Addis Ababa University

College of Social Sciences

Department of Geography and Environmental Studies

Application of RUSLE to Soil Erosion Risk Mapping in Arbit Watershed Northwestern Ethiopia.

By

Gebre Alamrew

Addis Ababa, Ethiopia

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A Thesis Submitted to Department of Geography and Environmental Studies, College of Social Science of Addis Ababa University in partial fulfillment of the requirement for the Degree of Master of Arts degree in Geography and Environmental Studies (specialization: Geographic Information System, Remote Sensing and Digital Cartography).

Advisor

Prof. Mohamed Assen

Addis Ababa, Ethiopia

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Declaration

I hereby declare that " Application of RUSLE to Soil Erosion Risk Mapping in Abit Watershed Northwestern Ethiopia" is an original work done by Gebre Alamrew Addis in the partial fulfillment of the requirement of the Master of Arts degree in Geography and Environmental Studies (specialization: in GIS, Remote Sensing and digital cartography) and compiles with the regulations of the University and meets the accepted standards with respect to originality and quality. This work has been completed under the guidance of my Advisor Prof. Mohamed Assen

Gebre Alamrew

Signature______________________

Date ______________________

Approval Sheet

This is to certify that the Thesis prepared by **Gebre Alamrew Addis** entitled: "Application of RUSLE to Soil Erosion Risk Mapping in Abit Watershed Northwestern Ethiopia" is approved for the degree of Masters of Arts in GIS, Remote Sensing and Digital Cartography.

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Chair of Department or Graduate Program Coordinator

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List of Acronyms

AfSIS	Africa Soil Information Service
CHIRPS	Climate Hazards Groups InfraRed Precipitation with Station Data
DEM	Digital Elevation Model
EI	Rainstorm Intensity
ERDAS	Earth Resource Data Analysis System
FAO	Food and Agriculture Organization
GCP	Ground Control Points
GII	Geospatial Information Institute
GIS	Geographical Information System
GPS	Global Positioning system
LS	Slope Length and Slope Steepness
LULC	Land Use Land Cover
NGO	Non-Govermental Organization
NMA	National Meteorological Agency
RS	Remote sensing
RUSLE	Revised Universal Soil Loss Equation
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
T/ha/Yr	Ton per Hectare per Year

Abstract

This study was conducted in Arbit watershed, Northwestern Ethiopia with the objective of mapping and predicting the annual soil loss rate and identify erosion hotspot areas by integrating Revised Universal Soil Loss Equation(RUSLE) model,GIS and remote sensing technology. The study employed the RUSLE to map soil erosion risk areas and help experts to prioritize soil conservation practice in Arbit watershed, Northwestern Ethiopia. The major required input parameters for the model were obtained from different satellite imagery sources. The input parameters such as rainfall pattern, topography, soil type, cover management and support practice were derived CHIRPS, DEM, AfSIS, SPOT-7 satellite image and generated by using ArcGIS10.5 software. ERDAS EMAGINE15 software were used for LULC classification. The annual soil loss of was classified in to very low, low, moderate, high, very high and severe to identify erosion hotspot areas in the watershed. The result showed that the potential annual soil loss (A) of the watershed ranges from 0 to 814.74 ton/ha/yr. The findings revealed that soil erosion risk was high in the North and Northwestern part of the study area. The vulnerability of soil erosion risk in the study area indicated that 34.61% was fall under moderate to high soil erosion risk.18.74% under very high to severe soil erosion risk class. Steep slope areas with poor vegetation cover experienced high soil erosion. Topography (LS factor) and vegetation (C factor) have a significant effect on soil erosion in the watershed. Implementation of immediate soil and water conservation practices are needed for areas where annual soil loss was above 25ton/ha/yr.

Key words: topographic factor, soil loss, watershed, management prioritization,

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Soil erosion is a complex and dynamic phenomenon affecting many areas all over the world in different severity and frequency (Aiello et al., 2015). It is considered as one of the most critical environmental problems throughout the globe (Abate, 2011; Nikolova et al., 2019). Soil erosion and agricultural practice in tropical and semi - arid countries have great relationship and it is the cause of soil fertility reduction which have a negative impact to the environment (Prasannakumar et al., 2012). According to Aiello et al., (2015), around the globe each year, 75 billion tons of soil is removed due to erosion largely from agricultural land. In Ethiopia soil erosion is one of the major facts which affect sustainability of agricultural production (Molla & Sisheber, 2016). It is the causes of reduction of topsoil thickness and reduce crop yield capacity of the land due to this it creates food insecurity across the different regions (Bewket & Teferi, 2009).

Moreover, Blanco and Lal (2008) indicated that soil erosion reduces the storage capacity of dams and shorten design life of reservoirs, as well as affects water resource quality by transporting sediment and chemicals which can be the cause of pollution, sedimentation and silting. As a result, prevention of soil erosion in watershed areas and the subsequent deposition in rivers, lakes and reservoirs have importance in environmental management (European Environment Agency, 1995). As stated (Miheretu & Yimer, 2018), soil erosion have a more impact on economy in developing countries than developed countries because they are poor in resource to replace the lost nutrients. In developing countries, there is a high population growth which leads to intensified use of the existed resources that result in unsustainable farming practice.

Soil erosion in Ethiopia is not a new phenomenon. It has an ancient history which is similar with the history of agriculture itself (Bekele & Drake, 2003). Ethiopia losses more than 1.5 billion tons of fertile soil from its highland per annum (Lulseged & Vlek, 2008). This indicates that soil erosion is a very serious problem and it requires rapid solution in order to afford food for the people by protect soil erosion (Tamene & Vlek, 2008). In this regard, soil erosion in the northwestern Amhara region of Ethiopia has resulted in a main environmental threat to the sustainability and productive capacity of agricultural areas (Addis & Klik, 2015). According to FAO_(1986), in the Northwestern highlands of Ethiopia 200 - 300 tons of eroded soils are quantified per hectare, making the total loss of 23,400 million tons per year. This indicates that soil erosion is very serious and leads to food insecurity and has a negative impact on livelihoods among rural communities in Ethiopia (Miheretu & Yimer, 2018).

Estimation of soil erosion has an advantage of providing information about the area which is exposed to soil erosion risk and this used to apply soil conservation practice and raising risk awareness due to erosion hazard (Zorn & Komac, 2011). As a result, organizations working on water and soil conservation practice estimate soil loss for the purpose of identifying hotspot areas in the watershed. Thus, estimation of soil loss and identification of hotspot areas for accomplishment of best management practice is very important to the achievement of soil conservation program (Ganasri & Ramesh, 2016). Therefore, in order to quantify the amount of erosion estimation of soil loss by using different models is very important by considering different factors of erosion (Ghosh et al., 2011). According to Ghosh et al., (2011), one of the most widely applied empirical models that used to estimate the amount of soil loss is Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1965), recently modified as Revised Universal Soil Loss Equation (RUSLE) by Renard et al., (1997) for measuring sheet and rill erosion.

Revised Universal Soil Loss Equation (RUSLE) uses the same empirical principles as USLE (Ganasri & Ramesh, 2016) and can be linked to RS and GIS application techniques. Soil erosion rate can be predicted by using empirical models and the models that used to estimate the amount of soil loss used spatial information as input data which is provided by GIS and remote sensing (RS) technology (Bengal et al., 2018).Therefore, the application of GIS and Remote sensing (RS) techniques are used to estimate soil erosion and its spatial distribution in order to identify highly erosion risk areas in a given watershed with fair cost and better accuracy (Kamuju, 2016).

1.2. Statement of the problem

Soil erosion is a natural process resulting from the taking away of soil particles by the agents of soil erosion and deposit them somewhere else. It is accelerated by anthropogenic activities. There are several man-induced impacts which accelerate soil erosion, some of which are deforestation, overgrazing and improper land use like cropping pattern and cultivation along the slope (Ganasri & Ramesh, 2016). Accelerated soil erosion needs a great attention because it has a negative impact on the world environment continuously, especially in developing countries like Ethiopia (Amsalu & Mengaw, 2014). At this time, environmental damages in Ethiopia are the result of agriculture because majority of the country's population depends on agriculture and soil is the most important input to increase production of agriculture. Prasannakumar et al., (2012) have also stated that, soil erosion has a relation with the agricultural practice that brings negative impact on the environmental problems, and has become a risk to maintain agricultural production. To overcome such problems and negative impacts on the environment related with soil erosion, highly vulnerable erosion areas should be identified in order to apply soil and water conservation management plan at different watersheds. To give more emphasis and direct resources on the area which is highly affected by erosion, identifying these hotspot areas is considered as a good strategy (McDowell & Srinivasan, 2009). McDowell & Srinivasan (2009) state that mapping and monitoring of the areas according to their vulnerability is needed to allocate our limited resource in the hotspot area for conservation practice. Thus, to implement and achieve best soil conservation management practice properly, estimation of soil loss and identification of critical areas are very important (Ganasri & Ramesh, 2016).

Some studies showing the spatial extent of soil erosion by water have been done in Ethiopia by integrating GIS and remote sensing with RUSLE model. For example, soil loss estimations using GIS and Remote sensing techniques are found in different works of Bewket & Teferi, 2009; Ayele, 2011; Amsalu & Mengaw, 2014; Gelagay,& Minale, 2016; Mekuriaw, 2017; Asmamaw &Mohammed, 2019. Although a number of studies have been done in Ethiopia in small individual watershed using RUSLE model, GIS and RS techniques, specific studies related with soil erosion in the Arbit watershed (the present case study area) were not conducted. Therefore, in this study RUSLE model is combined with remote sensing and GIS to map soil erosion risk area in the Arbit watershed. Because soil erosion has a variation spatially and temporally, works on soil erosion measurement should be done for each individual watershed. GIS and remote sensing integrated with RUSLE model can estimate or quantify the amount of soil loss, map and identify erosion hotspot areas in the watershed. Implementation of soil management practice in the whole watershed at a time is impossible because of limitation of resource and labor force. To apply effective soil management practice, the amount of soil loss should be expressed quantitatively and erosion hotspot area should also be identified in a certain watershed (Prasannakumar et al., 2012). Spatial and quantitative information about soil erosion on specific watershed play significant roles in planning for soil conservation, erosion control, and management of the watershed environment.

In the Arbit watershed, the local community has practiced agricultural activity for several years without any appropriate soil management practices. In the study area, severe soil erosion was observed along a steep slope consisting of sparse vegetation cover, exposed rocks and stones. In addition to this, gullies have developed in some area of the watershed specially in the mountainous part and previous cultivated areas. Thus, mapping of erosion hotspot area by application of RUSLE model and GIS techniques are essential in the Arbit watershed. So, this study is expected to estimate rate of soil erosion in the watershed and to identify hot spot areas for soil conservation and management planning by integrating GIS and remote sensing with RUSLE model in the study area.

1.3. Objectives

The general objective of this project is to assess the spatial extent of soil erosion risk area in the Arbit watershed by using RUSLE model.

The specific objectives include:

- To map and predict the annual soil loss rate in the Arbit watershed with the help of RUSLE.
- To identify hotspot areas of soil erosion in the Arbit watershed which requires immediate attention and intervention.

1.4. Project questions

Based on the above objectives, the following project questions were formulated.

- How much of soil is lost annually per unit area in Arbit watershed?
- What factors affect the spatial distribution of soil loss rate in Arbit watershed?
- Where are the locations of erosion hotspot areas in Arbit watershed?

1.5. Significant of the study

The study will focus on how GIS and remote sensing technologies integrated with RUSLE model are important for estimating and mapping soil erosion risk area. The nature of soil erosion has a spatial and temporal variability. The variability of soil erosion is mapped and computed to provide information for soil and water conservation intervention. Providing information on the extent, severity and geographical distribution of soil loss is important for different groups.

In this study, the primary beneficiaries will be the local communities. The study will provide information for secondary beneficiaries like experts, NGOs, decision-makers and other stakeholders who are working on soil and water conservation in Arbit watershed to make their projects cost effective and time-bound. The study could also be used as a source of information for other researchers who are intending to do related or similar project works.

1.6. Scope of the study

The study is a local micro-watershed level study. The study mainly focuses on quantifying the amount of soil loss rate in the Arbit watershed using GIS and remote sensing techniques. Verification or evaluation of the result is out of the scope of this project because soil erosion modeling needs extensive field data with plot sample to estimate the actual soil loss in the watershed. It is impossible to do this and to finish the project within the given time and available resources. A brief description of the amount of soil loss compared with the output of the previous studies is used as a base for the final result of this project. Therefore, plot sample data collection from the field in order to verify the soil loss of Arbit watershed is out of the scope of this project.

1.7. Limitation of the study

During the project work the researcher has faced different constraints. The project was conducted in a limited time set by the department. The researcher could not obtain additional data which increase the quality of the paper. For example, the researcher could not test a sample soil data in the laboratory in order to obtain a local or farm level inherent soil characteristics like soil particle size (silt, clay, sand), soil organic matter, soil structure and soil permeability. To overcome this problem, the researcher has used soil AfSIS in order to assign the soil erodibility factor (K) which is obtained at the website (https://ISRIC Data Hub - ISRIC - World Soil Information, 2016.)

1.8. Organization of the thesis

The overall organization of this thesis is divided into five chapters. Chapter one deals about introduction, statement of the problem, objectives, project questions, significance, scope, limitation and organization of the thesis. Chapter two is about review of related literatures and chapter three presents the description of the study area and methodology of the project. Results and discussion of the study are presented in chapter four and conclusion and recommendations are presented in chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1. Overview of soil erosion

Soil is the skin cover of the earth which is easily broken and holds all life on the earth (Nancy & Singh, 2015). It is the basic resource for economic development and for maintaining sustainable productive landscapes and people's livelihoods especially for countries with agricultural economy like Ethiopia (Gashaw, et al. 2018). It is also a vital resource that affords food, fuel and fiber (Blanco and Lal,2008). Soil is a non-renewable, finite and fundamental natural resource on the earth to support life (Meseret & Amsalu, 2017). The livelihood source of the people in the world greatly depends on soil resource that leads to accelerated soil erosion (Molla & Sisheber, 2016).

Soil erosion is a natural process resulting from the removal of soil particles by erosion agents and accelerated by human activities (Lal, 2003; Roux et al., 2007; Wolka et al., 2015,). Soil erosion is a naturally occurring process that affects all landforms (Abate, 2011; Balasubramanian, 2017; Halefom et al., 2018). Morgan (2005) and Roux et al. (2007) state that soil erosion is a natural process that detaches individual soil particles from the soil mass and transport by erosive agents such as water and wind. The agents of soil erosion are water and wind which accounts 56% and 28% of the observed damage respectively (Blanco and Lal, 2008). The causes and effects of soil erosion should be studied in order to control soil erosion (Balasubramanian, 2017).

According to Morgan (2005), soil erosion can damage the environment through sedimentation, pollution, and increased flooding. It is the main cause of soil degradation at a worldwide scale (Morgan, 2005) and it affects both agricultural productivity by reducing soil fertility and sedimentation of reservoir (Roux et al., 2007). Soil erosion mainly affects the physical and chemical properties of soils. Changes in chemical parameters are largely a function of changes in physical composition (Temesgen, 2015). It causes loss of fertile topsoil and reduces the productive capacity of the land and creates risk to global food security (Morgan, 2005). Morgan also states that, soil erosion not only affect agricultural area but also affects negatively the natural water storage capacity of catchments, design life of man-made reservoirs and dams, quality of surface water resources, aesthetic landscape beauty and ecological balance in general. On site and off site effects of soil erosion by water have negative effects on agricultural productivity (Kefi et al.,2010). Decreasing of agricultural productivity and ecological collapse are related with the on-site effects of because of loss of the nutrient-rich upper soil layers. Sedimentation of waterways, eutrophication of water bodies and damaging of roads and houses due to sedimentation are the off-site effects of soil loss (Bartelmus, 2002).

2.2. The extent of soil loss and it's severity in the world

Soil erosion occurs largely in developing countries particularly in the tropics and sub-tropics because of the high population pressure, scarcity of major agricultural lands and poor farmers (Blanco & Lal 2008). Soil erosion is a serious environmental crisis throughout the world (Pimentel & Burgess, 2013). It affects world food production seriously (Pimentel & Burgess, 2013). It is a well-known form of soil degradation in the world and it affects 1094 million ha by water erosion globally from this 752 Mha is affected severely (Lal, 2003). According to Pimental & Burgess (2013), 10 million ha of cropland are lost because of soil erosion each year. Because of the long dry seasons followed by heavy erosive rainfall events and steep slope with soils which is easily erodible, the Mediterranean region is prone to soil erosion (Rellini et al., 2019). The 12 million hectares of agricultural areas in the EU that suffer from severe erosion are estimated to lose around 0.43% of their crop productivity annually (Standardi et al., 2018). According to Standardi (2018), the annual cost of this loss in agricultural productivity is estimated at around €1.25 billion.

Blanco and Lal (2008), states that the magnitudes of soil erosion vary from region to region and is region specific. At the present, some of the areas which are highly prone to erosion are: Sub-Saharan Africa, china loess Plateau, the lower Himalayas (Blanco & Lal, 2008). At the global scale, around 1960Mha of lands are prone to erosion which represents about 15% of the earth's total land area, of which 50% is severely eroded (Lal et al., 2004). Soil erosion is serious in Africa and Asia due to high population and lack of resources for conservation and poor farmers to subsistence (Blanco &Lal, 2008). One third of the world's agricultural soils, or approximately 2 billion hectares of land was reported as being affected by soil degradation caused by soil erosion(Temesgen, 2015)

2.3. Soil erosion in Ethiopia

Soil erosion in the Ethiopian highlands begin with the introduction of agriculture several years ago (Hurni, 1988) and it is a serious problem in the country (Mesene, 2017; Halefom et al., 2019). In Ethiopia rates of soil erosion are being assessed since 1981 in the Soil Conservation Project (Hurni, 1985). Soil erosion by water in Ethiopia is the most critical environmental problems particularly in the highland areas due to a high rugged topography, population pressure and cultivation on steep slope lands (Bewket & Teferi, 2009). In the highlands of Ethiopia, soil erosion by water is one of the main damaging and nonstop environmental problems (Gashaw et al., 2017, Mesene, 2017). Hurni (1988) states that extent and distribution of soil degradation in Ethiopian highlands are high in the northern and Eastern regions. Ethiopia is considered to have one of the most chronic soil degradation problems in the world and its average annual soil loss rate is estimated to be 12 tons/ha/yr (Temesgen, 2015). This severe soil erosion has a huge economic cost in Ethiopia.

The Economy of Ethiopia is highly supported by its agricultural sector (Kassie et al., 2010). Sustainability of agriculture and soil resources are seriously affected by soil erosion (Govers et al., 2017) result in reduction of agricultural productivity (Morgan, 2005, Roux et al., 2007). In 1986 Ethiopia costs USD 30 million and by 2035 this cost was expected to raise to USD 900million (FAO,1986). Hurni et.al, (2015) calculated the annual cost of nutrient loss by water erosion from croplands in Ethiopia was USD 700million.

Soil erosion have a more serious impact on the economy of Northwestern part of Ethiopia due to mainly its rugged topographical features and lack of capacity to cope with it to replace lost nutrients (Gete, 2000; Amsalu & Mengaw, 2014). In the Northwestern highlands of Ethiopia the measured soil loss reached between 200 – 300 tons/ha, making the total loss of 23,400 million ton per year (FAO, 1986). Soil erosion by water is recognized to be a critical economic problem in highland Ethiopia (Bewket & Sterk, 2003). According to Bewket & Sterk (2003), in the highlands of northwestern Ethiopia, soil erosion is a threat to agricultural production and soil conservation is critically needed.

2.4. Factors affecting soil erosion

The major factors affecting soil erosion are climate, vegetation cover, topography and soil properties (Blanco and Lal,2008). The magnitude and rate of soil erosion are determined by the interactive effect of these factors (Blanco and Lal,2008).

The climate factors which affect soil erosion by water are rainfall and runoff. According to Blanco and Lal (2008), the main agent of water erosion is rainfall and the amount and rate of erosion depends on amount, intensity and frequency of rainfall. When there is high amount and intensity of rainfall, erosion will be serious because infiltration of soil is reduced.

Erosion in RUSLE is affected by the topography of LS factor (Renard et al., 19997). According to Renard et al., (1997), the effects of slope length and steepness to estimate erosion in RUSLE are evaluated together. A horizontal distance from the origin of overland flow to the point where either the inclined of slope is decreases or the deposition begins or runoff becomes concentrated into a specific channel is known as slope length (Wischmeier & Smith, 1978, Renard et al., 1997). The rate of soil erosion by water is significantly affected by the length and the steepness of the slope. Soil erosion increases with increase in field slope gradient and length (Wischmeier & Smith, 1978, Renard et al., 1997) due to the increase of accumulation of runoff in the surface in a down slope direction (Vijith, 2015). It determines the velocity at which water runs off the field (Blanco and Lal,2008). Blanco and Lal, (2008) states that, convex fields are more exposed soils for erosion than concave areas due to interaction with surface creeping by gravity.

Soil erosion is influenced by soil texture, the content of soil organic matter and infiltration capacity that can be detached and transported. Soil aggregate affects the resistance to detachment and transportability (Blanco and Lal 2008). Large and unstable aggregates are more detachable. Clay particles form more strong and stable aggregates but it can be transported easily than sand particles.

Vegetation cover is a cover management factor which is the ratio of soil loss from an area with definite cover and management to soil loss from the same area (Alkharabsheh et al., 2013). Vegetation cover reduces soil erosion by intercepting, absorbing and reducing the erosive energy of raindrops. Plant morphology such as height of plant and canopy structure influences the effectiveness of vegetation cover (Blanco and Lal 2008). According to Blanco and Lal (2008), soil detachment increases with decrease in vegetation cover. The denser the canopy and thicker the litter cover, the greater is the splash erosion.

The P- factor refers to the practices that are used to control erosion (Blanco & Lal, 2008). It is defined as the ratio of soil loss with a particular support practice to the corresponding loss with up and down slope tillage (Wischmeier & Smith, 1978; Renard et al., 1997). Contouring and tillage practice effect is the support practice (P) on soil erosion in the RUSLE model (Renard et al.,). The P value ranges from 0 to 1 where the highest value corresponds to a bare without any support practice (Wischmeier & Smith, 1978). The lower valve of P- factor is more effective for controlling soil erosion in the conservation practice. In order to decrease p- factor value supporting conservation practice would be applied such as contour farming, strip cropping, terracing and drainage on the surface of specific site, as they reduce the volume of runoff and velocity result in sediment deposition on the surface of hill slope is promoted (Panagos et al., 2015).

The conservation practice can reduce the amount and rate of runoff. Contouring, strip-cropping, terracing, and drainage are considered as some of the major support practice for agricultural land (Renard et al., 1997). Applying the combination of different support practice such as, contouring, strip-cropping and terracing are more advantageous than using a single support practice for controlling erosion in highly erodible soils.

2.5. Revised Universal Soil Loss Equation (RUSLE) model

Different models have been developed by scientists to estimate or evaluate soil loss in different times such as, Revised Universal Soil Loss Equation(RUSLE), European Soil Erosion Model (EUROSEM) and Water Erosion Prediction Project (WEPP). These different models usually rests on the level of complexity of soil erosion process and on the spatial and temporal resolution of the model (Roux et al., 2007). According to Merritt (2003), models developed by different scholars fall into three main categories. These are empirical, conceptual and physically based models. The Universal Soil Loss Equation (USLE) and its revised model (RUSLE) are the well-known empirical and most widely used models to estimate soil loss. Due to their moderate data demand and its ability to integrate with GIS and RS to estimate soil erosion RUSLE models have been widely applied. The empirical soil erosion model developed by Wischmeier and Smith (1978) is called the Universal Soil Loss Equation (USLE).

The USLE model can predict soil erosion in croplands which have a gentle slope topography whereas the Revised Universal Soil Loss Equation have a broad application to estimate and provide a quantitative and consistent approach to estimate soil loss under a wide range of topographical conditions including rangeland, forest and distributed areas (Renard et al., 1997; Ganasri & Ramesh, 2016). The RUSLE model was developed in 1997 by Renard et al., as an empirical model representing the erosion factors such as soil properties, climate, topography, and land cover and management. To show the relationship among these factors, RUSLE model use mathematical expression and the process occurring in the landscape (Rabia, 2016). The input parameters of these model were obtained from field measurements. Quantifying soil loss based on erosion plots have its own limitations in terms of cost, representativeness and consistency of the resulting data (Lu et al., 2004). These methods cannot provide spatial distribution of soil erosion prone area because of a small number of representative sample data about the complex environment (Lu et al., 2004). Mapping soil erosion risk area in a large geographical area by using the traditional method is a difficult task (Lu et al., 2004, Vijith, 2015). Problems related with these methods can be solved by combining remote sensing and Geographical Information System (GIS) techniques combined with RUSLE model (Chen & Li, 2011; Vijith, 2015).

Overlaying the Revised Universal Soil Loss Equation (RUSLE) parameters in the form of raster format in the GIS environment can estimate and provide the spatial distribution of soil erosion vulnerable area in the watershed (Kalambukattu & Kumar, 2017). The RUSLE model shows the effect of topography, soil property, and land use on soil erosion caused by surface runoff (Rnard et al., 1997). The revised version of the Revised Universal Soil Loss Equation (RUSLE) model, combined with RS and GIS technologies are used as a tool to estimate the average annual soil loss, produce soil erosion risk and soil erosion severity maps and identify areas of critical soil erosion conditions which require urgent need for appropriate conservation measures and land management (Farhan et al., 2013).

2.6. The role of Remote Sensing and Geographical Information System (GIS) for soil erosion measurements

Strategies of soil conservation in a specific watershed are planned based on the severity of the problem in that watershed and this severity is determined by taking in to account different factors such as annual soil loss, quantitative measure of topsoil (Kalambukattu & Kumar, 2017). As stated by Kalambukattu & Kumar (2017), confirmation of soil loss in different watersheds and micro-watersheds was difficult task until the development of remote sensing and Geographical information system techniques.

The advent of GIS and remote sensing technology has a considerable positive impact on the usefulness of soil erosion models (Blanco and Lal, 2008). As stated by Blanco and Lal (2008), the combination of remote sensing and GIS with soil erosion models have capability of improving soil erosion estimation. Demirci and Karaburun, (2012) also state that, coordination of RUSLE model with GIS and remote sensing technologies are used for the effective estimation of soil loss. Remote sensing and Geographical information system (GIS) is a techniques that used to make the estimation of soil erosion and the extent of its spatial distribution with low costs and better accuracy in larger areas (Chen & Li, 2010). Soil loss at different scales could be evaluated and identify its spatial distribution by integration of RS and GIS with RUSLE models (Alkharabsheh et al., 2013).

All the spatial data which can be used in erosion mapping, qualitative and quantitative erosion assessment can be obtained from existing topographic, soil, land use maps, field measurements, aerial photographs and satellite imagery (Niemiec, 2009). Among these possibilities, satellite imagery is a remotely sensed data which provides repeatable measurements over large areas with desirable spatial and temporal resolution. Remote sensing tools are effective for land use land cover (LULC) mapping. This data is very important to identify land cover of the area which used as one of the inputs for soil erosion model (Blanco and Lal,2008). The remote sensing data give us accurate and real time information about the watershed such as, land use/ land cover, soil types and drainage characteristics (Kalambukattu & Kumar, 2017). It is also used to identify the soil erosion risk area and provides input data for soil erosion and runoff models (Kalambukattu & Kumar, 2017). Niemiec (2009) also stated that it is possible to detect eroded areas, decide spatial resolution and assess erosion factors that used as input factors for erosion models by using satellite imagery. According to Niemiec, 2009), satellite images can be obtained with various resolution from low to high like Landsat, IKONOS and QuickBird respectively.

A GIS is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Burrough, 1986). As stated in Bonham (1996), GIS has made a tremendous impact in the application of many fields, because it has a spatial components tools that used to manipulate and analysis of spatial data layer.

Geographic Information Systems (GIS) have emerged as a powerful tool for handling spatial information and interact well with erosion models to provide robust problem solving capabilities useful for effective decision making (Esbah & Berberoglu, 2016). Esbah and Berberoglu (2016) noted that, moderate to high amount of spatial data are required by erosion models and handled through GIS effectively. The essential database needed as input for modeling erosion are stored in the GIS and shows the map of erosion prone areas (Blanco and Lal,2008). The integration of GIS with RUSLE has been shown in many cases to be an effective approach for estimating the magnitude of soil loss and identifying spatial locations vulnerable to soil erosion (Esbah & Berberoglu, 2016).

The process of soil erosion has different degree of severity in a given watershed and the integration of RUSLE model with GIS used for the analysing spatial location of the characteristics of erosion prone area (Tirkey et al, 2013). To identify the more sensitive erosion area spatial information is needed which used as an input to the model and these spatial information is provided by GIS and remote sensing whereas RUSLE model can be used estimate the overall erosion from the watershed (Tirkey et al., 2013). The thematic layers which is essential for the application of RUSLE is generated by the ArcGIS software based on RUSLE factors (Blanco and Lal, 2008).

As soil erosion is a function of rainfall erosivity, erodibility, slope length and steepness, cover management and support practice parameters in the revised universal soil loss equation (RUSLE) model, GIS environment is used to overlay those parameters (Uddin et al., 2016). The RUSLE equation factors are represented in the form of grid cell format in GIS environment (Demirci & Karaburun, 2012). The RUSLE-GIS interface can be used to integrate spatially referenced data, show the erosion maps in different form and update easily (Uddin et al., 2016). Chen and Li (2010) noted that predicting models and GIS and RS techniques have the opportunity to provide significantly better results for conservation practices and improvement of the management of our land resources. In general, GIS and Remote sensing are used as effective tools in generating spatial and quantitative information about soil erosion prone area, (Rabia, 2016).

Several studies revealed that the use of remote sensing and GIS techniques to assess and measure soil erosion risk are based on various models. There are a lot of scholars who have worked on soil erosion using remote sensing and GIS techniques integrated with RUSLE model. Gashaw et al., (2018) have worked on erosion risk assessment for prioritization of conservation measure in Geleda watershed, Ethiopia by integrating GIS and RS technique with RUSLE model. Similarly Bewket & Teferi (2009), Mekuriaw (2017), Sewnet and sewnet(2016) Esa et al.,(2018) and Asmamaw & Mohammed (2019) have also worked on RUSLE model in order to measure soil erosion by using RS and GIS technologies. Most of the researcher was used low spatial resolution satellite image (30m) in order to classify LULC map of the study area.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted in Arbit watershed, Ibinat woreda Amhara National Regional State, Northwestern Ethiopia. The Arbit watershed is found in the highlands of South Gonder and forms one of the upper parts of Tekeze basin. It is located at about 697 kilometers to the North West of Addis Ababa, the capital city of Ethiopia. The Geographical extent of the study area stretches from 37^0 95'80" W – 38^0 06' 49" E and 12^0 31' 27" N – 12^0 18' 32" S and covers about 31131.96ha (Fig 1).

The topographic pattern of the watershed is characterized by a flat plain, rugged and steep slope. It has an altitude ranging from 1,704 to 2,791m above mean sea level. In the study watershed, the slope ranges between 0 and 91% at the flat surface and on the mountain part respectively.

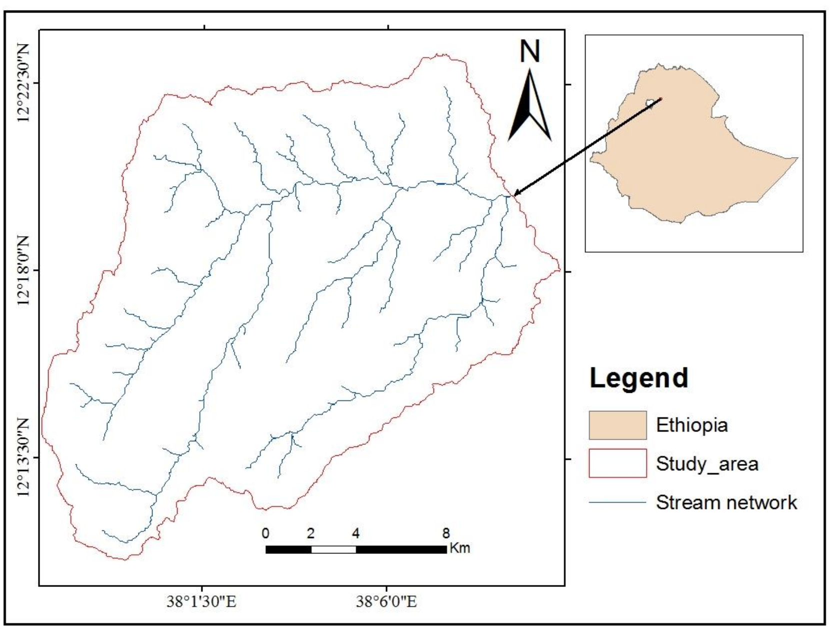

Figure 1. Map of Arbit watershed.

3.1.2. Climate and hydrology

Most of the time, the maximum rainfall in the watershed occurs from June to September, which accounts 84% the total rainfall in the watershed. In this season, the recorded maximum rainfall is 400mm. The months January, February, November and December record a little amount of rainfall (Fig 2). According to Addis Zemen meteorological station, the mean monthly temperature ranges from 18^{o}c in December to 21.9^{o}c in January & April. The highest (32^{o}c) mean maximum and the lowest (18.8^{o}c) minimum monthly temperature occur during March and December, respectively. The agro-ecological zones of the study area falls within tepid sub-moist mid highlands (Ministry of Agriculture, 1998).

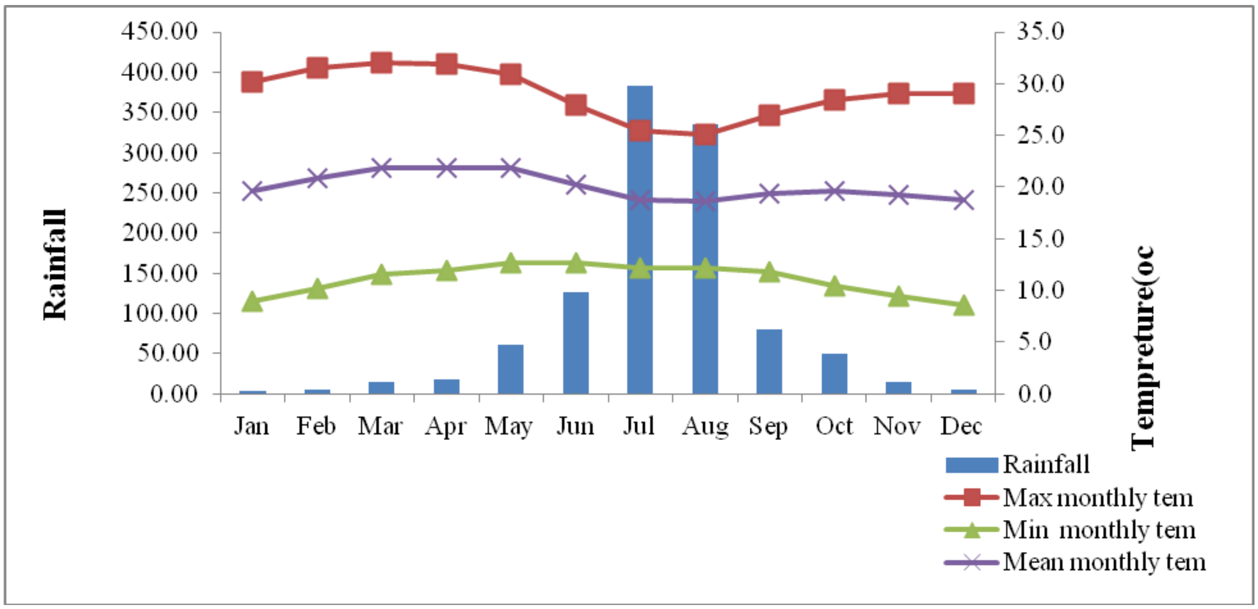

Figure 2. Mean, maximum and minimum monthly temperature (2016) and mean annual rainfall records (1996-2016) (NMA,2016; CHIRPS,1996-2016)

3.1.3. Land use and land cover

Agricultural activity is the main livelihood of the community in the Arbit watershed. A combination of crop and animal farming activity is applied in the watershed. The dominant crops in the study area were pea, barley, beans and wheat. In the study area, almost all the cultivated lands are used for annual cultivation. Some farmers who have lands close to the Arbit river commonly used supplementary irrigation. Often from the month of February till the rainy season, Arbit river runs dry which hinders farmers from using irregation.

Agricultural land is expanded by removing forest and bushes and this leads to erosion. In the Arbit watershed, there were remnant trees in cropping land and at the edge of agricultural fields. Shrub/ bushes are also available. The available natural forest in the watershed is degraded by the local community via cutting it for crop land expansion, firewood, construction and other purposes. However, the local government protect this forest from further degradation. Forestation programs were also being carried out in some corners of the watershed.

Vegetation cover in the watershed have significant roles by intercepting rain drops, reducing runoff on the surface and facilitate controlling erosion and maintain soil fertility. According to the local aged communities, most parts of the study areas were covered by dense forest. But now these ancient dense forests were vanished from different parts of the watershed due to increase demands of agricultural activity and fire wood.

3.2. Data source and techniques of data collection

In this project, different data sets were used. These included data on: rainfall, satellite image, ASTER DEM and Ground Control Points (GCPs). Some field observations were made to have direct observation on the extent and degree of soil erosion. Ground Control points have been taken during field observation by using handheld GPS and from Google Earth (Fig 3). The different data collection methods are discussed as hereunder:

3.2.1. Field data

A filed survey was made in the study watershed in order to get general idea about the environment conditions of the watershed (Fig 4). This include observations of major soil erosion hotspot areas, as physically observed e.g. by spatial distribution of gullies, bare land, deforested parts and other features. The field observation points were located or georeferenced supported using hand held global positioning system (GPS). The distribution of farm areas, forests, shrubs, and erosion sensitive corners of the watershed were recorded and identified in the field (Fig 4).

3.2.2. Rainfall data

There is no any meteorological rainfall station within the study area. Stations which are located around the study area have distances of 10 to 60 km from the study watershed. Using these stations to obtain the rainfall erosivity value of the Arbit watershed have coarse resolution. Using spare rainfall stations to obtain R-factor value will not represent accurately. As a result, rainfall data were obtained from CHIRPS version 2.0 which records rainfall within 0.05^{o} resolution (approximately 5km) (ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/).

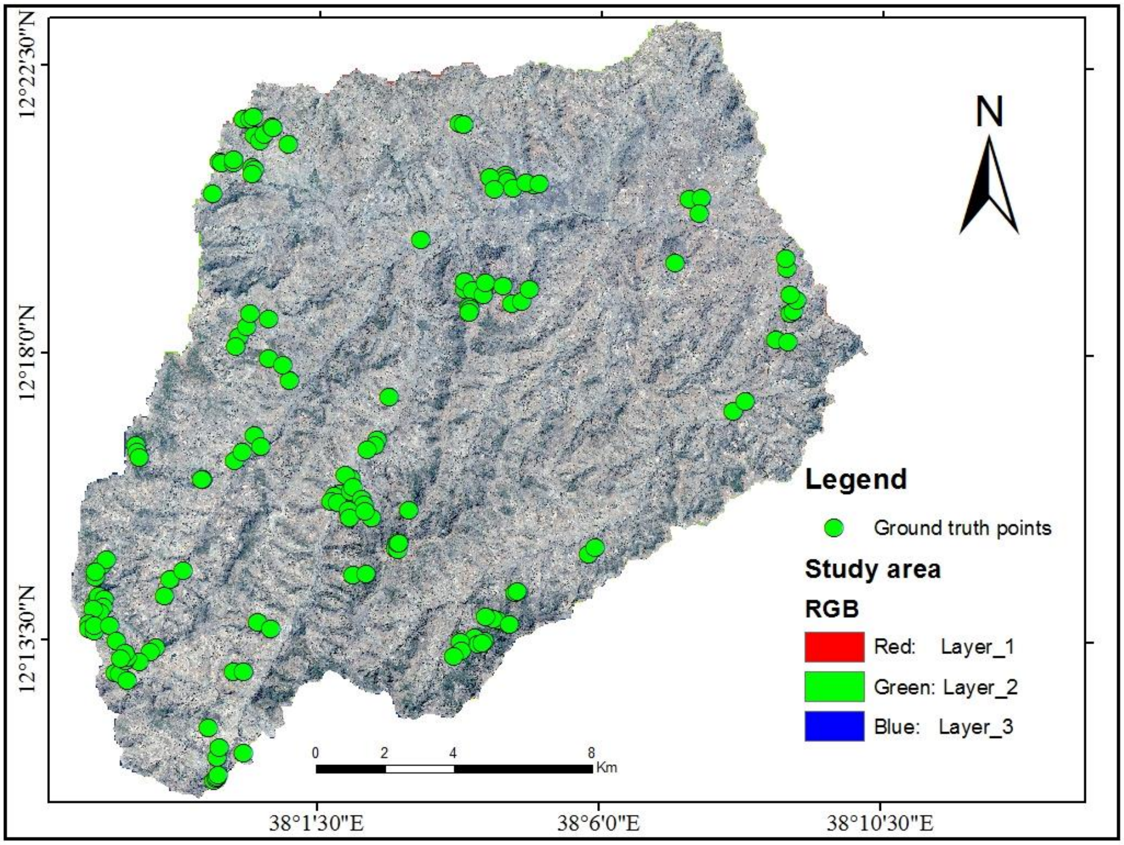

Figure 3. Ground truth points for LULC classification

3.2.3. Soil data

Soil map of the watershed was extracted from the soil map of the Ethiopia with the scale of 1:250,000 which is obtained from Ministry of Water Resource. The identified soil types in the study area are Lithic Leptosols, Eutric Cambisols, Eutric Nitisols and Orthic Luvisols. From these soil types, Eutric Cambisols and Eutric Nitisols are the dominant soil types. The total area coverage of these soil types in the Arbit watershed is about 80%, of which Eutric Cambisols contain 42.61% and Eutric Nitisols contain 37.57%. Soil properties which are used to determine the value of soil erodibility factor (k) was obtained from Africa Soil Information Service (AfSIS) at 250m resolution (https://ISRIC Data Hub - ISRIC - World Soil Information, 2016.).

Figure 4. Land use land cover types in Arbit watershed

3.2.4. Digital Elevation Model

The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) with 20m spatial resolutions were obtained from the Geospatial Information Institute (GII). ASTER DEM spatial resolution 20m resolution was used to generate Flow accumulation for the purpose of watershed delineation and to generate slope length and slope steepness (LS) or topographic factors of soil erosion.

3.2.5. Land use/land cover Layer

The current land use land cover map of the study area was classified based on SPOT-7 (2016) satellite image with a very high spatial resolution (1.5m). Ground Control Points collected from the field by using handheld GPS and Google earth also used for the purpose of verification. During field observation, informal interview with the local communities were undertaken. Supervised classification techniques were applied using ERDAS IMAGINE 15 software. The coordinates of minimum of 50 points for each land use land cover class have been recorded. Generally, the data and their source which are required to estimate soil erosion using RUSLE model for Arbit watershed are described in Table 1.

After collecting the data, five different input parameters of the RUSLE model to compute soil erosion rate is generated. These five different input parameters which used to compute soil erosion rate in the watershed are rainfall erosivity (R) factor, soil erodibility (K) factor, topographic (LS) factor, management practice (P) factor and land cover (C) factor. These parameters are overlaid in the ArcGIS10.5 environment by using raster calculator in order to generate the final soil erosion risk map of the study watershed.

Table 1. Materials and data sources for the study (R, K, L S, C, P)

Data Set	Source	Year	Spatial Resolution	Purpose
Rainfall	CHIRPS	1996 -2016	5.3km	Rainfall erosivity (R) factor
DEM	GII	2016	20m	To delineate watershed area and generate LS factor (LS)
Soil data	AfSIS	2016	250m	To generate soil erodibility factor(K)
Satellite image	EGII	2016	1.5m	For LULC classification, C and P factor
GCPs	Field visit & Google Earth	2016		Reference data for supervised classification and accuracy assessment

3.3. Remote Sensing Data Analysis

3.3.1. Image classification

Classification of remotely sensed data is used to assign corresponding levels with respect to groups with homogeneous characteristic in order to identify multiple features from each other within the image (Gonzalez and Woods, 2008). Digital image classification is a process of creating thematic maps from satellite imagery (Lillesand et al., 2015). The overall objective of image classification procedures is to automatically categorize all pixels in an image into land use / land cover classes. The main procedures followed by the researcher to identify the major land use/land cover classes of the study area were visual image interpretation, field visit and supervised image classification with maximum likelihood classifier. Africover land cover classification system/method (FAO, 1997) was used to classify the major land use/land cover classes of the study area. The major LULCs which were clearly identified from a high spatial resolution SPOT 7 (2016) image in the Arbit watershed were crop lands, open forest, bare land, built up area and shrub land (Table 2).

A number of representative training sample points (area of interest) have been taken to classify images into different land use/ land cover classes depends on the spectral response of each land cover type. The objective of a training sample is to collect a set of statistics that describe the spectral response pattern for each land cover type to be classified in the image (Lillesand et al., 2015) . According to Lillesand et al., (2015), the sample size of the representative training points depends on the spectral response of each LULC type. Minimum training points are needed for features that have homogenous spectral response pattern and maximum points should be required features that have heterogeneous spectral response. Therefore, a total of 155 training points was taken in this study area that used to classify an image. 105 points for cultivated land, 15 for bare land, 15 for shrub land, 10 for degraded forest and 10 for settlement were taken. The classified LULC map was used to generate the crop management (C) factor and support practice (P) factor which used as input for the RUSLE model.

Table 2. Description of land cover classes for the study area

No	Land cover classes	Description
1	Crop land	agricultural land cropped at least once per year and some rural settlements
2	Forest land	Area of land covered by forest
3	Bare land	Areas of land with little or do not have vegetation cover
4	shrub land	Area covered by small trees (their height is less than 3m), bushes, and shrubs mixed with grasses
5	Settlement	Built up areas which used for residential purpose

LULC classes were adapted Africover classification system of FAO,1997.

3.3.2. Classification of Accuracy Assessment

Accuracy assessment is a general term for comparing the classification map with reference data that are assumed to be true in order to determine the accuracy of the classification process. It is a quality assurance step in which classification results are compared with what is there on the ground at the time of imaging (Gao, 2009). The data used to cross-check the accuracy are usually collected from ground truth and calculated using a set of reference data. Reference data are points on the classified image for which actual data are represented. Reference data have been imported using user defined points from the accuracy assessment dialog box to the classified image.

In order to validate the classification image of the study area, ground truth points were obtained from field observation through interviews and Google earth image interpretation. The collected ground truth points from these different sources were used for image classification and accuracy assessment of the LULC map of the study area. In practice, it is recommended that a minimum of 50 points per class are required. Lillesand et al. (2015) states that the LULC maps which have classes of lower than 12 a minimum of 50 sample points for each LULCs should be collected. The study conducted by Girma et al., (2018) and Degife et al., (2019), also used similar approach in their study of urban green space supply in Sebeta town and Land use land cover dynamics, its drivers and environmental implications in Lake Hawassa Watershed of Ethiopia, respectvely. Therefore, in the Arbit watershed five LULCs were identified which is fewer than 12 classes, as a result a total of 270 ground truth points were used for the whole LULC catagory.

The accuracy of classification map can be calculated from sample points and presented in the form of error matrix. Error matrix can be expressed in terms of sample counts (Mekuriaw, 2017). Presentation of the error matrix interms of the unbaised estimator of the proportion of area in cell i,j of the error matrix is more informative (Olofsson,et al., 2013). Sample based absolute counts nij can be converted into estimated area proportions(pij) where i and j represents rows and columns in the error matrix respectively is calculated using the equation1 (Olofsson,et al., 2013).

$$P_{ij} = w_i * n_{ij} / n_i \qquad \text{Eq (1)}$$

where wi is the ratio of mapped area of land use class and the total area of the map, nij is the cell value at row i and column j and ni is the total number of samples land use class. Error matrix in terms of estimated area proportion have an advantage to calculate the accuracy and area estimates can be calculate directly from the error matrix (Olofsson,et al., 2013). Based on the error matrix area proportion of each land use class (pj) was computed based on Olofsson equation (Eq.2). Estimated proportion area of each category (pj) is the column summation of the estimated cell area proportions in the estimated error matrix.

$$Pij = \sum_{i=1}^{n} wi * \frac{nij}{ni} \qquad \text{Eq (2)}$$

Estimation of Standard error and confidence interval of each land use class is important in order to accept or reject the omission or commission error (Olofsson,et al., 2013; Mekuriaw, 2017). The estimated standard error must be caluclated to obtain the confidence interval of the area of each land class. Confidence interval can quantify the uncertainty associated with the sample-based estimate of the area of each class. Therefore, the estimated standard error of the estimated area proprtion SE(pj) was calculated using equation 3 (Cochran,1977; Olofsson,et al., 2013; Mekuriaw,2017). According to olofsson et al., (2013),the estimate standard error of the ajusted area was also calculated as the product of the total map area(31131.96ha) and estimated proportion area (pj).

The stratified estimator of the area of each land use class (settlement, shrub land,bare land, degraded forest and cultivated land) was calculated as a product of the total mapped area with the estimated area of proportions. The accuracy of each land use class was evaluate using 95% confidence interval (z = 1.96). Thus the confidence interval of the estimated area each land use class was claculated as estimated area of land use class ±1.96* standard error of the estimated adjusted area(SEi).

$$SE(pj) = \sqrt{\sum_{n=1}^{n} wi^2 * \frac{\frac{nij}{ni}(1-\frac{nij}{ni})}{ni-1}} \qquad \text{Eq(3)}$$

3.4. RUSLE model

RUSLE model is selected for this study because it can be easily applied with the available data on soil types and properties, land use land cover map, topographic, management practice and rainfall data, all of which are suitable for spatial interpolation and extrapolation. Some of these parameters are obtainable from RS data and easily integrated with GIS for analysis. Due to this, RUSLE model have a potential to calculate average soil loss over a given area with some degrees of certainty. The amount of soil loss was determined using the RUSLE model in ArcGIS environment (Renard et al.,1997). The equation is a function of five input RUSLE input factors.

These input factors are: rainfall erosivity, soil erodability, slope length and steepness, cover management and support practice (P) (Figure 3). Therefore, the RUSLE model is expressed as

A = R*K*LS*C*P --Eq.4

Where A is the average annual soil loss per unit area (metric tons/ha/year); R is rainfall erosivity factor(MJ mm/ha/h/y); K is soil erodibility factor (metric tons/ha/MJ/mm) ; LS is the slope length steepness (dimensionless); C is the cover management factor (dimensionless); and P is support practice management (dimensionless).

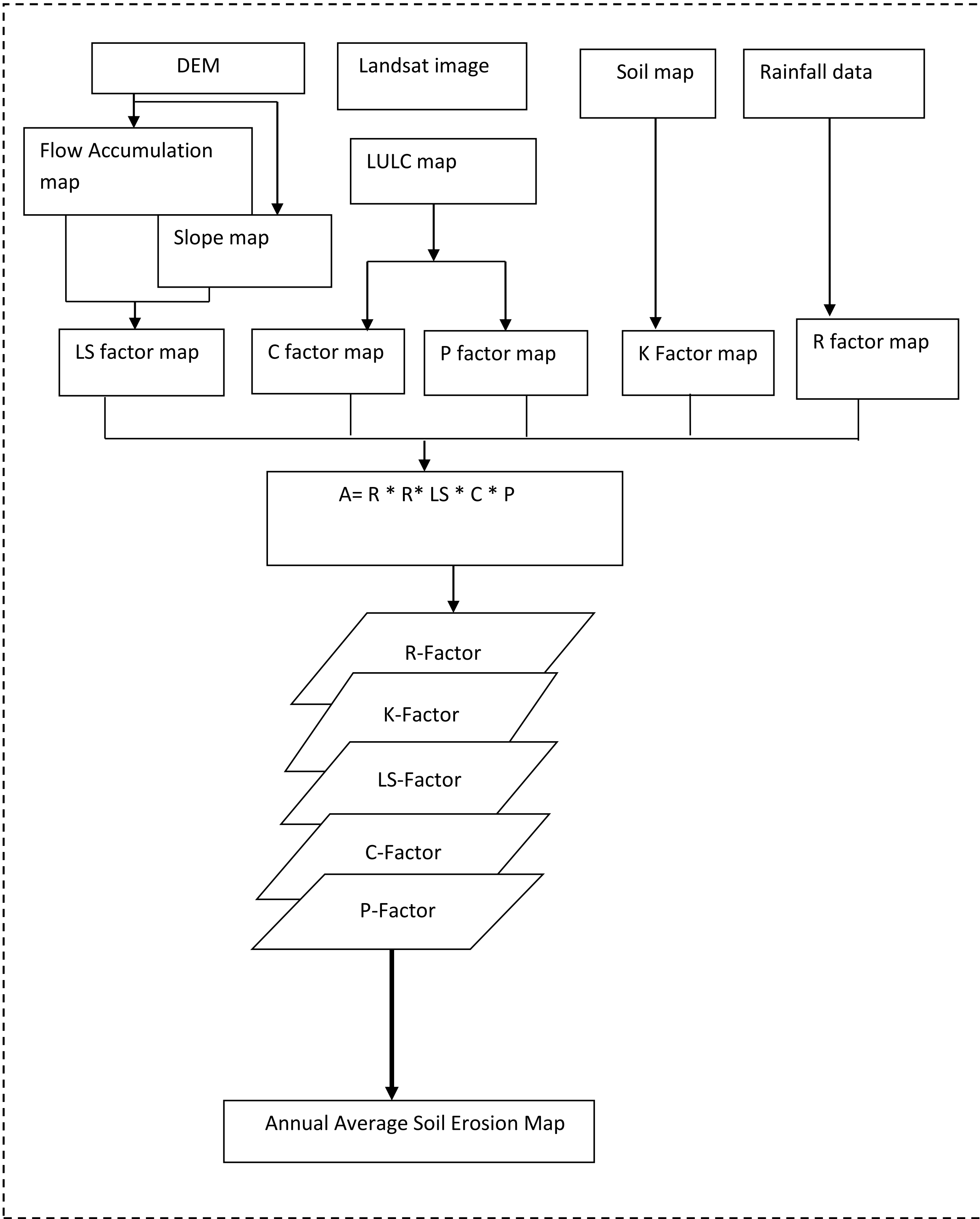

Figure 5. Flow chart for the preparation of soil erosion risk map.

3.5. Data processing and Methods of RUSLE Factor Generation

3.5.1. R – Rainfall Factor

The R-factor is a measure of the erosive force of a specific rainfall (Prasannakumar et al., 2012). Rainfall data represents the erosivity occurring from rainfall and runoff at a particular location (Wischmeier and Smith, 1978; Demirci & Karaburun, 2012). The availability of dense networks of gauge stations are used to mapping rainfall erosivity in the study area applying interpolation techniques. However, in the Arbit watershed there is no any meteorological stations. Thus, mapping of rainfall erosivity using spatial interpolation is not good. Due to this, the researcher was used satellite rainfall product (Climate Hazards Group Infrared Precipitation with stations (CHIRPS) at 5km spatial resolution.

The CHIRPS have a historical record rainfall data with high spatial resolution. But Before going to use the CHIRPS rainfall value comparison and validation of satellite derived rainfall with National Metrological Agency (NMA) of Ethiopia station rainfall values. To do this first 20 years (1996 - 2016) monthly rainfall values was obtained from NMA with selected rainfall stations. Based on the coordinates of the NMA rainfall stations the same year rainfall values were downloaded from CHIRPS using GeoCLIM software. The GeoCLIM software is a spatial analysis tool designed for climatological analysis of historical rainfall and temperature data (Pedreros & Magadzire, n.d.).

The rainfall value which is obtained from NMA have a missing value. To fill this missing data the researcher was used the average values. After this validation and comparison of the CHIRPS and NMA station rainfall values are done using mean annual rainfall of 20 years. In order to make sure validation is also done using monthly rainfall which have a complete record (year 2012) in the NMA station. The NMA station rainfall values was not used because of its sparse spatial distribution. Due to this the spatial variability of rainfall between the stations is high. As a result, the researcher was used CHIRPS in order to obtained R-factor value in this study.

Thus, to calculate the R- factor value of the study area a grid format 20 years CHIRPS rainfall value was downloaded and then extracted by the study area using extraction tools in ArcGIS10.5. Therefore, mean annual rainfall was calculated using raster calculator based on monthly rainfall data from 1996 - 2016. After calculating the mean annual rainfall, the R-factor value was computed by using the empirical equation developed by Hurni (1985) eq.5. Longer records of rainfall data are advisable when there is a large variation of annual precipitation (Renard et al., 1997).

R = -8.12+(0.562*p) -- Eq.5

Where R is the rainfall erosivity factor in MJ mm/ha/year and P is the mean annual rainfall in millimeters.

3.5.2. Soil erodibility (K) factor

In RUSLE soil erodibility factor is the influence of soil properties on soil loss during storm events on the upland areas (Renard et al., 1997). Information related with soil properties which used to determine soil erodibility factor was not available for the study watershed. It requires high cost to obtain all the required soil information which used to calculate the value of soil erodibility factor. Thus, to solve such problem, soil properties such as organic carbon, sand, silt and clay content of the study area were obtained from AfSIS website (https://ISRIC Data Hub - ISRIC - World Soil Information, 2016) in this study area.

All the downloaded soil properties from AfSIS have raster format with 250m resolution. Based on the percentage content of sand, clay and silt the top soil texture class of the study area have been identified by using USDA soil textural class triangle. The identified top soil texture class of the study area were clay, clay loam and silt clay loam (Table 3). Randolph (2004) adopted a method to obtain K- factor value using soil textural class and the content of soil organic matter. The soil organic matter content of the study area was obtained from the organic carbon using a conversion factor 1.724 (Eq.6). 1.724 is a constant conversion that used to convert organic carbon to organic matter (http://www.soilquality.org.au/factsheets/organic-carbon).This conversion factor believe organic matter contains 58% organic carbon.

Organic matter (%) = Total organic carbon (%) * 1.72 ------------------------------- Eq.6.

Thus, based on the soil texture class and soil organic matter K-factor value of the study area was assigned by using Randolph (2004) methods. Based on this calculation the content of soil organic matter in the study area was greater than four (Table 3).

Table 3. Soil texture and the estimated K-factor value of Arbit watershed.

No.	Top texture class	K value
1	Clay	0.19
2	clay loam	0.21
3	silty clay loam	0.26

3.5.3. LS-factor (topographic factors)

In RUSLE, the LS factor is a consequence of topographic impact on erosion. The consequence of slope length and slope gradient on erosion represents by the slope length and slope steepness (Lu et al., 2004). The slope length and slope steepness factors are commonly combined as LS and referred to as the topographic factor. The DEM of the study area was obtained from Geospatial Information institute (GII). This DEM has 20m spatial resolution and used to compute the slope length (L) and slope steepness (S) factors in the Arbit watershed. Using high spatial resolution DEM has an advantage to represent the study watershed precisely. In this study, the LS factor map was generated from a 20m spatial resolution DEM using the equation (eq.7) developed by (Wischmeier and Smith, 1978) as has been used by other researchers (Bewket and Teferi, 2009; Gashaw et al., 2017; Mekuriaw; 2017). To perform this calculation, spatial analysis tools such as hydrology tools was used.

$$LS = (\text{flow accumulation} * \text{cell size}/22.1)^{m} * (0.065 + 0.045s + 0.0065s^{2}) \quad \text{eq.7}$$

Where S is slope in percent, m is the exponent that depends on slope steepness. To perform the equation (eq.7) m map was generated by classifying the slopes of the study area based on the value of m shown in table 4. The generated m map is shown in Fig 6 and the researcher was used the Lookup tools in the ArcGIS10.5 to classify m map value. Finally, the LS- factor value was derived.

Table 4. M values with different slope class (Wischmeier and Smith 1978).

Slope class (percent)	M _ Value
< 1	0.2
1 – 3	0.3
3 – 5	0.4
> 5	0.5

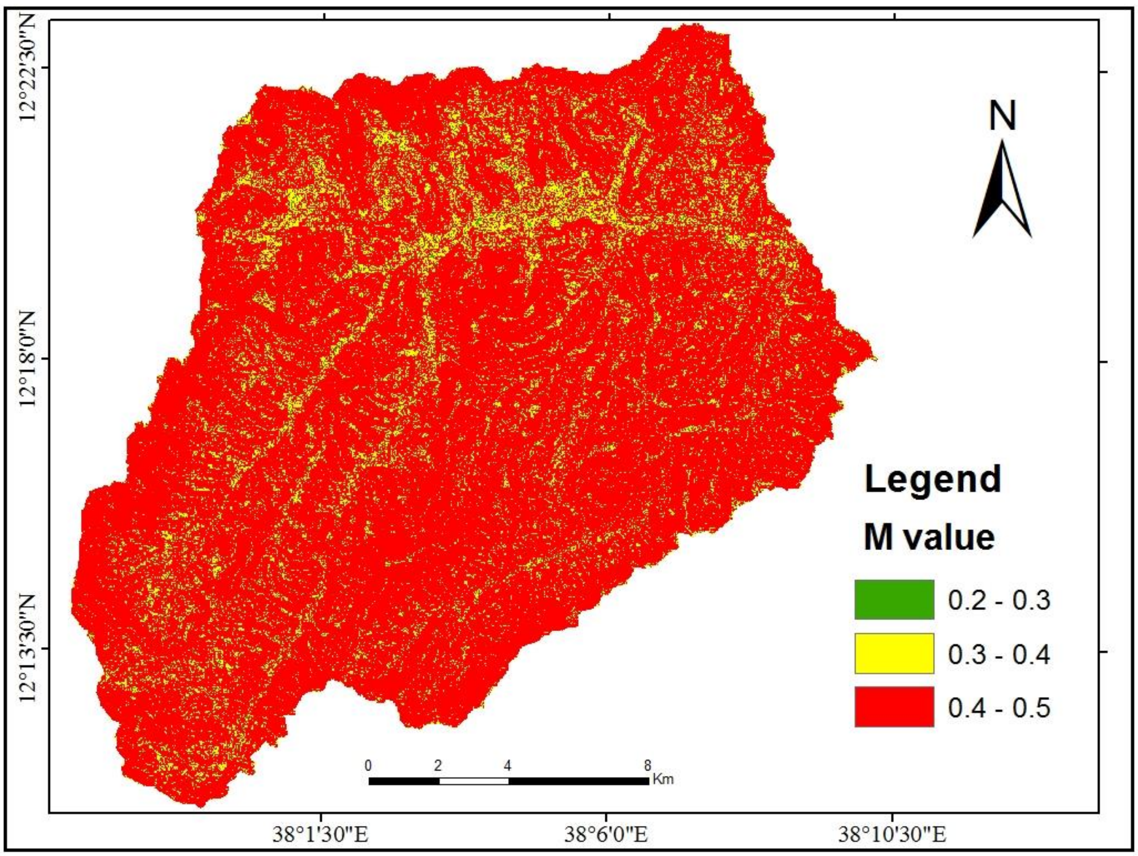

Figure 6. The generated m map of the study area

3.5.4. Land use/land cover management factor (C-factor)

The land use land cover (C factor) represents the effect of plants, crop sequence, and other soil cover surface on soil erosion (Molla & Sisheber, 2016). Management (C) factor is one of the factors which shows the land cover and playing significant role to reduce soil loss. According to

Wischmeier and Smith (1978), C factor is a ratio of soil loss under a certain crop land that incorporated in soil erosion model to consider the roughness of the surface. The management factor can determine the usefulness of crop management system to reduce soil loss (Esa et al., 2018).

In this study, SPOT - 7 (2016) satellite image with 1.5m resolution was used to prepare LULC map of the Arbit watershed. In order to improve the accuracy of the prepared the land use/land cover map of the study area, visual interpretation, field survey and Google earth were used. The corresponding C factor value for each land use/ land cover type suggested by Hurni (1985) and different researcher are shown in table 5.

Table 5. The management (C) factor values.

Land use/ cover	C value	Reference
Cultivated land	0.15	Hurni (1985)
Shrub land	0.02	ADSWE (2015)
Bare land	0.6	BCEOM (1998)
Forest land	0.001	Hurni (1985) ,
Settlement	0.005	Mekuriaw (2017)

3.5.5. P – Factor (management Practice)

P factor is the ratio of soil loss with specific management practice to the corresponding loss with up slope and down slope cultivation (Wischmeier and Smith, 1978, Blanco and Lal,2008). The management practice can reduce the speed of water on the surface of the earth as a result it reduce the amount of soil erosion rate in a specific watershed (Shiferaw, 2011).

Cultivated lands are mainly exposed to soil erosion and needs the management practice which slow down runoff and reduce the amount of eroded soils (Wischmeier & Smith, 1978). According to Wischmeier & Smith (1978), some of the supported management practices which is applied on the croplands are contour tillage, strip-cropping on the contour, and terracing system. However, in the Arbit watershed much of the area was not treated by any conservation practice. Conservation practice applied only in a small portion of the study area was not maintained by the government or local communities. In the study area farmers employed a traditional conservation practice which is called fesus, or called drainage ditch.

In such condition, different studies (Bewket & Teferi,2009; Prasannakumar et al., 2012; Shiferaw, 2011; Ayalew, 2015; Sewnet & Sewnet, 2016; Asmamaw & Mohammed, 2019) suggested that to assign P-factor value by considering agricultural land, non agricultural land and the slope of agricultural land. Thus, this method was applied in this study (Table 6). Agricultural lands are classified into six slope classes to assign P-factor values. Based on the assigned values (Table 6), P-factor map of the study area was prepared using ArcGIS10.5 spatial analysis tools.

Table 6. P-factor values adapted from Wischmeier and Smith (1978)

Land use type	Slope gradient (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 lands	all	1

CHAPTER FOUR

RESULT AND DISCUSSION

The results of different RUSLE parameter and final average annual soil loss of Arbit watershed are presented in this chapter. As described in chapter three, the input factors of RUSLE model were generated from different data sources.

4.1. Current land use/ cover classes

In this study one-year LULC map was generated (Fig 7). Based on 2016 Spot-7 satellite images five major land use classes of the watershed were classified as shown in Fig 7. These are cultivated land, forest, shrub, bare land and settlement. The result revealed that the study area dominantly covered by cultivated land (about 60%) followed by bare land (19.70 %). In the study watershed, settlement has a least area coverage and its proportion was in Geography and Environmental Studies (specialization in Geographic Information System, Remote Sensing and Digital Cartography) compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

only 0.44% of the total area. The overall area proportion of each LULCs of the watershed are shown in table 7.

Table 7. Current Land Use/ Cover Classes of Arbit watershed.

No	Land use/cover types	Area	
		(ha)	%
1	Settlement	138.26	0.44
2	Bare land	6142.23	19.73
3	Forest	179.46	0.58
4	Shrub land	6009.74	19.3
5	Cultivated Land	18662.3	59.95
	Total	31132	100

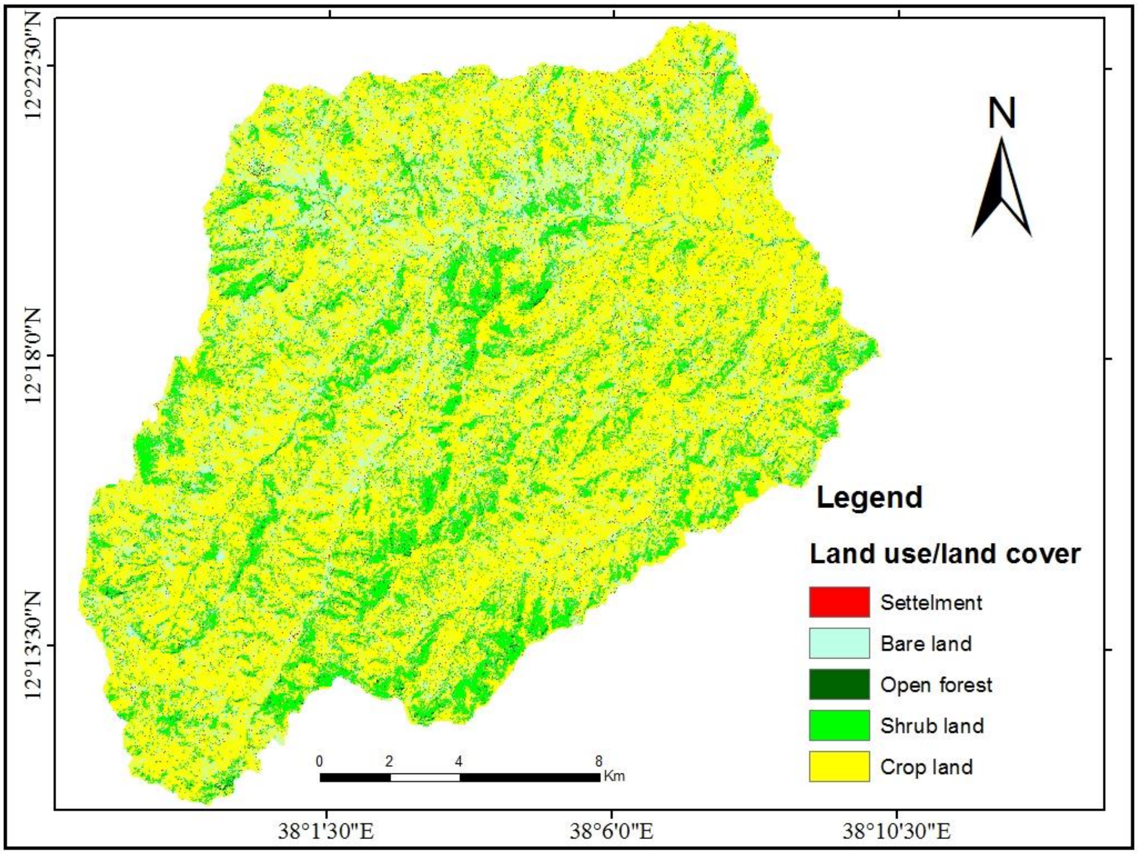

Figure 7. LULC classification map of the Arbit watershed.

4.2. Accuracy Assessment

The confusion matrix of each LULCs of the watershed resulted from a total of 270 points which compares ground truth (reference sample points) and mapped area are shown in table 8. The result of error matrix of estimated area proportions calculated using equation 1 are shown in table 9. Table 9 shows the user and producer accuracy of each land use land cover. The bare land has poor producer accuracy compared to other classes. The classifications have about 94% overall accuracy. The result of proportion area which is computed using equation 2 from error matrix in table 9 is shown in table 10. The stratified area of each land use class in the study area gained by multiplying the total mapped area with estimated proportion area (pj) are shown in table 11.

Table 8. Sample error matrix is constructed from the accuracy assessment sample point

Classes	Settlement	Shrub	Bare Land	Forest	crop land	Total	mapped area(ha)	wi
Settlement	46	0	2	0	2	50	138.26	0.00444
Shrub	0	51	0	3	0	54	6009.74	0.19304
Bare land	0	0	54	0	2	56	6142.23	0.1973
Forest	0	3	0	47	0	50	179.46	0.00576
crop Land	0	0	3	0	57	60	18662.3	0.59946
Total	46	54	59	50	61	270	31131.96	1

Table 9. Estimated error matrix based on table 8 with cell entries expressed as the estimated proportion of area and accuracies

Classes	Settlement	Shrub Land	Bare Land	Forest	Crop land	mapped area(ha)	wi	user's Accuracy	Producer's Accuracy
Settlement	0.00427	0.00000	0.00009	0.00000	0.00009	138.26000	0.00444	0.96	0.98
Shrub land	0.00000	0.18232	0.00000	0.00715	0.00000	6009.74000	0.19304	0.94	0.96
Bare land	0.00352	0.00000	0.19025	0.00000	0.00705	6142.23000	0.19730	0.96	0.93
Forest	0.00000	0.00023	0.00000	0.00542	0.00000	179.46000	0.00576	0.94	0.95
Cultivated Land	0.00000	0.00000	0.02997	0.00000	0.56948	18662.27000	0.59946	0.95	0.95
Total	0.00779	0.18255	0.22031	0.01257	0.57662	31131.96000	1.00000	-	-

Table 10. Estimate and confidence interval area.

	Proportion area		SE of adjusted area(ha)	Confidence interval (ha)	
Classes	Pj	SE (Pj)			
Settlement	0.00779	0.00353	109.759489	27.4	457.655026
Shrub land	0.18255	0.00608	189.1573595	5313.3	6054.8
Bare land	0.22031	0.01771	551.385658	5780.01	7941.44
Open forest	0.01257	0.00501	156.0171138	85.53	697.12
CropLand	0.57662	0.01771	551.385658	16872.63	19034.06

Table 11. Estimated and mapped area of each land use class

Classes	Estimated Area	Mapped Area
Settlement	242.52	138.26
Shrub land	5684.15	6009.74
Bare land	6860.78	6142.23
Open forest	392.12	179.46
Crop Land	17952.34	18662.27
Total	31131.96	31131.96

4.3. Comparison and validation of rainfall

The validation result of mean annual rainfall of year 20 years is shown Fig 8. As shown from Fig 8 both the CHIRPS and NMA station have a good correlation coefficient ($R^2 = 0.85$). The validation result of each station in 2012 show a high correlation coefficient (Table 12) compared with a mean annual rainfall of 20 years rainfall data. This is may be due to the effect of missing value in the 20 years mean annual rainfall data. The correlation coefficient of 2012 station data are presented in table 12. The table shows that the maximum and minimum correlation value was obtained at Ibnat, Addis zemen and Woreta stations. The CHIRPS rainfall product was evaluated in 2018 by Dinku et.al., with 1200 stations and reported that CHIRPS has a good performance in many areas of East Africa including Ethiopia.

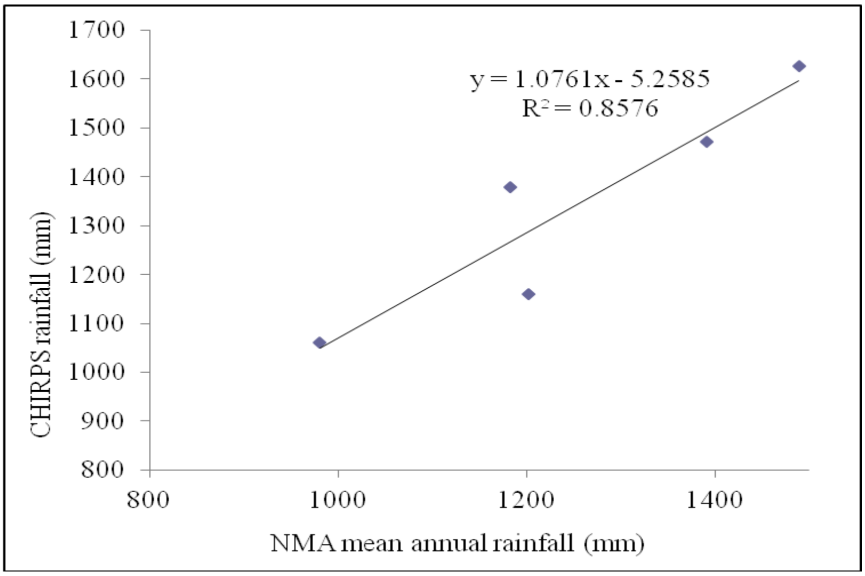

Figure 8. Validation of CHIRPS rainfall with NMA station data

Table 12. CHIRPS monthly rainfall validation with NMA station for 2012

No	Station Name	Correlation coefficient (R^2)
1	Addis zemen	0.89
2	Debre Tabor	0.94
3	Ibnat	0.97
4	Maksegnit	0.95
4	Bahir Dar	0.96
5	Woreta	0.89

4.4. R-Factor

The R- factor value of the study area was calculated from CHIRPS using eq.5 (Fig 9.) This map shows the spatial distribution of R values of Arbit watershed. The original generated R-factor map has approximately 5km spatial resolution and then re-sampling in to 10 m. The result shows that northern part and small portion of North- eastern part of the study area has the lowest R-factor value. The southwestern part of the study area has the highest R-factor value whereas the middle part of the study area has medium R-factor value. The major part of the study area (about 53%) falls between 535.81and 582.35 R value and only 21% of the study area has highest R-factor value (Fig 9). Based on the generated R-factor map, there is rainfall spatial variability in the Arbit watershed. The minimum and maximum R-factor values of the study area were 535.81 and 675.72 respectively.

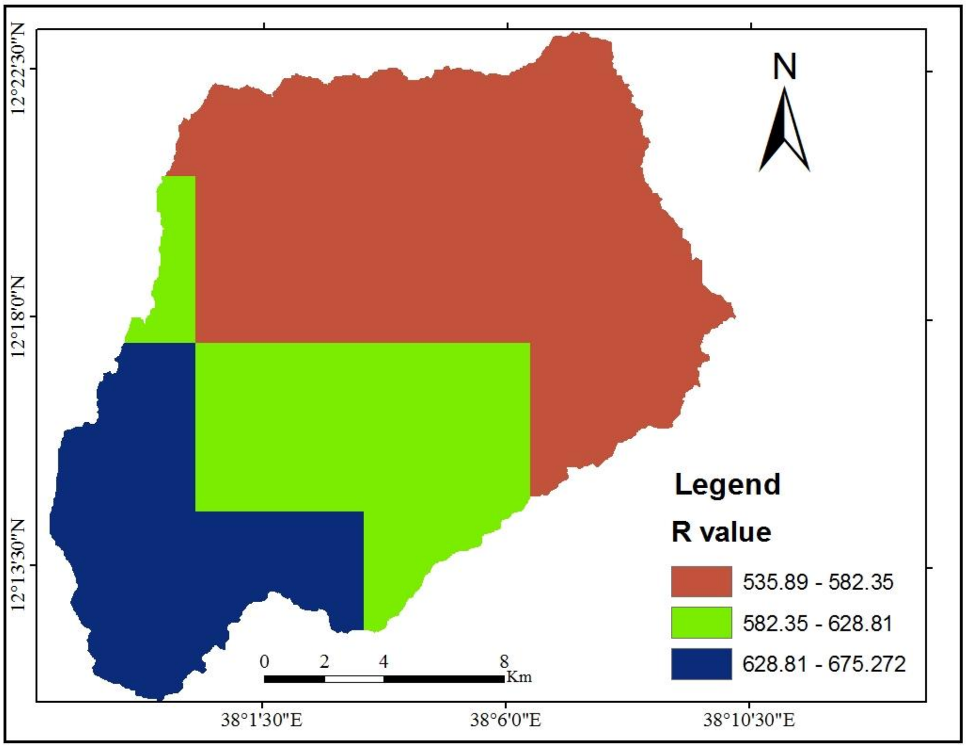

Figure 9. Rainfall erosivity in Arbit watershed.

According to Batjes (1996) the rainfall has low erosivity factor on soil erosion if the value of R is less than or equal to 800mm.Thus in this study the rainfall has a low erosivity factor on soil erosion because the maximum R-factor value is 675.72.

4 .5. K-factor

Based on the three different soil erodibility value the k- factor map of the study area was generated. According to the generated soil erodibility map the northern and north eastern part of the watershed (study area) has 0.21 soil erodibility value whereas some central and southern part of the study area has low soil erodibility value (Fig 10).

4.6. LS- Factor

In this study, DEM with 20 spatial resolutions was used to generate LS factor map by using equation.7. The result shows that the minimum and maximum value of LS factor were ranged between 0 and 43.55 (Fig 11). Figure 11 shows that LS factor value increase as slope steepness increase.

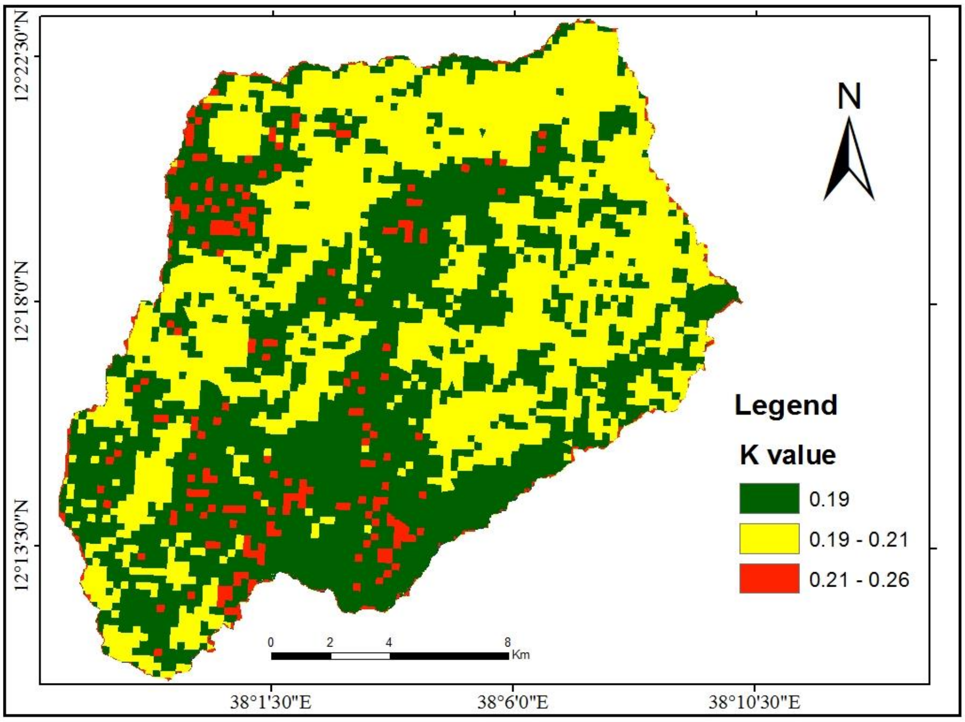

Figure 10. Soil erodibility in arbit watershed.

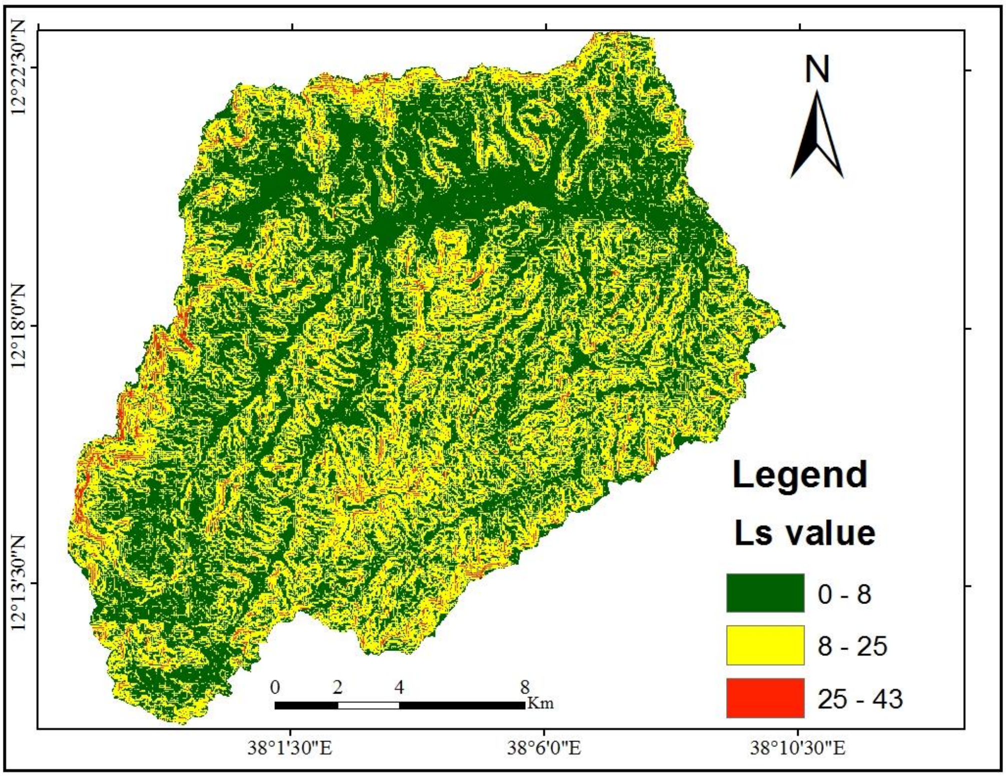

Figure 11. Slope length and gradient (LS) factors in Arbit watershed, Northwestern Ethiopia.

4.7. C-factors

In this study, the C factor was assigned from different previous literature based on cover values as proposed by Hurni (1985) (Table 5). To do so, the five land use/cover classes of the study watershed were classified from SPOT-7 satellite images with 1.5m spatial resolution. Based on the given value, the C- factor map was produced in the ArcGIS software (Fig 12). As shown from the C-factor map, the range of the C value varies from 0 to 0.6.

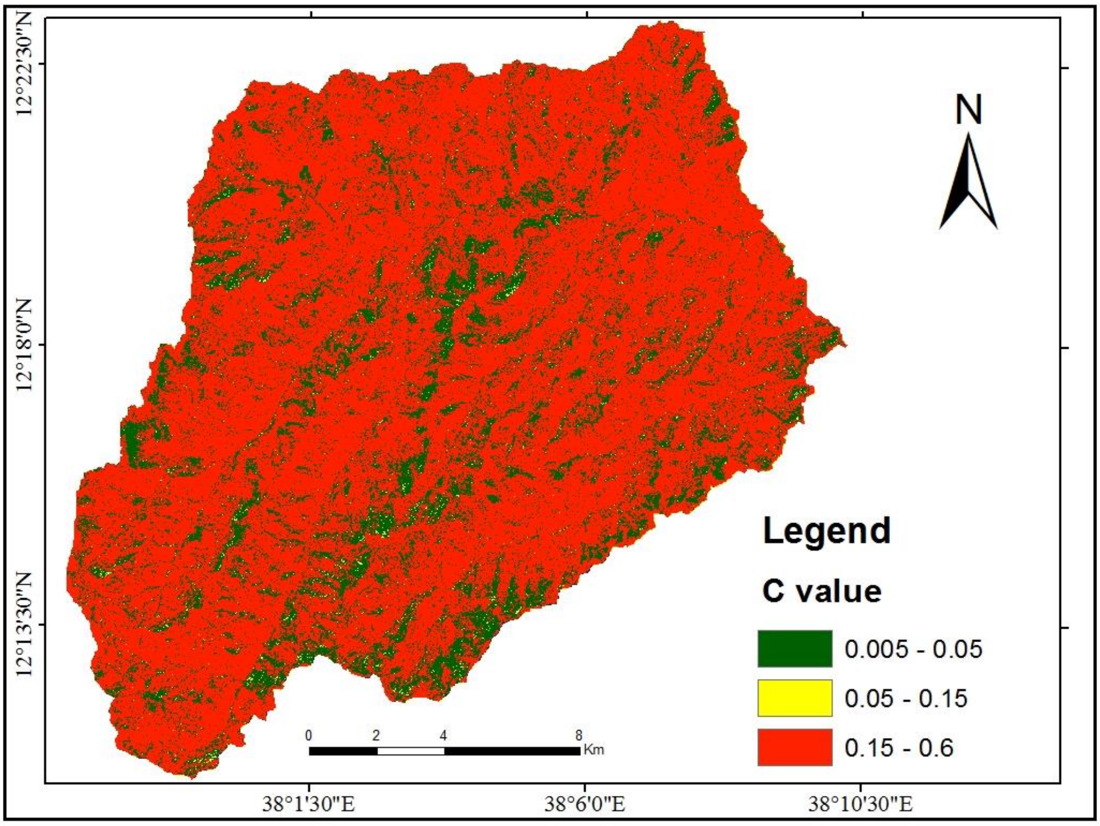

Figure 12. C factor map of the Arbit watershed

4.8. P-Factor

Based on the value suggested by Wischmeier and Smith(1978) in table 6 the P- factor map of the study area are generated using ArcGIS10.5. The minimum and maximum value of the study area were 0.1 to 1(Fig 13). In this study area majority (about 80%) of the area has a P-factor value 0.1- 0.14 and 0.33- 1. The rest 20% of the area has P-factor value.0.14-0.33. Thus, areas with higher P-factor values (0.33 – 1) are not controlling soil erosion whereas areas with the lowest P-factor value is more effective to control soil erosion.

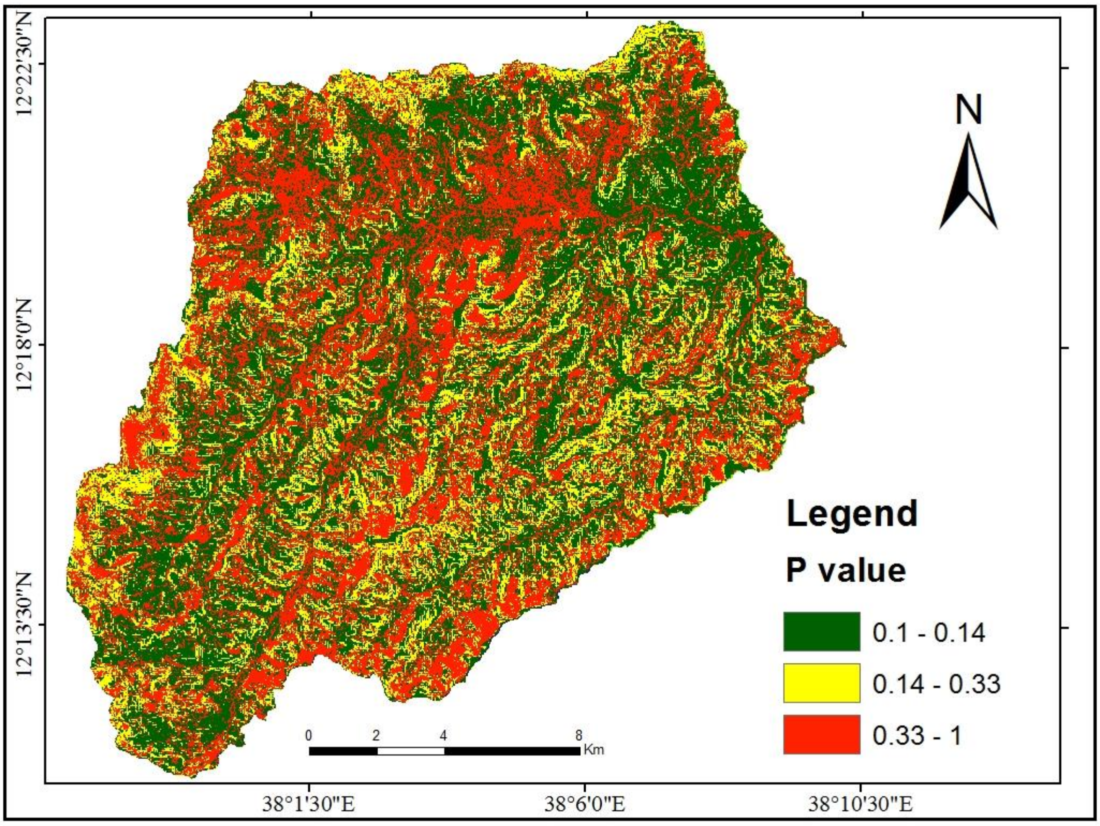

Figure 13. P- factor map of the Arbit watershed

4.9. Estimation of annual soil loss

The annual soil loss rate of the watershed was determined by overlaying the respective RUSLE input parameters values (R, K, LS, C and P) using raster calculator tool in the ArcGIS as given in Eq.4. Therefore, in this study overlaying these RUSLE model input factors in the form of raster layer by the help of raster calculator in the ArcGIS spatial analyst tools was used to estimate and provide soil loss map for the Arbit watershed. The resulting map for the Arbit watershed area is shown in Figure 14. The generated soil erosion risk map (Fig.14) of this study pointed out the mean annual soil loss of the study area has different spatial distribution. As shown in Figure 14, the amount of annual soil loss in the Arbit watershed varied from 0 (i.e area with little erosion in the watershed) to over 814.74 ton/ha/yr from the entire 31131.96 ha area of the study area. The average annual soil loss of the whole watershed was 66.75ton $ha^{-1}y^{-1}$ which is much greater than the tolerable limit of 18ton/ha/yr (Hurni 1983). However, the tolerable limit of soil loss depends on the local conditions such as soil type and its depth, land use/ land cover, topography and the amount of rainfall (Foster et al., 2002). In the soil erosion risk map of the Abit watershed (Fig 14) the highest raster value shows that areas which is critically vulnerable to soil erosion while lowest raster values indicate the study area which is less vulnerable to soil erosion. This may be due to variations with rainfall energy, characteristics of soil erodibility, slope length and steepness, the types of land use land cover and erosion control practice.

The spatial distribution (location) of soil loss in the study area has different severity. Because of the rugged nature of topography in the Arbit watershed, the severity of soil loss rate was distributed along different parts of the watershed. Thus, spatial pattern of the generated soil erosion risk map is generally realistic with the characteristic of topography (what can be observed in the field) and the results of previous studies. The computed mean annual soil loss values of the entire watershed of the study area have somehow similarity with the result of average soil loss rate which is found by different researchers (Yihenew and Yihenew 2013; Gelagay and Minale 2016; Tamene et al., 2017).

On the other hand, some other studies which is undertaken in different parts of Ethiopia estimated relatively high or low average soil loss rates (Bewket and Teferi 2009; Haregeweyn 2017) respectively. Furthermore, the average annual soil loss conducted at SCRP stations showed different soil loss rate (www.wlrc.eth.org) in Andit Tid and Anjeni. This indicates that soil erosion is a critical problem in Ethiopia and the estimated value of soil loss rate is still inconsistent and doubtful. The cause of this disparities of the estimated soil loss rate related with the heterogeneity of topography and environment and quality of input data.

As shown in Fig 14, the spatial variation of the result highest soil loss values was obtained in the bare land, along the river with steep slope and crop cultivated lands part of the watershed. In the study area bare land with steep slope is more susceptible to erosion among the other land types. This shows that LS factor plays a significant role in soil erosion. Minimum soil loss values were also obtained in the forest and shrub lands. From this we concluded that areas which is covered by forests and shrubs are less susceptible to erosion than bare and crop lands.

4.10. Hotspots of soil erosion areas in Arbit watershed

The quality of RUSLE model to estimate quantitative soil loss depends on the quality of erosion factors (Asmamaw & Mohammed, 2019).The generated soil erosion risk map of the study area shows that erosion hazards happen at different part of the watershed. According to the soil erosion risk map (Fig 14), the Northern and Northwestern part of the study area are more vulnerable to erosion as compared to the other part of the watershed. This is due to the fact that the areas in this part of the watershed have steep slope character and spare vegetation cover as compared to the other part of the watershed. Furthermore, some areas along the watershed was also exposed to high soil erosion. The vulnerability of the watershed to erosion is highly depend on the land use/ cover and the slope steepness in the Arbit watershed. Areas with steep slope and poor vegetation cover were expose to high erosion whereas the flat slope as well as the steep slope with dense vegetation cover have low soil erosion rates (Fig 14). Thus reducing slope steepness and covered areas with vegetation can play an important role for controlling soil erosion.

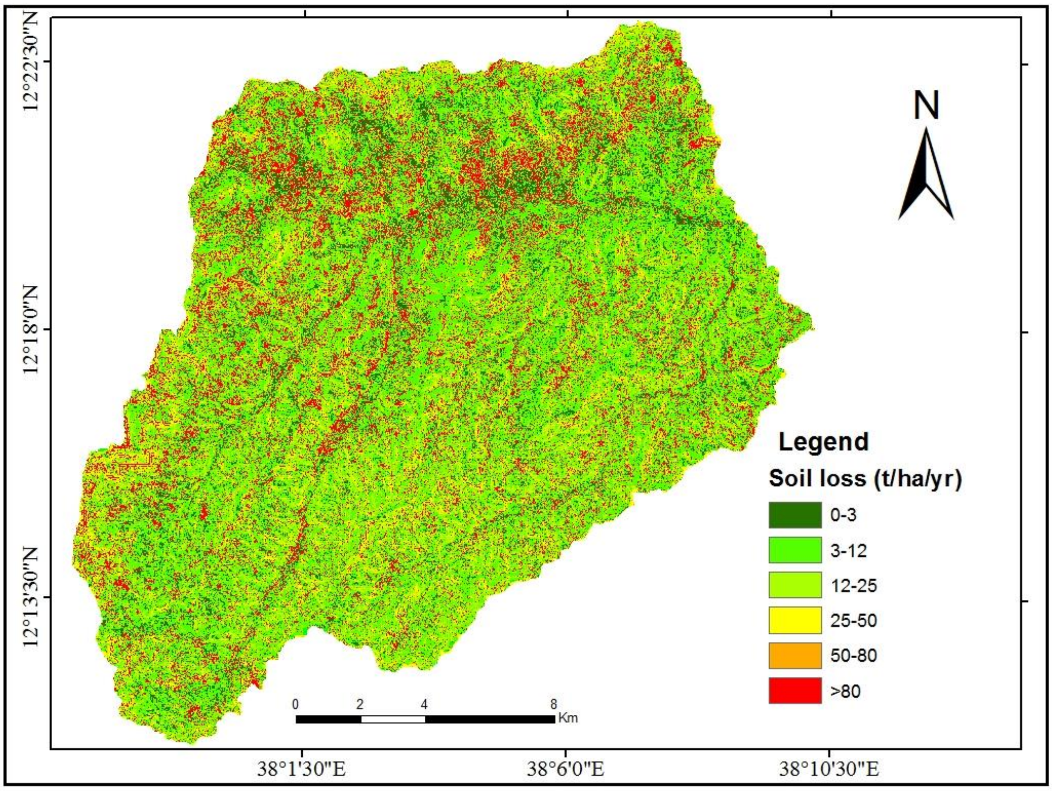

Figure 14. Mean annual soil loss rate and distribution of hotspot erosion areas in Arbit watershed.

As shown from Fig 14 the distribution of soil loss rate increases with increasing slope steepness in the study area. The bare lands with steep slopes topography have more soil erosion rates than gentle slope areas have high soil loss rate (>100ton/ha/yr) and these are considered as erosion hotspot areas which needs immediate soil conservation measures. This shows that soil erosion rate in a given watershed significantly affected by slope steepness. Therefore, applying various soil and water conservation practice could play a significant role in soil loss rate by reduce the slope length. Therefore, from the generated soil erosion risk map, we can understand that the main factors that affect soil loss rate in the study area are topography (slope length, slope gradient) and land use land cover. Based on the severity of mean annual soil loss rate, the average annual soil loss rate distribution was grouped in to six erosion severity class (Table 13). The areas which needs prioritization for soil and water conservation intervention is identified in table 13.

Table 13. Annual soil loss rate, severity class and priority classes in Arbit watershe.

Soil Loss (ton/ha/yr)	**Area**		**Severity class**	**Priority classes**
	ha	Percent		
0 – 5	6532.76	20.98	Very low	VI
5 – 10	7989.26	25.66	Low	V
10 – 25	5121.43	16.45	Moderate	IV
25 - 50	5654.97	18.16	High	III
50 -100	961.95	3.09	Very high	II
>100	4871.59	15.65	Severe	I
Total	31131.96	100	-	-

Table 13 shows that about 4870ha (15.65%) of the study area falls under the severe class and it needs an immediate attention of soil and water conservation treatment. About 6,620ha (21.25%) of the study area falls under the high and very high severity class and the mean annual soil loss rate is between 25 to 100ton/ha/yr. The moderate severity class covers 5120ha (16.45%) of the study area and mean annual soil loss rate is between 10 to 25 ton/ha/yr. The remaining 45% of the study area falls under the very low and low erosion class. Furthermore, 16,610ha (53.35%) of the Arbit watershed falls under moderate to severe soil erosion classes. Thus, areas with high erosion severity class needs urgent prioritized soil and water intervention measures to keep the sustainability of land in the Arbit watershed.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS.

5.1. Conclusions

In Ethiopian, because of poor land use and land management practice soil erosion rate is accelerated. Declining soil fertility and severe soil erosion is occurring in Ethiopian highlands due to exhaustive farming on steep slope areas and other factors related to population pressure. Quantifying the amount of soil loss rate with in a specific watershed level was difficult in the past year. But now soil erosion models integrated with GIS and RS techniques are used to estimate annual soil loss at a watershed level. Thus, using RUSLE model with GIS and RS techniques the potential soil erosion in the Arbit watershed was estimated.

The final soil erosion risk map shows that the spatial distribution of soil loss and erosion hotspot area which is very important to set prioritize for conservation practice. Because the first step to facilitate conservation planning is identification of critical soil erosion risk area. Therefore, GIS and RS techniques can show the spatial location of the critical erosion area and it has a significant role for environmental recovery, management and to plan conservation intervention in the Arbit watershed. This GIS and RS techniques are simple and cost-effective tools. In soil erosion studies GIS and RS techniques can show the spatial distribution of each RUSLE in put parameters. The data showed that, the topography (LS factor) and cover management (C factor) are significantly affect erosion process in the Arbit watershed.

The total amount of soil loss in Arbit watershed ranging from 0.0 to 814.74 ton/ha/yr and the mean annual soil loss of the entire watershed wass 66.75ton/ha/yr. Areas 5,121.43ha, 5,654.97ha, 961.95ha and 4,871.59ha of the study watershed were classified as moderate, high, very high and severe soil erosion classes respectively. The other part of the study area (6532.76ha and 7989.26ha) were classified as very low and low soil erosion classes respectively. Therefore, this situation indicates to take immediate action to implement soil and water conservation practice in the study watershed. Thus, fixation of prioritization for water and soil conservation treatment were assign based on the soil erosion severity classes. So, water and soil conservation practice must be first implemented in the areas which is more vulnerable to soil erosion. Thus, applying various conservation practice in the erosion hotspot areas help to reduce erosion hazard and finally a positive impact will be achieved.

5.2. Recommendations

In soil erosion model calibration on RUSLE parameters were needed for estimation of a correct soil erosion loss for conservation practice purpose. In this study soil erodibility factor was obtained from the AfSIS at 250m spatial resolution. The soil organic matter content of the study area was very high but in the study area agricultural practice takes place for a long time. Furthermore, there is protected and dense forest area in Arbit watershed. Thus, in such kind of degraded area the content of soil organic matter low. The soil organic matter content is high in the protected areas like semen national park. This parameter may be affecting the final result in the study area. Calibration of RUSLE model in this study was not apply by the actual measurement from the field to validate the result. Measuring data from the field is difficult to validate soil loss estimation in large area. Therefore, any researcher which is interested to conduct his project on soil erosion can fill this gap for further project.

Finally, the RUSLE model has an acceptable result when comparing with the results of previous researchers and the current area conditions. Therefore, taking in to consider the existing gaps the application of RUSLE model is possible to estimate soil erosion in large watershed. the following points are forwarded as a recommendation:

- ❖ Further studies will be recommended to estimate soil erosion by taking a continuous field measurement and collect samples in different part of the area and calibrate the model to get more accurate results.
- ❖ Further studies will be recommended to estimate soil erosion by testing different soil properties (soil physical and chemical) in the laboratories.
- ❖ Immediate soil and water conservation practice should be implemented where the area its mean annual soil loss is above the tolerance limit of soil loss based on the interest of the local communities and the topographic situations.
- ❖ The concerned body should give incentives for the local communities to mobilize the society and to have sustainable land management practice.
- ❖ To reduce removal of soil loss vegetation cover in the study area should be improved.
- ❖ Steep slope areas with poor vegetation cover should be free from animals and agricultural practice by creating awareness for the local communities.

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Appendixes

Appendix A: Monthly Rainfall in mm from 1996-2016 of seven stations.

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	8	9	25	52	97	120	264	259	38	11	25	5
	8	8	28	45	76	145	228	211	16	67	33	6
	9	12	17	14	61	87	394	375	54	14	7	4
	10	7	6	19	22	71	358	295	88	34	9	7
	5	5	7	51	25	70	267	344	54	38	23	5
	4	5	16	24	37	88	455	359	28	16	8	4
	7	5	30	28	25	87	237	243	47	9	8	8
	4	10	11	23	17	69	259	334	44	10	10	6
	5	8	15	35	14	87	232	235	25	15	16	4
A	7	8	24	24	31	88	325	258	47	10	13	3
	4	5	9	31	40	55	240	354	63	38	9	7
	7	5	8	32	39	131	317	298	69	7	10	3
	7	5	6	53	73	90	266	264	66	17	19	5
	4	6	17	17	14	54	276	181	19	12	10	9
	6	6	11	41	51	47	318	361	38	9	10	6
	6	5	23	27	74	64	266	261	49	11	27	3
	4	5	14	17	31	87	316	280	37	14	25	6
	7	11	13	30	47	128	343	266	38	33	19	4
	9	14	44	50	110	51	193	240	48	35	10	9
	6	15	14	27	95	67	140	224	48	17	17	15
	6	13	12	30	85	55	316	255	44	15	8	4

Station _Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	6	7	30	48	109	136	291	270	50	17	25	5
	6	6	35	41	87	165	251	221	23	98	33	7
	6	9	20	12	68	99	413	396	78	21	7	4
	7	5	7	17	26	81	387	311	111	51	8	7
	4	4	8	47	29	81	303	367	68	64	23	5
	3	4	17	21	41	105	502	375	41	25	8	4
	5	4	31	24	29	107	258	257	60	13	8	8
	3	8	13	21	20	77	281	352	56	14	10	6
B	3	7	18	33	16	99	269	256	38	21	18	4

	6	6	31	22	36	89	364	264	66	14	13	3
	3	4	11	29	46	60	271	373	74	53	9	7
	5	4	9	30	45	164	361	320	89	13	10	3
	7	4	7	53	85	118	300	284	76	24	20	5
	3	5	20	16	16	64	312	192	28	17	10	8
	4	4	13	37	60	52	351	371	54	13	10	6
	4	4	28	24	91	74	318	279	66	17	34	3
	3	4	17	15	34	111	352	288	50	21	26	7
	5	5	18	26	50	132	386	289	52	54	19	4
	6	6	59	48	119	57	220	257	59	55	10	9
	4	9	18	24	108	78	155	234	65	26	19	17
	4	6	14	25	93	67	358	279	60	20	9	4

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	5	4	23	28	97	160	323	262	65	21	16	4
	4	3	17	22	97	161	275	243	51	160	27	8
	6	5	13	7	73	102	505	430	104	42	6	4
	7	3	4	11	28	91	486	338	108	71	10	6
	4	3	5	33	33	111	359	402	78	89	21	5
	4	4	9	14	45	128	556	397	37	42	7	4
	6	4	16	13	32	138	285	269	73	24	7	8
	4	7	7	11	23	106	336	358	74	16	9	6
	5	6	10	21	16	112	298	276	41	31	22	4
	6	5	27	13	35	115	416	282	80	15	13	4
C	4	4	6	18	66	81	339	401	89	71	8	9
	7	4	7	19	51	206	390	354	97	25	9	4
	7	3	4	37	90	160	345	300	79	31	21	6
	4	5	17	12	17	101	341	213	37	28	9	7
	6	3	8	21	60	73	392	379	64	18	9	6
	6	3	16	14	94	106	368	315	78	21	30	4
	5	3	9	8	44	139	411	320	71	27	27	6
	3	2	10	14	46	157	466	310	69	85	14	2
	3	3	45	30	113	79	257	268	73	77	8	5
	2	5	9	14	113	82	210	259	92	50	17	8
	2	2	7	14	107	76	423	301	65	35	8	3

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	6	8	23	41	95	130	287	264	54	16	15	4
	6	7	16	32	106	152	262	232	34	116	32	6
	7	10	14	10	77	84	453	393	74	27	6	4
	8	6	4	14	25	92	470	320	100	48	11	7
	4	5	5	50	30	92	331	390	67	65	20	5
	3	4	8	19	41	114	528	380	33	28	7	4
	5	5	21	20	29	116	262	249	60	16	7	7
	3	9	7	16	21	88	304	350	60	13	10	5
	3	7	10	29	15	101	277	260	31	21	23	4
	6	8	19	18	34	99	396	264	69	12	12	3
D	3	5	6	26	57	58	304	384	75	57	8	11
	6	4	7	26	44	183	355	330	83	18	8	3
	6	4	4	51	90	128	297	287	63	25	19	5
	3	6	14	14	15	72	310	190	30	18	9	7
	5	5	8	30	55	52	344	366	53	14	9	4
	4	4	17	19	95	85	316	292	63	16	36	3
	3	4	10	12	38	118	369	300	50	21	26	7
	5	7	11	21	46	122	393	289	53	53	15	4
	6	7	40	42	113	62	220	252	55	59	9	8
	4	13	10	21	104	68	172	240	63	36	19	17
	4	6	7	20	100	69	363	291	55	22	8	4

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	8	9	24	43	106	148	272	269	49	15	24	5
	8	8	33	38	92	147	247	237	28	111	37	7
	8	13	22	11	63	78	440	375	68	26	6	5
	9	7	6	16	24	87	443	325	97	46	12	8
	5	6	7	44	29	77	302	377	65	57	21	4
	3	5	14	18	39	116	482	371	38	23	7	4
E	6	6	29	22	28	99	245	252	61	13	8	9
	3	11	13	20	19	77	275	352	57	13	11	5
	4	9	14	33	15	99	259	253	34	23	17	4
	6	11	27	21	35	95	354	257	61	12	12	3
	3	6	9	27	47	56	267	384	70	52	9	10
	8	5	8	28	44	162	342	327	78	15	9	3
	7	5	6	52	86	114	280	271	68	24	20	5

	3	7	18	15	14	57	295	182	30	15	9	8
	5	5	10	33	53	47	335	358	51	12	9	5
	5	5	24	23	88	69	289	283	60	16	41	3
	4	5	14	15	32	108	351	290	49	20	24	7
	6	11	15	26	45	123	366	279	48	55	20	4
	7	14	60	48	106	52	208	245	55	54	9	9
	5	18	15	23	102	61	147	231	58	29	20	17
	5	13	12	24	88	58	347	292	49	20	9	4

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	4	4	21	37	94	167	330	299	78	22	15	4
	3	4	15	26	105	173	269	271	73	187	27	7
	4	6	16	9	69	116	488	432	109	52	6	3
	5	3	5	12	28	90	488	371	133	54	10	6
	3	4	7	42	29	121	389	425	102	109	19	5
	3	4	10	16	47	143	558	414	52	43	7	4
	4	4	21	16	29	146	291	291	90	25	8	8
	3	8	9	13	21	109	386	387	92	18	11	6
	3	7	12	22	14	118	308	287	48	37	23	4
	4	5	26	14	32	127	442	298	103	19	13	3
F	3	4	8	21	65	92	373	433	111	79	8	8
	5	4	10	24	49	208	393	385	113	30	9	3
	5	4	5	45	90	165	349	314	106	36	22	6
	3	5	20	13	14	92	355	225	42	34	8	7
	5	4	13	23	50	84	413	403	79	23	9	6
	4	4	22	16	96	125	364	324	96	23	36	3
	3	4	13	9	36	160	431	334	93	30	25	4
	2	3	12	17	45	167	470	327	75	95	13	2
	3	4	59	34	115	87	264	271	91	85	8	5
	2	6	11	16	117	106	228	282	108	59	19	6
	2	4	8	15	111	93	441	322	73	38	8	2

tation Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	4	7	29	43	113	163	275	285	79	21	21	5
	3	6	30	35	102	153	283	267	42	152	41	7
	5	10	22	11	87	110	490	404	91	57	5	4
	5	5	7	15	24	101	551	349	116	53	10	7
	3	6	10	51	32	109	361	409	97	92	19	7
	3	6	16	19	43	134	552	403	53	36	6	6
	5	7	32	22	30	130	280	288	88	20	7	12
	3	13	14	18	21	99	372	383	87	17	9	7
	3	11	18	29	15	115	310	282	44	31	24	6
	4	9	36	19	37	109	431	292	95	16	12	4
G	3	6	11	28	62	77	342	421	103	74	7	13
	6	7	13	30	56	190	381	367	108	26	7	4
	5	6	8	56	99	130	319	315	98	32	19	8
	3	9	22	14	14	73	351	210	41	25	7	11
	4	6	13	32	56	56	382	387	77	23	8	8
	4	6	33	22	111	101	345	313	93	21	41	4
	3	6	22	13	35	142	399	323	79	27	23	6
	3	7	15	22	48	149	428	311	70	76	14	3
	3	8	77	43	124	74	245	261	79	79	7	7
	2	11	16	21	105	80	190	258	81	46	20	13
	2	7	11	20	115	89	405	324	65	30	8	3

Appendix B: monthly minimum and maximum T^{o} at 2016

Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	30.7	30.7	30.9	30.6	30.5	30.6	30.5	30.2	30.7	30.7	31.0	30.8
Min	13.8	14.0	13.9	14.0	3.1	14.2	14.2	13.9	13.8	14.2	14.2	14.2
Mean	22.3	22	22	22.3	16.8	22.4	22.4	22.1	22.3	22.5	22.6	23

Appendix C: Ground control points

No	X	Y	Reference
1	394813.25	1355391.26	crop
2	394905.32	1355330.14	crop
3	395195.36	1355573.82	crop
4	393868.73	1355014.49	crop
5	393917.42	1355056.83	crop
6	393992.56	1355235.68	crop
7	393736.44	1355191.23	crop
8	393281.76	1353677.02	crop
9	393142.59	1353772.27	crop
10	394309.52	1352245.61	crop
11	394247.29	1352164.75	crop
12	395800.56	1351828.04	crop
13	395792.42	1351302.22	crop
14	395609.86	1351346.67	crop
15	395058.20	1350896.93	crop
16	395120.65	1350941.38	crop
17	395031.22	1351389.68	crop
18	395195.86	1351491.38	crop
19	397688.13	1351327.34	crop
20	397694.75	1351263.84	crop
21	397867.26	1351347.98	crop
22	396539.21	1359033.34	crop
23	396580.22	1358916.92	crop
24	405226.44	1363125.34	crop
25	405296.55	1363034.06	crop
26	405225.11	1363000.32	crop
27	405776.85	1363111.39	crop
28	405755.69	1362983.07	crop
29	405933.95	1362978.77	crop
30	405991.50	1363057.48	crop
31	405151.73	1364077.96	crop
32	405194.32	1364119.24	crop
33	407278.86	1360261.64	crop
34	407398.98	1360276.99	crop
35	407499.00	1360296.57	crop
36	407280.45	1360352.13	crop
37	407094.71	1362235.39	crop
38	406945.13	1362054.73	crop
39	407047.26	1362059.49	crop
40	405355.12	1360724.20	crop
40	405355.12	1360724.20	crop
41	405495.61	1360833.34	crop
42	403899.77	1359157.29	crop
43	403974.38	1359135.07	crop
44	404218.86	1359273.97	crop
45	403992.24	1359418.43	crop
46	403756.10	1359456.14	crop
47	403831.11	1359649.02	crop
48	402828.47	1360207.57	crop
49	403225.71	1360234.71	crop
50	403487.67	1361075.65	crop
51	403507.52	1360950.64	crop
52	403133.91	1362541.26	crop
53	403208.42	1362845.22	crop
54	404289.50	1366643.94	crop
55	403783.90	1367395.67	crop
56	403937.27	1367496.43	crop
57	403995.37	1367460.87	crop
58	405384.93	1367812.42	crop
59	405699.37	1367939.24	crop
60	405452.73	1367924.31	crop
61	391682.15	1366253.11	Shrub
62	391754.38	1366278.51	Shrub
63	391819.47	1366371.38	Shrub
64	391905.19	1366346.77	Shrub
65	391884.76	1366198.13	Shrub
66	391925.51	1366209.77	Shrub
67	391898.52	1366105.53	Shrub
68	392339.45	1366374.39	Shrub
69	392418.83	1366327.56	Shrub
70	392601.39	1366288.66	Shrub
71	392699.02	1366319.62	Shrub
72	393404.38	1365784.26	Shrub
73	393660.12	1365788.83	Shrub
74	394064.29	1365872.71	Shrub
75	394350.57	1365991.45	Shrub
76	394352.16	1366040.66	Shrub
77	394445.82	1366051.78	Shrub
78	394445.29	1366149.14	Shrub
79	394459.58	1366222.70	Shrub

80	394537.37	1366289.37	Shrub

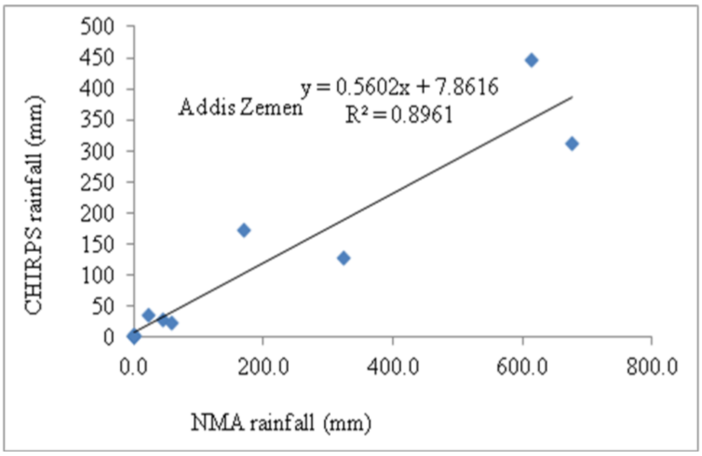
81	394646.195	1366172.639	Shrub
82	394710.258	1366211.923	Shrub
83	394764.0457	1366127.091	Shrub
84	394798.9708	1366074.703	Shrub
85	394817.4917	1366104.072	Shrub
86	394773.5707	1366045.07	Shrub
87	394848.448	1365989.243	Shrub
88	394861.4126	1365968.87	Shrub
89	396091.7661	1365220.533	Shrub
90	396195.505	1365112.991	Shrub
91	396349.2944	1365070.657	Shrub
92	396326.4741	1365003.188	Shrub
93	396429.9925	1364868.25	Shrub
94	396375.7528	1364805.742	Shrub
95	396468.6879	1364695.279	Shrub
96	396488.2009	1364657.576	Shrub
97	396494.8155	1364613.258	Shrub
98	396566.9146	1364542.482	Shrub
99	396658.5268	1364636.078	Shrub
100	396804.7094	1364692.964	Shrub
101	396819.923	1364793.175	Shrub
102	396934.1901	1364441.344	Shrub
103	396957.0105	1364353.37	Shrub
104	396867.3827	1364373.214	Shrub
105	396943.1286	1364165.52	Shrub
106	396969.587	1364137.368	Shrub
107	397013.1904	1364145.2	Shrub
108	397030.7588	1364079.16	Shrub
109	397035.4155	1364107.735	Shrub
110	398050.3934	1361760.197	Shrub
111	398057.1403	1361680.822	Shrub
112	399083.309	1351268.51	Shrub
113	399159.1123	1351282.798	Shrub
114	398794.8024	1351248.622	Shrub
115	392273.6942	1350058.611	Forest
116	392309.9422	1350062.58	Forest
117	392229.5087	1350081.63	Forest
118	392206.4899	1350089.832	Forest
119	392231.89	1350022.363	Forest
120	392272.7947	1350178.598	Forest
121	392304.76	1350130.34	Forest
122	392307.30	1350218.39	Forest
123	392943.35	1350015.56	Forest
124	392975.95	1350030.06	Forest
125	392990.44	1350027.41	Forest
126	393001.98	1350066.78	Forest
127	392972.88	1350079.48	Forest
128	392999.33	1350096.31	Forest
129	393035.95	1350111.97	Forest
130	393066.33	1350096.20	Forest
131	393089.08	1350092.18	Forest
132	393118.82	1350092.71	Forest
133	393147.93	1350079.06	Forest
134	393194.07	1350126.79	Forest
135	393165.06	1350474.18	Forest
136	393172.28	1350482.19	Forest
137	393186.89	1350489.89	Forest
138	393188.16	1350501.16	Forest
139	393235.22	1350494.18	Forest
140	393259.43	1350497.67	Forest
141	393280.07	1350498.07	Forest
142	393270.78	1350489.73	Forest
143	393677.42	1350713.71	Forest
144	393693.42	1350716.23	Forest
145	393706.65	1350722.05	Forest
146	393680.48	1350765.43	Forest
147	393743.13	1350788.19	Forest
148	393720.55	1350803.53	Forest
149	393734.97	1350812.65	Forest
150	393228.23	1351794.70	Forest
151	393243.98	1351806.87	Forest
152	393265.94	1351832.67	Forest
153	393340.42	1351846.42	Forest
154	393394.19	1351783.78	Forest
155	393550.96	1351842.98	Forest
156	393568.71	1352024.93	Forest
157	394309.80	1352497.35	Forest
158	394329.17	1352492.11	Forest
159	394381.87	1352501.32	Forest
160	394357.04	1352880.75	Forest

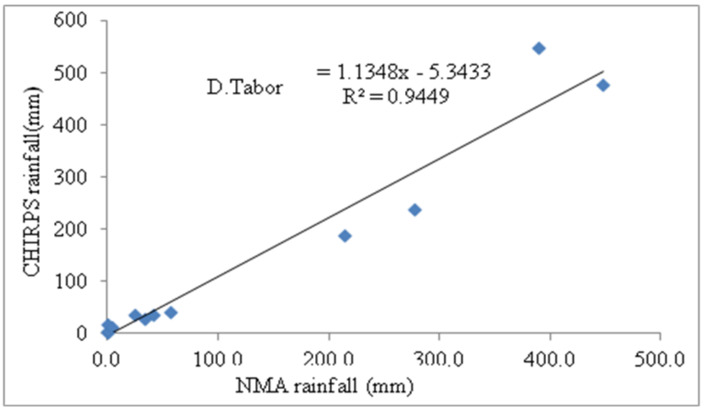
161	394414.19	1352873.76	Forest
162	394233.00	1353021.89	Forest
163	394469.47	1352888.21	Forest
164	394707.44	1353065.22	Forest
165	390834.52	1347763.52	Bare
166	390383.80	1348141.81	Bare
167	390450.74	1348130.17	Bare
168	390596.26	1348303.47	Bare
169	388435.53	1350494.84	Bare
170	388542.69	1350408.85	Bare
171	388468.14	1351965.40	Bare
172	388411.78	1352007.47	Bare
173	388391.94	1352090.02	Bare
174	388169.44	1351970.66	Bare
175	388167.33	1351930.17	Bare
176	388224.32	1352226.63	Bare
177	388250.06	1352233.36	Bare
178	389331.94	1353982.30	Bare
179	389459.60	1353907.55	Bare
180	389572.78	1354252.67	Bare
181	390884.56	1354285.49	Bare
182	390940.87	1354213.72	Bare
183	391036.57	1354341.32	Bare
184	390927.93	1354560.15	Bare
185	391852.58	1353336.30	Bare
186	391930.27	1353276.69	Bare
187	392091.79	1352718.27	Bare
188	392200.54	1352693.21	Bare
189	392350.70	1352878.57	Bare
190	393709.50	1353148.39	Bare
191	393776.97	1353173.79	Bare
192	393754.74	1353249.99	Bare
193	393876.30	1353263.96	Bare
194	393808.92	1353424.83	Bare
195	394018.67	1353155.27	Bare
196	393992.63	1353126.48	Bare
197	394070.10	1353127.97	Bare
198	394066.24	1353871.01	Bare
199	394038.87	1353921.78	Bare
200	394067.71	1353928.13	Bare

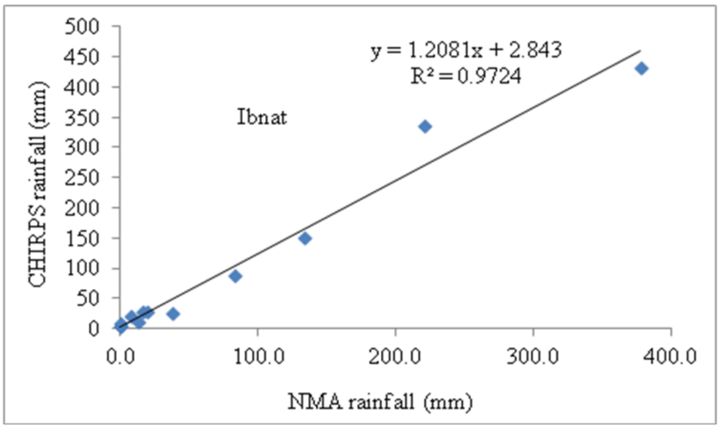
201	393826.04	1354397.52	Bare
202	393888.21	1354359.15	Bare
203	393975.69	1354500.90	Bare
204	395354.62	1360965.24	Bare
205	396698.70	1362903.39	Bare
206	396859.57	1362887.51	Bare
207	396985.51	1363228.82	Bare
208	397337.41	1362997.05	Bare
209	397468.64	1363138.87	Bare
210	397608.34	1363225.65	Bare
211	397571.83	1363303.97	Bare
212	397734.28	1363222.47	Bare
213	397779.79	1363438.90	Bare
214	397848.05	1363409.80	Bare
215	397914.73	1363432.02	Bare
216	398087.85	1363596.73	Bare
217	398054.51	1363592.36	Bare
218	398190.60	1363530.97	Bare
219	398228.70	1363513.77	Bare
220	397998.78	1363509.01	Bare
221	391933.03	1348199.31	Settlement
222	391929.22	1348215.02	Settlement
223	391911.02	1348253.39	Settlement
224	391936.71	1348288.47	Settlement
225	391909.72	1348293.98	Settlement
226	391970.35	1348385.47	Settlement
227	391782.75	1348781.01	Settlement
228	391762.27	1348797.58	Settlement
229	393001.43	1351914.76	Settlement
230	393008.62	1351903.11	Settlement
231	393030.85	1351877.71	Settlement
232	392958.36	1352006.26	Settlement
233	392995.11	1351988.08	Settlement
234	392984.63	1351989.99	Settlement
235	393017.18	1352009.12	Settlement
236	393035.19	1352006.74	Settlement
237	393048.37	1352028.88	Settlement
238	393068.61	1352011.98	Settlement
239	392813.76	1351938.71	Settlement
240	392837.78	1351935.43	Settlement

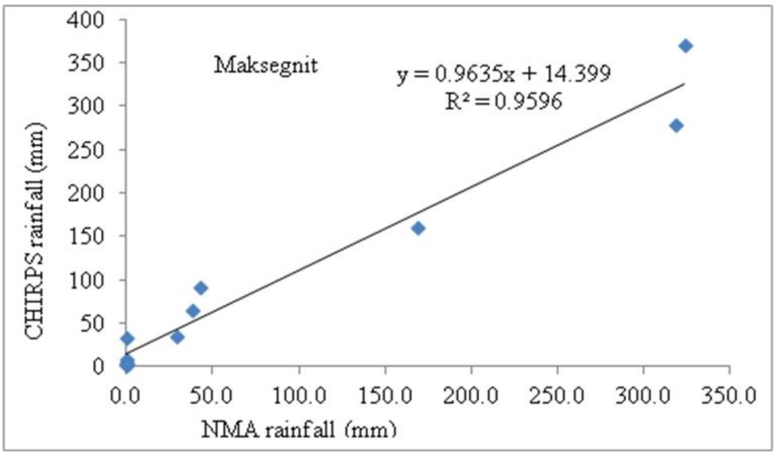
241	392860.11	1351932.68	Settlement
242	391816.59	1365264.34	Settlement
243	391803.50	1365254.82	Settlement
244	391886.84	1365161.55	Settlement
245	391965.02	1365181.00	Settlement
246	391986.28	1365326.45	Settlement
247	391989.14	1365293.64	Settlement
248	392013.06	1365279.25	Settlement
249	392053.17	1365282.95	Settlement
250	392058.41	1365093.09	Settlement
251	392131.33	1365092.66	Settlement
252	392104.13	1365121.03	Settlement
253	392137.36	1365107.16	Settlement
254	392143.18	1365147.59	Settlement
255	392233.02	1365268.70	Settlement
256	392210.00	1365259.49	Settlement
257	392223.57	1365249.33	Settlement
258	392236.75	1365235.12	Settlement
259	392247.62	1365250.44	Settlement
260	392119.76	1365319.91	Settlement
261	392130.87	1365297.53	Settlement
262	392117.22	1365289.27	Settlement
263	392020.37	1365171.96	Settlement
264	392031.90	1365171.54	Settlement
265	392052.12	1365177.04	Settlement
266	391777.72	1365204.04	Settlement
267	391779.87	1365092.56	Settlement
268	391822.47	1365110.82	Settlement
269	391882.58	1365217.27	Settlement
270	391869.35	1365194.52	Settlement

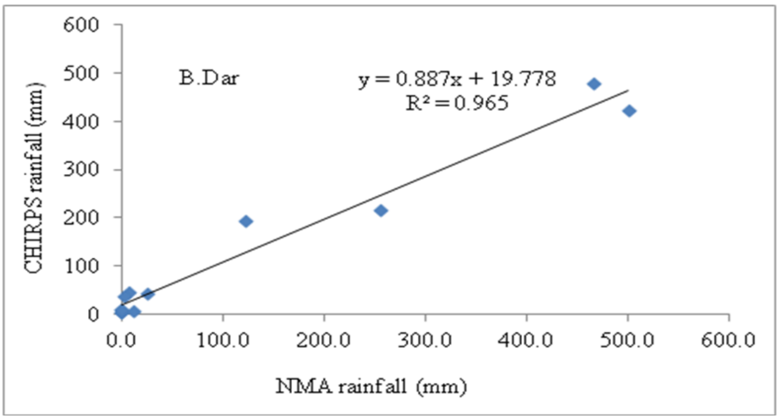
Appendix D: Reliability of NMA Stations

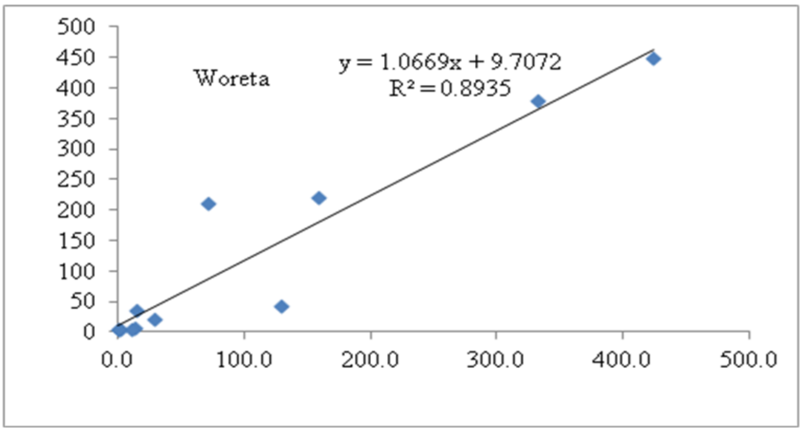







Maksegnit
y = 0.9635x + 14.399
R² = 0.9596
CHIRPS rainfall (mm)
NMA rainfall (mm)
400
350
300
250
200
150
100
50
0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0


B.Dar
y = 0.887x + 19.778
R² = 0.965
CHIRPS rainfall (mm)
NMA rainfall (mm)
600
500
400
300
200
100
0
0.0
100.0
200.0
300.0
400.0
500.0
600.0


Woreta
y = 1.0669x + 9.7072
R² = 0.8935
500
450
400
350
300
250
200
150
100
50
0
0.0
100.0
200.0
300.0
400.0
500.0