion, excessive to very excessive drained
V/SeLp	Eutric Leptosols	A grey to yellow soil of clay to coarse textured well drained, shallow, very stony soils overlying rock, limited amount of fine earth material, limited water holding capacity
V/ShLv	Haplic Luvisols	A yellowish medium to coarse soils, imperfectly drained to well drained, moderately well-structured surface horizons and show sub angular blocky structures
RxLv	Chromic Luvisols	Medium to coarse sandy clay loam whitish to yellow soil excessive to very excessive drained, low structure stability, devastating surface erosion
S/RrNt	Rhodic Nitisols	A dark red clay to coarse sand soils, imperfectly drained to well drained, moderately well-structured surface horizons and show sub angular blocky structures
V/ShAl	Haplic Alisols	A brown colored very friable to friable clay loam to clay well drained, very deep soil
VeVr	Eutric Vertisols	A black cracking heavy clay soil, poorly to very poorly drained, very deep, very dark when dry, friable, cracking heavy clay soil
VeRg	Eutric Regosols	A yellow clay to medium textured soil deep, well-drained, low organic matter content and vulnerable to soil erosion on sloping terrain

Various researchers has used similar method of determining k-factor value in Ethiopia for the R/USLE model (Bewket and Tefreri, 2009; Ayalew and Selassie, 2015; Molla and Sisheber, 2016; Gashaw *et al.,* 2017; Haregeweyn *et al.,* 2017). The soil unit map of the study area was extracted from Abbay basin soil map. To determine the K-factor the obtained soil data shape file was added as a layer in ArcGIS, the soil map contained about eleven different types of soil. The attribute table of the soil map was edited by adding a new field of K-factor values under the Edit menu and the K-factor values were assigned to each soil type. To create the soil erodibility map, the shape file was converted into raster format.

3.3.2.3. Slope (LS) factors

The influence of topography on erosion is complex. Among the six input layers, the combined slope length and slope angle (LS-factor) has the greatest influence on soil loss and describes the effect of topography on soil erosion (Moore and Burch, 1986; Moore and Wilson, 1992). S-factor measures the effect of slope steepness and the L-factor defines the impact of slope length. The local slope gradient influences flow velocity and thus the rate of erosion. L is the slope length factor and describes the distance between the origin and termination of inter-rill processes (Wischmeier and Smith, 1978).

The steeper and longer the slope can produce higher overland flow velocities and hence the higher is the erosion. As slope length increases, total soil erosion and soil erosion per unit area increase due to the progressive accumulation of runoff in the down slope direction. Together, LS-factors expresses the ratio of soil loss under given conditions to that at a site with the standard slope steepness of 9 percent and slope length of 22.1 m plot (Wischmeier and Smith 1978). Thus, the values of L and S are relative and represent how erodible the particular slope length and steepness is relative to the 22.1 m long and 9 percent steep unit plot.

Generating the LS values poses the largest problem in using the RUSLE (Griffin *et al.,* 1988; Renard *et al.,* 1991), especially when applying it to real landscapes within a GIS (Griffin *et al.,* 1988). Traditionally, the best estimates for L are obtained from field measurements, but these are rarely available or practical. Moreover, estimates of slope length were considered inadequate given the heterogeneity and scale of topography, land use practices and related land covers (Moore and Burch, 1986). Various researchers (Wischmeier and Smith 1978; Moore and Burch, 1986; Moore and Wilson, 1992; Mitas and Mitasova, 1996) have been developed method to calculate cumulative downhill slope length within ArcGIS.

The first requirement for estimating LS-factor is the Digital Elevation Model (DEM) which is a quantitative representation of the Earth's surface that provides basic information about the terrain and allows for the derivation of attributes such as slope, aspect, drainage area and network and topographic index. The DEM and the LS-factor determine the spatial resolution (cell size) of the soil erosion model results, and incorporate the soil erosion potential due to surface runoff. Equation (3) was used to estimate the slope factor (Wischmeier and Smith, 1978).

$$LS = \left(\frac{x}{22.13}\right)^{m} (0.065 + 0.045s + 0.0065s^{2}) \quad (3)$$

The value of x was derived by multiplying the flow accumulation with cell value (Moore and Burch, 1986; Moore and Wilson, 1992; Kamaludin *et al.*, 2013), m is an exponent that depends on slope steepness, being 0.5 for slopes exceeding 5 %, 0.4 for slopes 3-5 % and 0.3 for slopes 1-3 %, and 0.2 for slopes <1.0 %, and s is the slope in %.

Flow accumulation was derived from the 30 x 30 m resolution DEM dataset after fill and flow direction operation by using the watershed delineation tool in the hydrological modeling extension of the ArcGIS. To calculate the LS- factor DEM file was the first input data. Using the Arc Hydro extension tools, the fill sinks operation was performed in order to remove local depressions from the DEM by replacing them with a flat area in the output DEM. Then, the flow direction was generated from the fill grid which takes a terrain surface and identifies the down-slope direction for each cell. This grid shows the on surface water flow direction from one cell to one of the eight neighboring cells.

Flow accumulation, denoting the total contributing area of a given cell, was then calculated by summing the areas of all upslope cells draining into it. Cells with high accumulation values are usually stream or river channels. The slope map in percent rise was prepared using the slope tool from the Spatial Analyst tools. The lower the slope value the flatter the terrain and the higher the slope value the steeper the terrain. Finally Equation (3) was inserted into the Raster Calculator found in the Spatial Analyst tools to calculate the LS-factor.

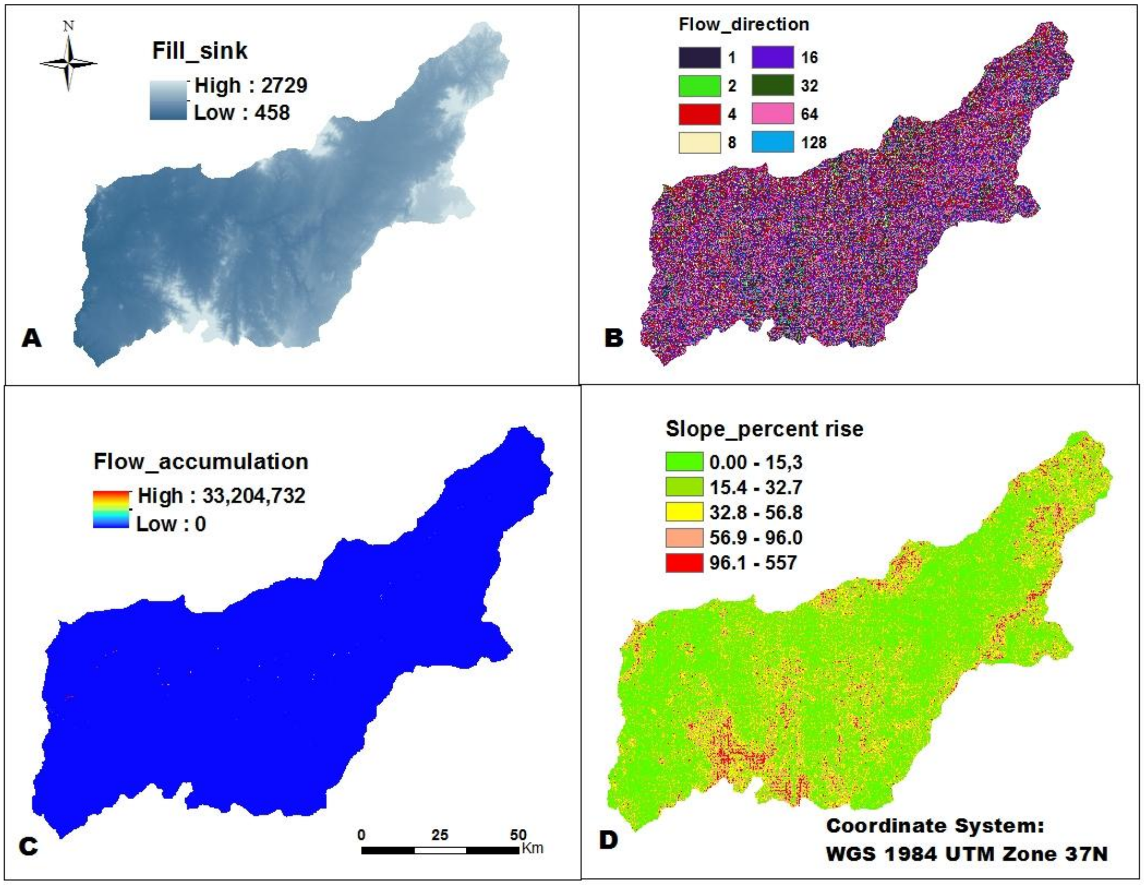

Figure 3.12 Fill sinks (A), flow direction (B), flow accumulation (C) and slope (D)

3.3.2.4. Crop management (C) factor

The vegetation cover and management factor represent the effect of cropping and management practices in agricultural management and the effect of ground, tree and grass covers on reducing soil loss in non-agricultural situation (Renard *et al.,* 1997). Hence, the C-factor indicates the effects of vegetation, management and erosion control practices on soil loss rates (Wischmeier and Smith, 1978; Robert and Hilborn, 2000; Mengistu *et al.,* 2015).

The vegetation cover factor together with slope steepness and length factors is most sensitive to soil loss (Biesemans *et al.,* 2000). Agricultural and management practices play an important role in controlling soil erosion. The C-factor and its associated soil loss rates can potentially be influenced by land-use changes, crop rotation and management practices. Land use change has the highest impact on the C-factor, especially deforestation due to cropland expansion. This land use change may have resulted in a significant increase in the C-factor, and consequently an increase in soil loss. The value of C-factor varies from 1 in completely bare land (no cover) to 0 in water body or completely covered land surface (Mengistu *et al.*, 2015).

Due to spatial and temporal variations, many studies used remote sensing data to classify land use and land cover units for quantification of C-factor values with intensive ground truth (Beskow *et al.*, 2009; Bewket and Teferi, 2009). For this study, a recently classified (2013) land use land cover of the whole Ethiopia for a specified year was used (Figure 3.5). From the classified map the land use land cover classes of the study area was clipped and identified eight major land use land cover types.

Table 3.3 C-factors value for the different land cover types under consideration

Land use/cover type	Area (km^2)	C-factor	Source
Dense woodland	4171	0.05	Eweg *et al.* (1996)
Moderately cultivated	3236	0.15	Hurni (1985), Bewket and Teferi (2009)
Bush land	1714	0.1	Mengistu *et al. (*2015)
Bamboo	1546	0.01	Mengistu *et al. (*2015)
Open woodland	1411	0.06	Eweg *et al.* (1996)
Dominantly cultivated	999	0.35	Meshesha *et al. (*2012)
Grassland	927	0.12	Ayalew (2015)
Shrub land	183	0. 20	Tiruneh and Ayalew (2016)
Rockland	11	0.05	Hurni (1985)
Urban areas	2	0.09	Ganasri and Ramesh (2016)

Land cover of the study area mainly consists of cultivated lands, dense woodland, bush land and bamboo which cover 29.83, 29.37, 12.07 and 10.89 % of the study area, respectively. Having the classified map, different C-factor values were assigned to each land cover class depending to the value given in Table 3.3. In the classified polygon map, the attribute table was edited by adding a new field of C-factor values under the edit menu and finally converted to raster format to obtain the C-factor.

3.3.2.5. Conservation practices (P) factor

The conservation or support practice factor reflects the effects of measures to reduce the amount and rate of water runoff and thus soil erosion. The P-factor represents the ratio of soil loss after implementation of a conservation practice to soil loss from straight-row cultivation running up and down a slope (Wischmeier and Smith, 1978; Meshesha, 2012). The P-factor accounts for control practices that reduce the erosion potential of runoff by their influence on drainage patterns, runoff concentration/velocity and hydraulic forces exerted by the runoff on the soil surface (Renard *et al.,* 1991; Ganasri and Ramesh, 2016).

Supporting conservation practices; such as contour farming, strip cropping and terracing principally affect water erosion by modifying the flow amount, pattern, grade or direction of surface runoff reducing the volume and rate of runoff (Renard *et al.,* 1997). Contouring which mean farming perpendicular to the normal flow direction of runoff is a specific support practice applied only in croplands. The value of P-factor ranges from 0 to 1 (Ganasri and Ramesh, 2016), the value approaching to 0 indicates good conservation practice and the value approaching to 1 indicates poor conservation practice. P values are chosen based on land use or soil management.

Table 3.4 P-factor values suggested by Wischmeier and Smith (1978)

land use type	Slope (percent)	P-factor
Agricultural land	0 - 5	0.1
	5 - 10	0.12
	10 - 20	0.14
	20 - 30	0.19
	30 - 50	0.25
	50 -100	0.33
Other land	all	1

In the study area, the entire basin is not treated with improved soil and water conservation measures. The widely used traditional conservation practice is the drainage ditch, which is meant to safely drain excess runoff from croplands during rainstorms. Hence, P-factor values suggested by Wischmeier and Smith (1978) that considers only two types of land uses (agricultural and non-agricultural) and land slopes were used in this study. As shown in Table 3.4, the agricultural lands were classified into six slope categories and assigned P-factor values, while all non-agricultural lands are assigned a P-factor value of 1.

For calculating the P-factor, the DEM file for the sub basin was added as a layer in ArcGIS. The slope was calculated in percent-rise by using the Slope tool from the Spatial Analyst toolbox. The slope map given in Figure 3.12 (D) was reclassified in to six different slope classes accordingly to the slope percentage values given in Table 3.4.

The classified slope map was converted to raster format and merged with the land use land cover data of the study area using the intersection tool from the analyst toolbox. The intersected map is converted to shape file and the attribute table is edited by adding a new field of P-factor. Finally the shape file was again converted back to the raster format to obtain the required P-factor map. The reclassified slope map was shown in Figure 3.13.

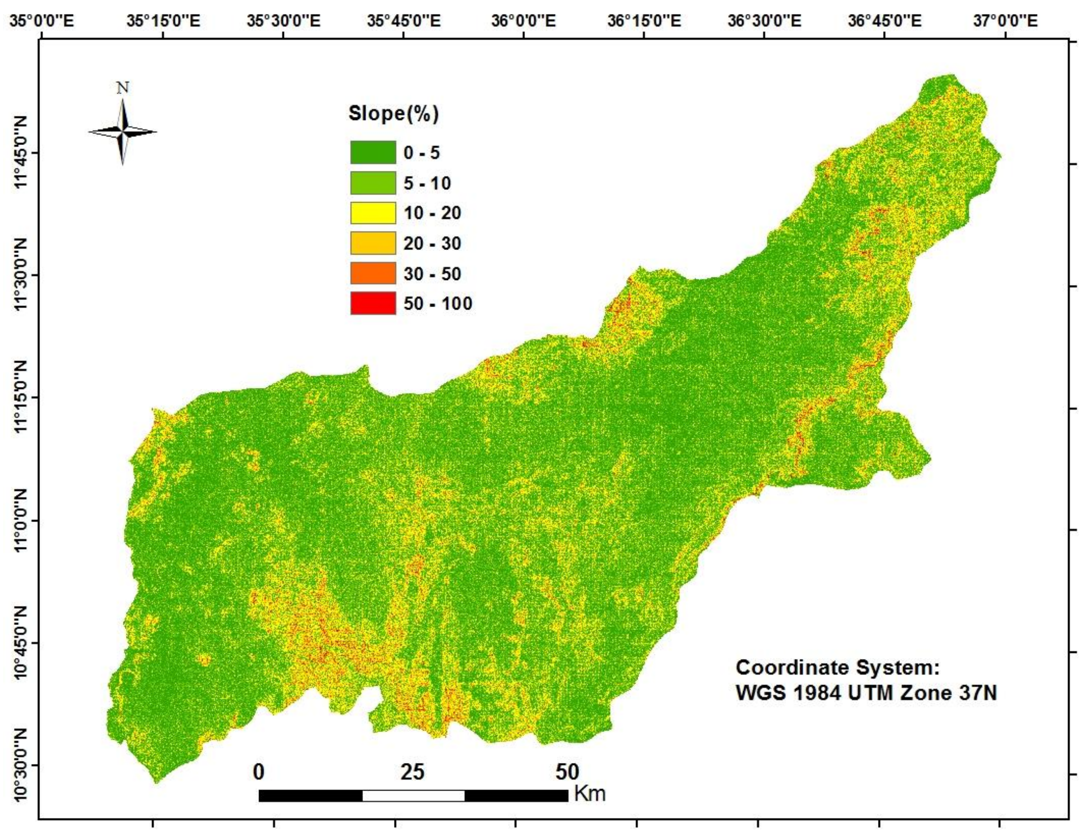

Figure 3.13 Reclassified slope map of the study area

4. RESULTS AND DISCUSSIONS

In the previous section, detail explanation of the study area, data needed and the methodology to estimate the RUSLE factor have been described. This section deals with the result and discussions of each factors and the overall result i.e. the annual soil loss rate. The results of each factor were analyzed in the first section. In the second section, the potential annual soil loss rate was estimated, analyzed and compared with other related studies. In the third section, soil erosion probability zone/area were delineated and analyzed at district level. Lastly, soil erosion control measures were described.

4.1. R-factor

Many studies revealed that the soil erosion rate in the basin is more sensitive to rainfall. The R-factor is a key parameter for estimating soil erosion loss and soil erosion risk which was derived from a rainfall map by interpolation techniques in GIS. The interpolation techniques are necessary when the study area includes more than one meteorological station, which provides long-term rainfall data.

The rainfall data was transformed to a point feature in ArcGIS by using the XY coordinate location of the stations. The points were interpolated to create a raster map of mean annual rainfall using Inverse Distance Weighted (IDW) technique which was used to prepare rainfall erosivity map. The result of the interpolation (Figure. 3.11) shows that the effect of rainfall on erosion is higher in the east and northeast parts of the sub basin. On the other hand, the erosion potential of rainfall gradually decreases from the eastern to the lower part of the area in south western parts.

The interpolated mean annual rainfall was used to calculate the rainfall erosivity map using Equation (2). The result from the estimation shows that *R*-factor value ranges from 618.06 -1102.57 $MJmmha^{-1}\ yr^{-1}$. It indicates that the higher value of erosivity occurs in the eastern and northeastern part of the basin and decreasing toward the western and southwestern of the sub basin area (Figure 4.1). The map of rainfall erosivity gives a spatial overview of the erosive energy of rain. The higher the erosivity value, the more powerful the rainfall to erode the soil from the surface.

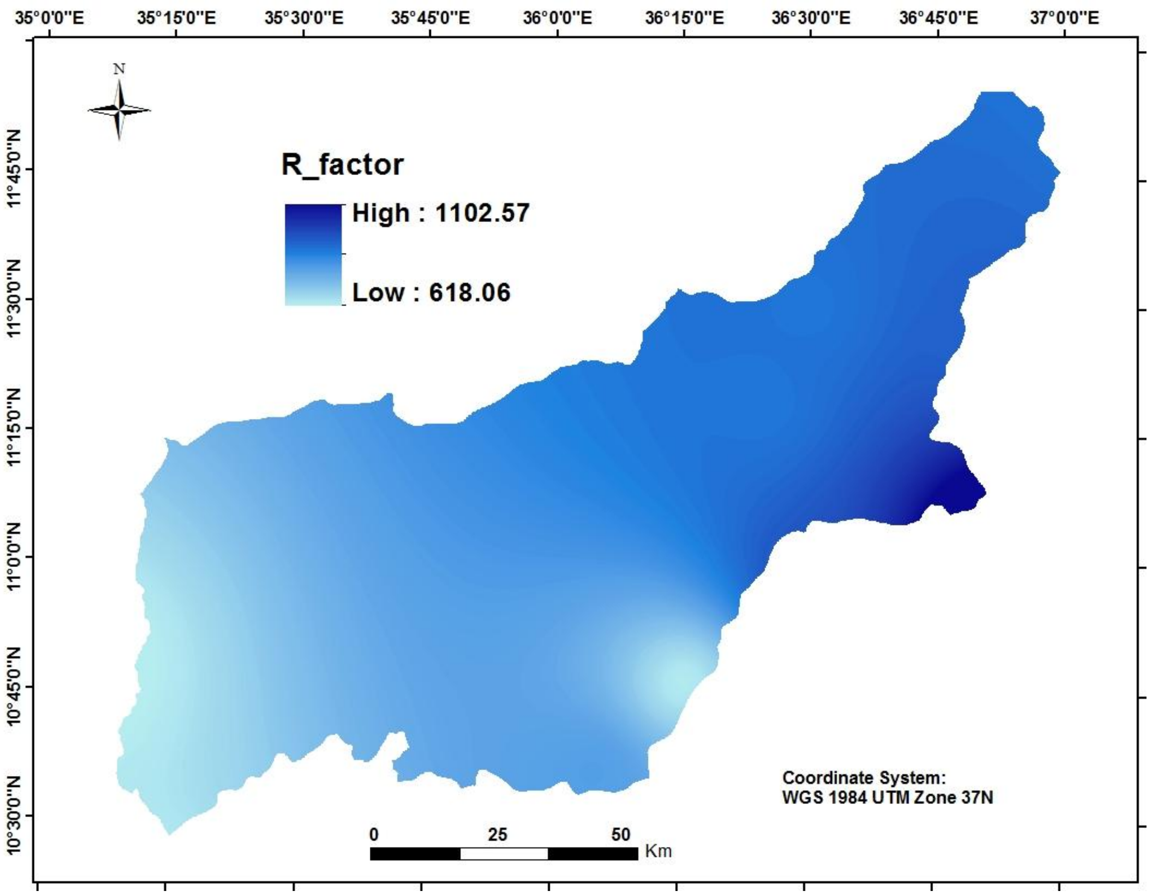

Figure 4.1 Rainfall erosivity map

4.2. K-factor

The K-factor reflects the combined effect of soil properties, showing the general proneness of a particular soil type to erosion. In general eleven types of soil groups were identified for the study area. The soil groups and their description were shown in Figure 3.8 and Table 3.2. The dominant soil types are Haplic Nitosols and Eutric Cambisols covers about 44.6 and 15.83 % of the sub basin, respectively. These soil types together constitute 60.43% of the area, found mostly in the central and lower parts of sub basin. They are characterized as redish clay to medium textured, deep, well-drained and moderate to high structural stability all this results in moderate erodibility. The K-factor was assigned to each soil type considering the soil characteristics to generate the soil erodibility map. The values of K-factor were found to be ranging between 0.15 and 0.35.

The erodibility map (Figure 4.2) shows that haplic acrisols, eutric leptosols and chromic luvisols are highly susceptible to soil erosion with K-factor values of 0.35 whereas eutric fluvisols and eutric vertisols are less susceptible to erosion with K-factor value of 0.15. The highest *K*-factor value implies that the soil is dominated by very fine sand with silt particle which gives rise to higher soil erodibility. The lower k value soils are less sensitive to erosion and associated with the soils having low permeability, low antecedent moisture content, etc.

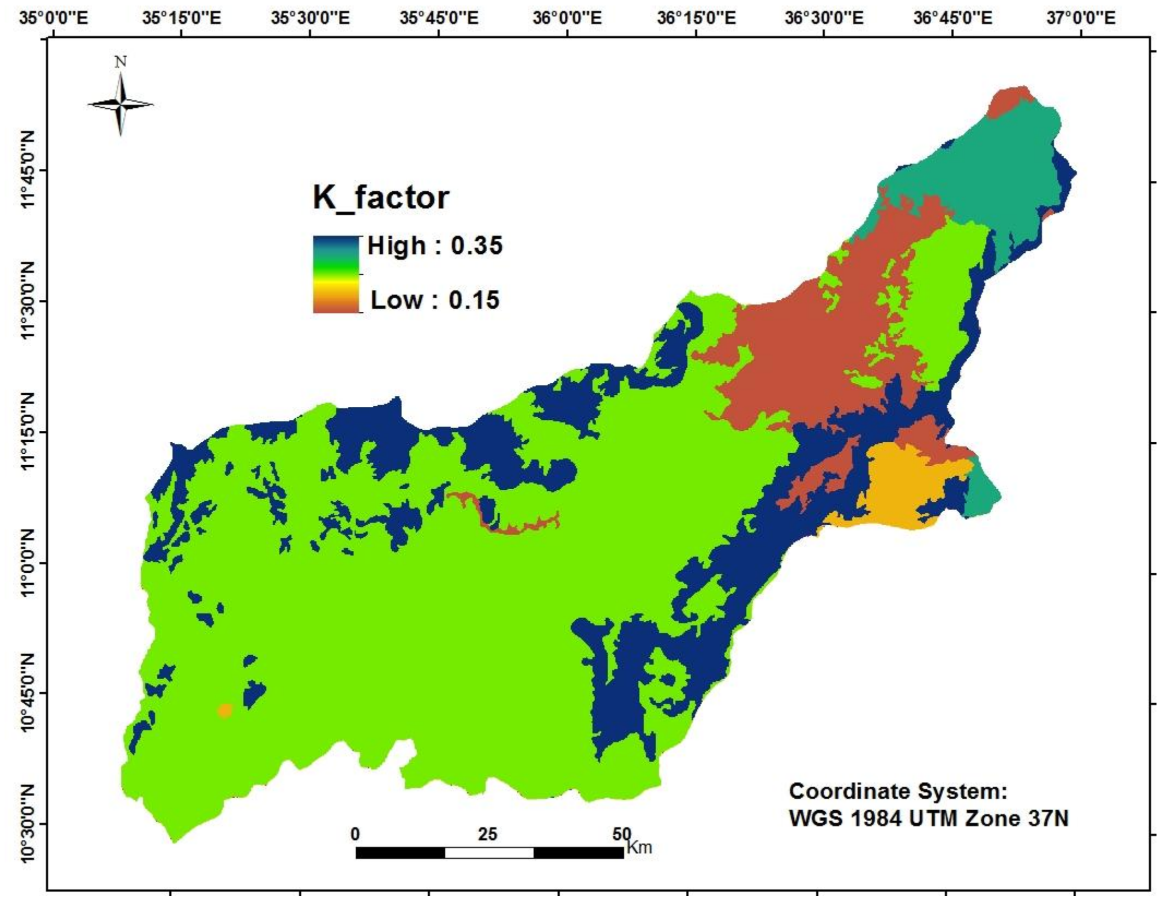

Figure 4.2 Soil erodibility map

4.3. LS-factor

The LS-factor is the important features of topography used in modeling soil erosion. It represents the influence of slope length and steepness on erosion process. The combined LS-factor value was calculated for every segment by considering the flow accumulation and slope in percentage as an input and the result varies from 0 to 42.97 (Figure 4.3). Majority of the study area have relatively lower LS-factor (0 - 3.03) and were observed to occur in all part of the study area. In this study, high LS-factor values (3.04 - 42.97) were mostly determined in the southern, northeastern and the mountainous region of the sub basin. The higher the value of LS-factor, the higher would be the susceptibility of the area to soil erosion by water.

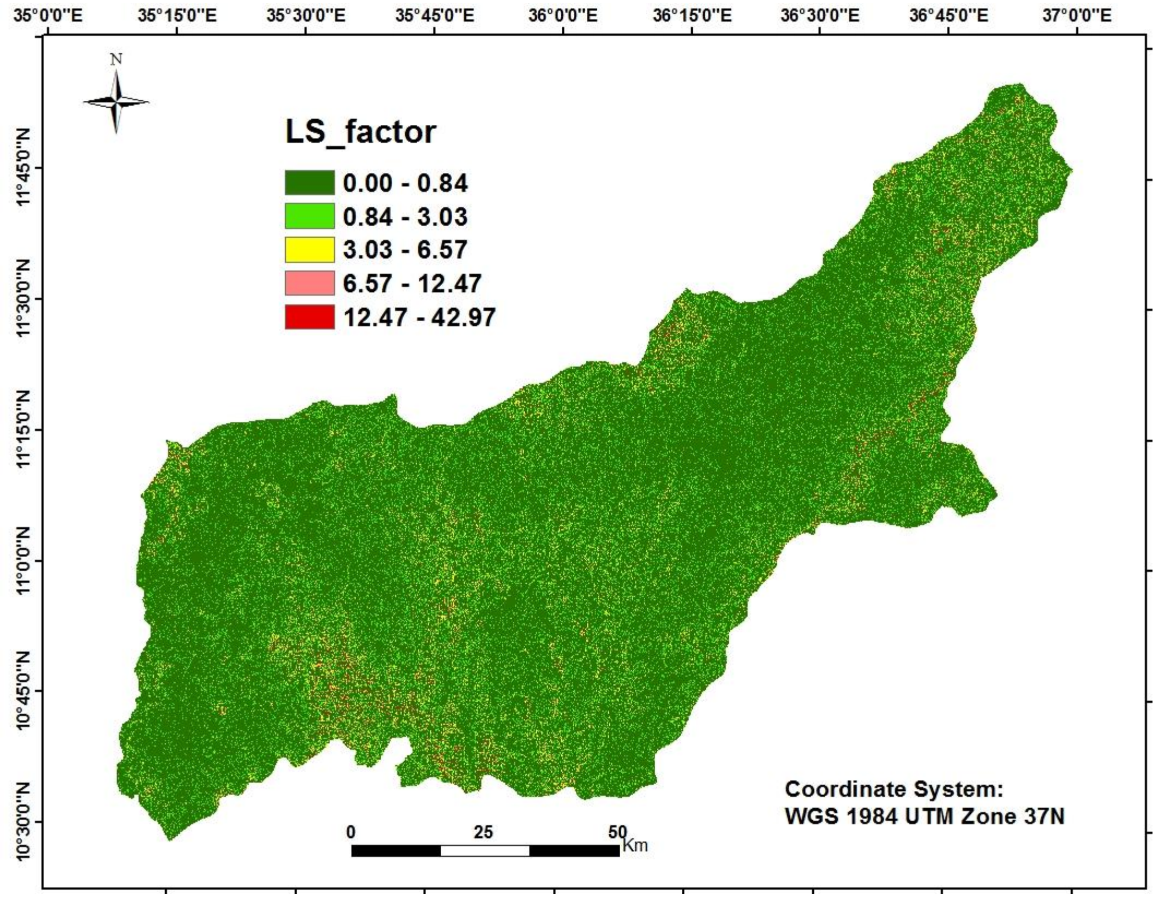

Figure 4.3 Slope length and steepness factor map

4.4. C-factor

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

As shown in Figure 3.5 and Table 3.3 eight land cover classes were recognized in the study area that were mainly consists of woodland (closed and open), cultivated land, bush land, bamboo, grass land which cover 39.31, 29.82, 12.07, 10.89, 6.53 %, respectively and the remaining was covered by shrub land, rock land and settlement area. These land cover class were used to determine the C-factor value as given in Table 3.3. The C-factor values for the study area ranges from 0.01 to 0.35.

As per the reference given in Table 3.3, C-factor value was assigned to each land cover class where the highest C-factor value (0.35) was given to dominantly cultivated land and the lower value (0.01) was given to bamboo. The smaller value of C-factor indicates that the area is covered by vegetation and less susceptible to soil erosion. Large values of C-factor, on the other hand, indicate that the area is less covered by vegetation so that it is highly vulnerable to soil erosion. The C-factor map was presented in Figure 4.4.

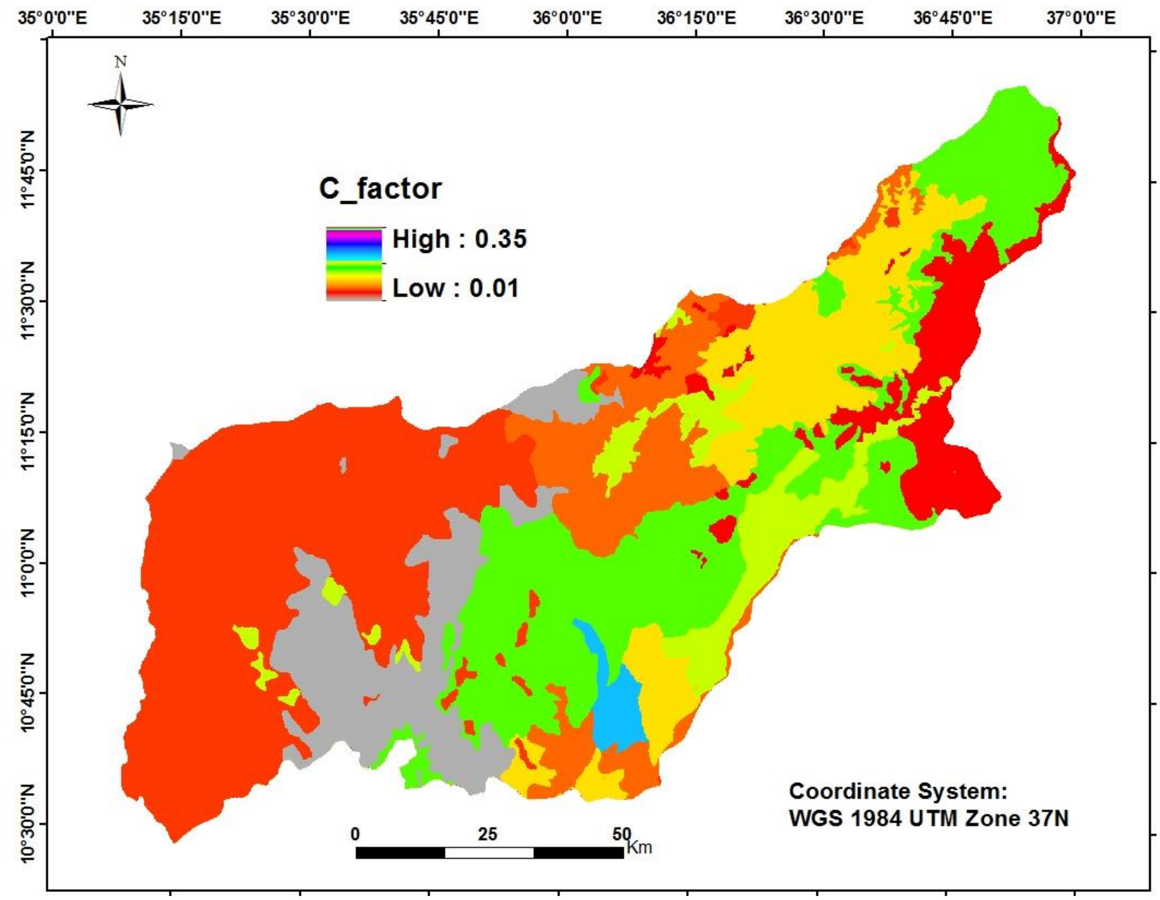

Figure 4.4 Crop management factor map

4.5. P-factor

The P-factor reflects the impact of specific erosion management practices on the corresponding erosion rate with values between 0 and 1. Conservation practices on cultivated land are rare. There were no management practices applied to the study area, except temporary terracing and strip cropping in a small area and ditch to safely remove excess runoff during rainy season from agricultural land. Hence, the P-factor values were assigned according to the suggestion by Wischmeir and Smith (1978) that consider only two types of land uses (agricultural and non-agricultural) and land slopes. Thus, the agricultural lands were classified into six slope categories and assigned P-values as given in Table 3.4, while all non-agricultural lands are assigned a P-value of 1.

Accordingly, the P-factor value varies from 0.1 to 1 as shown in Figure 4.5. A P-factor value of 0.1 is for cultivated land on flat and gentle slopes (less than 5 %). Smaller values indicate less vulnerability to soil erosion. These areas are found at low slope gradients. As slope values increase, the P-factor values for cultivated land increase as well. High P-factor values (0.33) are determined from cultivated land practiced on slope classes greater than 50 %. Conservation practices are also not common in non agricultural land cover types. Hence, P-factor value of 1 was given to all non agricultural land at any slope.

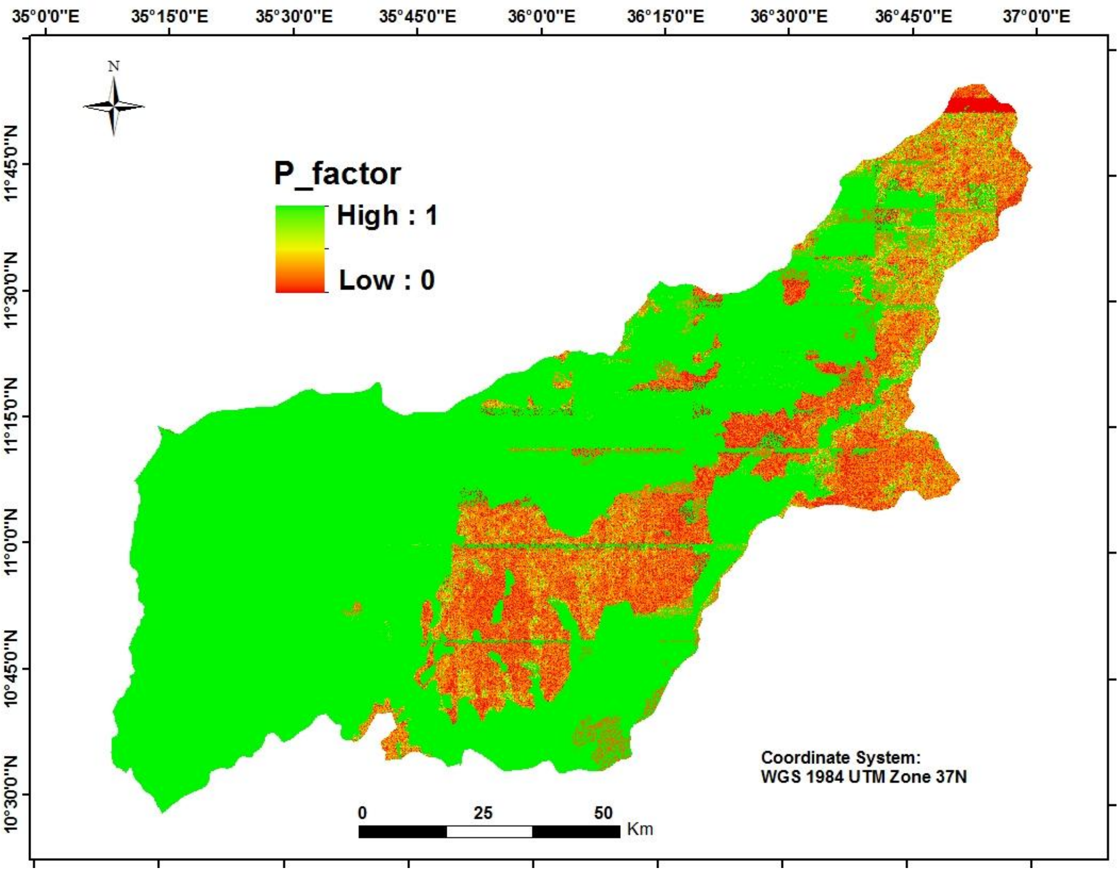

Figure 4.5 Support practice factor map

4.6. Estimation of potential annual soil erosion

Soil erosion risk was determined by multiplying the respective five RUSLE factor values interactively in ArcGIS using Equation (1). The resulting erosion risk map was shown in Figure 4.6. The study reveals that, the annual soil loss ranged from 0-370 ton ha^{-1} yr^{-1} in the study area. This indicates that the study area has a larger spatial variation of soil loss. The spatial variation is caused by the difference in soil erodibility, rainfall erosivity, slope steepness, land cover and improper land management.

As seen from the Figure 4.6, the majority of the study area experiences soil erosion between 0 and 12 ton ha^{-1} yr^{-1}, especially where the slope is very low. Based on the analysis, the average annual soil loss for the entire study area was estimated at 8.39 ton ha^{-1} yr^{-1} and the total annual soil loss potential was 11.91Mt yr^{-1} from the entire area.

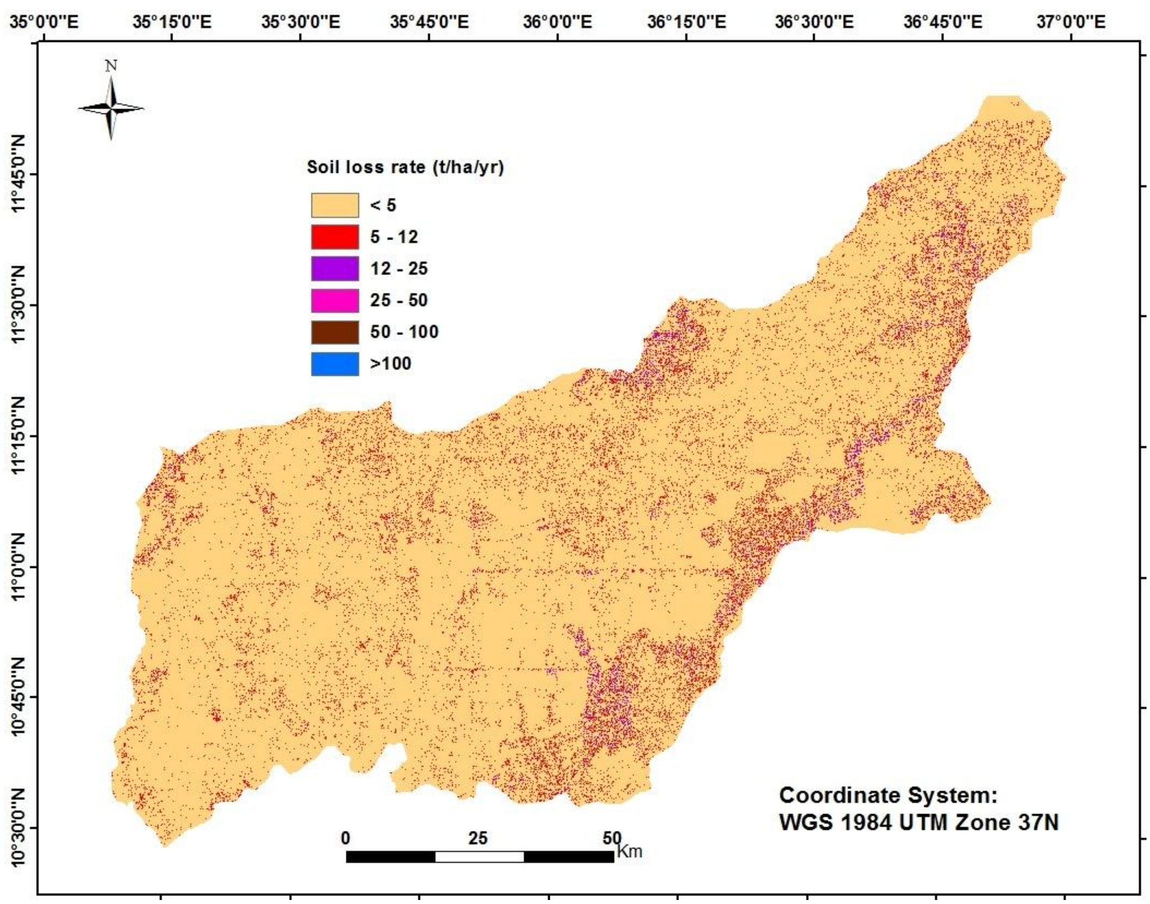

Figure 4.6 Annual soil loss rate map of the study area

The potential soil loss in the study area has been categorized into six types (Table 4.1) as low, moderate, high, very high, severe and very severe erosion based on the rate of erosion according to Bewket and Teferi (2009) and Ayalew and Selassie (2015). More erosion corresponds to very severe erosion and least rate of erosion corresponds to low erosion. The other four categories fall in between moderate and severe erosion. The basis for the categorization of the severity classes was the Soil Loss Tolerance (SLT) which denotes the maximum allowable soil loss that will sustain an economic and a high level of productivity (Wischmeier and Smith, 1978; Renard *et al.*, 1996).

About 74.71 % of the sub basin was categorized as low class which falls under the normal soil loss tolerable values ranging from 5 to 11 tons ha^{-1} $year^{-1}$ according to Renard *et al.* (1996). The remaining 25.29 % of the study area was classified under moderate to very severe class of which 15.85 % were above the maximum tolerable soil loss of 11 ton ha^{-1} $year^{-1}$. Generally, it was observed that most part of the study area comes under lower erosion category, which could be found in almost all areas, and very high erosion occurs only in a few regions where the steep slope exists and cultivation is intensive.

Table 4.1 Annual soil erosion rates and severity classes

Soil loss (ton ha^{-1} y^{-1})	Area (km^2)	Total area (%)	Severity classes
< 5	10,608.82	74.71	none to low
5 - 12	1,340.48	9.44	moderate
12 - 25	1,161.56	8.18	high
25 - 50	644.68	4.54	very high
50 - 100	286.84	2.02	severe
> 100	157.62	1.11	very severe

The result of this study has the same pattern as previous researches conducted on different parts of Abbay basin and other places in Ethiopia, even though there is a difference in value. For instance, in the Ethiopian highlands soil losses are extremely high with an estimated average of 20 ton ha^{-1} yr^{-1} and measured amounts of more than 300 ton ha^{-1} yr^{-1} on specific plots (Hurni, 1985).

Using RUSLE model Molla and Sisheber (2017) estimated annual soil loss rate for Koga watershed and its value ranges from 12 to 456 ton ha^{-1} yr^{-1}. Ayalew and Selassie (2015) estimated the mean annual soil loss potential for Guang watershed in Blue Nile Basin and was 24.95 ton ha^{-1} yr^{-1} for entire watershed. Ayalew (2015) also estimated average annual soil loss of 9.1 ton ha^{-1} yr^{-1} for entirely Zingin watershed in highlands of Ethiopia. For Chemoga watershed an average annual soil loss rate of 93 ton ha^{-1} yr^{-1} was estimated by Bewket and Teferi (2009) for entirely watershed using USLE model. In northeast Wollega, Adugna *et al.* (2015) indicates the soil losses have shown spatio-temporal variations that range from 4.5 ton ha^{-1} yr^{-1} in forest to 65.9 ton ha^{-1} yr^{-1} in cropland.

Shiferaw (2011) estimated an average annual soil loss of 30.88 ton ha^{-1} yr^{-1} for the Legemara watershed in Borena woreda (district), Mekonnen and Melesse (2011) estimated annual soil loss of 18 ton ha^{-1} yr^{-1} for Debremawi watershed, North Gojjam sub-basin. A related study by Haregeweyn *et al.* (2017), for the whole Upper Blue Nile Basin, also reports an average soil loss rate of 27.5 ton ha^{-1} yr^{-1} whereas Mengistu *et al*. (2015) reports the mean annual soil loss for the Abbay basin was estimated at 16 ton ha^{-1} yr^{-1}, reaching to maximum value of 1,511 ton ha^{-1} yr^{-1}.

Generally, the extent and magnitude of soil erosion in the Basin are spatially variable. Severe to very severe soil erosion were observed in the study area. The spatial variations of the soil erosion rates are normally due to the actual existing condition of the areas. A larger part of the study area was being flat possessing gently slope and covered by vegetation. These results in lower average annual soil rates compared to other related studies in watershed of Abbay basin. Hence, sedimentation of eroded soil from upstream area will be the major problem in the study area.

4.6. Prioritization of hotspot areas for treatment

The predicted amount of soil loss and its spatial distribution can provide a basis for comprehensive management and sustainable land use for the area. The areas with high to very severe soil erosion classes demand special priority for the implementation of soil erosion control measures. From the soil erosion risk map (Figure 4.6), it shows that the entire watershed does not require implementation of conservation measures.

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

In this case, prioritization involves ranking of the different areas in the sub basin according to the order in which they should be taken up for treatment with conservation technologies by considering the amount of soil loss occurring. For this study, the sub basin was delineated in to eleven sub areas based on the districts located within the Beles sub basin. The soil loss rate of each districts were analyzed and the erosion risk map for prioritization was shown in Figure 4.7.

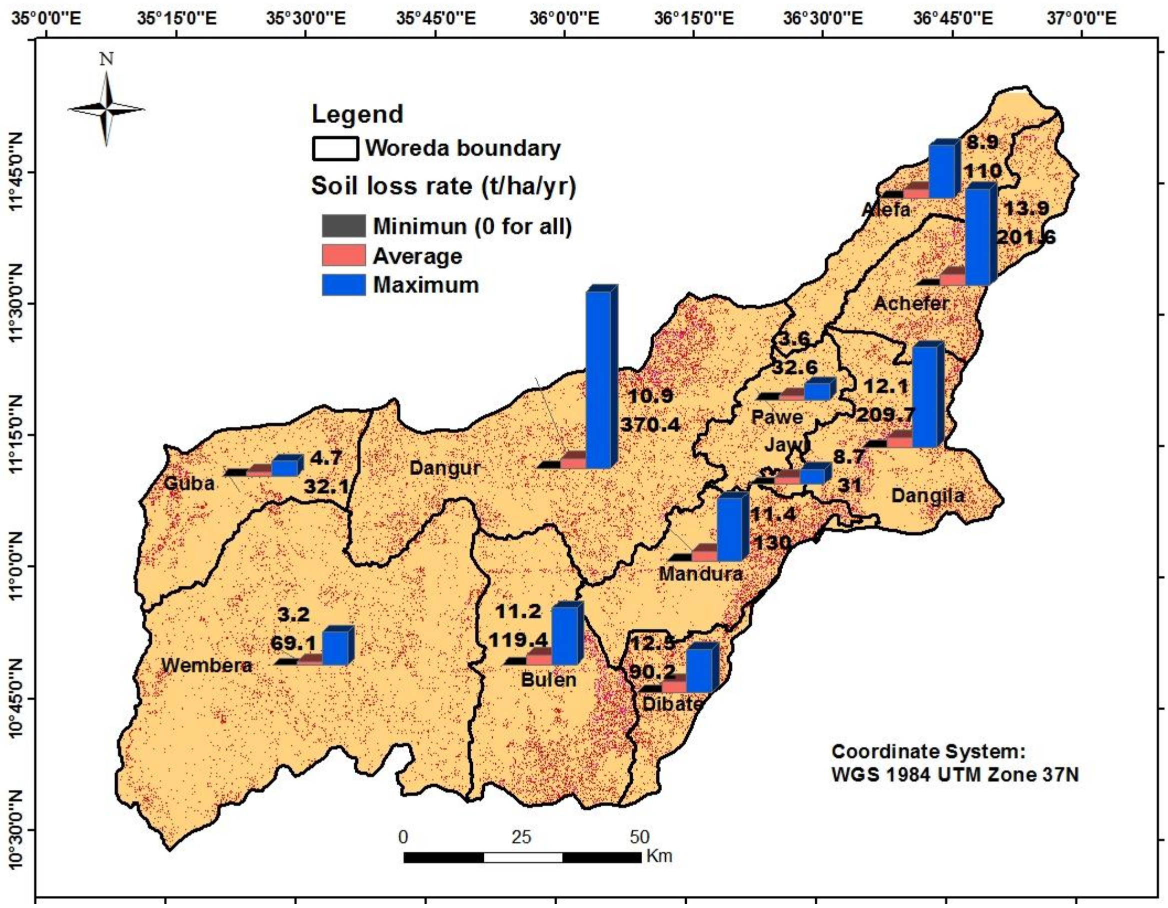

Figure 4.7 Soil erosion area/zone map at district level for conservation planning

Based on the spatial distribution of the erosion risk in the study area, three districts namely Guba, Pawe and Wombera have a maximum soil loss rate of 32.1, 32.6 and 69.1 ton $ha^{-1}yr^{-1}$ in order of sequence. Guba has mean soil loss of 4.7 ton $ha^{-1}yr^{-1}$. Pawe has mean soil loss of 3.6 ton $ha^{-1}yr^{-1}$ and Wombera has mean soil loss of 3.2 ton $ha^{-1}yr^{-1}$.

These district were assigned the forth priorities by considering the average annual soil loss from each districts. Two districts, namely Alefa and Jawi have a maximum soil loss rate of 110 and 31 ton ha^{-1} yr^{-1}, respectively. Alefa has a mean soil loss of 8.9 ton $ha^{-1}yr^{-1}$ and Jawi has a mean soil loss rate of 8.7 ton $ha^{-1}yr^{-1}$ from their respective entire area and hence, assigned the third priories. Bulen, Dangur and Mandura have a maximum soil loss rate of 119.4, 370.4 and 130 ton $ha^{-1}yr^{-1}$, respectively. Bulen has a mean soil loss of 11.2 ton $ha^{-1}yr^{-1}$. Dangur has a mean soil loss of 10.9 ton $ha^{-1}yr^{-1}$ and Mandura has a mean soil loss of 11.3 ton $ha^{-1}yr^{-1}$. These districts were assigned the second priorities.

The other three remaining districts namely Achefer, Dangila and Dibate have a maximum annual soil loss rate of 201.6, 209.7 and 90.2 ton $ha^{-1}yr^{-1}$ in order of sequence. Achefer has a mean soil loss of 13.9 ton $ha^{-1}yr^{-1}$. Dangila has a mean soil loss of 12.1 ton $ha^{-1}yr^{-1}$and Dibate have a mean soil loss of 12.5 ton $ha^{-1}yr^{-1}$. Hence, these three groups of districts were assigned the first priorities for conservation planning.

4.7. Soil erosion conservation measures

The basic principles of combating erosion stem from the underlying processes and factors contributing to erosion (FAO, 1986). These include reducing rainfall impact on the soil, reducing run-off volume and velocity and increase soil resistance to erosion. The soil erosion probability zone map shown in Figure 4.7 guides for phase wise implementation of conservation plan. This is because of managing the whole watershed at once is very difficult due to various constraints.

Conservation measures are described as vegetative or structural methods (FAO, 1986). Vegetative methods such as mulching, cover crops, reforestation and any other practice through which erosion is reduced through vegetation are effective in respect to all three of the principles listed above. Structural methods such as terracing, bunding, drains, waterways, check dams and tillage practices are effective in reducing run-off and have only limited effect in increasing soil resistance to erosion. In any given erosion situation, either soil detachment or sediment transport constrains the rate of erosion and retarding the slower of these two processes is usually the best way to reduce erosion. Thus both methods are recommended for areas falling in high to very severe soil erosion classes.

Structural methods are recommended for areas falling in low and medium soil erosion potential.

Conservation practices that increase infiltration or leave the soil surface so rough that it can pond major quantities of potential runoff, may reduce erosion appreciably. Large amounts of vegetation or mulches reduce soil-surface sealing and maintain higher infiltration rates. Tillage methods that leave the surface rough and cloddy may provide much surface storage potential. Conservation tillage systems dissipate both raindrop and run-off effects, which are why they are so effective on short to moderate slopes, increase soil's resistance to erosion.

Graded terraces and contour farming with ridged crop rows at small row gradients reduces run-off velocity on upland slopes. Conservation practices that maintain dense vegetation or anchored mulches are usually very effective in absorbing the scour force of run-off. Growing vegetation and vegetative residues increase organic matter content in the soil and make it less erodible. As FAO (1986) state, both vegetative and structural measures have feasibility limits, and usually both are necessary in varying degrees in an effective conservation programme, the exact mixture depending on land form, erosivity, erodibility and land use.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

For this study, RUSLE was used to calculate soil loss rate which was adopted and validated for Ethiopian highlands. The study was conducted with the objectives to calculate the annual soil loss rate, analyze the spatial distribution of soil erosion and locate the erosion prone areas for development of conservation planning. The soil erosion assessment reveal that erosion is a serious problem that affects many part of the sub basin.

The result of the analysis shows that the assessed annual soil erosion rates from 0 - 370 ton $ha^{-1}yr^{-1}$. The mean annual soil loss was 8.39 ton $ha^{-1}yr^{-1}$ and the total annual soil loss potential was 11.91Mt yr^{-1} from the entire study area. The result is relatively small compared to the results from plot level and small-watershed scale studies in the highlands of northern Ethiopia. About 74.71 % of the sub basin was categorized as low class which falls under the normal soil loss tolerable values ranging from 5 to 11 tons ha^{-1} yr^{-1}. About 25.29 % of the study area was classified under moderate to very severe class, out of which only 15.85 % of the area were above the maximum tolerable soil loss rate.

It is observed that most part of the study area comes under lower erosion category, which could be found in almost all areas. The high to very severe erosion class occurs only in a few regions at the steep slopes, grazing areas, stream banks and intensive cultivation. The lower erosion class is mainly related to the size of the study area in which big watersheds do have high surface roughness resulting in low mean soil loss values. It is further influenced by the existing huge environmental conditions as larger part of the study area was being flat possessing gently slope and covered by vegetation. Nevertheless, taking the lower ranges of the soil formation rate recommended by Hurni (1983) for Ethiopian highlands as 2 ton $ha^{-1}yr^{-1}$, the soil in the study area is being lost four or more times faster than the rate of renewal and sustainability.

In general, the study reveals that RUSLE and GIS based approach for erosion assessment model is effective techniques to estimate soil loss rate in watershed or basin that helps to delineate erosion-prone areas and prepare conservation plans for efficient use of soil resources timely and in a cost effective manner. Therefore, the method can be applied in other watershed or basin for assessment, delineation and prioritization of erosion prone areas for conservation interventions.

5.2. Recommendations

Soil erosion is the cause for degradation of large areas of productive soil, irrigation schemes, hydro power systems, water supply facilities and systems etc. The destructive effect of the erosion that are manifested in losses of the bio genetic nature, soil productivity, results in low yields per unit area, as well as in unproductive and degraded soil layers.

- Hence, taking into consideration the harmful effect of erosion, numerous protective and management measures should been taken.
- The result of the study indicates the need for soil conservation planning that requires comprehensive and cost effective plan, especially in the vulnerable parts of the basin.
- The collaboration of all the stakeholders such as the government, non-governmental organizations and the farmers who are the first victims of the problem are needed to combat soil erosion.
- Emphasize on increased vegetative cover on the land as the most important conservation component followed by bunds and terrace construction should be practiced.
- In all conservation practices farmers (local peoples) should be participated and the incentives for rural households to construct and maintain effective conservation structures are well established with clear right of ownership structures.
- In addition to this, policies such as land use policy, ownership right of land, family planning, create off farm employment or other income generating activities and appropriate technologies should be adopted and integrated with local/traditional practices that are known to be effective in conservation of the land resources.

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APPENDIXS

Appendix 1: Definition of the land use and land cover classes

Bamboo land	Areas occupied by bamboo trees
Bush land	Areas with sparse trees mixed with short bushes, grasses and open areas; less dense than the forest with little useful wood, mixed with some grasses
Dominantly cultivated land	Areas intensively cultivated (covered by grains or annual crops)
Grassland	Land areas predominately covered with grasses, forbs (any herbaceous plant that is not a grass), and grassy areas used for communal grazing.
Moderately cultivated land	Areas with a moderate cover of annual crops (50-70%) mixed with grassland or cropland (20-50%), with free grazing
Rock land	A bare land that consists of recent lava flows, exposed rock outcrops, and exposed sand and soil surfaces where vegetation hardly exists and not suitable for agricultural practices
Shrub land	Areas composed of patches of shrubs and bushes interspersing grasslands with some scattered trees
Urban areas	Settlement areas (urban centers as well as clustered and dense rural settlements)
Woodland dense	Areas occupied by trees with discontinuous canopy (>50 % canopy cover) and bushes and grass undergrowth. It includes deciduous and succulent trees and eucalyptus plantation
Woodland open	Areas occupied by trees including deciduous and succulent trees and eucalyptus plantation with discontinuous canopy (<50 % canopy cover), bushes and grass undergrowth

Appendix 2: Table that shows the annual rainfall data of the eleven rain fall stations

Years/ Station	Bullen	Chag ni	Dangi la	Enjab ara	Mandu ra	Pawe	Sherek ole	Sirba Abay	Worota	Bahir Dar	Dibate
1992	654.9	873.8	1325.0	2129.7	1287.1	1572.9	1170.5	1210.2	1472.9	1312.9	798.5
1993	1617.5	1320.5	1715.6	2506.4	1309.3	1433.6	1202.9	1904.3	1266	1715.6	1210.5
1994	1609.1	1649.6	1317.9	2231.6	1358.4	1097.7	976.8	898.6	1265.3	1390.5	1557.1
1995	1463.7	1826.4	1164.2	1953.6	1420.8	1563.7	775.4	816.4	1463.7	1184.6	1463.7
1996	1531.6	1724.7	1654.7	2386.9	1431.2	1593.2	609.3	637.9	1554.7	1634.9	1563.4
1997	1543.1	1106.9	1688.1	2816.5	1381.1	1439.2	1234.2	1223.9	1467.2	1667.2	1531.6
1998	2000.6	1825.6	1256.5	2301.2	1906.4	1831.0	1585.2	637.7	1244.9	1301.3	1973.6
1999	1638.7	1758.8	1959.4	2408.6	2149.2	1525.9	1193.2	1456.7	1459.4	1960.4	1618.9
2000	1374.6	1950.7	1895.7	2570.9	1684.9	1485.5	1383.6	2417.8	1495.7	1765.7	989.4
2001	1101.4	1631.9	1411.1	2285.0	290.5	1733.0	964.4	1858.3	1431.1	1314.1	1213.8
2002	1231.9	1393.3	1349.8	2157.0	1185.0	1353.1	1321.1	1010.5	1349.8	1349.8	721.1
2003	1448.9	1583.2	1369.4	2106.4	1438.5	1425.8	937	879.6	1369.4	1369.4	1040.5
2004	1387.8	1737.7	1627.9	2201.7	1990.2	1230.4	1182.1	976.7	1437.7	1647.9	1122.6
2005	1381.7	1734.3	1405.4	2194.8	1892.2	1215.5	1174.6	1005.4	1434.3	1405.4	982.6
2006	896.5	1712.8	1869.0	2759.2	1388.5	1932.5	1381.9	1214.3	1482.5	1870	1143.2
2007	1742.5	1828.3	1478.7	2157.7	1771.4	1616.9	1084.3	820.1	1528.3	1478.7	1363.4
2008	1663.6	1913.4	1858.1	1950.6	1869.7	1669.4	1127.8	1127.8	1513.4	1736.4	1336.8
2009	1137.7	1398.6	1454.6	2136.2	1802.4	1182.1	1156.5	1156.5	1536.2	1454.6	1041.9
2010	1428.3	1392.8	1090.2	2358.5	2146.1	1696.5	1298.1	1059.9	1658.5	1090.2	1076.7
2011	1157.1	1488.3	1599.2	2349.1	834.7	1253.4	1428.3	1239.7	1595.8	1599.2	1005.6
2012	1412.7	1651.2	1640.4	2484.6	2607.9	1829.2	1157.1	1082.6	1410.9	1441.8	1038.7
2013	1498.3	1752.1	1919.0	2988.8	1779.6	2087.1	1412.7	877.1	1321	1580.8	1014.4
2014	1741.7	1878.8	2008.2	2635.2	703.9	1940.2	2801.4	885.1	1678.8	1512.8	1144.8
2015	1330.0	1787.7	1731.0	1862.2	157.0	1140.9	1330	1187.9	1487.7	1190.8	1119.3
2016	1336.7	1390.9	1204.6	2077.0	2266.0	1108.9	2164.3	1217.4	1522.1	1613.5	1441.7

Appendix 3: Table that shows the name, location, mean annual precipitation value and erosivity of each of the metrological stations.

Station name	Longitude	Latitude	Average annual RF (mm)	Erosivity (R= -8.12 + 0.562xP)
Bahir Dar	37.36	11.60	1432	796.66
Bullen	36.08	10.60	1413.6	786.32
Chagni	36.50	10.97	1612.5	898.11
Dangila	36.85	11.43	1559.7	868.43
Dibate	36.26	10.77	1213.3	673.76
Enjabara	36.92	11.00	2320.4	1295.95
Mandura	36.50	11.50	1522.1	847.30
Pawe	36.41	11.31	1518.3	845.17
Sherekole	35.08	10.80	1184.4	657.51
Sirba Abay	35.27	10.33	1047.7	580.69
Worota	37.68	11.92	1285.8	714.50

Appendix 4: Graph that shows the consistency of rainfall data