



GIS BASED SOIL LOSS ESTIMATION USING USLE MODEL FOR SOIL CONSERVATION
PLANNING: IN KARESA WATERSHED, LOMA WOREDA, SOUTH WEST ETHIOPIA

MSc. Thesis

By

BAGEGNEHU BEKELE MENGISTU

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HAWASA UNIVERSITY
SCHOOL OF BIOSYSTEM AND ENVIRONMENTAL ENGINEERING
INSTITUTE OF TECHNOLOGY

GIS BASED SOIL LOSS ESTIMATION USING USLE MODEL FOR SOIL CONSERVATION
PLANNING: IN KARESA WATERSHED, LOMA WOREDA, SOUTH WEST ETHIOPIA

A Thesis submitted to the school of Biosystems and Environmental Engineering,

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Conservation Engineering

BY:-BAGEGNEHU BEKELE MENGISTU

Major Advisor :-Dr. Alemayehu Muluneh

Co advisor :-Dr. Nigatu Wondrade

Hawassa, Ethiopia

NOV, 2017

APPROVAL SHEET I

This is to certify that the thesis entitled “ GIS based Soil Loss Estimation using USLE Model in Karesa watershed , Loma Woreda, South West Ethiopia” submitted in partial fulfillment of the requirements for the degree of Master of Science in bio-system and environmental engineering, with specialization in soil and water conservation engineering, is a record of original research carried out by Bagegnehu Bekele Mengistu, Under my supervision, and no part of the thesis has been submitted for any other degree. The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirements.

Alemayehu Muluneh(PhD)

Major advisor

Signature

Date

Nigatu Wondrad(PhD)

Co- advisor

Signature

Date

APPROVAL SHEET II

We, the undersigned, members of the Board of Examiners of the final open defense by Bagegnehu Bekele Mengistu have read and evaluated his thesis “ GIS based Soil Loss Estimation using USLE Model in Karesa watershed, Loma Woreda, South West Ethiopia” and Examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Masters of Science in Bio-system and Environmental Engineering with Specialization in Soil and water conservation Engineering.

Chairperson	Signature	Date
<u>Mihret dananto (PhD)</u>	-----	<u>11/10/2017</u>
Major Advisor	Signature	Date
<u>Alemayehu Muluneh(PhD)</u>	-----	<u>11/10/2017</u>
Internal Examiner	Signature	Date
<u>Awdnegest Moges(PhD)</u>	-----	<u>11/10/2017</u>
External Examiner	Signature	Date
<u>Amare.B (PhD)</u>	-----	<u>11/10/2017</u>

Final approval and acceptance of the thesis is contingent up on the submission of the final copy of the thesis to the CGS through the DGC of the candidate’s department

DEDICATION

This thesis is dedicated to all my families

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my original work and all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree in Soil and Water Conservation Engineering at Hawassa University and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Name: Bagegnehu Bekele Mengistu

Place: Hawassa University

Date of Submission: NOV, 2017

e-mail address: bagegnehubekele@gmail.com

BIOGRAPHICAL SKETCH

The author was born on 27 December 1982 at Dawro Zone, Tocha Woreda , SNNPR,Ethiopia.

He attended his elementary school education in Tocha from 1987 to 1995, Tocha Secondary High school from 1996 to 1997. He attended preparatory at Waka Secondary School from 1998 to 1999. After completing his Preparatory program, he joined Mada Walabu University and studied a B.Sc. degree program in Natural Resource Management for three years from 2000 to 2002 and Graduated in 2002.

After graduation, he was employed at Essera Woreda Agriculture and Rural Development Office and Worked as Expert of Wild life resources Conservation and management and as a Coordinator of Participatory Forest Management Project in Natural Resource Department. During his service year, the author had trained Development Agents GPS and GIS application on watershed management, wild life resource conservation and management, scaling up of participatory forest management project for Sustainable Environment and livelihood improvement and Water harvesting techniques.

After 3 years of service in Essera Woreda Agriculture and Rural Development Office, he joined Worabe Agricultural Research Center under South Agricultural Research Institute(SARI) as Natural Resource Research Work process Coordinator and Soil and Water Conservation Researcher for two years and five months from 2006 to 2008. During his service year, the author had verified and demonstrated Conservation Agriculture (CA) technology for increased maize on dry land areas of Silte Zone, Farmer Research Group (FRG) based quantification and demonstration of soil loss from different soil conservation practices.

After 2.5 years of service in Worabe agricultural research center, he joined School of Graduate Studies at Hawassa University on 13/10/2015 to pursue his M.Sc. degree in Soil and Water Conservation Engineering.

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LIST OF ABBREVIATIONS

CREAMS	Chemical, Runoff and Erosion from Agricultural Management Systems
DEM	Digital Elevation Model
EEPCo	Ethiopian Electric Power Corporation
ETM+	Enhanced Thematic Mapper plus
EUROSEM	European Soil Erosion Model
EPIC	Erosion Productivity Impact Calculator
ENMA	Ethiopian National Meteorology Agency
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GPS	Global positioning system
IDW	Inverse Distance Weight
KE	Kinetic Energy
LS	Slope Length and Steepness
LULC	Land Use Land Cover
LWFNRDO	Loma Woreda Farm and Natural Resource Development Office
M.A.S.L	Mean Above Sea Level
MOA	Ministry of Agriculture
RS	Remote Sensing
SCRIP	Soil Conservation Research Project

SNNPR	Southern Nations Nationalities and People's Region
SLEMSA	Soil Loss Estimation for South Africa
SLM	Sustainable Land Management
SLT	Soil Loss Tolerance
SWAT	Soil and Water Assessment Tool
TM	Thematic Mapper
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
USA	United States Of America
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Program
WGS	World Geodetic System

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ABSTRACT

Soil erosion is the most challenging and continuous environmental problems resulting in both on-site and off-site effects in the world particularly in Ethiopia. Karesa watershed is one of the most erosion-prone watersheds which received little attention. Managing the on site erosion is to reduce the negative impacts of downstream water resources and requires an understanding of the rates of soil loss as well as identification of the major controlling factors that enhance or retard these processes. This study was conducted to estimate average annual soil loss rate using Geographic Information System and Universal Soil Loss Equation Model adapted to Ethiopian condition. The following datasets were obtained from different sources for estimating annual soil loss such as 15 years mean annual rainfall data for estimating Erosivity factor, digital soil map for estimating soil Erodibility factor, 30m x 30m resolution Digital Elevation Model for estimating slope length and slope steepness (LS) factor, Landsat6ETM+ images with 30mx30m resolution for detecting Vegetation cover and Conservation practice factor. Raster calculator was used to interactively multiply and produce annual soil loss. The result reveals that 42,413.72 ton per year soil loss from 9939 ha entire watershed and 4.27 tons per hectare per year average annual soil loss rate. The mean annual soil loss rate was classified in to four erosion severity classes as very less, less, moderate and High . The result also implies, two slope classes (0-15% and 15-30%) were categorized under very less to less soil loss (0-6.25 tons ha⁻¹yr⁻¹) which accounts an area of 9383.07 ha (94.4%) of the watershed areas and representing 81.13% of the total soil loss. On the other hand, the watershed slope classes (>30%) fell under moderate to High soil loss (6.25-25 tons ha⁻¹yr⁻¹) together covers 555.93ha (5.6%) of the watershed areas contributing 18.82% of the total soil loss mainly due to cultivation of marginal land, Intensive cultivation, poor vegetation cover during critical rainfall period. Moreover, about 2,184.93 ha of the watershed area was highly affected by erosion which contributes 18,182.25 tones yr⁻¹ (42.87%) total soil loss and requires integrated soil and water conservation measures.

Key words: GIS, USLE, Soil loss, Karesa Watershed, Conservation priority

1. INTRODUCTION

1.1. Background and Justification

Sustainability of agricultural production is majorly affected by land degradation. About 85% land degradation in the world is associated with soil erosion, most of which occurred since the end of World War II, causing a 17% reduction in crop productivity (Angima *et al.*, 2003). It is widespread in Africa and Asia, driven by high population pressure, land shortage and critical lack of resources for conservation by subsistence small holder farmers (Blanco and Lal, 2008). Its effects are also recognized to be severe threats to the national economy of Ethiopia due to cultivation on steep slopes, clearing of vegetation and over grazing (Tamene, 2005).

The impact of soil erosion results in on-site nutrient loss and off-site sedimentation of water resources in arid and semi-arid areas like Ethiopia where farmers are highly dependent on intrinsic land properties and unable to improve soil fertility through application of purchased inputs (Emrah *et al.*, 2007). Studies made in different parts of Ethiopia reported that annual soil loss show spatial and temporal variations. Based on the modeling, Soil Conservation Research Project (SCRIP) estimated that, about 1.5 billion tons of soil is eroded every year from the Ethiopian highlands (Hurni, 1984; Kruger, 1995). In the past FAO(1984); and Hurni(1993); reported annual soil loss from Ethiopian highlands to be 200-300 tons ha⁻¹yr⁻¹. Similarly, Hurni *et al.*, (2008) estimated that soil loss due to erosion of cultivated fields in Ethiopia amounts to about 42 tons ha⁻¹yr⁻¹. Tadesse and Abebe, (2014) also reported that, Ethiopia losses over 1.5 billion tons of topsoil annually from the highlands by erosion, that could have added about 1 to 1.5 million tons of grain to the country's harvest. The average crop yield from a piece of land in Ethiopia is very low mainly due to soil fertility decline associated with removal of topsoil by erosion (Sertu, 2000). As a result of soil erosion, Ethiopia losses USD 1 billion yr⁻¹ (Sonneveld, 2002) and still affecting 50 percent of the agricultural area and 88 percent of the total population of the country (Sonneveld *etal*, 1999). Erosion could also generate deposition of soil materials in the reservoirs, irrigation schemes and waterways downstream (Cerdeira and Doerr, 2008). Gibe-3, downstream of Gibe-1 and 2 are currently constructed by Ethiopian Government. After its completion, the dam will generate

the power capacity of 1,860MW (EEPCo, 2009). But, the storage volume of this reservoir is threatened by the soil erosion from the upstream of karesa watershed.

The severity and its impact of soil erosion require effective policy interventions and integrated soil and water conservation treatments to reverse soil degradation problems and this requires understanding of the rates of onsite erosion processes and its controlling factors that enhance or retard these processes. However, direct measurements of soil erosion are costly, labor intensive, and time consuming, spatial soil erosion model plays a vital role in the design of these interventions (Mirco *etal*, 2003).

Erosion prediction involves the use of process based, Empirical and conceptual models. However their large data requirement, the applications of process based models are not practical in Ethiopia and other developing countries (Sonneveld *et.al.*,1999). The most common empirical erosion prediction models are Universal soil loss equation(USLE) and Revised universal soil loss Equation (RUSLE). Universal Soil Loss Equation was used for the study because of its preferences to complex physical based models that can be implemented in situations with limited data and parameters inputs particularly as a first step in identifying sediment sources (Merritt *etal.*, 2003).

To meet the increasing demand of peoples on food, intensive agriculture will accelerate soil erosion in the country unless proper measures are taken to protect the soil (Gelaw *et al.*, 2013). This calls to develop conservation plan to protect the soil from erosion. Hence, designing of this plan requires effort on knowledge of spatial variations of soil erosion (Tamene *et al.*, 2006).

Though various studies have been conducted soil erosion at Omo gibe 3 basin and estimated soil erosion at woreda level (Example Gerawork, 2014) none of them have assessed soil erosion rate from specific watershed at woreda level for conservation planning. Therefore, the Objectives of this study were to: (1) To estimate values of soil erosion factors for the study area (2) to estimate the average annual soil loss rate and (3) to classify and prioritize critical erosion prone areas for conservation planning using USLE by integrating GIS and remote sensing technology.

1.2. Statement of the Problem

Soil erosion is a one of the most serious environmental problems in the world today, as it threatens agricultural and natural environment (Vrieling, 2006). Its associated effects are also recognized to be severe threats to the national economy of Ethiopia (Tamene, 2005) as result of loss of soil nutrients, declining crop yields and reduction in soil productivity in agricultural land use (Renard *etal.*1997). Moreover, soil moved by erosion carries nutrients, pesticides and other harmful farm chemicals into reservoirs, rivers, streams and ground water resources (Nyakatawa *etal.* 2001). However, different authors estimated the extent, magnitude and rate of soil loss in specific watershed, their result could spatially vary due to the variation of slope, climate, soil and land use and cover attributes, cropping pattern, geological structures and geomorphologic features (Renard *et al.*, 1997).

Though various studies have been conducted soil erosion at Omo gibe 3 basin and estimated soil erosion at woreda and kebeles level (Example Gerawork, 2014) none of them have assessed soil erosion rate from specific watershed at woreda level for conservation planning. USLE is used to estimate erosion rate from interaction of different factors from the catchment and GIS 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. Therefore, the tool of USLE with GIS technology could be used to speed, qualify, visualize and identify the erosion hotspot area for conservation planning (Saavedra, 2005).

1.3. Objectives

1.3.1. General Objective

To assess soil erosion rate Using Universal Soil Loss Equation (USLE) for Soil Conservation planning in Karesa watershed, South West Ethiopia.

1.3.2. Specific objectives

To estimate values of soil erosion factors for the study area

To estimate the average annual soil loss rate for the study area for the year 2016.

To classify and prioritize critical erosion prone area for conservation Planning

1.4. Significance of the study

Managing the onsite erosion is to reduce the risks and negative impacts of downstream water resources specifically Gilgelgibe-3 hydro-electric dam and improve upper soil fertility status due to water erosion. This study is initiated to estimate the extent of soil loss and develop soil loss intensity map which helps to identify severity areas, prioritize areas for specific soil conservation plans. The study also influences decision makers, land use planner and natural resource managers to formulate and implement effective soil conservation strategies. Moreover, the study will be used as a reference for others who want to conduct similar research.

2. LITERATURE REVIEW

2.1. Soil Erosion Status in Ethiopia

Soil erosion is defined as the gross amount of soil moved by drop detachment or runoff and Soil loss is the soil moved off a particular slope or field (Mitchell and Bubnezer, 1980).

Considering different Erosion factors, many researchers estimated soil loss by integrating USLE model with GIS and remote sensing. For example, Gebreyesus & Kirubel (2009) applied USLE, GIS and Remote sensing techniques and Estimated the average soil loss rate at Medego watershed, northern Ethiopia were $9.63 \text{ tons ha}^{-1} \text{ y}^{-1}$. Similarly, Ethiopian highland reclamation study FAO (1984), in mid 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. In the past, Ethiopian Highland Reclamation Study (FAO, 1986) also estimated that water erosion moves nearly 1.9 billion tons of fertile soil from highlands annually. Therefore, the soil formation rate for Ethiopia is less than 2 ton hectare per year which is low as compared to soil erosion rates. However, many researchers estimated soil erosion rate from the entire catchments using USLE model, their result could spatially and temporally vary due to the variation of rainfall, soil, topography, LULC and conservation practice factors (Renard *etal.* 1997).

2.2. Soil Erosion Studies and Limitations

Soil erosion and the consequent sedimentation are the major watershed problems in many developing countries like Ethiopia (Awulachew *et al.*, 2008). According to (Nanna, 1996) it is caused by the interaction between rainfall as an erosive agent and soil as a medium that is detached and transported. The major factors that increase soil erosion in Ethiopia are population growth, cultivation on steep slopes, clearing of vegetation and over grazing.

The effect of soil erosion was recognized in many parts of Ethiopia .In northern Ethiopia (tigray); soil moisture has been identified as the most limiting factor in agricultural production, loss of rain water through runoff as well as induced soil loss has been determined as a critical problem in the region in the last three decades. The high vulnerability of soil erosion in this

region is the result of mountainous and hilly topography, torrential rainfall and low degree of vegetation cover (Tewodros *et al.*, 2009).

2.2.1. Soil Erosion Models

There are different models available for estimating soil erosion rate from catchment. According to Petter, 1992, the objectives of soil erosion models are either predictability or explanatory. Soil erosion measurement on the field or using models at office level was started during 1940 and 1956.

Direct measurement of soil erosion in the field consider different factors like experimental area, topographic factors and soil types and is carried out at permanent research or experimental station based on bounded runoff plots with the above factors with which both runoff and soil loss are measured. Direct measurements of soil losses are costly, labor intensive, and time consuming, which may lead to few replications. Variability in data caused by differences in plot preparation or soil characteristics can result in misleading conclusions. Extrapolation of results from field experiments to field conditions can be made only with careful analysis. Field experiments can be classified as runoff plots and rainfall simulators (Foster *et al.*, 1999).

Erosion models can be classified based on the time and spatial scale for which a model can be used. It allow users to ascertain temporal trends, examine spatial variations, identify critical processes and explore the possible impacts of remedial measures and the relative effectiveness of implementations strategies for erosion and sedimentation controls (Baigorria and Romero, 2007). Black box, grey- box and white type model are mostly used in erosion assessment. Grey type is used by defining input factors through experiment, observation, measurement and statistical techniques, Grey box is used where some details of how the system works is known and White box is used where all details of how the system works is known. Even though this method was observed unsatisfactory in achieving the model objectives in assessing spatial variability of soil erosion, advanced models how erosion system works are in progress. Some models are designed to predict long-term annual soil losses and others predict single storm losses. Soil erosion models can simulate erosion processes in the watershed and take into account many of the complex interactions that affect rates of erosion. Available of data, time

and money can largely determine the choice of a particular model. Modeling in soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces. In general, the models fall into three main categories: conceptual, empirical and physically based models (Lal, 2001).

Empirical models-The most common empirical erosion prediction models are Universal soil loss equation (USLE) and Revised universal soil loss Equation (RUSLE). These models are a simplified representation of natural processes based on empirical observations and measurements. These models are frequently utilized for modeling complex processes and, in the context of erosion and soil erosion, particularly useful for identifying the sources of sediments (Merritt *et al.*, 2003).

Physical based models-Models that represent natural processes by describing each individual physical process of the system, which affect erosion, including the complex interactions between various factors and their spatial and temporal variability. Physical equations hereby describe natural processes, such as stream flow or sediment transport. Physically based models are able to explain the spatial variability of most important land surface characteristics such as topography, slope, aspect, vegetation, soil, as well as climate parameters including precipitation, temperature and evaporation. Soil and Water Assessment Tool (SWAT), CREAMS (Chemical, run-off and erosion from agricultural management systems), WEPP (Water erosion prediction program), EPIC (Erosion productivity impact calculator), EUROSEM (European soil erosion model) are examples of physically based models (Legesse *et al.*, 2003)

Conceptual models -These models are a mixture of empirical and physically based models and their application is more applicable to answer general questions like reflecting hypotheses about the process governing system behavior (Beck, 1987). According to Renschler (1996), conceptual models tend to include a general description of catchment processes, without including the specific details of process interactions, which would require detailed catchment information. This allows these models to provide an indication of the qualitative and quantitative effects of land use changes, without requiring large amount of spatially and temporally distributed input data (Merritt *et al.* 2003).

2.3.USLE Model

USLE is one of the most common empirical erosion prediction models which use different erosion factors like rainfall erosivity factor, Erodibility factor, topographic factor, crop and land management factor and conservation practice factor. It represent the effects of different factors value on soil loss rather than explicitly representing the fundamental processes of detachment, deposition, and transport by rainfall and runoff, It has been used widely used all over the world (Mellerowicz *etal.*,1994) including Ethiopia (Kaltenrieder, 2007). The underlying assumption in the USLE is that detachment and deposition are controlled by the sediment content of the flow. The erosion material is not source limited, but the erosion is limited by the carrying capacity of the flow. When the sediment load reaches the carrying capacity of the flow, detachment can no longer occur (Kaltenrieder, 2007)

2.3.1. Description of USLE Model

2.3.1.1.USLE factors

2.3.1.1.1. Rainfall erosivity factor

The amount and intensity of rainfall is the main climatic factor governing soil erosion by water. Erosivity of rain is the product of storm kinetic energy (KE) and maximum 30-minute intensity (EI30). There are Intensity of rainfall, size and velocity of rain drops are the major factors determining erosivity in the mid western USA. The higher rainfall intensity results in more soil erosion by water. The larger size of rain drop and higher velocity of rain drops have greater kinetic energy and will displace soil particles by larger distances than smaller. In the tropics, erosivity of rain is significantly higher than in moderate and cold climates. The semi – arid to semi-humid tropics are characterized by very high rainfall intensities and the total alternating with periods of no or little rainfall (Humberto & Lal, 2010). Rainfall events during dry seasons are of high intensity and thus, erosivity forces are very strong.

When other factors are constant, storm losses from rainfall are directly proportional to the product of total kinetic energy of the storm (E) times its maximum 30-minute intensity (I₃₀) (Wischmeier and Smith, 1958).

$$R = \frac{\sum_{i=1}^j (EI_{30})_i}{N} \quad [2-1]$$

Where, EI₃₀ = erosion index, KE = kinetic energy of the storm (metric tons/ha. cm) I= maximum 30 minutes rainfall intensity of the storm (cm/h). N= period in a year. This equation is only used for storms exceeding 12.5 mm for computation of EI₃₀ values.

The other common formula used to estimate the average annual erosivity is:

$$R = \sum_{i=1}^j (EI_{30}) \quad [2-2]$$

Where R = average annual rainfall erosivity ft·ton f·in·acre⁻¹ h⁻¹ yr⁻¹

EI₃₀ = the erosivity of individual storms, J = number of storms in the year

The energy of a rainstorm is a function of the amount of rainfall and of all storm's component intensities. The median drop size is generally increase with greater rain intensities (wischmeier and smith 1958), and the terminal velocity of free falling water drop increases with larger drop size (Gunn and kinzer 1949). As Laws and parsons (1943), the energy of a given mass in motion is proportional to the velocity squared; rainfall energy is directly related to rain intensity.

$$e = 916 + 311 \log_{10} i \quad i \leq 3 \text{ in.h}^{-1} \quad [2-3]$$

$$e = 1074 \quad i > 3 \text{ in.h}^{-1} \quad [2-4]$$

Where e is kinetic energy in ft.tonf.acre⁻¹ .in⁻¹ , and i is intensity in in. h⁻¹(wischmeier and smith 1958). A limit of 3 in. h⁻¹ is imposed on i because median drop size does not continue to increase when intensities exceed 3 in.h⁻¹(Carter *et al.*1974).

According to Foster et al.(1981b) the SI metric –unit version of the equations are as follow

$$e_m = 0.119 + 0.0873 \log_{10}(i_m) \quad i_m \leq 76 \text{ mm.h}^{-1} \quad [2-5]$$

$$e_m = 0.283 \quad i_m > 76 \text{ mm.h}^{-1} \quad [2-6]$$

where e_m has units of mega joule per hectare per millimeter of rainfall($\text{MJ.ha}^{-1} \cdot \text{Mm}^{-1}$)

Most of the time rainfall intensity and storm kinetic energy data are not available at national meteorological station. Therefore, using two to five years research data from SCRP site, Hurni(1985) established the regression equation to estimate R-factor for Ethiopian-Eritrean Highland condition using mean annual rainfall data as shown below

$$R = 0.562 * p - 8.12 \quad [2-7]$$

Where R is the rainfall erosivity factor in $\text{MJ.mm.ha}^{-1} \cdot \text{yr}^{-1}$ and P is the mean annual rainfall (mm)

Using five to eleven years from SCRP site, Kaltenrieder (2007) performed an adaptation of USLE to the Ethiopian-Eritrean Highland conditions and were found the following regression equation to estimates R-value from mean annual rainfalls in general (Eq. 2-8) and particularly to Gununo station (Eq. 2-9) with a correlation coefficient of 0.792 and 0.952 respectively:

$$R = 0.36 * P + 47.6 \quad [2-8]$$

$$R = 0.729 * P - 376.2 \quad [2-9]$$

where R is the rainfall erosivity factor ($\text{J} \cdot \text{m}^{-1} \cdot \text{hr}^{-1} \cdot \text{year}^{-1}$) and P is the mean annual rainfall (mm).

Most of the time rainfall intensity and storm kinetic energy data are not available at national meteorological station. By the absence of rain fall intensity and storm kinetic energy data for the specific study area, mean annual and monthly rain fall data have been used to estimate the R-factor (Arnoldus, 1978).

2.3.1.1.2. Soil erodibility factor (K)

Soil Erodibility factor (K) defines as mean annual rainfall soil loss per unit of K for a standard condition of bare soil, recently tilled up-and-down with slope with no conservation practices and on a slope of 5° and 22 m length (Morgan, 1994). According to Hurni (1985) and Hellden (1987) erodibility factor value developed for Ethiopian condition by adapting different sources and proposed the K values of the soil based on their color and their value ranges from 0 to 1.

Main determinants of soil erodibility are infiltration capacity and structural stability of soil which in turn depends on texture, structure, organic matter content, soil depth and other physical and chemical properties of the topsoil. Soil texture affects the susceptibility of soil to erosion. Sediments containing more clay are more resistant to erosion than sand or silt, because the clay helps bind soil particles together (Ibrahim, 2008). Whereas Soil containing high levels of organic materials often more resistant to erosion because it coagulate soil colloids and create more stable soil structure (Humberto *etal*,2010).

The other methods of computing Soil erodibility (K-factor) other than soil color is textural nomograph which is only suitable for less aggregated and medium textured soil as given by wischmeier et al,(1971). A useful algebraic approximation (Wishchimeier and smith 1978) of the nomograph for those cases where the silt fraction does not exceed 70% is given in the equation [2-10] below

$$K = \frac{0.00021 \times M^{1.14} (12-OM) + 3.25(S-2) + 2.5 (P-3)}{100} \quad [2-10]$$

Where OM- organic matter in percent

M- Product of primary particle size fractions :(% modified silt or particles size of 0.002 to 0.1 mm fraction size). (% silt + % sand), P- Soil profile permeability (saturated hydraulic conductivity class) and S- Soil structure cod. K is expressed as ton acre per erosion index unit with US customary units of tone acre.h

On basis of FAO soil classification, Tadesse & Abebe (2014) reported five major soil types namely, Chromic Vertisols, Pellic Vertisols, Lithosols, Orthic Luvisols and Eutric Nitosols from the study watershed and assigned k-values on the basis of soil color. Similarly, Gerawork (2014) reported five soil types from the study watershed namely Humic Nitosols, Chromic Luvisols, Lithic Leptosols, Eutric Vertisols and Humic Alisols from the study watershed and assigned K-values on the basis of Kaltenrieder (2007).

2.3.1.1.3. Slope steepness and Slope Length (LS) Factors

The effect of topography on erosion is accounted for by the LS factor in USLE, which combines the effects of a hill slope-length factor, L, and a hill slope-gradient factor, S. In the definition slope length(L_ factor) is defined as the point where the origin of the run-off to the point where run-off is concentrated with a defined channels or deposition occurs. The topography of the land determines the velocity at which surface runoff will flow, which in turn determines the erosivity of the runoff. Longer, steeper slopes (especially those without adequate vegetative cover) are more susceptible to very high rates of erosion during heavy rains than shorter, less steep slopes (Humberto *etal*, 2010). In USLE, for uniform slope both L and S are computed independently from the field and their combined effect(LS) is determined directly from effect of slope steepness chart where as for the non-uniform slope both are computed together using different formula (wishchimeier and smith,1978).

Slope length factor (L) - is the ratio of soil loss under actual slope length to the standard pilot. According to wishchimeier and smith (1978) reported the average erosion for the slope length λ (in ft) varies as shown below

$$L = (\lambda/72.6)^m \quad [2-11]$$

Where λ = horizontal projection, not distance parallel to the soil surface in ft

m = A variable Slope length exponent (wishchimeier and smith 1978)

72.6 = the USLE unit plot length in ft

The slope length exponent m is related to the ratio β of rill erosion (caused by flow) to interill erosion(principally caused by raindrop impact) by the following equation(Foster *et al.*, 1997):

$$m = \beta / (1 + \beta) \quad [2-12]$$

Values for the ratio β of rill to interrill erosion for conditions when the soil is moderately susceptible to both rill and interrill erosion were computed from (McCool *et al.* 1989)

$$\beta = (\sin \theta / 0.0896) / [3.0(\sin \theta)^{0.8} + 0.56] \quad [2-13]$$

Where θ = slope angle

Slope steepness factor(S)- is defined as the ratio of soil loss from the actual field slope steepness to that of standard slope steepness (9%). Soil loss increases more rapidly with slope steepness than it does with the slope length. The slope steepness factor(S) is evaluated from (McCool *et al.* 1987)

$$S = 10.8 \sin \theta + 0.03 \quad S < 9\% \quad [2-14]$$

$$S = 16.8 \sin \theta - 0.50 \quad S \geq 9\% \quad [2-15]$$

Interaction of angle and length of slope has an effect on the magnitude of erosion. As the result of this interaction, the effect of slope length and degree of slope should always be considered together (Edward, 1987), Wischmeier and Smith (1978)

$$LS = (X/22.1)^m (0.065 + 0.045 S + 0.0065 S^2) \quad [2-16]$$

$$X = (\text{Flow accumulation} * \text{Cell value}) \quad [2-17]$$

Where LS is slope length- steepness factor, X=slope length (m), m=a variable slope-length exponent, and S=slope gradient (%)

The slope length exponent (m-value) could vary. As the soil condition and management condition are more susceptible to rill erosion than inter rill erosion m-value increases, conversely, as the soil condition is less susceptible to rill erosion the value of m decreases. In other case, when there is deposition in the furrow between ridges, the soil loss is independent of slope length (in these case the value of m is zero). The value of m varies from 0.2 –0.5 depending of the slope as shown in table below (Wischmeier and Smith, 1978).

m-value

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

Interaction of angle and length of slope has an effect on the magnitude of erosion. As the result of this interaction, the effect of slope length and degree of slope should always be considered together (Edward, 1987). Soil loss is much more sensitive to changes in slope steepness than to changes in slope length. For slopes less than 20 percent, computed soil losses are similar in the USLE and RUSLE. However, on steep slopes, computed soil loss is reduced almost by half with the RUSLE (Kenneth, 1991). Tadesse and Abebe (2014) reported that derivation of slope length from the DEM in GIS environment is a very good cost and time effective methods than measuring at the field level. Several studies showed a relationship between the slope of the watershed and the erosion rate; the higher the slope, the higher the erosion risk (Hoyos, 2005, Andrade *etal*, 2010, Jha and Paudel, 2010).

2.3.1.1.4. Cover management factors(C)

Cover management factor is the crop or land cover management factor and measures the combined effect of all the interrelated vegetative cover and management variables. Vegetation acts as an interface between the atmosphere and the soil and increases the permeability of the soil to rainwater, thus decreasing runoff. The roots of the plants bind the soil together, and interweave with other roots, forming a more solid mass that is less susceptible to both water and wind erosion. The values of cover management factors can vary from 0 for very well protected soils to 1.5 for finely tilled, ridged surfaces that produce much run-off, leaving it susceptible to rill erosion (vander *etal*, 2000).

In USLE, C-factor value results from a temporal integration of the distribution of erosivity during the year and crop stage period. Experimental erosion data were used to determine cover-management factor values by crop stage period (soil loss ratios) (Wischmeier *et al.* 1978). Crop stage periods mark crop development and events like primary tillage, seedbed preparation, and harvest that change cover management conditions. Values for C are increased when the most erosive period coincides with the period when cover-management conditions are most vulnerable to erosion.

$$C = \sum (f_j c_j) \quad [2-18]$$

Where, f_j = the temporal distribution of erosivity during the year and j = an index for a “crop stage” time step. Experimental erosion data were used to determine cover-management factor (c_j) values by crop stage period (soil loss ratios).

Gizachew; Yihenew (2015) reported that Crop management C factor values of the study watershed were ranging from 0.01 to 0.15. Gizachew (2015) reported that Crop management C factor values of the study watershed were ranging from 0.01 to 0.35.

2.3.1.1.5. Support practice (P-factor)

The support practice factor is the support or land management practices that affect erosion. In USLE, the support practice is generally applied to disturbed lands and represents how surface and management practices such as contouring, terracing and strip cropping are used to reduce soil erosion. The values of the areas where there is no support practice the P-factor is set to 1.0 (Simm, 2003). According to Hurni(1985), P values of contour ploughing and terracing are 0.9 and 0.5 respectively. Due to absence of management practices in the study watershed, Gizachew & Yihenew (2015), and Gizachew(2015) used the P-values suggested by Wischmeier and Smith (1978) that consider only two types of land uses (agricultural and non-agricultural) and land slopes. They classified agricultural lands into six slope categories and assigned P-values. Their results indicated that most of the watershed was covered by wood land and crop cultivation

2.3.2. Limitations of USLE Model

The Universal Soil Loss Equation (USLE) is an empirically based model that predicts soil erosion from sheet and rill erosion. The USLE 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). GIS 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 (Saavedra, 2005). The model uses different input factors like rainfall pattern, soil type, topography, crop system and management practice factors and ability to predict the long term average annual rate of soil erosion (Renard *et al.*, 1997). USLE was designed primarily for agricultural regions, soil-erosion potential as identified in non-agricultural regions may be inconsistent (Hickey *et al.*, 2004). In USLE, environmental variables (RKLS) are relatively constant over the timescale of tens of years (at a minimum), while the management variables (CP) may change over the course of a year or less. Consequently, it is difficult to obtain current and accurate management variable coverage (Hickey *et al.*, 2004). Several algorithms are required when processing data for input into USLE. Each of those algorithms may accentuate existing errors in data. Because USLE requires six input data layers to be multiplied together, the errors inherent in each layer are similarly multiplied, contributing to an even greater error in the derived soil loss values (Shi *et al.*, 2002).

2.3.3. GIS and Remote Sensing in Soil Erosion Modeling

2.3.3.1. GIS application on erosion modeling

GIS is one of the tools used to model soil erosion and land degradation spatially and temporally. It isolates and query erosion hotspot locations to identify the role of individual variables in contributing to the observed erosion potential value (Fistikoglu & Harmancioglu, 2002; Hoyos, 2005). Understanding its usefulness, Abate (2011) reported that the use of GIS strengthens conservation planning and analysis of multi-layer data spatially and quantitatively within the study area.

2.3.3.2.Remote Sensing (RS)

Remote Sensing is a technology of gaining information on the characteristics of a phenomenon, object, or area by using electromagnetic (light) wave radiation without directly connecting with the object (Meer and Jong, 2004). The basic fundamentals in this technology are the properties of electromagnetic radiation and their interaction with matter. RS enables an analysis of the characteristics of vegetation cover by an analysis of electromagnetic waves reflected by the vegetation on earth surface represented in a form of images. Multispectral are used to differentiate different ground features and used to prepare thematic land use/land cover. In many studies, Satellite imagery has been well utilized for watershed characterization and management (Saxena *et al.*, 2000) and they have capability in measuring qualitative and quantitative terrestrial land-cover changes (Lu *et al.*, 2004).

2.3.4. Classification and prioritization of erosion prone area for conservation Planning

Many authors estimated the total and mean annual average soil loss potential of a specific watershed using USLE model integrating with GIS and remote sensing technology on the basis of SLT to Ethiopian condition which is from 5 to 11 tons ha⁻¹ y⁻¹ (Hurni,1985). Soil loss tolerance (SLT) denotes the maximum allowable soil loss that will sustain an economic and a high level of productivity (Wischmeier & Smith, 1978).By delineating watersheds as erosion prone areas according to the severity level of soil loss, priority is given for a targeted and cost-effective conservation planning (Kaltenrieder,2007). Gebreyesus & Kirubel (2009) categorized the mean annual soil (9.63 tons ha⁻¹ y⁻¹) of Medego watershed, northern Ethiopia on the basis of Singh and Phadke (2006) classes of soil loss range (very slight, slight, moderate, severe and very severe) which is under slight class of soil erosion (5 – 9.99 tons ha⁻¹ y⁻¹). landforms having very slight class of soil loss (0 - 4.99 tons ha⁻¹ y⁻¹) are the flat plains, undulating plains and the flat-flood prone areas; and followed by slight soil loss (5 – 9.99 tons ha⁻¹ y⁻¹) for the very steep escarpment of the watershed; and moderate soil loss class (10 – 24.99 tons ha⁻¹ y⁻¹) on rolling to hill landforms of the watershed, where as severe class of soil loss (25 – 44.99 tons ha⁻¹ y⁻¹) was estimated using USLE on slopes 30- 50%. According Gebreyesus & Kirubel, very slight to slight soil loss classes in the study watershed need high priority for SWC implementation using the available existing resource. Nature takes 200–400 years to build up 1

cm of top soil however thousand tons of soil is lost in a season from a watershed (Pimentel, 1995). Each millimeters of cultivated soil loss could cost 10 kg of nitrogen and 2 kg of phosphorus per ha (Pimentel, 1995). Soil loss estimated from landforms with very steep slope (> 50%) in the study watershed is smaller than slopes in the rage of 15-30% and 30-50%. The reason is cover factors and land management's factor are better in the very steeper slopes of the watershed and they are less exposed to human and livestock interferences, intensive terraces and relatively better vegetation cover of bushes and shrub.

3. MATERIALS AND METHODS

3.1. Study Area Description

Location

Karesa watershed is located in Loma Woreda of Dawro Zone of Southern Nation Nationalities and people's Region (SNNPR). It is located 282 km SW, Hawassa and 470 km SW, Addis Ababa. It is geographically located between $37^{\circ} 15' 0''$ E - $37^{\circ} 19' 0''$ E longitude and $6^{\circ} 51' 30''$ N - $7^{\circ} 01' 00''$ N latitude. The watershed covers 9939ha. The watershed has parts of twelve villages, namely Gesa Town, Tulema Tema, Gesa Chere, Olo-Woyde, Gumerkocho, Afuki Weyiro, Dode Angela, Ela Bacho, Subo Tulema, Fulasa Borze, Fulas Bale, and Gato Gufo.

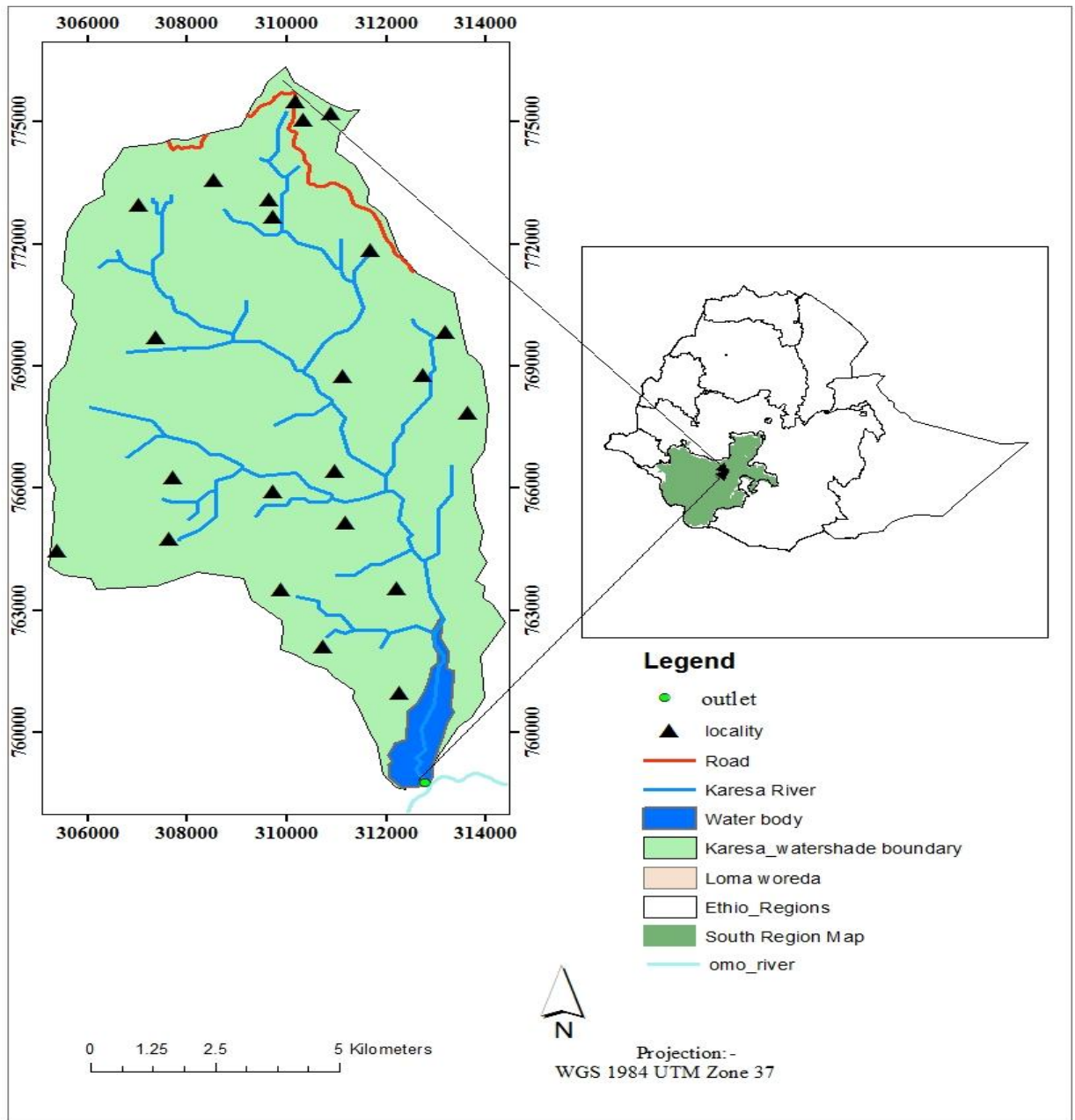


Figure 1. Location map of the study are

Topography

Karesa watershed covers 99.39 Km² areas. The major physiographic units found in the catchment area are: undulating, rugged, hilly topography. The watershed drains into the ***Omo Gibe III dam*** at upper part. Karesa watershed area is characterized with altitude ranging from 678 m.a.s.l around the Gibe III dam site (Southern edge) to 2489 m.a.s.l in the Northern ridge.



Plate 1. Partial view of watershed topography

Climate

There are no meteorological stations within the watershed but in the nearby three meteorological stations outside the watershed. Gessa station is far away 1 km from Gessa town, 27 km from Tercha station and 30 km from Halale Station. Based on the data obtained from three meteorological stations (Gessa Chere, Tercha and Halale), the annual rainfall of the study area ranges from 1636.49 mm to 1783.92mm. The 15 years average annual precipitation of the area is 1728.79 mm.

The rainfall is unimodal type but one long rainy season. March, April, May, Jun,,Jul.Aug, Sep and October receive >100mm Average annual rainfall. From three stations, Gessa chere station receives peak rainfall in August. The mean monthly rainfall of the study watershed is shown in fig. 2 below. Based on the three meteorological stations data (Gessa chere Tercha and Halale), the mean annual temperature varies from 14.2 °C to 26.6 °C.

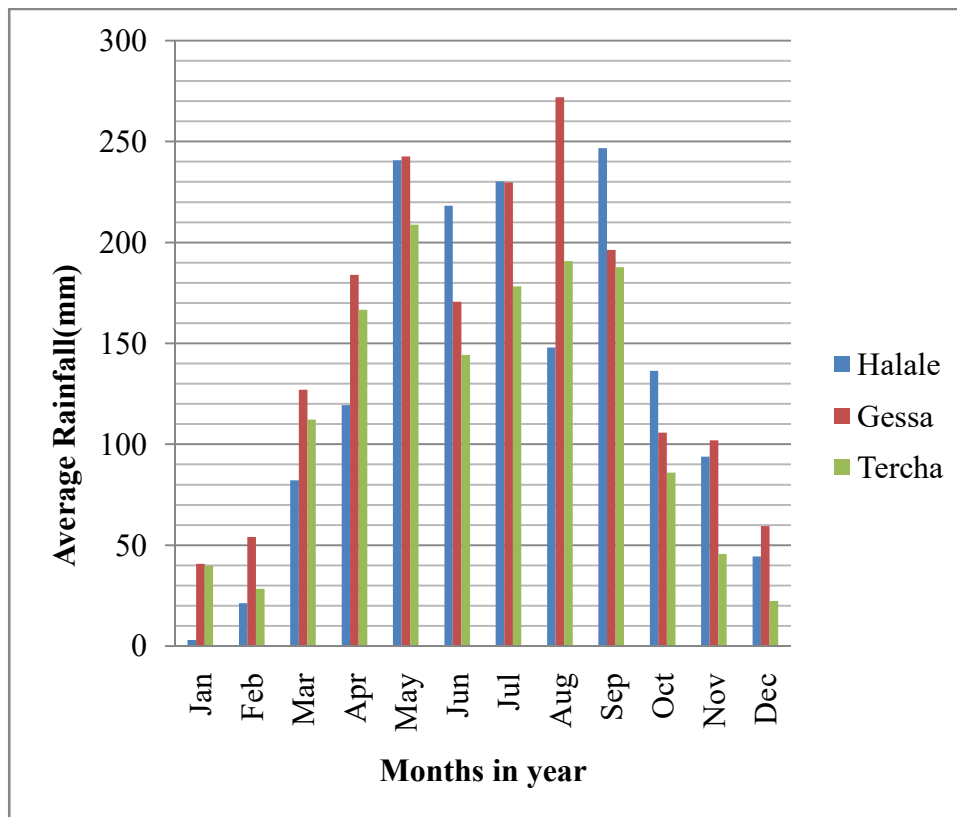


Figure 2: 15Years Mean Monthly Rainfall of the stations(2002-2016)

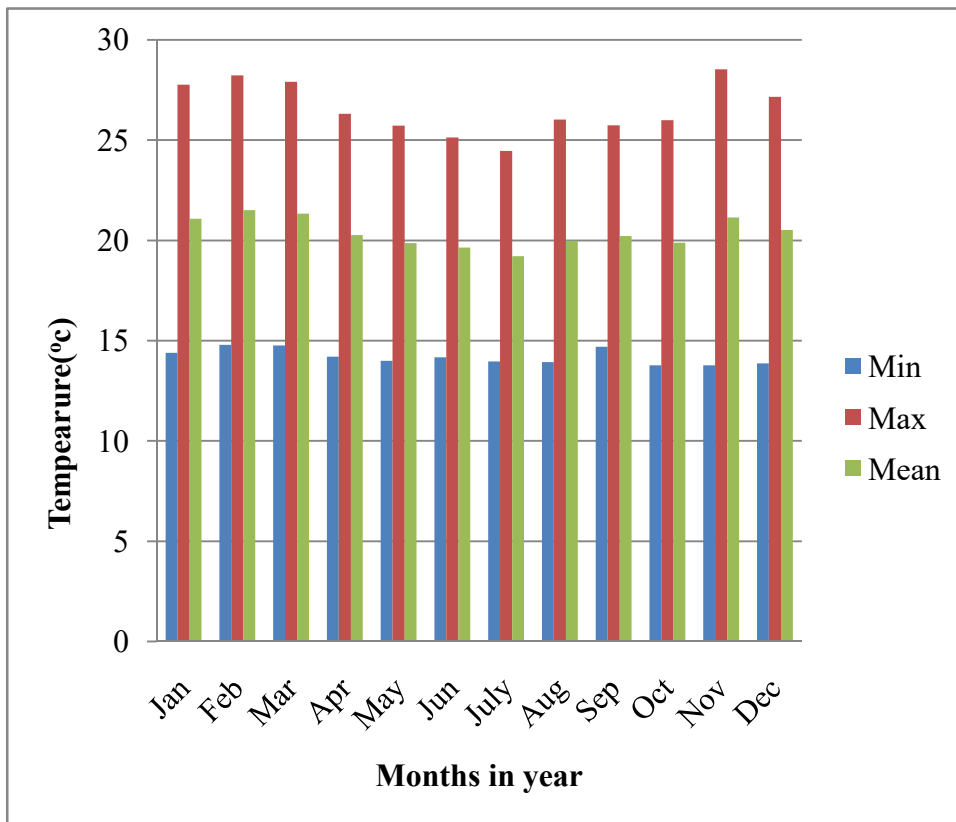


Figure 3. 15 Years Mean Monthly temperature of the stations (2002-2016)

Soils

According to FAO soil classification (2012) and visual interpretation of the area, Karesa watershed is covered by three major soil types which are *Humic Alisols*, *Eutric cambisols* and *Lithic Leptosols*. *Lithic Leptosols*, *Eutric cambisols* and *Humic Alisols* covers 8096.40 ha, 1118.94 ha and 723.66 ha respectively. *Leptosols* are the dominant soil types of the watershed.

Table 1. Major soil types, soil units and their Characteristics of the study area (FAO, 2012)

Major Soil types	Soil units	Characteristics
<i>Alisols (AL)</i>	<i>Humic</i>	Strongly acid soils with accumulated high activity clays in their subsoils. Surface horizons have low contents of high activity clays and iron oxides tend to have an unstable structure and reduced permeability which restricts internal soil drainage and increases the danger of erosion in sloping lands and yellowish red in color
<i>Leptosols (LP)</i>	<i>Lithic</i>	Thin soils or soils with many coarse fragments, Medium textured, and Excessive/well drained soils Soils that are either shallow (< 25 cm deep) over hard rock, or extremely gravelly (> 80% gravel, stones or boulders by volume) and brownish in color Low water holding capacity due to their limited depth or extremely coarse texture and brownish in color
<i>Cambisols(CM)</i>	<i>Eutric</i>	Soils with medium and fine-textured and have good structural stability, high porosity, and good water holding capacity and good internal drainage and brownish in color

Land use and Land cover

Land use

The Major land use/land cover units of the watershed area include cultivated land, Shrub land, Forest, Grass land and Water bodies. The cultivated land is dominant land use types which cover 41.21 % and the other land use such as Grass land, Forest, shrub land and water bodies' covers 58.79%. Cultivated land is Situated on the steep and undulating slope and in most parts of this land use, there is no conservation measures implemented. The farming system of the watershed is mixed farming with dominantly cereal crop production.

According to Loma Woreda Farm and Natural Resource Development department, the major crops grown in both upper and lower watershed are Maize, Sorghum, and Barely, teff, field pea, faba bean.

Table 2. Land use/land cover of Karessa watershed (Land sat image, 2016)

Land cover	Area coverage	
	Hectare	Percent
Cultivated land	4095.86	41.21
Grass land	1986.33	19.99
Forest	1627.28	16.37
Shrub land	1987.14	19.99
Water bodies	242.39	2.44
Total	9939	100

Vegetation

The vegetation cover of the study watershed is dominated by forest, Bush and shrub, Sesal plantation integrated with stone bund and banana plantation in the check dam are the common practices in the Western and southern parts of watershed while some *juniperus procera*, *gravilia robusta*, and *Eucalyptus* plantations are common in upper watershed (Field observation by the author, 2017).

As the elders in the watershed indicated, much of the Natural vegetation specially, Mountainous area of *Atso* forest has been destroyed due to uncontrolled felling and excessive cultivation.

Erosion Status

The upper, middle and lower catchments of the study watershed vary in their topography and management practices. Steepness of the land, intensive cultivation, and absence of conservation structures and deforestation are factors for soil erosion in the study area. As the result of these factors, there are visible erosion features like sheet and rill (very shallow channels formed by the concentration of surface run-off) at upper catchment parts of the watershed, both Erosion and deposition at the middle part of the watershed and deposition at lower catchment (Field observation by the author, 2017).

Population

The total population of Karesa watershed is estimated at 24,954 (10,800 in the upper, and 14,154 in the lower watershed (*LWFNRDO,2013*)).

3.2.Data Sources and Materials

3.2.1. Data Sources

Primary and secondary data was used as data sources. Primary data was collected by topographic transect walk & field observation. During transect walk Vegetation types, major LULC and land management practices including improved and local soil and water conservation measures implemented under different slope classes on agricultural land use in the study watershed was collected. Secondary data such as Land sat image ETM+ (30mx30m Resolution) acquired at March 5, 2016, FAO digital soil map, 30 m resolution DEM, Climatic data (time series temperature and rainfall data) and Soil conservation and farm management information was collected.

3.2.2. Materials and software used

Various materials and soft ware packages were used for the study namely Landsat6 ETM+ image with spatial resolution of 30m acquired at March 5, 2016 from Ethiopian Mapping Agency for land use land cover classification, Time series climatic data particularly rainfall and temperature (2002-2016) from National meteorology Agency Hawassa sub meteorological station, GPS to collect ground information of land use/land cover, Clinometers to measure slope and observe land management practices under different agricultural land slope classes, DEM and Digital soil map from Ethiopian Ministry of Agriculture to process each USLE factors, Erdas Imagine 9.2 for satellite image processing and ArcGIS 10.1 for DEM processing, watershed delineation, and soil loss analysis.

3.3.Methods of determining USLE factors

3.3.1. Determination of Rainfall erosivity (R_factor)

The erosivity factor for the erosive power of rainfall is related to the amount and intensity of rainfall over the year. Within the original Equation of USLE, the rain fall-run off erosivity factors are the products of kinetic energy of the storm and maximum 30 minute rain fall intensity (Renard *et al.*, 1997). Most of the time there is lack of data information on rainfall intensity and storm kinetic energy in developing countries like Ethiopia. In the study area, due to the absence of rain fall intensity and storm kinetic energy data, long term recorded monthly and mean annual rain fall data was used to estimate the R-factor on the basis of Kaltenrieder (2007) to Ethiopian condition.

15 years of monthly rainfall data for study watershed covering from 2002 to 2016 were collected from three meteorological stations (Gessa chere, Tercha and Halale) to estimate rainfall erosivity factor. In the Excell sheet, R_factor was calculated for each station using mean annual rainfall data from regression equation developed by Kaltenrieder (2007) to Ethiopian conditions as shown in Equation [3-1] below. The calculated point R_factor values were exported to ArcGIS10.1 and an attribute table was created. Continuous rainfall regime for each grid cell was generated and R_factor value map was produced from developed point using Inverse Distance Weighted (IDW) Interpolation, with 12 neighborhoods in spatial analyst tool. The cell size for interpolation was 30m. Then, Extraction by mask from command of spatial analyst tool was used to compute the mean annual rainfall map for the study watershed.

$$R = 0.36 * p + 47.6 \quad [3-1]$$

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

3.3.2. Determination of Soil erodibility (K_ factor)

Soil Erodibility Factor (K) defines as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up-and-down with slope with no conservation practices and on a slope of 5 degree and 22 m length (Morgan, 1994). It is an expression of inherent resistance to particle detachment and transport by rainfall and determined by the cohesive force between the soil particles, which may vary depending on the presence or absence of plant cover, the soil's water content and the development of its structure (Wischmeier and Smith, 1978) and depends on the amount of organic matter in the soil, the texture of the soil, the structure of the surface horizon and permeability (Robert and Hilborn, 2000). FAO digital soil map was collected from ministry of agriculture to derive soil map of the study watershed using clip extension from commands of 'Analysis tools' in GIS 10.1 Environment. Hence, the soil erodibility (K_ factor) were estimated based on Kaltenrieder (2007) soil erodibility estimation for different soil types adapted to Ethiopian condition as shown in the Table 3 below . On the vector soil data format, attribute table opened and the corresponding K-value collected was assigned for each of soil types based on value given by Kaltenrieder (2007) and changed to raster format using spatial Analyst tool convert from feature to raster. The raster data then converted in to grid format with a cell size of 30x30 m and reclassified using 'reclass' method in arc GIS 10.1 Environment.

Table 3. Soil Erodibility(K_Factor) value Estimated by Kaltenrieder (2007)

No	Soil type	Soil erodibility(K_ factor value)	
		Hurni(1985)	Kaltenrieder (2007)
1	<i>Humic Alisols</i>	0.28	0.22
2	<i>Lithic Leptosols</i>	0.22	0.24
3	<i>Eutric Cambisols</i>	0.33	0.35

3.3.3. Determination of Conservation practice (P- value) factor

It is the specific soil and water conservation practices implemented to reduce run-off speed and increase infiltration, ultimately lowering soil loss and sediment delivery (Renard and Foster, 1983).

P-factor is calculated for agricultural land only and for all other land use is assumed as 1, because there is no any control practice measures (Wischmeier and Smith, 1978). The P-value ranges from 0 to 1 depending on the soil management activities employed in the specific plot of land. To produce P-factor map of the study watershed, topographic transect walk was employed to assess major LULC and types of the existing soil and water conservation measures in agricultural land. Transect walk was carried out in two directions to obtain valuable watershed information from east to west and South to north. In addition, Interview of Woreda farm and natural resource department was carried out to assess major land use in the watershed and types of the soil and water conservation measures. According to woreda information, Karesa Watershed area was treated with different physical soil and water conservation measures by Meret project, SLM, safety net and agricultural extension program. During transect walk from East to West and South to North, in most part of the land slope classes, Small parts of the Watershed area have been treated with terracing .There is no improved permanent conservation measures practiced under different slope classes. Drainage ditch are the traditional conservation measures practiced to drain excess run-off during rainstorm in the farm land.

Land use land cover types were extracted from Erdas imagine 9.2, imported to arc GIS 10.1 Environment, coded in to two categories(Agricultural land and other land) and then converted in to raster format. The agricultural lands were classified into six slope categories. The two raster map i.e. land use and slope map (%) was combined using spatial analyst tool 'local' extension to get combined land use-slope map of the study area and the attribute table opened. Because of no permanent soil and water conservation measures implemented to control runoff, the corresponding P-value for the study watershed were collected from similar techniques used in Wischmeier & Smith (1978) was assigned for each land use.

Finally, the assigned P_ factor value were lookup in spatial Analyst tool extension Re-class, converted in to grid format with a cell size of 30x30 m and finally, reclassified using ‘reclass’ method in arc GIS 10.1 Environment.

Table 4. Estimated Support Practice(P-Factor) values

Land use type	Slope(percent)	P factor
Agricultural land	0-5	0.1
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other land use type	All	1.00

Source- Wischmeier & Smith,(1978); Gerawork(2014)

3.3.4. Determination of Topographic (LS_factor)

In USLE, the LS factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22 m plot (Robert & Hilborn, 2000). Slope steepness factors of the study Watershed in degree are generated from digital elevation model of 30 m x30 m spatial resolution using ‘Slope’ from Spatial Analyst Tool in arc GIS 10.1 environment. Slope length is defined as the point where the origin of the run-off to the point where deposition occurs. In this study, the slope length and slope steepness factors are commonly combined in a single index to compute topographic factor. Sin slope in degree was computed first. The Flow accumulation was computed from DEM after conducting fill and flow direction processes in arcGIS 10.1. Topographic factors (LS) are computed by multiplying the power of flow accumulation and sin slope. In arcGIS 10.1 environment, raster calculator from commands of “Spatial Analyst” Tool was used to multiply the power of flow accumulation and sin slope in degree to map the topographic (LS factor) as defined by (Wischmeier and Smith, 1978) as shown in Equation[3-2] below. Finally, LS factor map was converted in to grid format with cell size of 30m resolution.

$$LS = (\text{flow accumulation} \times \text{cell size} / (22.13))^{0.4} \times (\text{local sin slope}(\text{degree}) / 0.0896)^{1.3} \quad [3-2]$$

Where: Cell size represents the resolution of the grid (30m) and 22.13 is the length of the research field plot, flow accumulation is the number of cells contributing flow in to a given cell.

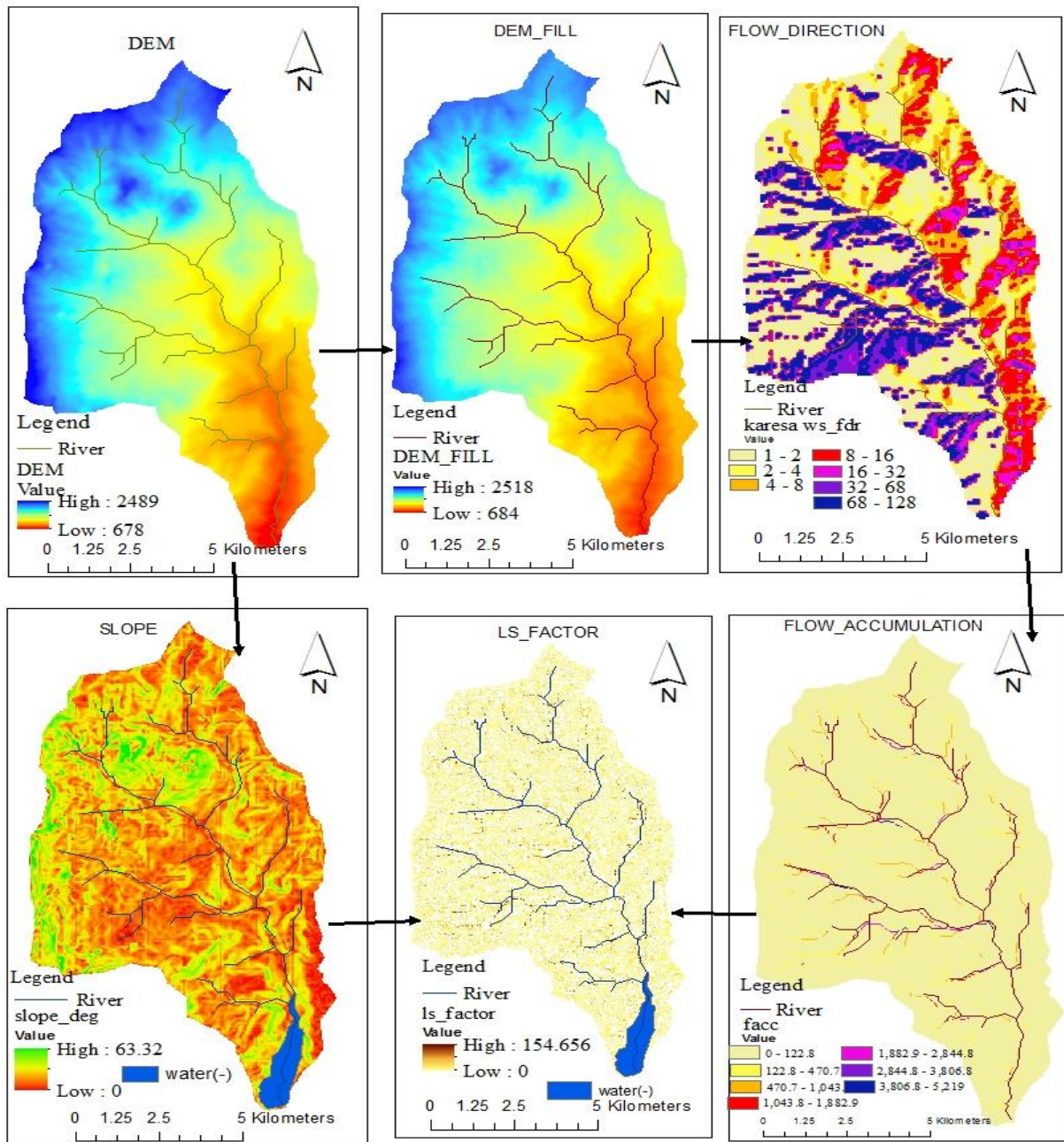


Figure 4. Derivation of topographic Map of the study area

3.3.5. Determination of Crop and management Cover (C_factor)

The crop management factor represents the ratio of soil loss under a given crop to that of the bare soil (Morgan, 1994). The cover management factor (C-values) reflects the effect of cropping and management practices on the soil erosion rate (Renard *et al.*, 1997).

Landsat6 ETM+ image with spatial resolution 30m x 30m resolution acquired on March 5, 2016 was used to derive Land use/ land cover map of the study watershed (Fig.10). Using signature editor of unsupervised classes, supervised image classification technique was employed to classify the current Land use land cover map using Erdas imagine 9.2 software. In supervised image classifications technique, land use and land cover types was classified to use the classified images as inputs for generating crop management (C) factor and support practice (P) factor. Based on the information collected from field, C_factor for the study area was estimated. Hence, during C_factor estimation for cultivated lands, the average C_factor values of the dominant crop types were used. Table 5 lists the average C_factor values for different land use categories of the study area. Then, the corresponding C-value was assigned for each of land use classes and it was converted in to raster format using a command spatial Analyst extension convert from feature to raster. The raster data then converted in to grid format with cell size of 30m x 30m and reclassified using 'reclass' method in arc GIS 10.1 Environment to obtain C_factor map of the study area.

Table 5. Estimated C_Factor values for Land use/Land cover Classes

Land use/cover type	C-factor	Sources
Forest	0.01	Hurni,1985
Cultivated land(cereals/pulses)	0.15	Morgan(2005)
Grass land	0.05	Morgan(2005)
Shrubs	0.014	Gelagay and Minale(2016)

3.4. Methods of Classification and prioritization of critical erosion area for conservation planning

To identify and prioritize critical erosion prone area for conservation planning, the average annual soil loss rate of the study area were categorized into four severity classes following (WBISPP, 2001). Since the normal SLT values for Ethiopian condition range from 5 to 11 t/ha/yr (Hurni, 1985), the study area erosion severity was classified on the basis of SLT. For priority areas of conservation planning:- High , Moderate , less and very less classes are need to be conservation priorities of the first, second, third, fourth order respectively.

3.5. Data analysis

3.5.1. Remote sensing data analysis

3.5.1.1. Image pre-processing; - All data collected from different sources may have different projections, spatial resolutions and data quality which produce errors on the final soil loss. To minimize errors on final soil loss, all the data was geo-referenced into Universal Transverse Mercator (UTM) and datum WGS-1984 Zone 37 and preprocessed before image processing, LANDSAT6 ETM + image acquired at March 5, 2016 was used and the Area of interest was delineated using Erdas imagine 9.2 software.

3.5.1.2. Image classification:- The objective of image classification is to automatically categorize all pixels in an image into land use/land cover classes. Using signature editor of unsupervised classes, supervised image classification technique was employed to classify the current Land use land cover map using Erdas imagine 9.2 software. 108 ground truth points on the major types of LULC from field using Global positioning System (GPS) for the year 2017 was collected and the Pixels of LULC classes having similar spectral classes was defined. Maximum likelihood image classification was utilized for the supervised image classification. In supervised image classifications technique, land use and land cover types was classified to use the classified images as inputs for generating management factors crop management (C) factor and support practice (P) factor.

3.5.1.3. Accuracy assessment

Accuracy assessment was carried to compare classified image with field data. The major cover types within the study watershed are cultivated land, Forest, Bush and shrubs, Water bodies and Grass land. To assess accuracy assessment, it is important to compare the remote sensing driven classification map and the reference test information (Jensen, 1996). Error matrix is most commonly used to summarize the relationship between remote sensing driven classification and reference test information and usually aligned in columns and rows. The ground truth point was located at columns of error matrix where as Predicted classes for the random sample point is aligned in rows. Classification accuracy was calculated by dividing the sum of diagonal cells to the total number of cells. Kappa statistical scale (0-1) was used to measure the classification accuracy (>0.8 strong agreement, 0.4-0.8 Moderate and <0.4 poor agreement (Congleton, 1991). Kappa statistical scale is lies between 0 and 1. The value >0.8 strong agreement, 0.4-0.8 Moderate and <0.4 poor agreement. In this study, the overall classification accuracy is $(2 + 12 + 6 + 13 + 14) / 54$ which is equal to 0.87 or 87 percent which is under strong agreement range as shown in the table 6 below.

Table 6. Overall classification accuracy and Kappa statistics

Class name	Water bodies	Bush and shrubs	Grassland	Cultivation	Forest	Row total
water bodies	2	0	0	0	0	2
Bush and shrubs	0	12	4	0	0	16
Grassland	0	0	6	2	0	8
Cultivated land	0	0	0	13	0	13
Forest	0	1	0	0	14	15
Column total	2	13	10	15	14	54

3.5.2. Soil loss analysis

Both quantitative and qualitative data analysis techniques were used. GIS layers were formed in raster format for both Environmental (RKLS) and management factors (C and P) as input for the USLE model. Each factor were converted in to grid with a cell size of 30x30 m and multiplyied by their respective values in arc GIS 10.1 using raster calculator from command of spatial analyst. The output map was converted to hectare basis to obtain the annual soil loss per hectare per year. In order to minimize errors on soil loss, all the USLE factor layers were projected to WGS 1984 UTM Zone 37N. The following procedures as shown in the figure 5 below were used to generate the factor grids and produce the soil loss potential of the study watershed in the arc GIS environment.

$$A=R*K*LS*C*P \quad [3-3]$$

Where: - A = Annual soil loss in ton/ha/yr, R =Rainfall erosivity factor in MJ mm.ha⁻¹.yr⁻¹

K= Soil erodibility factor in t.hr. MJ⁻¹ . mm⁻¹, LS = Slope Steepness and Slope Length factor (dimensionless), C = Cover factor (dimensionless), P= Conservation practice factor (dimensionless).

UNIVERSAL SOIL LOSS EQUATION ANALYSIS IN GIS

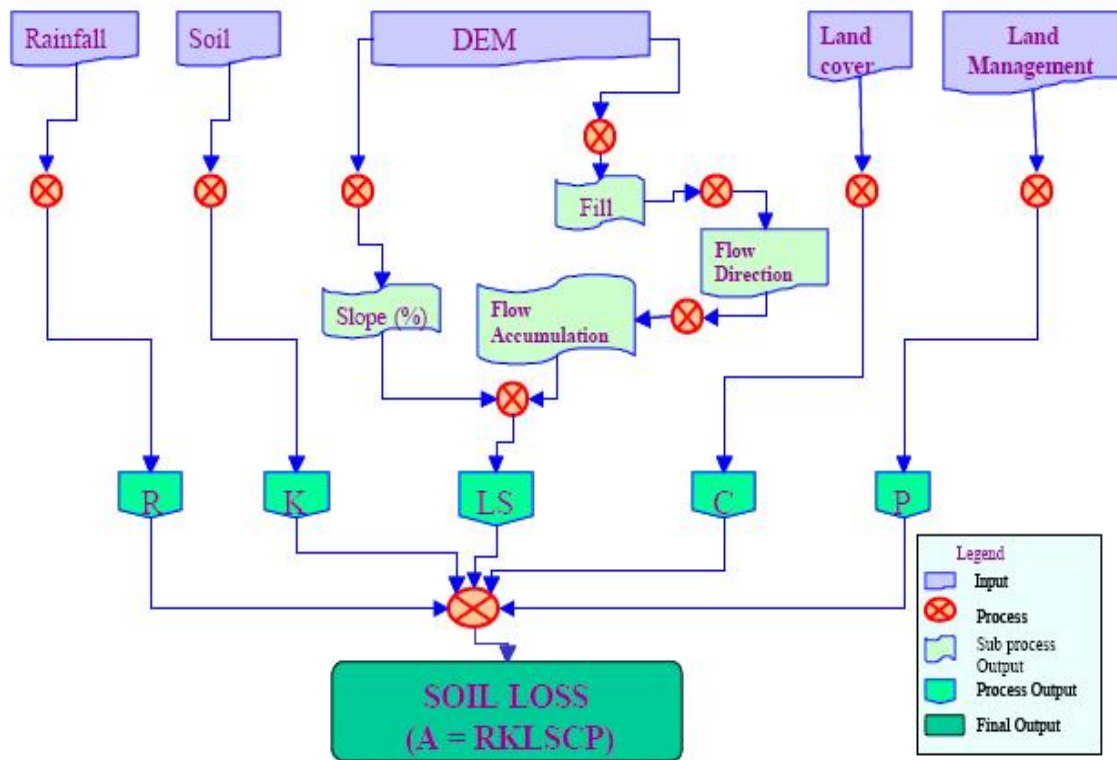


Figure 5. Flow chart of USLE model to estimate soil loss rate in Arc GIS Environment

4. RESULTS AND DISCUSSIONS

4.1. Rainfall erosivity (R_{Factor})

The distribution of Average annual rainfall of the study area for 15 years period is different from place to place in the watershed. The average of 1636.5 – 1685.1mm annual rainfall regime have R-value of 636.7 -654.2 MJmm ha⁻¹ yr⁻¹, 1685.1-1719.7 mm have R-value of 654.2- 666.7 MJmm ha⁻¹ yr⁻¹, 1719.7-1750.9mm have R-value of 666.7-677.9 MJmm ha⁻¹ yr⁻¹ and 1750.9-1783.9mm have R-value of 677.9- 689.8 MJmm ha⁻¹ yr⁻¹. This shows that the Value of R_{Factor} could vary according to rainfall distribution. The average annual rainfall of karesa watershed is ranging from 1636.49 to 1783.92mm. For the average of 1728.79mm average annual rain fall, the R-factor value in the watershed ranged from 636.7 to 689.8 MJmm ha⁻¹ yr⁻¹. From Fig.7, about 75.65% of the study watershed areas have R_{Factor} values greater than 666.71 MJmm ha⁻¹ yr⁻¹ with the maximum R_{Factor} values of 689.8 MJmm ha⁻¹ yr⁻¹. The remaining 24.34% of R_{Factor} values ranges from 654.22 to 666.71 MJmm ha⁻¹ yr⁻¹. The rainfall erosivity is higher at the Northern part, and decreases at its Southern part. Therefore, the rainfall distribution of the study area clearly explains its high potential to cause erosion at its northern and low at Southern part. The average R-factor value in the watershed was 669.96 MJmm ha⁻¹ yr⁻¹, which are within the ranges of Amsalu and Mengaw (2014) estimated erosivity factor value for Jabi Tehinan Woreda, ANRS, and Ethiopia from 441.5 to 1166.4 MJmm ha⁻¹ yr⁻¹.

Table 7. Stations Mean annual rainfall and Erosivity factor result

stations	Location			Available data	Average Annual precipitation(m)	No of years	Erosivity(R)
	Longitude	Latitude	Altitude	Duration			
Gessa chere	37.283	7.024	2251m	2002-2016	1784.06	15	689.86
Tercha	37.068	7.148	1335m	2002-2016	1410.91	15	555.53
Halale	37.337	6.750	1854m	2009-2015	1584.35	7	617.97

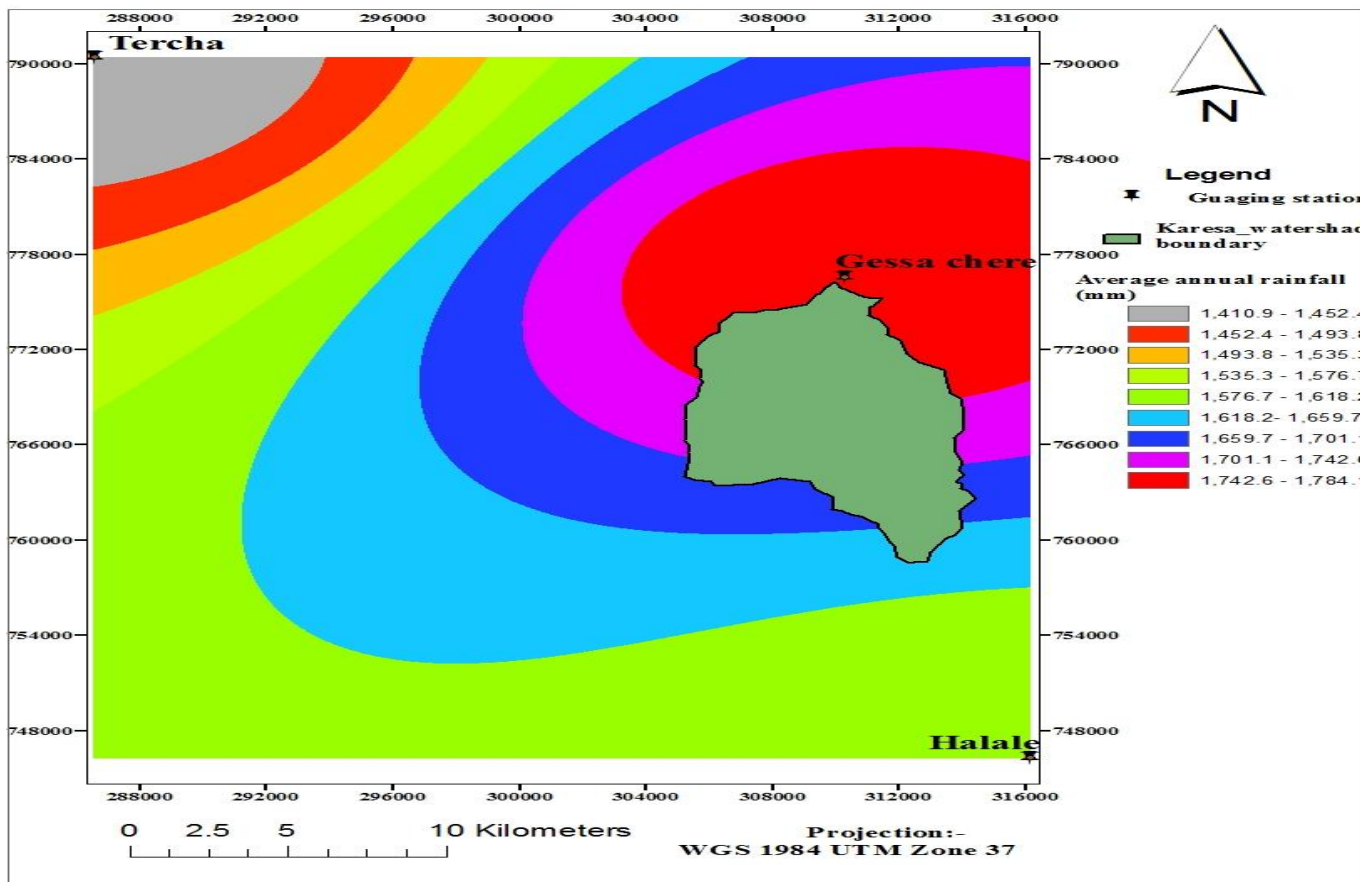


Figure 6. Meteorology station and Rain fall interpolation result map

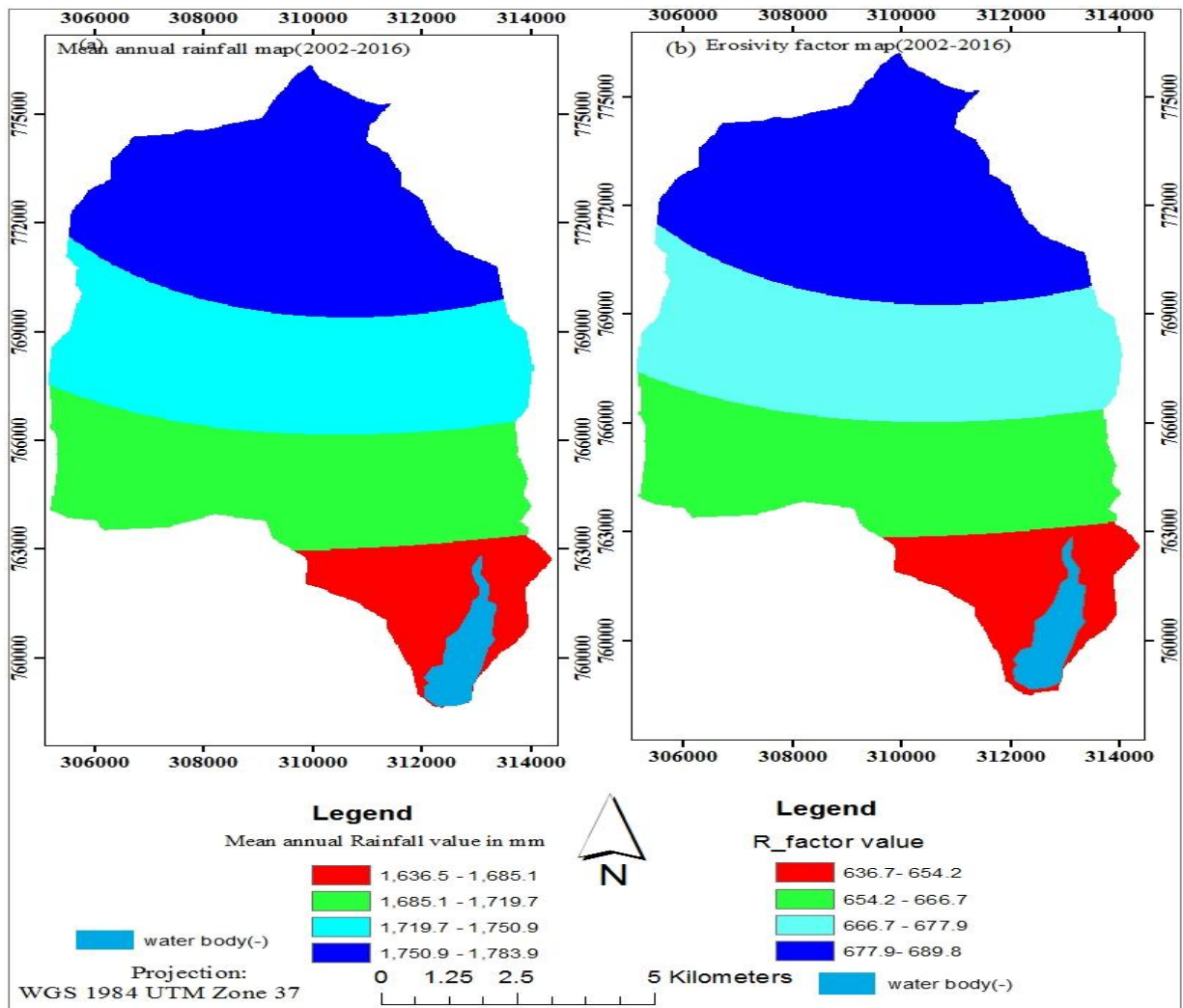


Figure 7. (a) Mean Annual rainfall Map and (b) Erosivity(R-factor) Map of the study area

4.2. Soil Erodibility (K_Factor)

Three major Soil types were identified from the study watershed including *Humic Alisols*, *Eutric Cambisols*, and *Lithic Leptosols* as shown in **Fig (8)** below. The erodibility values and proportion from the total area are *Humic Alisols*-0.22(7.28%), *Eutric Cambisols*-0.35(11.26%), and *Lithic Leptosols*-0.24(81.46%).The soils of the study area contain three distinctive erodibility values which range from 0.22 to 0.35. Higher value indicates more susceptibility while lower value indicates less susceptibility to erosion. The susceptibility of soil to erosion in the study water shed is expressed by very shallow, soils with thin or many fragments and low water holding capacity of *Leptosols*, high accumulated clay in the subsoil of *Alisols*, and soils with medium and fine-textured *cambisols*. The soil in the study area is dominated by

Leptosols having > 80% coarse fragment. According to Mati *et al.*, 2000 Soils high in sand content were poorly aggregated and structurally weak which contribute to easy soil disintegration. Therefore, they were easily detached and transported by runoff.

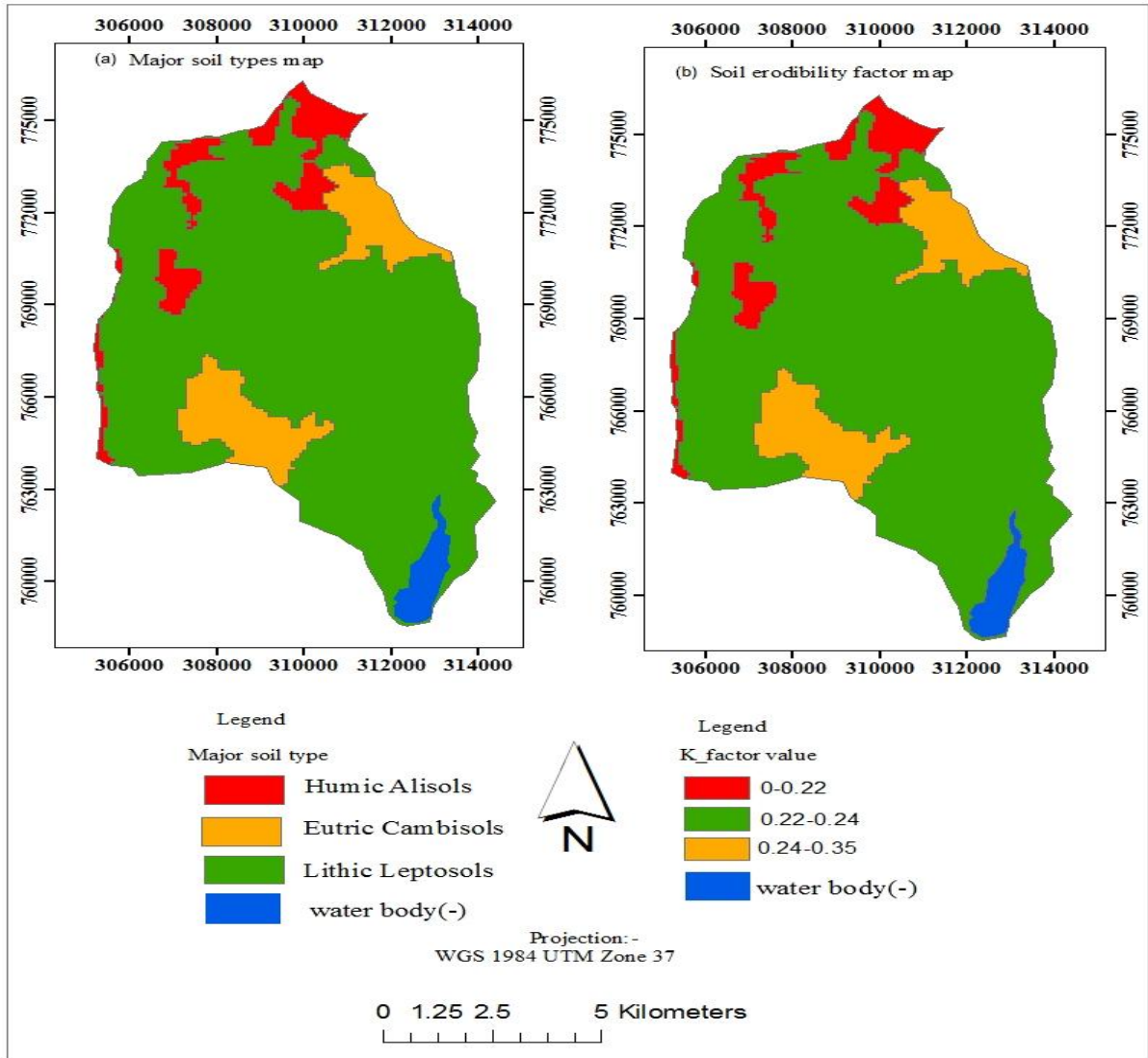


Figure 8. (a) Major soil types (b) Soil Erodibility(K_factor) map of the study area

4.3. Topographic (LS_Factor)

Interaction of angle and length of slope has an effect on the magnitude of erosion. As the result of this interaction, the effect of slope length and degree of slope should always be considered together (Edward, 1987). In this study, LS factor were computed from 30m x 30m resolution DEM data in the arc GIS environment. The result shows that, the LS factors of the study area ranges from 0 in flat areas to 154.6 steeper and longer slope area of the water shade in Fig 9. The increments of LS factors from 0 to 154.6 shows that the potential erosion increases as the slope steepness increases. 51.15% of the study area have slope gradient <30%(Flat to moderately steep) , 48.85% of the study area have slope gradient >30%(steep slope). This clearly shows that the landform of the study area contributes for high soil loss rate. The steeper and longer slopes are combined in 48.85% of the area to result in higher runoff velocities and, therefore, greater potential for erosion. Longer, steeper slopes especially those without adequate vegetative cover are more susceptible to very high rates of erosion during heavy rains than shorter, less steep slopes (Humberto *et al.*, 2010). The data shows that factors taking into account the topography (LS factor) are affecting in a stronger way the erosion process (Adediji *etal*,2010).

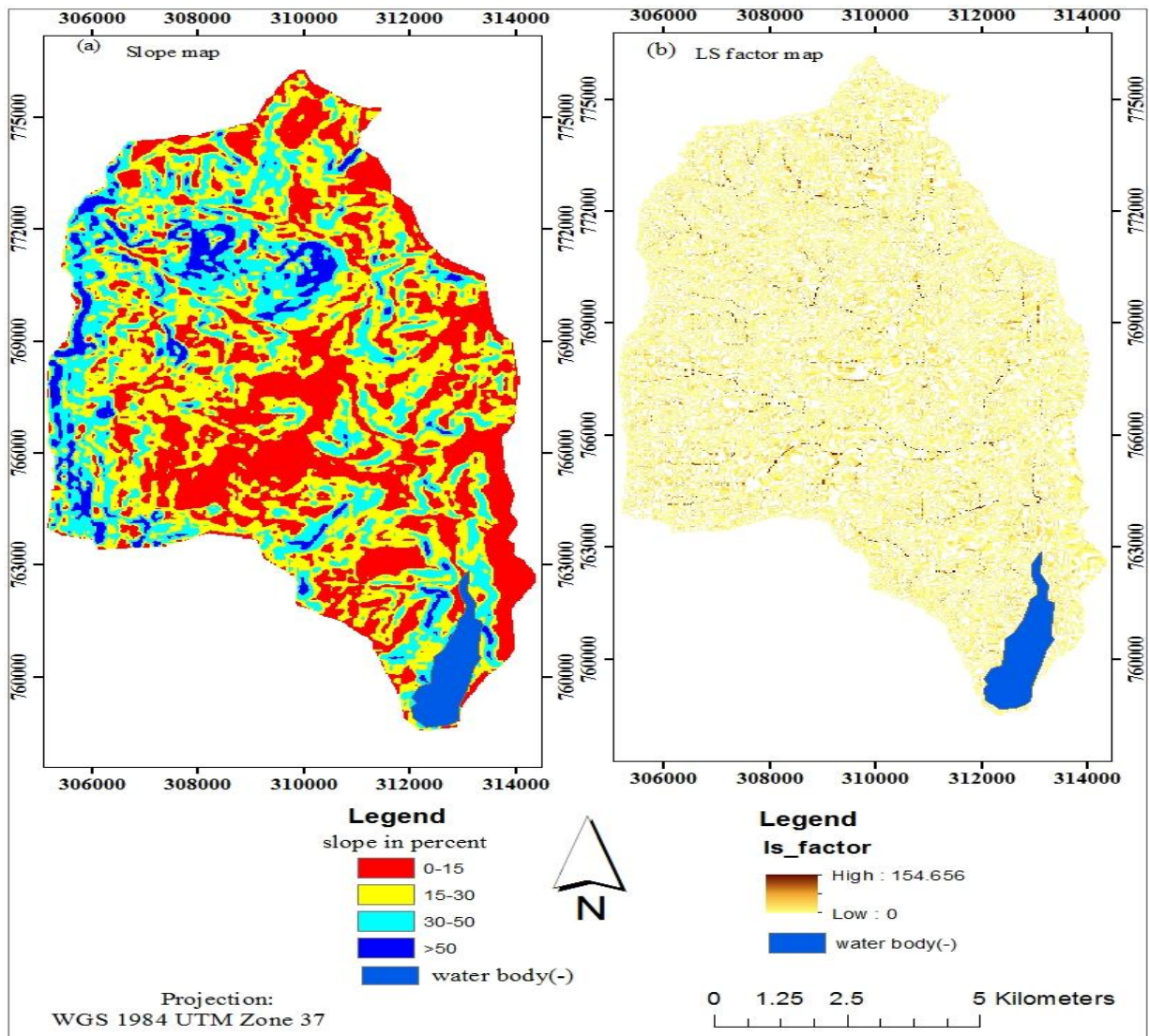


Figure 9. Topographic Factor(LS_factor) map of the study area

4.4. Cover and management (C_Factor)

Based on the analysis, the study water shed LULC was classified into five classes namely Cultivated land, Forest, Bush and shrubs, Grass land and water body as shown in **Fig.10 below**. Cultivated land is the dominant land use type in the study area which covers 41.21% of the total study area, while other land use covers 58.79%. The C-factor result for the study water shed ranges from 0.01 for the area covered by natural vegetation to 0.15 cultivated land, which is similar with the finding of Gizachew; Yihenu(2015) reported that Crop management C_factor values of the Guang watershed ranging from 0.01 to 0.15. Based on the study area LULC result, there is variation on c-factor value. Cultivated lands have maximum

c-value. This condition results on higher soil erosion rate. Study shows that finely tilled, ridged surfaces produce much run-off, leaving it susceptible to rill erosion (vander *etal.*2000).

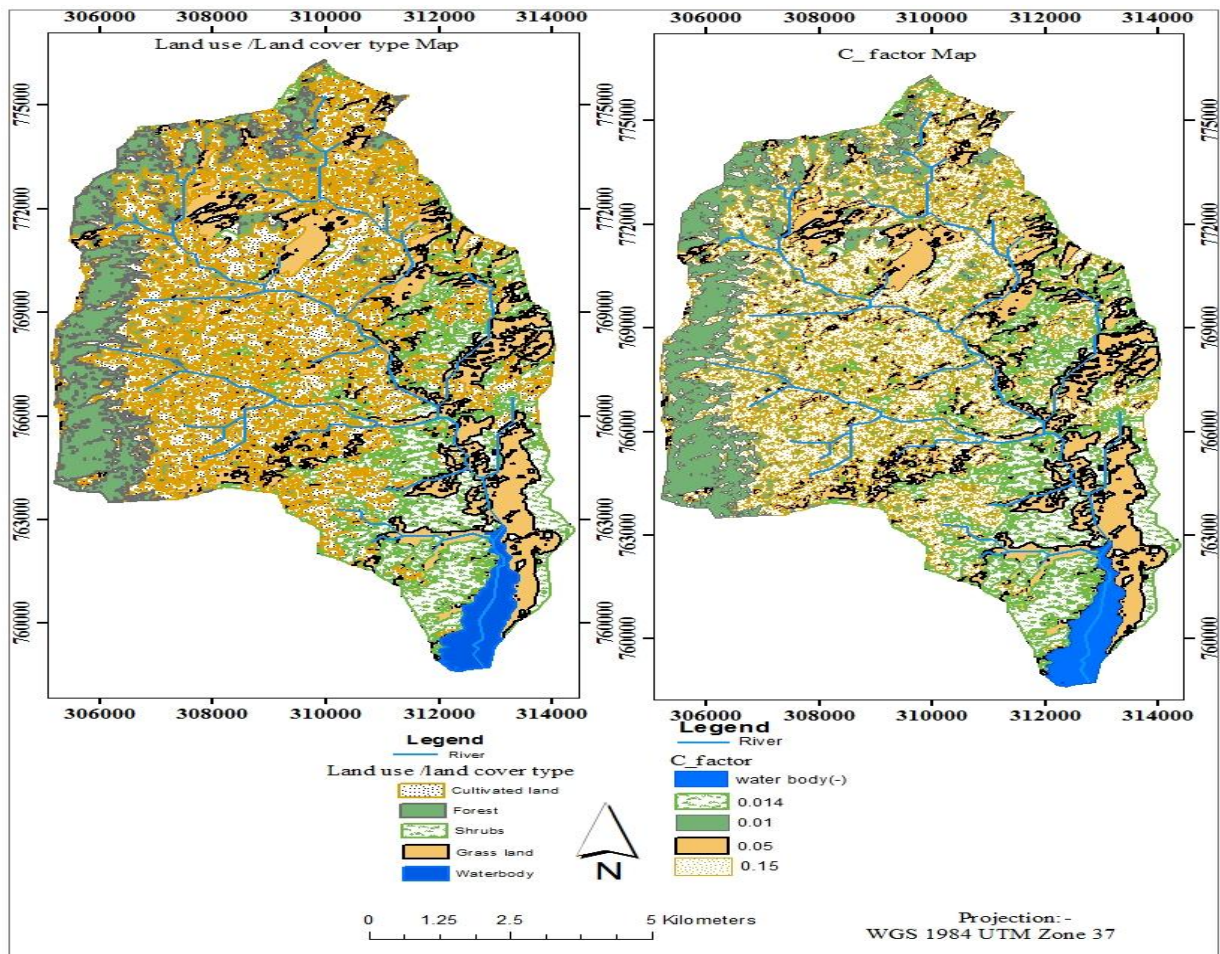


Figure 10. (a) Land use /Land cover type map (b) Cover (C_factor) Map of the study area

4.5. Conservation practice (P- Factor)

From 41.21% of cultivated land most of the area was covered by cereal cultivation where as 58.79% was covered by other land use which has P value of 1 in Fig.11. Even though, a small part of watershed area was treated by terracing, periodic maintenance of structure by land users were ignored. This condition coupled with poor vegetation cover in watershed area has large influence on soil loss rate. According to Renard *etal.*1997, conservation practice factor is an expression supporting conservation practices such as contour farming, strip cropping, terracing, and subsurface drainage on soil loss at a particular site, which principally affect

water erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the volume and rate of runoff.

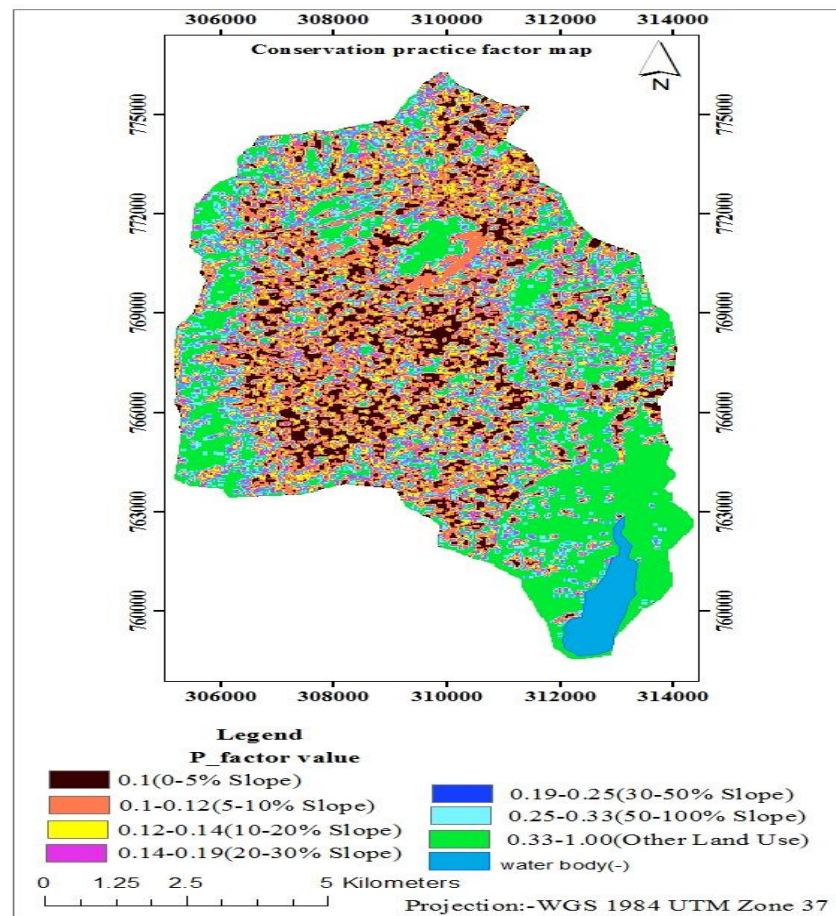


Figure 11. Conservation practice (P_ factor) Map of the study area

4.6. Soil loss Estimation, classification and prioritization for conservation planning

4.6.1. Soil loss rate Estimation

The annual soil loss rate of the study watershed was determined by a cell-by-cell analysis of Each RUSLE factors. Each factor were converted in to grid with a cell size of 30x30 m and multiplied by their respective values in arc GIS 10.1 using raster calculator from command of spatial analyst. The mean annual soil loss rate map of the study watershed ranges from 0 tones $\text{ha}^{-1} \text{yr}^{-1}$ in the flat areas to a little over 25 tones $\text{ha}^{-1} \text{yr}^{-1}$ in steep slope of the watershed

in Fig.12 and table 8. The soil loss rate map of the study watershed has been divided in to four classes of erosion severity and its largest categories were that of 0-3.125 tons ha⁻¹yr⁻¹.

The total and mean annual soil loss rate estimated by the USLE model for the study watershed was **42,413.72** tons yr⁻¹ and **4.27** tones ha⁻¹ yr⁻¹ from 9939 ha respectively. The amount of estimated annual average soil loss rate for the study watershed is low as compared to the past studies. For example, Tadesse and Abebe (2014) reported 30.4 tones ha⁻¹ yr⁻¹ soil loss for jabi tehinan woreda in the north western high land. Gerawork (2014) estimated the soil loss from Loma woreda as 10.28 tones ha⁻¹ yr⁻¹. Similarly, Gebreyesus & Kirubel (2009) estimated soil loss due to erosion of Medego watershed as 9.63 tons ha⁻¹ y⁻¹, Hurni (1988) ;and Hurni *et al.*(2008) estimated that soil loss due to erosion of cultivated fields in Ethiopia amounts to about 42 tones ha⁻¹ yr⁻¹ and in the past, FAO (1986) reported the annual average soil loss rate for Central and Northern high land as 35 tones ha⁻¹ yr⁻¹. Therefore, the relatively low estimated average annual soil loss in the current study watershed could be due to the topography, which is largely flat to moderately steep (< 30%), which accounts 51.15% of the watershed area. The other reason could be due to the contribution of different soil conservation interventions implemented by different project and agricultural extension program for at least the last decades in the country in general and the study watershed in particular in decreasing the rate of soil loss.

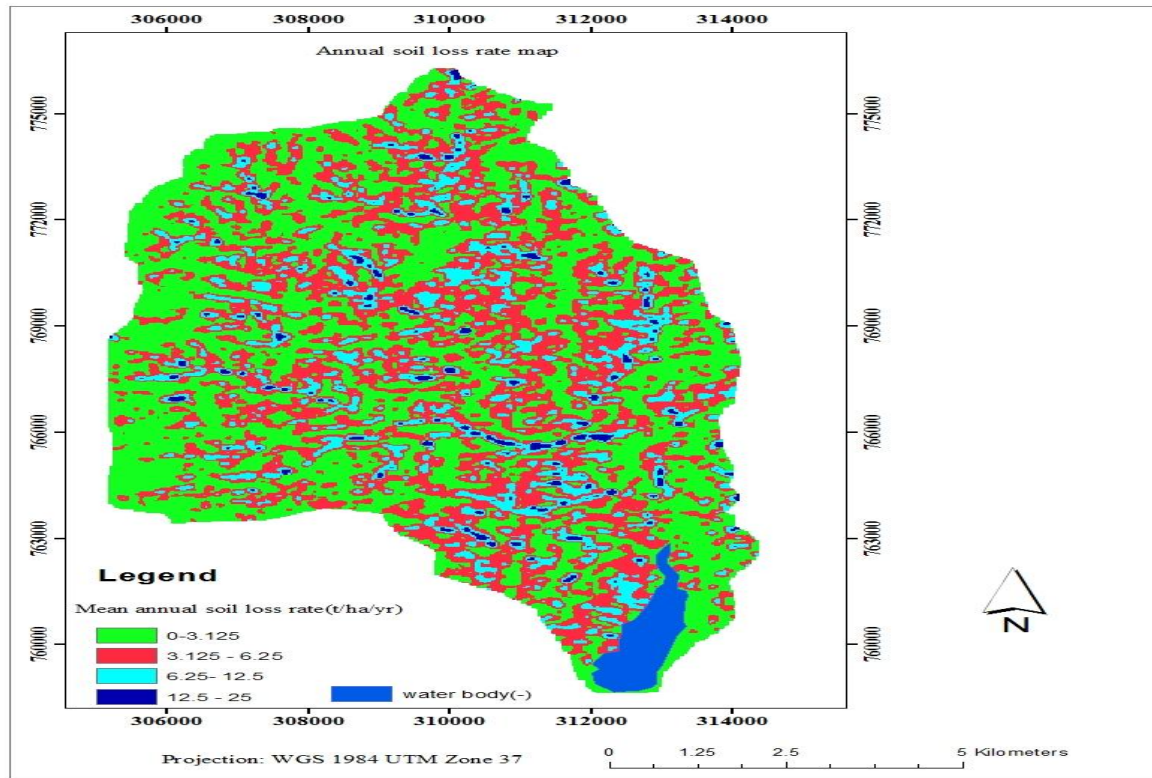


Figure 12. Soil loss rate map of the study area

4.6.2. Classification and prioritization of critical erosion prone area for conservation planning

One of the objectives of this study was to classify and prioritize critical erosion prone areas for conservation planning. Therefore, delineation of micro watersheds as erosion prone areas according to the severity level of soil loss, priority is given for a targeted and cost-effective conservation planning (Kaltenrieder, 2007). According to WBISPP (2001), the mean annual soil loss potential of the study watershed ($4.27 \text{ tones ha}^{-1} \text{ yr}^{-1}$) was classified into four soil erosion severity classes ($0-3.125 \text{ tones ha}^{-1} \text{ yr}^{-1}$ as very less, $3.125-6.25 \text{ tones ha}^{-1} \text{ yr}^{-1}$ less, $6.25-12.5 \text{ tones ha}^{-1} \text{ yr}^{-1}$ moderate and $12.5-25 \text{ tones ha}^{-1} \text{ yr}^{-1}$ High). The threshold for each of the risk level is presented in Table 8 and Fig.12. The final risk classes was Prioritized for intervention on the bases of the maximum allowable soil loss that will sustain an economic and a high level of productivity (Wischmeier & Smith, 1978). Based on result, the mean annual soil loss rate for the entire watershed ($4.27 \text{ tons ha}^{-1} \text{ yr}^{-1}$) is within the tolerable soil loss of $5-11 \text{ tons ha}^{-1} \text{ yr}^{-1}$ estimated for Ethiopia by hurni (1985).

Table 8. Annual soil loss rates, Severity classes and conservation priority of the study area

Soil loss rate(t/ha/yr)	Equivalent top soil removal(m m)	Severity classes	Priority	Area coverage (ha)	Proport ion of total area(per cent)	Total Annual soil loss (tone per year)	Proporti on of total soil loss(per cent)
0-3.125	0-0.25	Very less	4	7754.07	78.01	24231.47	57.13
3.125-6.25	0.25-0.5	Less	3	1629	16.39	10181.25	24.00
6.25-12.5	0.5-1	moderate	2	471.78	4.75	5897.25	13.91
12.5-25	1-2	High	1	84.15	0.85	2103.75	4.96
Total				9939	100	42413.72	100

As shown in the table 8 above, 555.93ha (5.6%) of the watershed area experiencing moderate to high erosion severity classes which was estimated from steep slope watershed classes (>30%) and representing 18.82% of the total soil loss (more than 0.5mm of topsoil removal per annum) which requires the conservation priority of first and Second order . These areas in the watershed was highly affected by erosion, with soil loss rate higher than SLT, greater than 6.25tons ha⁻¹ yr⁻¹ .our current result clearly shows as slope steepness increases, the severity of erosion increases. Several studies shows that the relationship between the slope of the watershed and the erosion rate; the higher the slope, the higher the erosion risk (Hoyos, 2005). The main causes of high soil erosion on steeper bank of the watershed area could be due to in appropriate land management practices like deforestation, cultivation of marginal land,Intensive cultivation, poor vegetation during critical rainfall period. In our study area watershed slope classes the largest soil loss rate could be mainly due to High Erosivity(R_factor) value from heavy rainfall, Erodibility (K_factor), high LS value specially slope steepness, soils without support practice factors(p=1, which accounts 58.79%) (Fig 7, 9, 11).

Flat to moderately steep (0-30%) watershed slope classes experiencing very less to less erosion severity classes which accounts 9383.07 ha (94.4%) of the watershed areas and representing 81.13% of the total soil loss. These areas remove less than 0.5mm topsoil per annum and requires third and fourth conservation priority. The soil loss rate in this flat to moderately steep parts of watershed area are low as compared to steep slope (>30%) due to the forest, bush and shrub, Sesal plantation integrated with stone bund and banana plantation in the Western and southern parts of watershed and *junipers procera*, *gravilia robusta*, and *Eucalyptus* plantations in upper parts of watershed.

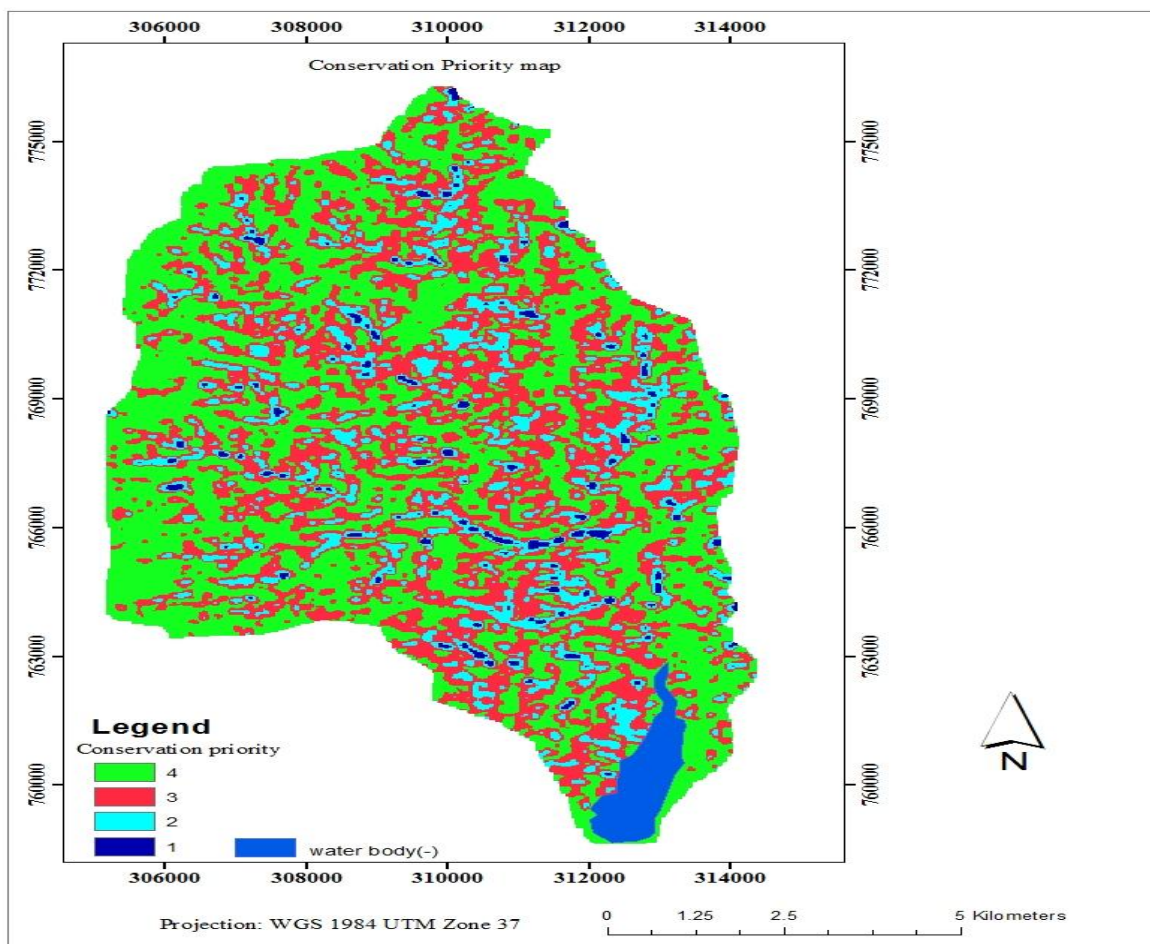


Figure 13. Conservation priority map

Field observation report reveals that, the steeper parts of the land slope lack vegetative cover and coupled with intensive tillage operation, in adequate soil and water conservation measures, ignorance of land users periodically maintain structures such as removing sediment from the channel and repairing the embankment was the major problems identified and resulted high soil loss potential in this area. In general, the final result in table 8 and Fig.12 reveals that , 2,184.93 ha (21.99%) of the watershed area was affected by erosion which contributes 18,182.25 tones yr⁻¹ total soil loss which accounts greater than 0.25 mm top soil removal. According to Pimentel (1995) nature takes 200–400 years to build up 1 cm of top soil however thousand tons of soil is lost in a season from a watershed this calls sustainable soil and water conservation strategies for the study area.

5. SUMMARY AND CONCLUSIONS

5.1. SUMMARY AND CONCLUSIONS

The objective of this study was to assess soil erosion rate in Karessa watershed which is located in Loma woreda. Both Environmental (RKLS) and management factors (C and P) grid were established in GIS layer and each factors value was estimated and mapped. Therefore, from the empirical erosion models, USLE integrated with geographical information systems and remote sensing technology is an effective tool to provide information for decision makers, land use planner and natural resource managers to formulate and implement effective soil conservation strategies.

The total and average annual soil loss estimated in karesa watershed as **42,413.72** tons yr⁻¹ and **4.27** tons ha⁻¹yr⁻¹ from **9939** ha respectively. Of the four erosion severity classes (0-3.125 tons ha⁻¹yr⁻¹ , 3.125-6.25 tons ha⁻¹yr⁻¹ , 6.25-12.5 tons ha⁻¹yr⁻¹ , 12.5-25 tons ha⁻¹yr⁻¹) two erosion severity classes (6.25-12.5 tons ha⁻¹yr⁻¹ and 12.5-25 tons ha⁻¹yr⁻¹) which account 5.6% of the total watershed area experiencing annual average soil loss rate greater than the watershed average of 4.27 tons ha⁻¹yr⁻¹ where as the other two erosion severity classes(0-3.125 tons ha⁻¹yr⁻¹ and 3.125-6.25 tons ha⁻¹yr⁻¹) represent 94.4% of the total watershed area at which annual soil losses were within the range of annual average.

The result also reveals that, two slope classes (0-15% and 15-30%) categorized under very less to less soil loss (0-6.25 tons ha⁻¹yr⁻¹) which accounts an area of 9383.07 ha (94.4%) of the watershed areas and representing 81.13% of the total soil loss. On the other hand, the watershed slope classes (>30%) fell under moderate to High soil loss (6.25-25 tons ha⁻¹yr⁻¹) together covers 555.93ha (5.6%) of the watershed areas contributing 18.82% of the total soil loss. Moderate to high soil loss in the study watershed is aggravated by topographic factor specially slope steepness factor, high erosivity (R_factor) from heavy rainfall, high erodibility(k-factor) and poor conservation practice factors which could finally changes in the hydrological, biological, and geochemical cycles, result lack of the services that the soil offers to the human beings (Berendse *et al.*, 2015). This influences annual crop production and land productivity impacting local farmer's food security (Brevik, 2013). The erosion severity may also have off-site sedimentation in the Gibe-3 dam

5.2. RECOMMENDATION

To decrease the amount of soil loss in the study area, the following watershed rehabilitation measures should be required.

- Watershed slope classes which are moderate to high erosion risk classes need urgent soil and water conservation measures that intercept runoff by decreasing the transport capacity of flow and improve soil infiltration in the steep slope namely terracing, contouring, strip cropping, reduce the intensity of tillage and growing cover crops.
- Enclosure of denuded hill slopes areas specially Atso Mountain from human and livestock interferences and rehabilitating it with different indigenous and Exotic tree species.
- Participating farmers during conservation strategies from plan preparation to implementation.
- The increased practices of sesal plantation integrated with stone bund at the lower catchment, some *juniperus procera*, *gravilia robusta*, and *Eucalyptus* plantations practiced in upper watershed area played a great role on reducing soil erosion rate and should be maintained and scaled up.
- The combination of GIS and USLE model is an important tools to map and estimate value of soil erosion factors. Therefore, the input parameter values need to be calibrated to the specific watershed.

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7. APPENDIX

Table 1. Monthly rainfall data for Gessa Chere Station(2002-2016)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	51.7	4.9	232.0	113.7	166.7	186.1	114.6	380.2	173.7	54.8	0.0	188.6
2003	69.8	52.2	108.0	135.1	78.1	211.4	225.5	225.1	290.6	37.8	171.9	42.1
2004	136.1	49.0	44.7	278.5	54.2	125.7	218.4	267.7	175.7	191.9	149.1	0.8
2005	1.4	104.0	95.5	117.9	231.6	129.6	190.0	215.6	152.8	42.8	90.3	1.7
2006	6.9	76.0	107.2	82.6	182.9	104.5	174.7	95.9	187.9	162.5	34.9	139.4
2007	136.6	183.5	256.9	358.3	479.5	198.8	327.1	266.2	254.4	85.5	15.3	3.5
2008	40.0	42.8	84.7	196.9	244.1	219.7	261.9	448.6	165.6	127.5	127.4	0.0
2009	8.3	19.7	61.2	142.6	125.6	175.1	349.0	152.9	99.5	129.5	170.7	105.3
2010	20.3	110.7	324.7	153.0	214.6	206.4	130.9	236.1	103.8	90.2	23.4	35.2
2011	10.8	22.6	111.0	179.8	506.6	221.0	148.1	348.9	213.5	211.4	191.2	X
2012	X	X	X	X	86.0	117.7	X	X	X	X	68.5	X
2013	100.0	X	X	X	129.4	X	X	X	150.1	X	106.4	30.0
2014	17.9	92.8	142.4	207.9	375.2	205.6	479.9	413.1	336.8	133.9	122.6	19.5
2015	0.0	9.7	70.5	81.6	605.7	172.4	167.9	306.6	252.2	X	189.9	135.1
2016	X	X	X	369.0	158.4	171.1	237.8	182.1	239.9	X	X	X

Source: National Meteorological Agency, 2016(computed)

TABLE 2. Monthly rainfall data for Tercha Station(2002-2016)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	57.4	0.8	192.9	175.8	121.2	192.6	149.7	363.2	188.4	68.0	0.6	99.1
2003	38.8	50.4	92.4	108.9	109.2	158.7	249.8	218.5	245.8	40.3	68.4	5.5
2004	72.0	48.9	80.9	178.9	103.5	136.1	152.2	149.7	239.3	161.6	18.9	51.7
2005	37.2	17.7	136.9	95.3	349.2	154.4	209.1	119.1	120.9	180.5	17.8	0.0
2006	28.2	47.6	108.5	162.5	171.2	150.4	195.5	261.7	216.7	115.3	5.0	39.5
2007	135.0	99.1	145.4	172.0	391.3	143.1	225.9	143.2	215.0	37.2	8.8	0.0
2008	27.8	13.0	80.2	151.4	222.5	131.8	189.3	231.2	181.4	119.5	53.4	1.2
2009	59.8	16.3	99.3	130.8	75.3	156.5	211.4	174.9	X	109.7	26.6	X
2010	11.3	68.2	121.6	119.8	279.3	128.1	140.3	236.6	245.3	36.0	49.8	23.6
2011	15.4	5.8	86.7	283.7	248.5	131.9	126.9	146.0	123.2	12.7	114.8	0.2
2012	0.0	0.0	37.9	194.8	101.8	110.7	185.1	107.2	256.1	27.3	88.0	25.3
2013	44.6	11.9	151.0	176.4	218.5	190.7	222.9	189.7	182.2	153.1	X	0.6
2014	4.3	1.2	124.2	196.9	240.0	122.2	148.5	X	142.6	90.0	86.6	0.0
2015	1.3	0.0	137.3	113.6	348.5	123.7	155.1	261.3	188.4	93.5	60.7	36.6
2016	62.9	39.8	88.3	238.4	151.6	133.0	111.5	159.8	150.7	45.5	31.7	X

Source: National Meteorological Agency, 2016(computed)

TABLE 3. Monthly rainfall data for Halale Station(2009-2015)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	X	X	X	X	129.1	123.2	83.8	82.0	133.7	118.8	42.6	84.4
2010	X	X	X	X	21.6	112.2	128.6	103.6	244.8	85.8	49.9	42.2
2011	14.1	19.9	X	X	377.8	360.8	369.0	388.3	247.9	70.1	X	45.5
2012	X	X	X	X	151.5	219.5	254.6	0.0	272.4	X	147.9	X
2013	0.0	X	197.2	418.7	280.8	244.4	461.8	331.2	338.3	204.9	149.7	6.9
2014	0.0	60.7	106.3	171.6	481.1	174.7	168.6	0.0	338.3	X	X	14.4
2015	0.0	44.8	105.7	124.4	242.9	292.6	145.5	130.1	152.1	164.7	202.5	72.1

Source: National Meteorological Agency, 2015(computed)

TABLE 4. Location, Available data duration and Annual Average Rainfall data for each Station

Stations	Location			Available data duration		Average Annual precipitation(mm)	No of years
	Longitude	Latitude	Altitude	Starting	Ending		
Gessa chere	37.283	7.024	2251m	2002	2016	1784.06	15
Tercha	37.068	7.148	1335m	2002	2016	1410.91	15
Halale	37.337	6.750	1854m	2009	2015	1584.35	7

Source: National Meteorological Agency, 2016(computed)

TABLE 5. Mean Monthly minimum and maximum Temperature and Rainfall data for three Stations

Station name	Climatic data	Months												Annual Average
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	
Gessa Chere	Precipitation(mm)	40.81	54.09	126.9	183.	242.5	170.6	229.7	272	196.3	105.	101.9	59.5	1784.06
	Maximum (T ⁰)	25.0	24.9	24.4	24.3	23.3	22.4	22.2	27.3	25.3	23.4	29.7	24.5	24.7
	Minimum(T ⁰)	11.0	11.3	11.0	10.7	10.6	11.2	11.0	10.8	12.0	10.9	11.4	11.2	11.1
Tercha	Precipitation(mm)	39.81	28.32	112.2	166.	208.7	144.2	178.2	190.	187.8	86.0	45.67	22.3	1410.91
	Maximum (T ⁰)	31.79	33.1	32.73	30.7	29.47	27.98	27.07	27.3	27.80	29.6	30.70	31.1	29.96
	Minimum T ⁰)	16.5	17.9	18.1	17.8	17.5	17.2	17.0	16.9	16.8	16.3	15.6	15.2	16.90
Halale	Precipitation(mm)	2.98	21.23	82.16	119.	240.6	218.2	230.2	147.	246.7	136.	93.94	44.4	1584.35
	Maximum (T ⁰)	26.5	26.7	26.6	23.9	24.4	25.0	24.1	23.5	24.1	24.9	25.2	25.9	25.1
	Minimum T ⁰)	15.7	15.2	15.2	14.1	13.9	14.1	13.9	14.1	15.3	14.1	14.3	15.2	14.6

Source: National Meteorological Agency, 2016(computed)

APPENDIX FIGURE

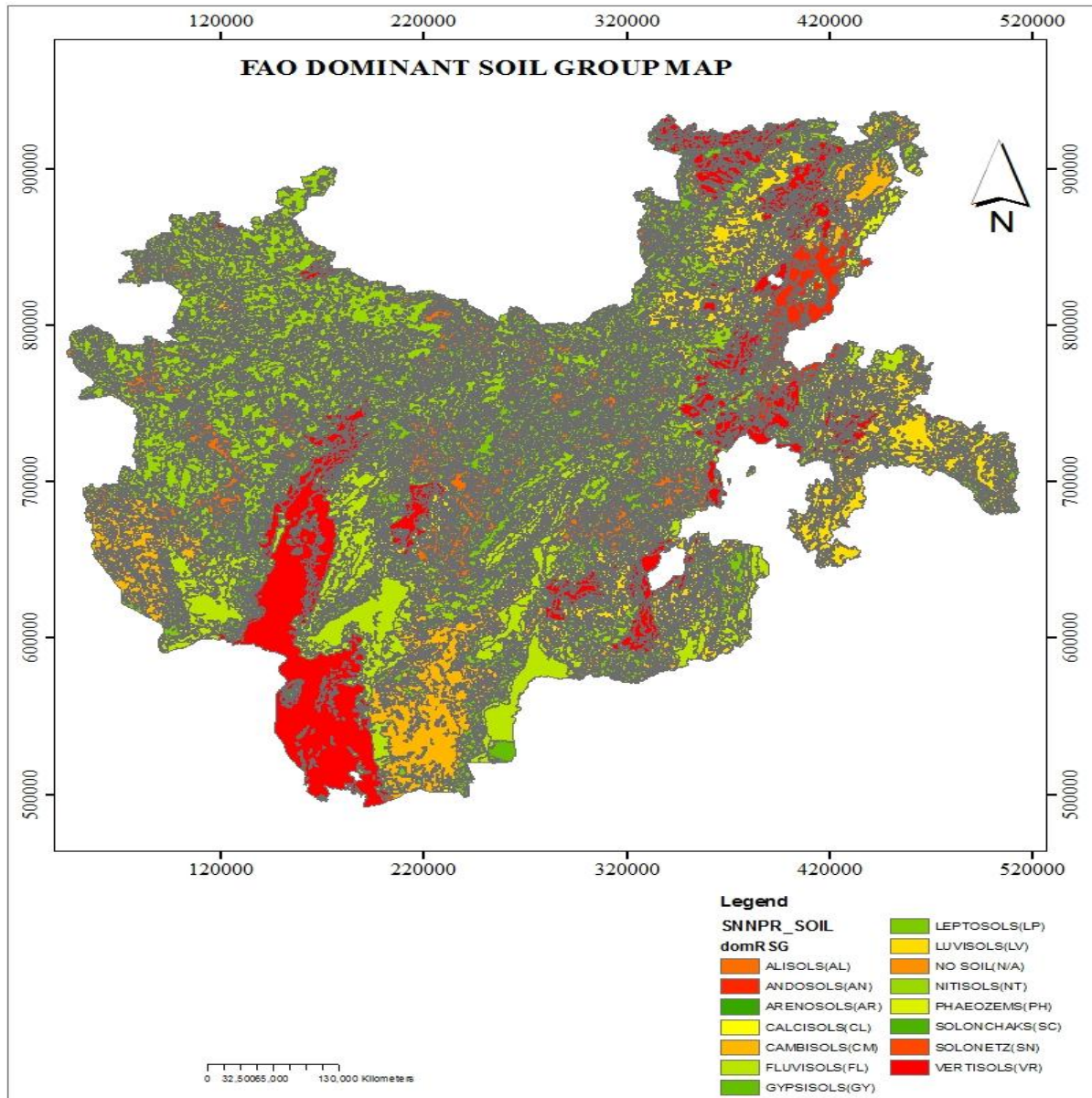


Figure 1.FAO digital soil map used for the study

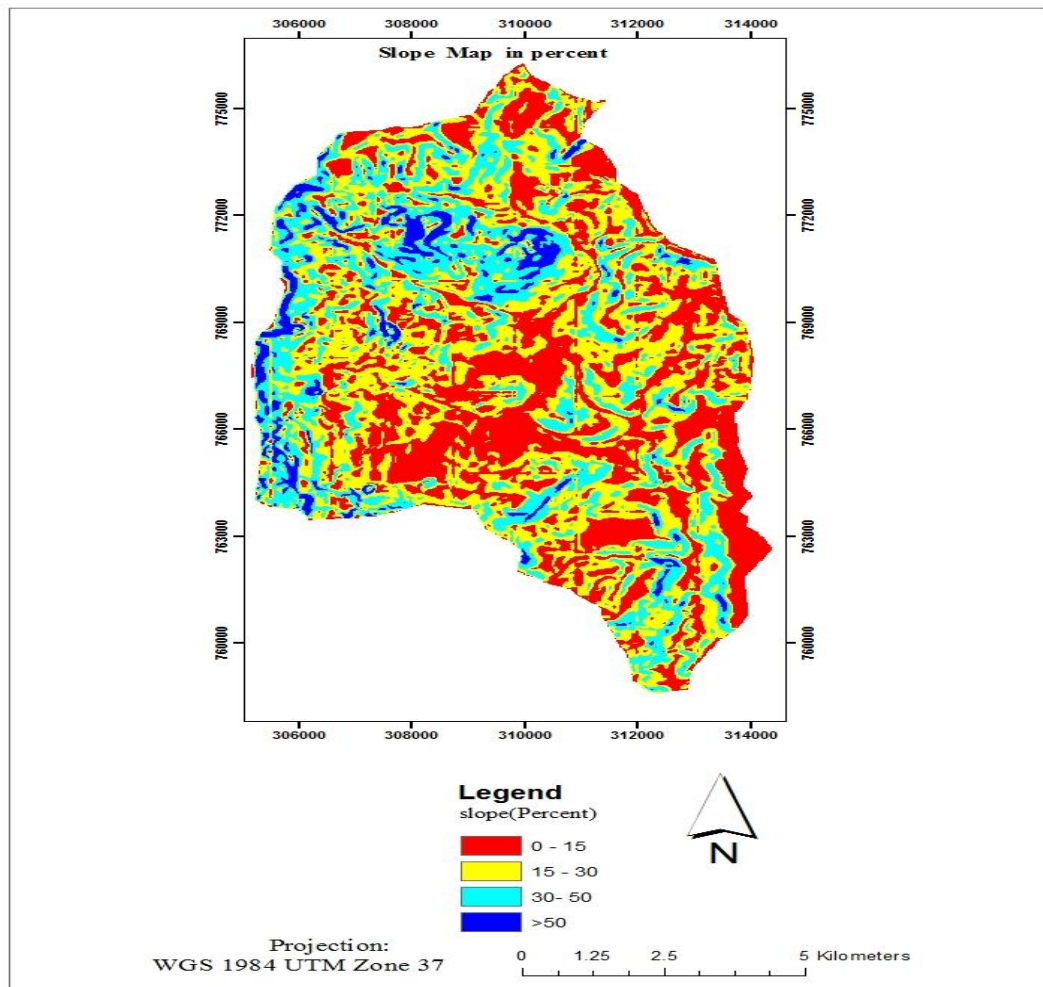


Figure 2. Slope of the study area in percent