SOIL EROSION ASSESSMENT USING THE RUSLE MODEL AND GIS TECHNIQUES: A CASE OF LAGA HAYA WATERSHED, EASTERN WOLLEGA, WESTERN ETHIOPIA.

By:

Yobsan Tesfaye Wedajo

A Thesis Submitted to the Department of Geomatics Engineering, School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements for the Degree of master's in Geo-informatics Engineering

Office of Graduate Studies

Adama science and Technology University

Adama, Ethiopia

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of board of examiners of the final open defense by Yobsan Tesfaye Wedajo have read and evaluated his thesis" Soil Erosion Assessment using the RUSLE model and GIS Techniques: A Case of Laga Haya Watershed" and examined the candidate. This is, to certify that the thesis has been accepted in partial fulfillment of the Degree of Master's in Geo-Informatics Engineering.

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CANDIDATE'S DECLARATION

I her by declare that this MSc thesis is my original work and has not been presented for a degree in university, and sources of material used for this thesis have been duly acknowledged.

Name: Yobsan Tesfaye Wedajo

Signature: ___________________

This MSc thesis has been submitted for examination with our approval as thesis advisor.

Advisor

Name: Roba Gemechu (Ph.D.)

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Date of Submission: ______________

ADVISOR’S APPROVAL SHEET

To: Geomatics Engineering Department

Subject: Thesis Submission

This is to certify that the thesis “Soil erosion Assessment using RUSLE modeling and GIS Techniques: A Case of Laga Haya Watershed” submitted in fulfillment of the requirements for the degree of Master’s in Geo-Informatics Engineering, the graduate program of the department of Geomatics Engineering , and has been carried out by Yobsan Tesfaye Wedajo ID. No. PGR/18170/11, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby He can submit the thesis to the department.

Advisor

Name: Roba Gemechu (Ph.D.)

Signature: ________________

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LISTS OF ACRONYMS AND ABBREVIATIONS

ASTER DEM	Advanced Space Born Thermal Emission and Reflection Radiometer
C factor	Cover factor
DEM	Digital Elevation Model
ERDAS	Earth Resource Data Analysis System
FAO	Food and Agricultural Organization
GIS	Geographic Information Systems
GPS	Global Positioning System
IDW	Inverse distance weight
K factor	Erodibility factor
LULC	Land Use Land Cover
MoA	Ministry of Agriculture
NGO	None Governmental Organization
R factor	Erosivity factor
RS	Remote sensing
RUSLE	Revised Universal Soil Loss Equation
USDA-ARS	United States Department of Agriculture- Agricultural Research Service
USGS	United State Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal transverse Mercator

ABSTRACT

Soil erosion is one of the critical problems in Ethiopia. It is estimated that the country loses 1.9 to 7.8 billion tons of soil in a year and this cost the country lose to about one billion in Ethiopia birr. The rate of soil loss can be estimated and erosion hotspots can be identified by using revised Universal soil loss equation (RUSLE) model and GIS Techniques. This study was carried out with the main objective of quantifying the rate of annual soil loss and identification of soil erosion risk (erosion hotspots) area through prioritizing Sub-watersheds in the Laga Haya watershed. Rainfall data, Soil data, Landsat image and digital elevation model data were collected and then processed to generate RUSLE input factors. RUSLE parameters were analyzed and overlain using raster calculator in spatial analyst tools in ARCGIS 10.5 environment to estimate annual erosion rates and map erosion risk areas in the Laga Haya watershed. The result showed that the total annual soil losses was about 311,535 from 0.00 ton/ha/year in plain areas to 150.917 ton/ha/year by the rate of 23 ton/ha/year which was steep slope areas of Laga Haya watershed. The annual soil loss was classified in to Very low, low, moderate, high and very high severity classes. The vulnerability of soil erosion severity classes in the study area indicated that 3.28% fall under high to very high soil erosion risk class. Steep slope with poor vegetation cover experienced with high soil erosion. To identify erosion hotspots in the Laga Haya watershed the five sub-watersheds were prioritized for soil and water conservation. The study finding s revealed that soil erosion was high and very high in the northern and northeastern part of the watershed and the sub-watersheds "A" and conservation since it has higher rate soil loss, which is 23 t ha/yr and 15.2 ton/ha/yr, and the remaining sub-watersheds could be conserved according to the "D" and sub-watershed "E". Vegetation cover (C factor) and topography (LS factor) have a significant effect on soil erosion in the watershed from the five soil erosion factors. Implementation of Immediate soil and water conservation practices are needed where areas its annual soil loss above 10 ton ha^{-1} year^{-1}.therefore, the local experts and administrative bodies uses this information to prepare plan for prioritized sub-watersheds and area fallen under very high and high severity classes to conserve and monitor the degraded land resources.

Key words: *Laga Haya watershed, GIS. RUSLE modeling, Hotspots, prioritization*

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Soil erosion is one of the global threats that causes land degradation and negative impact on the environment by threatening the natural environment, agriculture and the economy (Pimentel, D., 2006, Pimentel, D. and M. Burgess, 2013).Soil erosion by water is the process of particle detaching and particle transporting by flowing water to downhill areas (Kunta, 2009).This ultimately leads to loss of top soil in large quantity a common phenomenon in agricultural areas. In Ethiopia, soil erosion is a serious problem, which threatens the agricultural sector (Bezuayehu Tefera Olana, 2006) and causes increased sedimentation of reservoirs and lakes (Ritchie, J.C., D.E. Walling and J. Petere, 2003). According to Ethiopian Highland Reclamation Study (FAO., 1984) 60 million hectares of Ethiopian land are estimated to be used for agricultural productive. Out of these lands that used for agricultural purpose, about 27 million hectares are significantly eroded, 14 million hectares are seriously eroded and 2 million hectares have reached the point of no return with an estimated total loss of 2 billion m^3 of topsoil per year (Hurni, H., K. Herweg, B. Portner and H. Liniger, 2008) estimated that soil loss due to erosion of cultivated fields in Ethiopia amounts to about 42 t /ha/yr. Kebede *et al*. (2015) overpopulation, poor cultivation and land use practices, deforestation and overgrazing, loss of soil fertility, rapid degradation of natural systems, significant sediment positions in the lakes and reservoirs and sedimentation of irrigation infrastructures in the highlands of Ethiopian are the main causes that trigger problems of soil erosion. 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 M ha is affected severely (Lal, 2003).

In Ethiopia rates of soil erosion are being assessed since 1981 in the Soil Conservation Project (Hurni, 1985).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). Ethiopian highlands are considered as the most seriously degraded parts of the world and in general, it is estimated that the country loses 1.9 to 7.8 billion tons a year and this cost the country close to 1 Billion ETB (Gete *et al*., 2014) and each year 1.9 up to 3.5 billion tons of top soil has been lost in the highlands of Ethiopia which has been affecting the production capacity of the crop land (EFAP, 1993; Tadesse, 2001). Out of the total area of productive agricultural lands in Ethiopia, about 27 and 14 million hectares have been significantly and seriously eroded respectively with a probable total soil loss of 2 billion m3 of top soil per year (Bobe, 2004). Since soil loss had such on-site and off-site impacts, accurate and timely estimation of soil erosion loss or evaluation of soil erosion risk has to become an urgent task (Lu *et al.*, 2004) especially in developing counties like Ethiopia, which is fully dependent on the resource.

Soil Erosion modeling provides useful information for selection of appropriate soil conservation practices. Universal Soil Loss Equation (USLE) is the most widely known and used empirical soil loss model all over the World (Wischmeier and Smith, 1978).In the 1980, the United States Department of Agriculture Research Service (USDA-ARS) modified the model to the Revised Universal Soil loss Equation (RUSLE), which was an improved version of USLE incorporating new approaches and corrections of the USLE limitations. The RUSLE followed the same formula as USLE but got several improvements in the determining factors and a broader application to different situations, including forest lands, range lands and disturbed areas compared to USLE (Trojacek and Kadlubiec, 2004). It is a computation method that may be used for site evaluation and planning purposes and also for assisting in the decision process of selecting erosion control measures. It provides an estimate of the severity of erosion and also numerical results that can validate the benefits of planned erosion control measures in risky areas (Silleos, 1990).

GIS technique is an effective tool for assessing soil erosion risk by integrating different soil erosion assessment models (Abate, 2011; Trabucchi et al. 2012). These models can be categorized into: physical models, conceptual models and empirical models (Kirkby et al., 2008; Kinnell, 2010; Wischmeier & Smith, 1978). The most widely applied empirical erosion model is the USLE (Kinnell, 2010). The RUSLE model can predict erosion potential on a cell by-cell basis (Shinde et al., 2010). The use of RUSLE in a GIS environment has enabled application for large areas and satisfactory results have been reported (Gansari and Ramesh, (2015), Gashaw et al., (2018), for delineation of erosion prone areas and prioritization of micro watersheds for a targeted and cost-effective conservation planning purposes. Geographic Information System (GIS) has emerged as basic tool for data management, mapping and analysis of automated spatial and non-spatial geo-referenced data. There is considerable potential for use of GIS technology to erosion modeling and hazard assessment (Bocco,1985) and Mapping. GIS is characterized by its capability to integrate layers of spatially oriented information. The number and type of applications and analysis that can be performed by GIS in a watershed are as large and diverse as the available geographic datasets (Deore, 2005) soil erosion using GIS can easily identify areas that are at potential risk of extensive soil erosion and provide information on the estimated value of soil loss at various locations in the watershed (Shi et al., 2003). It can also be used to identify areas that are highly vulnerable and at high risk of soil erosion (Chen et al., 2010). According to Millward and Mersey (1999) as cited by Lu *et al*. (2004), a combination of RS, GIS, and RUSLE provides the potential to estimate soil erosion loss and makes its spatial distribution feasible with reasonable costs and better accuracy in larger areas.

Generally, Revised Universal Soil Loss Equation (RUSLE) erosion model with GIS techniques was preferred method for soil erosion prediction model that can be easily applied at the local or regional level (B.P. Ganasri, Ramesh, 2015).According to (Renard *et al.* 1997) RUSLE are the best known and widely used soil erosion modeling tools in the world. RUSLE uses the same empirical principles as Universal Soil Loss Equation (USLE), but includes numerous improvements in computation of various factors. RUSLE predicts long time average annual soil loss as a product of rainfall erosivity (R), soil erodibility (K), slope length (L), terrain steepness (S), vegetation cover (C) and conservation practices (P) factors.

Therefore, this study was designed mainly to estimate amount of soil loss from Laga Haya watershed by integrating RUSLE Model and Geographic Information System (GIS) techniques. These techniques is important for identifying highly eroded areas, mapping soil erosion risk area (Erosion hotspots area) and prioritizing sub-watershed for further planning and implementation of watershed management strategies and making policies by giving attention for more erosion prone areas (hotspots) of the Sub-watershed.

1.2 Problem Statement

Laga Haya watershed was one of the upper Abbay river basin which is tributary to Angar river. The watershed is heavily affected by water erosion as a result of steep slope cultivation and heavy deforestation. Soil erosion is a serious environmental problem in Sasiga Woreda, especially along the Laga Haya watershed during the rainy season (June-August). According to Sasiga Woreda Natural Resource Management Administration office report (unpublished, 2010 E.C). As the amount of rainfall is highly intensive, it causes destruction of (soil loss, loss of vegetation, loss of soil fertility indirectly, land degradation, loss of resident properties and others) is happening during the rainy season (June - August) since it was upper abbay basin soil erosion in the watershed was relatively high. The highly erratic nature of the rainfall which is concentrated in one particular rainy season (June - August) carries a considerable amount of sediment load and nutrient in to Laga Haya rivers. This contributes to the significant amount of amount of sedimentation to the Upper Abbay basin. This threatens the potential use of the area and may lead to loss of soil and water productivity and ultimately to land degradation (soil erosion).In the world status of human induced soil degradation deforestation, removal of natural vegetation and overgrazing are reported to be the main causes of soil erosion (Morgan, 1986). Laga Haya watershed (the study area) is characterized by uneven topography of irregular and steep terrains which makes agricultural practices, human and livestock mobility difficult in this area, extensive agricultural and overgrazing activities, and very limited plant cover and there is poor implementation of soil conservation measures. According to Kebede *et al,2015*. Overpopulation, poor cultivation and land use practices, deforestation and overgrazing, loss of soil fertility, rapid degradation of natural systems, significant sediment depositions in the lakes and reservoirs and sedimentation of irrigation infrastructures in the highlands of Ethiopian are the main causes that triggers problems of soil erosion.

Farmers are not aware of the loss of soil from their farmland until it reaches the stage of gully formation (Gizaw & Hunri, 2011), it is imperative for researchers to quantify the soil loss and make recommend solution. In a watershed management program due to time and financial limitation, it is difficult to make rehabilitation, and soil and watershed conservation work at one time in all places. Thus, it is important to study the watersheds of the area and make ordering by their risk of erosion (Tripathi, et al, 2003). Normally, the amelioration processes are developed and applied following prioritization and landscape planning. Prioritization plays a key role in identifying areas that require attention (Kanth and Zahoor-ul, 2010). Estimation of soil loss and identification of critical erosion hotspots area for implementation of effective management practice in the watershed is core of a soil conservation and watershed conservation program. According to the report from Sasiga natural resource management and environmental protection office NGOs ,Sustainable land management (SLM) project program, One wash program and etc., foreign project supporting program on watershed management and land degradation in sasiga woreda, was failed in last five years since there was neither identified erosion risk area and nor prioritized erosion hotspots sub-watersheds was exist. None of the study was assessed along the Laga Haya watershed for soil and watershed conservation planning.

New technology of erosion assessment and recent developments of GIS techniques and RUSLE modeling integration offer considerable potential in estimating rates of soil erosion and mapping of soil erosion risk area and identification of erosion hotspots. Such approach provides relatively accurate information on amount of soil loss which is the basis for prioritizing severe erosion risk areas for the implementation of soil conservation and watershed management as well as monitoring land degradation. Generally, this study was focused to Compute average annual soil loss and identify high erosion risk areas (erosion hotspots) through prioritization of the Sub-watersheds for further soil conservation and watershed management planning by using of RUSLE model and GIS technique's in the Laga Haya Watershed.

1.3 Objectives

1.3.1 General Objective

To assess soil erosion risk using the RUSLE Model and GIS Techniques for soil conservation and watershed management planning activities in Laga Haya Watershed, eastern wollega, western Ethiopia.

1.3.2 Specific Objectives

- To estimate the average annual soil loss in Laga Haya Watershed.
- To produce soil erosion severity map of the study area
- To identify the erosion hotspots by prioritizing sub-watersheds in Laga Haya Watershed.

1.4 Research Questions

Based on the stated objectives, the following questions have been used to guide the research process and finally it must be answered from the finding of the research.

- What is the average annual soil loss in Laga Haya Watershed?
- How to produce soil erosion severity map of the study area?
- Where is the prioritized erosion hotspots sub-watershed in the study area ?

1.5 Significance of Study

The final output of this study will provide information for different stakeholders in study area either communities or management sectors as well as NGOs, who need to participate in environmental protection program, in the soil conservation and watershed management and for further researcher in will be used as input. The finding of this study also could be useful for projects related to the watershed management and soil conservation Strategy in the studied watershed for mitigating rate of soil erosion directly applying soil erosion conservation in the identified erosion hotspots and prioritized sub-watersheds in the study area. It will be used as an input data for further land use study to manage the Sub-watersheds. Generally, the primary beneficiaries from this findingbcould be local communities, experts, NGOs, decision-makers and other stakeholders who are working on soil and water conservation in Laga Haya watershed to make their projects cost effective and time-bound.

1.6 Scope of the Study

This study was actually Watershed level and thus focused mainly on the quantifying amount soil loss rate from the watershed and identification of soil erosion risk area (hotspot area) through prioritizing sub-watersheds depending on the rate soil eroded from the Laga Haya Watershed and finally soil losses in the study area was estimated and erosion hotspots was identified to overcome the identified soil erosion risk area in the watershed.

1.7 Organization of Thesis

The overall organization of thesis was divided into five chapters. The chapter one deals about introduction, problem statement, Objective of the study, which were general and specific, research questions, significance of the study, scope of the study and organization of the thesis. Chapter two was about review of related literatures and chapter three presented the description of study area and methodology of the study including RUSLE modeling parameters analysis (derivation). Results obtained from the analysis which can achieve the objectives the study and discussion of the study were presented in the chapter four and conclusion and recommendation were presented in the chapter five.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of Soil Erosion

Soil erosion is a complex and dynamic phenomenon affecting many areas, all over the world. The three main phases of soil erosion are detachment, transport and deposition. Detachment of soil particles is due to raindrop impact, caused by its kinetic energy. Soil erosion is the removal of soil from the earth's surface by erosive agents such as water and wind. Water erosion involves the detachment, transport and deposition of soil particles by the erosive forces (Renard *et al*., 1997). The potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape), soil characteristics, local climatic conditions, and land-use and management practices implemented on the watershed (Suresh, 2000; Arora, 2003). It is accounted that loss of topsoil and terrain deformation due to soil erosion are the consequences of deforestation, removal of natural vegetation and overgrazing in the mountainous regions (Shrestha, 1997).There are different forms of top soil removal or soil erosion, which are given to the following**.**

2.2 The extent of soil loss and itôs seve

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). 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). 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). As mentioned by Hawando (1995), the recorded annual soil erosion in Ethiopia ranges from 16- 300 tons/ha/yr depending mainly on the slope, land cover, and rainfall intensities. According to the Ethiopian highland reclamation study (FAO, 1984), in middle 1980's 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation.

2.4 Soil Erosion type

Soil erosion by water occurs in various forms (e.g., splash, sheet, rill, gullies) depending on the stage of progress in the erosion cycle and the position in the landscape. Some of the types of erosion are discussed below:

2.4.1 Raindrop (splash) Erosion

Rain splash erosion is the result of water falling directly on to the ground during rainstorms or when it is intercepted by the canopy and finds its way to the ground (Morgan, 1995). Some of the water infiltrates into the soil, while some water stays on the surface saturating it and weakening natural soil aggregates so that the impact of subsequent raindrops breaks them down. Splash erosion is caused by the bombardment of soil surface by impacting raindrops (TesfayeAbebe, 2015).

2.4.2 Sheet Erosion

Sheet erosion is movement of soil from raindrop splash resulting in the breakdown of soil surface structure and surface runoff. It occurs rather uniformly over the slope and may go unnoticed until most of the productive topsoil is lost. As a result of this detachment and transportation of the detached sediment by runoff take place. On slope areas, sheet wash can take place and remove shallow layer of soil. Raindrops detach the soil particles, and the detached sediment can reduce the infiltration rate by sealing the soil pores. The eroding and transporting ability of overland flow depends on the rainfall intensity, infiltration rate, slope steepness, soil properties, and vegetative cover (Fangmeier *et al*., 2006).

2.4.3 Rill Erosion

Rill erosion is the detachment and transport of soil by concentrated flow of water. Rills are eroded channels that are small enough to be removed by normal tillage operations. Rill erosion is the predominant form of surface erosion. Rill initiated at a critical distance down slope where surface runoff concentrates and becomes channeled. Rill erosion can be reduced by reducing the volume and speed of surface water with grassed waterways and filter strips, ripped mulch lines, and contour drains. Rill erosion is often described as the intermediate stage between sheet erosion and gully erosion (Jenkins, 2002).

2.4.4 Gully Erosion

Gully erosion is defined as the erosion process whereby runoff water accumulates and often recurs in narrow channels, and over short periods, removes the soil from this narrow area to considerable depths (Poesen *et al.,* 2003).

2.5 Factors affecting Soil Erosion

Soil erosion is a complex phenomenon influenced by many natural and socioeconomic factors (Alemu *et al*., 2005). The major factors that influence the extent and rate of soil erosion from any area are: climate, soil properties, topography of the area, vegetation cover and land use and Human disturbances, such as tillage and construction, and natural disturbances, such as severe weather or fire, dramatically increase erosion levels. Of these, the vegetation and some disturbances, and, to a lesser extent, the soil and topography can be managed to reduce erosion (Fang Meier *et al.,* 2006).

2.5.1 Climatic Factor

Climatic attributes affecting soil erosion are precipitation, temperature, wind, humidity, and solar radiation. Among these, erosion by water is the most predominant in terms of its contribution to soil degradation. The basic energy input required to drive erosion processes is provided by rainfall and runoff. Soil erosion by water occurs when raindrops act upon the soil particles. Soil loss is closely related to rainfall partly through the detaching power of raindrops due to striking the soil surface and partly through runoff. Potential ability of rain to cause erosion is known as erosivity (R) factor (Renard *et al.*, 1991).

2.5.2 Soil Factors

The susceptibility of soil is dependent on the soil's texture, content of organic matter, surface roughness, moisture and depth to be eroded by erosion agents (Mitiku, *et al.*, 2006).Soil texture refers to the relative proportion of clay, silt and sand. Fine particles have cohesive property, as a result, they can resist detachment but easy to be transported, whereas, large particles are resistant to transport because they need greater energy to be transported (Morgan, 2005). Silts and sands are the least detachment resistant particles. Organic materials stabilize soil structure and coagulate soil colloids so; it is possible to decrease soil erosion (Blanco & Lal, 2008). Roughness of the soil surface provides storage of rainwater, that helps the water to soaks into the soil slowly and if the depth and porosity of the soil is high, runoff will decrease through the increment of infiltration volume.

2.5.3 Topographic Factors

Topography is features of the earth. The slope steepness and slope length of an area has greater impact on soil erosion rate; as slope steepness and length increases, the velocity and volume of surface runoff increases (Morgan, 2005). Soil erosion by water is a function of steepness (gradient), slope length, and shape, which modify the energy of the hydrologic inputs. Erosion is directly proportional to the steepness and length (Doere, 2005). Naturally, the steeper the slope of a field, the greater the amount of soil erosion by water. Soil erosion by water also increases as the slope length increases due to greater accumulation of runoff. Topographic features that influence erosion are slope length, steepness and shape (including concave, uniform or convex) and size and shape of the watershed. The slope factors (LS) refer to topographic and/or relief factor. According to Stern (1990), put when the slope gradient increases, the ability of overland flow alone to erode and transport sediments rapidly until the erosion by the surface flow becomes the dominant mechanism contributing to the sediment transport. Erosion would normally be expected to increase with increase in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff (Doere, 2005).

2.5.4 Cover management Factors (C factor)

Cover management (Vegetation) determines the soil erosion in so many different ways; leaves and stems which are called the above ground components, absorb some of the energy of falling raindrops, running water and wind, so there would be less contact with the soil, while the below-ground components which contain the root system help the soil to get mechanical strength (Morgan, 2005). Cover management includes plant canopy, mulches, plant residues, or densely growing plants in direct contact with the soil surface. It has a greater impact on erosion than any other single factor. Vegetation cover is one of the most crucial factors in reducing soil erosion. Vegetation reduces soil erosion by protecting the soil against the action of falling raindrops, increasing the degree of infiltration of water into the soil, reducing the speed of the surface runoff, binding the soil mechanically, maintaining the roughness of the soil surface, and improving the physical; chemical and biological properties of the soil (De Asis and Omasa, 2007). Differences in erosion rates are commonly related to land-use in areas where soil, climate and topography are similar. T o account for the effect of vegetation in erosion assessments, a cover and management factor (C-factor) has often been used. The C- factor is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding clean-tilled continuous fallow (Wischmeier and Smith, 1978). The C- factor is used within the RUSLE to reflect the effect of cropping and management practices on erosion rates, and is the factor used most often to compare the relative impacts of management options on conservation plans (USDA-ARS, 2001). Assessment of the type of land use/land cover was made separately for each land unit and the corresponding value for land use/land cover was obtained from Hurni (1985) which was adapted to Ethiopian condition.

2.3.5 Support Practice Factor (P factor)

Land conservation practices like contouring, strip-cropping, terraces, crop rotations, reduced tillage and leaving crop residue on the land helps to reduce soil erosion directly or indirectly. Crop residues, like straw, stubble and maize stalks can reduce soil losses by one halve or more depending on other factors (FAO, 1965). Terraces reduce slope length and velocity of running water. Specific cultivation practices affect erosion by modifying the flow pattern and the direction of runoff and by reducing the amount of runoff (Renard *et al*., 1994). Especially in agricultural areas, conservation practices as contouring, strip cropping, or terracing, reduce soil losses**.** The effectiveness of such practices is often analyzed with a support practice factor (P-factor), which is defined as the ratio of soil loss with the practice applied to that of up-and down slope cultivation (Wischmeier and Smith, 1978; Renard *et al.*, 1991). P-values have been assigned to land-use classes using ranges from 0 to 1 (Kaltenrieder, 2007).

2.6 Watershed

A watershed is a surface area from which runoff which is resulting from rainfall is collected and drained through a common outlet. Most of the time the term is similar with a drainage basin or catchment area. Hydrologically, it is an area from which the runoff drains through a particular point in the drainage system. It is made up of the natural resources in a basin, especially water, soil, and vegetative factors. Socioeconomically a watershed includes people, their farming system and interactions with land resources, cropping strategies, social and economic activities and cultural aspects (MoARD, 2005). Those it is very important to identify the most erosion vulnerable micro-watershed and give priority for soil and water conservation activities. Based on that it is possible to implement effective and efficient of watershed management programs. It is important to consider various factors to identify the most erosion vulnerable area because in the watershed there is an integration of different variables such as precipitation, runoff, erosion and sediment discharge as they relate to input and output in an open hydrological system (Deore, 2005).

2.6.1 Concept of sustainable watershed management

Watershed management is the process of guiding and organizing land-use and use of other in the watershed to provide desired goods and services without adversely affecting soil and water resources. Watersheds have been identified as fundamental planning units for the management of land and water resources, particularly in the fragile and heterogeneous erosion susceptible hilly ecosystems (Doere, 2005). Watershed management implies the wise use of natural resources like land, water and biomass in a watershed to obtain optimum production with minimum disturbances to the environment. At present, the overall objectives of watershed development and management programs take the watershed as the hydrological unit and aim to adopt suitable measures for soil and water conservation, provide adequate water for agriculture and domestic use, and improve the livelihoods of the inhabitants. Watershed management is practiced as a means to increase rain fed agricultural production, conserve natural resources and reduce poverty in the semi-arid tropical regions of South Asia and Sub–Saharan Africa, which are characterized by low agricultural productivity, severe natural resource degradation, and high level of poverty (Kerr, 2002).

2.7 Soil Erosion modeling

Modeling in soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces. to predict and evaluate soil erosion problem models which are the simplification of reality have effectively been developed and employed. Field studies for prediction and assessment of soil erosion are expensive, time-consuming and need to be collected over many years. Besides providing detailed understanding of the erosion processes, field studies have limitations because of complexity of interactions and the difficulty of generalizing from the results. Soil erosion models can simulate erosion processes in the watershed and may be able to take into account many of the complex interactions that affect rates of erosion. The reasons for soil erosion modeling are used because they are used as a tool: to predict and assess soil loss for conservation planning, project planning, soil erosion inventories, and for regulation, To predict where and when erosion is occurring and hence helping the conservation planner target efforts to reduce erosion and For understanding erosion processes and their interaction and for setting research priorities (Lal 1994). According to Petter in 1992the objective of soil erosion models is either predictability or explanatory. Several models were developed for the assessment of soil loss and numerous are in the process of development. In general, the models are categorized into three: namely conceptual, empirical and physically based models (Saavedra, 2005).

2. 7. 1 Conceptual Model

The Conceptual model method is based on the representation of physical erosion processes with empirical equations; SWAT, MMMF (Modified Morgan- Morgan- Finney) and CREAMS (Chemical, Runoff and Erosion from Agricultural Management System) are some of such models (Rapidel et al., 2011). Model includes only general description of catchment processes, without including the details occurring in the complex process of interactions (Renschler 1996).

2.7.2 Empirical model

Empirical model refers to a simplified representation of a system or phenomenon which is based on experience or experimentation. Examples of these models are SLEMSA, MUSLE, USLE, RUSLE etc. The computational and data requirements for such models are usually less than for conceptual and physically based models (Li et al., 1996). RUSLE is the empirical model that has been most widely used and generally accepted by the natural resources community because it is relatively easy to use (Saavedra,2005). By considering its ease of implementation, reliance on easily accessible data and its relatively accurate results in this study RUSLE was chosen and used from the other methods.

2.7.3 Physical based model

Physical based model represent a synthesis of the individual components which affect erosion, including the complex interactions between various factors and their spatial and temporal variability (Lal, 1994). Such a model helps to identify which part of the system are the most important to the overall soil erosion process; WEPP is one of these models. Include the laws of conservation of mass and energy, where energy can change form but total energy remains the same (Petter, 1992). they are based on the understanding of the physics of erosion processes. these models are based on an understanding of the physics of the erosion and sediment transport processes (Deore, 2005).

2.8 Revised Universal Soil Loss Equation (RUSLE) Model

The Revised Universal Soil Loss Equation (RUSLE) is an empirical based model which has the ability to predict the long term average annual rate of soil erosion on a field slope caused by rainfall pattern, soil type, topography, crop system and management practices (Renard et al., 1997). The RUSLE model in GIS environment can predict erosion potential on a cell-by-cell basis, which is effective when attempting to identify the spatial pattern of soil loss present within a large watershed area (Shi *et al.*, 2003).From this GIS can be used to isolate and query these locations to identify the role of individual variables in contributing to the observed erosion potential value (Saavedra, 2005). The RUSLE model in GIS environment can predict erosion potential on a cell-by- cell basis, which is effective when attempting to identify the spatial pattern of soil loss present within a large watershed area. RUSLE computes average annual erosion as a function of six factors (Renard *et al.*, 1997) as follows:

$A = R \times K \times LS \times C \times P$ ……………………………………………………………….Equation **2.7**

Where, A is the computed spatial annual soil loss (ton/ha/year); R is the rainfall erosivity factor (MJ mm/h*ha*year); K is the soil erodibility factor (ton/ha*MJ*MM); LS is the slope length and steepness factor (dimensionless); C is the land surface cover management factor (dimensionless); and P is the erosion control or conservation practice factor (dimensionless).

2.9 Application of GIS and Remote Sensing in mapping soil erosion modeling

A Geographic Information System (GIS) is an arrangement of computer hardware, software, and geographic data that people interact with to integrate, analyze, and visualize data; identify relationships, patterns, and trends; and find solutions to problems. The system is designed to capture, store, update, manipulate, analyze, and display studied data and used to perform analyses (ESRI, 2005). GIS have been used in various environmental applications since the 1970s; however, extensive application of GIS to hydrologic and hydraulic modeling and flood mapping and management did not begin until the early 1990s (Moore et al., 1991; Vieux and Gauer, 1994; Maidment and Djokic, 2000). The ability to represent elevation in terms of topographic surfaces is 18 central to geomorphological analyses and thus to the importance of representing topography using DEM.

Several studies showed the potential utility of Remote Sensing (RS) and Geographic Information System (GIS) techniques for quantitatively assessing erosional soil loss (Saha *et al.*, 1991; Mongkolsawat *et al.*, 1994).the advancements in Remote Sensing and GIS technologies provide effective means in the modeling of soil erosion. Soil erosion is spatial phenomena, thus geo-information techniques play an important role in erosion modeling (Yazidhi, 2003). The potential utility of remotely sensed data in the form of aerial photographs and satellite sensors data has been well recognized in mapping and assessing landscape attributes controlling soil erosion, such as physiography, soils, land use/land cover, relief, soil erosion pattern (Pande *et al.*, 1992).According to Yazidhi (2003), the use of digital elevation models and GIS offers possibilities to estimate topographical parameters that are useful in soil erosion modeling.

2.9.1 Remote Sensing Technology in modeling Soil Erosion

Remote sensing becomes valuable in planning and development of watershed management, because satellites imagery provides a fast and economic way to analyze large watersheds by their advantage in synoptic and repetitive coverage (Jain and Goel, 2002). It is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. Satellite imagery has been well utilized in different studies for watershed characterization and management aim (Saxena *et al.,* 2000) and to measure qualitative and quantitative terrestrial land-cover changes in a watershed (Lu *et al.,* 2004). For soil erosion assessments in a watershed, RS has been used for both detecting erosion features and obtaining erosion model input data (Petter, 1992).Remote Sensing can facilitate studying factors enhancing

The processes, such as soil type, slope gradient, drainage, geology and land cover. Multi-temporal satellite images provide valuable information related to seasonal land use dynamics. Digital Elevation Model (DEM) is one of the vital inputs required for soil erosion modeling that can be created by analysis of stereoscopic optical and microwave remote sensing data (Pande *et al.*, 1992).

2.9.2 Use of Geographic Information System (GIS) in Erosion Risk assessment

Geographic information system software capabilities become important when they are combined into various kinds of other analytical models. These include resource allocation, population forecasting and spatial distribution, land-use forecasting, transportation, and site selection models (Dangermond, 1992). A GIS based approach was used in order to take into account the spatial distribution of the model's individual factors. Each factor was described by a digital map, with the layers being overlaid in order to calculate soil loss. Such delineation provided a more accurate simulation of soil erosion, considering the climatic, geological, topographic and land cover variations occurring throughout the catchment. Moreover, the data processing was easier, faster and more cost-effective. The LS factor was calculated using the SEAGIS 1.0 graphical interface (abbreviation for "Soil Erosion Assessment using GIS") developed by the Danish Hydraulic Institute (DHI, 1999) as an ArcView extension, while all other factors by the Arc Map 10 platform. Mapping soil erosion using GIS can easily identify areas that are at potential risk of extensive soil erosion and provide information on the estimated value of soil loss at various locations in the watershed (Shi *et al.*, 2003).Remote sensing and GIS techniques were utilized in the present study to identity priority areas for conservation measures on the basis of erosion risk map.

CHAPTER THREE: MATERIALS AND METHODS

This section describes the Laga Haya watershed site along with the various data needed to analyze soil erosion assessment in the Laga Haya watershed. The Laga Haya watershed, topography, soil types, land use land cover types and precipitation data were illustrated for the application of soil erosion modeling. Precipitation data was used to used to estimate the rainfall erosivity factor (R factor) and Soil and land use type data was used to predict the soil erodibility factor and cover management factor respectively. Finally, DEM was used to calculate slope length and slope steepness and support practice factors in the Laga Haya watershed.

3.1 Description of Study Area

3.1.1 Geographical location of Laga Haya watershed

The study was conducted in the upper part of Abay (Nile) river basin at Laga Haya Watershed in Sasiga Woreda, Eastern Wollega zone of Oromia regional state, Western Ethiopia. It is located about 350 kilometers to the West of Addis Ababa, Capital City of the country and its geographical location was between 9˚07’09’’ to 9˚32’33” North latitude and 36˚12’25’’ to “36˚30’55’’ East longitude and Laga Haya watershed was covered total area of 16,334.882 ha. Location of Laga Haya watershed study map is as follows.

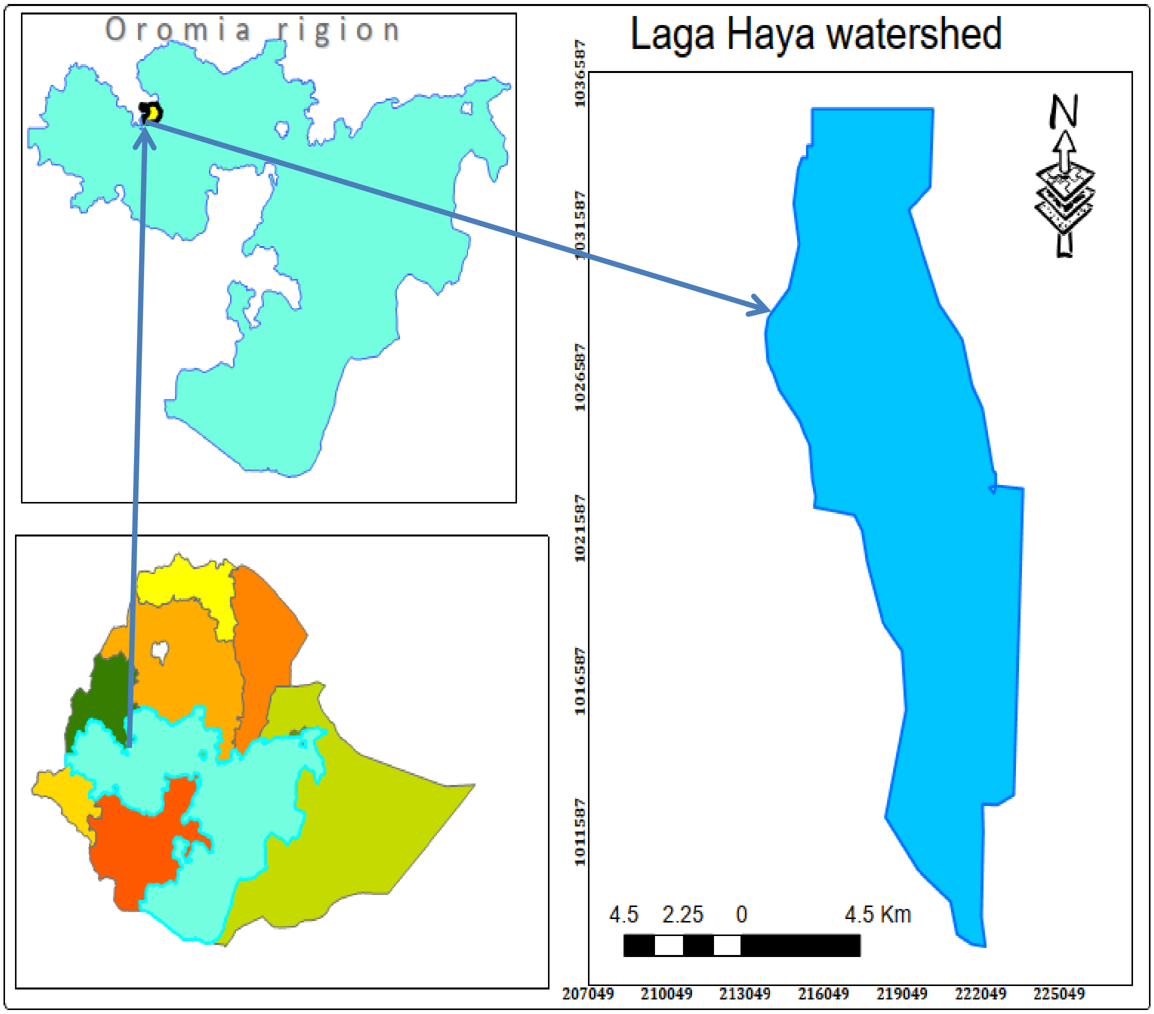

Figure 3. 1.0 Study area map Laga Haya watershed

3.1.2 Climate property of study area

Over 30 years recorded data of rainfall was collected from three metrological stations found around the watershed. According to these data the area receives annual rainfall varies from 623.83mm-1190.52mm which is nekemte and sasiga station respectively. The monthly precipitation data of study area was presented in the following figure 3.2

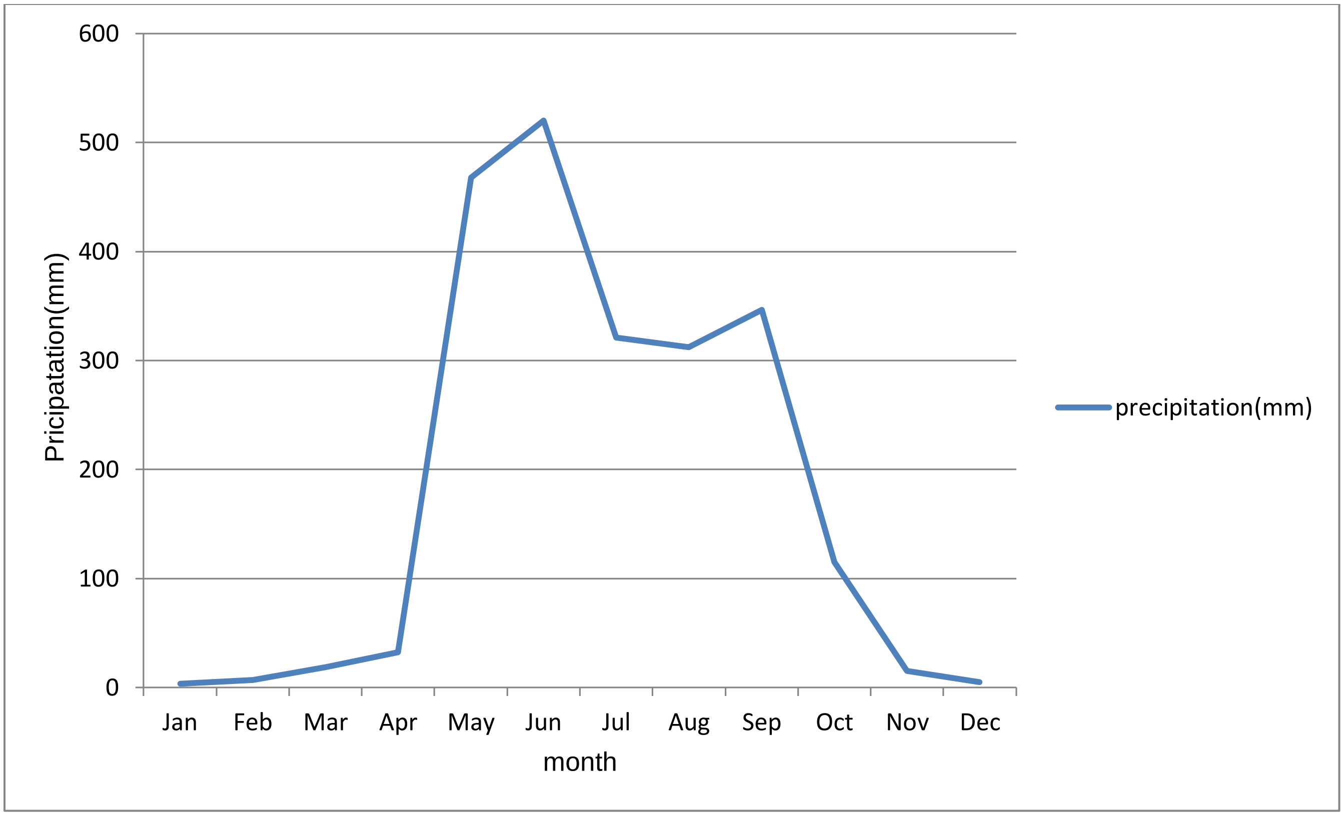

Figure 3. 1: Annual rainfall of study area

3.1.3 Soil type property of Study area

According to the data obtained from MoA there are three types of soil in the study area: namely dystric nitosols, orthic acrisols and dystric glyesols, an which have area coverage of 93.77%, 3.13 %and 3.1% respectively. dystric nitosols was the most abundant in the whole soin content in the Laga Haya watershed.

Table 3. 1: Soil type Laga Haya watershed and its area coverage

Soil type	Area(ha)	Content in percent (%)
dystric nitosols	13042.18	93.77%
orthic acrisols	435.2842	3.13%
dystric glyesols	431.5587	3.1%

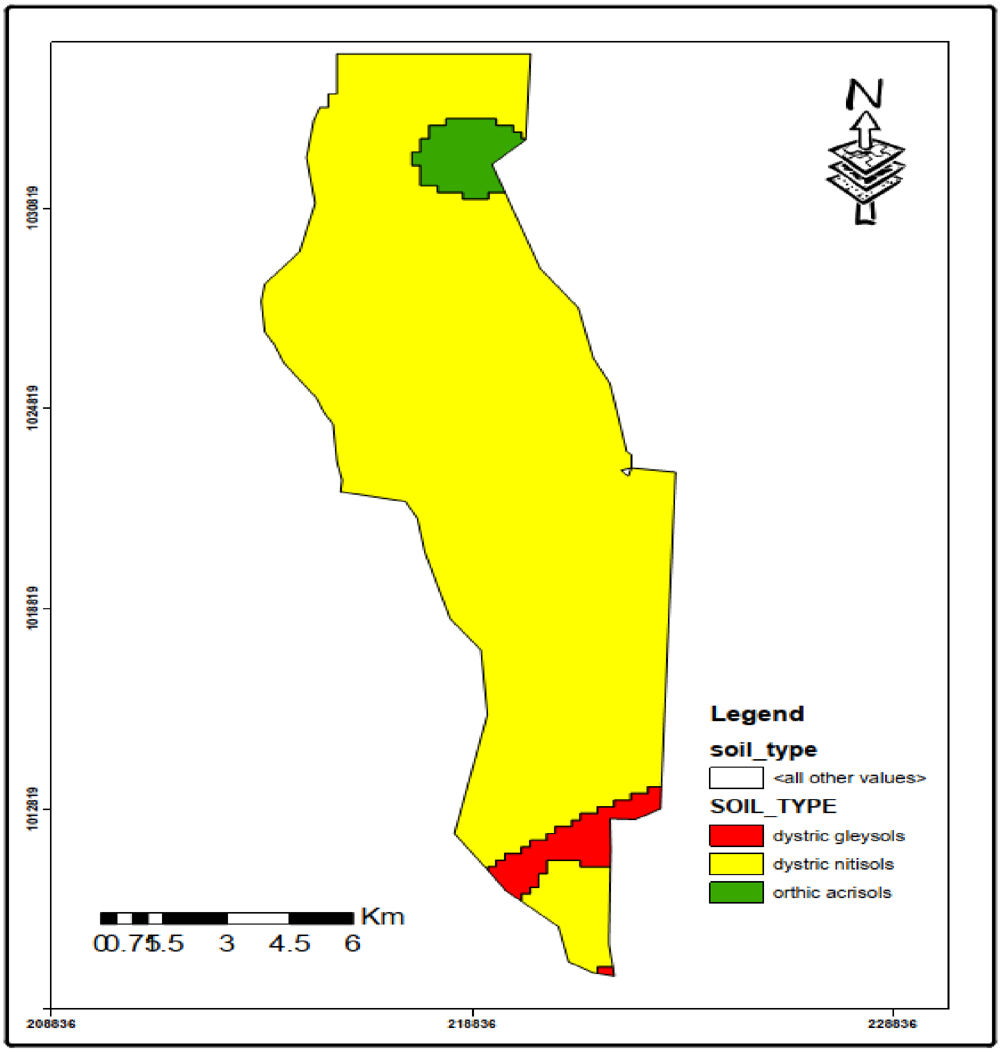

Figure 3. 2: Soil map of the Laga Haya watershed

3.1.4 Land use land cover of study area

The main land use unit of the Laga Haya watershed are Cultivated land, Settlements, Bare land, grazing land and forest land. Major crops grown in the study area Maize, Teff, Coffee and some barley. To increase the productivity; the farmers who lives in the study area were using inorganic fertilizer. In addition, animals are allowed to graze on the cultivated land after harvest.

3.1.5 Socio economic activity

The most of society (community) around the Laga Haya watershed(study area) based on the subsistent agricultural farming system mostly producing Teff, maize, enset, coffee and different vegetables. The farming community is totally seasonal rainfall dependent. Therefore, we can say, the majority of the societies in the watershed area rely on agriculture for their livelihood.

3.2 Data Sources

Primary data were generated from satellite image, and ground truth data were collected from the field. Besides, secondary data such as, Digital elevation mode (DEM), Digital soil map and rainfall data. The general data source of the study was listed table 3.2 below:-

Table 3. 2: Data source of study area

	No.	Data type	Specific Year	source	Use
Data	1	Landsat 8 image	June 2019	USGS Landsat 8 OLI/TIRS	Land use land cover classification and C-calculation
	2	Rainfall	30 years RF data from 4 stations near to Laga Haya watershed	ENMA	R factor generation
	2	DEM	ASTER DEM with 30m resolution	MoA	Slope and LS generation and P calculation
	4	Digital soil map	FAO (2012)	MoA	Soil erodibility factor (K-factor) computation
	5	Ground control point (GCP)	Random coordinates from each land use using handheld GPS	From the field	Accuracy assessment for C factor calculation

3.2.1 Precipitation (Rainfall) data

There is one metrological station within watershed and other two metrological station were located around the watershed were used in this study. The monthly amounts of precipitation for these stations were collected over years by the National Metrological Agency. The majority of these monthly precipitations were derived from more than 30 years of precipitation data. According to the number of years, average monthly rainfall data was prepared for each stations and then for the study area. This data was used to calculate and analyze the soil erosivity factor (R-value). The annual rainfall surface was interpolated from these three points observations in ArcGIS by the spatial analyst tool. The analysis was done using the raster data model.

3.2.2 Soil Data

The soil data for this study was obtained from digital soil map of FAO (1986)and used to develop the soil map of for soil erosion risk analysis. The soil feature map of the study area was obtained by Clipping the FAO soil map of Ethiopia within the watershed in the GIS environment. Soil type of the study is used to generate erodibility factor (k factor) and classify dominated soil type of the study area.

3.2.3 The digital elevation model (DEM)

The Digital Elevation Model (DEM) of Ethiopia, having 30 meter spatial resolution was collected from Ministry of Water, Irrigation and Energy. This data had multipurpose in this thesis; it has been used to delineate watershed, calculate fill, watershed flow direction, watershed flow accumulation and map the watershed and also to generate slope length and slope steepness (LS) or topographic factors of soil erosion in the study area.

3.2.4 Land Use Land Cover

The current land use land cover map of the area was classified based on the Landsat 8 satellite image with 30m resolution. Ground control points collected from the field by using handheld GPS and Google earth also used for the purpose of the verification. Supervised clarification techniques were applied using ARCGIS 10.5 and maximum likelihood was undertaken. The satellite images having 168/054 path/row was downloaded from USGS archive. The data were used to classify and map the land use/ land cover of the study area.

3.3 Post-processing data analysis

3.3.1 Image classification

Image classification of remotely sensed data is post processing and 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 the image classification is to automatically categorize all pixels in an image in to land use /land cover classes. The main procedures followed by the researcher to identify the major land use land cover of the area were visual image interpretation, field visit and supervised 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 land use land cover which were clearly identified from a high spatial resolution OLI/TIRS USGS Landsat 8 in the Laga Haya watershed were classified as bare land, forest, settlement, cultivation land and grass land LULC classes. A number of representative training samples points (area of interest) have been taken to classify images in to different land use classes depends on the spectral response of each land cover eachtype. The objective of 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 needed for features that have homogenous spectral response and maximum points should be required features that have heterogeneous response. Therefore, a total 172 points was taken in the study area that used to classify in image. For bare land 39 points, 37 points for forest, 22 for settlement, 43 for cultivated lands and 31 points were taken for grass land land use/land cover classes. The classified LULCs. The classified map was used to generate the cover management (C factor) which was used one of RUSLE modeling parameters. The description of land cover classes was shown as table bellows.

Table 3. 3: Land use land cover and its description

No	Land cover classes	Description
1	Bare land	Areas of open/do not have vegetation coverage
2	Forest	Area of land covered by forest
3	Settlement	Built up areas which used for residential purpose
4	Cultivation land	Cultivated by humans such as coffee, Agricultural crop ,vegetation, etc
5	Grass land	Areas of land used for grazing very short nearly bare land.

3.3.2 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. One of the most important final step at classification process is accuracy assessment. The aim of accuracy assessment is to quantitatively assess how effectively the pixels were sampled into the correct land cover classes. Moreover the key emphasis for accuracy assessment pixel selection was on areas that could be clearly identified on both Landsat high resolution image and Google earth 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 Google earth to cross check the existing feature and calculated using a set of reference data. Reference data are points on classified image for which actual data are represented and it had been imported using user defined points from the accuracy assessment dialog box to the classified images.

The overall accuracy of land cover classes were verified by kappa error matrix (confusion matrix).This matrix computed a confusion matrix with error of omission and error of commission and derived kappa index of agreement and overall accuracy between the classified map and reference data in ARCGIS 105 software. This tool computes a confusion matrix using the random accuracy assessment points. The accuracy assessment points were generated by the create accuracy random points tool in ARCGIS spatial analysis tool. Those two tools ensure that each point with have valid class values for the classified and ground truth fields. The tool calculates the user's accuracy and producer's accuracy for each class as well as an overall kappa index of agreement. These accuracy rates range from 0 to 1, where 1 represents 100 percent accuracy.The following is the overall accuracy assessment of a confusion matrix in study area land cover classes.

Table 3. 4: The overall accuracy assessment of a confusion matrix in the study area land caver classes

		Bare land	Forest	settlement	Cultivation land	Grass land			
Classification	bare land	**35**	**0**	**2**	**0**	**2**	**39**	11.43%	*89.74%*
	forest	**0**	**32**	**2**	**3**	**0**	**37**		
	settlement	**0**	**0**	**17**	**4**	**1**	**22**	15.63%	*86.49%*
	cultivation land	**0**	**3**	**40**	**40**	0	**43**	9.41%	*77.27%*
	grass land	**3**	**0**	**1**	**0**	**27**	**31**	50%	*93.02%*
	total	**38**	**35**	**22**	**47**	**30**	**172**	4.81%	*87.10%*
omission error %		**7.89%**	**8.57%**	**22.73%**	**14.89%**	**10.00%**			

producer's accuracy %	**92.11%**	**91.43%**	**77.27%**	**85.11%**	**90.00%**			
overall accuracy %	**87.79%**							
Kappa coefficient =(P(a) – P(r)) – (1-P(r))								
P(a) =0.878								
p(r)=((38/172)*(39/172))+((35/172)*(37/172))+((22/172)*(22/172))+((47/172)*(43/172))+((30/172)*(31/172))=0.21								
Kappa coefficient or error matrix =(P(a) – P(r)) – (1-P(r))= 0.878-0.21= 0.845								
Kappa coefficient or Error matrix of LULC class = 0.845 OR 84.5%								

3.4 Data analysis

3.4. 1 Derivation of RUSLE model Parameters

Since the erosion process is gradual, there are difficulties in differentiating between the natural and accelerated rate of erosion. The physical measurement of soil erosion is made worse by the complexities of temporal and spatial variations (Eaton, 1996). To overcome these problems, statistical modeling of the process of erosion was developed. This can be used to estimate soil loss based on the climate, topography, soil properties and land-use conditions of an area. Revised Universal Soil Loss Equation is considered the alternative improved version of the proto USLE model (Renard *et al.*, 1991). Revised Universal Soil Loss Equation is an empirically based model that has the ability to predict the long-term average annual rate of soil erosion in a field slope as a result of rainfall pattern, soil type, topography, crop coverage and management practices (Renard *et al.*, 1997). The RUSLE model in GIS environment can predict erosion potential on a cell-by- cell basis, which is effective when attempting to identify the spatial pattern of soil loss present within a watershed area. Geographic information system can then be used to isolate and query these locations to identify the role of individual variables in contributing to the observed erosion potential value. In spite of this advantage, RUSLE does not estimate sediment deposition and gully erosion.

The overall methodology involved the use of the RUSLE in a GIS environment, with factors obtained from meteorological stations, Digital soil map, Satellite Images, Digital Elevation Model and results of other relevant studies. More recently, Renard et al. (1997 modified the USLE into a Revised Universal Soil Loss Equation (RUSLE) by introducing improved means of computing the soil erosion factors. The advent of GIS technology has allowed the equation to be used in a spatially distributed manner because each cell in a raster image comes to represent a field-level unit. The following five parameters were used in the RUSLE model to estimate soil loss. Rainfall erosivity (R), soil erodibility (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice factor (P). The application of this Model was calculated by using raster calculator method in ArcGIS spatial analysis tool function, which enables the multiplication of the parameters cell by cell. The syntax is given as follow:

Annual soil loss, $A = R \times L \times S \times C \times P$……………………………………………Equation 3.1

Where, A is the computed spatial annual soil loss (ton/ha/year); R is the rainfall erosivity factor (MJ mm $ha^{-1}y^{-}$); K is the soil erodibility factor (t /ha/MJ/mm); LS is the slope length and steepness factor (dimensionless); C is the land surface cover management factor (dimensionless); and P is the erosion control or conservation practice factor (dimensionless). To identify the spatial pattern of potential soil erosion in the study area, all the considered erosion factors (R, K, LS, C and P) had been surveyed from different data source and calculated differently. RUSLE doesn't estimate deposition, sediment yield at a downstream location and ephemeral gully erosion and doesn't represent fundamental erosion processes and interactions (Kenneth *et al*., 1991). It is however, found to adequately represent the first order effect of the factors that affect sheet and rill erosion. Individual GIS files were built for each factor in the RUSLE and combined by cell grid modeling procedures in GIS software to predict soil loss in a spatial domain. The flow chart of erosion risk mapping is presented in Figure 3.4 below.

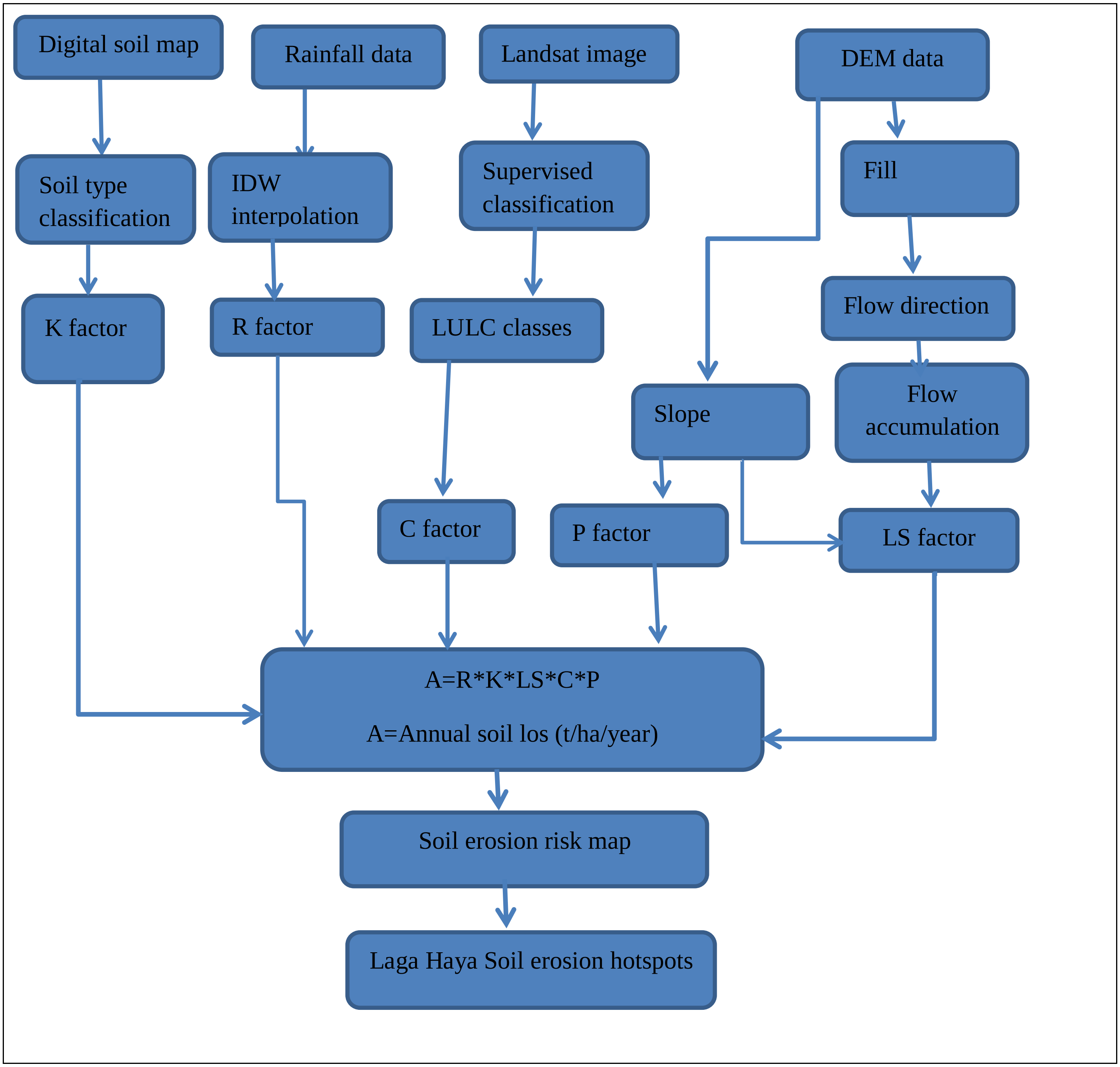

Figure 3. 3 :The overall analysis flow chart of study area

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Results

The results of different RUSLE model layers parameter and final average annual soil loss of Laga Haya watershed were generated by integrating multiple RUSLE modeling factors layers in in this section. As described in earlier data analysis was carried out in ARCGIS 10.5 software and the input factors of RUSLE model were generated from the different source and the study identify soil erosion hotspots areas and prioritize erosion risk conservation in the study area.

4.1.1 Determination of RUSLE factors

The Revised Universal Soil Loss Equation (RUSLE) is an empirical soil loss model designed to estimate the long term annual average soil loss carried by runoff from specified cropping and management systems (Renard et al 1996, Renard 1997). The RUSLE modeling factors was calculated as the following procedures

4.1.1.1 Rainfall erosivity factor

The rainfall factor ,an index unit, is the measure of the erosive force of a specific rainfall.in this particular study the R factor was estimated by taking average of historic rainfall event(30 years) .R value was calculated based on the equation given by Hurn (1985) which is derived from a spatial regression analysis (Hellden, 1987 for Ethiopian conditions. The equation is highly preferred for Ethiopian case since rainfall intensity data which is used to derive rainfall kinetin energy is not available for Ethiopian conditions and the equation is based on the easily mean annual rainfall (P).

$$R = 0.562 * P - 8.12 \text{..............................equation 4.1}$$

Where:-

R is the erosivity factor (MJ mm $ha^{-1}y^{-1}$), P is the mean annual rainfall in mm. The average annual rainfall of three meteorological stations was calculated based on 30 years (1981-2011) recorded data. The annual average rainfall of each station was Nekemte ((623.8307 mm/year),Anger Guute (709.8237 mm/year) and Sasiga (1133.233mm/year). The highest mean monthly rainfall was recorded from June to September. Wischmeier and Smith (1978) recommended that at least 20 years of rainfall data should be used to accommodate natural climatic variation. the following Rainfall gauge station was used for the erosivity factor calculation.

Lastly, the inverse distance weight of spatial interpolation methods in ARCGIS software under spatial analysis tool was used for assessing spatial variability of rainfall in the study area. Then R factor was calculated from the generated inverse distance weight interpolation from the annual rainfall by using regression equation. The rainfall data of the study area was then converted to erosivity map of the study area

Table 4. 1: The average annual precipitation the around the study area

No	Station	Longitude	Latitude	mean Annual rainfall(mm)
1	Nekemte	36.463333	9.0833333	623.8307
2	Anger Gute	36.333333	9.2666667	709.8237
3	Sasiga	36.811972	9.13333	1190.52

Based on the generated R-factor ,there is spatial variability in the Laga watershed. the minimum and maximum r-factor values of the study area were Based on the generated R-factor map, there is 343.25 and 390.67 respectively. The mean annual rainfall value of Laga Haya watershed was shown as figure 4.1 below.

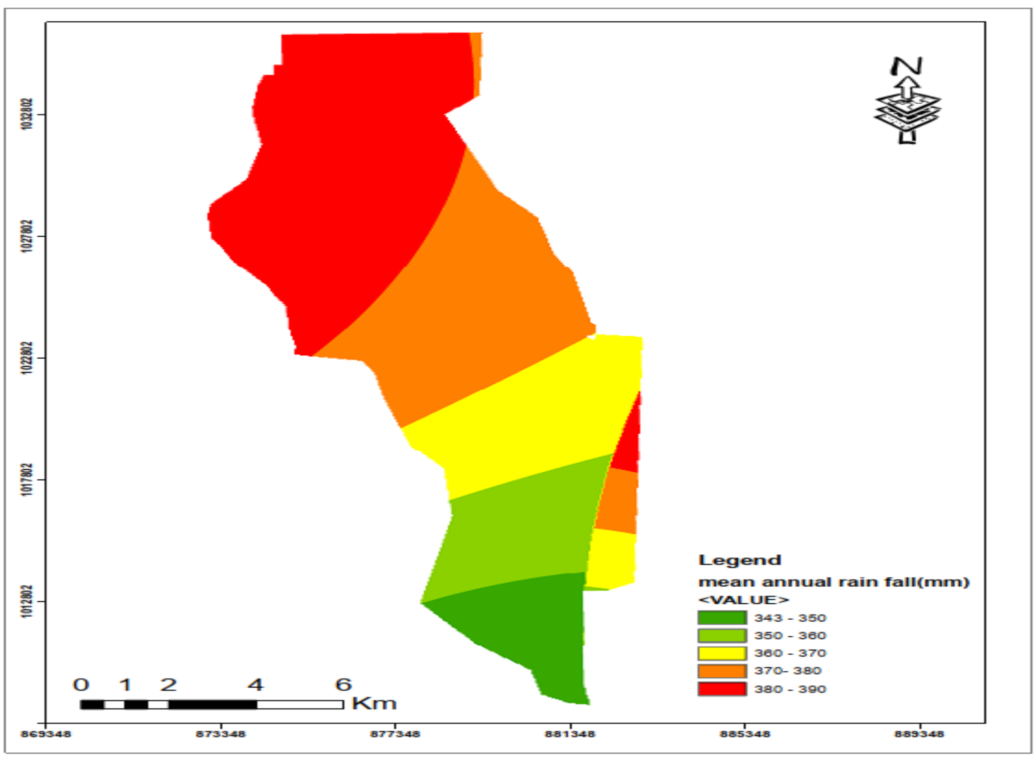

Figure 4. 1: Annual rainfall map of Laga Haya watershed

4.1.1.2 Soil erodibility factor

Soil erodibility factor (k factor)is the suspectiviblity of soil to erosion (detachment or transport) and the rate of runnof.it is more sensitive for soil texture type and organic matter content because of their ability to govern the permeability of ,infiltration rate and structural stability of soil(suresh,R,2012.). Depending on the soil texture and organic carbon content of the soil K factor will be estimated using the equation(Wiliam,1995).

K_{RUSLE}= fcsand * fcl-si * forgC * fhisand……………………………….Equation 4.2

Where:,

F_{csand} is the factor that lower the K indicator in soils with high coarse sand content and higher for soils with little sand.

F_{cl_si} gives low erodibility factors for soils with high clay to silt ratios

F_{orgc} reduces k values in soils with high organic carbon content while

F_{hisand}lowers k values for soils with extremely high sand content

$$Fcsand = (0.2 + +0.3 * \exp[-0.256 + ms *(1-msilt/100)$$

$$Fcl\_si = (msilt/(mc +msilt))$$

$$ForgC = (1-(0.2\ 5 * orgC) / (orgC + \exp(3.27 – 2.95 * orgC)))$$

$$Fhisand = (1 –(0.7 *(1-ms/100))/((1-ms/100) + \exp(-5.51 +22.9 * (1-ms/100))))$$

Where top soil properties:

m_s = sand fraction content (0.05-2.00mm diameter in %)

M_{silt} = the silt fraction contentment (0.002-0.005mm diameter in %)

m_c = the clay fraction content (< 0.002mm in diameter in %)

m_{OrgC} = organic carbon content in %

Based on the data from ministry of water resource soil mapping units, three major types soil unit were identified in the study area shape file. The most abundant soil type was dystric nitosols with 13042.18 ha of area coverage followed by orthic acrisols with 422.941 ha of area coverage. The least soil type area coverage was dystric gleysols with 422.94 ha. When expressed in percent it can be showed as table 4.2 below.

Table 4. 2: Soil type and erodiblity factor of the Laga Haya watershed

Soil unit	K_values	Area (ha)	Percent
dystric nitisols	0.135	13042.1816	93.83%
orthic acrisols	0.141	435.28418	3.13%
dystric gleysols	0.136	422.944061	3.04%

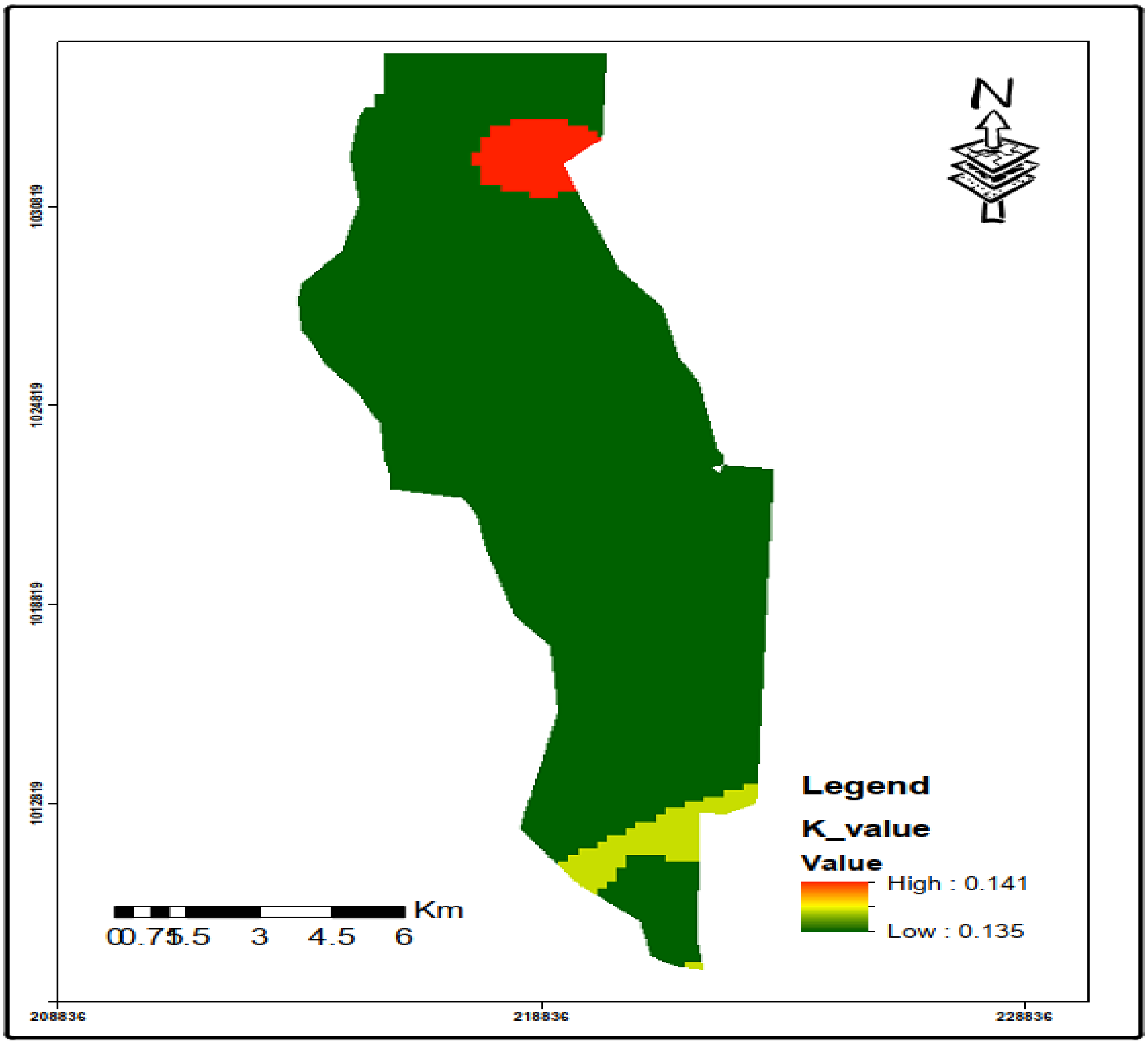

Figure 4. 2: The erodiblity (k factor) value of the study area

4.1.1.3 Topographic factor (LS factor)

The LS factor illustrates the effect of topography on erosion in RUSLE model. Topography (LS) factor is comprised of the individual slope length (L) and slope steepness(S) factors, combined into single index. The L factor represents the effects of length on erosion, defined as the distance from the point where runoff begins to the deposition area (or to where runoff flows into the defined channel) and S factor represents the effect of slope steepness on erosion, defined as ratio of the vertical change to the horizontal change between any two distinct points. Computing flow accumulation from DEM needs making the DEM agreed to the digitized rivers and streams, then processing fill sink, flow direction and flow accumulation respectively by using Hydro extension in the ARC GIS software. In this study, the flow accumulation and slope were used to calculate and map the LS-factor (Bewket and Teferi, 2009; Kamaludin et al., 2013)

$LS = (FA * \text{cell size} /22.1)^m * (0.065 + 0.045 *S +0.0065(S^2)$…………………equation 4.3

Where:-

FA =flow accumulation; Cell size is resolution of the grid (eg. 30m) and m is an exponent that depends on the slope steepness and S is the slope gradient in percent. Moreover slope(%) also derived from the DEM under spatial analysis tools in ARCGIS softaware. The values m varies from 0.2-0.5 depending on the slope value in percent as shown table below.(Wischmeier and Smith 1978).

Table 4. 3: Slope value depending on the m exponent (slope steepness)

m-value	Slope(%)
0.2	>5
0.3	3-5
0.4	1-3
0.5	<1

To perform the LS factor calculation m map was generated by classifying the slope of the study area based of value of m shown table below. Finally, the LS factor was derived. Therefore, in this study, Digital elevation model data was used to generate LS factor map using equation 4.3.the result shows that the minimum and maximum value of LS factor were range between 0 and 15 which is dimension less. The slope length and slope gradient factor of study area was shown as figure 4.3 below.

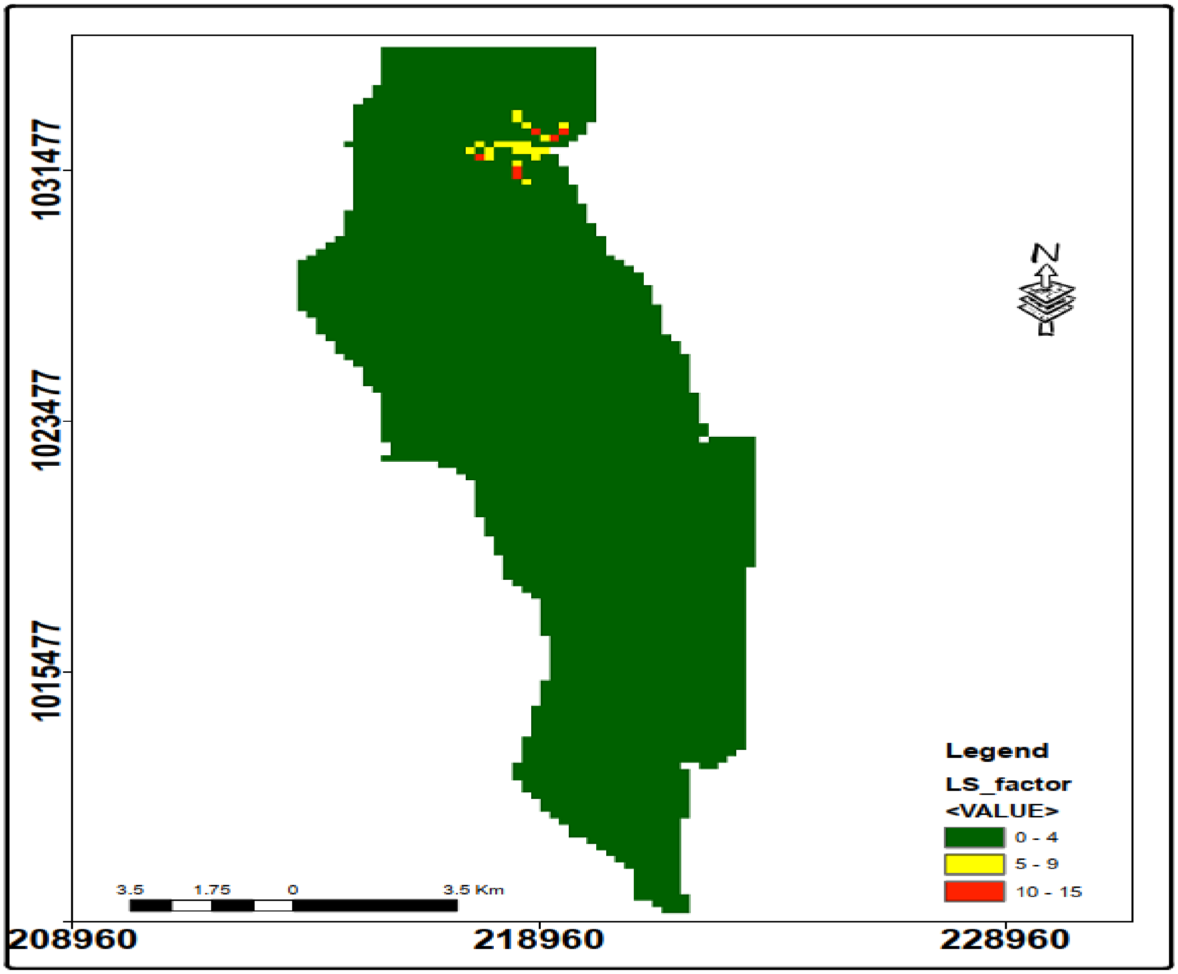

Figure 4. 3: LS factor of the Laga Haya watershed

4.1.1.4 Support Practice factor (P factor)

Support practice factor (p factor) indicates the rate of soil loss according to the various cultivated lands on the earth. There are contouring, farming strip cropping and terrace as a method and as an important factor that can control the erosion. The management practice factor can reduce the speed of water (runoff) on on the surface of the earth as a result it reduce the amount of soil erosion rate in the 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 and Shine, 1999).,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 Laga Haya watershed much of the area was treated by terracing conservation practice depending on the Topography (nature) of the study area.. The table below shows the value of support practice factor according to the cultivation methods and slope (shine, 1999). P values ranges from 0 to 1, whereby the value 0 represents a very manmade erosion resistance facility and the value 1 no manmade erosion resistance erosion facility. Depending on the nature of study area contouring method was selected to determine p factor values. Based on the assigned values (Table 4.4), P-factor map of the study area was prepared using ArcGIS10.5 spatial analysis tools. Table 4.4. P factor values adapted from (Shine,1999)

Table 4. 4: P factor values of depending on slope gradient (shine, 1999)

Slope (%)	P values by Contouring methods (shine. 1999)
0-7	0.55
7-11.3	0.6
11.3-17.6	0.8
17.6-26.8	0.9
26.8>	1

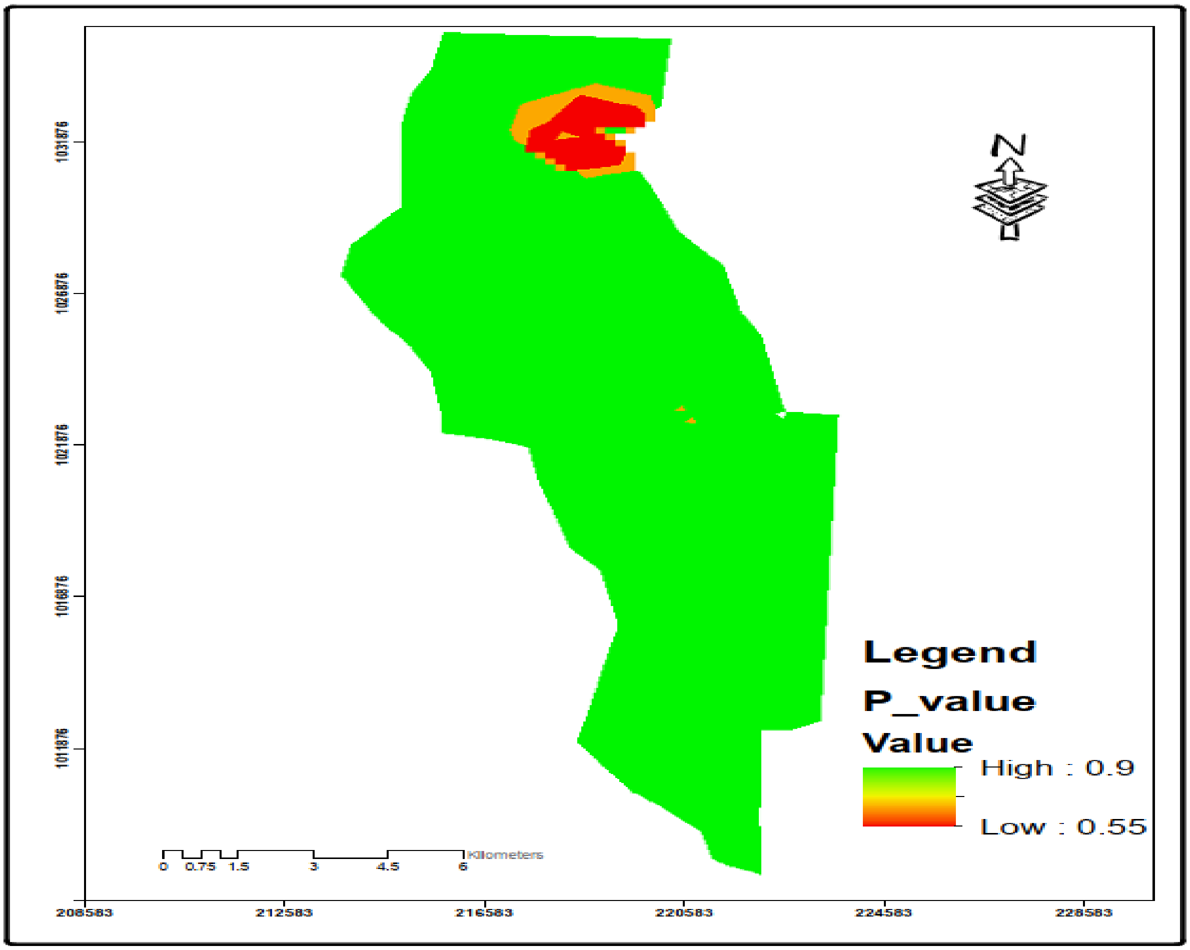

Figure 4. 4: P factor map of Laga Haya watershed

4.1.1.5 Cover Management factor (C factor)

The cover management factor represents the ratio of soil loss under a given cover types to that the bare land. The factor indicates the level of protection of a soil under certain land cover. In this study one year land use land cover map was generated. Based on 2019 Landsat 8 satellite images first land use land cover layer map was generated and converted to vector format to calculate area coverage and Caver factor was finally generated. Five major land use classes of watershed were classified as shown in earlier (fig.3.4). These were cultivated land, forest plantation, bare land, settlement and grass land as described with their description in table 3.4 earlier section. The result revealed that the study area dominantly covered by cultivated land about

(23%) followed by forest plantation (30%), bare land (18%), Settlement (8%) and grazing land (20%). In the study area cultivation land was the highest coverage and the least coverage was settlement land use land cover. As a result cover factor values for each land use type have been assigned (table 4.6). based on the values suggested by different authors and researchers such as (Kumar and Kushwaha, 2013),(morgan, 1995), Prasannakumar et al. (2012), Wischmmer and smith (1978) and Gashaw et al (2017).

Table 4. 5: Land use land cover map of the study area

Land use land cover	Area covered (ha)	Percentage of area coverage(%)
Cultivated land	2553.32	23%
Forest cultivation	3249.91	30%
Bare land	4580	20%
Settlement	1831.23	8%
Grass land	4120.422	18%
Total	16,334.882	100%

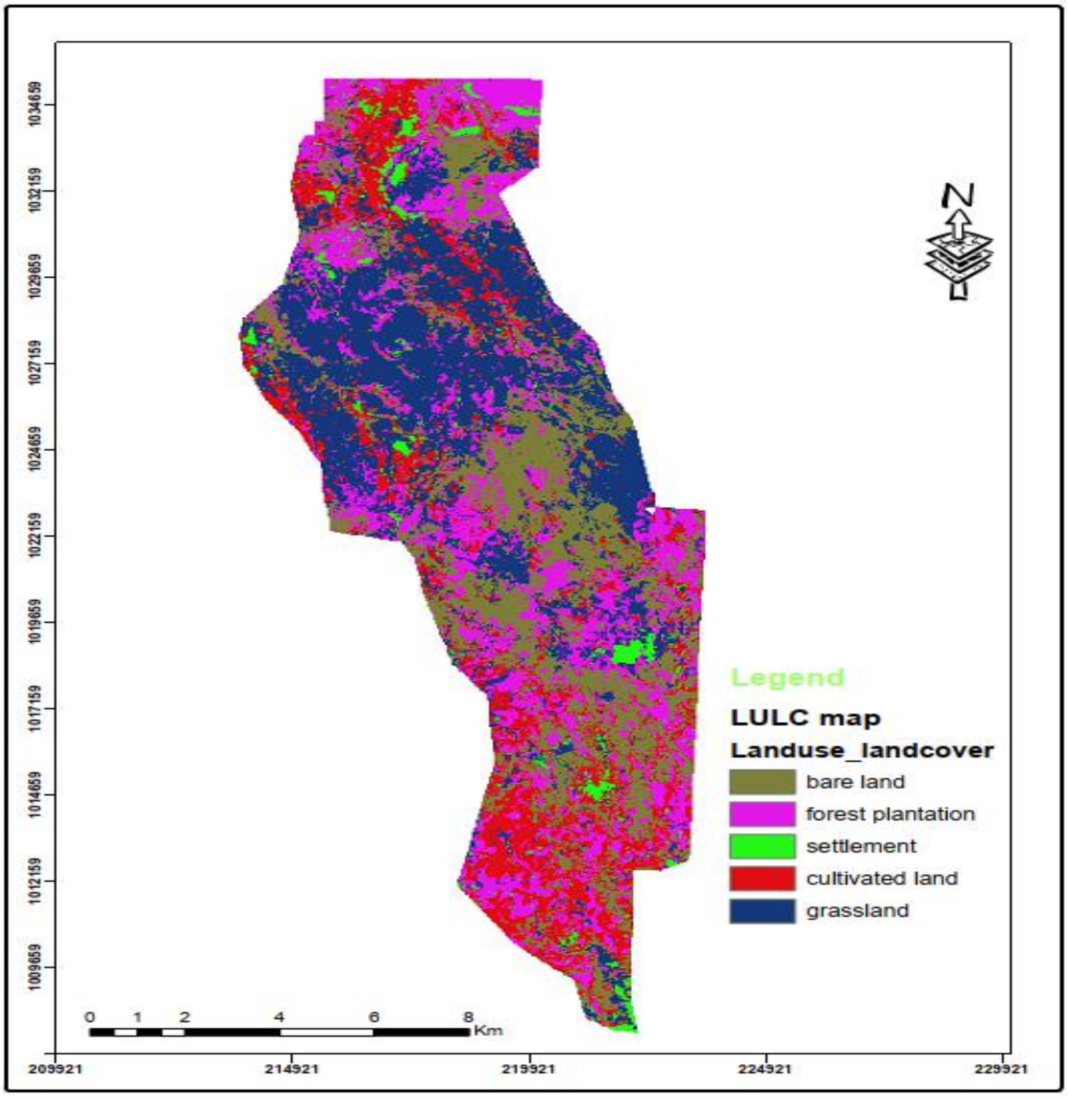

Figure 4. 5: LULC map of Laga Haya watershed

Assessment of the type of land use and land cover was made separately for each land unit and the corresponding value for land use /land cover was obtained from Hurni(1985) which was adapted to Ethiopian condition. In order to determine C-factor, Laga Haya watershed was classified into five land use classes generated from Landsat images 0f 2019, path 168 and Row 054 by applying supervised classification and maximum likelihood of supervised classification. After getting the classified image raster format was changed vector format in order to enter C-factor value depending on the following reference authors (Table 4.6).

Table 4. 6: Land use land covers types and its corresponding C-factor values

Land use land cover types	C-factors	Authors
Cultivated land	0.18	Hurni(1985);Abebe(2014)
Forest Cultivation	0.18	Morgan(1985 &2005);Amare et al.(2014)
Bare land	0.05	Hurni(1985)
Settlement	0.009	Gansari and Ramesh(2015)
Grass land	0.05	Hurni(1985);Abate(2011);Tadese(2014)

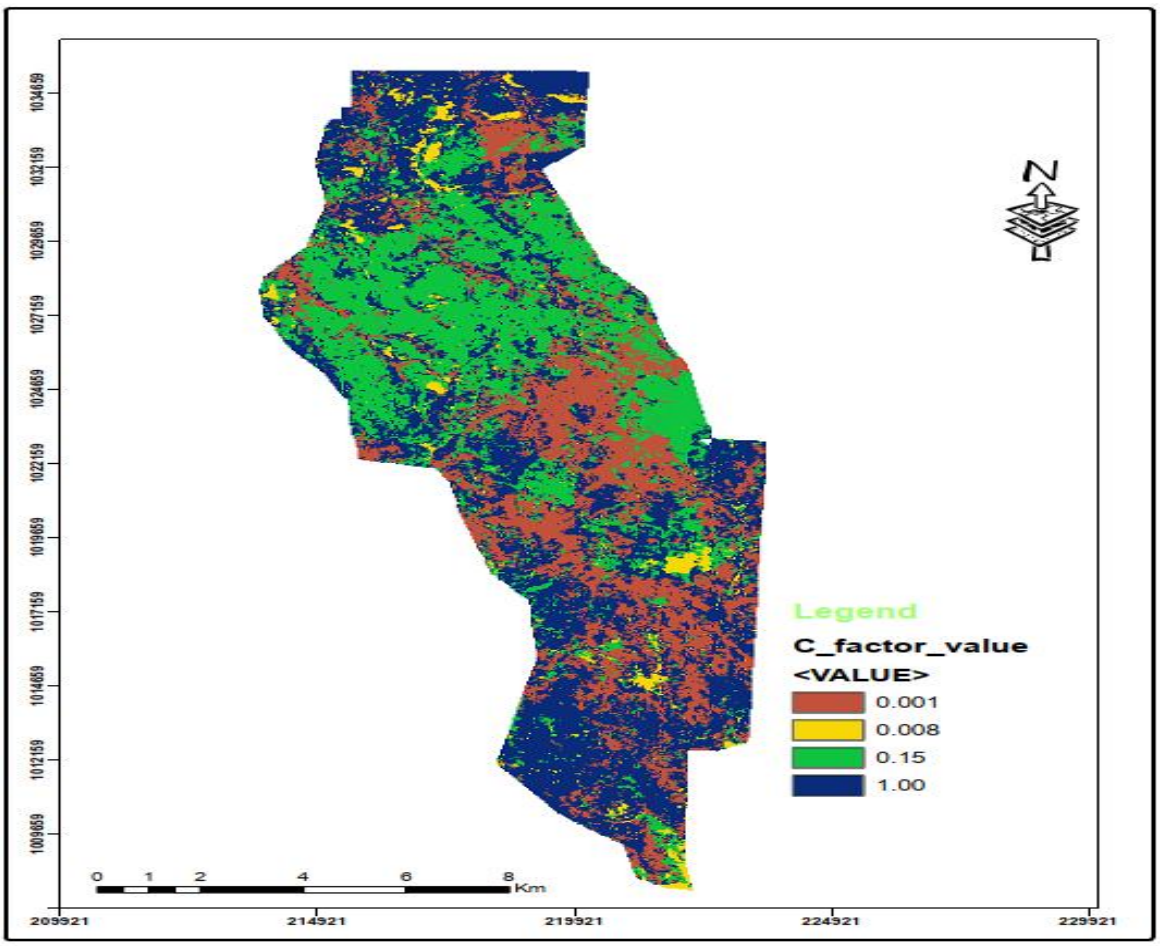

Figure 4. 6: C factor of the Laga Haya watershed

4.1.2 Estimated annual soil loss from the watershed

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 in spatial analyst tools in the ARCGIS as given in equation 3.1 above. Therefore, in this study overlaying this 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 Laga Haya watershed. The finding showed that the annual soil loss of the Laga Haya watershed ranges from 0.00 to 150.917 ton/ha/year The calculated average annual soil loss rate of study area was 27 ton ha^{-1} $yr^{-1.}$ Accordingly, the quantitative output of the actual soil loss erosion rate for Laga Haya watershed was calculated as figure 4.7 below.

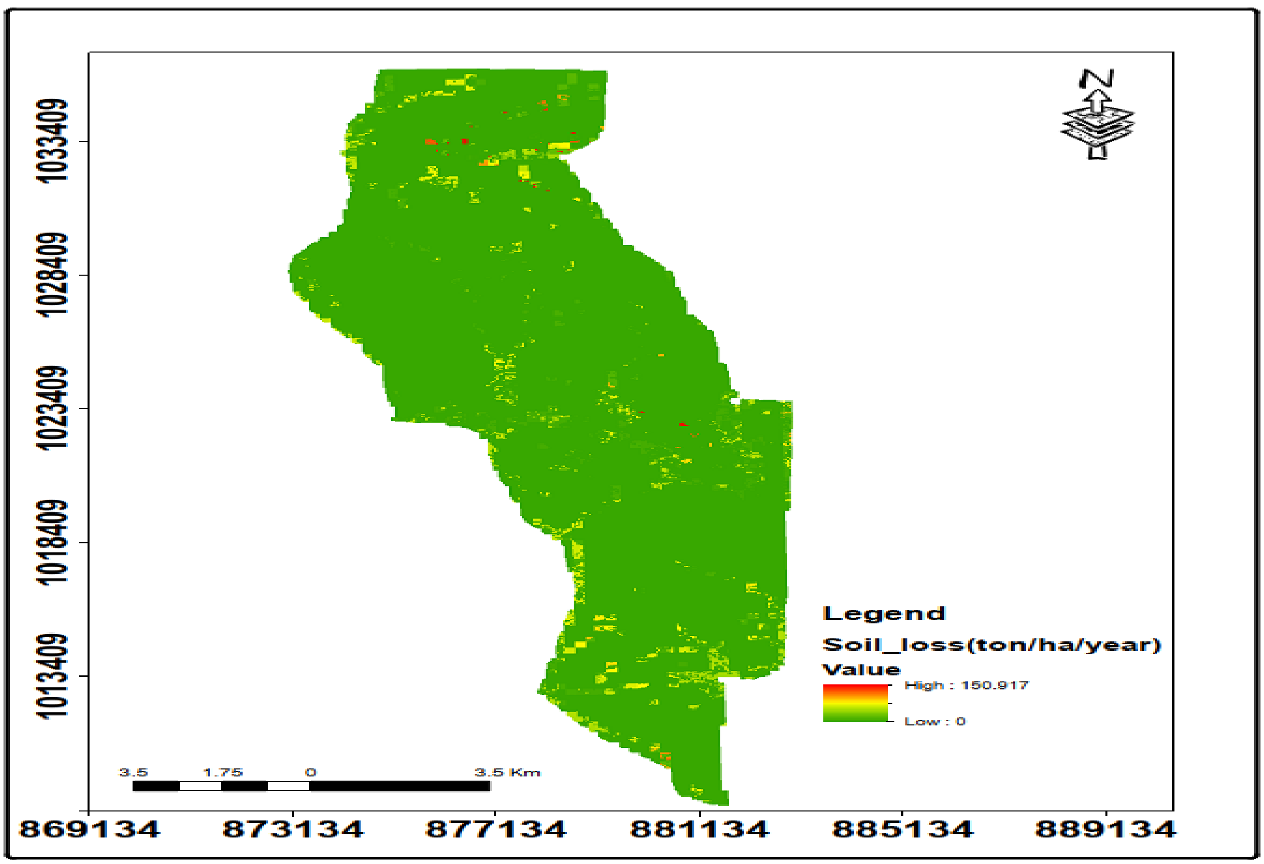

Figure 4. 7: Estimated annual soil loss of Laga Haya watershed

4.1.3 Identification of erosion risk (hotspots) and soil erosion severity in Laga Haya watershed

The spatial distribution (location) of soil loss in the study area has different severity because of rugged nature of topography in the study area. In order to obtain a better understanding at the same time and be able to compare the soil erosion risk area ,the average soil loss of the study area was categorized into different severity classes in the the study area. The soil erosion severity class based on the rate average annual soil loss from the study area presented in table 4.8 below.

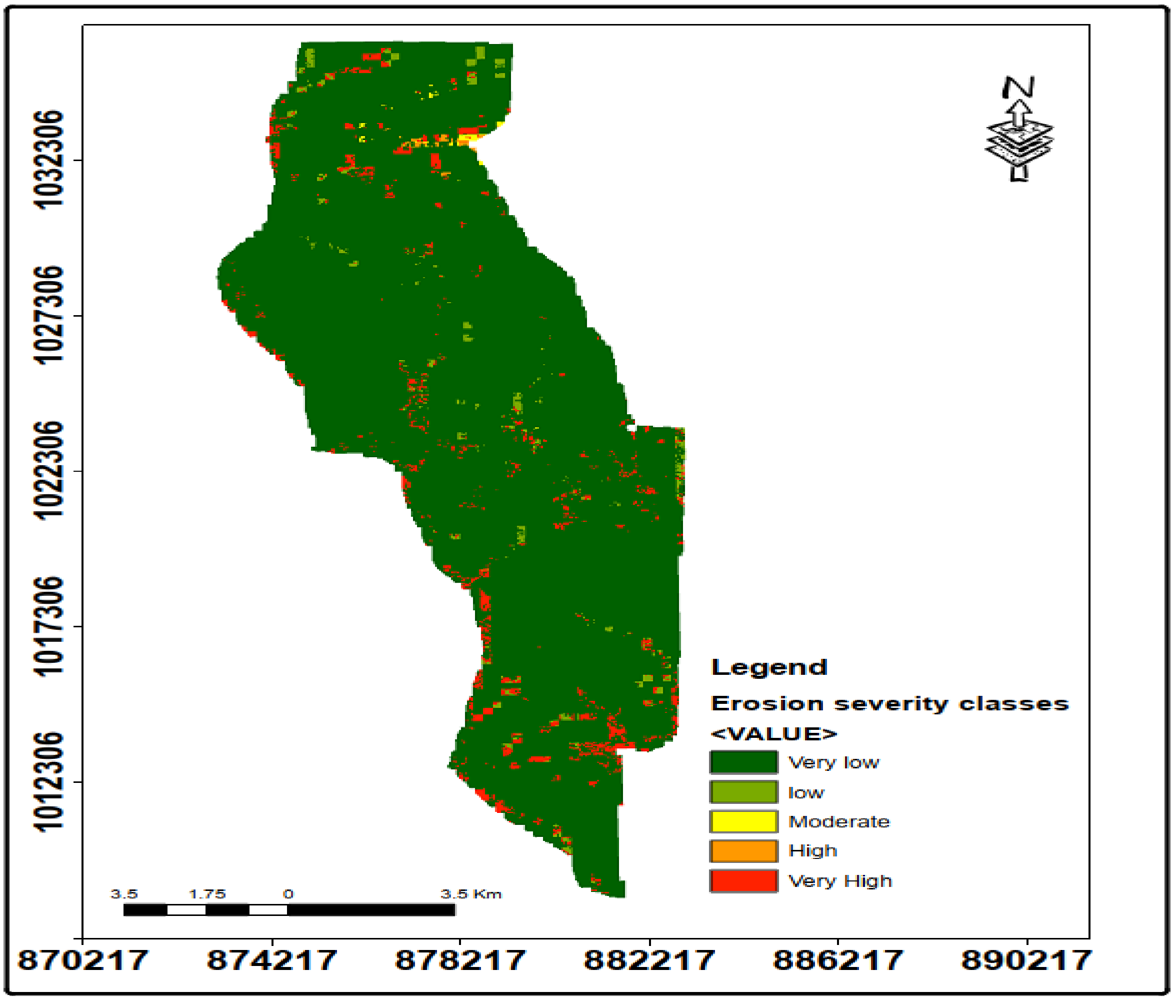

Figure 4. 8: Soil loss severity class map of the Laga Haya watershed

Based on the annual soil loss rate distribution severity classes of study area were grouped in to five classes (Table 4.7).

Table 4. 7: Annual soil loss rate, severity classes and priority soil erosion risk map of the Laga Haya Watershed

Soil loss (ton/ha/year)	Severity Classes	Area of coverage (ha)	Percent of coverage
0-3	Very Low	13022.33	95.21 %
3-6	Low	174.06	1.27 %
6-10	moderate	18.02	0.13 %
10-15	High	296.03	2.16 %
15-150.92	Very high	167.46	1.22 %

Table 4.7 shows that about 167 ha (1.22%) of the study area falls under the very high severity class and it needs an immediate attention of soil and water conservation treatment. About 314.05 ha (2.29%) of the study area falls under the high and moderate classes and the mean annual soil loss rate is between 6 to 15 ton/ha/year. The low severity class covers 174.06 ha (1.27%) of the study area and mean annual soil loss rate is between 3 ton $ha^{-1}yr^{-1}$ to 6 ton ha^{-1}yr.-1 The remaining 95.21% of the study area falls under the very low class. Thus, areas with high and very high erosion severity classes needs urgent soil and water conservation measures to keep the sustainability of land in the study area.

4.1.4 Identification and prioritization sub-watershed of soil erosion risk area

In this study, five total sub-watersheds were delineated based on the watershed flowing outlet properties (their drainage system) and the erosion risk map were reclassified based on the prioritization (Fig 4.9). Table 4.8 shows prioritization of Laga Haya sub-watersheds involved for ranking different sub-watersheds according to the order in which they were taken up for sustainable management by taking into consideration the rate of average annual soil loss occurred in these sub-watersheds. Depending on the rate average soil loss of the study area the area with priority classes I and II were prioritized for implementation of soil erosion control measures. The table 4.8 below shows the priority of sub watershed based on the rate of average soil loss from each sub-watershed

Table 4. 8: Average annual soil loss rate and priority classes of Laga Haya sub-watersheds

Priority class	Sub-watershed	Area(ha)	Area (%)	Average soil loss(ton/ha/year)	Ranges of annual soil loss (t/ha/yr)
I	A	3051	22.5	23	0 – 150.97
II	B	3300	24.6	15.2	0 – 50.12
III	C	2735	20.2	13.7	0 – 42.53
IV	D	2358	17.41	9	0 – 80.78
V	E	2101	15.51	7.4	0 – 112.8

Soil loss priority classes for Laga Haya watershed were computed on the basis of average annual soil loss. The output of average soil loss indicated in table 4.8, their ranges from 7.4 to 23 t/ha/yr, in different sub-watersheds of the study area. According to this classification, an erosion risk map based on the distribution of an average annual soil loss of Laga Haya watershed, was identified figure 4.9 below.

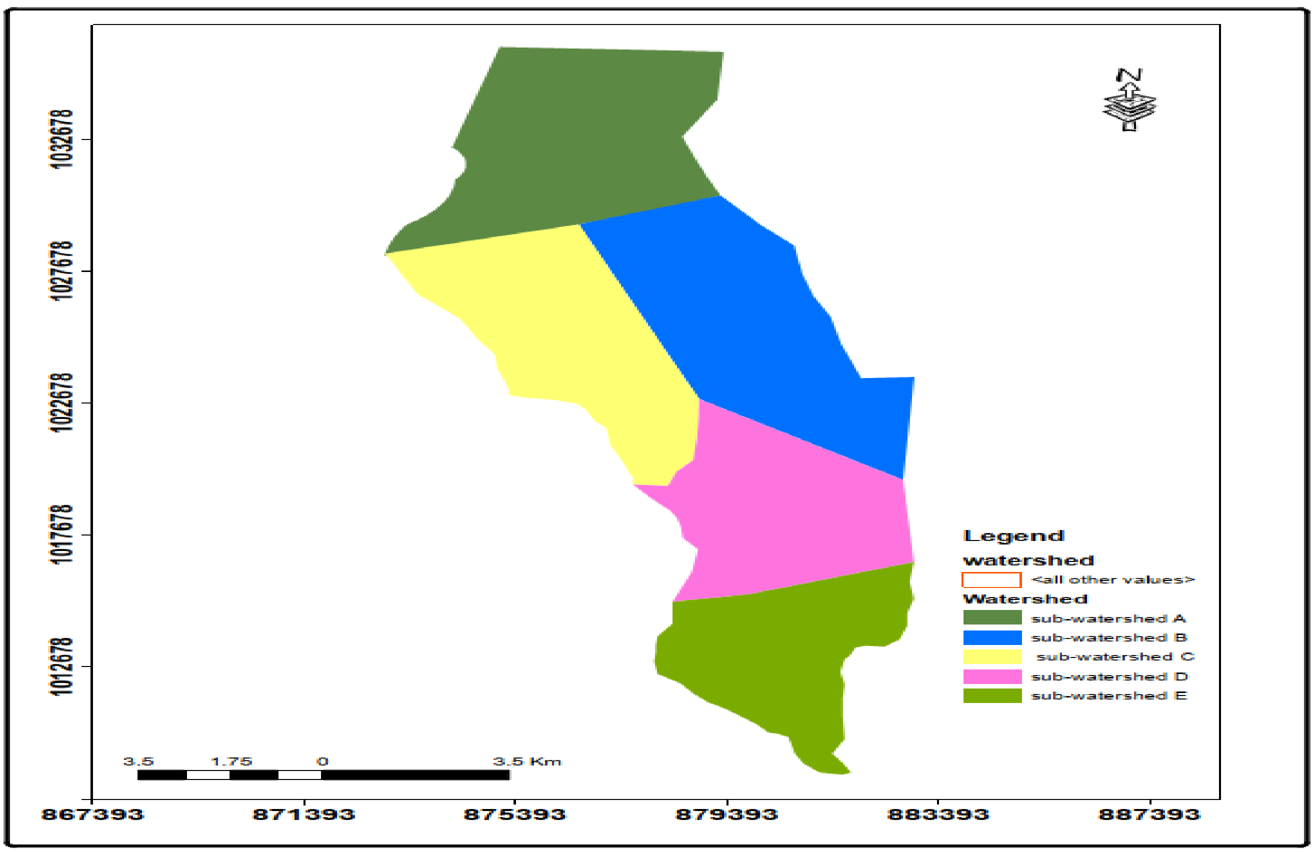

Figure 4. 9: Map of prioritized sub-watersheds of Laga Haya watershed

The ranges of the erosion rates and their suggested classes were inferred to identify the critical sub-watersheds. The critical sub-watersheds were prioritized regarding to water and soil conservation management scenarios and reduce soil losses from study area. A sub-watershed may get top priority due to intensity of land degradation or rate of average soil eroded from the sub-watersheds. The results from the identified sub-watersheds shows that; sub-watershed “A” needs urgent conservation and then sub-watersheds ” B”,”C”, “D” and “E” needs conservation management respectively. The identified critical sub-watersheds were ranked in the table 4.8 and mapped for sub-watersheds management in order to reduce the soil losses and to conserve the resources within the sub-watershed. Top priority for soil conservation measures must be given to the sub-watershed “A” as first stage and sub-watershed “B” can be considered in the second stage. Sub-watersheds “C” and “D’ could be in the third stage for treatment and finally sub-watershed “E” could be undertaken as last stage for soil conservation for treatment.

4.2 Discussion

4.2.1 Soil loss rate and severity classes of soil erosion in Laga Haya watershed

The current study findings agrees with similar findings reported in Gashaw et al. (2018) for geleda watershed ; Blue Nile Basin, North western highlands(23.7 t $ha^{-1}yr^{-1}$) and also relative with the findings of Amare et al. (2014) studied in the wondo Genet watershed in the eastern highlands (26 t $ha^{-1}yr^{-1}$)and Abebe and Tadesse (2014) for Jabi Tehinan water shed in the northwestern highlands of Ethiopia(30.4 t $ha^{-1}yr^{-1}$). The result of RUSLE model showed that it is more reliable result compared previous research findings. The result showed that the annual soil loss of the Laga Haya watershed ranges from 0.00 to 150.917 ton/ha/year as shown Figure 4. 7 above and the entire watershed loses a total of about 311,535 tons of soil annually.

The findings of study also falls within the ranges of findings of FAO (1984). This was equivalent to 16 to 300 t $ha^{-1}yr^{-1}$and also the findings similar with the assessment has been reported by (Gete, 2000) north western highlands and reported a very high rate of erosion ranging from 130 to 170 t $ha^{-1}yr^{-1}$ .The present study revealed that five priority classes identified and prioritized according to the average annual soil loss of the study area. Land use land cove classes in the study was Five major land use classes of watershed were classified as shown in figure 4.6. These are cultivated land, forest plantation, bare land, and settlement and grass land. The result revealed that the study area dominantly covered by forest plantation (30%) followed by cultivated land about (23%) , bare land (18%), Settlement (8%) and grass land(20%). In the study area forest land was the highest coverage and the least coverage was settlement land use land cover. As a result cover factor values for each land use type have been assigned (table 4.5) based on the values suggested by different authors and researchers such as (Kumar and Kushwaha, 2013),(morgan, 1995),Prasannakumar et al. (2012), Wischmmer and smith (1978) and Gashaw et al (2017). Thus the result RUSLE model shows that it is more reliable compared to previous studies. Soil loss rates in the Ethiopian highlands measured on test plots amount to 130-170 t $ha^{-1}year^{-1}$(Hurni 1985; Hurni et al. 2008).

4.2.2 Identification of soil erosion hotspots area

The quality of RUSLE model to estimate quantitative soil depends on the quality of erosion factors (Asmamaw & Mohammed, 2019). The generated soil erosion risk map (hotspots) of the study area shows that erosion risk area was at different part of the Laga Haya watershed. According to the soil erosion risk map (figure 4.2), the Northern, Southern and some central part of the watershed were more vulnerable to erosion as compared to the other part of the watershed. This is due to 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 depending on the land use land cover and slope steepness in the watershed and areas with steep slope and poor vegetation cover were expose to high erosion. As above table 4.1 shown that about 167 ha (1.22%) of the study area falls under the severe class and it needs an immediate attention of soil and water conservation treatment. About 314.05 ha (2.29%) of the study area falls under the high and moderate classes and the mean annual soil loss rate is between 6 to 15 ton/ha/year. The low severity class covers 174.06 ha (1.27%) of the study area and mean annual soil loss rate is between 3 to 6 ton/ha/year. The remaining 95.21% of the study area falls under the very low severity class. The generated soil erosion risk map of the study area show that erosion hazards happen at different part of the watershed. According to the generated soil erosion risk map (figure 4.8) the north and some north eastern part of the Laga Haya watershed was more vulnerable to soil erosion as compared to the other part of the watershed. Thus, areas with high erosion severity class needs urgent prioritized soil and water intervention measures to keep the sustainability of land in the Laga Haya watershed.

Hurni (1883) has conducted a research to estimate the rates of soil formation for Ethiopia. The maximum tolerable soil loss rates range for medium soils in serious agro-ecological zones of Ethiopia was found from 1 ton/ha/yr for berha agro-climatic zone to 16ton/ha/ yr for wet Weyna Dega agro-ecological zone. According to the findings of this study the rate of soil loss in the Laga Haya watershed exceeds the maximum tolerable rate 16 ton/ha/yr. This fact shows how far soil erosion is serious threat to the Laga Haya watershed. Similarly, the five sub-watersheds were prioritized depending on the average soil loss of each sub-watersheds in order conserve soil and overcome the identified erosion hotspots sub-watersheds according to their priority class since it is difficult to conserve all sub-watersheds at the same time.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The objective of this study was to assess soil erosion risk in the Laga Haya watershed which was located in the upper Abay basin by using empirically erosion assessment RUSLE model and GIS techniques. In Ethiopia because of poor land use land cover management practice rate of soil erosion was accelerated Severe soil erosion occurrence and declining in Ethiopian highland was due to exhaustive farming steep slope areas and other factors related to the population pressure such as deforestation. Soil and watershed conservation was difficult at the same time but through prioritizing erosion risk area with its level of erosion rate using RUSLE modeling integration with GIS techniques. This was an effective way to map the spatial distribution of soil erosion risk in the study area and the RUSLE modeling demonstrate that an empirically based erosion assessment model integrated with geographical information system can provide useful information for soil and water conservation decision -making. The important findings of the study include soil erosion value layer map of the Laga Haya watershed and the prioritization watershed into conservation priority categories, which can be used for preparation of a conservation plan for management for the watershed.

In the Laga Haya soil erosion assessment RUSLE modeling and GIS techniques was used to show spatial distribution of rate of annual soil loss and identification of critical soil erosion risk area to facilitate conservation planning of soil and watershed management. Therefore, GIS techniques and RUSLE modeling can estimate soil loss from the watershed and show the spatial location of critical erosion hotspots and prioritize the level of erosion rate in the sub-watersheds. Assessment of soil erosion using GIS and RUSLE modeling has a significant role for environmental recovery and conservation planning soil and watershed in the Laga Haya watershed. This RUSLE modeling and GIS techniques are simple and cost effective tools. In the soil erosion assessment study RUSLE modeling and GIS techniques can show the spatial distribution of each RUSLE parameters. As a result data showed that the topography factor (LS factor) and management cover(C factor), which is resulted from land use land cover, are significantly affect erosion rate in the Laga Haya watershed.

The total amount of soil loss from the Laga Haya watershed was 311,535 tons yr^{-1} averagely. The area 13022.33ha, 174.06 ha, 1802ha, 296.03ha and 167.46 ha of the watershed were classified as very low, low, moderate, high and very high(severe) soil erosion classes respectively and the five total sub-watersheds were prioritized based on the rate of soil losses from the sub-watersheds. The prioritized erosion risk map were reclassified sub-watershed ‘A”,”B”, “C”, “D” and “Corresponding to the priority classes I,II, II, IV and IV respectively. Therefore, this situation indicates to make immediate action to implement soil and water conservation practice in the watershed within short time. Thus, Prioritization for water and soil conservation treatment practice must be assigned based on soil erosion priority classes described in table 4.8 above. Therefore, water and soil conservation practice must be implemented first in the area vulnerable to soil erosion (hotspots) as a result in this study sub-watershed “A’ and thus helps to reduce erosion risk in the study area and finally positive impact will be achieve.

5.2 Recommendation

The following statements are recommendations drawn from the findings of study for further researchers policy makers, NGOs, communities and planners of the concerning bodies.

- ✓ The use of RUSLE modeling and GIS techniques should be applied to estimate soil losses from the watershed and to identify erosion hotspots by prioritizing erosion risk classes in order to conserve soil and water management effectively and orderly and ,also it assists planners and policy makers in decision making
- ✓ To reduce removal of soil losses vegetation cover in the study area should be improved and free from animal and agricultural practices by creating awareness about the land for the local communities.
- ✓ From the delineated sub-watersheds the priority classes I and II , which means sub-watershed “A” and “B”, should be conserve urgently in the in the Laga Haya watershed.
- ✓ The low and moderate soil erosion severity classes could be managed through local soil erosion mechanism such as contouring, terracing and strip cropping based on their soil type and land use type.
- ✓ Since RUSLE model couldn’t estimate gully and sedimentation further researchers should be overcome the gullies and sedimentations in the study area.

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APPENDICES

Appendixe-1: Average annual precipitation of three station (for 30 years)

Name of Station	Elevation	Longitude	Latitude	Year	Annual average precipitation(mm)
Nekemte	2080	36.463333	9.083333	1981	123.4583333
Nekemte	2080	36.463333	9.083333	1982	148.0333333
Nekemte	2080	36.463333	9.083333	1983	140.9416667
Nekemte	2080	36.463333	9.083333	1984	52.00833333
Nekemte	2080	36.463333	9.083333	1985	139.4166667
Nekemte	2080	36.463333	9.083333	1986	88.35833333
Nekemte	2080	36.463333	9.083333	1987	163.95
Nekemte	2080	36.463333	9.083333	1988	83.21666667
Nekemte	2080	36.463333	9.083333	1989	116.9083333
Nekemte	2080	36.463333	9.083333	1990	157.2333333
Nekemte	2080	36.463333	9.083333	1991	116.2583333
Nekemte	2080	36.463333	9.083333	1992	204.25
Nekemte	2080	36.463333	9.083333	1993	209.2166667
Nekemte	2080	36.463333	9.083333	1994	174.0333333
Nekemte	2080	36.463333	9.083333	1995	170.4666667
Nekemte	2080	36.463333	9.083333	1996	191.4916667
Nekemte	2080	36.463333	9.083333	1997	181.9833333
Nekemte	2080	36.463333	9.083333	1998	211.6416667
Nekemte	2080	36.463333	9.083333	1999	150.4166667
Nekemte	2080	36.463333	9.083333	2000	174.775
Nekemte	2080	36.463333	9.083333	2001	157.6666667
Nekemte	2080	36.463333	9.083333	2002	139.4166667
Nekemte	2080	36.463333	9.083333	2003	152.3333333
Nekemte	2080	36.463333	9.083333	2004	148.35
Nekemte	2080	36.463333	9.083333	2005	187.3916667
Nekemte	2080	36.463333	9.083333	2006	170.9
Nekemte	2080	36.463333	9.083333	2007	181.0833333
Nekemte	2080	36.463333	9.083333	2008	203.4416667
Nekemte	2080	36.463333	9.083333	2009	167.0333333
Nekemte	2080	36.463333	9.083333	2010	205.5083333
Nekemte	2080	36.463333	9.083333	2011	167.3916667
Nekemte	2080	36.463333	9.083333	2012	174.5166667

Nekemte	2080	36.463333	9.083333	2013	163.775
Nekemte	2080	36.463333	9.083333	2014	166.925
Nekemte	2080	36.463333	9.083333	2018	93.65833333
Nekemte	2080	36.463333	9.083333	1981	50.08333333
Nekemte	2080	36.463333	9.083333	1981	33.5
Nekemte	2080	36.463333	9.083333	1981	36.66666667
Nekemte	2080	36.463333	9.083333	1982	62.5
Nekemte	2080	36.463333	9.083333	1982	40.25
Nekemte	2080	36.463333	9.083333	1982	40.41666667
Nekemte	2080	36.463333	9.083333	1983	55.41666667
Nekemte	2080	36.463333	9.083333	1983	34.75
Nekemte	2080	36.463333	9.083333	1983	36.66666667
Nekemte	2080	36.463333	9.083333	1984	38.16666667
Nekemte	2080	36.463333	9.083333	1984	27.33333333
Nekemte	2080	36.463333	9.083333	1984	30.16666667
Nekemte	2080	36.463333	9.083333	1985	27.91666667
Nekemte	2080	36.463333	9.083333	1985	20.5
Nekemte	2080	36.463333	9.083333	1985	22.08333333
Nekemte	2080	36.463333	9.083333	1986	20.91666667
Nekemte	2080	36.463333	9.083333	1986	23.41666667
Nekemte	2080	36.463333	9.083333	1986	24.75
Nekemte	2080	36.463333	9.083333	1987	12.91666667
Nekemte	2080	36.463333	9.083333	1987	11.41666667
Nekemte	2080	36.463333	9.083333	1987	9.916666667
Nekemte	2080	36.463333	9.083333	1987	10.08333333
Nekemte	2080	36.463333	9.083333	1987	3.333333333
Nekemte	2080	36.463333	9.083333	1988	15
Nekemte	2080	36.463333	9.083333	1988	13.66666667
Nekemte	2080	36.463333	9.083333	1988	10.33333333
Nekemte	2080	36.463333	9.083333	1988	9.916666667
Nekemte	2080	36.463333	9.083333	1988	11.5
Nekemte	2080	36.463333	9.083333	1989	21.08333333
Nekemte	2080	36.463333	9.083333	1989	19.16666667
Nekemte	2080	36.463333	9.083333	1989	18.41666667
Nekemte	2080	36.463333	9.083333	1989	12.08333333
Nekemte	2080	36.463333	9.083333	1989	7
Nekemte	2080	36.463333	9.083333	1990	54.66666667
Nekemte	2080	36.463333	9.083333	1990	45.5

Nekemte	2080	36.463333	9.083333	1990	43.08333333
Nekemte	2080	36.463333	9.083333	1990	47
Nekemte	2080	36.463333	9.083333	1991	30.58333333
Nekemte	2080	36.463333	9.083333	1991	26.75
Nekemte	2080	36.463333	9.083333	1991	26.16666667
Nekemte	2080	36.463333	9.083333	1991	29.08333333
Nekemte	2080	36.463333	9.083333	1992	73.08333333
Nekemte	2080	36.463333	9.083333	1992	60.5
Nekemte	2080	36.463333	9.083333	1992	58.33333333
Nekemte	2080	36.463333	9.083333	1992	65
Nekemte	2080	36.463333	9.083333	1993	76.5
Nekemte	2080	36.463333	9.083333	1993	66.58333333
Nekemte	2080	36.463333	9.083333	1993	58.58333333
Nekemte	2080	36.463333	9.083333	1993	60.91666667
Nekemte	2080	36.463333	9.083333	1993	40.58333333
Nekemte	2080	36.463333	9.083333	1994	51.91666667
Nekemte	2080	36.463333	9.083333	1994	55.41666667
Nekemte	2080	36.463333	9.083333	1994	47.16666667
Nekemte	2080	36.463333	9.083333	1994	46.83333333
Nekemte	2080	36.463333	9.083333	1994	46.5
Nekemte	2080	36.463333	9.083333	1995	63.5
Nekemte	2080	36.463333	9.083333	1995	58.41666667
Nekemte	2080	36.463333	9.083333	1995	48.41666667
Nekemte	2080	36.463333	9.083333	1995	47.83333333
Nekemte	2080	36.463333	9.083333	1995	51.91666667
Nekemte	2080	36.463333	9.083333	1996	80.91666667
Nekemte	2080	36.463333	9.083333	1996	73.75
Nekemte	2080	36.463333	9.083333	1996	64.91666667
Nekemte	2080	36.463333	9.083333	1996	63.83333333
Nekemte	2080	36.463333	9.083333	1996	70.33333333
Nekemte	2080	36.463333	9.083333	1997	79.75
Nekemte	2080	36.463333	9.083333	1997	72.66666667
Nekemte	2080	36.463333	9.083333	1997	61.5
Nekemte	2080	36.463333	9.083333	1997	59.16666667
Nekemte	2080	36.463333	9.083333	1997	66.66666667
Nekemte	2080	36.463333	9.083333	1998	78.41666667
Nekemte	2080	36.463333	9.083333	1998	72
Nekemte	2080	36.463333	9.083333	1998	60.33333333

Nekemte	2080	36.463333	9.083333	1998	54
Nekemte	2080	36.463333	9.083333	1998	63.08333333
Nekemte	2080	36.463333	9.083333	1999	69.75
Nekemte	2080	36.463333	9.083333	1999	68.41666667
Nekemte	2080	36.463333	9.083333	1999	56.58333333
Nekemte	2080	36.463333	9.083333	1999	53.91666667
Nekemte	2080	36.463333	9.083333	1999	58.58333333
Nekemte	2080	36.463333	9.083333	2000	70.08333333
Nekemte	2080	36.463333	9.083333	2000	64
Nekemte	2080	36.463333	9.083333	2000	51.58333333
Nekemte	2080	36.463333	9.083333	2000	49.91666667
Nekemte	2080	36.463333	9.083333	2000	54.08333333
Nekemte	2080	36.463333	9.083333	2001	77.41666667
Nekemte	2080	36.463333	9.083333	2001	72.16666667
Nekemte	2080	36.463333	9.083333	2001	59.91666667
Nekemte	2080	36.463333	9.083333	2001	57.75
Nekemte	2080	36.463333	9.083333	2001	61.83333333
Nekemte	2080	36.463333	9.083333	2002	76.91666667
Nekemte	2080	36.463333	9.083333	2002	71.16666667
Nekemte	2080	36.463333	9.083333	2002	57.66666667
Nekemte	2080	36.463333	9.083333	2002	54.83333333
Nekemte	2080	36.463333	9.083333	2002	59.83333333
Nekemte	2080	36.463333	9.083333	2003	73.83333333
Nekemte	2080	36.463333	9.083333	2003	68.75
Nekemte	2080	36.463333	9.083333	2003	55.5
Nekemte	2080	36.463333	9.083333	2003	51.91666667
Nekemte	2080	36.463333	9.083333	2003	56.91666667
Nekemte	2080	36.463333	9.083333	2004	75.16666667
Nekemte	2080	36.463333	9.083333	2004	69.75
Nekemte	2080	36.463333	9.083333	2004	56.5
Nekemte	2080	36.463333	9.083333	2004	53.41666667
Nekemte	2080	36.463333	9.083333	2004	58.66666667
Nekemte	2080	36.463333	9.083333	2005	75.08333333
Nekemte	2080	36.463333	9.083333	2005	69.75
Nekemte	2080	36.463333	9.083333	2005	56.5
Nekemte	2080	36.463333	9.083333	2005	53.5
Nekemte	2080	36.463333	9.083333	2005	59.83333333
Nekemte	2080	36.463333	9.083333	2006	76.41666667

Nekemte	2080	36.463333	9.083333	2006	71.33333333
Nekemte	2080	36.463333	9.083333	2006	57.91666667
Nekemte	2080	36.463333	9.083333	2006	56
Nekemte	2080	36.463333	9.083333	2006	61.08333333
Nekemte	2080	36.463333	9.083333	2007	77.75
Nekemte	2080	36.463333	9.083333	2007	71.58333333
Nekemte	2080	36.463333	9.083333	2007	58.91666667
Nekemte	2080	36.463333	9.083333	2007	56.08333333
Nekemte	2080	36.463333	9.083333	2007	61.58333333
Nekemte	2080	36.463333	9.083333	2008	77.58333333
Nekemte	2080	36.463333	9.083333	2008	72.41666667
Nekemte	2080	36.463333	9.083333	2008	60.08333333
Nekemte	2080	36.463333	9.083333	2008	57.5
Nekemte	2080	36.463333	9.083333	2008	62.25
Nekemte	2080	36.463333	9.083333	2009	78.25
Nekemte	2080	36.463333	9.083333	2009	73.25
Nekemte	2080	36.463333	9.083333	2009	59.16666667
Nekemte	2080	36.463333	9.083333	2009	56.5
Nekemte	2080	36.463333	9.083333	2009	62.41666667
Nekemte	2080	36.463333	9.083333	2010	80.5
Nekemte	2080	36.463333	9.083333	2010	75.58333333
Nekemte	2080	36.463333	9.083333	2010	61.25
Nekemte	2080	36.463333	9.083333	2010	59.5
Nekemte	2080	36.463333	9.083333	2010	64.66666667
Nekemte	2080	36.463333	9.083333	2011	79.33333333
Nekemte	2080	36.463333	9.083333	2011	75.08333333
Nekemte	2080	36.463333	9.083333	2011	60.91666667
Nekemte	2080	36.463333	9.083333	2011	57.5
Nekemte	2080	36.463333	9.083333	2011	64.25
Nekemte	2080	36.463333	9.083333	2012	78.58333333
Nekemte	2080	36.463333	9.083333	2012	73.08333333
Nekemte	2080	36.463333	9.083333	2012	59.16666667
Nekemte	2080	36.463333	9.083333	2012	56.66666667
Nekemte	2080	36.463333	9.083333	2012	62.75
Nekemte	2080	36.463333	9.083333	2014	23.91666667
Nekemte	2080	36.463333	9.083333	2014	22.16666667
Nekemte	2080	36.463333	9.083333	2014	18.75
Nekemte	2080	36.463333	9.083333	2014	18.75

Nekemte	2080	36.463333	9.083333	2014	20.83333333
Nekemte	2080	36.463333	9.083333	2016	16.41666667
Nekemte	2080	36.463333	9.083333	2016	15.91666667
Nekemte	2080	36.463333	9.083333	2016	13.66666667
Nekemte	2080	36.463333	9.083333	2016	13.33333333
Nekemte	2080	36.463333	9.083333	2016	14.83333333
Nekemte	2080	36.463333	9.083333	1982	3.191666667
Nekemte	2080	36.463333	9.083333	1983	4.5
Nekemte	2080	36.463333	9.083333	1984	2.5
Nekemte	2080	36.463333	9.083333	1985	2.425
Nekemte	2080	36.463333	9.083333	1986	2.483333333
Nekemte	2080	36.463333	9.083333	1987	2.341666667
Nekemte	2080	36.463333	9.083333	1988	1.375
Nekemte	2080	36.463333	9.083333	1989	3.366666667
Nekemte	2080	36.463333	9.083333	1990	5.725
Nekemte	2080	36.463333	9.083333	1991	4.05
Nekemte	2080	36.463333	9.083333	1992	5.341666667
Nekemte	2080	36.463333	9.083333	1993	5.666666667
Nekemte	2080	36.463333	9.083333	1994	2.625
Nekemte	2080	36.463333	9.083333	1995	0.666666667
Nekemte	2080	36.463333	9.083333	1996	3.675
Nekemte	2080	36.463333	9.083333	1997	5.925
Nekemte	2080	36.463333	9.083333	1998	5.7
Nekemte	2080	36.463333	9.083333	1999	6.225
Nekemte	2080	36.463333	9.083333	2000	3.691666667
Nekemte	2080	36.463333	9.083333	2002	4.7
Nekemte	2080	36.463333	9.083333	2003	5.841666667
Nekemte	2080	36.463333	9.083333	2004	5.433333333
Nekemte	2080	36.463333	9.083333	2005	5.458333333
Nekemte	2080	36.463333	9.083333	2006	5.808333333
Nekemte	2080	36.463333	9.083333	2007	5.816666667
Nekemte	2080	36.463333	9.083333	2008	5.825
Nekemte	2080	36.463333	9.083333	2009	6.166666667
Nekemte	2080	36.463333	9.083333	2010	4.983333333
Nekemte	2080	36.463333	9.083333	2011	5.641666667
Nekemte	2080	36.463333	9.083333	2012	4.758333333
Nekemte	2080	36.463333	9.083333	2013	5.391666667
Nekemte	2080	36.463333	9.083333	2014	1.2

Nekemte	2080	36.463333	9.083333	2016	0.608333333
Nekemte	2080	36.463333	9.083333	2018	2.991666667
Nekemte	2080	36.463333	9.083333	1981	17.8
Nekemte	2080	36.463333	9.083333	1982	21.38333333
Nekemte	2080	36.463333	9.083333	1983	20.25
Nekemte	2080	36.463333	9.083333	1984	11.96666667
Nekemte	2080	36.463333	9.083333	1985	15.36666667
Nekemte	2080	36.463333	9.083333	1986	14.375
Nekemte	2080	36.463333	9.083333	1987	20.08333333
Nekemte	2080	36.463333	9.083333	1988	6.158333333
Nekemte	2080	36.463333	9.083333	1989	13.49166667
Nekemte	2080	36.463333	9.083333	1990	19.8
Nekemte	2080	36.463333	9.083333	1991	10.9
Nekemte	2080	36.463333	9.083333	2009	22.625
Nekemte	2080	36.463333	9.083333	2010	22.56666667
Nekemte	2080	36.463333	9.083333	2011	22.46666667
Nekemte	2080	36.463333	9.083333	2012	23.025
Nekemte	2080	36.463333	9.083333	2013	22.94166667
Nekemte	2080	36.463333	9.083333	2014	20.075
Nekemte	2080	36.463333	9.083333	1993	21.26666667
Nekemte	2080	36.463333	9.083333	1994	13.18333333
Nekemte	2080	36.463333	9.083333	1995	20.2
Nekemte	2080	36.463333	9.083333	1992	21.21666667
Nekemte	2080	36.463333	9.083333	1996	21.88333333
Nekemte	2080	36.463333	9.083333	1997	22.06666667
Nekemte	2080	36.463333	9.083333	1998	22.55
Nekemte	2080	36.463333	9.083333	1999	22.21666667
Nekemte	2080	36.463333	9.083333	2000	20.26666667
Nekemte	2080	36.463333	9.083333	2001	22.11666667
Nekemte	2080	36.463333	9.083333	2002	22.68333333
Nekemte	2080	36.463333	9.083333	2003	22.71666667
Nekemte	2080	36.463333	9.083333	2004	22.625
Nekemte	2080	36.463333	9.083333	2005	22.75
Nekemte	2080	36.463333	9.083333	2006	22.33333333
Nekemte	2080	36.463333	9.083333	2007	22.08333333
Nekemte	2080	36.463333	9.083333	2008	21.89166667
Nekemte	2080	36.463333	9.083333	2016	3.808333333
Nekemte	2080	36.463333	9.083333	2018	13.85833333

Nekemte	2080	36.463333	9.083333	1981	9.7
Nekemte	2080	36.463333	9.083333	1982	9.641666667
Nekemte	2080	36.463333	9.083333	1983	10.70833333
Nekemte	2080	36.463333	9.083333	1984	6.091666667
Nekemte	2080	36.463333	9.083333	1985	7.066666667
Nekemte	2080	36.463333	9.083333	1986	8.266666667
Nekemte	2080	36.463333	9.083333	1987	8.841666667
Nekemte	2080	36.463333	9.083333	1988	4.891666667
Nekemte	2080	36.463333	9.083333	1989	7.108333333
Nekemte	2080	36.463333	9.083333	1990	10.85833333
Nekemte	2080	36.463333	9.083333	1991	5.341666667
Nekemte	2080	36.463333	9.083333	1992	11.78333333
Nekemte	2080	36.463333	9.083333	1993	11.61666667
Nekemte	2080	36.463333	9.083333	1994	7.333333333
Nekemte	2080	36.463333	9.083333	1995	11.025
Nekemte	2080	36.463333	9.083333	1996	11.84166667
Nekemte	2080	36.463333	9.083333	1997	12.01666667
Nekemte	2080	36.463333	9.083333	1998	12.38333333
Nekemte	2080	36.463333	9.083333	1999	11.825
Nekemte	2080	36.463333	9.083333	2000	10.725
Nekemte	2080	36.463333	9.083333	2001	11.96666667
Nekemte	2080	36.463333	9.083333	2002	12.325
Nekemte	2080	36.463333	9.083333	2003	12.44166667
Nekemte	2080	36.463333	9.083333	2004	12.15
Nekemte	2080	36.463333	9.083333	2005	12.25833333
Nekemte	2080	36.463333	9.083333	2006	12.125
Nekemte	2080	36.463333	9.083333	2007	11.83333333
Nekemte	2080	36.463333	9.083333	2008	11.69166667
Nekemte	2080	36.463333	9.083333	2009	12.11666667
Nekemte	2080	36.463333	9.083333	2010	12.38333333
Nekemte	2080	36.463333	9.083333	2011	12
Nekemte	2080	36.463333	9.083333	2012	12.13333333
Nekemte	2080	36.463333	9.083333	2013	12.24166667
Nekemte	2080	36.463333	9.083333	2014	12.01666667
Nekemte	2080	36.463333	9.083333	2016	2.158333333
Nekemte	2080	36.463333	9.083333	2018	7.508333333

Angerguten	36.33333	9.266667	1981	92.7
Angerguten	36.33333	9.266667	1982	92.20833333
Angerguten	36.33333	9.266667	1983	96.10833333
Angerguten	36.33333	9.266667	1984	127.825
Angerguten	36.33333	9.266667	1985	115.2916667
Angerguten	36.33333	9.266667	1986	88.55833333
Angerguten	36.33333	9.266667	1987	87.06666667
Angerguten	36.33333	9.266667	1988	162.4083333
Angerguten	36.33333	9.266667	1989	249.6583333
Angerguten	36.33333	9.266667	1990	149.9416667
Angerguten	36.33333	9.266667	2006	16.7
Angerguten	36.33333	9.266667	2009	133.5666667
Angerguten	36.33333	9.266667	2010	95.05833333
Angerguten	36.33333	9.266667	2011	72.09166667
Angerguten	36.33333	9.266667	1981	72.91666667
Angerguten	36.33333	9.266667	1981	89.16666667
Angerguten	36.33333	9.266667	1981	90.75
Angerguten	36.33333	9.266667	1982	90.58333333
Angerguten	36.33333	9.266667	1982	79.58333333
Angerguten	36.33333	9.266667	1982	82.66666667
Angerguten	36.33333	9.266667	1983	31.08333333
Angerguten	36.33333	9.266667	1983	27
Angerguten	36.33333	9.266667	1983	24.08333333
Angerguten	36.33333	9.266667	1984	85.16666667
Angerguten	36.33333	9.266667	1984	55.33333333
Angerguten	36.33333	9.266667	1984	62.5
Angerguten	36.33333	9.266667	1985	85.91666667
Angerguten	36.33333	9.266667	1985	82.5
Angerguten	36.33333	9.266667	1985	82.91666667
Angerguten	36.33333	9.266667	1985	83.16666667
Angerguten	36.33333	9.266667	1985	83.91666667
Angerguten	36.33333	9.266667	1986	66.91666667
Angerguten	36.33333	9.266667	1986	68.25
Angerguten	36.33333	9.266667	1986	66.75
Angerguten	36.33333	9.266667	1986	67.75
Angerguten	36.33333	9.266667	1986	68.66666667
Angerguten	36.33333	9.266667	1987	12.58333333
Angerguten	36.33333	9.266667	1987	12.08333333
Angerguten	36.33333	9.266667	1987	5.333333333
Angerguten	36.33333	9.266667	1981	30.46666667

Angerguten	36.33333	9.266667	1982	27.8
Angerguten	36.33333	9.266667	1983	13.89166667
Angerguten	36.33333	9.266667	1984	30.61666667
Angerguten	36.33333	9.266667	1985	28.13333333
Angerguten	36.33333	9.266667	1986	27.55
Angerguten	36.33333	9.266667	2006	2.441666667
Angerguten	36.33333	9.266667	2009	25.90833333
Angerguten	36.33333	9.266667	2010	26.73333333
Angerguten	36.33333	9.266667	2011	20.65833333
Angerguten	36.33333	9.266667	1981	15.05833333
Angerguten	36.33333	9.266667	1982	8.341666667
Angerguten	36.33333	9.266667	1983	6.175
Angerguten	36.33333	9.266667	1984	12.325
Angerguten	36.33333	9.266667	1985	10.38333333
Angerguten	36.33333	9.266667	1986	8.683333333
Angerguten	36.33333	9.266667	2006	1.5
Angerguten	36.33333	9.266667	2009	12.86666667
Angerguten	36.33333	9.266667	2010	13.625
Angerguten	36.33333	9.266667	2011	10.04166667
Sasiga	36.81197	9.13333	2008	172.9416667
Sasiga	36.81197	9.13333	2009	57.04166667
Sasiga	36.81197	9.13333	2010	0
Sasiga	36.81197	9.13333	2011	197.9
Sasiga	36.81197	9.13333	2012	63.15
Sasiga	36.81197	9.13333	2013	171.975
Sasiga	36.81197	9.13333	2014	94.69166667
Sasiga	36.81197	9.13333	2015	67.01666667
Sasiga	36.81197	9.13333	2016	25.20833333

Appendix 2: Ground truth points with land use land classes

Point No.	POINT_X	POINT_Y	Land use description
1	217972	1021744	bare land
2	222078	1020870	bare land
3	219914	1020056	bare land
4	222285	1016664	bare land
5	223485	1019431	bare land
6	216751	1025676	bare land
7	218246	1032663	bare land
8	215370	1031740	bare land
9	220506	1023380	bare land
10	218732	1031494	bare land
11	220819	1023181	bare land
12	219986	1022564	bare land
13	221153	1025961	bare land
14	219073	1020884	bare land
15	221558	1018039	bare land
16	219953	1022423	bare land
17	219783	1028464	bare land
18	219880	1014058	bare land
19	219733	1030305	bare land
20	222177	1012585	bare land
21	218252	1021064	bare land
22	217758	1022407	bare land
23	219895	1018206	bare land
24	221066	1025622	bare land
25	217955	1021337	bare land
26	220633	1022220	bare land
27	219878	1023428	bare land
28	223448	1020991	bare land
29	221598	1011524	bare land
30	219038	1023390	bare land
31	221641	1016537	bare land
32	219075	1032945	bare land
33	220265	1019151	forest
34	217867	1034967	forest

35	215704	1030455	forest
36	220649	1014264	forest
37	222748	1022327	forest
38	219651	1018729	forest
39	222880	1018065	forest
40	215753	1029162	forest
41	218803	1013703	forest
42	223242	1015208	forest
43	215921	1029308	forest
44	216684	1022451	forest
45	214937	1030046	forest
46	221270	1013788	forest
47	219351	1025222	forest
48	218743	1034271	forest
49	220998	1018537	forest
50	218489	1032144	forest
51	221613	1016796	forest
52	216216	1030175	forest
53	219794	1017343	forest
54	222417	1022051	forest
55	215216	1029482	forest
56	219880	1034822	forest
57	221252	1011565	forest
58	220938	1027006	forest
59	220514	1021322	forest
60	219026	1032451	forest
61	217957	1020602	forest
62	216068	1023775	forest
63	220887	1015445	forest
64	217213	1029447	forest
65	215537	1029973	settlement
66	221691	1018721	settlement
67	221352	1014590	settlement
68	219719	1034480	settlement
69	218435	1018612	settlement
70	215581	1030330	settlement
71	216791	1034604	settlement

72	222039	1012827	settlement
73	221992	1018532	settlement
74	217208	1032886	settlement
75	222136	1018869	settlement
76	223147	1018792	settlement
77	221996	1007887	settlement
78	217346	1025617	settlement
79	221277	1018831	settlement
80	217481	1031408	settlement
81	220957	1009766	settlement
82	217484	1034253	settlement
83	223001	1020763	settlement
84	221791	1008010	settlement
85	216586	1028167	settlement
86	222940	1012756	settlement
87	217373	1032877	settlement
88	219659	1027732	settlement
89	216431	1030210	settlement
90	217663	1025524	settlement
91	221870	1007956	settlement
92	220118	1020075	settlement
93	222172	1016015	settlement
94	219986	1034426	settlement
95	215605	1030098	settlement
96	219520	1011453	settlement
97	221386	1008858	cultivation land
98	220958	1013549	cultivation land
99	214044	1027178	cultivation land
100	219318	1018357	cultivation land
101	217483	1029135	cultivation land
102	221454	1016992	cultivation land
103	219994	1017163	cultivation land
104	223308	1016878	cultivation land
105	215666	1031661	cultivation land
106	218520	1030612	cultivation land
107	220894	1011500	cultivation land
108	219482	1016229	cultivation land

109	214652	1026549	cultivation land
110	220736	1012697	cultivation land
111	222707	1014196	cultivation land
112	221449	1008704	cultivation land
113	219793	1016158	cultivation land
114	217298	1030607	cultivation land
115	219326	1011389	cultivation land
116	219549	1012702	cultivation land
117	220339	1009823	cultivation land
118	220050	1012905	cultivation land
119	219125	1028643	cultivation land
120	215762	1031258	cultivation land
121	216574	1031460	cultivation land
122	220352	1014296	cultivation land
123	219250	1015263	cultivation land
124	221256	1008785	cultivation land
125	216464	1031772	cultivation land
126	213815	1027956	cultivation land
127	216793	1023802	cultivation land
128	219685	1012485	cultivation land
129	221764	1009317	grass land
130	216139	1025252	grass land
131	218017	1027622	grass land
132	215706	1024048	grass land
133	216873	1022254	grass land
134	215207	1029365	grass land
135	217577	1027635	grass land
136	215246	1029608	grass land
137	214917	1027247	grass land
138	216312	1027503	grass land
139	218366	1021573	grass land
140	216552	1026925	grass land
141	222051	1025174	grass land
142	216940	1025550	grass land
143	221109	1008410	grass land
144	217048	1027128	grass land
145	221309	1023135	grass land

146	215953	1025746	grass land
147	216866	1027082	grass land
148	216058	1033271	grass land
149	217638	1031115	grass land
150	219927	1029374	grass land
151	218586	1026749	grass land
152	216850	1032341	grass land
153	218736	1019063	grass land
154	215286	1027566	grass land
155	217412	1028211	grass land
156	216950	1024030	grass land
157	218926	1026364	grass land
158	218505	1030774	grass land
159	216307	1024745	grass land
160	216445	1031635	grass land