MEKELLE UNIVERSITY

COLLEGE OF SOCIAL SCIENCE AND LANGUAGES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES
POST GRADUATE STUDY PROGRAM

ASSESSMENT OF MICRO-WATERSHED VULNERABILITY FOR SOIL EROSION IN RIBB WATERSHED USING GIS AND REMOTE SENSING

BY: ESTIFANOS ABERA

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTEROF SCIENCE (M.Sc.) IN A GEOGRAPHY AND ENVIRONMENTAL STUDY SPECIALIZATION IN GIS AND RS

MAJOR ADVISOR: AMANUEL ZENEBE (PhD)

CO-ADVISOR: YONAS GETANEH (M.Sc.)

AUGUST, 2014

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This is to certify that this thesis entitled "**Assessment of micro-watershed vulnerability for soil erosion in Ribb watershed using GIS and remote sensing"**, submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Geography and Environmental Studies with specialization in **GIS and RS** at Mekelle University, department of Geography and Environmental Studies done by **Estifanos Abera** is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for an award of any degree or diploma to the best of our knowledge and belief.

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ACKNOWLEDGEMENTS

First of all, I would like to thank the almighty God and His Mother, Saint Virgin Mary, for giving me strength and courage to continue my study and for all things done in all my life. I can say it is with the mercy of God and his holy mother that I succeeded in finishing this paper.

Then, I wish to express my deepest gratitude to my major advisors Dr. Amanuel Zenebe and co-advisor Yonas Getaneh for their guidance, advice, criticism, encouragements and motivation during this study. My sincere appreciation also goes to Ministry of Water and Energy, National Meteorological Authority and to all my instructors and staff members of the department of geography and environmental studies for sharing their experience, materials and valuable cooperation throughout my study.

'True friends are hard to find and harder to leave and impossible to forget'. All of my friends, I will never forget your support and love during the study time and my entire life.

Finally, my grateful thanks belong to my family, for their moral support and belongingness throughout the study.

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LIST OF ACRONYMS AND ABBREVATIONS

AGNPS Agricultural Non-Point Source

CEI Composite Erosion Index

CREAMS Chemical Runoff and Erosion from Agricultural Management Systems

DEM Digital Elevation Model

ERDAS Earth Resource Data Analysis System

ETM+	Enhanced Thematic Mapper Plus
EUROSEM	European Soil Erosion Model
FAO	Food and Agricultural Organization
GIS	Geographical information system
GLCF	Global Land Cover Facility
GPS	Global Positioning System
GUESS	Griffith University Erosion Sedimentation System
Ha	hectare
Km	kilometer
LULC	Land Use Land Cover
LS	Slope Length and Slope Steepness
m.a.s.l	meter above sea level
MCA	Multi Criteria Analysis
Mm	Millimeter
MoARD	Ministry of Agriculture and Rural Development
MUSLE	Modified Universal Soil Loss Equation
MW	Micro-Watershed
NMA	National Meteorological Agency
RMMF	Revised Morgan, Morgan Finny
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SLEMSA	Soil Loss Estimator for Southern Africa
SPI	Stream Power Index
SRTM	Shuttle Radar Topographic Mission
t/ha/yr.	tone per hectare per year
USGS	United State Geological Survey
USLE	universal soil loss Equation
UTM	Universal Transverse Mercator
WEPP	Water Erosion prediction project
WGS	World Geodetic Survey

ABSTRACT

The major objective of this study is assessment of the most erosion vulnerable micro-watersheds in Ribb watershed. This is because it is difficult to launch soil and water conservation and other environmental protection projects in all micro-watershed at the same time. So, the most erosion vulnerable micro-watersheds have to be identified. In this study Revised Universal Soil Loss Equation (RUSLE) and Multi-criteria Analysis (MCA) have been applied to quantify the soil erosion risk and identify the most vulnerable micro-watersheds. For this remotely sensed data and other ancillary data in GIS and remote sensing techniques are used. To assess the potential gully areas Topographic threshold concept are used. From The result of RUSLE model the potential average annual soil loss of the micro-watersheds ranges from 10.93 to 95.5 t/ha/year with a mean annual soil loss of 39.8 t/ha/year. The upper five micro-watersheds (MW-16, MW-23, MW-26, MW-27 and MW-29) covering 17.6% of the watershed shows very high mean soil loss rate. In the high mean soil erosion rate classes there are three MWs (MW-3, MW-18 and MW-20) and it covers 8.28% of the study area. Thus, they are above the annual average soil loss of the entire watershed (39.8 ton/ha/year). These micro watersheds under high and very high class demand immediate attention in terms of management and planning perspective. From the total area of the watershed which is 1240.12 km2, 92 km2 are potential areas for gully development. Based on the MCA, the micro- watersheds 3, 16, 23, 26 and 27 covering 19.47% of the study area have a Very high CEI and the largest portion (27.61%) of the study area is under high class of CEI and it includes seven Micro-watersheds. Thus these micro-watersheds are more vulnerable to erosion compared to the others and these needs immediate action. Considering the result of RUSLE model and MCA from the slope, gully, land cover and soil factors, micro-watersheds with large value of mean soil loss rate and CEI value are more soil erosion vulnerable micro- watersheds. Thus they should be prioritized for conservation and other environmental protection activities.

Keywords: *Vulnerable micro-watershed, GIS, Remote Sensing, RUSLE, MCA, Ribb watershed.*

CHAPTER - I

1. INTRODUCTION

1.1 Background

Soil erosion is one of the principal causes of land degradation and it has an adverse impact on the environment by threatening the natural environment, agriculture and the economy (Lal, 1998). Specially, its effects are visible in developing countries because of the incapacity of their farming population to replace lost soils and nutrients (Erenstein, 1999). To alleviate this problem Ethiopia started to plan in a watershed bases starting from 1980's. But it was mostly unsatisfactory due to lack of effective community participation, unmanageable planning units and lack of deep study about the watershed (CBPWD, 2005).

More recently, extending agriculture to marginal lands such as steeper slopes and swampy plains and traditionally unexploited part of the environment in the Ethiopian highlands may indicate the presence of pressure on land, vegetation and water resources (Hurni, 1983). Due to over population, 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 highlands of Ethiopian is severely affected by watershed management problems (Hurni, 1985). Thus Understanding Watershed characteristics and Watershed management is very important part to maintaining healthy productive rivers.

Blue Nile Basin is one of the largest basins found in highlands of Ethiopia characterized by high population pressure, degradation of land and highly dependent on agricultural economy (Akalu T *et al*., 2009). Lake Tana Sub basin has a major contribution to Nile river basin. Due to the rapid growth of population, deforestation and overgrazing, soil erosion, sediment deposition, storage capacity reduction, drainage and water logging, flooding, pollutant transport, overexploitation of specific fish species, the land and water resources of the sub-basin and its ecosystem are in high risk. Gilgel Abay, Ribb, Gummara and Megech are the main watersheds which contribute more than 93 % of the inflow for Lake Tana sub-basin (Abeyou, 2007). In a watershed management program due to time and financial limitation, it is difficult to make rehabilitation and soil and water 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).

Now a day's watershed is started to be studied in scientific ways by using different models, Remote Sensing (RS) and Geographical Information System (GIS). Different researches are undertaken to estimate the rate of soil erosion and in mapping erosion risk areas using remote sensing and GIS with RUSLE and it showed its efficiency in estimating rate of soil erosion and in mapping erosion risk areas. For instance, Millward and Mersey (1999) showed the potential of using a combination of remote sensing, GIS, and RUSLE in estimating soil erosion loss on a cell-by-cell basis. Besides, assessment of soil erosion risk based on a simplified version of RUSLE using digital elevation model (DEM) data and land-units maps (Boggs et al, 2001). Moreover, interpolation of RUSLE parameters for sample plots to determine the soil erosion risk at Camp Williams using GIS techniques by (Bartsch et al, 2002) are some of them. In this study the vulnerability of micro-watersheds for Soil Erosion in Ribb watershed will be assessed by Using RUSLE model formulated by Wischmeier & Smith (1978), GIS and RS Techniques. These technics are important for planning and implementation of watershed management, degraded land restoration and environmental protection programs by giving attention for more erosion prone micro-watersheds to protect from further land degradation and for the proper planning and management of soil and water. It will also be a valuable input for decision makers and other institutions who are working on environmental protection, watershed management, irrigation, water harvesting and others.

1.2 Problem Statement and Justification of the Study

Ribb is one of the largest watersheds that discharge to Lake Tana. It has a total area of 1240 km^2. In Lake Tana basin, the fertility of soil in crop fields are degraded largely because of water erosion and the Landscapes are extremely prone to soil erosion. About 27% of the rugged topographies greater than 15% slopes were found to be threatened by severe soil erosion which is predicted >60 t/ha/year**.** On the other hand, it was found to fall in the range of 15-25 t/ha/year, depending on the characteristics of the individual catchments (Birru, 2007). In Ribb watershed, gully formation and sheet erosion with exposure of rock and stones on previously cultivated steep upper slopes are the most visible evidence to show erosion problem. Those problems are also associated with areas of communal grazing. 8.75 million m^3 per year of suspended sediment entering Lake Tana from the Gilgel Abay, Koga, Megech, Ribb and Gumara rivers (JICA, 1977).

Active deforestation, overgrazing, heavy and intense rainfall and steep slopes accelerate the speed of runoff in Lake Tana basin. Soil fertility is declining fast in the upstream caused by severe soil erosion, continuous cultivation, and removal of crop residue and manure. The Ribb watershed has been subjected to prolonged use for agriculture without conserving natural resources and Clearing of forest cover. Thus it causes very severe soil erosion. In the lower stream, there is an incidence of flooding caused primarily by certainly minimal upper watershed treatment (Akalu *et al*., 2009).

To alleviate those problems with minimum cost and time, in addition to well study about the watershed of the area the micro watersheds that contribute more for erosion must be identified and used for the recommendation of proper watershed management techniques.

There are some studies concerning the extent of soil erosion by water by applying GIS and remote sensing in Abay and other basins of Ethiopia For instance Soil Erosion Risk and farmers perception to soil erosion in Holeta Watershed (Ayele, 2011) Landuse/Landcover and Soil Erosion Risk Analysis in Antsokia-Gemza Woreda (Abiy,2010), identification of critical micro watersheds which are under very high and high category and recommendation for intervention of conservation measures in Mojo river watershed (Kiflu, 2010), Average annual soil losses in the sub-watersheds and conservation intervention in Dire Dam Watershed (Israel, 2011) and others but no specific study is done concerning the vulnerability of micro- watershed for erosion in Ribb watershed. The purpose of this study is therefore very important for the decision makers, NGOs and experts who are working on soil and water conservation and environmental protection works to make their projects in an exact place, cost effective and well-timed manner.

1.3. Objectives

This study has both general and specific objectives

1.3.1. General Objective

The overall objective of this study is to assess the vulnerability of Ribb micro-watersheds for soil erosion by water by Using GIS and Remote Sensing Techniques

1.3.2. Specific Objectives

The specific objectives of the study are:

i. To characterize the land use Landuse/land cover that control soil erosion
ii. To estimate potential soil loss in the study area using RUSLE model
iii. To predict the potential location and spatial patterns of gullies
iv. To identify high erosion risk areas in the watershed
v. To make a comparative analysis among micro-watersheds on the basis of vulnerability to erosion

1.4. Research Questions

Based on the stated objectives, the following questions have been used to guide the research process and finally answered from the findings of the study.

i. What are the characteristics of the Landuse/land cover that control soil erosion
ii. What is the mean annual rate of soil loss in the study area?
iii. Where does most severe accelerated soil erosion occur?
iv. Which part of the area is gullies potentially be formed?
v. Which micro-watersheds are more prone to soil erosion?

1.5 Scope of the Study

This study is, actually a watershed level study and thus focuses mainly on the identification of the most soil erosion vulnerable micro-watersheds from the watershed. Thus, RUSLE model were used for the estimation of potential soil loss rate of the watershed. Since the model cannot estimate soil loss due to gully erosion, potential gully areas were mapped by using topographic threshold concept and applied for the identification of the risk of soil erosion spatially.

1.6 Limitation of the Study

Though the study has a significant role in the in the planning and implementation of environmental protection programs on time and in a cost effective way it has also some limitations. Among these, the soil erosion rate map using RUSEL model did not consider gully erosion. Thus, the potential area for gully locations were trained to map using topographic thresholds concept. Getting the most recent Landsat image was difficult and it is assumed that all parameters within each cell (30m x 30m) are uniform. Moreover, to maximize the representativeness of the result of the soil erosion rate map relatively dense metrological stations were required to spatially represent rainfall over the study area, but only 1 stations were available within the watershed. Thus, in the study additional five rainfall data were taken from the stations nearby. In the study area, since the soil loss are not measured manually using soil loss measuring materials, it only shows the vulnerability of the micro-watersheds spatially and it needs a deep study in a micro-watershed level. Finance and time were also identified as real constraints in assessing the study area fully and buying appropriate imageries.

1.7. Significance of the study

Water erosion moves nearly 1.9 billion tons of fertile soil from the highlands of Ethiopia annually. This amount is found to be equivalent to an average soil loss of 130 tons per hectare per year from cultivated lands (FAO, 1986). As one part of the watershed in the highlands of Ethiopia, Ribb watershed is highly affected by soil erosion problem. Due to time and financial problem, it is difficult to implement rehabilitation and soil and water conservation works in all the watershed at one time.

Thus, the overall purpose of the study is to assess the vulnerability of the micro-watersheds for soil erosion by water and characterize the land use Landuse/land cover that control soil erosion. The result of this study will be used as an input data for land use study in the study area and development plan as well as decision making.

In general, the study will have significant contribution in mitigating erosion problem on time and in a cost effective way. The planning and interventions will be in line with the identified erosion vulnerable micro-watersheds. The soil erosion risk map on the micro-watershed bases was developed by integrating remote sensing and GIS application. It provide information on Areas that are more prone to soil erosion based on the estimated value of soil loss and multi craiteria analysis. It is importance as the database of erosion risk of the micro-watersheds in the development of integrated watershed management.

1.8. Organization of the study

The thesis is organized in five chapters. In chapter one, introductory part includes background of the study, statement problem, objective, scope, limitation and significance of the study. Chapter two provides a review of existing literature. In chapter three, the methodologies which includes a description of the study, the materials, methods and techniques of data collection are described. It also gives an overview of the stages gone through during the study. In chapter four, the results and discussion of the study are presented. It includes land use Landcover classes that control soil erosion, factors of the RUSEL model and the predicted soil loss rates by RUSLE models. Gully potential areas and based on the multi-criteria analysis erosion risk were also presented in chapter four. Lastly the discussion of obtained results is presented. In chapter six, the conclusions drawn from the study and recommendations are discussed.

CHAPTER - II

2. LITERATURE RIVEW

2.1. Land degradation

Land degradation is defined as a decline in the productive capacity of the land in relation to actual or possible land uses thus it is a problem to those who use the land (Berry, 2003 cited in Kumela 2007). There are three categories of land degradation which are: - I) Physical land degradation such as water and wind erosion, crusting and sealing, compaction, water logging and reduced infiltration, II) Chemical land degradation which includes acidification, salinization, nutrient depletion, pollution and III) Biological land degradation such as soil organic matter decline, biomass burning and depletion of vegetation cover and soil fauna (FAO, 2001).

2.2. Erosion

This research was designed to identify vulnerable micro-watersheds for soil erosion by water. The process of Soil erosion by water starts from detachment of soil particles by raindrop impact then transportation by the force of flowing water and when the flowing water losses its energy deposition will occur. (Foster and Meyer, 1977; Wischmeier and Smith, 1978).

Depending on the stage of progress in the erosion cycle and the position in the landscape, there are various forms of soil erosion by water. Splash, sheet, rill and gullies are the major ones (Mitiku, 2006).

Rain splash Erosion occurs when water falling directly on to the ground during rainstorms or intercepted by the canopy and make contact with the ground. Thus it weakens the natural soil aggregates and breaks them down (Morgan, 1995).

Water that cannot infiltrate in the soil will be changed in to runoff (overland flow). If the runoff does not concentrate**,** sheet erosion will occur. Thus it uniformly moves the productive topsoil particles equipped by rain-splashdown slope (Mitiku, 2006).

Rill erosion is a concentrated runoff resulted from intensive rainstorms produces more observable features of linear erosion often on steep slopes and in depressions. This feature forms channels up to 50 cm deep (Nyssen et al., 2006).

2.3. Gully Erosion

Gully erosion is formed when runoff water accumulates and often recurs in narrow channels and removes the soil from this narrow area to considerable deeper than 50 cm. it can be formed from rill erosion (Nyssen *et al*., 2006).

Gully erosion has been widely neglected in erosion modelling (Sidorchuk et al., 2003), and even if it has a substantial contribution to overall soil loss, most research dealing with soil erosion has concentrated on sheet and rill erosion. Relatively few studies have taken gully contribution into account when assessing soil losses in upland areas or when quantifying sediment production (Poesen et al., 2003). Gullies are efficient sources and pathways of runoff and sediment from hill slopes to sediment sinks located in stream channels. Thus, gullies are the key elements of landscape connectivity, functionality and conversion to dis functionality and it affects the functionality of ecology (Thorne et al., 1986).

Most soil erosion models do not predict the location of gullies. The threshold concept predicts locations where gully heads might develop (Poesen *et al*., 2003). In this study, the relationship between the spatial distribution of gully erosion and topographic thresholds in the form of slope angle, position and configuration is examined based on the value of stream power index (SPI) as proposed by Moore *et al,*. (1988). *SPI* is used to estimate terrain erosive power and indicative of the potential energy available to entrain sediment. Thus, areas with high stream power indices have a great potential for erosion (Tagil and Jenness, 2008).

2.4. Factors of erosion

Generally there are five primary types of Factors that affected soil erosion. These are Climatic factor, Soil, topography, land use and agricultural support practice. These factors are dependent on each other, as geology affects topography, which can influence climate and the like. Human disturbances and natural disturbances dramatically increase erosion (Costick, 1996).

2.4.1. Climatic Factors

When raindrops act upon the soil particles Soil erosion will occurs. By the detaching power of raindrops striking the soil surface and through the contribution of rain to runoff soil erosion is highly affected by rainfall. Precipitation, temperature, wind, humidity, and solar radiation are Climatic attributes that affect erosion. Rainfall erosivity is a property of rainfall that can quantify the potential capacity of rain to cause erosion in a given circumstances. It measures the combined effect of rainfall and its associated runoff. Those this energy is responsible for breakdown of the soil aggregates, splashing them and subsequently carrying them with runoff and on impact (Saavedra, 2005).

2.4.2. Soil

Due to a function of a range of soil properties such as soil texture, structure, soil moisture, roughness, organic matter content and chemical and biological characteristics, soils are different in their resistance to erosion (Vrieling, 2007).The susceptibility of soil to erosion agents is known as soil erodibility (Lal, 2001). Those soil erodibility factor refers the effect of soil on erosion through the resistance of soil to both detachment and transport (Morgan, 1995). In general, soils having faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion (Saavedra, 2005). In addition as greater force is required to move, larger particles are more resistant to transportation and the erodibility of soil with particle size less than 0.06 are low due to cohesiveness properties. Therefore silt and fine sand are the particles that are less resistant to erosion (Petter, 1992). In this study soil Erodibility Factor (K) was quantified by considered soil color. The value of K ranges from 0 to 1 (Hellden, 1987).

2.4.3. Topographic Factors

The effect of topography on erosion is complex. The local slope gradient (S) influences flow velocity and thus the rate of erosion. Slope length (L) describes the distance between the origin and termination of inter-rill processes (Renard et al., 1997). Increase in slope steepness and slope length will increase erosion as a result of respective increases in velocity and volume of surface runoff (Doere, 2005).

For erosion studies to calculate LS- factor few researchers have applied DEM successfully which is derived from satellite data. In this study DEM-30 was used to derive LS-factor.

2.4.4. Land use/land cover

The meaning of Land use and land cover are different. According to FAO, (2000) Landcover is defined as "the observed biophysical cover on the earth’s Surface." And Landuse as “the arrangements, activities and inputs that people under-take on a certain land cover type". Those the difference is the intentional role of people to adapt the natural land cover to their benefit. In general land cover types refers to the vegetation the area. 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). The category and description of these land cover classes are presented in table 2.1.

Table 2-1: Description and area of land cover categories

No	Land cover category	General description
1	Forest land	An area made of a main layer of natural trees with a cover from 10 to 100 %.
2	Shrub land	An area with a main layer of natural shrubs covering from 10 to 100 %.
3	Farm/Crop land	Areas currently under crops (rain-fed or irrigated crops). This class include small inter-field cover types (e.g. hedges, grass strips, small windbreaks, etc.)
4	Bare land	Areas with degraded lands bare ground or inundation areas
5	Built-ups	Area any type of artificial surfaces areas under residential or industrial places
6	Water body	Areas with any type of inland water body persistence of 12 months/year including natural lakes, wetlands, rivers and manmade small dams
7	Grazing Land	Area with a main layer of natural herbaceous vegetation with a cover from 10 to 100%.

Source: (FAO, 2011)

2.4.5 Accuracy assessment

In land use land cover classification it is important to check the compatibility of the produced classification with what actually exists in reality. And it is one of the major part of the classification process. The accuracy assessment involve the production of references or facts from the field that evaluate the produced classification. It may be produced from maps, aerial photos or visits to the field with help from the GPS system and may be represented by points or areas (Congalton, 1991).

2.4.6 Cover(C) factor

The ratio of soil loss from land under certain type of cover to the corresponding land with no cover is known as C-factor (Wischmeier and Smith, 1978). Land use classification is often used to map vegetation types that differ in their effectiveness to protect the soil. After classification, a qualitative ranking of vegetation types is made, or C-factors are assigned from reported values in different literature described in table 2.2.

Table 2-2: Cropping and land-cover C-values used in different studies

No.	Land-use and land-cover type	C factor value	References
1	Forest	0.02	Hurni (1988)
2	Grassland	0.01	Eweg and van Lammeren (1996)
3	Farm land	0.17	Hurni (1988)
4	Shrub	0.02	CGIP,1996
5	Bare land	0.6	BCEOM (1998)
6	Water body	-	-
7	Urban	0.05	Hurni (1988)

2.4.7. Conservation Practice Factor

Soil which is covered by crop plants, cover crops, mulches, or residues would be protected from wind and water erosion. Those infiltration of water and organic matter would be enhanced. Minimum tillage, cover cropping, managed grazing, contour planting, strip cropping, crop rotation, control structures and diversions are some of the practices that maintain soil cover and protect soils from water erosion. These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster, 1983).

Especially in agricultural areas, conservation practices such as contouring, strip cropping, or terracing, reduce soil losses. For instance, in areas where there is terracing, runoff speed could be reduced with increased infiltration, ultimately resulting in lower soil loss and sediment delivery. 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 and up- and down slope cultivation (Wischmeier and Smith, 1978; Renard et al., 1997). P-values have been assigned to land use classes using literature values and ranges from 0 to 1 (Kaltenrieder, 2007). As data were lacking on permanent management factors and most soil conservation support practices being utilized in the study area are not functional due to lack of regular maintenance, in this study the P factor was assigned to be equal to 1.

2.5. 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).

2.6. Micro-Watersheds vulnerability

All parts of the micro-watershed cannot be eroded at the same extent because of their differences in environmental attributes across landscapes (Tamene and Vlec, 2007; Tripathi et al., 2003). 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).

2.7. Hydrologic model

To predict and evaluate soil erosion problem models which are the simplification of reality have effectively been developed and employed. According to soil erosion modeling is the process of describing soil particle detachment, transport and deposition mathematically on land surfaces. The reasons for soil erosion modeling are used because they are used as a tool: (1) to predict and assess soil loss for conservation planning, project planning, soil erosion inventories, and for regulation. (2) To predict where and when erosion is occurring and hence helping the conservation planner target efforts to reduce erosion. (3) For understanding erosion processes and their interaction and for setting research priorities (Lal 1994). According to Petter in 1992 the 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 and some of which are CREAMS, WEPP, SLEMSA, EUROSEM, GUESS, USLE, RUSLE, RMMF and MUSLE etc. In general, the models are categorized into three: namely conceptual, empirical and physically based models (Saavedra, 2005).

Conceptual models include only a general description of catchment processes, without including the details occurring in the complex process of interactions (Renschler 1996). 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).it reflect the hypotheses about the process governing system behavior. It plays an intermediary role between empirical and physical based models (Beck, 1987).

Physically based models includes 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. Examples of these models are SWAT, WEPP, CREAMS, ANSWERS, EUROSEM, and AGNPS etc.

Empirical models 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). 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.

2.7.1. Revised Universal Soil Loss Equation (RUSLE)

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). In GIS environment, it can predict erosion potential on a cell-by-cell basis, which is successful in attempting to identify the spatial pattern of soil loss present within a 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 disadvantage of RUSLE is that it does not estimate sediment deposition and gully erosion. RUSLE estimates the average annual soil loss from:

A = R.K.LS.C.P

Where A is the amount of soil erosion (t ha-1yr-1) which is eroded within unit area during the corresponding period of rainfall; R is a rainfall erosivity factor; K is a soil erodibility factor; LS is a surface characteristic factor (slope-length and steepness factor, L is the slope length while S is the slope gradient); C is a cover management factor; P is support practice factor (Wischmeier and Smith, 1978).

2.8. Application of GIS and RS for mapping of erosion vulnerable area

The potential utility of RS and GIS techniques for quantitative assessment of soil erosion vulnerable area. (Saha *et al*., 1991; Mongkoisawat *et al*., 1994). RS and GIS techniques becomes an effective analytical tool that makes the watershed management relatively simpler because of its improvement from time to time.

2.8.1. Remote sensing

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. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. "For the assessment of erosion vulnerable area remote sensing becomes very important in detecting erosion features and obtaining erosion model input data (Petter, 1992; Vrieling, 2006). With appropriate use of multispectral data, it is possible to differentiate different ground features from each other and prepare a thematic map depicting land use/land cover. Now a days different studies utilize Satellite imagery for the characterization of watershed and management aims (Saxena *et al.,* 2000).

2.8.2. Geographic Information Systems

Geographic Information Systems are databases that have a spatial component for the storage and processing of the data. So that, they have the potential to store and create maps. It has also the potential for performing multiple analyses or evaluations of scenarios such as model simulations (Maidment and Djokic, 2000).

There are a number of strengths that GIS technologies has a number of advantages in watershed management studies by allowing improved database organization and storage. Obtaining different variables which is important for watershed studies has been difficult to do from paper maps and aerial photographs as it subjects to errors related to manual operations and it is proved to be time-consuming. In addition to this, the capabilities of modern GIS for modeling and visualization, offer fundamentally new tools to understand the processes and dynamics that shape the physical, biological and chemical environment of watersheds (Jain and Goel, 2002). 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).

2.9. Multi-criteria decision analysis

Multiple Criteria Decision Making (MCDM) implies the assignment of values to alternatives that are evaluated along multiple decisions or criteria (Pereira et al., 1993). The techniques adopted in the various approaches of decision analysis are called multi criteria decision methods (MCDM). These methods incorporate explicit statements of preferences of decision-makers. Such preferences are represented by various weighting scheme, constraints, and other parameters.

CHAPTER - III

3. METHODOLOGY

3.1 Study area description

3.1.1 Location of the study area

The Ribb watershed is located in the Amhara regional state near Lake Tana, which is the source of the Blue Nile River. The area lies between 11^{o}50’00” - 12^{o}10’00” North Latitude and 37^{o}50’00” – 38^{0}10’00” East Longitude. The total watershed area of Ribb is 1240 km^{2}.The source of Ribb River is Guna Mountain. This river is 84 km long and has 34 other small tributaries (MWRE, 2008). Figure 3.1 shows the location of Ribb watershed in the Lake Tana basin together with nearby towns.

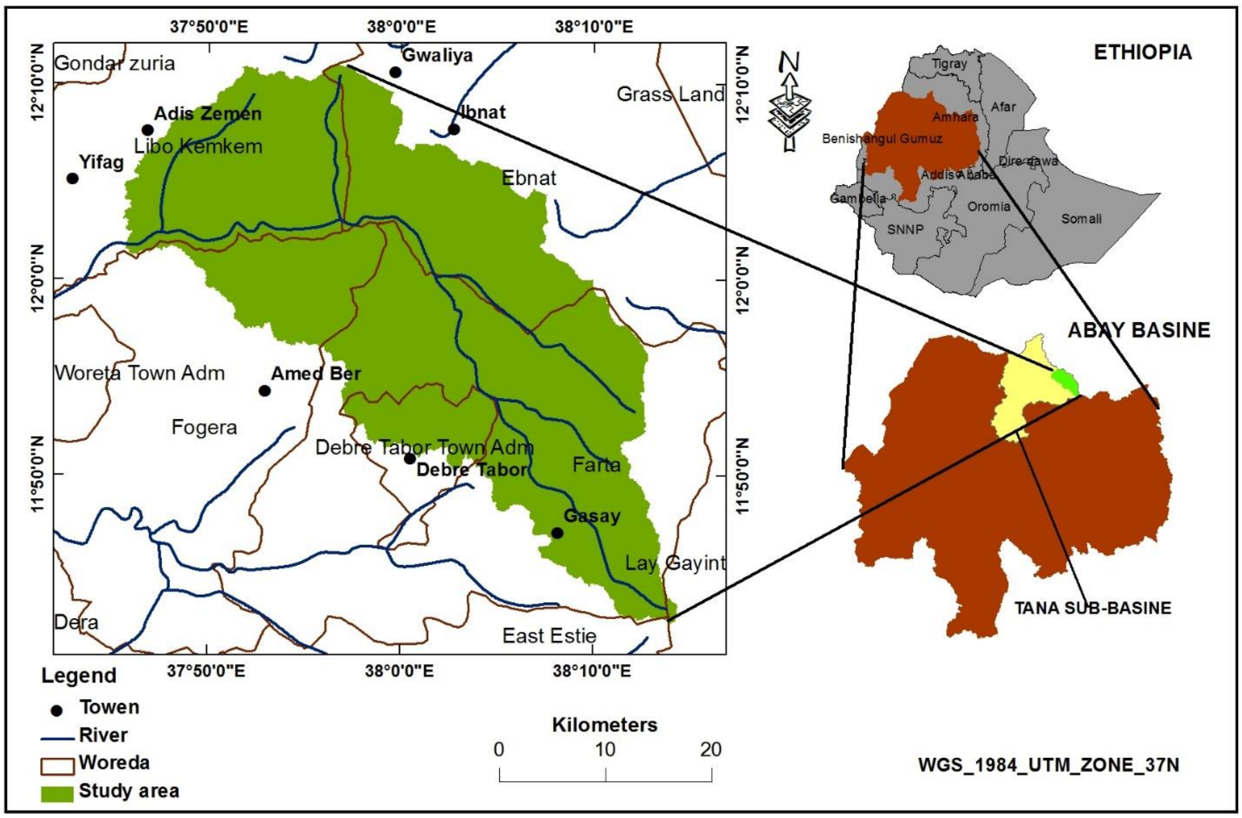

Figure 3-1: Map of the study area

3.1.2. Climate of the Study Area

The annual climate of Ribb watershed can be divided in to rainy and dry season. The rainy season may be divided into a major rainy season from June through September. The dry season occurs between January, February and December. As shown in Figure 3-2, the long-term average annual rainfall (1997-2011) of the five station near Ribb watershed shows an average of 1074.6 mm and long term average maximum and minimum temperature of the five stations (A. Zemen, Bahirdar, Debretabor, Maksegnit & Nefas mewcha) 19.6°C and 7.2°C respectively.

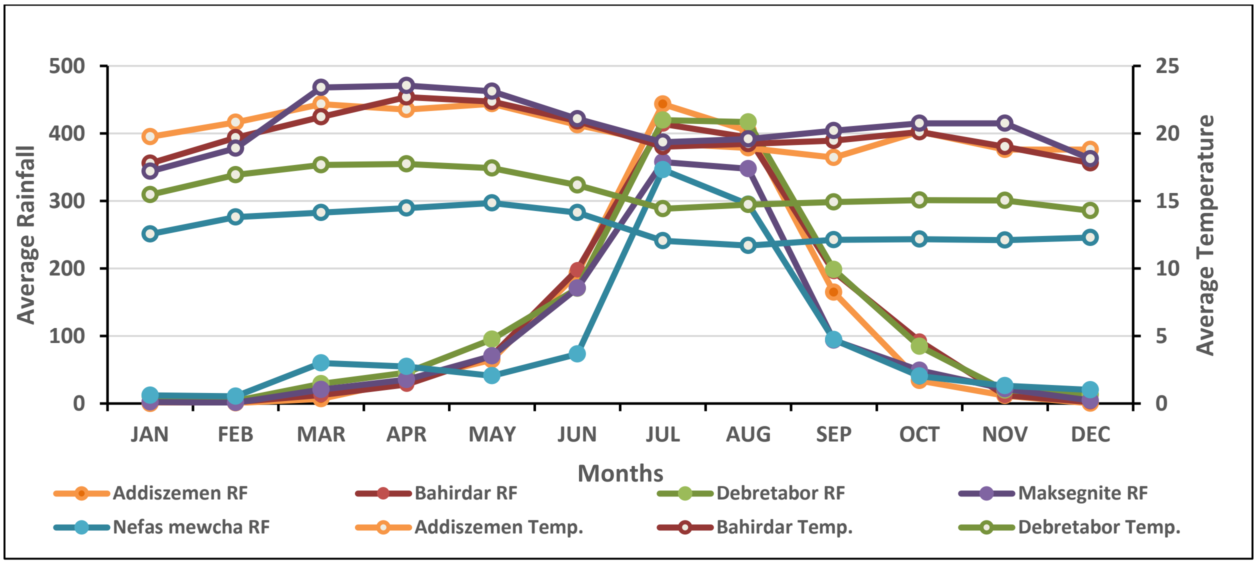

Figure 3-2: Average Monthly Rainfall and Temperature of Five Stations (1997 to 2011) (source: NMA)

3.1.3 Soil type

For this study a soil data as per FAO soil group were collected from MWRE GIS department. The soil types identified in the study area are Eutric Leptosols, Eutric fluvisol, Chromic luvisol and Haplic Nitosol. From these Chromic luvisol (40.2%) and Eutric fluvisol (36.9%) are dominant. In Ribb watershed the major land use is farm land which is 61.3%, the second dominant land use group for Ribb watershed is Grass land (22.7%).

3.1.4. Topography

The average slope of Ribb watershed estimated as 21.49˚. The slope sliced based on FAO slope classes namely 0 - 2, 2 - 10, 10 - 15, 15 - 30 and more than 30 percent slope. Large portion of the area fall in the Hilly terrain (31.5%) and gently flat to undulating terrain (25.77%) slope class.

The elevations of the study area vary from 1800m to 4100m above mean sea level and majority of the watershed area are from 1800m – 2055m above mean sea level.

Table 3-1: Slope range of the area in percent

SLOPE (%)	CLASS NAME	AREA(km^2)	Percent
0 - 2	Flat to almost flat terrain	18.56	1.5
2 - 10	Gently flat to undulating terrain	319.87	25.77
10 - 15	Rolling terrain	212.39	17.13
15 - 30	Hilly terrain	390.66	31.5
>30	Steep dissected to mountainous terrain	298.64	24.1
Total Area		1240.12	100

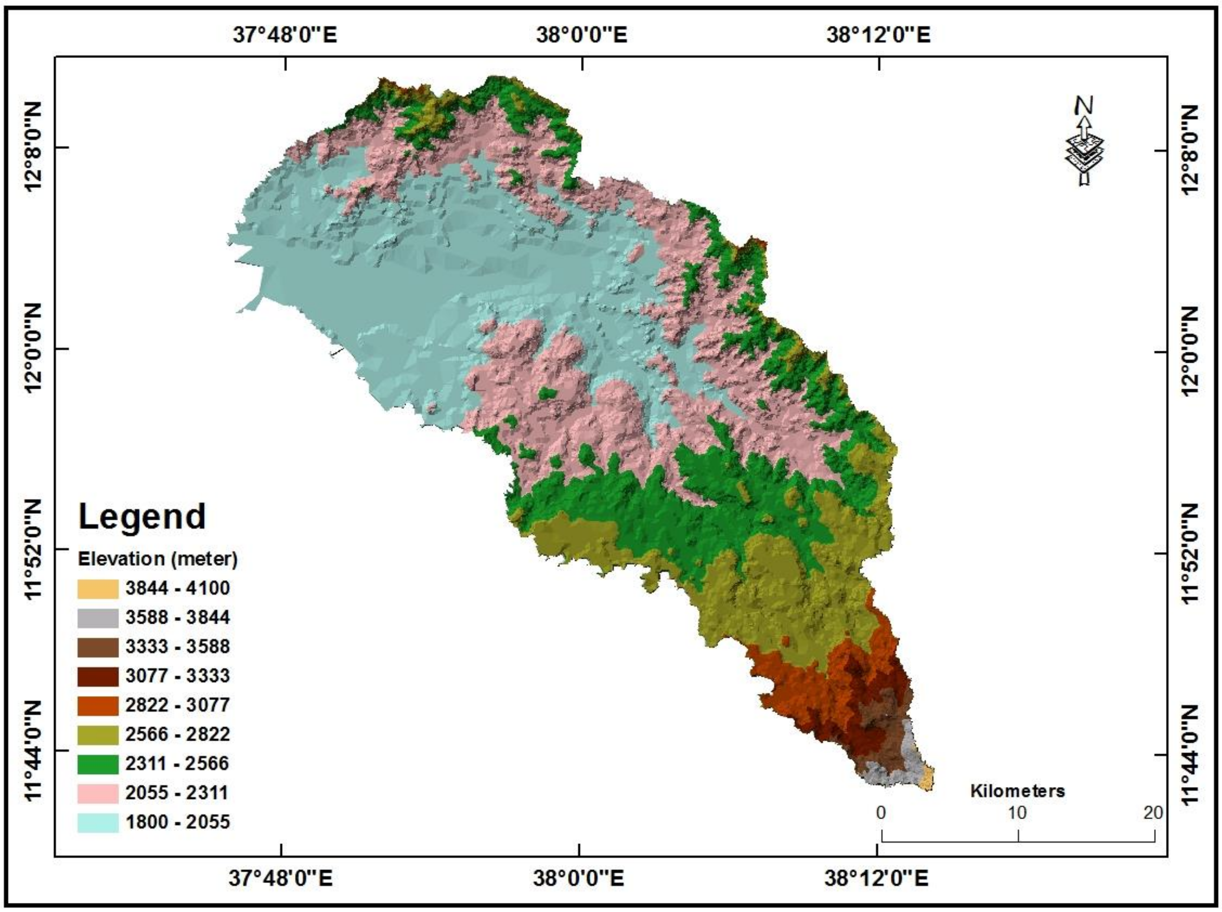

Figure 3-3: Elevation of the study area

3.2. Data Sources and Methods of Collection

3.2.1. Satellite Data

Cloud free 2009ETM+ Landsat-7 scene covering the study area was downloaded from GLCF for supervised land use land cover classification. 30m*30m resolution ASTER DEM were downloaded from J-Space and it is used for watershed delineation, micro-watershed, slope and flow accumulation generation. Additionally random sample of gully area polygons were generated from Google earth for the verification of gully potential map.

3.2.2. Field Data

The field data collection were done randomly to verify the classified image and to collect the necessary land use/land cover data for accuracy assessment. Additionally random field data were collected to validate the gully potential map. All field data are collected using Garmin GPS model 60 device

3.2.3 Ancillary data

Monthly rainfall of six stations (Addis zemen, Bahirdar, Debretabor, Ebnat, Maksegnit and Nefas mewcha) and the temperature data from 5 stations (Addis zemen, Bahirdar, Debretabor, Maksegnit and Nefas mewcha) from 1997-2011 were gathered from National Meteorological Agency. Mean annual rainfall data are generated from the monthly rainfall data of 15 years and well adopted for the analysis. For this study a soil data of the major soil groups of Amhara Region as per FAO soil group were collected from Ethiopian Ministry of Water Resources and Energy (MWRE), GIS department. The soil polygon feature map is obtained by clipping the FAO soil map of Amhara Region with the study watershed in the GIS environment. In addition, to rank the contribution of the four factors (Slope, Gully, LULC and Soil type) for soil erosion informal interview with the natural resource experts and development agents who work near the study area were undertaken and used as an input for pairwise comparison in IDRISI Andes 32 software.

Table 3.2: Source, description and purpose of the data used in the study

No.	Types of data	Source	Description	Purpose
1	DEM	USGS	• Aster 30m resolution	For Watershed delineation and slope & flow accumulation generation
2	Landsat7 ETM+ (Feb, 2009)	USGS	• 30m*30m spacial resolution • 8 bit spectral resolution • 16 days Temporal resolution • Path/raw - 169/52	For supervised LULC classification
3	Digital Soil map	Ministry Of Water Resources (MoWR)	• FAO (1986)	To generate soil map for the model
4	Rainfall	National Meteorological Agency, Ethiopia	• 15 years RF data from 6 stations near the study area	To extract the R-map from mean monthly RF data
5	GCPs		• Random coordinates from each land use using Garmin GPS model 60 device	For accuracy assessment of the supervised classification
6	Informal interview	Natural resource experts and Development Agents who work in the study area	• Rank the contribution of erosion factors	Input for the Multi-craiteria analysis

3.2.4. Software and tools used for the study

For the success of this research different software and tools are used. Those software and tools with their purpose are indicated below in table: 3.3.

Table 3-3: Software and tools used for the study

No.	**Software Tools& Material**	**Purpose**
1	ERDAS	Land use/land cover classification
2	ArcGIS10	Analyzing, Displaying and viewing Spatial data
3	IDRISI Andes 15	For pair wise comparison (weighting soil erosion factors)
4	Arc Hydro extension	Watershed, Micro and sub watersheds delineation
5	GPS(Garmin GPS)	To take GCPs for LULC classification Gully map
6	Compass	Used for direction location on field survey
7	Munsell soil color chart	Munsell soil color

3.3. Methods of data analysis

3.3.1 GIS data base construction

ArcGIS10 was used for the generation of R, K, LS, and C layers, generation of potential gully location, integration of layers, reclassification of derived datasets and weighted overlay analysis. Watershed, Micro and sub watersheds delineation were performed using Arc hydro extension with in ArcGIS10. IDRISI Andes 15 Software was used for pairwise comparison and weighted overlay analysis. For digital image processing including preprocessing of satellite image data, masking the image with the watershed boundary enhancement, visual interpretation. ERDAS Imagine 9.1 software was used. All derived maps was projected into WGS1984 Zone 37N and held in grids of 30-m cell size.

3.3.1.1 Micro-watershed Delineation

The watershed under study was delineated by automatic delineation option using Arc Hydro Extension with in ArcGIS 10. For the delineation of the watershed, from Aster 30m*30m resolution DEM, Fill, Flow direction and flow accumulation were generated respectively. As shown in figure: 3-4, 31micro-watersheds were delineated by increasing the threshold value in the stream definition. Thus, it is easy for the analysis and to compare the micro-watersheds each other. The area of the micro-watersheds ranges from 1.15 km^2 to 132.3 km^2.

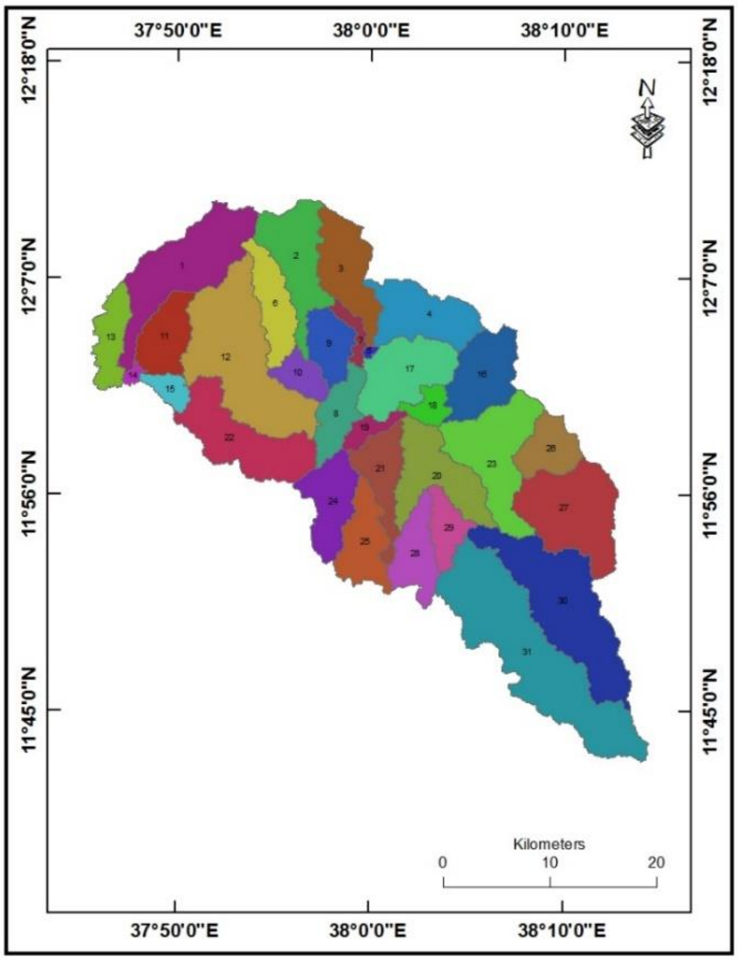

Figure 3-4: Ribb micro-watersheds

3.3.1.2. Image Classification

From the downloaded 8 bands of Landsat ETM+ by subtracting the two bands (the panchromatic band and the thermal band) 6 bands were combined by layer stack in ERDAS imagine 9.2 software. Then combined bands of the image data were classified. Next to this; the land use/land cover classes to be considered in the image classification process were identified. This was done by using field survey and visual image interpretation of the source image. The FAO 2011 land use/land cover classification system was used to define the land use/ land cover classes. The overall objective of image classification procedures is to automatically categorize all pixels in an image into land use/land cover classes (Lillesand and Kiefer, 1994). For this study supervised land use and land cover classification were undertaken by ERDAS Imagine 9.2 software using the maximum likelihood image classification.

Accuracy assessment were undertaken to validate and compare the classified image with geographical data that are assumed to be true. The accuracy assessment of the LULC maps has been undertaken by comparing the field data collected by GPS with the classified images in ERDAS imagine 9.2 software.

Seven land-use and land-cover classes were recognized using visual image interpretation and field survey. Thus from the supervised digital image classification and 79.5% accuracy was recorded from the collected ground truth information. These include forest, shrub, Farm land, bare land, built-ups, water body and grass.

3.3.1.3. Cover (C) factor

From the Supervised digital image classification seven land-use and land-cover classes were recognized. These include water body, built-up, forest, shrub, grass, Farm land and bare land. The cover (C) factor corresponding to each land use land cover was estimated from different literature listed in Table 5. A corresponding C-value was assigned to each land use class using the “reclass” method in ARC GIS 10 after changing the coverage to grid.

3.3.1.4. Rainfall Erosivity (R)

The erosivity factor R was calculated according to the equation given by Hurni (1985) which is derived from a spatial regression analysis (Hellden, 1987) for Ethiopian conditions. It is based on the available mean annual rainfall data.

$$\mathbf{R = -8.12 + (0.562*P)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \mathbf{(1)}$$

Where P is the mean annual rainfall in mm

In this study, historic rainfall data of 15 years (1997-2011) was collected from six rainguage stations (Bahirdar, Ebnat, Maksegnit, Nefas mewca, Addis Zemen and Debre Tabor) shown in Table: 3-4. A rainfall map was generated from the average rainfall data of the six stations. By using spline interpolation technique in Arc GIS 10. The R-value was calculated from the rainfall map with a cell size of 30m*30m using raster calculator function of ArcGIS. Based on this the rainfall of the study which ranges from 980mm -1531mm has been plotted.

Table 3-4: Average annual Rainfall (mm) of the six stations from 1997-2011

NO.	Rainguage station	Average annual RF(mm)
1	Addis Zemen	1357.7
2	B.Dar	1425.0
3	Debretabor	1508.3
4	Ebnat	996.4
5	Maksegnite	1174.9
6	Nefas mewcha	1074.6

(Source: National Meteorological Agency)

3.3.1.5. Soil Erodibility Factor (K) Index

The Soil Erodibility (K-factor) refers to the liability of the soil to "suffer" erosion due to the forces causing detachment and transport of soil particles (Hellden, 1987). For Ethiopian condition an attempt was made to classify the soil types of the study area based on their color by referring the FAO soil database.

Table 3-5: Soil Erodibility factor (Modified from Hellden, 1987)

Soil color	Black	Brown	Red	Yellow	Grey	White
K factor	0.15	0.2	0.25	0.3	0.35	0.40

In this study the vector format soil map of the FAO (1996) classification was clipped by the study area converted into raster grids and after assigning values for each soil types the soil map was reclassified with a grid map of 30m*30m -cell size using adopted K values shown in table: 3-5 (Kaltenrieder, 2007). From figure: 6 the largest portion of the study area covered by Chromic luvisol (40.2%) and Eutric Leptosols (36.9%) types of soil. And 21% of the study area is covered by Haplic Nitosol. Only one percent of the watershed is covered with Eutric fluvisol and built-up.

3.3.1.6. Topographic (LS) factors

In using RUSLE, the effects of topography on soil erosion are estimated by the slope length (L) and slope steepness (S). It has been demonstrated that increases in slope length and slope steepness can produce higher overland flow velocities and correspondingly higher erosion (Haan *et al*., 1994).The upslope drainage area for each cell in a Digital Elevation Model (DEM) was calculated with multiple flow algorithms. Multiple flow algorithms can divide flow between several output cells (Desmet & Govers, 1996).

The LS-factor has been derived from slope and flow accumulation. Slope were generated from 30m*30m resolution DEM using ArcGIS 10. To generate flow accumulation which is the unit contributing area first, any spurious single-cell sinks within the DEM were filled to produce a depression less DEM. In this process, individual sink elevations were flattened. Then by using filled DEM the flow directions of each DEM cell was calculated. From flow directions Flow accumulation was determined ArcGIS 10. Then the LS factor grid was estimated with the following equation using raster calculator in which is proposed by (Wischmeier and Smith 1978).

$$LS = (\text{Flow accumulation} * \text{Cell value} / 22.1)^{m} (0.065 + 0.045 S + 0.0065 S^{2}) \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where LS is slope steepness-length factor, the cell value is the resolution of DEM which is 30and S is slope in percent generated from DEM. The value of m ranges from 0.2 –0.5 depending of the slope (Wischmeier and Smith 1978). The value of m is estimated from table 3-6 below.

Table 3-6: m-value

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

3.3.1.7. Conservation practice (P) factor

The management practice factor P indicates the effect of conservation practices on soil erosion, wherein the land which has adequate conservation interventions. Specific cultivation practices affect erosion by modifying the flow pattern and direction of runoff and by reducing the amount of runoff (Renard and Foster, 1983). Values for this factor will be assigned considering local management practices and based on values suggested in Hurni (1985). The P values are between 0 and 1.For this study, As data were lacking on permanent management factors and most soil conservation support practices being utilized in the study area are not functional due to lack of regular maintenance, the P factor was assigned to be equal to 1.

3.3.1.8. Soil Erosion Risk Analysis using RUSEL model

The five erosion factors (Cover (C) factor, Rainfall Erosivity (R), Soil Erodibility Factor (K), slope steepness- length factor (LS) and Conservation practice (P) factor) which are estimated in the above was used for the estimation of average annual erosion in RUSLE. Each factor grid had a cell size of 30 m and All the layers were projected with UTM Zone 37N using the WGS 1984 datum. All the five factors were multiplied by applying the following equation in Arc GIS10 using raster calculator (Renard et al., 1997).

A = R. K. L.S. C. P --- (3)

Where: - A is the computed spatial average soil loss rate (t/ha /year),

R is the rainfall-runoff erosivity factor [MJ mm/ (ha h year-1)],

K is the soil erodibility factor [t ha h/ (ha MJ mm)],

L is the slope length factor,

S is the slope steepness factor,

C is the cover management factor, and

P is the conservation support practice factor.

The factors L, S, C, and P are all dimensionless.

3.3.2. Potential location and spatial patterns of gullies

For the prediction of potential location for gully formation, a threshold concept has been used. When contributing area together with local slope exceed a given threshold, gully incision is expected to appear. Different thresholds can be applied for different environmental conditions and different gully initiating processes, (Poesen *et al.*, 2003).

Topographic thresholds in the form of slope angle and position have a significant influence on gully initiation, as they influence the magnitude and direction of water flow. Areas contributing runoff into individual gully heads are largely determined by hill slope form. For this study, a 30 m DEM of the study area obtained from J-space system was used to extract topographic variables at hill slope scale. Random sample of gullies polygons are digitized from Google earth and changed into shape file in arc GIS10.In addition to these, field surveys were undertaken to assess and validate the present condition of the gullied sites. Thus using a GPS, gully point data were recorded at 31 test sites. Slope characteristics with a high potential for gullying were compared with actual gully erosion using the Stream Power Index (*SPI*) (Moore et al., 1993).

$$SPI = \ln (A_s \tan\beta) \quad (4)$$

Where A_s is specific contributing area and β is local slope.

SPI is used to estimate terrain erosive power and indicative of the potential energy available to entrain sediment. Thus, areas with high stream power indices have a great potential for erosion (Tagil and Jenness, 2008). A_s and β surfaces for the respective hill slopes were calculated and integrated using the above equation in Arc GIS10 Spatial Analyst raster calculator to derive corresponding *SPI* surfaces. This served to identify areas with high potential for sediment removal and hence prone to gullying. To compare potential and actual gully erosion as well as identify a preferential topographic zone for gully initiation, an overlay of gullied areas on *SPI* surfaces were undertaken. High SPI values are the characteristics of Hilly and upper parts of the area and it shows areas of high erosion. Thus reclassification was done by giving a code 1 to indicate low gully potential erosion and 5 to indicate very high gully potential.

3.3.3. Multi-Criteria Analysis factor generation and reclassification

With the help of certain criteria Multi-criteria analysis compares various alternatives. These criteria are often a translation of the project objectives. The outcomes are more often in the form of selection, classification or ranking of alternatives. MCA can help to assess a watershed's tendency to erosion using easily available data. To perform MCA for the assessment of erosion vulnerable micro-watershed in Ribb watershed, four criteria which are slope, soil, gully location and LULC have been used. On the basis of the range (Minimum and maximum) of their values, are reclassified and ranked 1 to 5 sub-classes. Then, weights were given to the four craiteria (slope, soil, gully location and LULC) as per their contributions to soil losses using Pairwise comparison.

3.3.4. Pairwise comparison for weighting

Weighting is used to assess the relative importance of one evaluation criterion from other criteria under consideration (Jankowski, 1995). Pairwise comparison method was used in this study. Which is important to reduce the complexity of decision making. In Pairwise comparison method the step is development of a comparison matrix then computation of weights for each element of the hierarchy and finally estimation of consistency ratio. IDRISI Andes 32 software was used to generate the weight for pairwise comparison by using informal interview of Development agents and natural resource experts and development agents who work near the study area.

3.3.5. Erosion Risk in the Watershed based on Multi-Criteria Evaluation

3.3.5.1 Composite Erosion Index (CEI)

The four reclassified craiteria layers (slope, soil, gully location and LULC) were multiplied by an appropriate weight derived from pairwise comparison of criteria (Kiflu G, 2010). Then added by Weighted Linear Combination (WLC) equation using raster calculator operation in ArcGIS10. The final output map indicates micro-watershed wise CEI that relates to the erosion intensity of the area under the relative contribution of the given criteria. The algebraic operation performed on four layers is as follow:

$$\mathbf{CEI = (W1*S) + (W2*G) + (W3*LC) + (W4*St) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (5)}$$

Where CEI is Composite Erosion Index;

W1, W2----W4 are pairwise weights derived from IDRISI; and

S, G, LC and St are reclassified slope, gully, Land cover and soil type.

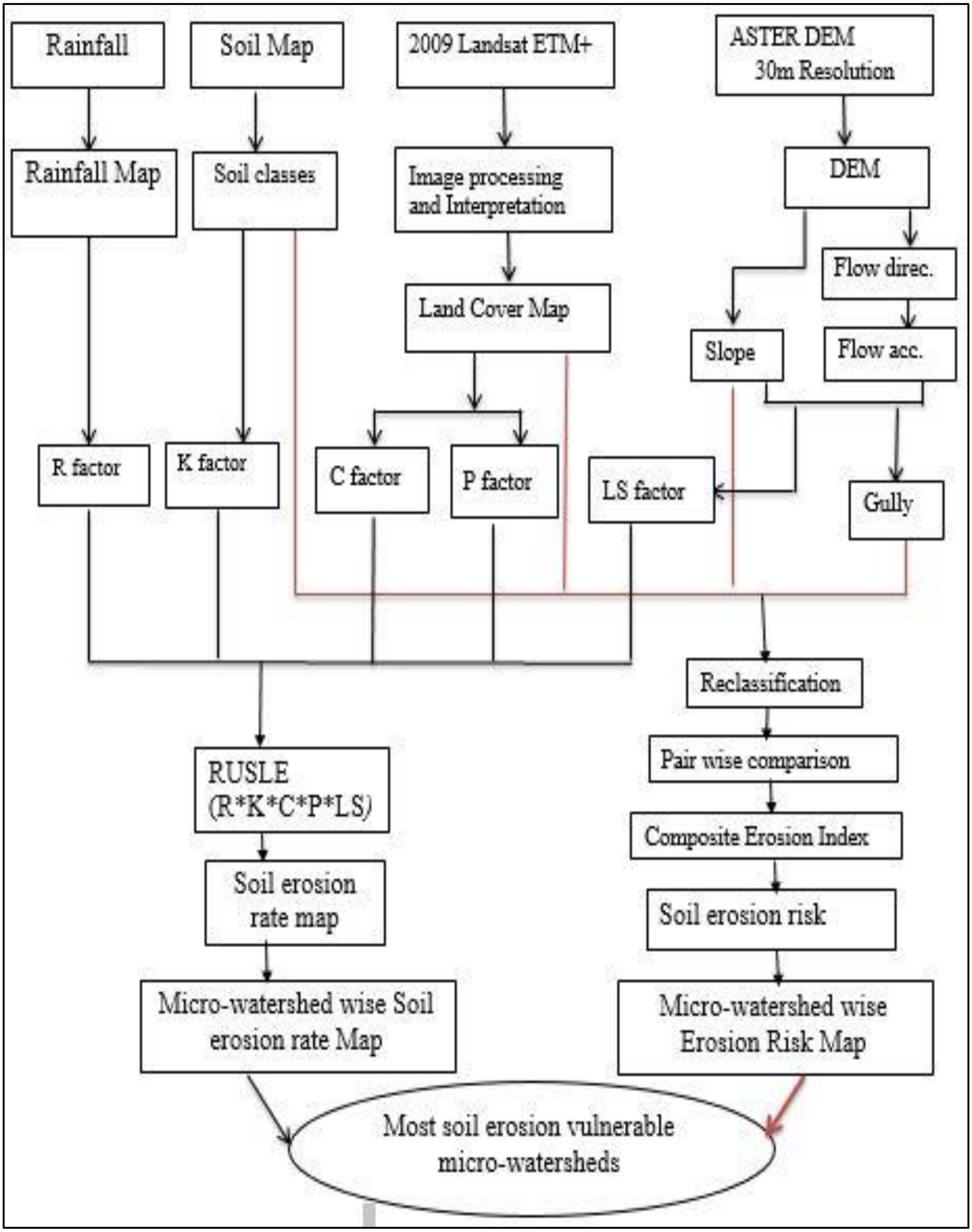

Figure 3-5: Flow chart of the overall methodology

CHAPTER - IV

4. RESULTS AND DISCUSSION

4.1 Factors of RUSLE Model

4.1.1 Land Use Land Cover Data

From identified seven land use and land cover types which is indicated in Table: 4-1, the largest portion of the study area is covered by three land uses (Farm land (61.3%), grass land (22%) and Shrub land (8%)). As it is shown from table: 10 the overall accuracy of the classification is 79.57%. As it is difficult to identify the land use in the image of the study area the accepted (>80%) accuracy cannot be estimated.

Table 4-1: Area and percent of Land-use land-cover types (2014)

No.	Land-use and land-cover type	Area(km^2)	% total
1	Farm land	759.91	61.30
2	Grassland	282.82	22.81
3	Shrub	100.55	8.12
4	Bare land	46.76	3.74
5	Forest	35.93	2.90
6	Water body	10.94	0.88
7	Urban	3.09	0.25
	Total	1240	100

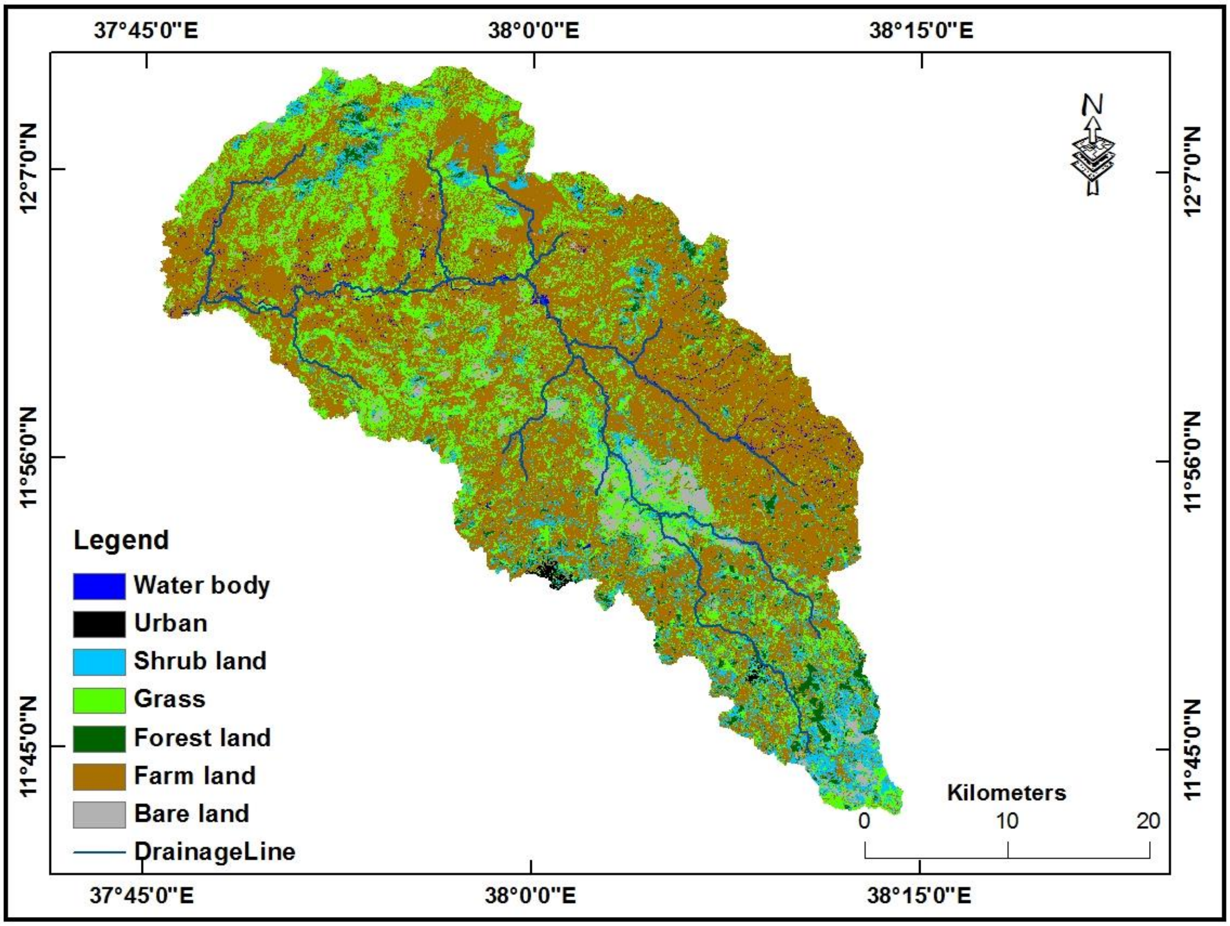

Figure 4-1: Land use/Land cover map of the study area (2014)

Table 4-2: Accuracy assessment of the supervised LULC classification

Class name	Reference total	Classified totals	Number correct	Accuracy (%)
Forest land	50	43	41	82.00
Farm land	52	63	44	84.62
Shrub land	49	43	36	73.47
Grass land	51	43	36	70.59
Bare land	50	47	42	84.00
Water body	15	15	14	93.33
Urban	12	9	9	75.00
Total	279	279	222	
	Overall Classification Accuracy			*79.57%*

4.1.2 Land cover's vulnerability to erosion

The value of c-factor ranges from 0 – 0.6 which is estimated from different literatures listed in Table 4-2. Thus, based on c-factor the large value shows more vulnerable land use to erosion and on the other hand the lower value shows less vulnerable land use for erosion. From the result bare lands have a large value of c-factor which is highly vulnerable to erosion. Next to bare land farm lands (0.17) are more vulnerable than the others. Grass lands, forest and shrubs having the c-factor value 0.1, 0.2 and 0.2 respectively are less vulnerable to erosion.

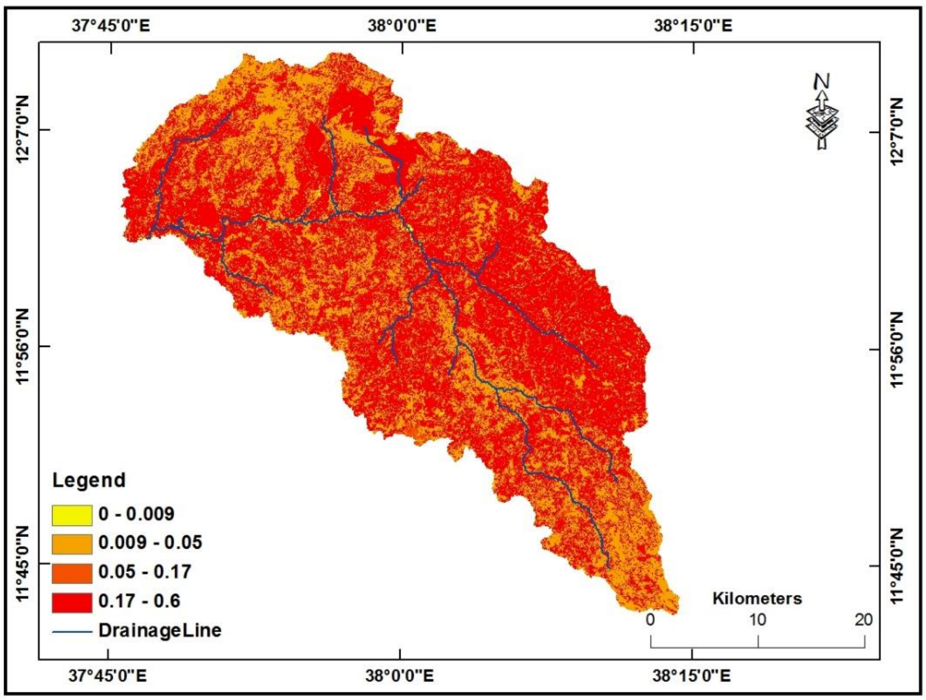

Figure 4-2: The cover factor (C-values) in the study area

4.1.3 Erosivity

The value of R-factor ranges from 542– 862. From this result shown in figure: 4-4, the higher value which is 862 found in the lower part of the study area showing high rainfall erosivity. Thus based on R-factor value it is more vulnerable to erosion. The lower value of R-factor in the upper part of the study area indicates that this part of the watershed is less vulnerable to erosion.

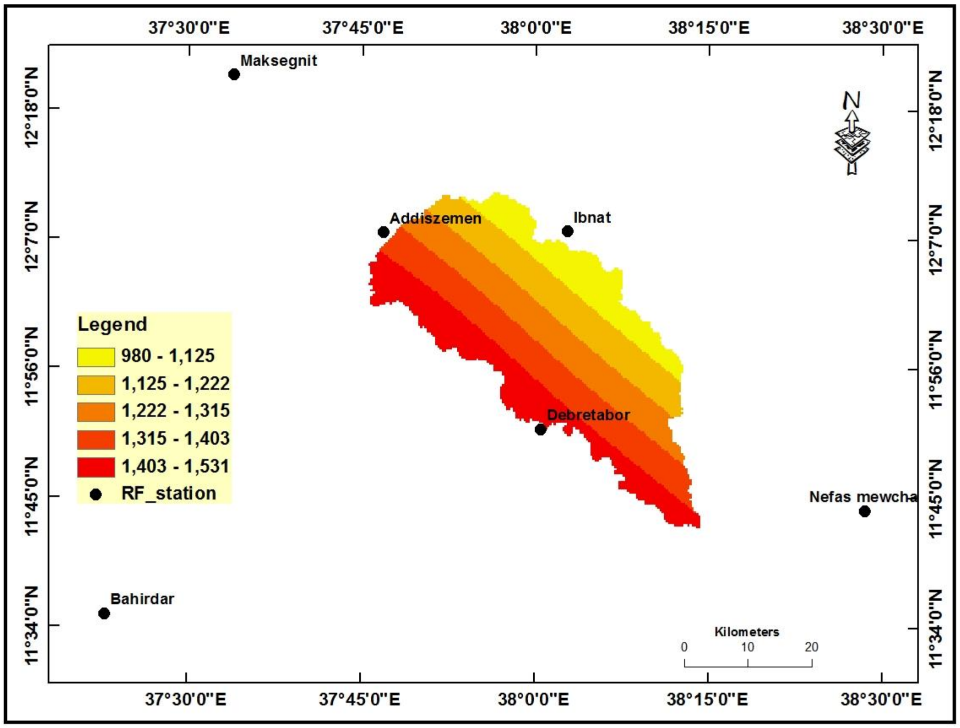

Figure 4-3: Average Rainfall map and its stations of the study area from 1997-2011

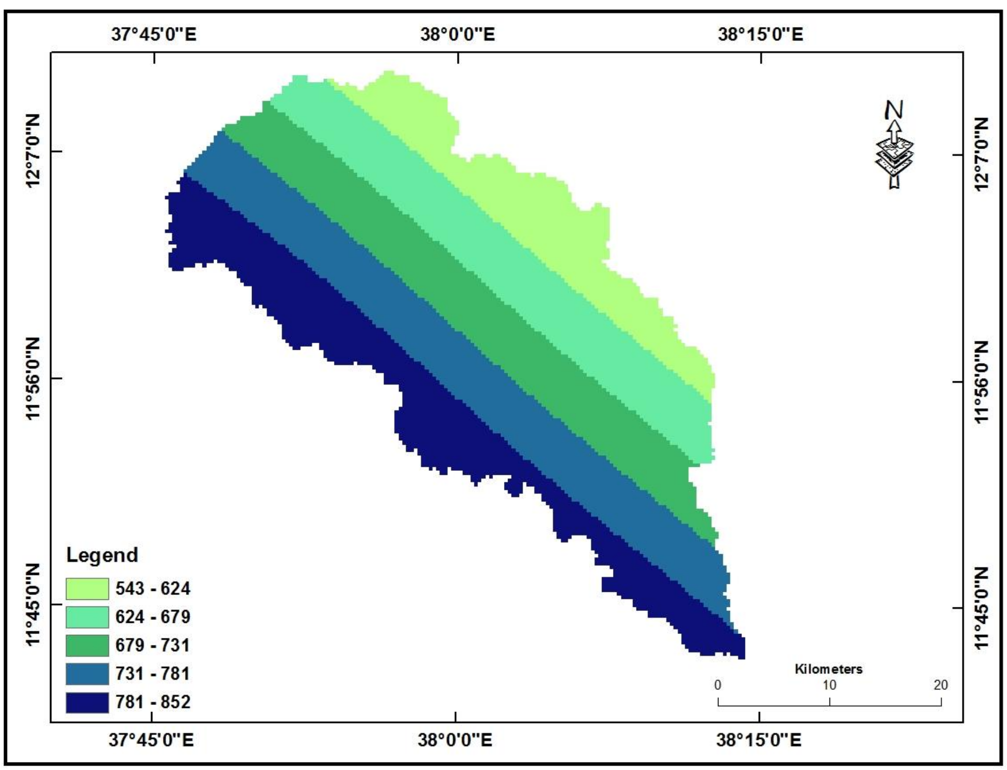

Figure 4-4: R-factor map of the study area

4.1.4 Soil vulnerability to soil erosion (Erodibility)

Based on the color of the soil the value of k-factor in the study area ranges from 0 to 0.3. The high k-factor value indicates more vulnerable soil type to soil erosion and the smaller value shows less vulnerable soil type to erosion. As it is shown in table:4-6 the high k-factor value is shown in Eutric Leptosols major soil type which is found the upper side of the watershed and the largest portion of low value is shown in the lower side of the watershed which is chromic luvisol major soil type. Thus result the high k-factor value indicates more vulnerable soil type to soil erosion and the smaller value shows less vulnerable soil type to erosion.

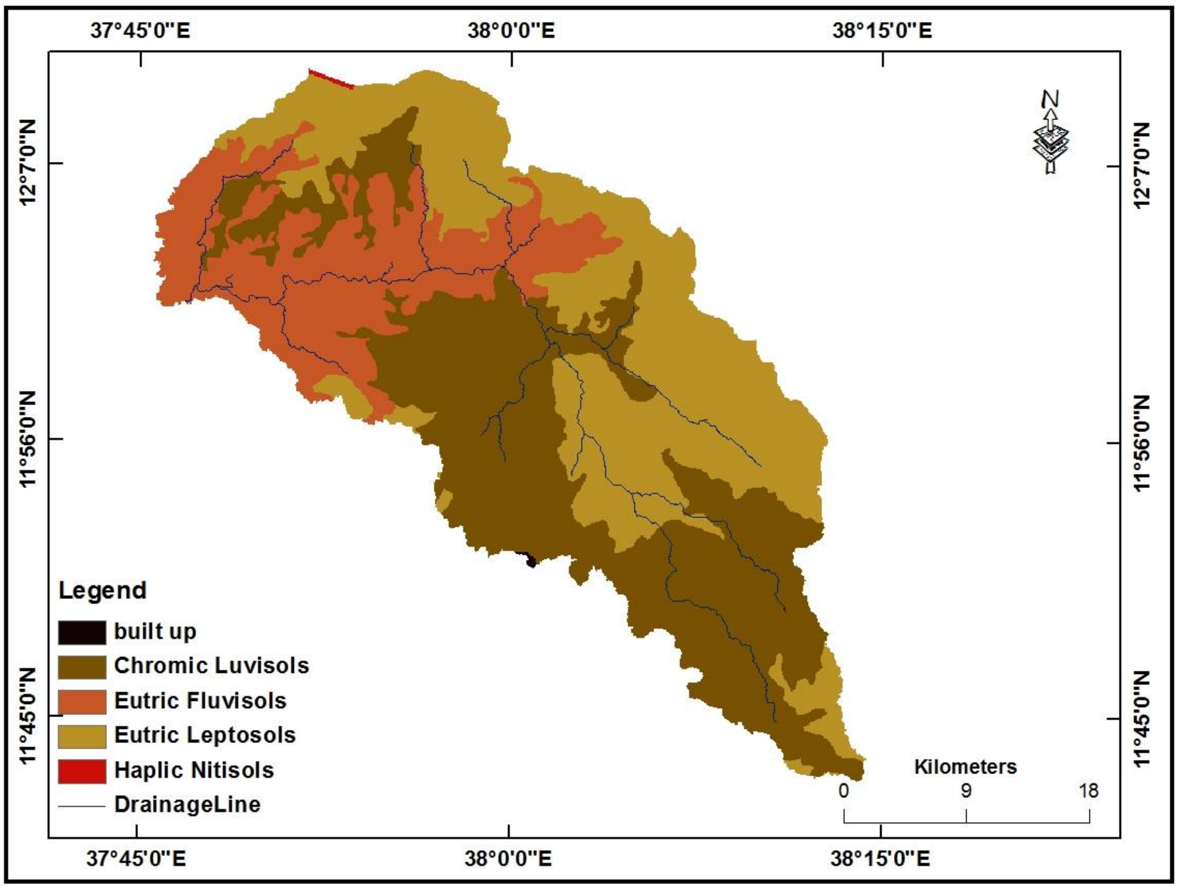

Figure 4-5: soil map of the study area

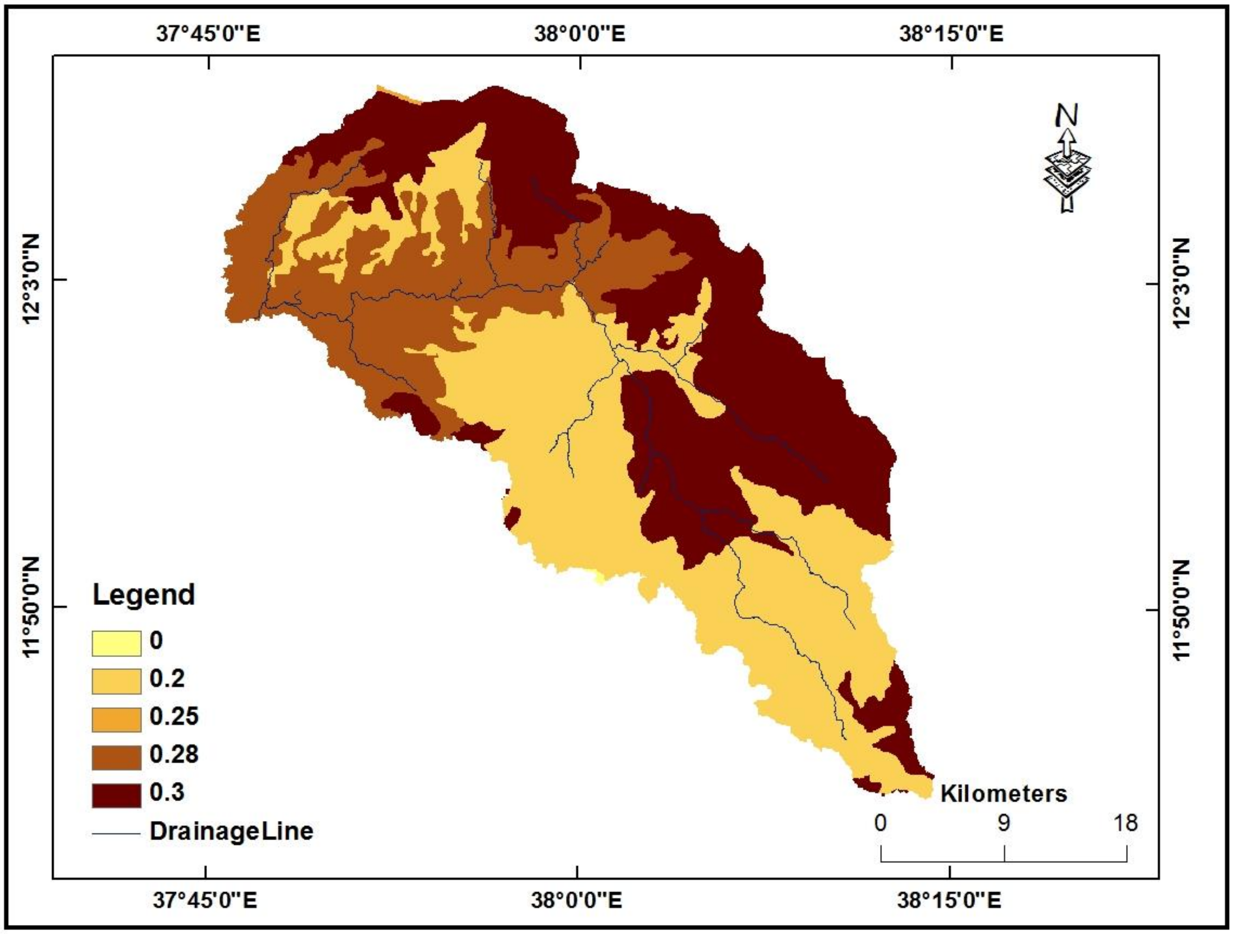

Figure 4-6: K-factor map of the study area

4.1.5 Soil erosion vulnerability based on Topography LS-factor

The values of LS factor ranges from 0 –253. As it is shown in |Table: 4-3 and Figure :4-7, based on the mean and standard deviation the LS-factor was classified into five LS factor classes Three micro-watersheds (MW-16, MW-23 & MW-26) covering 13.19% of the watershed are in very high class of LS-factor. MW-1, MW-2, MW-3, MW-18 & MW-27 covering 8.95% of the study area are in the class of high LS-factor. These two LS factor classes found in the northern part of the watershed more vulnerable to soil erosion. The very low and low class of LS-factor covering 27.86% and 23.94% of the watershed respectively in the north-west part are relatively less vulnerable.

Table 4-3: LS-factor classes and their distribution in the watershed

No.	LS-factor class	LS-class range	Micro-watersheds	No. of micro-watersheds	Area (km^2)	% total
1	Very low	0.39-0.70	5, 11, 13, 14, 15	5	345.49	27.86
2	Low	0.70-1.34	6, 7, 9, 10, 12, 22, 28	7	296.92	23.94
3	moderate	1.34-2.03	4, 8, 17, 19, 20, 21, 24, 25, 29, 30, 31	11	323.17	26.06
4	High	2.03-2.88	1, 2, 3,18, 27	5	111.03	8.95
5	Very high	2.88-3.86	16, 23, 26	3	163.61	13.19
Total				31	1240.12	100

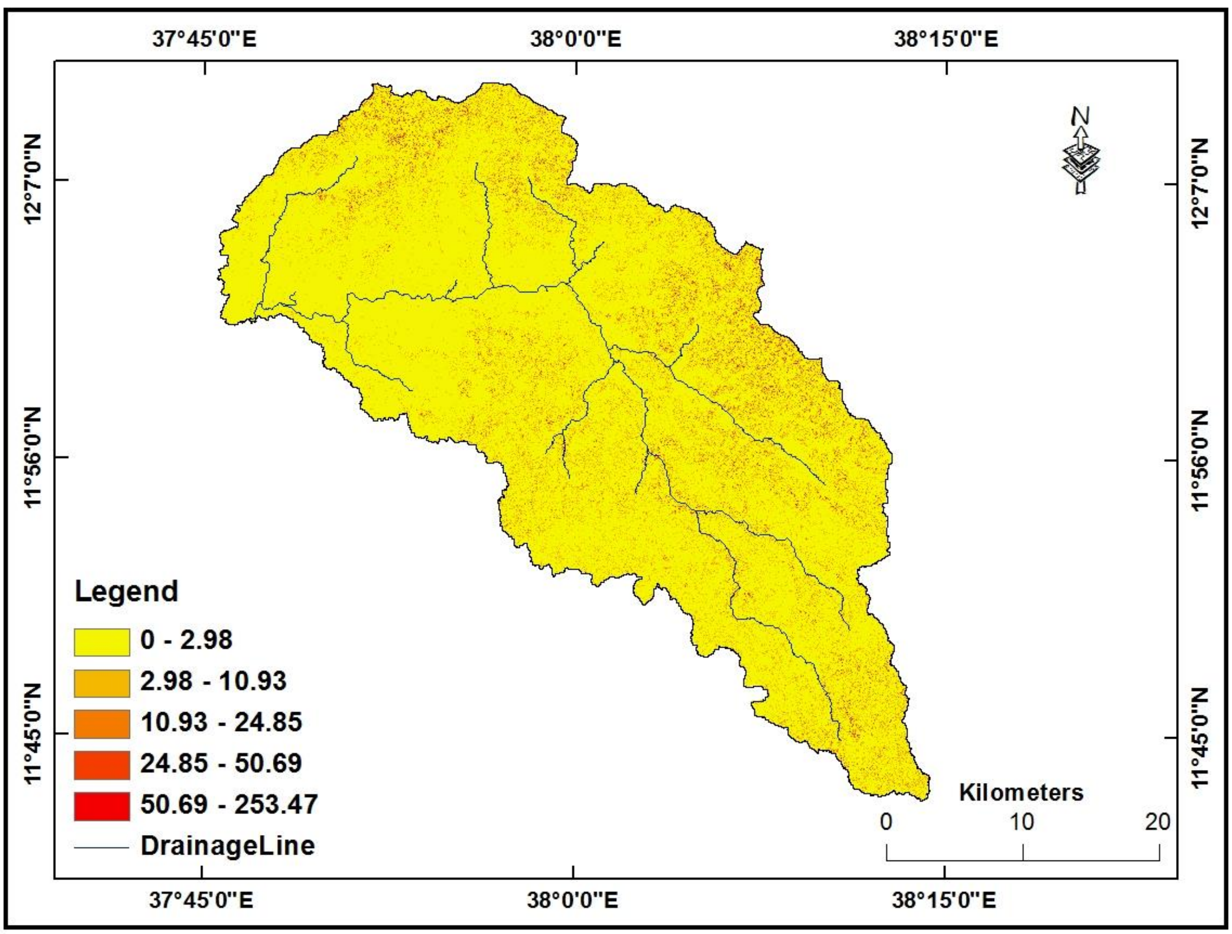

Figure 4-7: LS map of the study area

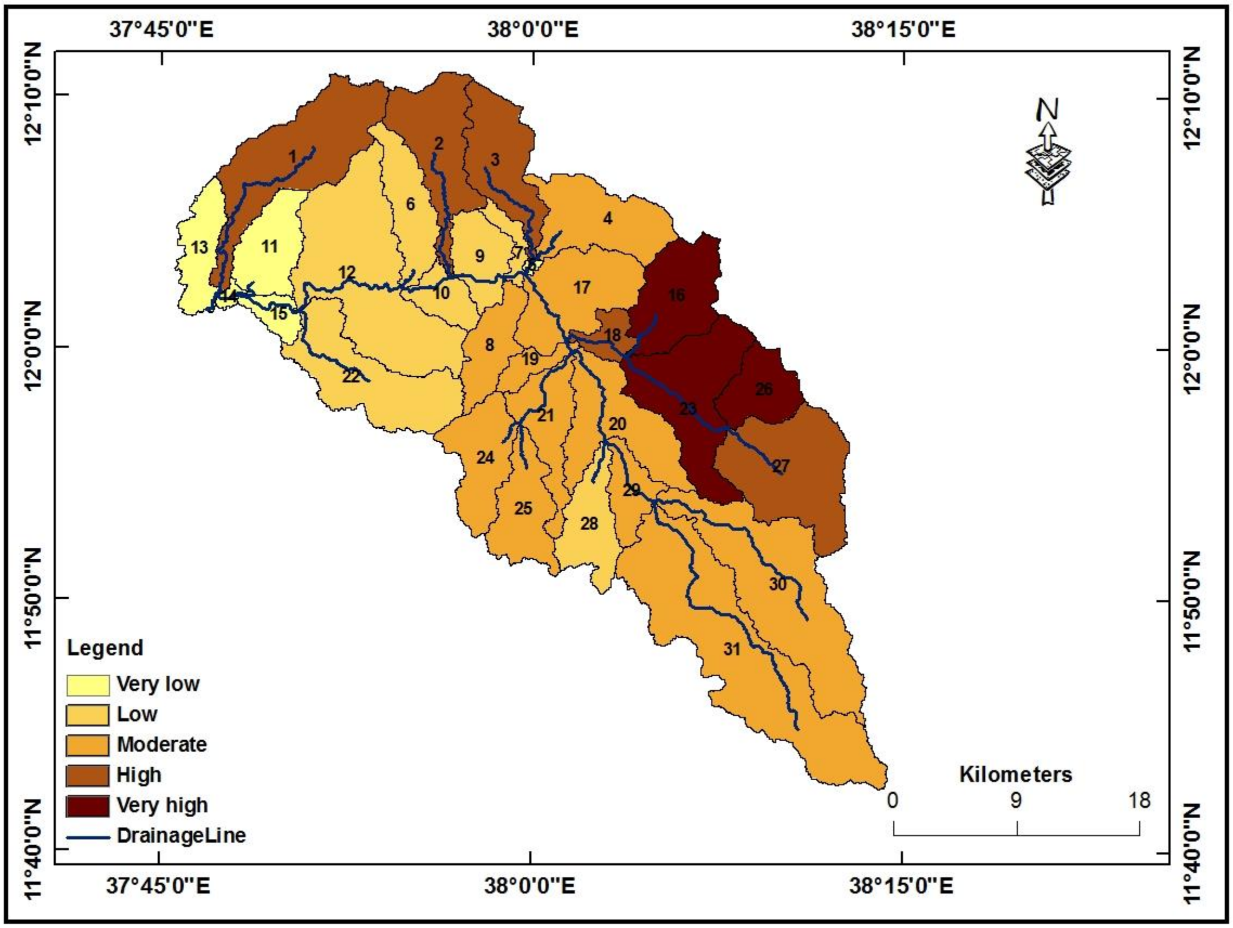

Figure 4-8: Micro-watershed wise LS-factor map

4.2. Soil Erosion Rate Estimates

The annual soil loss rate of the study area was determined by multiplying the respective RUSLE factor (erosivity (R), erodibility (K), topographic(LS), cover management (C) and conservation support practice (P) factor) values interactively in ArcGIS 10 using Equation;

$$A = R^* K^* L.S^* C^* P.$$

The result shows that the potential annual soil loss of Ribb micro-watersheds ranges 10.93 to 95.5 ton/ha/year which is agreed with the annual soil loss of the highlands of Ethiopia (16 - 300 t/ha/yr.). When it is compared to soil loss of the neighboring Gumera watershed ranging from 11 – 22 t/ha/yr., it is very large value. The mean annual soil loss rate of the whole study area is 39.8 ton/ha/year; which is much greater than the tolerable level 10 ton/ha/year (Hurni, 1983). The annual soil loss of the highlands of Ethiopia ranges from 1248 – 23400 million ton per year from78 millions of hectare of pasture, ranges and cultivated fields throughout Ethiopia. Which is equivalent to 16 to 300 t/ha/yr. (FAO, 1984). The result of this study falls within the ranges of the findings of FAO. When we compare this result with the predicted annual soil loss rate in Lake Tana basin which is >60 t/ha/year in rugged topographies and it decreases up to 15 t/ha/year on the area with better catchments characteristics (Birru, 2007). Ribb becomes one of the watershed that contribute a large amount of soil loss in Lake Tana basin.

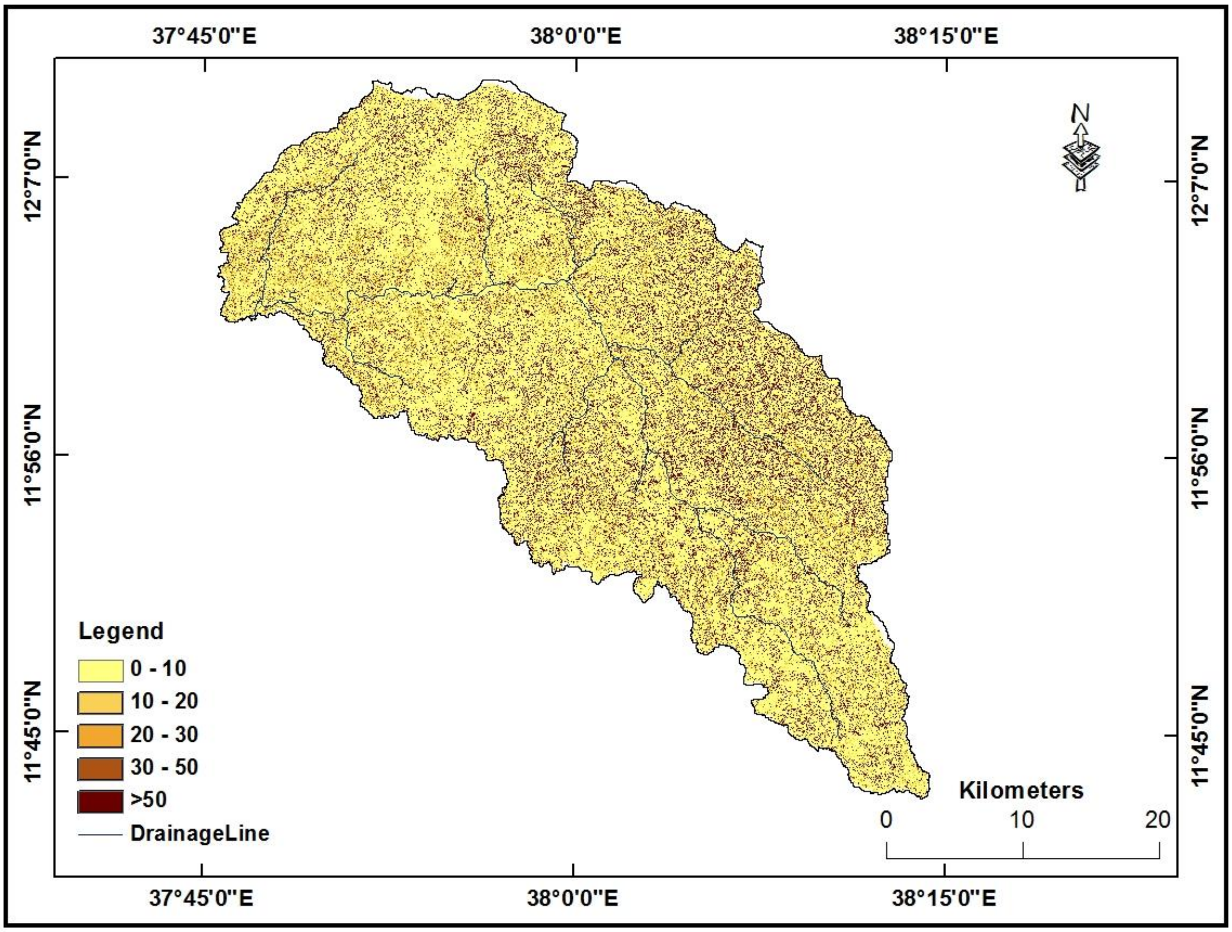

Figure 4-9: Soil erosion rate map of the study area

4.2.1 Erosion vulnerable micro-watersheds Based on Potential Soil Loss rate

Some micro-watersheds may get highly vulnerable to soil erosion due to various reasons. One of the major reasons for this is the intensity of land degradation (Trimphati, *et al.*, 2003). In this study, identification of vulnerable micro-watersheds on the basis of soil loss rate was done.

As it is shown in Table: 4-4, the values of micro-watershed wise soil loss rate are classified in to 5 classes. Named as Very low, Low, moderate, high and Very high. Which on the basis of mean and standard deviation. Thus the very high and high shows relatively more vulnerable and he very low and low shows less vulnerability to soil erosion.

Table 4-4: Classification of micro-watersheds based on soil loss

Erosion Risk Class	**Mean soil loss (t/ ha/yr.)**	**Micro watersheds**	**No. of MWs**	**Area (km2)**	**% total**
Very low	10.93 - 21.22	5, 6, 9, 10, 11, 12, 13, 14, 15	9	243.55	19.64
Low	21.22 - 31.16	7, 8, 17, 19, 22, 25	6	184.37	14.87
moderate	31.16 - 41.45	1, 2, 4, 21, 24, 28, 30, 31	8	491.25	39.61
High	41.45 - 57.36	3, 18, 20	3	102.7	8.28
Very high	57.36 - 95.5	16, 23, 26, 27, 29	5	218.25	17.6
Total				1240.12	100.00

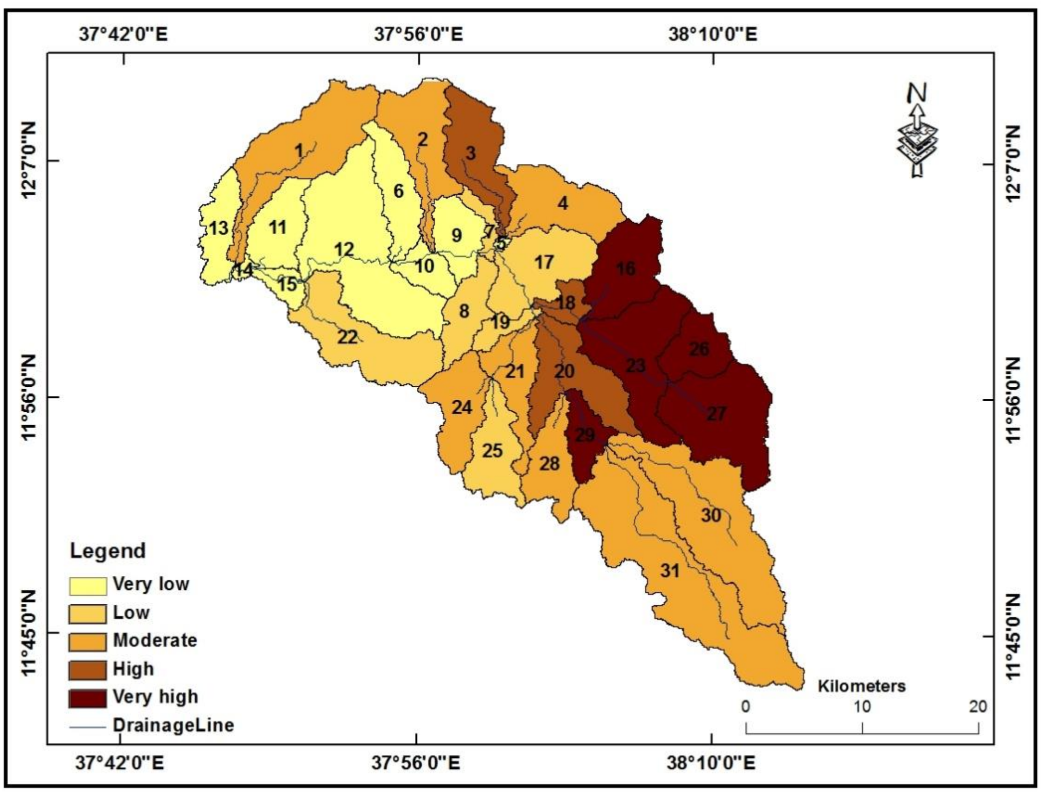

Figure 4-10: Micro-watershed wise soil loss rate map

As shown in figure: 4-10, out of the 31 micro-watersheds, four micro-watersheds (MW-16, MW-23, MW-26, MW-27 and MW-29) covering 17.6% of the watershed shows very high soil loss rate it may be due to high contribution of LS factors. These very high values found in the upper part of the watersheds. In the high soil erosion classes there are three MWs (MW-3, MW-18 and MW-20) and it covers 8.28% of the study area. The largest portion (39.61%) of the watershed fall in moderate erosion classes. About 14.87% of the watershed (MW-7, MW-8, MW-17, MW-19, MW-22 and MW-25) are found in the low erosion classes which is below the annual average soil loss of the entire watersheds (39.8 ton/ha/year). Very low soil loss category (10.93 - 21.22 t/ha/yr.) includes nine MWs (MW-5, MW-6, MW-9, MW-10, MW-11, MW-12, MW-13, MW-14 and MW-15) which are located in the lower reach of the study area and it covers 19.64% of the study area. The micro-watershed under this class is not immediate area of action plan. Based on the annual soil losses, erosion vulnerable micro-watersheds are identified and ranked in ascending order. The micro –watershed that comes first is more erosion vulnerable micro-watershed. Thus priority is given for developing the management plan to reduce the soil and nutrient losses. Based on this - MW-16, MW-23, MW-26 and MW-29 with mean soil loss between 57.36 and 95.5 t/ha/yr. are the most erosion vulnerable micro-watershed and immediate attention can minimize the soil loss rate.

4.3 Estimation of erosion criteria for multi criteria evaluation

4.3.1. Potential location and spatial patterns of gullies

From the polygon which was digitized from google earth shown in Figure: 4-12, a distinct cluster of gully sites was identified within the range of 2 to 6 Stream Power Index values and Stream Power Index of 0–2 are devoid of gullying. The higher Stream Power Index (SPI) with in the range of 6.1–8 in the field were identified as areas that have linked up with stream channels. Based on this result gully potential areas other than the natural stream channels are areas with stream power index from 2-6 which is shown in Figure: 4-13. From the total area 92 $km^2$are found in the SPI value from 2-6 which shows gully potential areas. The other 1147.17 km^2 are areas with no gully potential.

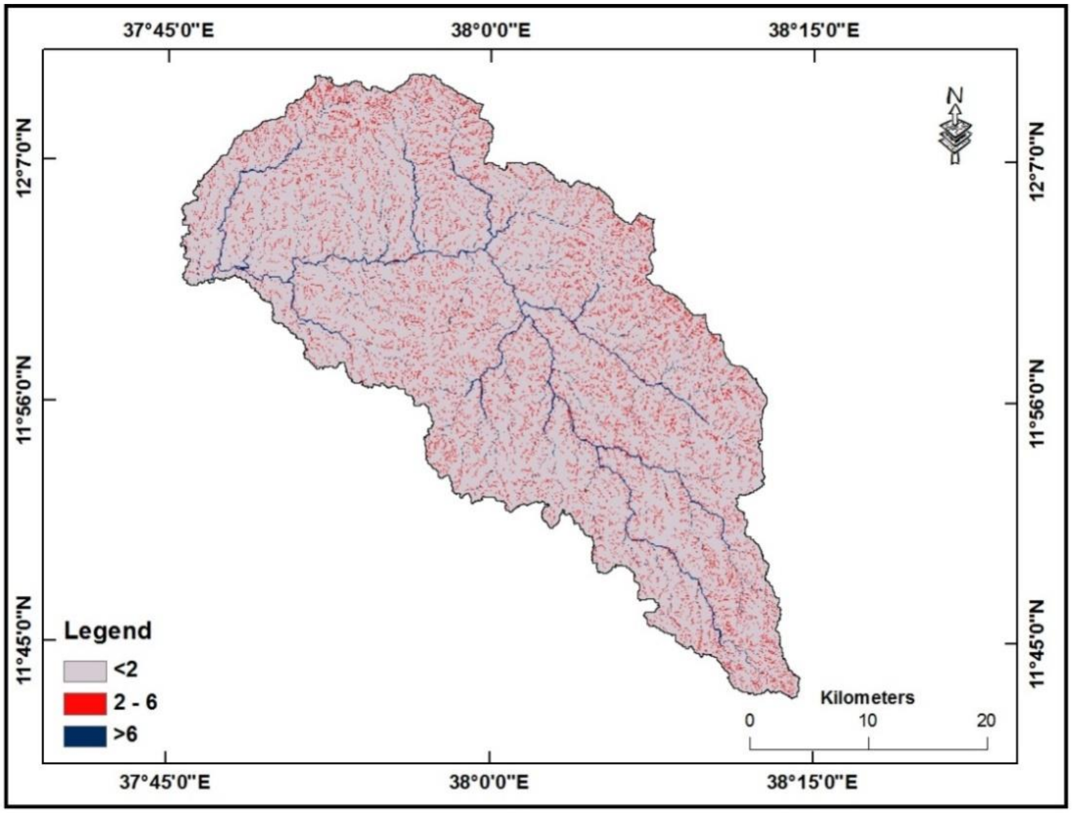

Figure 4-11: Stream Power Index

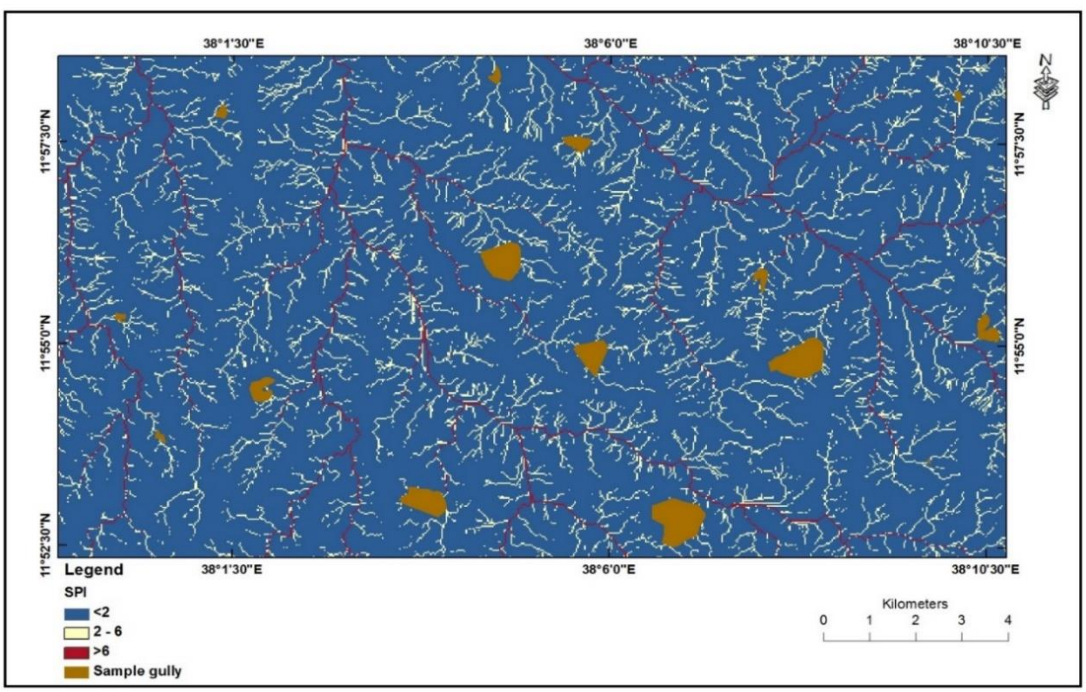

Figure 4-12: Examples of gully polygon digitalized from Google earth

Table 4-5: Sample gully polygons and values of SPI

SPI value	No. of polygons
< 2	2
2 – 6	77
>6	11
Total	90

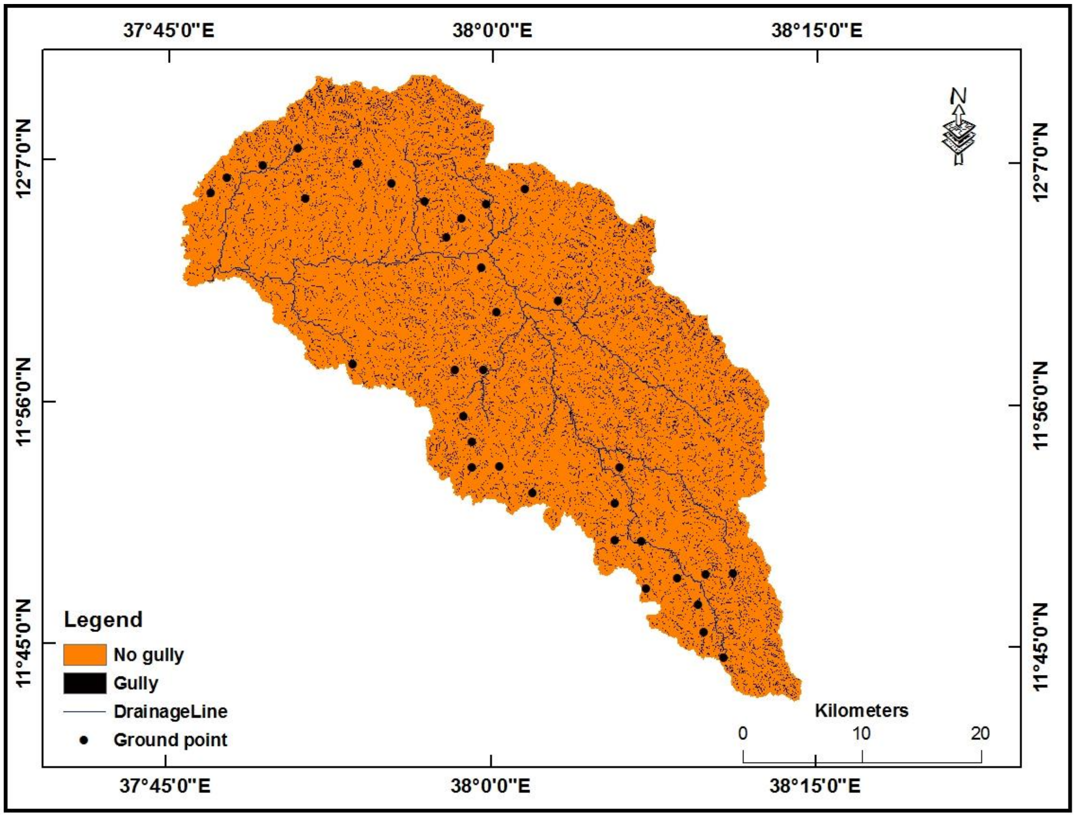

Figure 4-13: Gully ground points in the SPI

Table 4-6: Accuracy assessment of potential gully area using ground control points

Area	No. of ground points
Gully	26
No gully	7
Total	33
Overall Accuracy = (26/33)*100 = 78.8%	

4.3.2. Slope

Slope steepness is one of the criteria for the estimation of erosivity potential. Runoff and erosion potential will increases as the slope steepness increase. Based on FAO, 2001 five classes are identified from the slope map of the watershed. The Slope map of the watershed was reclassified and ranked from 1 to 5 as shown in Table: 4-7. Where 1 represent slopes with the lowest runoff potential and 5 with the highest.

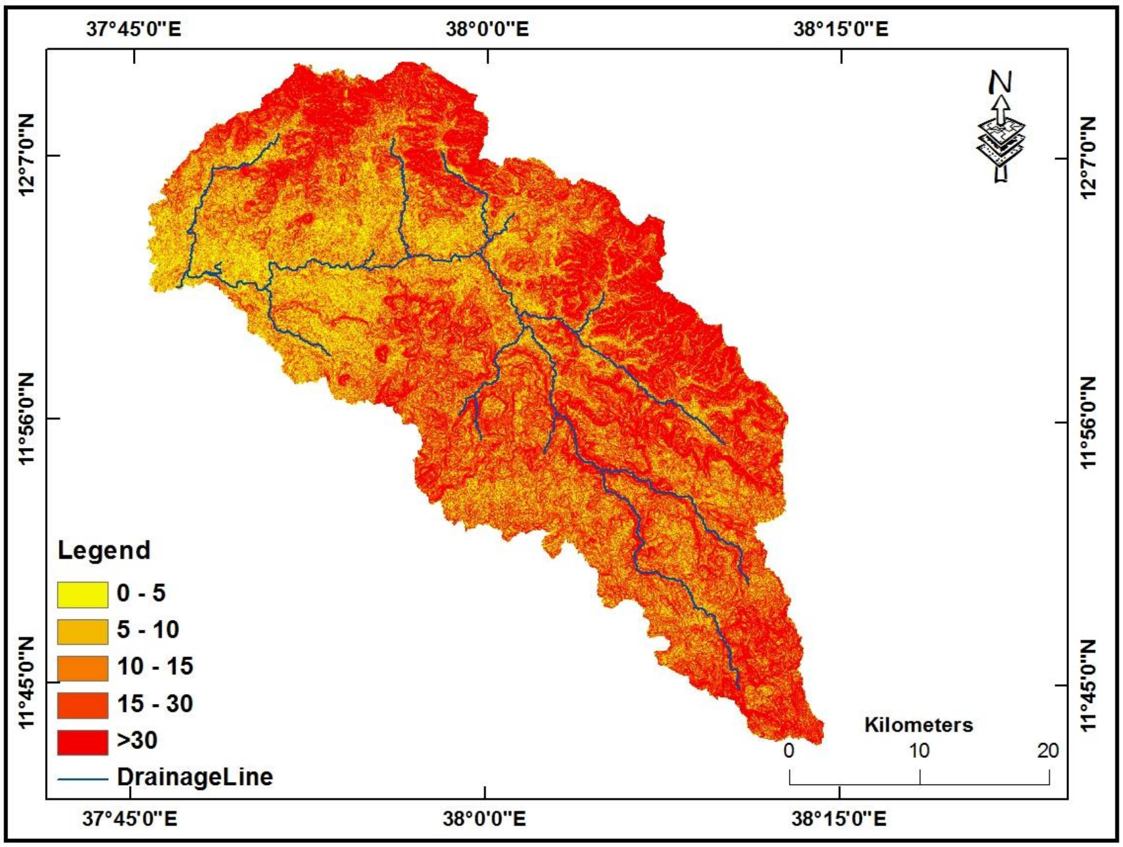

Figure 4-14: Slope map of the study area (in degree)

Table 4-7: Slope parameter used in MCA to generate Composite Erosion Index

Slope	0 -5˚	5 -10˚	10 -15˚	15 -30˚	>30˚
Erosion class	Very low	Low	Medium	High	Very high
Rank	1	2	3	4	5

4.3.3. Landuse/Landcover

A Land which has a good surface cover characterized by low runoff while land with poor surface cover characterized by high runoff and quick response to rainfall which is because of low surface roughness. Thus spatial data on surface cover types is used to assess the resistance of terrain units to erosion as a result of surface protection. The seven major LULC categories which is generated using supervised classification method were reclassified and ranked from 1 to 5 as shown in Table: 4-8. Where 1 representing lowest erosion potential and 5 representing the highest.

Table 4-8: LULC Classification of parameter used in MCA to generate Composite Erosion Index

LULC	Grass land	Forest	Shrub Land	Crop land	Bare land
Erosion class	Very low	Low	Medium	High	Very high
Rank	1	2	3	4	5

4.3.4 Soil Type

Soil Erodibility was taken as one of the factor for MCA. It refers susceptibility of soil to erosion. Thus it was reclassified and ranked 1 to 5 based on their K factor as shown in Table: 4-9. Soil types having low K factor value are less vulnerable to soil erosion and thus were assigned 1 and those soils having high K value were assigned 5.

Table 4-9: Soil Classification of parameters used in MCA to generate Composite Erosion Index

Soil type	Chromic luvisol	Haplic Nitosol	Eutric fluvisol	Eutric Leptosols
Erosion class	Very low	Low	Medium	High
Rank	1	2	3	4

4.4. Weighting using Pairwise comparison

Based on the result from IDRISI Andes 32 software from the four craiteria (Slope, Gully, Landcover and Soil) slope (56.5%) has a high contribution to soil erosion. Next to slope gully, LULC and soil have second, third and fourth respectively in contributing for soil erosion in the study area.

Table 4-7: Pairwise weights

Criteria	Slope	Gully	Landcover	Soil
Weigh	0.565	0.262	0.1176	0.053

Consistency ratio = 0.04

4.5 Erosion Risk in the Watershed based on Multi Criteria Evaluation

4.5.1 Composite Erosion Index (CEI)

Thus finally output map of the Composite Erosion Index indicates micro-watershed wise erosion risk map from CEI that relates to the erosion intensity of the area under the relative contribution of the given criteria. Values of CEI in the study area range between 1.55 and 2.92. The low erosion potential was present under low slope gradient. And it increases with higher slope values.

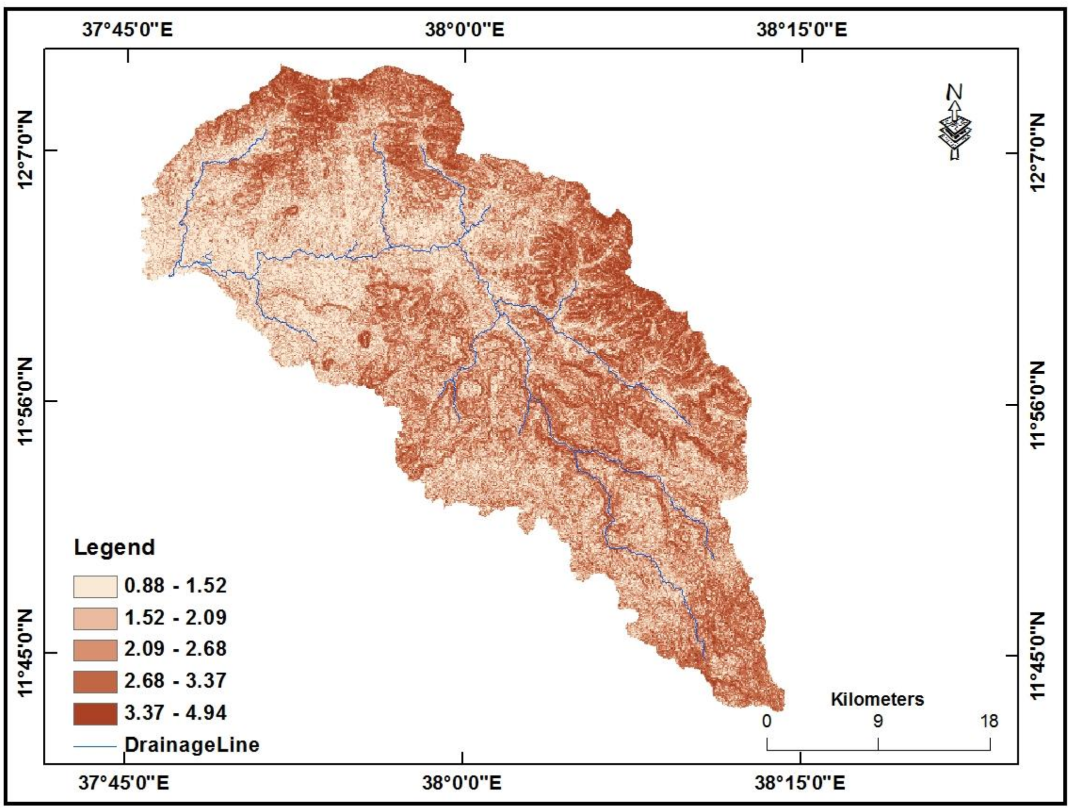

Figure 4-15: CEI Map of the study area

4.5.2. Identification of erosion vulnerable micro-watershed based on the CEI

Composite Erosion Index shows the intensity of soil erosion which is important for the identification of Micro-Watersheds affected by erosion. Thus it will help prioritization Micro-Watersheds for selection and implementation of conservation measures and plan appropriate Landuse to minimize the soil losses in them. The composite erosion index Values of the micro-watersheds are classified in to five based on their mean and standard deviation in ArcGIS environment. Thus, the very high and high class value (2.25-2.92) shows more vulnerable micro-watershed and the very low value shows less vulnerable to soil erosion. Table 4-8 shows area and proportion of the micro-watersheds classes based on their CEC. Most of the study area (27.61%) lays on the high CEI class values between 2.25 and 2.53.

Table 4-8: CEI classes and Area proportion of the study area

Erosion Risk Class	Mean CEI	Micro watersheds	No. of MWs	Area (km2)	% total
Very low	1.55-1.75	5, 11, 13, 14, 15,	5	67.37	5.44
Low	1.76-1.95	6, 7, 9, 10, 12, 22, 25	7	277.43	22.37
moderate	1.96-2.24	8, 17, 19, 21, 24, 28, 31	7	311.43	25.11
High	2.25-2.53	1, 2, 4, 18, 20, 29, 30	7	342.4	27.61
Very high	2.54-2.92	3, 16, 23, 26, 27	5	241.49	19.47
Total				1240.12	100

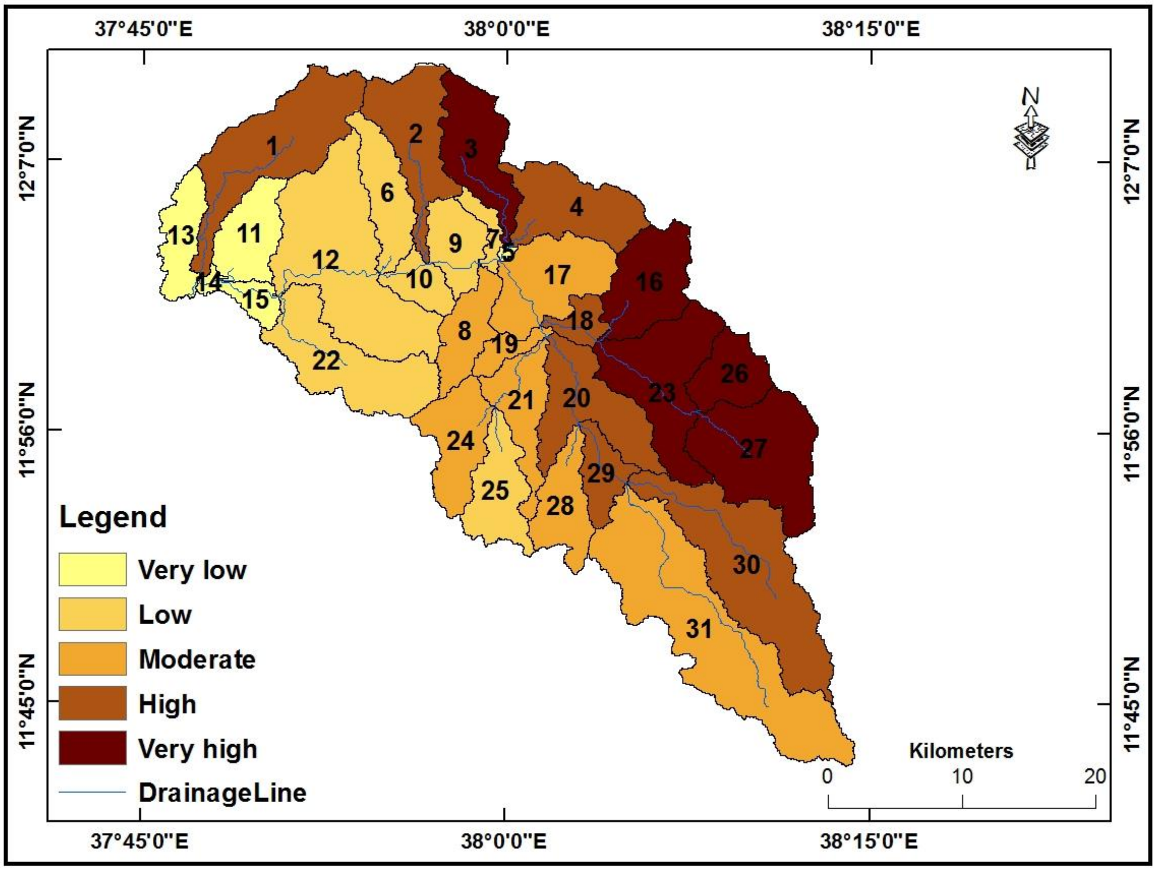

Figure 4-16: Micro-watershed soil erosion vulnerability based on CEI

Based on the Mean CEI classes MW-5, MW-11, MW-13, MW-14 and MW-15 fall in the very lower class of CEI and it covers only 5.44% of the study area. And seven micro-watersheds that covers 22.37% of the watershed are in the low class of CEI. Thus, these Micro-watersheds are less vulnerable to soil erosion. MW-3, MW-16, MW-23, MW-26 and MW-27 have a Very high CEI which is highly vulnerable to soil erosion and these micro-watersheds are 19.47% of the study area coverage. 27.61% of the study area is under high class of CEI and it includes seven Micro-watersheds. 25.11% of the study area are found in moderate classes of CEI.

CHAPTER - V

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

The major objective of this study was to identify the most erosion vulnerable micro-watersheds for soil erosion in Ribb watershed which is located in the upper north-eastern narrow parts of Lake Tana River basin. The study uses an empirically based erosion assessment model. Thus RUSLE model integrated with satellite remote sensing and geographical information systems has provided useful information for the assessment and decision-making about the vulnerability of micro-watersheds. In line with these the land use land cover of the study area are classified and characterized using supervised classification. In addition, since RUSEL model cannot estimate gully erosion, by using the method proposed by Moore *et al.,* (1988) the potential location and spatial patterns of gullies were identified in the study.

Using supervised image classification, the study area were classified in to seven land use land cover classes. On the base of their cover factor bare land covering 3.74% of the study area are the highly vulnerable to soil erosion. Next to bare land farm lands which cover the largest portion of the study area (61%) are sensitive to soil erosion the seven land use land cover class classification,

From the result of RUSLE model in Arc GIS environment, the average annual soil loss of each micro-watersheds ranges from 10.93 to 95.5 t/ha/year. The mean annual rate of soil loss in the watershed is 39.8 ton/ha/year, which is very large enough to degrade the area. Five micro watersheds that cover 17.6% of the area experience very high erosion rate and they are in the northern part of the study area within steep dissected to mountainous terrain and hilly terrain slope classes which is due to high contribution from LS factor. 8.28% of the study area that include three micro watershed fall in a high erosion rate. The very high and high value may be due to the large slope in the northern part of the study area. Under moderate erosion rate there are 8 micro-watersheds covering 39.61% of the study area. This may be due to the low slope class. Fifteen micro-watersheds with 34% of the study area fell in the low and very low erosion risk class. This may be due to the low average slope.

From Prediction of potential location for gully formation by using Topographic thresholds concept, 92 $km^2$of the study area are gully potential areas. The other 1148 $km^2$are areas with no gully potential. Gully potential areas are largely found in the upper and higher slope of the study areas. Gully erosion is common even in the plains. Because Vertisols crack in the dry season, accumulated runoff from uphill enters the crack and widens it, ready to form gullies. Overgrazing and livestock trampling also create gullies in the grazing land.

From the multi-criteria analysis, four micro-watersheds found in the northern part of the study area which cover 19.47% of the area are categorized as a very high composite erosion index (2.53-2.92). 27.61% of the study area which includes nine micro-watersheds are in the class of high CEI value. Thus they are relatively under high risk of erosion. Seven micro-watersheds covering 25.11% of the watershed are in the moderate class of CEI. Only 5.44% of the study area that includes five micro-watersheds are under the very low class of CEI which shows relatively less vulnerable to soil erosion

Considering the above results micro-watersheds having large mean soil loss rate and CEI value gets the first rank to be vulnerable to soil erosion.

5.2 RECOMMENDATIONS

This study focused on the identification of vulnerable micro-watersheds for soil erosion based on soil loss rate using RUSLE model and multi-criteria analysis. Based on the soil loss rate and CEI value, the most erosion vulnerable micro-watersheds should have to be prioritized for conservation activities.

As the result of the study is the most important base line data in the implementation conservation activities that reduce soil loss and increase productivity the soil, responsible bodies including governmental and non-governmental organizations who work on environmental protection and other related issues should incorporate it during planning and implementation of soil and water resource conservation and management practices.

Diverting the runoff entering the gully by constructing cutoff drains and check dams are recommended to control gully erosion.

Further studies need to be done in order to assess the conservation measures required for different stages of erosion vulnerable micro-watershed under different factors.

A dedicated policy has to be developed by local authorities regarding the management of identified vulnerable micro-watersheds.

REFERENCES

Abeyou W. W., 2007. Hydrological balance of Lake Tana Upper Blue Nile Basin Ethiopia. M.Sc. Thesis. ITC the Netherlands

Abiy D., 2010 Landuse/Landcover Dynamics and Soil Erosion Risk Analysis, for Sustainable Land Management in North Central Ethiopia: The Case of Antsokia-Gemza Woreda.

Akalu Teshome, Melaku Wale, Fentahun Mengistu and Birru Yitaferu., 2009. Agricultural potentials, constraints and opportunities in the Megech and Ribb rivers irrigation project Areas in the Lake Tana Basin of Ethiopia. Ethiopian Nile Irrigation and Drainage Project Bahir Dar, Ethiopia

Ayele F, 2011 Assessment of Soil Erosion Risk in the Holeta Watershed, Central Oromiya, Ethiopia

Badri, M.A., 1999 Combining the Analytic Hierarchy Process and Goal Programming for Global Facility Location- Allocation Problem. International Journal of Production Economics, 62, 237-248.

BCEOM, 1998. Abay River Basin Integrated Development Master Plan, Main Report. Ministry of Water Resources: Addis Ababa.

Beck, M.B., 1987. Water quality modeling: A review of uncertainty. Water Resources Research 23, 1393-1442.

Berry, L., 2003. Land Degradation in Ethiopia: Its Extent and Impact. Commissioned by the G.M with W.B support.

Birru Yitaferu, 2007. Land degradation and options for sustainable land management in the Lake Tana Basin (LTB), Amhara Region, Ethiopia. PhD Thesis, Centre for Development and Environment (CDE), Geographisches Institute, University Bern, Bern, Switzerland.

Boggs G, Devonport C, Evans K, Puig P. 2001. GIS-Based Rapid Assessment of Erosion Risk in a Small Catchment in the Wet/Dry Tropics of Australia. Land Degradation & Development.

Community Based Participatory Watershed Management. 2005. Integrated Watershed Management in Rain fed Agriculture. CRC press Leiden, Netherlands.

Congalton, R.G., 1991. A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. Remote Sensing of Environment 37.

Costick, 1996. Spatial information for land use management. Gorden and Breach science Publishers.

De Asis, A. M. and Omasa, K., 2007. Estimation of vegetation parameter for modeling soil Erosion using linear Spectral Mixture Analysis of Landsat ETM data. ISPRS Journal of Photogrammetry & Remote Sensing 62, 309–324 Deore, 2005

Deore, S.J., (2005). Prioritization of Micro-watersheds of Upper Bhama Basin on the Basis of Soil Erosion Risk Using Remote Sensing and GIS Technology. PhD thesis, University of Pune, Pune.

Desmet, P. J. and Govers, G., 1996. USLE2D.EXE (Release 4.1): User documentation

Erenstien, 1999. Sustainable poverty reduction in less favored area. Cromwell Press, Trowbridge, UK.

Eweg HPA, van Lammeren R., 1996. The application of geographic information system at the Rehabilitation of degraded and degrading areas of Tigray, Ethiopia. Research Report, Wageningen Agricultural University, Wageningen..

FAO. 2000. Landover Classification System (LCCS): Classification Concepts and User Manual. Retrieved 1-July-2003.

FAO. 2001 Preparation of Land Cover Database of Bulgaria through Remote Sensing and GIS, Vershion 6. Bulgaria, Europe.

FAO. 1986. Highlands Reclamation Study of Ethiopia Final Report. Vol. I & II. Rome, Italy

Foster, G. R. and Meyer, L. D., 1977. "Soil erosion and sedimentation by water – an overview. Pros. National Symposium on Soil Erosion and Sedimentation by Water, Am. Soc. Of Agric. Eng., St. Joseph, Michigan, 1-13.

Haan, C.T, Barfield, B.J, Hayes, J.C., 1994. Design hydrology and sedimentology for small catchments. Academic Press, San Diego.

Hellden, U., 1987. An Assessment of Woody Biomass, Community Forests, Land Use and Soil Erosion in Ethiopia. Lund University Press.

Hurni, H. 1988. Climate, soil and water. Degradation and conservation of the resources in the Ethiopian Highland. University of Berne, Switzerland

Hurni, H. 1983. Soil erosion and soil formation in agricultural ecosystems in Ethiopia and Northern Thailand. Mountain research and development.

Hurni, H., 1985. Erosion-productivity-conservation systems in Ethiopia. IV. International Conference on Soil Conservation, Venezuela, 20.

Israel T., 2011 Soil Erosion Risk Assessment with RUSLE and GIS in Dire Dam Watershed

Jain, S.K. and Goel, M.K. 2002. Assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS. Hydrological Sciences—Journal 47(1), 31-40

Jankowski, P. 1995. Integrating geographical information systems and multiple criteria decision making methods. International Journal of Geographical Information Systems 9, 251- 273.

Kaltenrieder. V.V.J., 2007. Adaptation and Validation of the Universal Soil Loss Equation (USLE) for the Ethiopian Eritrean Highlands. MSc, thesis. University of Bern. Switzerland.

Kiflu G., 2010. GIS-Based Conservation Priority Area Identification in Mojo River Watershed on the Basis of Erosion Risk, Mojo, Ethiopia.

Lal R., 1998. Agronomic consequences of soil erosion. IN: Vries F.W.T., Agus F. and Kerr J. 1998. Soil erosion at multiple scales: principles and methods for assessing causes and effects. CABI publishing. New York, USA.Lal, 1998)

Lal, R., 2001. Soil conservation for C sequestration. In: Stott D.E, Mohtar RH, Steinhardtb G.C (eds) Proceedings of the 10th international soil conservation organization meeting, 24–29 May 1999, West Lafayette.

Li, Z., O'Neill, A.L. and Lacey, S., 1996. Modelling approaches to the prediction of soil erosion in catchments. Environmental Software 11(1-3), 123-133.

Lilisand, T.M. and Kiffer, R.W, 1994, Remote Sensing and Image Interpretation, Fourth edition. John Willy and Sons Inc. New York.

Malczewski, J., 1999a. GIS and Multicriteria Decision Analysis. J. Wiley & Sons, New York.

Merritt, W.S., Letcher, R.A. & Jakeman, A.J., 2003. A review of erosion and sediment transport models, Environmental modeling & Software 19, 761-799.

Mitiku H., Herweg K., and Stillhardt B., 2006. Sustainable Land Management: A New Approach to Soil and Water Conservation in Ethiopia. Land Resources Management and Environmental Protection Department Mekelle University, Ethiopia, and Centre for Development and Environment (CDE), Swiss National Centre of Competence in Research (NCCR) North-South University of Bern, Switzerland.

MoWR, 2008. Nature and features of the Ethiopian River basins, Ministry of Water Resources, Addis Ababa, Ethiopia.

MOARD. 2005. Guide line for integrated watershed management, Addis Ababa, Ethiopia.

Mongkolsawat, C., Thurangoon, P. & Sriwongsa, 1994. Soil erosion mapping with USLE and GIS. Proc. Asian Conf. Rem. Sens., C-1-1 to C-1-6.

Moore, I.D., Gessler, P.E., Nielsen, G.A., Peterson, G.A., 1993. Soil attribute prediction using terrain analysis. Soil Science Society of America Journal 57, 443–452.

Morgan, R.P.C., 1995. Soil Erosion and Conservation. Edinburgh: Addison-Wesley Longman.

Nyssen, J.; Haregeweyn, N.; Descheemaeker, K.; Gebremichael, D.; Vancampenhout, K.;Poesen, Haile, M.; Moeyersons, J.; Buytaert, W.; Naudts, J.; Deckers, J.; Govers, G. 2006. Comment on "Modelling the effect of soil and water conservation practices in Ethiopia" (Agriculture, Ecosystems and Environment 105: 29-40), Agriculture, Ecosystems and Environment.

Pereira, J. M. C., and Duckstein, L., 1993. A multiple criteria decision-making approach to GIS-base land suitability evaluation. International Journal of Geographical Information Systems.

Petter, P., 1992. GIS and Remote Sensing for Soil Erosion Studies in Semi-arid Environments. PhD thesis. University of Lund, Lund.

Poesen, J. Nachtergaele, J. Verstraeten, G. and Valentin, C., 2003. Gully erosion and environmental change: importance and research needs. Catena 50, 91– 133 Remortel et al., 2001

Renard, K.G. & Foster, G.R., 1983. Soil Conservation: Principles of erosion by water. In H. E. Dregne and W. O. Willis, eds., Dry land Agriculture, PP. 155 – 176.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and Yoder, D.C., 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook No. 703. Agricultural Research Service, Washington, DC

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C. 1996. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA, Washington, DC.

Renschler, C., 1996. Soil erosion hazard mapping by means of Geographical Information systems (GIS) and Hydrological modelling. MSc, Technical University of Braunschweig, Braunschweig.

Saavedra, C., 2005. Estimating spatial patterns of soil erosion and deposition in the Andean region using geo-information techniques: a case study in Cochabamba, Bolivia Ph.D. dissertation, Wageningen University, The Netherlands.

Saha, S.K., Kudrat, M. & Bhan, S.K., 1991. Erosional soil loss prediction using digital Satellite data and USLE, pages 369-372. In Applications of Remote Sensing in Asia and Oceania – environmental change monitoring (Shunji Muraied.). Asian Association of Remote Sensing

Saxena, R. K., Verma, K. S., Chary, G. R., Srivastava, R. and Barthwal, A. K., 2000. IRS-1C Data application in watershed characterization and Management. Int. J. remote sensing

Shi, Z.H., Cai, C.F., Ding, S.W., Wang, T.W. & Chow, T.L., (2003). Soil conservation planning at the small watershed level using RUSLE with GIS: a case study in the Three Gorge Area of China. Catena 55, 33–48

Sidorchuk, A., Märker, M., Moretti, S., Rodolfi, G., 2003. Gully erosion modelling and landscape response in the Mbuluzi River catchment of Swaziland. Catena 50, 507–525.

Tagil, S., Jenness, J., 2008. GIS-based automated landform classification and topographic, Landcover and geologic attributes of landforms around the Yazoren Polje, Turkey. Journal of Applied Sciences 8, 910–921.

Tamene, L. and Vlek, P. L. G., 2007.Assessing the potential of changing land use for reducing soil erosion and sediment yield of catchments: a case study in the highlands of northern Ethiopia.

Thorne, C. R., L. W. Zevenbergen, E. H. Grissinger, and J. B. Murphey. 1986. Ephemeral gullies as sources of sediment. In Proc. 4th Federal Interagency Sed. Conf., 3.152-3.161. Reston, Va.: U.S. Geological Survey.

Tripathi, M.P., Panda R.K. and Raghuwanshi, N.S., 2003. Identification and prioritization of critical sub-watersheds for soil conservation management using the SWAT model. Biosystems Engineering.

Vrieling, A., 2006. Satellite remote sensing for water erosion assessment: a review. Catena 65, 2 – 18

Vrieling, A., 2007. Mapping Erosion from Space. Doctoral Thesis Wageningen University – with ref. – with Summaries in English and Dutch. ISBN: 978-90-8504-587-8.

Wischmeier, W.H. and. Smith D.D., 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agriculture Handbook No. 537, US Department of Agriculture, Washington DC.

APPENDICES

Appendix 1: Mean monthly Rainfall data of Six Stations (1997 – 2011)

Stations	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
A. Zemen	0	0.8	6.9	34.4	64.7	192.9	443.3	403.8	165	33.9	11.8	0.2
B.Dar	2.3	2	12.8	28.4	70.9	198.3	413.9	394.3	195.2	92.6	12	2.3
D. tabor	11.2	4	29.4	45.7	95.3	170.3	419.7	416.7	198.4	84.7	19.9	12.9
Ebnat	3.5	9.1	19.4	13.8	33.7	115.5	323.5	316.7	96.5	48.9	13.5	2.4
Maksegnite	2.2	1.2	20.9	35.6	70.4	170.7	357.7	347.5	93.5	49.1	21.7	4.4
N. mewcha	12.1	10.7	60	54.8	41	73.1	346.5	294.9	94.4	40.5	26.6	20

Appendix 2: Mean monthly temperature of five stations (1997 – 2011)

Stations	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
A.zemen	19.75	20.81	22.18	21.76	22.19	20.64	19.29	18.92	18.22	20.13	18.8	18.8
B.Dar	17.79	19.68	21.22	22.69	22.36	20.91	19.03	19.23	19.46	20.1	19.02	17.8
D.tabor	15.46	16.94	17.66	17.73	17.44	16.18	14.42	14.72	14.93	15.07	15.05	14.29
Maksegnit	17.2	18.89	23.4	23.55	23.12	21.09	19.35	19.6	20.21	20.75	20.74	18.12
N.mewcha	12.56	13.81	14.15	14.46	14.84	14.15	12.05	11.69	12.13	12.17	12.11	12.3

Appendix: 3 Ground Control Point for Gully erosion

S/No.	x	y
1	371903	1339394
2	401402	1307926
3	403668	1307833
4	404020	1303854
5	408933	1300215
6	408417	1302529
7	401407	1311070
8	390423	1322228
9	387977	1322254
10	379436	1322738
11	367491	1337085
12	391737	1314144
13	411363	1305133
14	382705	1337867
15	368852	1338386
16	374831	1340816
17	401844	1314026
18	406655	1304774
19	409036	1305085
20	410547	1298100
21	394548	1311893
22	393915	1337429
23	390627	1336138
24	388555	1334981
25	382828	138379

26	379798	1339579
27	391461	1327074
28	390242	1330850
29	389451	1314021
30	389429	1316161
31	388721	1318326
32	375426	1336614
33	387250	1333323

Appendix: 4 Informal interview with Natural resource experts in the study area

1. Rank the following erosion factors in their contribution to soil erosion.

S/No.	Factors	Rank
1	Slope	
2	Gully	
3	LULC	
4	Soil	

Appendix: 5 Pairwise comparison – 9 Points Continuous Rating Scale

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	Very strong	strong	moderate	equally	moderate	strong	Very strong	extremely
Less important				important	More important			

	Slope	Gully	LULC	Soil
Slope	1			
Gully	1/3	1		
LULC	1/5	1/3	1	
Soil	1/7	1/5	1/3	1

Appendix 6: Micro-watershed wise LS factor in descending order

Rank	Micro-watershed	Area(km2)	Mean soil loss (t/ha/yr.)
1	16	73.39	3.87
2	26	47.95	3.51
3	23	42.27	2.89
4	3	45.83	2.63
5	2	1.15	2.30
6	1	30.92	2.24
7	27	7.92	2.18
8	18	25.2	2.04
9	29	24.16	1.99
10	4	15.51	1.78
11	30	29.9	1.77
12	24	105.68	1.75
13	31	23.82	1.72
14	20	2.49	1.61
15	19	10.01	1.56
16	21	42.5	1.55
17	8	48.58	1.55
18	17	11.09	1.50
19	25	9.43	1.34
20	28	49.34	1.26
21	6	30.86	1.23
22	7	60.15	1.07
23	12	62.6	1.07
24	10	35.26	0.97
25	22	33.09	0.95
26	9	25.62	0.70
27	11	68.6	0.70
28	5	29.89	0.60
29	15	18.93	0.57
30	13	96.87	0.58
31	14	132.3	0.39

Appendix 7: Micro watershed wise potential soil loss rate

Rank	Micro-watershed	Area(km2)	Mean soil loss (t/ha/yr.)
1	29	18.93	94.76
2	26	25.62	95.5
3	16	42.5	79.26
4	23	62.6	78.97
5	27	68.6	57.51
6	20	49.34	31.4
7	3	42.27	50.62
8	18	11.09	41.69
9	30	96.87	38.98
10	2	47.95	37.85
11	4	45.83	37.96
12	28	29.89	34.63
13	31	132.3	36.24
14	24	35.26	34.91
15	1	73.39	35.03
16	21	30.86	31.40
17	17	48.58	30.61
18	8	25.2	29.88
19	22	60.15	29.76
20	19	9.43	26.73
21	25	33.09	25.69
22	7	7.92	21.31
23	10	15.51	21.09
24	12	105.68	19.50
25	6	30.92	17.75
26	9	24.16	16.89
27	11	29.9	16.56
28	15	10.01	16.66
29	13	23.82	15.97
30	14	2.49	11.37
31	5	1.15	10.93

Appendix: 8 Micro-watershed wise erosion intensity based on CEI

Rank	Micro-watershed	Area(km2)	CEI
1	26	25.62	2.92
2	16	42.50	2.87
3	3	42.27	2.75
4	23	62.60	2.63
5	27	68.60	2.53
6	29	18.93	2.48
7	2	47.95	2.47
8	1	73.39	2.39
9	4	45.83	2.38
10	20	49.34	2.37
11	18	11.09	2.34
12	30	96.87	2.29
13	24	35.26	2.29
14	31	132.30	2.24
15	21	30.86	2.17
16	8	25.20	2.17
17	17	48.58	2.16
18	19	9.43	2.14
19	28	29.89	2.08
20	25	33.09	2.06
21	7	7.92	2.04
22	10	15.51	1.95
23	6	30.92	1.93
24	12	105.68	1.91
25	22	60.15	1.89
26	9	24.16	1.85
27	11	29.90	1.75
28	15	10.01	1.74
29	5	1.15	1.74
30	13	23.82	1.71

Appendix 8 some images of the Land use/Land cover in the study area