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**ADDIS ABABA UNIVERSITY**  
**COLLEGE OF NATURAL AND COMPUTATIONAL**  
**SCIENCES**  
**SCHOOL OF EARTH SCIENCES**

**Assessment of Soil Erosion by RUSLE Model Using Remote  
sensing and GIS Techniques: A Case Study of Huluka  
Watershed, Central Ethiopia**

**A Thesis Submitted to**

**The School of Graduate Studies of Addis Ababa University  
Presented in Partial fulfillment of the Requirements for the Degree  
of Masters of Science in Remote Sensing and Geo-informatics**

**By Habtamu Atoma Feda  
ID. No: GSR/6769/09**

**Addis Ababa, Ethiopia**

**May 2018**

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**Addis Ababa, Ethiopia**

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# Addis Ababa University

## School of Graduate Studies

This is to certify the thesis prepared by Habtamu Atoma Feda entitled as “**Assessment of Soil Erosion by RUSLE Model Using Remote sensing and GIS Techniques: A Case Study of Huluka Watershed, Central Ethiopia**” is submitted in partial fulfillment of the requirements for the Degree of Master of Science in Remote Sensing and Geo-informatics compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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# Contents

ACKNOWLEDGMENTS .....	i
List of Figures .....	v
List of Tables .....	vi
List of Acronyms .....	vii
Abstract .....	ix
CHAPTER ONE .....	1
1 INTRODUCTION .....	1
1.1 Background .....	1
1.2 Statement of the problem .....	3
1.3 Objectives .....	5
1.3.1 General Objective .....	5
1.3.2 Specific Objectives .....	5
1.4 Research Questions .....	5
1.5 The scope of the study .....	5
1.6 Significance of the study .....	5
1.7 Limitation of the study .....	6
1.8 Organization of the thesis .....	6
CHAPTER TWO .....	7
2 LITERATURE REVIEW .....	7
2.1 Soil Erosion and Types of Erosion .....	7
2.1.1 Rain splash erosion .....	8
2.1.2 Sheet erosion .....	8
2.1.3 Rill erosion .....	8
2.1.4 Gully erosion .....	9
2.2 Factors affecting soil erosion by water .....	10
2.2.1 Climatic factors .....	10
2.2.2 Soil factors .....	10
2.2.3 Topographic factors .....	11

2.2.4	Ground cover factors.....	12
2.2.5	Conservation practices .....	12
2.3	Soil erosion models.....	13
2.3.1	Revised Universal Soil Loss Equation (RUSLE) Model .....	14
2.4	The Use of Remote Sensing and GIS in soil erosion Modelling .....	15
2.4.1	Remote Sensing.....	16
2.4.2	Use of Geographic Information System (GIS) in erosion risk assessment .....	16
2.5	Soil erosion risk in Ethiopia.....	17
2.6	Watershed .....	19
2.6.1	Concept of sustainable watershed management.....	19
2.6.2	Remote sensing and GIS application in watershed management.....	20
2.6.3	Land-Use/Land-Cover Change .....	21
CHAPTER THREE .....		22
3	Materials and Methods.....	22
3.1	Description of the study area .....	22
3.1.1	Physiography.....	23
3.1.2	Agro-ecology and Climate .....	23
3.1.3	Soils and Geology .....	25
3.1.4	Land-use/Land-cover .....	27
3.1.5	Socio-economic condition.....	29
3.2	Data Sources and software.....	29
3.2.1	Data Acquisition .....	29
3.2.2	Software packages.....	31
3.3	Remote Sensing data analysis .....	31
3.3.1	Image processing.....	31
3.3.2	Image Classification.....	32
3.3.3	Accuracy Assessment .....	33
3.4	Methods of spatial Data generations.....	35
3.4.1	Model description .....	35
3.4.2	Rain fall Erosivity (R) factor .....	37

3.4.3	Soil Erodibility (K) factor .....	39
3.4.4	Slope length and slope steepness (LS).....	41
3.4.5	Cover management (C) factor.....	42
3.4.6	Conservation practice (P) factor.....	44
CHAPTER FOUR.....		46
4	RESULTS .....	46
4.1	Land-use/land-cover change detection.....	46
4.1.1	Land-use/land-covers change detection in Huluka watershed .....	46
4.1.2	Trends of LU/LCC in Huluka watershed.....	47
4.1.3	Land-use/land-cover change matrix.....	49
4.1.4	Accuracy assessment.....	50
4.2	Assessment of Soil loss in the study area .....	50
4.3	Identification and Prioritization critical sub-watershed for treatment .....	52
CHAPTER FIVE .....		55
5	DISCUSSION .....	55
CHAPTER SIX.....		58
6	Conclusion and Recommendations .....	58
6.1	Conclusion .....	58
6.2	Recommendations.....	59
References.....		60
Appendix I: Confusion matrix of the Land-use/land covers classification accuracy assessment .....		72
Appendix II: Meteorological data used for Soil erosion modeling .....		73

## List of Figures

Figure 2.1: Rill erosion in the study area. (photo from field observation).....	8
Figure 2.2: Gully erosion of the study area (photo from field observation) .....	9
Figure 3.1: Location map of the study area .....	22
Figure 3.2: Physiographic map of Huluka watershed.....	23
Figure 3.3: Agro-ecological zone of Huluka watershed. ....	24
Figure 3.4: Mean monthly rainfall of the study area.....	25
Figure 3.5: The major soil types map of Huluka watershed. ....	26
Figure 3.6: Geological map of Huluka watershed. ....	27
Figure 3.7: Partial view of land-use/land-covers of the study site.....	28
Figure 3.8: Water boy, at the eastern part of the watershed.....	28
Figure 3.9: The overall flow chart of the methodology .....	37
Figure 3.10: Interpolated mean annual rainfall(a) and rainfall erosivity factor(b) map.....	39
Figure 3.11: Major soil type (a) and soil erodibility factor(b) .....	41
Figure 3.12: Slope map (a) and LS factor map(b) .....	42
Figure 3.13: Land-use and land-cover map (a) and Crop management(C) factor map(b).....	44
Figure 3.14: Land-use/Land-cover map (a) and conservation practices(P) factor map(b) .....	45
Figure 4.1 Land-use/land-cover map of Huluka watershed from 1998, 2008 and 2018.....	46
Figure 4.2 Distribution of land-use/land-cover from 1998 to 2018 .....	47
Figure 4.3 Trend of Land-use/land-cover change in Huluka watershed .....	48
Figure 4.4 Estimated potential annual soil loss map of the study area. ....	51
Figure 4.5 Map of the Sub watershed of the study area .....	53

## **List of Tables**

Table 3.1: The summary of remote sensing data sources and their description.....	30
Table 3.2: Software used and their respective application .....	31
Table 3.3: Land-use/land-cover category and their description.....	33
Table 3.4: Mean annual rainfall and Erosivity factors result .....	38
Table 3.5: The major soil types and erodibility factors .....	40
Table 3.6: P-value suggested by Hurni (1985); adapted by Tadesse et al. (2017).....	45
Table 4.1 Land-use/land-cover classes in area and percentage of different periods.....	47
Table 4.2 Land-use and land-cover change in Huluka watershed during 1998–2018.....	49
Table 4.3 Land-use/land-cover change matrix between 1998 and 2008.....	49
Table 4.4 Land-use/land-cover change matrix between 2008 and 2018.....	50
Table 4.5 Land-use/land-cover change matrix between 1998 and 2018.....	50

## **List of Acronyms**

<b>ACRU</b>	Agricultural Catchment Research Units
<b>AGNPS</b>	Agricultural Non-point Source Pollution
<b>DEM</b>	Digital Elevation Model
<b>EMA</b>	Ethiopian Mapping Agency
<b>ERDAS</b>	Earth Resource Data Analysis System
<b>ESA</b>	European Satellite Agency
<b>ETM+</b>	Enhanced Thematic Mapper plus
<b>FAO</b>	Food and Agricultural organization
<b>FCC</b>	False Color Composite
<b>GCP</b>	Ground Control Point
<b>GIS</b>	Geographic Information System
<b>GPS</b>	Global Positioning System
<b>HSPF</b>	Hydrologic Simulation Program and Fortran
<b>ITCZ</b>	Inter Tropical Convergence Zone
<b>LULC</b>	Land Use and Land Cover
<b>LULCC</b>	Land Use and Land Cover Change
<b>Masl</b>	Meter above sea level
<b>MMF</b>	Morgan- Morgan and Finney
<b>MoA</b>	Ministry of Agriculture
<b>NIR</b>	Near Infra- Red
<b>NMA</b>	National Meteorological Agency
<b>OLI</b>	Operational Land Imagery

<b>RDE</b>	Rural Development of Ethiopia
<b>RGB</b>	Red Green Blue
<b>RS</b>	Remote Sensing
<b>RUSLE</b>	Revised Universal Soil Loss Equation
<b>SLEMSA</b>	Soil Loss Estimation Model for South Africa
<b>SRTM</b>	Shuttle Radar Topographic Mission
<b>SWAT</b>	Soil and Water Assessment Tool
<b>t/ha/yr</b>	Ton per hectare per year
<b>TM</b>	Thematic Mapper
<b>UNEP</b>	United Nation Environmental Program
<b>USDA-ARS</b>	United States Department of Agriculture- Agricultural Research Service
<b>USGS</b>	United States Geological Survey
<b>USLE</b>	Universal Soil Loss Equation
<b>UTM</b>	Universal Transverse Mercator
<b>WEP</b>	World Environment Programme
<b>WGS</b>	World Geodetic System

## Abstract

Assessment of Soil Erosion by RUSLE Model Using Remote sensing and GIS Techniques: A Case Study of Huluka Watershed, Central Ethiopia

Habtamu Atoma Feda, Msc. Thesis  
Addis Ababa University, May 2018

Soil erosion is the deterioration of soil by the physical movement of soil particles from a given site and a cause for land degradation. The present study was carried out in Huluka watershed, Oromia Region, Central Ethiopia, with the main objective to assess soil erosion risk by RUSLE using remote sensing and GIS techniques and to investigate land-use/land-cover changes of 20 years using satellite image of Landsat 5 TM 1998, Landsat 7 ETM+ 2008 and Landsat 8 OLI 2018. To assess and map the soil erosion extent and to determine the potential annual soil loss, RUSLE model was used on the basis of the adapted methodology and parameter for Ethiopian highland conditions. To generate the parameter for the model and compute the rate of annual soil loss different spatial data were collected. To achieve this, Digital Elevation Model (DEM), Sentinel2A (2018), Rainfall data and Digital soil map were used. The generated factors were combined to compute potential soil loss in the study area. The output of the study shows an expansion of agriculture/settlement and reduction of shrub/bushland, woodland and grass land over 20 years between 1998 and 2018. Agriculture/settlement replaced about 3096 ha of the land, that used to be covered by other land-use/land-cover types. The result of the study revealed that the total amount of potential soil loss was from 0.00 to 400 tons/ha/yr. Moreover, the total soil loss in Huluka watershed was 495,715 metric tons/year from 18,571 hectares of land. Based on the level of soil erosion rates, the watershed divided into five priority categories for soil conservation. Areas which are classified as severe erosion class covered an area of 1,115 ha, (6%) of the total watershed, while high to very high erosion risk class covered an area of 4032 ha (21%) and low to moderate erosion risk class covered an area of 13,424 ha (73%), respectively. Critical sub-watersheds were identified and prioritized based on their average annual soil loss for future intervention and soil and water conservation measures. Finally, five sub-watersheds were delineated and identified. The average annual soil loss from these sub-watersheds were ranged from 14.4 ton/ha/yr to 27 ton/ha/yr. Based on the results, it is recommended that the study area having large rate of erosion (27 tons/ha/yr) should be given first priority during the introduction of intensive and well-designed integrated management interventions for soil conservation.

**Key words:** Land-use and land-cover, Remote sensing, GIS, RUSLE, Soil erosion, Watershed

## CHAPTER ONE

### 1 INTRODUCTION

#### 1.1 Background

Soil erosion is a major environmental problem that threatens world food production (Dudal, 1981). It can be described as the removal of organic as well as inorganic soil surface materials by wind and water (Gabriels, 1991). Soil erosion by water is the process of particle detaching and particle transporting by flowing water to downhill areas (Kunta, 2009). This ultimately leads to loss of top soil in large quantity a common phenomenon in agricultural areas. Negative effects caused by soil erosion are soil degradation adversely affecting hydrological system, agriculture and water quality. The impacts of soil erosion continue to pose severe threats to human sustenance. It is one of a forms of soil degradation, which leads to the deterioration of physical, chemical and biophysical properties of the soil (FAO, 1978). Soil erosion is the most serious form of land degradation, in which its on-site and off-site effects threaten the food security and the natural economy of the country (Hurni, 1993). Most studies in Ethiopia indicated that sheet and rill erosion by water and burning of cow dung and crop residue are the major components of land degradation that affect on-site land productivity (Hurni, 1993; Zeleke Gete and Hurni, 2001). Changes in farming system and natural resources utilization have led to severe land degradation through enhanced soil erosion in different parts of the world (FAO, 1984). There are multiple interacting forces, which have caused and are causing land degradation in Ethiopia (Berry, 2003). Soil erosion is a complex process and its multiple and hidden social and environmental impacts are increasing threat for human existence (Ownegh, 2003). This phenomenon with decreased soil fertility causes destruction of natural ecosystems like forest, pasture and agricultural ecosystems. Soil erosion rate is a key index for the assessment of land management strategies and sustainability of development programs (Ownegh, 2003). The study of soil erosion risks in the landscape, and interactions among the major factors that affect this process are essential, particularly, in humid mountainous areas (Hoyos, 2005). This is due to the steep topography and frequent, high rainfall amounts and intensities. In developing nations, expansion of farming practices and pastures into remote, steep hill slopes increase the potential for accelerated rates of soil erosion (Tesfaye Abebe, 2015). The degradation and loss of soil resulting from soil erosion was estimated to be about 20 tons per hectare, which means about 1

mm of soil depth per year across the country (Hurni, 1985). Ethiopia loses about 1.9 billion tons of fertile soil from the highlands every year and the degradation of land through soil erosion is increasing at higher rates (Hurni, 1989). According to the Ethiopian Highlands Reclamation Study (FAO, 1986), soil erosion had been forecasted to cost the country 1.9 billion US\$ between 1985 and 2010. Erosion models can be used as predictive tools for assessing soil loss and soil erosion risk for conservation planning (Popp *et al.*, 2000). Modeling soil erosion provides useful information for selection of appropriate soil conservation practices. Universal Soil Loss Equation (USLE) is the most widely known and used empirical soil loss model all over the World (Wischmeier and Smith, 1978). In the 1980, the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) modified the model to the Revised Universal Soil Loss Equation (RUSLE), which was an improved version of USLE incorporating new approaches and corrections of the USLE limitations. The RUSLE followed the same formula as USLE but got several improvements in the determining factors and a broader application to different situations, including forest lands, range lands and disturbed areas compared to USLE (Trojacek and Kadlubiec, 2004). It is a computation method that may be used for site evaluation and planning purposes and also for assisting in the decision process of selecting erosion control measures. It provides an estimate of the severity of erosion and also numerical results that can validate the benefits of planned erosion control measures in risky areas (Silleos, 1990).

The livelihood of the people in Huluka watershed is based on mixed farming agricultural system in which the proportion of crop production is dominating other economic activities. In this area, continuous cropping (Barely, maize (*Zea mays*), teff (*Eragrostistef*), and wheat (*Triticumaestivum*), overgrazing, deforestation and using crop residues for animal feeds accelerate the soil erosion and cause soil fertility decline from year to year. Soil erosion by water is a dynamic spatial phenomenon. Increasing soil erosion is detrimental both in terms of reduced agricultural productivity and fertility of the soil as well as in increasing poverty. The information on the spatial extent of erosion risk area and its severity are pre-requisites for soil conservation planning and watershed management programs. Awareness of suitable management practice is important to maintain soil fertility, decrease soil erosion problems and to reclaim eroded areas (Bobe, 2004). Therefore, this study provides a valuable input for planning soil conservation strategies and identify high-priority areas for the implementation of best management practices. Soil erosion should be minimized in the study area, to increase soil fertility and agricultural

productivity. It is also essential to protect Huluka reservoir from sedimentation and is improve the capacity of the reservoir.

The present study was aimed to estimate the actual average of annual soil loss from areas in Huluka watershed by RUSLE model using remote sensing and geographic information system (GIS) and to investigate time series land-use and land-cover changes in this area.

## **1.2 Statement of the problem**

The present study focuses on assessment and mapping of soil erosion risk using remote sensing and GIS techniques in Huluka watershed, Oromia Region, Central Ethiopia. Soil is an essential resource for agricultural productivity. For a country like Ethiopia, where farming is the backbone of the economy and the livelihoods of the majority of the population depend on agriculture, soil resources play a vital role in the national productivity. Agricultural land-use in Ethiopia often results in the degradation of natural soil fertility leading of reduced productivity. Soil degradation under farming conditions mostly brings about soil erosion (MoA and RDE, 2005). The highlands of Ethiopia are favorable for human habitat and the most important farming areas. But the highlands are rugged topography dissected by deep gorges with slopes associated with diverse climatic condition (Hurni, 1986). In the beginning of the agricultural era, most of the land cover of the country was believed to have been forest. Since then, forest clearance was started in favor of crop production. With the rapid growing population of the country, there was more demands for land for further farm expansion, grazing land and extraction of fuel and constructional wood (Krauer, 1988). These events have contributed for further soil erosion and degradation. Currently, considerable portion of the country is threatened by soil degradation. Soil loss through water erosion is evident in Ethiopia and it is estimated that the country loses an estimated 1.3 billion metric ton of fertile soil each year (Krauer, 1988, Teshome, 2007), out of which, 1 billion tone is from the highlands (Krauer, 1988). This is an indicator as stated by Gemechu (2007), for the low and declining agricultural productivity, food insecurity and rural poverty in the country.

Soil erosion risk in the highlands of Ethiopia was assessed by a number of researchers using USLE model. Hurni (1985), adapted the USLE model to the Ethiopian conditions by modifying some of the factors based on experimental outputs. Using this adapted model factors, various soil loss assessments have been conducted in Ethiopia. Girma (2005) and Tsegaye (2007), have

applied the model and obtained the actual soil loss over different parts of the country. Various estimates pointed out as the rate of soil loss in the country is high and increasing at an alarming rate. Hurni (1988), have estimated the annual soil loss by erosion as 12 t/ha. The study made by Hurni (1993), raised the annual soil loss due to erosion from croplands of Ethiopia to 42 t/ha/year, where maximum loss (300 t/ha) is recognized over the highlands. Berry (2003), raised the rates of soil erosion in the country as 130 t/ha/year for crop lands. However, none of them assessed and mapped soil erosion risk in Huluka watershed. This area is known for its rugged topographic features, surplus food crop production, significant deforestation and overgrazed land that causes highland of soil loss by water erosion. The risk of soil erosion has persisted and will persist as a serious threat to farmers life and economic development of the country in general and in the study area in particular. Huluka reservoir is the source of water for Ambo town and around. This reservoir is in a serious risk because of sedimentation, which eroded from the upper catchments. Even though soil erosion by water is believed to be among the major land degradation processes in the region; the spatial variability of susceptibility of soils of the study area to erosion has not been assessed and mapped. Hence, the present study has aimed to assess the extent and mapping soil erosion risk area using RS and GIS that can easily identify areas that are at potential risk of extensive soil erosion in the study area. It is also a major watershed problem in many developing countries causing significant loss of soil fertility, loss of productivity and environmental degradation (Seleshi and Mequanint, 2008). Considering the severity of soil erosion and its impacts, it is necessary that appropriate management measures to be undertaken. To achieve this, a sound knowledge of spatial variations in soil erosion is necessary when planning conservation efforts (Tamene *et al.*, 2006). By considering these problems, this study was conducted to assess the rate of soil erosion and the time series land-use/land-cover change analysis in the Huluka watershed, of Ethiopia.

### **1.3 Objectives**

#### **1.3.1 General Objective**

The general objective of this study was to assess and map areas at risk of soil erosion by RUSLE model using remote sensing and geographic information system and to investigate time series land-use and land-cover change in Huluka watershed.

#### **1.3.2 Specific Objectives**

The specific objectives of this study were:

- to estimate the actual average annual soil loss in Huluka watershed
- to produce soil erosion risk and soil erosion severity maps of the study area
- to analyze and quantify the time series land-use and land-cover changes over the past 20 years 1998 to 2018 in this study area and
- to identify areas of critical soil erosion conditions, which require urgent conservation measures and land management in the study area.

### **1.4 Research Questions**

- ❖ What is the actual average of annual soil erosion in Huluka watershed?
- ❖ How to produce soil erosion risk area and soil erosion severity map of the study area?
- ❖ How to analyze and quantify the time series land-use and land-cover changes over the past 20 years?
- ❖ Which areas of the critical soil erosion conditions require urgent conservation measures and land management in the study area?

### **1.5 The scope of the study**

The present study actually at a local level study and thus focuses mainly on the issues related with the extent and dynamics of soil erosion with in the study area. The study only focused on quantifying the amount soil loss caused by water from Huluka watershed.

### **1.6 Significance of the study**

Environmental deterioration has become one of the most serious problems confronting mankind. Soil erosion is one of the major non-point pollution sources in many watersheds (Wang *et al.*,

2002). Therefore, assessing the extent of soil erosion risk of the study watershed and forwarding possible solution measures which help the future soil conservation and watershed management efforts in the future. This study is expected to provide important data for policy makers, land-use planners, and natural resource managers to formulate and implement effective soil conservation strategies. Huluka reservoir is the source of water for Ambo town and it contributes in minimizing sedimentation yield from the reservoir and this will increase the capacity of the reservoir. Furthermore, this work could also be used as source of information for those researchers who want to do similar research for the future.

### **1.7 Limitation of the study**

Concerning constraints, this study also had some limitations. Among the significant constraints, getting the most recent and time series high resolution satellite data and even images taken in similar periods of the considered years was difficult. Moreover, to maximize the representativeness of the result of the soil erosion risk map relatively dense meteorological stations were required to spatially represent rainfall over the study area, but there is few and sparse stations were available within the watershed.

### **1.8 Organization of the thesis**

The thesis is organized into six chapters. Chapter one deals with the introduction, statement the problem, objectives, scope and limitation, research questions, significance of the study and organization of the thesis. Chapter two reviews related literature. Methodological issues including the study area description were presented in chapter three. The fourth chapter presents the results of the research, when chapter five talk about discussions of the study. The sixth chapter includes conclusion and recommendations.

## CHAPTER TWO

### 2 LITERATURE REVIEW

#### 2.1 Soil Erosion and Types of Erosion

Soil erosion is a complex and dynamic phenomenon affecting many areas, all over the world. It is the physical movement of soil particles from one location to another, due to forces of water or wind. The three main phases of soil erosion are detachment, transport and deposition. Detachment of soil particles is due to raindrop impact, caused by its kinetic energy. It occurs when erosive forces of raindrop impact and surface runoff exceed the soils' resistance to erosion. Transport is the process of water flow by taking the detached soil particles from its origin. Deposition occurs when the sediment load of a given particle type exceeds its corresponding transport capacity and the speed of the flowing water. There are two major types of soil erosion, such as geologic and accelerated erosions. Geologic erosion is a normal process of weathering that generally occurs at minimum rates in all soils as part of the natural soil-forming processes. It occurs over long geologic time horizons and is not influenced by human activity. The wearing of rocks and formation of soil profiles are processes affected by the slow, but continuous geologic erosion. Low rates of erosion are essential for the formation of soil. In contrast, soil erosion becomes a major concern when the rate of erosion exceeds a certain threshold level and becomes rapid, known as accelerated erosion. This type of erosion is triggered by anthropogenic causes such as deforestation, slash and burn agriculture, intensive plowing, intensive and uncontrolled grazing, and biomass burning. The potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape), soil characteristics, local climatic conditions, land-use and management practices implemented on the watershed (Suresh, 2000; Arora, 2003). Various human activities disturb land surfaces of the earth, and thereby induce significant erosion rates. Soil erosion by running water has been recognized as the most severe hazard threatening the protection of soil as it reduces soil productivity by removing the most fertile topsoil. It is accounted that loss of topsoil and terrain deformation due to soil erosion are the consequences of deforestation, removal of natural vegetation and overgrazing in the mountainous regions (Shrestha, 1997). There are different forms of top soil removal or soil erosion, which are given to the following.

### 2.1.1 Rain splash erosion

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

### 2.1.2 Sheet erosion

Sheet erosion is movement of soil from raindrop splash resulting in the breakdown of soil surface structure and surface runoff. It occurs rather uniformly over the slope and may go unnoticed until most of the productive topsoil is lost. As a result of this detachment and transportation of the detached sediment by runoff take place. On slope areas, sheet wash can take place and remove shallow layer of soil.

### 2.1.3 Rill erosion

Rill initiated at a critical distance down slope where surface runoff concentrates and becomes channeled. It refers to the soil erosion that occurs in small channels or rills (Fig 2.1). These channels are called rills when they are small enough to not interfere with field machinery operations. Rill erosion can be reduced by reducing the volume and speed of surface water with grassed waterways and filter strips, ripped mulch lines, and contour drains. Rill erosion is often described as the intermediate stage between sheet erosion and gully erosion (Jenkins, 2002).



**Figure 2.1:** Rill erosion in the study area. (photo from field observation).

### 2.1.4 Gully erosion

Gully erosion is defined as the erosion process whereby runoff water accumulates and often recurs in narrow channels, and over short periods, removes the soil from this narrow area to considerable depths (Poesen *et al.*, 2003) (Fig 2.2). Gullies can be either permanent or ephemeral. Permanent gullies are channels too deep to easily ameliorate with ordinary farm tillage equipment, typically ranging from 0.5 to as much as 25–30 m depth (Poesen *et al.*, 1996). In concept, ephemeral gullies are easily defined as the “missing link” between rills and permanent waterways (Thorne *et al.*, 1986). Ephemeral gullies are small channels eroded by concentrated overland flow that can be easily filled by normal tillage, only to reform again in the same location by additional runoff events (Poesen *et al.*, 2003). Runoff becomes concentrated in low points, or swales, where flow lines converge from neighboring high points, or spurs. As concentrated surface runoff is found mostly in swales, it is to be expected that ephemeral gullies that form due to concentrated flow erosion should be found there also (Poesen *et al.*, 2003).

Gully systems in Ethiopia can often be considered as discontinues ephemeral streams (Bull. 1997). Assessments of gully erosion volumes in Ethiopia are rare. Using photogrammetric techniques (Shibru *et al.*, 2003), estimate that between 1966 and 1996, 700,000 tons of soil was lost by gully erosion from a 9 km<sup>2</sup> catchment in the eastern highlands (26t/ha/yr). Using monitoring and interview techniques to establish average long-term soil loss rates by gully erosion in Central Tigray, Nyssen, (2001) obtained 5t/ha/yr.

Most soil erosion models do not predict the location of gullies. An approach to predict locations where gully heads might develop is presented by the threshold concept (Poesen *et al.*, 2003). In order to predict the potential location and spatial patterns of gullies in the study area, the method proposed by Nyssen, (2001) and Moore *et al.* (1988) were used.



**Figure 2.2:** Gully erosion of the study area (photo from field observation)

## **2.2 Factors affecting soil erosion by water**

Major factors affecting soil erosion are climate, soil properties, vegetation characteristics, and topography. Human disturbances, such as tillage and construction, and natural disturbances, such as severe weather or fire, dramatically increase erosion levels. Of these, the vegetation and some disturbances, and, to a lesser extent, the soil and topography can be managed to reduce erosion (Fang Meier *et al.*, 2006).

### **2.2.1 Climatic factors**

Climatic attributes affecting soil erosion are precipitation, temperature, wind, humidity, and solar radiation. Among these, erosion by water is the most predominant in terms of its contribution to soil degradation. The basic energy input required to drive erosion processes is provided by rainfall and runoff. Soil erosion by water occurs when raindrops act upon the soil particles. Soil loss is closely related to rainfall partly through the detaching power of raindrops due to striking the soil surface and partly through runoff. Potential ability of rain to cause erosion is known as erosivity (R) factor (Renard *et al.*, 1991). Raindrops while falling acquire kinetic energy and on impact; the kinetic energy is used up in detaching the soil particles. Energy is required to break the soil aggregates, splashing them and subsequently carrying them with runoff (Saavedra, 2005). Soil movement by rainfall is usually greatest and most noticeable during short duration, high-intensity thunderstorms.

### **2.2.2 Soil factors**

Physical properties of the soil affect the infiltration capacity and the extent to which particles can be detached and transported. In general, soil detachability increases as the size of the soil particles or aggregates increase, and soil transportability increases with a decrease in the particle or aggregate size. Clay particles are more difficult to detach than sand, but clay is more easily transported. Soils differ in their resistance to erosion, which is a function of a range of soil properties such as texture, structure, soil moisture, roughness, and organic matter content (Deore, 2005). The properties that influence erosion also include soil water content, clay mineralogy, and density, as well as chemical and biological characteristics of the soil (Fangmeier *et al.*, 2006). The susceptibility of soil to erosion agents is generally referred to as soil erodibility (Renard *et al.*, 1997). The erodibility of the soil is the resistance of the soil to both detachment and transport by the eroding agent. Hudson (1996), defines erodibility as the specific property of soil,

which can be quantitatively evaluated as the vulnerability of the soil to erosion under specific circumstances. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Soils high in clay have low erodibility (K) values, because they are resistant to detachment. According to Mainam (1999), soil aggregate stability and infiltration rates can be affected by aggregate size and bulk density, soil texture and soil structure. Coarse textured soils, such as sandy soils also have low K values, because of low transportability even though these soils are easily detachable. Medium textured soils, such as silty loam soils, have a moderate K values, because they are moderately susceptible to detachment and they produce moderate runoff. Soils having high silt content ( $K= 1$ ) are the most erodible of all soils as they cause a decrease in infiltration (Saavedra, 2005).

### **2.2.3 Topographic factors**

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

Steeper terrain slope causes higher runoff velocities, more splashes downhill and faster flow and therefore contributes greater soil erosion. Erosion doubled for a steepness change from 2-20% and the erosion rate tends to level off (Remortel *et al.*, 2001). A slight increase in detachment rate probably occurs as the raindrops strike at a greater angle, but this effect should not cause a major change in total splash detachment.

#### **2.2.4 Ground cover factors**

Cover includes plant canopy, mulches, plant residues, or densely growing plants in direct contact with the soil surface. It has a greater impact on erosion than any other single factor. Vegetation cover is one of the most crucial factors in reducing soil erosion. Vegetation reduces soil erosion by protecting the soil against the action of falling raindrops, increasing the degree of infiltration of water into the soil, reducing the speed of the surface runoff, binding the soil mechanically, maintaining the roughness of the soil surface, and improving the physical; chemical and biological properties of the soil (De Asis and Omasa, 2007). No detachment occurs by raindrop impact where the soil surface is covered because there is no fall distance for drops to regain energy.

Differences in erosion rates are commonly related to land-use in areas where soil, climate and topography are similar. Cover in contact with the soil surface also absorbs much of the flow's eroding and transporting force, which greatly reduces erosion. Strips of dense mulch and grasses can induce deposition and filter sediment from the runoff. To account for the effect of vegetation in erosion assessments, a cover and management factor (C-factor) has often been used. The C-factor is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding clean-tilled continuous fallow (Wischmeier and Smith, 1978). For deriving and mapping ground cover factor or C-factor, various approaches have been used. Traditionally, spatial estimates of vegetation cover, or C-factor, have been done by simply assigning C-factor values from literature or field data into a classified land-cover map (Folly *et al.*, 1996).

#### **2.2.5 Conservation practices**

Specific cultivation practices affect erosion by modifying the flow pattern and the direction of runoff and by reducing the amount of runoff (Renard *et al.*, 1994). Especially in agricultural areas, conservation practices 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 to that of up-and down slope cultivation (Wischmeier and Smith, 1978; Renard *et al.*, 1991). P-values have been assigned to land-use classes using ranges from 0 to 1 (Kaltenrieder, 2007).

### 2.3 Soil erosion models

A model is a simplified representation of a complex system, or models are the necessary simplifications of reality. Modeling in soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces. Field studies for prediction and assessment of soil erosion are expensive, time-consuming and need to be collected over many years. Besides providing detailed understanding of the erosion processes, field studies have limitations because of complexity of interactions and the difficulty of generalizing from the results. Soil erosion models can simulate erosion processes in the watershed and may be able to take into account many of the complex interactions that affect rates of erosion. Erosion models can be used as predictive tools for assessing soil loss, conservation planning, soil erosion inventories and project planning. Moreover, they can be used as tools for understanding erosion processes and their impacts (Nearing *et al.*, 1994). Developing erosion prediction or modeling approaches are not new concepts. However, these technologies emerged after mainframe computers became readily available and interest in erosion was stimulated by concern for surface water quality in the 1970s (Foster, 1988). Subsequently, like hand tools, many types of erosion assessment methods have been emerged: each is best at performing a particular task. Hence, no single prediction method meets all needs (Foster, 1988). The objective of soil erosion models is either predictability or explanatory (Petter, 1992). Available model can be categorized in many ways. Understanding of the principles behind the development of erosion models and types of models may be useful to study the models' behavior for different locations with variable parameters. Many types of water erosion models can be found in literature and can be categorized according to principles used in the development of model. Erosion models can be divided broadly into three categories that can be used to assess soil erosion, based on the development principle. These are empirical or statistical, conceptual and physically based or analytical component models (Morgan, 1995; Bergsma *et al.*, 1996).

- I. **Empirical Models:** These are generally the simplest of the three model types. Empirical models are based primarily on defining important factors through field observation, measurement, experimentation and statistical techniques relating erosion factors to soil loss (Petter, 1992). They are generally based on the assumption of stationeries as it is assumed that the underlying conditions remain unchanged for the duration of the study

period (Bobe, 2004). These models relate input to output through some transformation function. Among the commonly used empirical erosion models include the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE) and the Soil Loss Estimation Model for South Africa (SLEMSA). RUSLE is the empirical model that has been most widely used and generally accepted by the natural resources community because it is relatively easy to use (Saavedra, 2005). In this study, RUSLE was chosen over other models because of its ease of implementation, reliance on easily accessible data and its relatively accurate results.

- II. **Conceptual models:** These models are based on spatially lumped forms of water and sediment continuity equations. As explained by Merritt *et al.* (2003), these models are general description of catchment processes, without including the specific details of process interactions, which would require detail catchment information. Conceptual models play an intermediary role between empirical and physically based models. The main feature that distinguishes the conceptual models from the empirical models is that the conceptual models, whilst they tend to be aggregated, they still reflect the hypothesis about the processes governing the system behavior. The Agricultural Non-Point Source Pollution Model (AGNPS), Agricultural Catchment Research Unit (ACRU), Hydrologic Simulation Program and Fortran (HSPF) are among the conceptual models used in erosion and/or water quality studies.
- III. **Physically based models:** These models are based on an understanding of the physics of the erosion and sediment transport processes (Deore, 2005). In theory, the parameters used in physical-based models are measurable and so are known (Merritt *et al.*, 2003). In principle, they can be applied outside the range of conditions used for calibration and, as their parameters have a physical meaning, they can be evaluated from direct measurements and without the need for long hydrometeorological records (Saavedra, 2005). Examples of physically based models are the Morgan-Morgan and Finney (MMF), Water Erosion Prediction project (WEP) and the Soil and Water Assessment Tool (SWAT).

### 2.3.1 Revised Universal Soil Loss Equation (RUSLE) Model

The first attempt to develop a soil loss equation for areas such as hill slopes and fields was that of Zingg (1940), who related erosion to slope steepness and slope length. Further developments

led to the addition of a climatic factor based on the maximum 30-minute rainfall total with a two-year return period (Musgrave, 1947), a crop factor, to take account of the protection effectiveness of different crops (Wischmeier and Smith, 1958), a conservation factor and a soil erodibility factor. Changing the climatic factor to the rainfall erosivity index (R) ultimately yielded the USLE (Wischmeier and Smith, 1978).

The RUSLE is an empirically based model that has the ability to predict the long-term average annual rate of soil erosion on a field slope as a result of rainfall pattern, soil type, topography, crop system and management practices (Renard *et al.*, 1991). It retains the factors of the USLE by including improved means of computing soil erosion factors. The RUSLE model in GIS environment can predict erosion potential on a cell-by-cell basis, which is effective when attempting to identify the spatial pattern of soil loss present within a large watershed area (Shi *et al.*, 2003).

Geographic information system 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). In spite of this advantage, RUSLE does not estimate sediment deposition and gully erosion. RUSLE computes average annual erosion as a function of six factors (Renard *et al.*, 1991).

RUSLE computes average annual erosion as:

$$A = R \times K \times LS \times C \times P \text{ (Renard } et al., 1997)$$

Where, A = computed average annual soil loss in tons/ha/year; R = rainfall runoff erosivity factor; K = soil erodibility factor; L = slope length factor; S = slope steepness factor; C = cover management factor and P = conservation practice factor.

#### **2.4 The Use of Remote Sensing and GIS in soil erosion Modelling**

Several studies showed the potential utility of Remote Sensing (RS) and Geographic Information System (GIS) techniques for quantitatively assessing erosional soil loss (Saha *et al.*, 1991; Mongkolsawat *et al.*, 1994). The advancements in RS and GIS technologies provide effective means in the modeling of soil erosion. Soil erosion is spatial phenomena, (Yazidhi, 2003). Potential utility of remotely sensed data in the form of aerial photographs and satellite sensors data is well recognized in mapping and assessing landscape attributes controlling soil erosion,

such as physiography, soils, land-use/land-cover, relief, soil erosion pattern (Pande *et al.*, 1992). In a GIS environment, it is possible to link data generated from remote sensing with their spatial locations (Beck, 1987).

In general, the use of geo-information techniques offers fast and cost-effective estimates, possibilities to investigate larger areas, greater possibilities of continuous monitoring of these areas and possibilities to refine the soil erosion model depending on the required output scale, i.e. rough global to more precise local scale. According to Yazidhi (2003), the use of digital elevation models and GIS offers possibilities to estimate topographical parameters that are useful in soil erosion modeling.

#### **2.4.1 Remote Sensing**

Basic fundamentals in remote sensing are the properties of electromagnetic radiation and their interaction with substances. Remote sensing has opened a new era in the planning and development of watershed management, as satellites imagery provides a fast and economic way to analyze large watersheds by virtue of their synoptic and repetitive coverage (Jain and Goel, 2002). Thus, by using multispectral data, different ground features can be differentiated from each other and a thematic map depicting land-use/land-cover can be prepared. Satellite imagery has been well utilized in different studies for watershed characterization and management aim (Saxena *et al.*, 2000) and to measure qualitative and quantitative terrestrial land-cover changes in a watershed (Lu *et al.*, 2004). For soil erosion assessments in a watershed, RS has been used for both detecting erosion features and obtaining erosion model input data (Petter, 1992). Remote Sensing can facilitate studying factors enhancing the processes, such as soil type, slope gradient, drainage, geology and land cover. Multi-temporal satellite images provide valuable information related to seasonal land use dynamics. Digital Elevation Model (DEM) is one of the vital inputs required for soil erosion modeling that can be created by analysis of stereoscopic optical and microwave remote sensing data (Pande *et al.*, 1992).

#### **2.4.2 Use of Geographic Information System (GIS) in erosion risk assessment**

Geographic information system software capabilities become important when they are combined into various kinds of other analytical models. These include resource allocation, population forecasting and spatial distribution, land-use forecasting, transportation, and site selection models (Dangermond, 1992). Modeling in a GIS environment refers to creation of a digital

database that can interact with a mathematical model. Soil loss by erosion is most frequently assessed by USLE (Spanner *et al.*, 1982), and the first demonstrated the potential of GIS for erosional soil loss assessment using USLE. Geographic information system is characterized by its capability to integrate layers of spatially oriented information. The number and type of applications and analysis that can be performed by GIS in a watershed are as large and diverse as the available geographic datasets (Deore, 2005).

Geographic information system has been widely used in characterization and assessment studies, which require a watershed-based approach (Khan *et al.*, 2001). In addition, modeling visualization capabilities of modern GIS 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).

## **2.5 Soil erosion risk in Ethiopia**

Soil erosion is a common phenomenon in the East African highlands, where it causes widespread soil degradation (Edwards, 1979; Tiffen *et al.*, 1994; Gachene, 1995). Rapid population growth, cultivation on steep slopes, clearing of vegetation and overgrazing are the main causes for accelerated soil erosion in Ethiopia. Such unsustainable and exploitative land-use practices due to the increasing demand for food, fiber and fodder by the growing human and livestock populations are responsible for accelerated soil erosion in many parts of Ethiopia. These practices diminish the protective plant cover thereby exposing soil surface to destructive impacts of high-intensity rainfall (Abate Shiferaw, 2012). The impact of soil erosion can be most problematic in the developing countries, where farmers are highly dependent on intrinsic land properties, and are unable to improve soil fertility through application of additional inputs (Lulseged and Vlek, 2008). Agricultural sector in Ethiopia is under small holder farming system which accounts for more than 90% of agricultural produce, about 95% of cultivated land and support employment for some 7 million farmers (Assefa Sisay and Zegeye Tesfaye, 2003). Ethiopia has great potential for increasing agricultural production and productivity, but unable to find ways of tackling causes of food insecurity due to various factors that are worsening vulnerability out of which land degradation mainly due to soil erosion, deforestation, inconsistent

and inadequate rainfall are the main causes (Drimie *et al.*, 2006). In the Ethiopian highlands only, the annual rate of soil loss reaches to 200–300 tons ha<sup>-1</sup>yr<sup>-1</sup>, while the soil loss can reach to 23400 million metric tons per year (FAO, 1984; Hurni, 1993). Hurni, (1988) and Hurni *et al.* (2008) estimated that soil loss due to erosion of cultivated fields in Ethiopia amounts to about 42 metric tons ha<sup>-1</sup>yr<sup>-1</sup>. In Ethiopian highlands, soil erosion rates measured on test plots amount to 130 to 170 metric tons/ha/year on cultivated land (Hurni *et al.*, 2008). The impact of this loss of fertile soil in Ethiopia is multifaceted. It affects 50% of the agricultural area and 88% of the total population of the country (Sonneveld *et al.*, 1999). The average crop yield from a piece of land in Ethiopia is very low by international standards mainly due to the decline of soil fertility associated with removal of topsoil by erosion (Sertu, 2000). This removal of the upper part of the soil always entails loss of nutrient and water by runoff, reduction of rooting depth and water and nutrient storage capacity resulting, sooner or later, in reduced crop production. In relation to this, Belay, (1992) found a very high correlation ( $r=0.96$ ) between soil productivity and erosion in southern Ethiopia. Taddese (2001), indicated that Ethiopia loses over  $1.5 \times 10^6$  metric tons of soil each year from the highlands by erosion resulting in the reduction of about  $1.5 \times 10^6$  metric tons of grain from the country's annual harvest. In general, soil erosion is one of the major factors causing severe land degradation risk in Ethiopia, which is threatening the agricultural productivity and the very survival of the overwhelming majority of the rural population. The rate of soil loss and depletion of soil organic matter and nutrients as a result of soil erosion are so high and much faster in Ethiopia than they can be replaced.

By considering the severity of soil erosion and its impacts in the study area, it is necessary that appropriate management measures should be taken. Sound knowledge of spatial variations in soil erosion is mandatory when planning conservation efforts (Lulseged *et al.*, 2006). Given the high costs of conservation and the competing production objectives such as population increase, infrastructure development, and land degradation, there is a need to target responses and resources to areas of high risk, hereafter referred to as 'hotspots', rather than spreading them equally across the landscape (Adinarayana *et al.*, 1998). Different management and land-use planning scenarios can then be implemented to address the various land degradation problems taking into account the biophysical and socioeconomic conditions of the respective sites.

## **2.6 Watershed**

A watershed is a surface area from which runoff, which is resulting from rainfall is collected and drained through a common outlet. Most of the time, the term is similar with a drainage basin or catchment area. Hydrologically, it is an area from which the runoff drains through a particular point in the drainage system. It is made up of the natural resources in a basin, especially water, soil and vegetative factors. Socioeconomically, a watershed includes people, their farming system and interactions with land resources, cropping strategies, social and economic activities and cultural aspects (MoARD, 2005). A watershed is a geo-hydrological unit, which drains at a common point. Watershed is a region (or area) delineated with a well-defined topographic boundary and outlets. Within the topographic boundary or water divided, watershed comprises a complex of soils, landforms, vegetation, and land-uses. The terms watershed, catchment and basin are often used interchangeably. A watershed is made up of its physical and hydrological natural resources as human resources.

### **2.6.1 Concept of sustainable watershed management**

Watershed management is the process of guiding and organizing land-use and use of other resources in the watershed to provide desired goods and services without adversely affecting soil and water resources. Watersheds have been identified as fundamental planning units for the management of land and water resources, particularly in the fragile and heterogeneous erosion-susceptible hilly ecosystems (Doere, 2005). Watershed management implies the wise use of natural resources like land, water and biomass in a watershed to obtain optimum production with minimum disturbances to the environment. In the past, the concept of watershed management focused mainly on the management of these resources in medium or large river valleys, designed to slow down rapid runoff and excessive soil erosion, and to slow the rate of siltation of reservoirs and limit the occurrence of potentially damaging flash flooding in river courses (Paul, 1997). At present, the overall objectives of watershed development and management programs take the watershed as the hydrological unit and aim to adopt suitable measures for soil and water conservation, provide adequate water for agriculture and domestic use, and improve the livelihoods of the inhabitants. Watershed management is practiced as a means to increase rain fed agricultural production, conserve natural resources and reduce poverty in the semi-arid tropical regions of South Asia and Sub-Saharan Africa, which are characterized by low

agricultural productivity, severe natural resource degradation, and high level of poverty (Kerr, 2002).

### **2.6.2 Remote sensing and GIS application in watershed management**

A GIS can be defined as a system, which facilitates the storage and intelligent use of geographic data and human activities (Srivastava, 2003). Essential features of GIS are the use of sophisticated computer hardware and software to collect, store, manipulate and process geographic data (Doere, 2005). Geographic information system is a tool that allow for the processing of spatial data into information (Samarakoon, 2005). It has the ability to manipulate spatial data and corresponding attribute information to integrate different types of data in a single analysis at high speed, which is unmatched with manual methods (Kerr, 2002). Geographic information system provides a digital representation of landform, which could be used in hydrological modelling. GIS is characterized by its capability to integrate layers of spatially oriented information. The number and type of applications and analysis that can be performed by GIS in a watershed are as large and diverse as the available geographic datasets (Deore, 2005). The database available in GIS environment facilitates assimilation of different thematic datasets to understand interrelationships. Geographic information system plays an important role in information management, analysis, and providing solutions to the planning of natural resources. The application of GIS for land-use surveys and mapping is gaining importance, largely because of its ability to provide rapid and reliable data within a given time framework (Sertu, 2000). Many GIS-based watershed applications have been developed since the early 1990s due to advances in desktop GIS capabilities, programming languages, and data availability (Lulseged et al., 2006). In addition, it facilitates integration of socioeconomic information with the resources data to understand the local needs. Once the potential of resources and development needs of the watershed are understood, it is possible to evolve specific action plan for development of land and water resources. It plays a key role in implementing soil and water conservation practices that are essential for sustainable agriculture production. Geographic information system offers technologically suitable tools for land resource assessment, delineating different land-use patterns, flood management, irrigation water management, and assessment and monitoring of environmental impact of watershed projects. It is also useful in delineating hydro-morphological units in the area to decide suitable sites for land and water harvesting structures in problematic sites. Remote sensing is the non-contact recording of information from various electro-magnetic

spectrum regions by means of instruments such as cameras, scanners, lasers, linear arrays and/or area arrays located on the ground or areal platforms (Jensen, 2007) and the analysis of the acquired information by means of visual and digital image processing (Sabins, 1987). Remote sensing, with or without GIS technology, has emerged as an indispensable scientific tool for mapping and planning of natural resources (Saxina et al., 2000; Lulseged *et al.*, 2006; Hana Mokonen, 2014; Lemlem et al., 2017). It plays a hastily escalating role in the field of hydrology and sustainable water resources development and management. Remote sensing has opened a new era in the planning and development of watershed management, as satellites imagery provides a fast and economic way to analyze large watersheds by virtue of their synoptic and repetitive coverage (Jain and Goel, 2002). Thus, by using multispectral data appropriately, different ground features can be differentiated from each other and a thematic map depicting land-use can be prepared. Satellite imagery has been well utilized in different studies for watershed characterization and management aims (Saxina *et al.*, 2000) and for measuring qualitative and quantitative terrestrial land-cover changes (Lu *et al.*, 2004a) in a watershed.

For soil erosion assessment in a watershed, RS has been used for both detecting erosion features and obtaining erosion model input data (Petter, 1992; Vrieling, 2005). Satellite data can be applied to directly detect erosion features or to detect erosion consequences. Direct detection has been achieved through identification of individual large erosion features such as gullies. Detectable effects include the damage occurred due to major erosion events, and the sedimentation of reservoirs (Vrieling, 2005).

### **2.6.3 Land-Use/Land-Cover Change**

Land-use and Land-cover are the two interrelated ways of observing earth's surface (Duhamel, 2011). The former represents the biophysical state of the earth's surface and immediate subsurface, while the later indicates the manner human population manipulate the biophysical attributes of the land and the purpose for which land is used (Meyer, 1995; Turner et al., 1995; Lambin et al., 2003; Pellikka, 2008; Duhamel, 2011). Land-use/land-cover change refers to the human modification and conversion of the earth terrestrial surface (Lambin et al., 2003; Hamza and Iyela, 2012; Shrestha, 2012). Modification occurs when the change affect only the characteristics of the land cover without causing a complete shift from one Land-use/land-cover type to the other.

## CHAPTER THREE

### 3 Materials and Methods

#### 3.1 Description of the study area

The study was conducted in Huluka watershed west shoa zone of the Oromia Regional State Central Ethiopia located between latitude  $8^{\circ}46'34''$ – $8^{\circ}56'49''$ N and longitude  $37^{\circ}52'39''$ – $38^{\circ}3'8''$ E covering a total area of 18,571 ha (Fig 3.1). Huluka Watershed is located in western part of the Oromia Regional State at a distance of 125 km from Addis Ababa. It lies within the altitudinal ranges of 2270 and 3328 m asl. This Watershed has 18 administrative Kebeles.

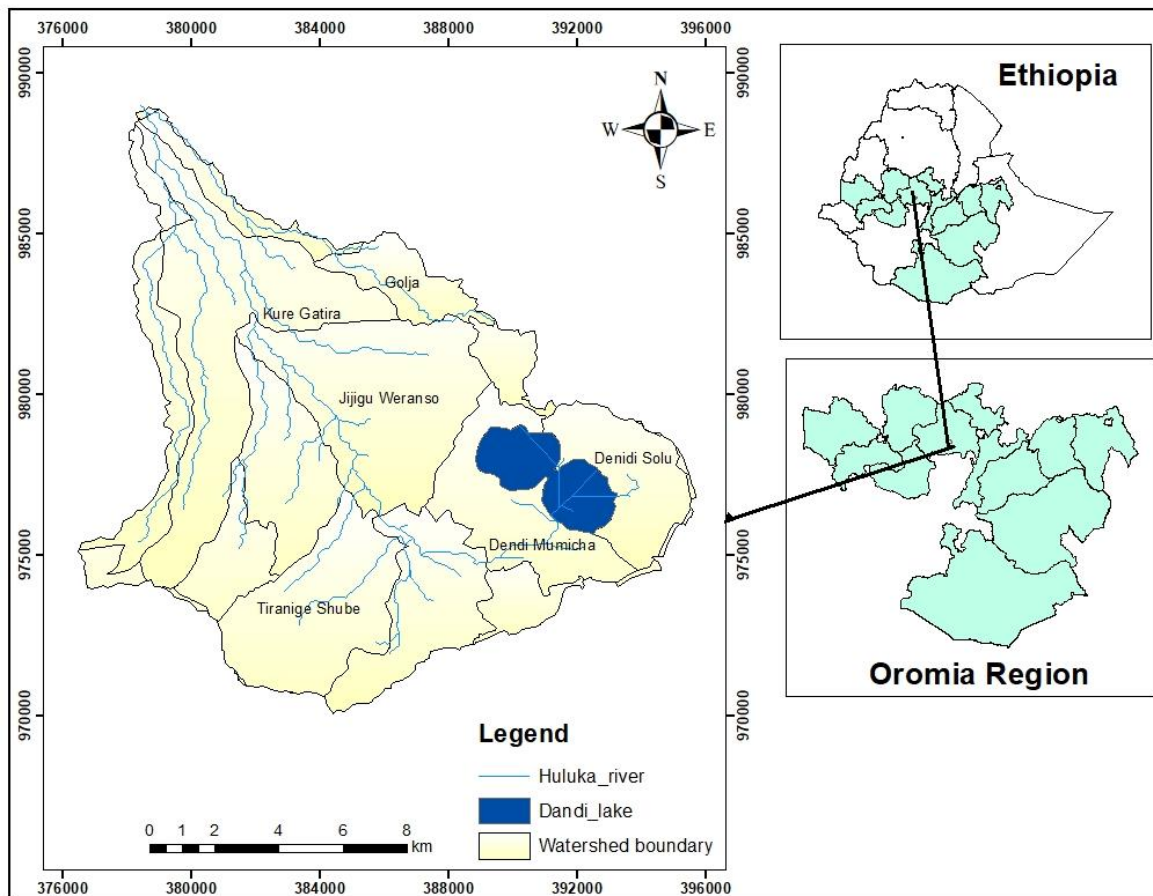
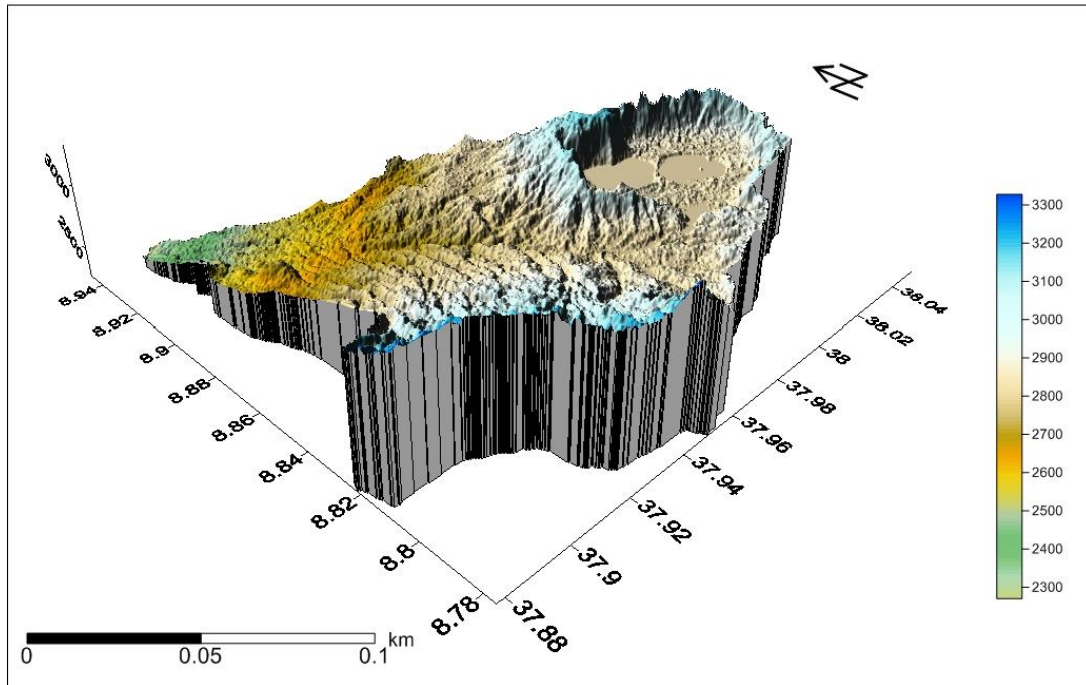


Figure 3.1: Location map of the study area

### 3.1.1 Physiography

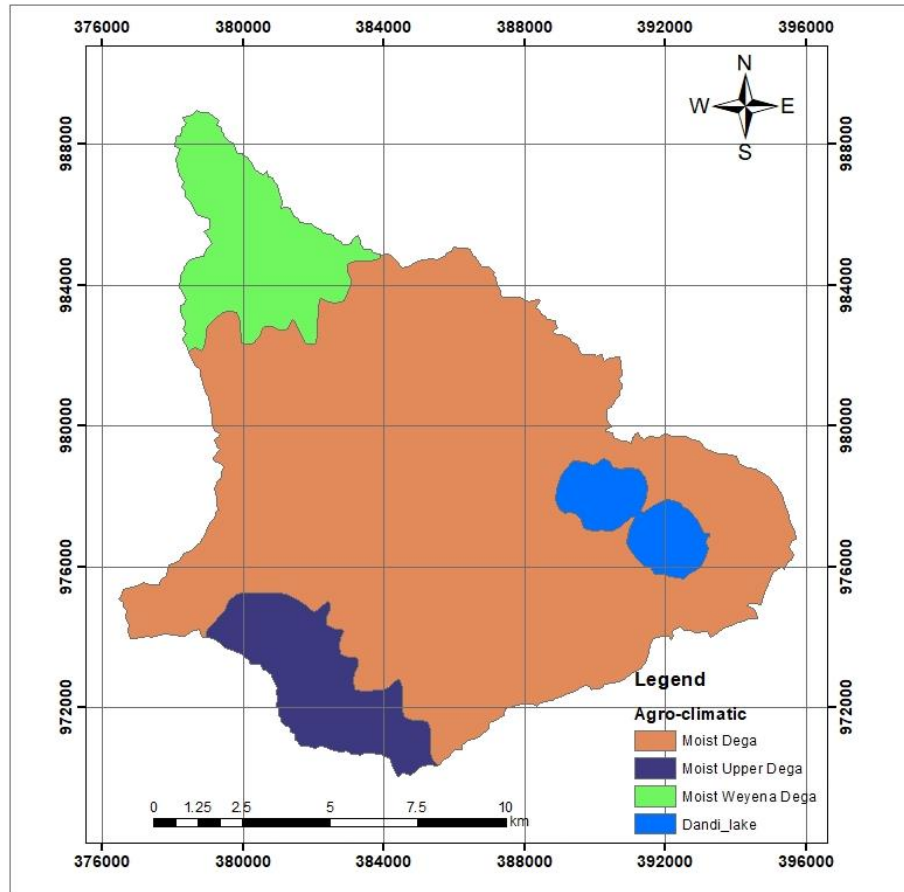
The altitude of the study area ranges between 2300 and 3300 m asl (Fig 3.2). The slope gradient of the watershed ranges from 0° to 59°. The higher elevation ranges are located at the southeast and eastern part of the watershed.



**Figure 3.2:** Physiographic map of Huluka watershed.

### 3.1.2 Agro-ecology and Climate

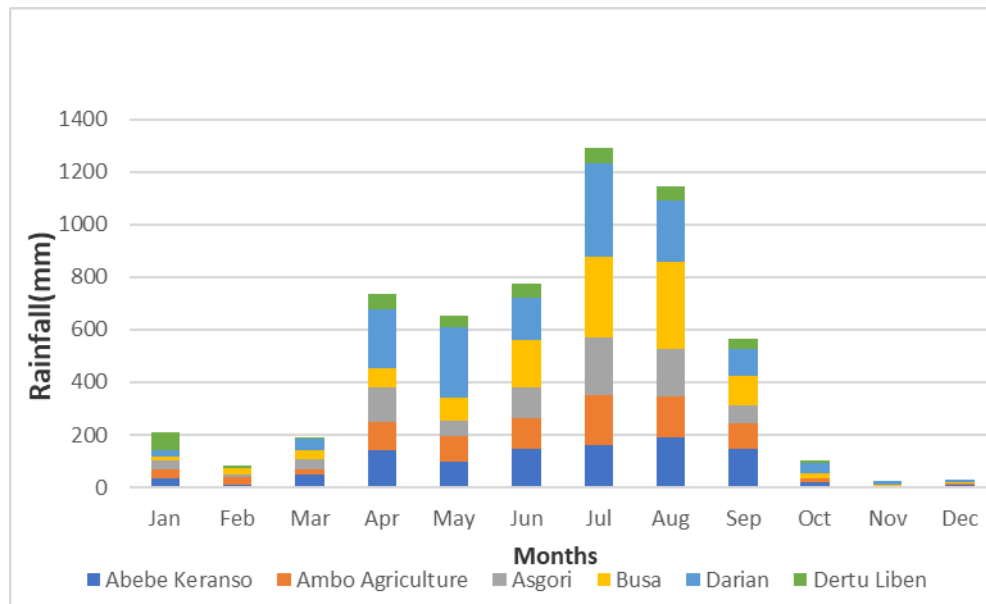
According to Ethiopian Agro-climatic zone classification, Huluka watershed encompasses agro-ecologies of Upperdega, dega (highland), and woynadega (mid altitude) with area proportion of 17 km<sup>2</sup>, 147.8 km<sup>2</sup>, and 21 km<sup>2</sup>, respectively, distributed in the watershed (Fig 3.3). Percentage distribution of agro-ecologies in the watershed is 11% woynadega, 80% dega and 9% of Upperdega. The wide area of the watershed is included in the highland (dega) agro-ecological zone.



**Figure 3.3:** Agro-ecological zone of Huluka watershed.

This study area is characterized by a sub humid to humid climate with mean annual rainfall and temperature varying from 800 mm and 20°C on mid highland, and to 1200 mm and 15°C on the humid plateau, respectively. Mean monthly rainfall data are collected from six selected stations in the study area organized by National meteorological Agency of Ethiopia. These stations are Abebe keranso, Ambo agriculture, Asgori, Busa, Darian and Dertu lebu (Fig 3.4). The region is characterized by three main seasons. The long rainy season in the summer (June – September; summer monsoon rainfall, locally known as ‘kiremt’) is primarily controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ), which lies to the north of Ethiopia at that time. The ‘Kiremt’ rain represents 50–70% of the mean annual total (Degefu, 1987). The dry period extends between October and February (known as ‘baga’) when the ITCZ lies south of Ethiopia. The short rain season ‘belg’ representing 20–30% of the annual rainfall amount occurs during March to May when the ITCZ moves from south to north over the country. The pattern of increasing rainfall associated with increasing altitude is modified in the high-altitude area by the

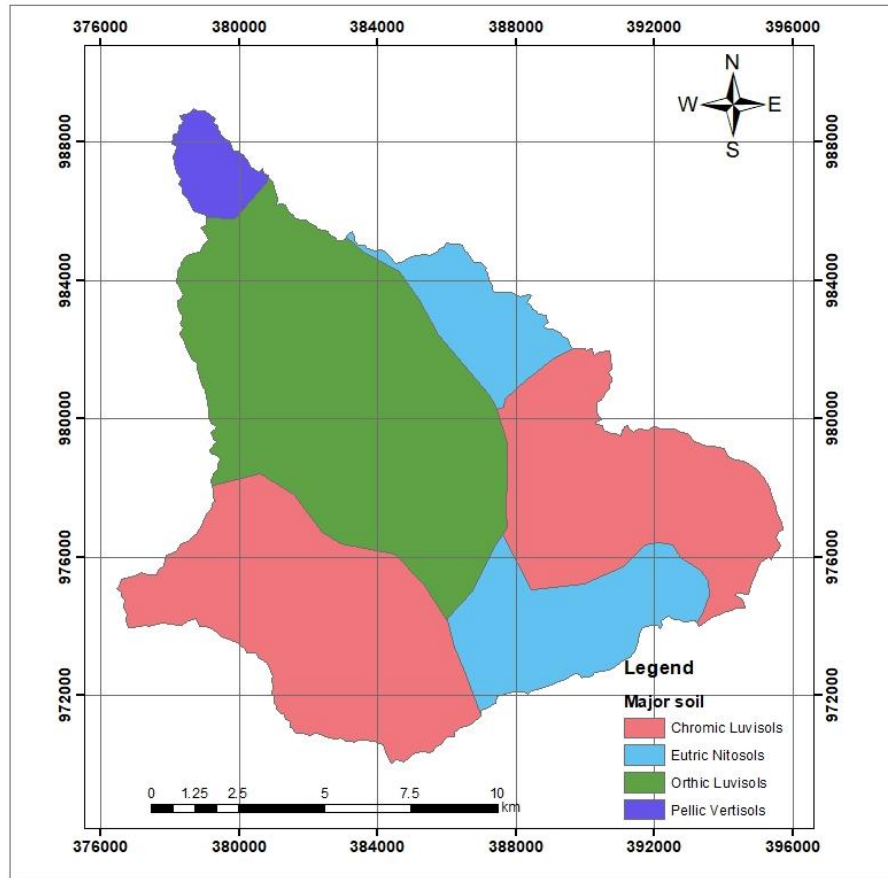
influence of the high mountains, which may cause either rain shadows or areas of heavy orographic rainfall (Makin *et al.*, 1975).



**Figure 3.4:** Mean monthly rainfall of the study area.

### 3.1.3 Soils and Geology

Luvisols are the major soil types accounting for about 80.14% of the total land mass of the study area. The two dominant Luvisols in the watershed are Orthic Luvisols (37.1%) and Chromic Luvisols (43.04%). Other soil types of minor importance are Pellic Vertisols and Euthric Nitosols, which cover about 2.9% and 16.9% of the land mass, respectively, (Fig 3.5). Nutrients are concentrated in topsoil and they have low levels of organic matter. Luvisols have moderate resilience to degradation and moderate to low sensitivity to yield decline (FAO, 1974). Nitosols is one of the best and most fertile soils of tropics. They can suffer acidity and P-fixation, and when organic carbon decreases, they become very erodible. But, erosion has only slight effect on crops. Nitosols have moderate resilience and moderate to low sensitivity. Finally, the two most dominant soil types, which found in Huluka watershed are susceptible to water erosion.



**Figure 3.5:** The major soil types map of Huluka watershed.

The geology of Huluka watershed is dominated by the Pyroclastic deposit, which covers 78.4% of the total area. Another part of the present-day geology of the study area falls into transitional basalts (rocks) forming shield in the tertiary highland volcanoes with minor trachyte (14.8%) and 2.7% is covered by Basalts (Fig 3.6). The eastern part of the watershed is covered by water body like Dendi Lake (4%).

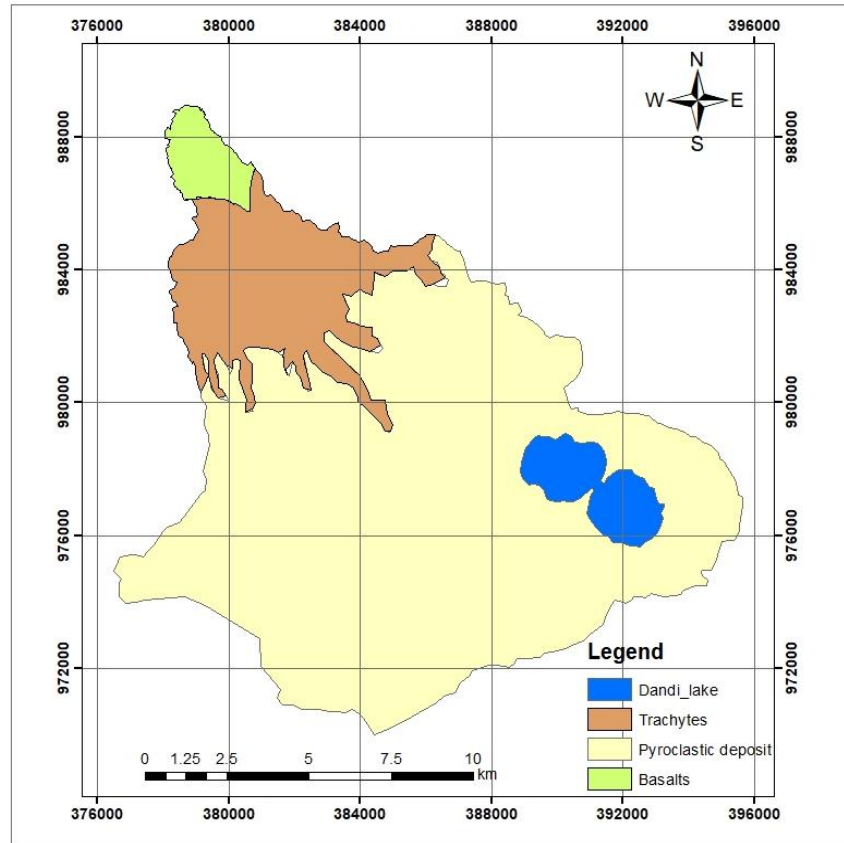


Figure 3.6: Geological map of Huluka watershed.

### 3.1.4 Land-use/Land-cover

The main land-covers in the study area are grass (grazing land), cultivated land, woodland, water body and shrub/bush land (Fig 3.8). Major crops grown in the area are wheat, barley, enset and legumes crop. Few scattered trees such as *Acacia albida*, *Cordia african* and *Juniperus procera* are found in the farm land whereas, *Eucalyptus camendulensis* are grown around the homestead. To increase the productivity; the farmers who live in the study area were using inorganic fertilizer. They usually use crop residues for livestock feed. In addition, animals are allowed to graze on the cultivated land after harvest. The vegetation consists of evergreen and semi evergreen bushes, small trees and occasionally larger trees are found sparsely. Depending on the landscape and topography of the watershed, there are different types of indigenous vegetation existing in the area. The partial view of the study site is presented in (Fig 3.7).



**Figure 3.7:** Partial view of land-use/land-covers of the study site.



**Figure 3.8:** Water boy, at the eastern part of the watershed

### **3.1.5 Socio-economic condition**

As in most part of the country, the majority of the societies in the watershed area rely on agriculture for their livelihood. Likewise, the livelihoods of the community are based on subsistent agricultural farming system mostly producing legumes crop, potato, wheat, barley, enset and vegetables. Agriculture is the main income source for the community in Huluka watershed. The farming community is totally dependent on seasonal rainfall. As there is no sufficient land available for free grazing due to population density, the community use stalk feeding. Besides the fragmented land holding, the small land holding (on average less than 0.3 ha per farmer) determines the economic base of the community. The community members, who did not have farm land are participating in daily labor work at nearby Ambo town, the Capital of West Shoa Zone. This shortage of land has forced the nearby community to encroach on the forest. Thus, crop production is practiced even at slopes of more than 30°. Over-grazing and increased settlements caused by increasing population pressure have also aggravated the situation.

## **3.2 Data Sources and software**

### **3.2.1 Data Acquisition**

To achieve the objectives designed in the section 1.3, the following relevant information and data were collected and generated from various sources.

- **Digital Image data sets**

A time series Landsat (TM, ETM<sup>+</sup> and OLI) satellite data, of 30 m spatial resolution with path/row-169/54 and Sentinel 2A of 10 m resolution and Shuttle Radar Topographic Mission (SRTM) digital elevation data of 90 m resolution was used for this study. The Digital Image data files were downloaded in zipped files from the United State Geological Survey (USGS) archive website: <http://earthexplorer.usgs.gov>. Details of RS data, secondary data used, source and description of these data are summarized in (Table 3.1).

- **Field Data**

Field work was carried out during the dry season in February, 2018 Prior to the fieldwork, a detailed analysis of False Color Composite of a Landsat image and topographic map of the study area was made to get an overall view and to systematically identify and select sampling areas

depending on the accessibility of each site. Field data collections were conducted randomly to verify the classified image and to collect necessary land-use/land-cover data for accuracy assessment. A GPS was used to locate and define the sampling areas. Information on physical aspects of vegetation cover in the area were also generated.

- **Ancillary data**

Ancillary data were collected from different reports and departments in the study area. The soil map and agro-climatic zone map of the study area were obtained from the soil database compiled by Food and Agricultural Organization (FAO) were collected from Ministry of Agriculture (MoA), GIS department and used in the analysis and interpretation of the results. Climatic data such as rainfall data from 1987 to 2017 were gathered from National Meteorological Agency (NMA) and well adopted for the analysis interpretation of the results. Geological map was collected from the Ethiopian Geological Survey and used to identify the geological setup of the study area.

**Table 3.1:** The summary of remote sensing data sources and their description

No	Data Type	Description	Source
1	Landsat image (TM Jan 30, ETM, Jan 25 1998, 2008 and OLI, Jan 28, 2018)	30 m spatial resolution 8-bit spectral resolution 16days temporal resolution Path/Row-169/054	USGS
2	Sentinel2A	10 m spatial resolution 5 days temporal resolution	ESA Copernicus
3	DEM	Shuttle Radar Topographic Mission (SRTM) data 90m resolution	USGS
4	Digital Soil map	FAO (2012)	Ministry of Agriculture (MoAE)
5	Rainfall data	30 years RF data from 6 stations near to Huluka watershed	From National Meteorological Agency, Ethiopia
6	Ground control points (GCPs)	Random coordinates from each land use using Garmin GPS model GARMIN etrex 12 channels	From field work

### 3.2.2 Software packages

Image processing and image classification was carried out by using ERDAS Imagine 2015 software and Impact tool was used for sentinel 2A processing. Geographic information system analysis was conducted by using ArcGIS 10.3. Stream Extraction, fill sinks and flow accumulation generation were performed using ArcHydro 10.3 Software plug-in into ArcGIS software. The DEM for the study area was analyzed and processed using ArcGIS 10.3 software. Documentation and statistical analysis tasks were accomplished using MS Office 2016 software. The software used and specific applications are summarized in (Table 3.2).

**Table 3.2:** Software used and their respective application

Software	Application
ERDAS	Image pre-processing, LULC classification and Post Classification Change Detection
ArcGIS	Database creation, dataset preparation, raster calculation, Displaying and viewing Spatial data and map lay out preparation.
IMPACT Tool	For sentinel image processing
MS Office	Documentation, statistical analysis and presentation

### 3.3 Remote Sensing data analysis

#### 3.3.1 Image processing

Pre-processing of satellite images before detection of changes is a vital procedure and has a unique aim of building a more direct association between the biophysical phenomena on the ground and the acquired data (Coppin *et al.*, 2004). Data were preprocessed in ERDAS imagine for geo-referencing and sub-setting of the image on the basis of Area of Interest (AOI). Standard image processing techniques such as image extraction, rectification, restoration, atmospheric and sun angle correction, radiometric correction and classification were used for analysis of satellite imageries using ERDAS imagine and impact tool software. Landsat imageries of three bands (4, 3, and 2) for Landsat TM, whereas bands (5, 4, and 3) to Landsat-8 were used in image enhancement to identify changes in land-use/land-cover features. All satellite images had original format in TIFF. They were exported to .img format in ERDAS Imagine 2015 software using layer stack function. The images were georeferenced in to the same map projection of WGS (World Geodetic System) 1984 Zone 37N. All satellite images were subset for covering

only the study area using the Shape file of the study area. In order to interpret and discriminate surface features clearly, all satellite images were composed using Red Green Blue (RGB) color composition. False Color Composites (FCC) of satellite imageries were prepared for the years 1998, 2008 and 2018 using band 4 (NIR), band 3 (Red), and band 2 (Green) combination.

### **3.3.2 Image Classification**

Image classification is necessary to convert image data to thematic data. According to Lillesand and Kiefer (2000), the overall objective of image classification procedures is to automatically categorize all pixels in an image into land-use/land-cover classes. As there was no prior knowledge about the study area, unsupervised classification method was used to get an idea of approximate land-use/land-cover of the study area, and to use it in sampling prior to field visit. This technique was used for classifying features in an image, which have common characteristics in to clusters based on the software analysis of an image without the user providing sample classes. The user has to define the maximum number of clusters, maximum cluster size and minimum distance. Computer uses this information located arbitrary vectors as the center points of the clusters. Then, each pixel was assigned to a cluster using minimum distance cluster centroid decision rule. The result from this process was a raster map, with each pixel had a class of the cluster.

In supervised classification process, user-defined polygon function reduces the chance of underestimating class variance as it involves a high degree of user control. A supervised classification was performed using the maximum likelihood algorithm methodology for the extraction of land-use/land-covers of the study area in ERDAS Imagine software. Supervised classification requires a prior knowledge of the area in order to provide the software with unique training classes. It is up to the user to define the original pixels that contain similar spectral classes representing certain land-cover classes. Five land-use/land-covers such as agriculture/settlement, grass land, woodland, shrub/bush land and water body were considered as training areas in image classification based on samples collected from fields. These, major land-use and land-cover types were identified by using the field data and satellite images of Landsat TM, 1998, ETM, 2008 and OLI, 2018. In ERDAS Imagine software, the signature editor was created for defining classes. By using Area of Interest (AOI) tools with the help of google earth pro, the boundaries and number of pixels for each class were added into signature editor. After

that the decision-making phase was taken place, and maximum likelihood algorithm was selected because of the advantage of considering the center of the clusters together with shape, size and orientation. It was difficult to identify settlements especially rural settlements from agricultural land on 30 m spatial resolution image and in most cases the two are spatially integrated. Therefore, settlements were grouped under agricultural land covers. Finally, land-use/land-cover maps for the year 1998, 2008, and 2018 were classified. The land-use/land cover types and description of the study area were summarized in (Table 3.3)

**Table 3.3:** Land-use/land-cover category and their description

LU/LC types	Their description
Woodland	The land covered with both open and closed woodland with dominant species of <i>Juniperus procera</i> , <i>Eucalyptus globules</i> and other remnant trees forming closed canopies. It also includes the scattered rural settlements found within the Woodland (Molla <i>et al.</i> , 2010).
Shrub/Bush land	Land area covered by alpine vegetation communities dominated by low, woody, self-supporting, multi stemmed plants branching at or near the ground, between 0.2–2 m in height.
Grassland	Both communal and/or private grazing lands that are used for livestock grazing. The land is basically covered by small grasses, grass like plants and herbaceous species. It also includes land covered with mixture of small grasses, grass like plants and shrubs less than 0.2 m and it is used for grazing.
Agriculture/settlement	Made to include areas allotted to rain fed cereal crops (e.g. legumes, Barley, Teff, and Wheat), horticultural crops particularly vegetables (e.g. onion, potato and cabbage). Crop cultivation both annuals and perennials, mostly in subsistence farming and the land covered by rural villages and scattered rural settlements surrounded by Enset.
Water body	Land area covered by Lake and rivers

### 3.3.3 Accuracy Assessment

Accuracy assessment is a general term used to compare the classification to geographical data that are assumed to be true, in order to determine the accuracy of the classification process. The common way to represent classification accuracy was taken in the form of an error matrix. An

error matrix is a square array of rows and columns and presents the relationship between the classes in the classified and reference data. Reference data used for accuracy assessment were obtained from field observations. A set of reference points were taken to assess its accuracy. Accuracy assessment points were independent from those used in land-cover class assignment. Using the ERDAS Imagine software accuracy assessment utility, reference random test pixels in the study area were located, which were not used in the training of the classification algorithm to eliminate the possibility of bias of training samples chosen in classification. A set of reference pixels representing geographic points on the classified image is required for the accuracy assessment. These points were verified and labeled against the reference data. Error matrices were then designed to assess the quality of the classification accuracy of 1998, 2008 and 2018 LULC maps. Overall accuracy was computed by dividing the total correct number of pixels (i.e. summation of the diagonal) to the total number of pixels in the matrix (grand total). Various standard threshold levels were applied to the lower and higher tail of each distribution in order to find the threshold value that produced the highest change classification accuracy (Kiflu Gudeta, 2010). Producer's accuracy refers to the probability of a reference pixel being classified correctly. It is also known as omission error because it only gives the proportion of the correctly classified pixels. It is obtained by dividing the number of correctly classified pixels in the category by the total number of pixels of the category in the reference data. User's accuracy assesses the probability that the pixels in the classified map or image represent that class on the ground (Congalton, 1991), and obtained by dividing the total number of correctly classified pixels in the category by the total number of pixels on the classified image. Kappa coefficient was also used to assess the classification accuracy. It expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification (Congalton, 1991). Kappa statistic incorporates the off-diagonal elements of the error matrices (i.e., classification errors) and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance.

### **Land-use and land-cover change detection**

LU/LCC statistics were computed in the following three different ways:

1) Total LU/LCC in hectare calculated by:

$$\text{Total LU/LCC} = \text{Area final year} - \text{Area initial year} \quad \text{Eq. (1)}$$

Where, area is the extent of each LU/LC type. Positive values suggest an increase whereas negative values imply a decrease in the extent.

2) Percentage LU/LCC was calculated using the following equation:

$$\text{Percentage LU/LCC} = \left( \frac{\text{Area final year} - \text{Area initial year}}{\text{Area initial year}} \right) * 100 \quad \text{Eq. (2)}$$

Where, Area is the extent of each LU/LC type. The positive values suggest an increase whereas negative values imply a decrease in extent.

3) Rate of LU/LCC: computed using the following simple formula:

$$r = \frac{Q2 - Q1}{t} \quad \text{Eq. (3)}$$

Where, r, Q2, Q1 and t indicate rate of change, recent year LU/LC in ha, initial year LU/LC in hectare and interval year between initial and recent year in the order.

### 3.4 Methods of spatial Data generations

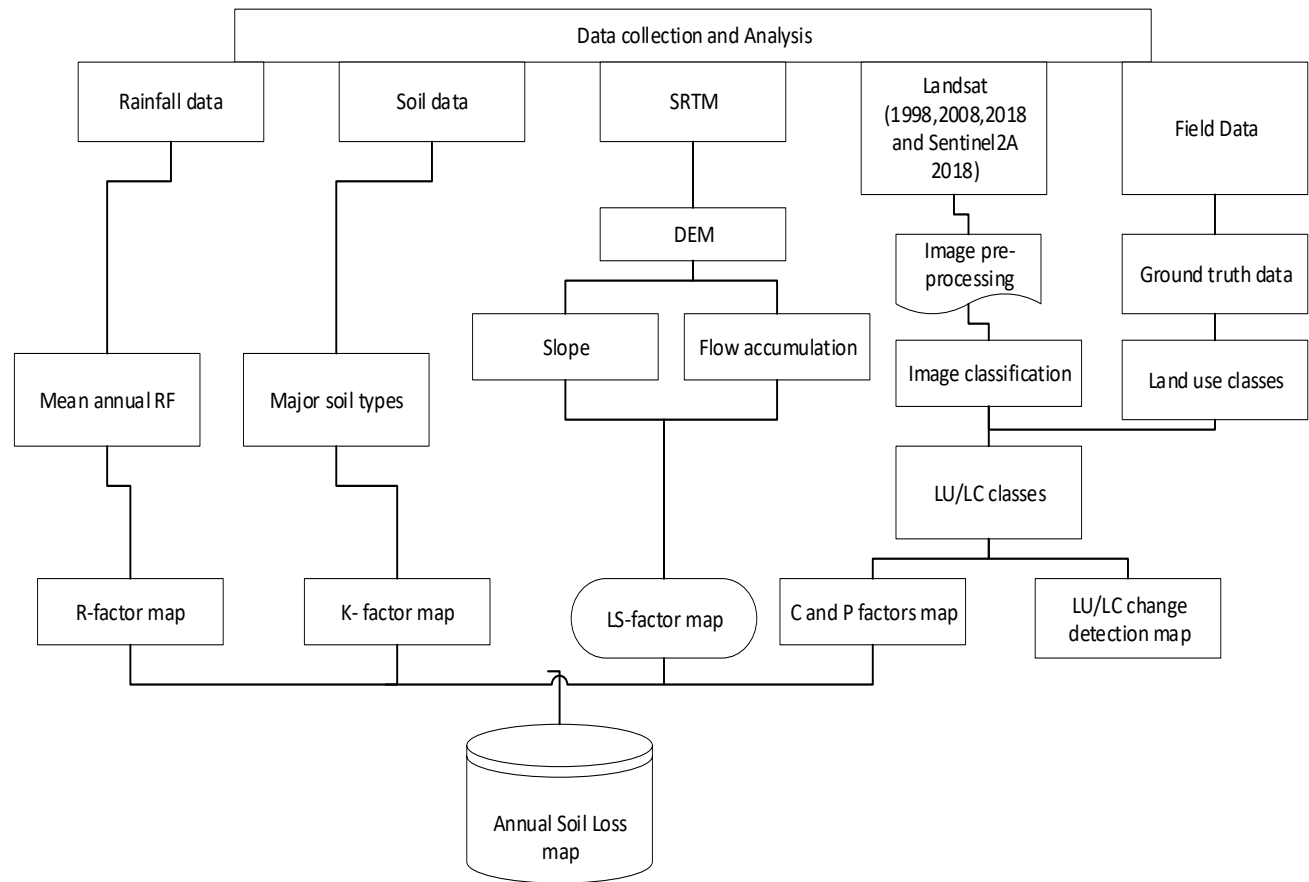
#### 3.4.1 Model description

Since the erosion process is gradual, there are difficulties in differentiating between the natural and accelerated rate of erosion. The physical measurement of soil erosion is made worse by the complexities of temporal and spatial variations (Eaton, 1996). To overcome these problems, statistical modeling of the process of erosion was developed. This can be used to estimate soil loss based on the climate, topography, soil properties and land-use conditions of an area. Revised Universal Soil Loss Equation is considered the alternative improved version of the proto USLE model (Renard *et al.*, 1991). Revised Universal Soil Loss Equation is an empirically based model that has the ability to predict the long-term average annual rate of soil erosion in a field slope as a result of rainfall pattern, soil type, topography, crop coverage and management practices (Renard *et al.*, 1997). The RUSLE model in GIS environment can predict erosion potential on a cell-by-cell basis, which is effective when attempting to identify the spatial pattern of soil loss present within a large watershed area. Geographic information system can then be used to isolate and query these locations to identify the role of individual variables in contributing to the observed erosion potential value. In spite of this advantage, RUSLE does not estimate sediment deposition and gully erosion. The model estimates sheet and rill erosion as a function of five major factors (Maria *et al.*, 2009). The parameter values of the factors are location-specific and need to be calibrated to the specific area to enable reasonable prediction of the rate of soil loss. Numerous variations and local calibrations of these factors have made this equation to be the

most widely used tool in the prediction of erosion (Okan and Nilgun, 2002; Angima *et al.*, 2003; Lee, 2004). The advent of GIS technology has allowed the equation to be used in a spatially distributed manner because each cell in a raster image comes to represent a field-level unit. The following five parameters were used in the RUSLE model to estimate soil loss. Rainfall erosivity (R), soil erodibility (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice factor (P). Referring to RUSLE model, the relationship is expressed as:

$$A = R \times LS \times K \times C \times P \quad \text{Eq. (4)}$$

Where, A is the computed spatial annual soil loss ( $t \text{ ha}^{-1}y^{-1}$ ); R is the rainfall erosivity factor ( $MJ \text{ mm h}^{-1} \text{ ha}^{-1}y^{-1}$ ); K is the soil erodibility factor ( $t \text{ ha}^{-1}MJ^{-1}mm^{-1}$ ); LS is the slope length and steepness factor (dimensionless); C is the land surface cover management factor (dimensionless); and P is the erosion control or conservation practice factor (dimensionless). To identify the spatial pattern of potential soil erosion in the study area, all the considered erosion factors were surveyed and calculated depending on the recommendations of Hurni (1985), in the Ethiopian context. Individual GIS files relevant for the RUSLE were built for each and combined on a cell by cell-grid modeling procedure in ArcGIS 10.3 to predict soil loss in a spatial domain. Each factor grid had a cell size of 30 m resolution. All layers were projected with UTM Zone 37N using the WGS 1984 datum. These correspond to standards used by the Ethiopia Mapping Agency (EMA). The schematic representation of the methodology is showed in (Fig 3.9).



**Figure 3.9:** The overall flow chart of the methodology

### 3.4.2 Rain fall Erosivity (R) factor

Rainfall erosivity is defined as the potential ability of rain to cause erosion and given as the product of the total energy of rainstorm (E) and the maximum 30-min intensity and the annual erosivity will be estimated by summing rainfall erosivity of individual erosive storms of the year or season (Wischmeir and Smith, 1978). However, rainfall intensity data are usually unavailable, mostly in the data-scarce remote regions of developing countries. It requires long-term data of rainfall amounts and intensities, which might not be available for most of the area and hence, relationship between rainfall erosivity index and annual/seasonal rainfall was developed with the data available from various meteorological observatories near by the watershed and interpolated to estimate the rainfall data within the study area in ArcMap10.3 using Spatial Analysis Tool by IDW interpolation. For the present study, a time series rainfall data of 30 years was used to estimate “R” value for the year 1987 to 2017, which were collected from six stations. These stations are; Abebe keranso, Ambo agriculture, Asgori, Busa, Darian and Dertu lebu found near

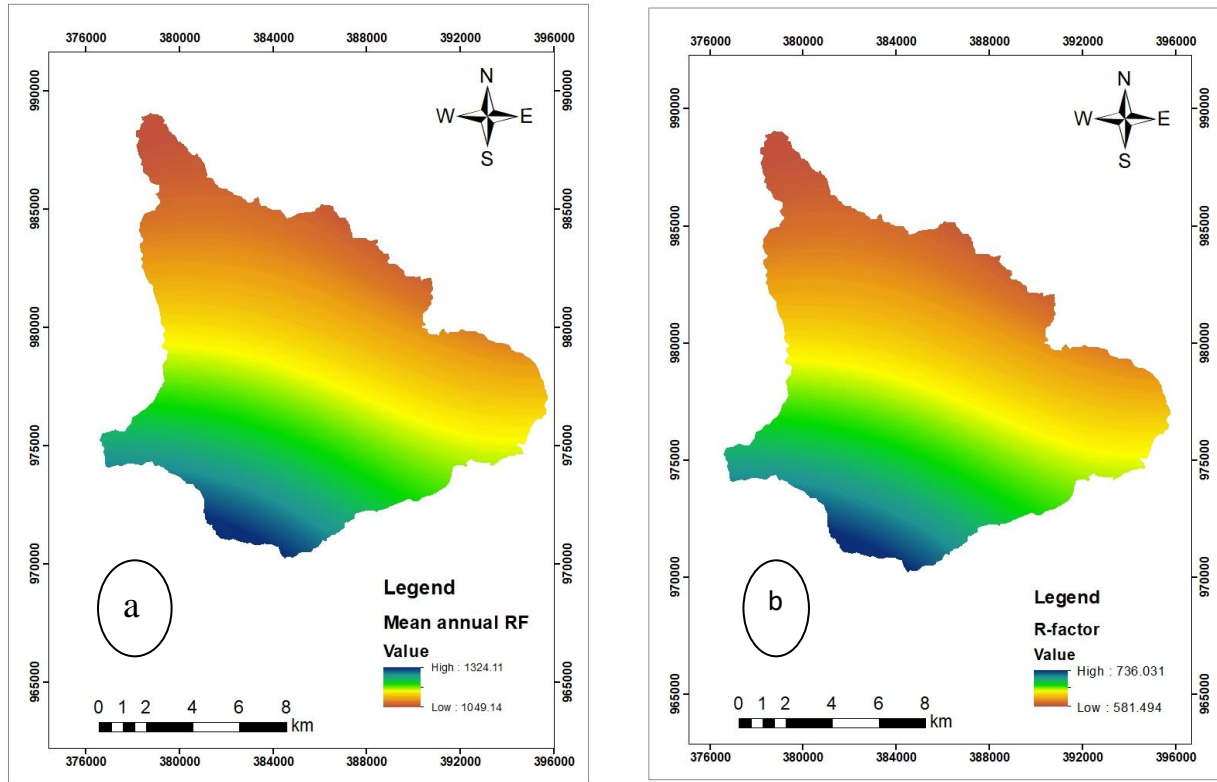
and within the watershed (Table 3.4). After having the interpolated rainfall data, R-factor within the study area were assigned based on the equation number five. In this study, Hurni’s empirical equation (Hurni, 1985a), which estimates R-value for the Ethiopian highlands from annual total rainfall, was used. It is represented by the following equation:

$$R = -8.12 + (0.562 \times P) \quad \text{Eq.(5)}$$

**Table 3.4:** Mean annual rainfall and Erosivity factors result

Name of Stations	Easting	Northing	Elevation	Mean Annual RF	R-factor
Abebe Keranso	38.16917	8.978056	2456	1112.3	617
Ambo Agriculture	37.83967	8.984667	2068	1029.4	570.4
Asgori	38.3342	8.79	2072	985	545.5
Busa	38.1382	8.7725	2166	1281.7	712.2
Darian	37.892	8.69167	2604	1509.5	840.2
Dertu Liben	38.1232	8.97	1991	735.6	405.3

Owing to variation in mean annual precipitation amount within and nearby the study area, variations in rainfall erosivity were observed. The rainfall erosivity, as estimated from mean annual total rainfall of the respective stations, varied from 840.2 MJmm/ha/h/yr at Darian to 405.3 MJmm/ha/h/yr at Dertu liben. The rainfall erosivity was high at the Southeast, and low towards, the northwest (Fig 3.10a). Similarly, the rainfall erosivity value estimated from the rainfall map ranged from 581.49 to 736.031 MJmm/ha/h/yr (Fig 3.10b), which was close to the erosivity values estimated using the mean annual rainfall. According to Hudson (1981), high rainfall may have high erosive power, but the total erosivity is not directly proportional to the total amount of annual rainfall. Therefore, based on this the eastern part of the study area receives relatively higher rainfall that have high erosive power.



**Figure 3.10:** Interpolated mean annual rainfall(a) and rainfall erosivity factor(b) map

### 3.4.3 Soil Erodibility (K) factor

The Soil erodibility (K) factor represents both susceptibility of soil to erosion by the amount and rate of runoff. Erodibility is determined by the cohesive force between the soil particles, which may vary depending on the presence or absence of plant cover, by soil moisture content, and by the development of its structure (Wischmeier and Smith, 1978). Soil texture, organic matter, structure and permeability determine the erodibility of a particular soil (Efe *et al.*, 2008). The K factor reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow, and therefore shows the change in the soil per unit of applied external force of energy (Dumas and Printemps, 2010). It is related to the integrated effects of rainfall, runoff, and infiltration on soil loss, accounting for the influence of soil properties on soil loss during rain storm events on upland areas (Lu *et al.*, 2004). For Ethiopian condition, an attempt was made to classify the major soil types of the study area based on their color by referring the FAO soil database (Fig 3.11a). In this study, a digital soil classification map was obtained from Ministry of Agriculture (MoA). This map was used for analyzing the soil erodibility factor (K-value). The major soil types, which found in the study area were classified into four according to FAO

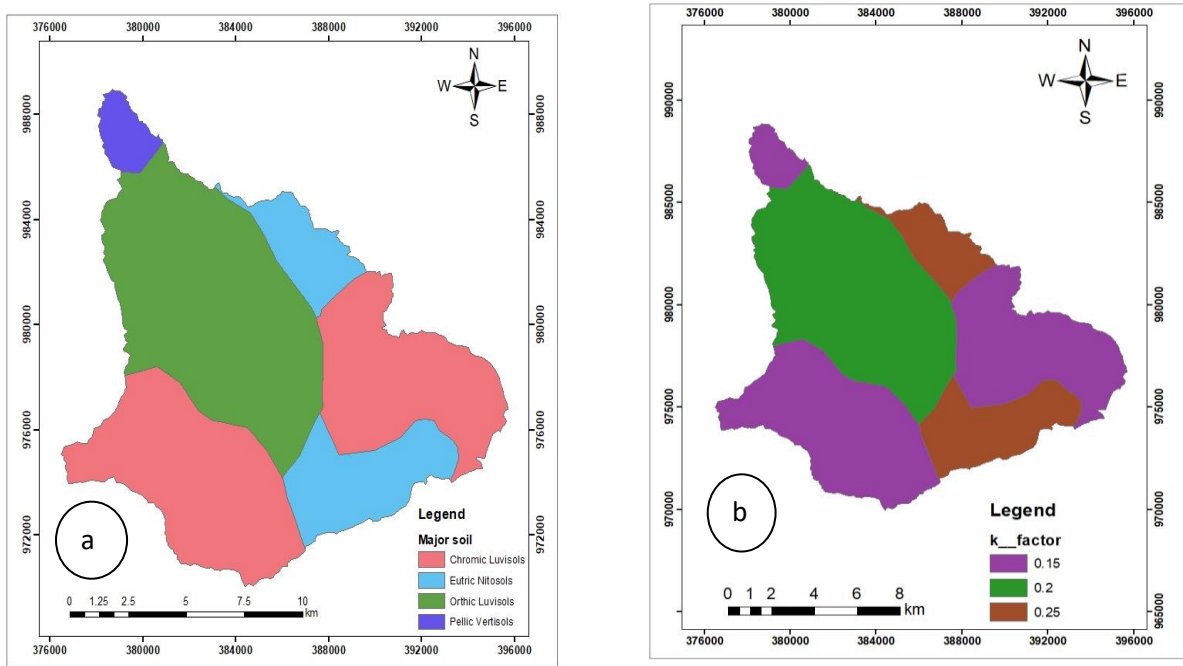
(1974), (Table 3.5). According to Hurni (1985), the erodibility factor was determined for the classified major soil types.

**Table 3.5:** The major soil types and erodibility factors

Major soil types		Area coverage (km <sup>2</sup> )	Erodibility(K) factor
1	Orthic Luvisols	68.98	0.2
2	Chromic Luvisols	79.97	0.15
3	Euthric Nitosols	31.48	0.25
4	Pellic Vertisols	5.35	0.15

(Source: Hurni, 1985).

From the digital soil map data obtained from the MoA and RDE, Orthic Luvisols, Chromic Luvisols, Euthric Nitosols and Pellic Vertisols were recognized in the study area. The values indicate that Pellic Vertisols and Chromic Luvisols have lower erodibility, while Nitosols had relatively medium erodibility and Euthric Nitosols higher erodibility. This implies that the Vertisols are more resistant to erosion because of their low detachability, while the Nitosols and Luvisols are more susceptible to erosion under similar conditions that affect soil loss. The results indicated that soil erodibility value in the study watershed ranged from 0.15 MJ mm/ha/year to 0.25 MJ mm/ha/year. Highest erodibility values were found to be in the eastern, central and northwestern parts of the study area. This indicates that the soils are highly vulnerable to erosion because they have low stability and low infiltration rate, which may lead to high runoff and soil loss. The soils in the southeastern corner, northeastern and western parts of the study area have relatively low K-factor values (Fig 3.11b).



**Figure 3.11:** Major soil type (a) and soil erodibility factor(b)

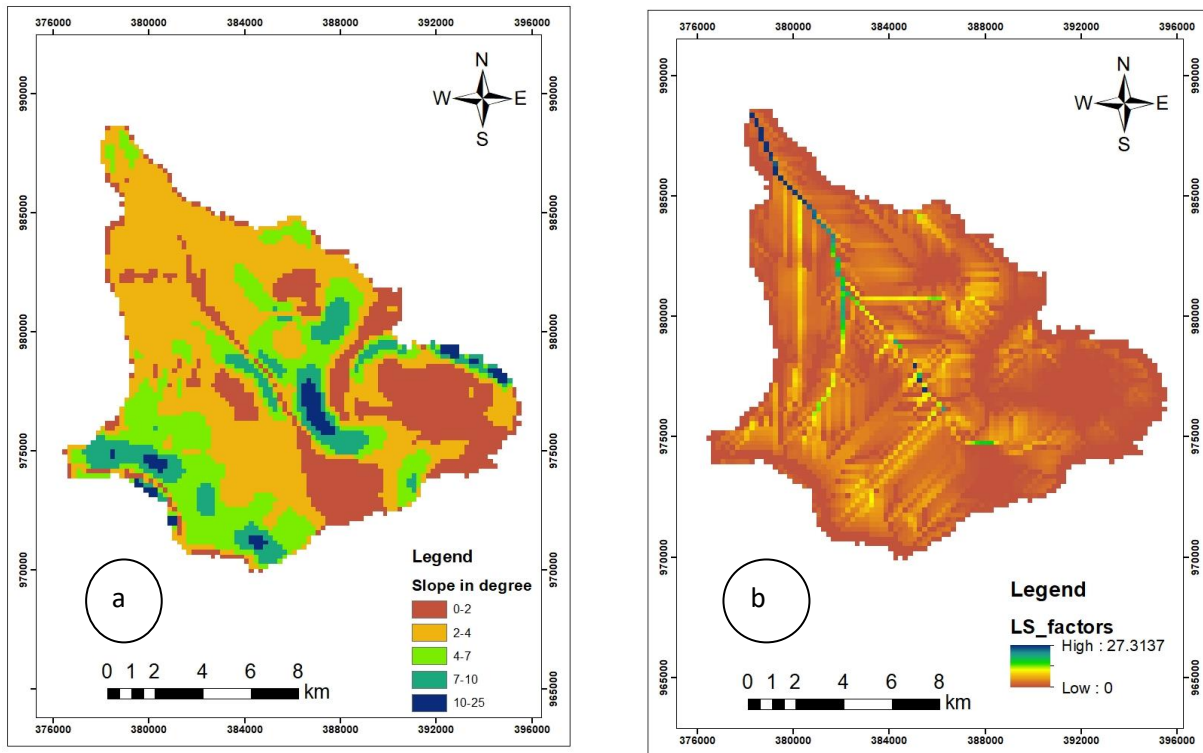
### 3.4.4 Slope length and slope steepness (LS)

The L and S factors in RUSLE reflect the effect of topography on erosion. 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). Moreover, gross soil loss is considerably more sensitive to changes in slope steepness than to changes in slope length (McCool *et al.*, 1987). The slope-steepness factor (S) is the ratio of soil loss from the field slope gradient to that from a 9% slope under, otherwise identical conditions. Slope length factor (L) can be defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff water enters a well-defined channel that may be part of a drainage network or a constructed channel. Digital Elevation Model dataset of 90 m resolution was clipped to encompass the zone of interest and used for generating LS factors. Recent advancements in GIS technology have enabled more accurate estimation of slope length and steepness. In order to derive LS-factor values, a series of DEM derived grids are produced using ArcGIS 10.3, with its extension Arc hydro 10.3. As the first, any false single-cell sinks within the source DEM are filled to produce a depression less DEM. In this process, individual sink elevations were flattened to correspond with the

surrounding cells. The flow directions of each DEM cell are then calculated using the flow direction toolset. From the flow direction, flow accumulation was calculated. The slope length (L) and slope steepness (S) were calculated from flow accumulation and slope in degree of the local area (Fig 3.12a). Finally, LS factors were derived from the following equation.

$$LS = (\text{Flow Accumulation} * \text{Cell Size} / 22.13)^{0.4} * (\sin \text{slope} * 0.01745 / 0.0896)^{1.3} \quad \text{Eq.(6)}$$

The LS factor was then computed using Raster Calculator in ArcGIS based on flow accumulation and slope steepness by using equation number six. Accordingly, LS factor in the watershed ranged from 0 to 27.1317, with the mean value for the entire watershed at approximately 1.67 and a standard deviation of 2 (Fig 3.12b). The map was resampled to 30 m cell size.



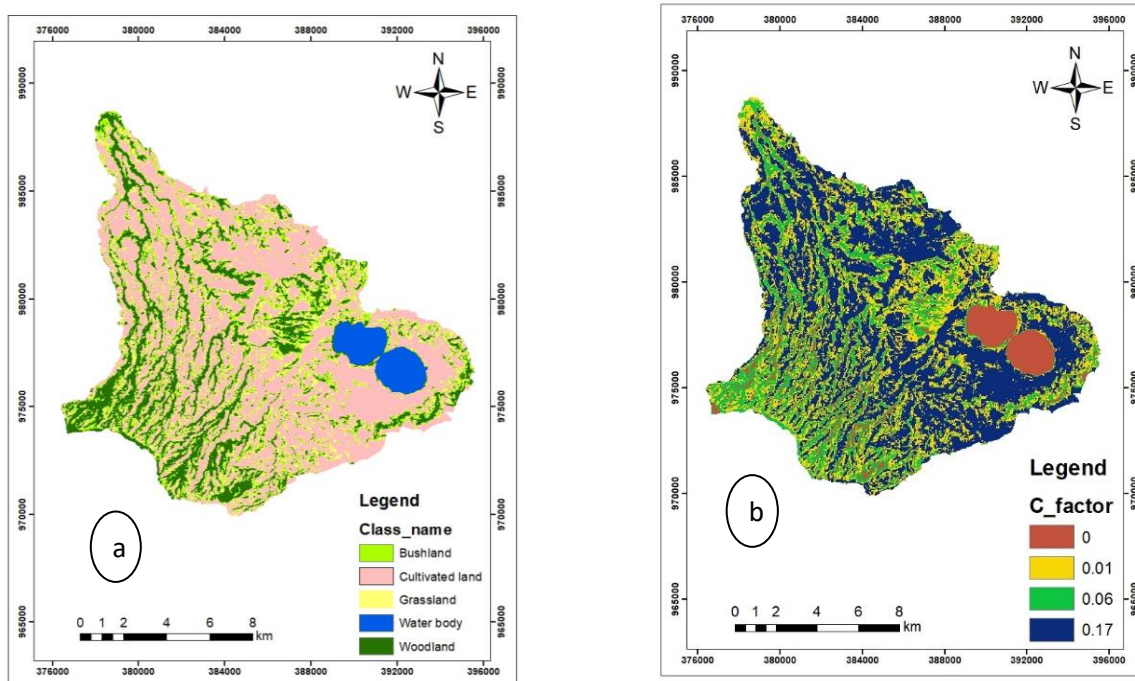
**Figure 3.12:** Slope map (a) and LS factor map(b)

### 3.4.5 Cover management (C) factor

The vegetation cover management factor (C) represent the effect of cropping and management practices in agricultural management, and the effect of ground, tree, and grass covers on reducing soil loss in non-agricultural situation. According to Benkobi *et al.* (1994) and

Biesemans *et al.* (2000), the vegetation cover factor together with slope steepness and length factors most sensitive to soil loss. The value of C-factor is defined as the ratio of soil loss from a certain kinds of land surface cover conditions (Wischmeier and Smith, 1978). The C factor combines plant cover, the level of its production, and the associated cropping techniques.

In this study, Sentinel2A of 10 m resolution were used for land-use/land-cover classification. Google Earth pro, Field observation and ground truth data collection were done to support classification for accuracy. After the classification is done, the raster layer was converted into vector layer and C-factor value was assigned for each land-use/land-cover unit based on Hurni (1985), which is adopted for Ethiopian condition. In order to identify specific values for each land-use/land-cover category, the image data was classified into five categories (Fig 3.13a). Most parts of the lands in the area are intensively cultivated lands. It was exposed to erosion because the higher the C-factor, the higher the soil loss will be occurred. In general, 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). Therefore, soil cover management in the form of crop plants, mulches, or residues can protect soils from wind and water erosion, enhance water infiltration, and help maintain or increase organic matter (Bobe, 2004). Thus, they have low C-factor values that have low contributions to the soil loss the C-factor values of the study area range from 0 to 0.17(Fig 3.13b).



**Figure 3.13:** Land-use and land-cover map (a) and Crop management(C) factor map(b)

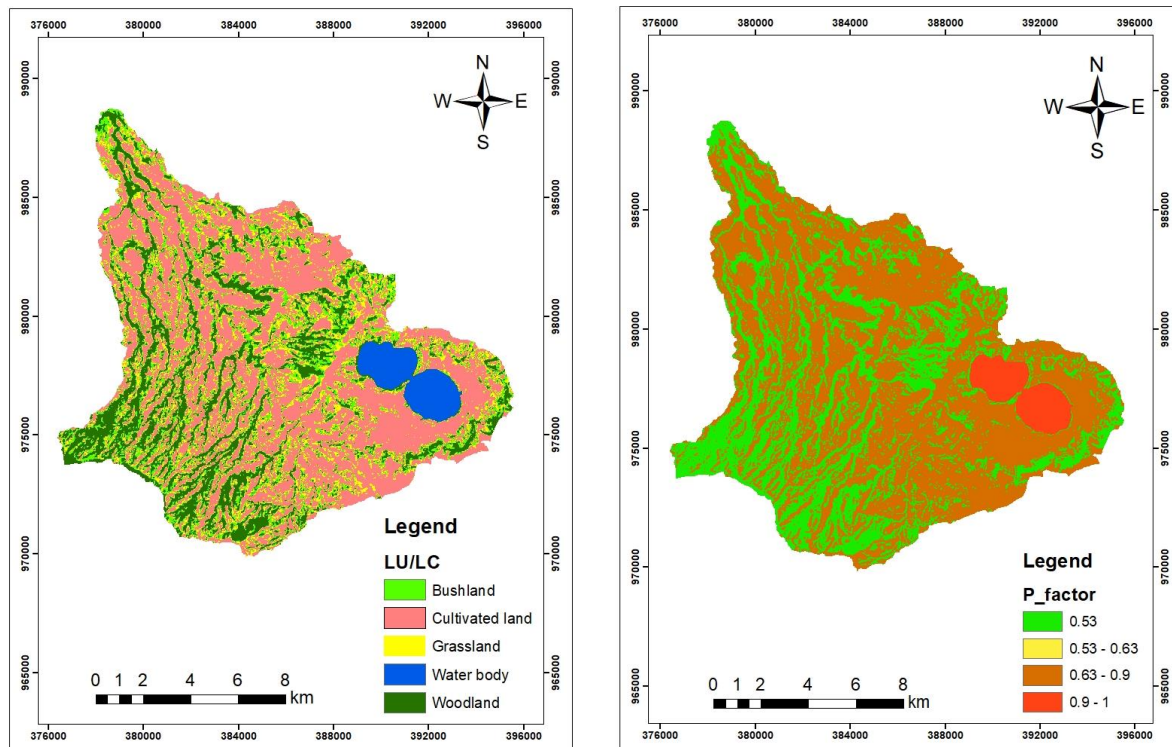
### 3.4.6 Conservation practice (P) factor

The conservation practice factor (P) is also known as support factor. It represents the soil loss ratio after performing a specific support practice to the corresponding soil loss, which can be treated as the factor to represent the effect of soil and water conservation practices (Omuto, 2008; Renard *et al.*, 1997). The range of P factor varies from zero to one. The lower the value is the more effective the conservation practice. The entire study area is not treated with improved permanent soil and water conservation measures. Considering lack of data in the area on permanent management factors and an absence of soil management practices, P-values, suggested by Hurni (1985), for Ethiopian condition. The P-factor takes into account based on land-use/land-cover, which extracted from Seninel2A image. In order to identify specific values for each management practice category, the image data was classified into five major land-use/land-cover categories (Fig 3.14a). P-values were assigned for each class based on Hurni (1985), adapted by Tadesse *et al.*, (2017). Then a corresponding P-value was assigned to each land-use type using the reclass- method in ArcGIS 10.3 (Fig 3.14b). The greater proportion of the study area is under farmland (including rural settlement). Practices that maintain soil cover include minimum tillage, cover cropping, managed grazing, contour planting, strip cropping,

crop rotation, control structures and diversions to protect soils from water erosion by decreasing the effective slope length along a field. The high level of conservation practices was given to cultivated land (Table 3.6).

**Table 3.6:** P-value suggested by Hurni (1985); adapted by Tadesse et al. (2017).

Land-use/land-cover types	P- factor value
Bushland	0.53
Cultivated land	0.9
Grassland	0.63
Water body	0
Woodland	0.53



**Figure 3.14:** Land-use/Land-cover map (a) and conservation practices(P) factor map(b)

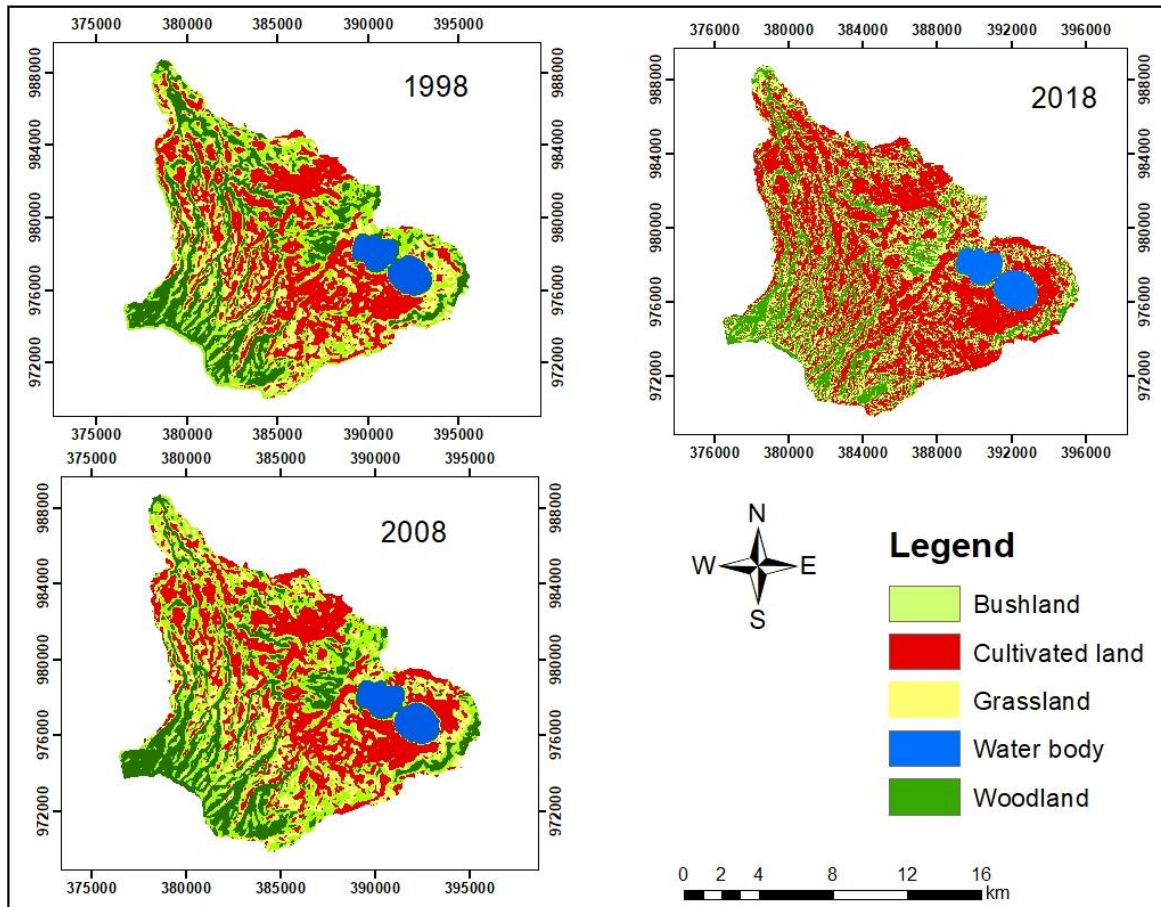
## CHAPTER FOUR

### 4 RESULTS

#### 4.1 Land-use/land-cover change detection.

##### 4.1.1 Land-use/land-covers change detection in Huluka watershed

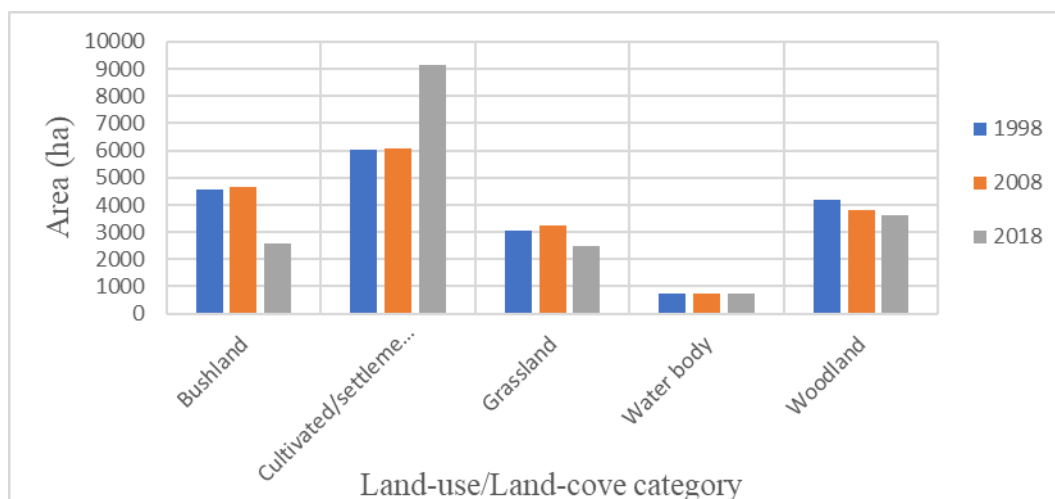
The proper management of watershed requires accurate measurement of the past and present land-use/land-cover. Huluka watershed experienced a variety of land-use/land-cover types. Figure 4.1 presenting the distribution of land-use/land-cover map of the study area of the year 1998, 2008 and 2018 were produced, respectively. The study analyzed the area of each LU/LC distribution in hectare and percentage cover of different periods is tabulated on (Table 4.1). The changes between land-use/land-cover of the study area was measured.



**Figure 4.1** Land-use/land-cover map of Huluka watershed from 1998, 2008 and 2018

**Table 4.1** Land-use/land-cover classes in area and percentage of different periods

Land-use/land-cover classes	1998		2008		2018	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Bush/shrubland	4541	24.5	4668	25	2573	14
Agriculture/settlement	6039	32.5	6086	33	9135	49
Grassland	3056	16.5	3245	17.5	2492	13
Waterbody	759	4	755	4	758	4
Woodland	4176	22.5	3817	20.5	3613	20

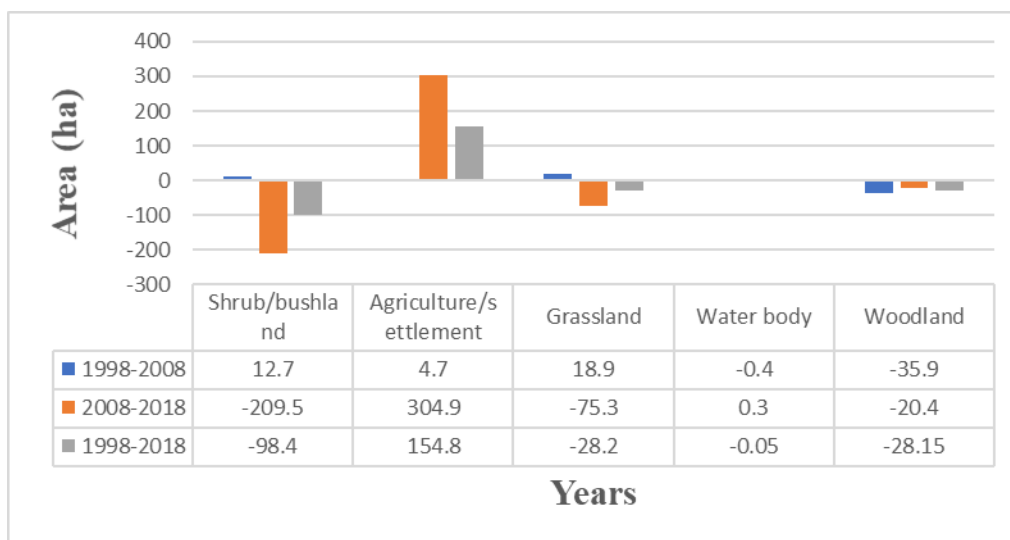


**Figure 4.2** Distribution of land-use/land-cover from 1998 to 2018

#### 4.1.2 Trends of LU/LCC in Huluka watershed

The trend of LU/LC changes presented in the (Table 4.2). The negative values in trend or rate of change shows decreased in that particular land-use/land-cover and the positive values shows the increased of land-use/ land-cover types. According to the findings, the bush/shrub covered the study area increased by 3% from 1998 to 2008 and rapidly decreased by 45% in 2018 Table 4.2. It was decreased about 43% from 1998 to 2018. The agricultural/settlement lands were increased rapidly from the year of 1998 to 2018. Grassland is one of the land-use/land-cover type of the study area, which increased about 6.2% in 1998 to 2008 and decreased by 23% from 2008 to 2018. The extents of grassland decreased about 18.5% from 1988 to 2018. Water body covered

only about 4%. Woodlands, which were initially consist of 22.5% of the LU/LC in 1998 has decreased about 8.6% in 2008 and further decreased is about 5% in 2018. Extents of woodlands decreased by 13% from 1998 to 2018 (Table 4.2). Huluka watershed experienced different LU/LC chandes during 1998 and 2018. The land under woodland decreased continuously during the indicated years. In contrast, the area of shrub/bushland and grassland showed a fluctuating trend between the study periods (Fig 4.3).



**Figure 4.3** Trend of Land-use/land-cover change in Huluka watershed

Woodland had the largest decline with a rate of decline of about 28.15 ha/year from 1998 to 2018. Agriculture/settlement had the highest increment by an estimated 154.8 ha/year in the period from 1998 to 2018 (Table 4.2). During the period 1998 and 2008, the land under woodland decreased by 35.9 ha (8.6 %), while the extents of agriculture/settlement, shrub/bushland and grassland have increased by 4.7 ha (0.78 %), 12.7ha (3%) and 18.9ha (6.2%), respectively (Figure 4.3, Table 4.2). The result of land-use/land-cover change of the study area shows that the extents of agriculture/settlement continuously increased, while woodland continuously decreased. The result for the second period (2008–2018) indicated that the land under shrub/bushland and grassland cover had rapid decrease by 209.5 ha/year (45%) and 75.3 ha (23%), respectively as compared to the first phase of this study (1998–2008). On the other hand, extents of agriculture/settlement continued to increase in the second period. Woodland decreased by 20.4 ha/year (5%), while agriculture/settlement increased by 304.9 ha/year (50%) (Figure 4.3 and Table 4.2).

**Table 4.2** Land-use and land-cover change in Huluka watershed during 1998–2018

Land-use/land-cover classes	1998–2008		2008–2018		1998–2018	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Bush/shrubland	12.7	3	-209.5	-45	-98.4	-43
Agriculture/settlement	4.7	0.78	304.9	50	154.8	51
Grassland	18.9	6.2	-75.3	-23	-28.2	-18.5
Waterbody	-0.4	-0.5	0.3	0.4	-0.05	-0.1
Woodland	-35.9	-8.6	-20.4	-5	-28.15	-13

**4.1.3 Land-use/land-cover change matrix**

Conversion matrixes were analyzed for each period to clearly show the source and destination of the major LU/LCCs. The land-use/land-cover change matrix were computed (Table 4.3, 4.4). In all change matrixes the row of the table stands for the initial year and the column of the table symbolize the final year of the change. Moreover, all change matrixes show gross gain and loss of each land cover category during the study periods. The diagonal numbers, which written in bold show the unchanged pixels. During the study period between 1998 and 2018 about 8080.1 ha (43.5%) of the study area landscape remained unchanged (Table 4.5). This implies around 56.5% of the total landscape of the study area was converted from one land-use/land-cover type to the other. Bushland and grassland in the watershed was mainly converted to agriculture/settlement. Agriculture/settlement replaced about 3096 ha of the land, that used to be covered by other land-use/land-cover types. Major conversion was from woodland (563 ha), shrub/bushland (1968 ha) and grassland (564 ha).

**Table 4.3** Land-use/land-cover change matrix between 1998 and 2008

	2008						
	LU/LC	Bushland	Agriculture	Grassland	Water	Woodland	Total
1998	Bushland	<b>1681.17</b>	1057.61	773.32	21.34	984.32	4517.76
	Agriculture	929.24	<b>3865.13</b>	1116.36	23.34	179.19	6070.3
	Grass land	890.22	854.4	<b>1001.22</b>	7.06	300.9	3053.81
	Water body	19.26	22.22	17.93	<b>681.28</b>	18.6	759.29
	Woodland	1137.84	349.36	331.99	22	<b>2328.64</b>	4169.83
	Total	4657.73	6105.77	3240.82	755.01	3811.66	18571

**Table 4.4** Land-use/land-cover change matrix between 2008 and 2018

		2018					
2008	LU/LC	Bush	Agriculture	Grassland	Water body	Woodland	Total
	Bushland	<b>1253.19</b>	1450.6	1104.94	1.97	845.22	4655.92
	Agriculture	177.83	<b>5474.06</b>	415.85	0.14	42.28	6112.2
	Grassland	412.92	2055.85	<b>638.91</b>	0.58	132.02	3240.29
	Water body	1.03	0.24	0.32	<b>745.58</b>	7.8	754.98
	Woodland	719.46	177.85	322.47	9.46	<b>2580.37</b>	3809.61
	Total	2564.44	9153.99	2482.54	757.73	3607.7	18571

**Table 4.5** Land-use/land-cover change matrix between 1998 and 2018

		2018					
1998	LU/LC	Bush	Agriculture	Grassland	Water body	Woodland	Ttotal
	Bushland	<b>769.41</b>	2050.07	714.09	23.26	966.28	4523.11
	Agriculture	537.73	<b>4412.08</b>	679.53	25.40	413.95	6068.69
	Grassland	441.23	1682.84	<b>482.82</b>	7.46	437.96	3052.31
	Water body	14.11	32.16	12.99	<b>680.82</b>	19.21	759.29
	Woodland	803.67	977.85	594.09	20.79	<b>1771.2</b>	4167.6
	Total	2566.14	9153.99	2484.55	757.72	3608.6	18571

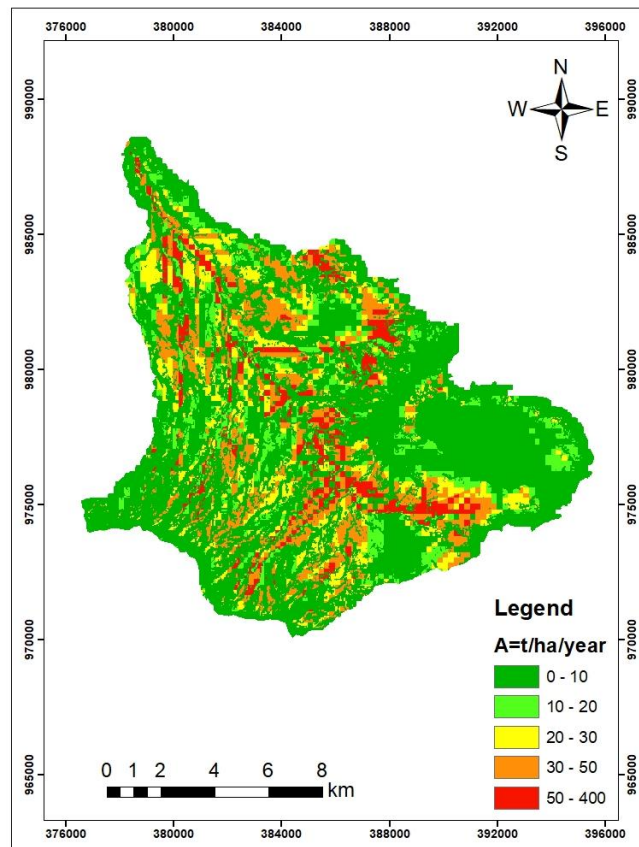
#### 4.1.4 Accuracy assessment

The ground truth data were utilized in the classification report as the independent data set from which the classification accuracy was compared. An overall accuracy of 83.2%, 88.64% and 88.33% was achieved, with a Kappa coefficient of 0.78, 0.85 and 0.85 for the three Scenes (Landsat TM 1998, ETM+ 2008 and OLI 2018), respectively. An error report containing the error matrix and accuracy report summarizing the agreement and disagreement are produced (Appendix D).

#### 4.2 Assessment of Soil loss in the study area

Soil erosion hazard was estimated by RUSLE model from the statistics and map output of the cell by cell multiplied parameter layers, such as rainfall erosivity (R), soil erodibility (K), slope

length (L) and slope steepness, cover management (C) and support practice (P) factors. The amount of soil loss in Huluka watershed was estimated about 495,715 metric tons per year from 18,571 ha of land. The spatial distribution of potential annual soil loss of the study area is quite different, that vary from 0.00 t/ha.yr to 400 t/ha/yr (Fig 4.4). The average annual soil loss rate was calculated to be 27 ton/ha/year. In order to obtain a better understanding, at the same time be able to compare the risk area; the average soil loss of the study area was first categorized into different severity classes with some modifications to suit the condition of the study area. The Soil Loss Tolerance (SLT) value was used as a basis for the categorization of the severity classes. Accordingly, the quantitative output of the actual soil erosion rate for Huluka watershed were computed and grouped into five ordinal severity classes. Soil erosion severity class based on the average soil erosion rate and the total annual soil loss from the study area presented in (Table 4.6).



**Figure 4.4** Estimated potential annual soil loss map of the study area.

**Table 4.6** Annual soil loss rates and severity classes in the study area

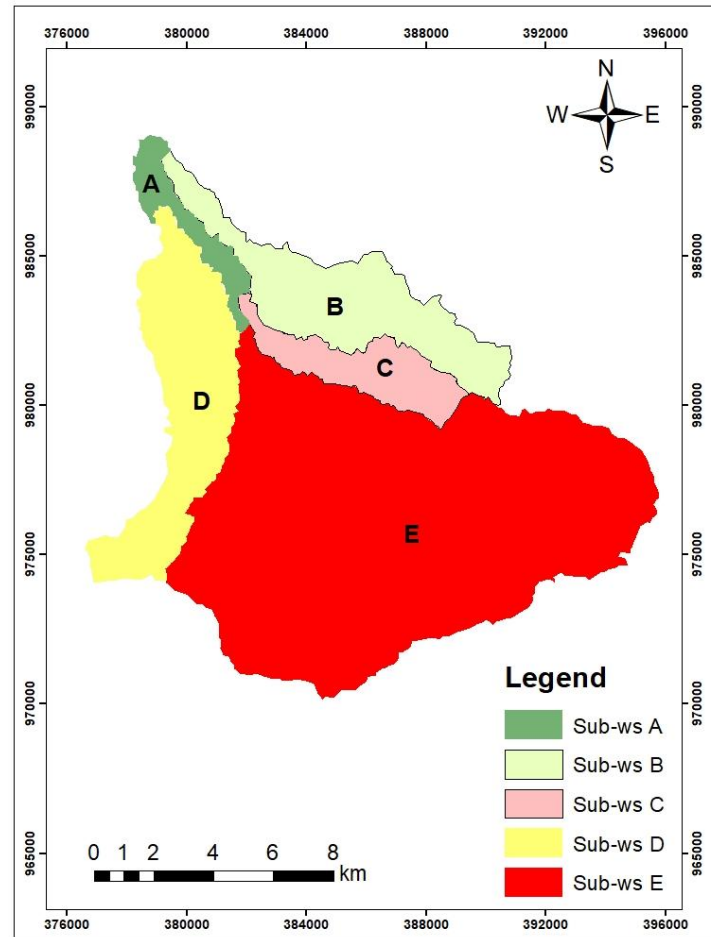
Annual soil loss(to/ha/yr)	Severity classes	Area (ha)	Area (%)	Annual soil loss (tons)	Percent of total soil loss
0–10	Low	11,989	65	59,945	13
10–20	Moderate	1,435	8	21,525	4
20–30	High	1,719	9	42,975	9
30–50	Very high	2,313	12	92,520	20
>50	Severe	1,115	6	278,750	54
Total		18,571	100	495,715	100

### 4.3 Identification and Prioritization critical sub-watershed for treatment

In this study, a total of five sub-watersheds were delineated based on drainage systems and the erosion risk map were reclassified based on prioritization (Fig 4.5). Prioritization of sub-watersheds involved for ranking different sub-watersheds according to the order in which they will be taken up for sustainable management, by taking into consideration the amount of average annual soil loss occurred in these sub-watersheds. The areas with high and severe soil loss were prioritized for the implementation of soil erosion control measures. Table 4.7 show the priority of sub-watershed based on the average annual soil loss from each sub-watershed.

**Table 4.7** shows the average annual soil loss of sub-watershed of the study area

Priority classes	Sub-watershed	Area (ha)	Area (%)	Average soil loss (t/ha/yr)	Ranges of potential soil loss (t/ha/yr)
V	A	748	4	14.4	0–304
IV	B	2113	11.3	15	0–147
II	C	1304	7	21	0–219
III	D	2915	15.7	20.1	0–279
I	E	11491	62	27	0–400



**Figure 4.5** Map of the Sub watershed of the study area.

Soil erosion risk maps and critical classes based on distribution of soil loss for the Huluka watershed were computed on the basis of average annual soil loss. The output of average soil loss indicated in (Table 4.8), were ranges from 14.4 t/ha/yr to 27 t/ha/yr in different sub-watershed of the study area. This approach of prioritizing watersheds based on actual soil loss rates is possible only when the number of sub-watersheds to be prioritized is low and the necessary data are available. Furthermore, this method is helpful when the soil loss potentials of different sub-watersheds do not have considerable variations. According to this classification, an erosion risk map based on the distribution of average annual soil loss in Huluka watershed, was prepared (Fig 4.5). The ranges of the erosion rates and their suggested classes were inferred for identification of the critical sub-watersheds. The critical sub-watersheds were prioritized related to management scenarios for reducing soil loss. A particular sub-watershed may get top priority

due to various reasons, but often the intensity of land degradation is used as the basis. The result indicates that from the identified sub-watershed; sub-watershed “E” need urgent conservation rather than “D”, “C”, “B” and “A” sub-watersheds. According to the study result, areas which are classified as sever erosion class covers an area of 11491 ha, which is about 62% of the total watershed while high to very high erosion risk class covers an area of 4219 ha (22.5 %) and moderate erosion risk class covers an area of 2861 ha (15.3%), respectively. The area, of high to sever potential soil loss locations were need immediate interference by soil conservation practices. The critical sub-watersheds were ranked and presented on Table 4.8 and Mapped for sub watershed treatment in order to reduce the potential soil losses and to conserve the resources within the watershed. Top priority for soil conservation measures must be given to sub-watershed “E”, in the first stage, sub-watersheds “C”, and “D” can be considered in the second stage, sub-watershed “B” in the 3rd stage and finally sub-watershed “A” could undergo at last.

## CHAPTER FIVE

### 5 DISCUSSION

Land-use/land-cover changes in the Huluka watershed shows that most of the area is agricultural land (51%) and shrub land (20.75%), the smallest area of the water body (4%) from the total area. It was difficult to identify settlement especially rural settlements from agricultural land on 30 m spatial resolution image and in most cases the two were integrated. Therefore, settlements were grouped under agricultural land-covers. This classification is in agreement with Desalegn et al. (2014), who grouped agriculture and settlement under one class for the same reason listed above. The finding of the study indicate that woodland, grassland and shrub/bushland were reduced during 1998 to 2018. Studies conducted in dry and semi-dry land parts of Ethiopia such as Garedeu (2010), Tefera (2011), Alemu *et al.* (2015), documented reduction of area under woodland and increase in area under agricultural land. There were different factors, which led land-use/land-cover changes in the study area, such as human population growth, agricultural expansion and non-agricultural activities (charcoal production, firewood collection, harvesting of poles for construction and logging for timber) on a marginal scale. Increased anthropogenic activities have altered the land-use/land-cover (Mdemu *et al.*, 2012). The spatial resolution of the images also provided the necessary level of accuracy in the results. The final accuracy achieved using supervised classification method for Huluka watershed are 83.2%, 88.64% and 88.33%, which is comparable to Lemlem *et al.* (2017), of overall classification accuracy result achieved by her research were 85%, 91% and 93.2%.

Soil erosion is the most serious cause of land degradation, which has influenced tremendous pressure on productivity and environmental stability of arid and semiarid areas. Serious impacts led the demand for conservation and management measures to reduce the magnitude of soil loss and the extent of its associated impacts in many parts of the world. There are many models to estimate soil erosion. RUSLE was originally developed for USA, but also has proven as valuable for estimation of soil erosion loss in other regions of the world (Millward and Mersey, 1999; Reusing et al., 2000; Angima et al., 2003, Ma et al., 2003). In general, RUSLE is used for estimating average annual soil loss based on available geospatial data. The use of remote sensing and GIS allows to map the spatial distribution of soil erosion risk. Five parameters were derived

from different data sources, such as Digital Elevation Model, digital soil map, monthly precipitation data, and remotely sensed data (Sentinel2A).

The estimated rate of soil loss and the spatial patterns are generally realistic compared to what can be observed in the field as well as from the results of previous studies. For instance, Mati *et al.* (2000), estimated average soil loss from croplands in the highlands of Ethiopia at 100 metric tons/ha/yr. In the highlands of Ethiopia and Eritrea, soil losses are extremely high with an estimated average of 20 metric tons/ha/yr (Hurni, 1985a) and measured amounts of more than 300 metric tons/ha/yr on specific plots. Accounting for re-deposition of mobilized sediments, Hurni (1993) estimated mean soil loss from cultivated fields as 42 metric tons/ha/yr. The average annual soil loss for the entire Chemoga watershed in the Blue Nile Basin, Ethiopia, was estimated at 93 metric tons/ ha/yr (Woldeamlak and Ermias, 2009). When the result of the present study was interpreted, the annual soil loss as a proxy to watershed erosion, it was possible to see that the magnitude of annual soil loss reported in Table 4.5 was higher than the tolerable soil loss of 2 to 18 tons ha<sup>-1</sup> y<sup>-1</sup> estimated for Ethiopia by (Hurni, 1985), except flat landforms of the watershed. The implication is that there is a need to integrate a sound management practices so that to decrease the amount of soil loss in Medego watershed, to a hard tolerable for the country. However, the result of study falls within the ranges of the findings of FAO (1986) in the highlands of Ethiopia. According to Bobe (2004), the average soil loss in the Ethiopian highlands is being 70t/ha/year. According to the present results of soil loss in Huluka watershed, the quantified value of erosion ranging from (0 to severe soil loss rates 400 t/ha/yr). The average annual soil loss from the study area was 27 t/ha/yr. Therefore, the present investigation has demonstrated that the estimation of soil loss rate using RUSLE modeling and land-use/land-cover change detection is a good agreement with those obtained by other studies. The potential soil loss results show, that the northeastern and central parts of Huluka watershed the value falls with high to severe class of soil erosion. This is because the soil type of the area (Chromic and Orthic Luvisols) have a high K factor value of 0.2 to 0.25 compared to other soil types. The area has the most mountainous and rugged terrain compared to other parts of the watershed area. Therefore, the soil type together with the topography make the area high soil erosion prone zone. In addition to the central part, most of the mountainous area of the watershed also shows a higher soil erosion rate. Results of soil loss assessment in Huluka watershed

revealed the fact that majority of the watershed area characterized by moderate or low erosion risk levels. However, high resolution erosion risk maps show its substantial spatial diversity.

Therefore, the result of RUSLE model showed that it is more reliable result compared to previous research. Soil loss rates in the Ethiopian highlands measured on test plots amount to 130 to 170 metric tons/ha/yr (Hurni, 1988; Hurni *et al.*, 2008). The present study was emphasized on assessment of soil erosion risk and identify the land-use/land-cover change in the study area. It is necessary and strategic to prioritize micro- watershed for treatment with appropriate soil and water conservation measures (Woldeamlak and Ermias, 2009). This approach of prioritizing watershed based on actual soil loss rates is possible only when the number of sub-watershed to be prioritized is low and the necessary data are available. The present study revealed that five sub-watersheds identified and prioritized according to the average annual soil loss. The soil-loss rate map, (Fig 4.5, Table 4.8), clearly show that, nearly 69% of the total study area requires implementation of different types of soil and water conservation measures for a sustainable land use.

## CHAPTER SIX

### 6 Conclusion and Recommendations

#### 6.1 Conclusion

The present study attempts to estimate the actual average of annual soil loss from areas in Huluka watershed by RUSLE model using remote sensing and geographic information system (GIS) techniques and to investigate time series land-use and land-cover changes in Huluka watershed west shoa zone, Oromia regional state, central Ethiopia. Based on the results and the further analysis, the following conclusions could be drawn. Firstly, the land-use/land-cover change detection was investigated in the study area. From the analysis of this study land-use/land-cover change of twenty years was determined. The result indicates the agriculture/settlement in the watershed continuously increased by the rate of 154.8 ha/yr, while woodland is continuously decreased by the rate of 28.15 ha/yr. Other land-use/land-cover types were fluctuated in the first season from 1998 to 2008. Finally, agriculture/settlement was dominate over all other land-use/land-cover types from 1998 to 2018 in Huluka watershed.

Secondly, the RUSLE model integrated with RS and GIS supported by field observations revealed, that majority of the watershed area is potentially experienced to soil erosion hazards. The current potential soil erosion rate in Huluka watershed was estimated to be in the range of 0.0 to 400 ton/ha/year. The average soil loss for the entire watershed was calculated to be 27 ton/ha/year and the total soil loss in the watershed was calculated to be 495,715 ton from an area of 18,571 hectares. Results of the annual soil loss rates and the severity classes showed that almost the entire study area (83%) is classified under high to severe soil erosion class.

The research also has tried to prioritize the sub-watersheds based on the average annual soil erosion rate. According to the study result, areas which are classified as sever erosion class covers an area of 11,491, which is about 62% of the total watershed while high to very high erosion risk class covers an area of 4,219 ha (22.5%) and moderate erosion risk class covers an area of 2,861 ha (15.3%), respectively. The area, which were located in high to sever potential soil loss locations were need immediate interference by soil conservation practices. As a result, the critical sub-watersheds were ranked and presented and recommended for sub watershed treatment in order to reduce the potential soil losses and to conserve the natural resources within the watershed. As the result of the study showed, top priority for soil conservation measures

must be given to sub-watershed “E”, in the first stage, sub-watersheds “C”, and “D” can be considered in the second stage, sub-watershed “B” in the 3rd stage and finally sub-watershed “A” could undergo at last stage for this investigation.

## 6.2 Recommendations

- ❖ Expansion of agriculture especially small-scale agriculture by small holder farmers is the major direct causes of LU/LCC in Huluka watershed causing loss of several hectares of shrub/bushlands and woodlands. Therefore, controlling the expansion of agriculture at the expense of shrub/bushlands and woodlands requires the right policy packages by national and regional governments such as livelihood diversification and improving the productivity of existing farm lands through the provision of improved production inputs.
- ❖ Poverty and food insecurity which, occurred through population growth and shortage of farmlands were the other most important root cause for land use/land cover change in the study area. Combating this problem; requires designing of good polices and strategies. Thus, the considered body should design policies and strategies like creating and strengthening environmental friendly non-farm/off-farm income generating activities.
- ❖ Since the top soil of the watershed is lost by water erosion, the water-holding capacity and nutrient availability of the soil would be decreased. To overcome such problems applying physical and agronomic/biological conservation schemes, that help for increasing agricultural productivity and minimize loss of biodiversity in the area.
- ❖ For proper soil and water conservation plan, the researcher also recommends for further studies to be undertaken mainly that focuses on the main drivers of the soil erosion in the farming system (i.e., Socio-economic, agronomic and biophysical factors that trigger soil erosion) by using high resolution satellite data to establish the suitable soil and water conservation measures that should be implemented in this area.

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**Appendix I: Confusion matrix of the Land-use/land covers classification accuracy assessment**

**Table 1:** Confusion matrix of the Land-use/land cover Classification in year 1998.

LU/LC	Agriculture	Bushland	Grassland	Waterbody	woodland	Total	UA (%)
Agriculture	<b>85</b>	5	7	0	3	100	85
Bushland	3	<b>37</b>	4	0	6	50	74
Grassland	5	3	<b>35</b>	0	2	45	77.8
Waterbody	0	0	0	<b>35</b>	0	35	100
woodland	2	4	3	0	<b>41</b>	50	82
Total	95	49	49	35	52	280	
PA (%)	89.5	75	74.4	100	78.8		

**Table 2:** Confusion matrix of the Land-use/land cover Classification in year 2008.

LU/LC	Agriculture	Bushland	Grassland	Waterbody	woodland	Total	UA (%)
Agriculture	<b>69</b>	1	4	0	2	75	92
Bushland	1	<b>40</b>	2	0	2	45	88.9
Grassland	2	4	<b>27</b>	0	2	35	77.4
Waterbody	0	0	0	<b>25</b>	0	25	100
woodland	0	5	1	0	<b>34</b>	40	85
Total	72	50	34	25	40	220	
PA (%)	95.8	80	79.41	100	85		

**Table 3:** Confusion matrix of the Land-use/land cover Classification in year 2018.

LU/LC	Agriculture	Bushland	Grassland	Waterbody	woodland	Total	UA (%)
Agriculture	<b>89</b>	4	6	0	1	100	89
Bushland	1	<b>57</b>	4	0	3	65	87.7
Grassland	5	43	<b>41</b>	0	1	50	82
Waterbody	0	0	0	<b>40</b>	0	40	100
woodland	0	5	2	0	<b>38</b>	45	84.4
Total	95	69	53	40	43	300	
PA (%)	93.7	82.6	74.4	100	88.4		

**Appendix II: Meteorological data used for Soil erosion modeling  
Abebe Keranso Station**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1999	14.8	23.0	60.0	85.5	94.7	147.2	263.0	222.2	102.7	149.8	0.1	0.0	1163.0
2000	0.0	26.9	19.4	89.5	82.6	181.3	164.2	323.7	120.6	75.3	37.1	47.3	1167.9
2001	15.8	30.7	148.9	45.7	116.8	220.9	265.2	171.7	132.8	51.5	4.2	2.1	1206.3
2002	53.1	44.5	88.4	44.2	22.7	128.7	216.3	234.2	84.2	0.0	0.0	47.6	963.9
2003	21.3	26.1	78.1	244.4	29.3	212.2	262.0	189.4	128.3	0.3	3.5	26.2	1221.1
2004	43.8	7.7	58.6	203.2	59.9	188.8	240.2	229.2	159.5	10.4	0.0	3.3	1204.6
2005	63.8	1.9	34.2	81.9	92.3	201.8	220.7	269.0	193.1	7.4	5.3	0.0	1171.4
2006	0.3	47.6	297.1	157.5	89.3	172.8	218.3	237.7	148.4	18.6	0.2	8.5	1396.3
2007	6.9	12.6	41.2	46.7	201.8	265.6	215.8	215.1	108.2	51.6	0.0	0.0	1165.5
2008	0.0	0.0	0.0	32.7	159.1	184.2	275.8	250.4	116.9	56.5	77.2	2.2	1155.0
2010	17.7	143.7	73.5	99.4	113.3	209.5	223.4	191.3	125.0	8.0	11.6	26.7	1243.1
2011	8.3	5.6	57.6	39.1	171.6	195.7	171.0	214.0	81.4	0.0	10.5	18.3	973.0
2012	0.0	0.0	14.7	80.7	17.2	181.9	186.7	236.6	154.4	65.4	9.4	9.8	956.8
2013	2.7	18.0	70.5	86.4	108.9	231.1	247.9	202.0	159.4	130.8	4.2	1.9	1263.8
2014	0.0	31.7	25.7	49.5	200.5	74.8	146.2	202.4	127.7	19.3	10.0	0.7	888.5
2015	0.0	2.1	21.9	95.8	141.6	111.0	155.2	195.4	172.2	3.7	15.8	10.2	924.8
2016	32.2	10.7	47.7	142	96.9	147.2	163.1	188.3	144.85	19.865	0	10	1002.8
2017	0	31.3	59.9	85.5	94.7	147.2	171	191.825	117.5	36.03	9.4	9.8	954.2

**Ambo Agriculture Station**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1987	1.5	38.1	47.8	119.8	185.4	129.1	211.1	188.0	93.0	13.6	8.53	6.23	1042.2
1988	9.5	232.6	8.5	31.5	35.6	136.5	213.5	169.0	171.6	32.7	0.0	24.5	1065.4
1989	17.5	173.7	43.4	25.5	52.9	143.8	219.2	171.7	134.5	51.8	0.0	42.7	1076.6
1990	20.0	114.7	78.2	19.5	89.2	185.1	315.9	197.1	94.8	3.3	0.0	24.5	1142.3
1991	12.6	58.7	52.4	100.7	105.2	181.7	292.2	206.3	108.1	14.2	0.0	6.23	1138.2
1993	0.0	35.6	10.5	181.9	121.2	178.3	268.5	215.4	121.3	25.1	0.0	0.0	1157.8
1997	28.7	0.0	31.0	83.1	59.7	132.0	206.2	183.4	59.2	29.1	22.1	2.2	836.6
1998	74.3	10.4	40.6	30.7	79.5	120.2	143.8	158.2	77.6	74.5	11.7	0.0	821.3
1999	8.4	0.1	39.5	20.1	99.2	108.4	195.9	132.9	95.9	119.9	1.3	0.0	821.6
2000	0.0	0.0	9.3	51.5	93.7	121.2	186.4	191.6	131.2	83.7	20.7	14.8	904.1
2001	0.0	12.5	60.5	70.4	177.9	148.5	197.9	243.1	110.5	41.8	5.4	11.0	1079.5
2002	78.7	16.9	55.6	56.3	39.5	178.0	166.1	192.9	40.3	25.6	0.0	17.2	867.0
2003	41.7	100.0	54.8	154.1	9.4	209.0	134.2	142.7	89.6	9.3	1.0	0.0	945.8
2004	39.2	16.6	70.8	108.7	26.8	137.1	203.6	215.0	138.9	19.0	0.0	8.9	984.6
2005	25.2	0.0	86.8	47.5	58.1	166.3	158.0	187.1	98.4	19.0	10.2	0.0	856.6
2006	0.0	4.7	150.7	72.3	157.7	109.9	195.3	298.6	76.5	17.9	18.8	0.0	1102.4
2007	49.3	54.3	40.2	38.9	131.6	275.2	232.6	218.3	111.7	11.0	0.0	0.0	1163.1
2008	0.0	0.0	1.0	18.7	157.3	161.8	308.0	260.2	84.0	64.8	101.8	2.7	1160.3
2009	26.9	23.1	28.7	61.2	47.5	96.4	285.7	271.9	65.3	56.1	1.7	41.9	1006.4
2010	22.4	48.4	76.3	33.5	126.7	166.4	315.7	235.1	116.0	0.0	22.6	21.0	1184.1
2011	17.5	7.0	90.0	120.0	185.8	358.7	456.4	387.1	144.5	0.0	0.0	0.0	1767.0
2012	8.8	0.0	75.8	56.5	152.8	142.5	276.8	167.6	173.0	53.2	0.0	18.0	1124.9
2013	0.0	3.9	18.6	88.0	119.8	158.8	226.3	172.3	73.4	94.9	4.0	0.0	960.0
2014	2.8	18.2	61.5	44.8	202.9	138.8	130.1	134.2	91.3	28.2	8.9	4.4	866.1
2015	4.3	23.7	40.1	74.6	150.0	166.7	184.7	166.7	103.9	0.0	4.5	4.5	923.6
2016	37	29.1	21.1	104.4	97.1	113.7	185.7	156.4	98.455	14.54	0	4.5	862.0
2017	0	37.9	46.14074	67.2	102.3	143.8	211.06	188	93.01	29.08	8.53	6.23	933.3

**Asgori Station**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1987	0.0	26.8	130.3	135.4	140.4	100.2	156.8	251.9	42.0	4.2	0.0	2.7	988.0
1988	3.6	45.5	2.0	112.8	8.9	75.4	293.3	256.5	177.4	15.7	0.0	0.0	991.1
1989	1.7	77.6	87.4	66.7	8.2	113.9	239.2	200.2	114.9	11.0	0.0	5.1	920.8
1990	0.0	51.3	36.7	116.4	17.4	173.1	348.3	307.2	88.5	25.2	0.0	3.6	1164.1
1991	1.6	24.9	63.7	4.8	45.1	213.6	253.1	345.6	115.7	3.5	0.0	2.1	1071.6
1992	53.5	54.9	19.7	77.7	59.0	135.5	308.5	329.9	114.5	70.8	0.0	0.8	1224.0
1993	26.3	150.0	0.0	210.6	80.9	99.5	291.8	299.5	78.6	13.9	0.0	4.7	1251.1
1994	0.0	0.0	60.8	88.4	90.4	162.3	290.1	294.8	168.8	0.0	14.3	0.0	1169.9
1995	0.0	27.2	56.8	149.3	66.7	121.8	232.3	277.4	145.1	4.5	0.0	30.2	1081.1
1996	82.4	0.0	133.2	108.7	117.0	189.4	218.2	353.1	186.4	10.9	9.7	0.0	1409.0
1997	16.0	0.0	41.3	81.5	43.6	129.3	180.1	178.8	60.8	64.5	52.8	0.0	848.7
1998	69.2	70.4	31.2	80.8	79.7	166.5	315.4	312.6	51.6	20.4	0.0	0.0	1197.8
1999	3.5	0.0	69.2	8.9	66.0	137.2	254.8	199.1	130.6	59.1	0.0	0.0	928.4
2000	0.0	0.0	0.0	15.9	63.2	111.6	238.1	167.9	143.6	1.4	8.3	0.0	750.0
2001	1.4	12.5	103.4	22.8	127.9	183.9	253.8	128.3	55.8	5.8	0.0	0.0	895.6
2002	27.7	41.4	48.1	41.0	52.2	97.3	258.4	252.7	93.4	0.0	0.0	20.7	912.2
2003	45.1	24.5	65.2	119.8	43.9	169.6	264.8	272.0	107.9	2.0	1.3	10.5	1116.1
2004	30.8	4.5	44.6	172.0	24.6	151.8	183.6	173.8	74.3	57.1	0.0	0.0	917.1
2005	28.9	2.4	77.2	57.9	140.8	149.0	164.2	146.8	123.2	10.5	0.0	0.0	900.9
2006	0.2	11.5	59.0	66.6	100.5	135.0	193.1	181.9	79.1	2.7	0.0	1.2	829.5
2007	8.7	5.8	40.7	75.3	60.2	121.0	222.0	217.0	76.6	12.7	0.0		
2008	19.9	0.0	0.9	60.9	103.2	140.3	283.2	190.2	74.0	22.6	65.0	0.0	960.2
2009	31.1	1.5	1.0	26.2	80.4	149.3	278.0	170.3	86.3	14.3	35.2	2.7	873.5
2010	23.0	89.2	91.6	104.4	57.6	158.3	272.8	150.3	98.6	14.3	5.3	1.3	1065.4
2011	14.8	44.6	46.4	82.6	49.6	146.5	242.1	190.3	91.1	14.3	5.3	0.7	927.5
2012	0.0	0.0	1.2	60.7	41.5	134.7	211.3	230.3	83.6	14.3	5.3	2.7	782.9
2013	2.7	0.0	19.6	59.1	80.0	117.9	212.4	218.0	139.7	11.5	5.3	0.0	866.0
2014	0.0	54.2	38.0	57.4	118.4	101.0	213.5	205.6	195.8	8.7	2.9	0.0	995.5
2015	16.9	31.0	11.7	0.8	89.3	111.0	196.3	226.7	110.9	0.4	0.0	2.7	794.9
2016	33.7	7.7	40.7	134.1	60.2	121	222	182.3	70.6	0.7	3.9	1.3	876.9

**Busa Station**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1987	6.0	46.4	133.3	39.8	81.1	77.1	160.6	140.9	30.7	0.0	0.0	0.0	715.9
1988	8.8	21.0	18.3	44.8	20.8	122.8	213.6	170.4	160.2	8.4	0.0	0.0	789.1
1989	5.6	67.0	86.6	79.2	49.6	101.2	191.1	194.7	57.5	23.2	0.0	17.4	873.1
1990	0.0	76.2	83.9	53.8	95.4	186.3	344.5	132.3	52.8	4.3	0.0	0.0	1029.5
1991	10.0	44.4	26.4	3.6	40.8	167.3	281.2	359.6	33.0	0.0	0.0	21.6	987.9
1992	36.5	116.2	41.0	66.1	36.8	140.6	359.5	559.4	98.2	45.7	0.0	0.8	1500.8
1993	2.8	61.6	35.1	292.2	225.9	150.9	212.8	296.0	172.3	29.9	0.0	0.0	1479.5
1994	0.0	0.0	29.2	57.9	33.2	249.8	466.7	251.8	103.6	6.4	21.2	0.0	1219.8
1995	0.0	35.4	42.6	97.8	143.6	135.6	220.8	337.1	37.9	4.4	0.0	31.6	1086.8
1996	17.2	0.0	77.7	161.4	320.1	406.5	437.3	422.4	476.0	39.6	19.3	6.9	2384.4
1997	51.2	0.0	47.1	14.0	19.6	238.6	399.7	540.9	77.9	24.7	66.1	5.4	1485.2
1998	5.4	76.4	16.4	29.5	177.4	217.3	371.8	493.8	88.5	30.0	0.0	0.0	1506.5
1999	8.4	0.0	25.8	0.0	109.2	237.1	567.2	362.1	306.2	75.1	0.0	0.0	1691.1
2000	10.2	0.0	10.3	44.5	21.0	151.2	337.6	522.2	182.9	28.3	25.2	32.0	1365.4
2001	12.0	3.9	0.0	41.4	74.7	150.7	566.7	632.8	45.8	0.8	6.8	0.0	1535.6
2002	25.3	11.0	25.0	89.4	43.2	315.6	432.3	449.8	134.1	0.0	0.0	38.2	1563.9
2003	37.1	18.8	35.6	152.0	50.9	254.9	278.4	517.8	221.0	3.3	16.0	0.0	1585.7
2004	48.9	26.6	46.1	214.5	60.8	139.6	390.1	298.8	63.3	29.3	5.6	3.7	1327.3
2005	42.4	0.0	81.6	32.2	19.9	109.6	494.8	427.7	137.2	6.1	4.4	0.0	1355.9
2006	0.1	4.7	131.6	225.9	109.0	223.3	457.8	524.6	65.7	48.0	0.0	1.4	1792.1
2007	7.8	16.8	54.6	65.6	335.0	381.9	309.9	521.1	72.0	15.5	0.0	0.0	1780.2
2010	21.8	88.2	45.1	61.9	167.5	209.7	239.6	338.6	89.9	16.4	3.0	1.5	1283.0
2011	29.5	4.9	35.5	0.0	0.0	219.0	169.2	156.1	107.7	17.3	5.9	2.9	748.0
2012	0.0	0.0	40.3	116.7	26.7	220.0	227.8	173.1	131.1	0.0	5.9	5.7	947.2
2013	0.0	23.6	45.0	78.1	58.7	108.9	250.3	190.0	95.7	50.7	0.0	5.7	906.7
2014	0.0	47.2	55.4	39.4	90.7	100.3	159.8	207.1	67.7	10.2	0.0	5.7	783.5
2015	6.9	36.9	44.0	57.3	88.4	139.7	232.4	268.2	105.2	0.0	0.0	0.0	979.0
2016	13.8	26.6	32.6	75.1	86.1	179.1	305	329.3	107.7	17.3	5.9	5.7	1184.2

**Darian Station**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1989	37.6	33.6	79.6	108.9	155.3	248.8	209.4	294.5	140.7	32.3	0.0	46.0	1386.7
1990	30.3	143.9	81.5	83.7	120.5	177.8	273.7	317.9	147.1	3.4	0.0	0.0	1379.8
1991	56.9	24.7	129.6	4.9	84.1	180.0	238.9	215.5	111.6	0.0	0.0	24.2	1070.4
1992	83.5	122.3	71.4	0.0	54.3	188.0	252.0	379.7	252.6	65.9	20.6	0.6	1490.9
1993	19.5	66.4	13.6	203.2	206.4	294.2	206.0	323.9	216.3	127.4	0.0	0.0	1676.9
1994	0.0	0.0	87.3	97.1	141.1	254.4	317.2	595.1	274.7	0.0	5.8	0.0	1772.7
1995	69.0	30.8	55.0	353.5	157.4	214.6	428.3	352.0	82.6	35.4	8.2	37.3	1824.1
1996	138.0	0.0	173.1	84.8	124.9	231.0	474.5	413.2	133.6	9.6	16.0	0.0	1798.7
1997	35.3	0.0	78.4	121.3	151.0	305.2	239.0	225.9	104.2	45.2	61.6	0.0	1367.1
1998	107.6	75.7	84.3	106.0	138.6	255.8	287.2	309.6	73.0	76.7	0.0	0.0	1514.5
1999	9.3	24.3	22.1	46.6	126.4	225.5	375.5	272.7	281.8	288.0	0.0	0.0	1672.2
2000	0.0	0.0	54.8	169.9	223.0	162.1	224.3	324.0	272.9	52.6	36.3	9.6	1529.5
2001	0.0	8.9	140.8	63.5	266.7	421.9	469.6	358.8	162.7	63.8	27.8	0.0	1984.5
2002	56.0	82.8	368.4	25.1	140.3	217.4	288.1	209.3	132.5	2.4	0.0	37.4	1559.7
2003	27.7	62.0	80.0	146.2	86.7	214.7	267.0	465.0	202.4	8.3	18.2	35.8	1614.0
2004	141.6	38.8	86.5	159.5	109.0	297.0	434.2	441.2	94.5	56.2	6.4	2.4	1867.3
2005	96.6	2.0	110.1	195.9	187.6	195.0	158.6	133.7	135.3	43.9	19.4	0.0	1278.1
2006	2.0	35.0	199.0	121.3	92.2	291.0	388.1	503.2	199.1	24.8	6.3	2.1	1864.1
2007	16.4	61.0	60.0	150.6	194.8	244.9	423.4	302.8	270.6	24.7	0.0	0.0	1749.2
2008	0.0	1.2	30.5	62.1	168.6	254.1	244.0	274.2	98.8	83.6	68.6	0.0	1285.7
2010	50.0	79.5	9.5	114.7	190.5	205.0	275.5	433.8	101.4	0.0	45.3	32.6	1537.8
2011	28.2	39.8	15.7	34.9	181.1	259.5	341.7	149.3	121.0	19.4	27.2	20.6	1238.3
2012	0.0	0.0	0.0	154.9	206.3	227.0	297.6	180.5	140.6	38.7	9.0	8.6	1263.2
2013	0.0	0.0	125.3	171.2	226.1	231.7	253.5	211.7	147.9	0.0	12.8	4.3	1384.5
2014	6.4	5.9	5.3	27.5	141.6	153.3	361.2	273.0	155.1	0.0	9.0	0.0	1138.3
2015	15.8	3.0	24.1	18.7	205.0	155.8	355.3	198.1	49.8	0.0	5.1	5.6	1036.1
2016	25.1	0	42.9	222.5	268.3	158.2	358.25	235.55	102.45	38.7	12.8	8.6	1473.4

**Dertu Lebu Stetion**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1987	0.0	22.0	98.8	137.3	147.5	80.4	89.3	194.7	45.0	13.5	0.0	0.0	828.5
1988	7.0	40.8	7.8	130.5	13.7	156.5	254.9	189.8	186.8	24.5	0.0	0.0	1012.3
1989	1.0	30.3	70.1	144.2	2.3	77.7	159.9	199.6	140.9	46.5	0.0	0.0	872.5
1990	0.0	225.5	60.1	157.8	15.7	53.1	219.9	169.2	107.1	0.0	0.0	0.0	1008.4
1991	0.0	123.9	48.3	108.7	13.3	70.9	212.7	179.8	111.5	15.3	1.2	0.3	885.7
1992	1.2	22.2	36.4	59.6	10.9	88.6	205.5	190.4	115.9	30.6	2.3	0.6	764.2
1993	2.4	38.6	5.7	105.0	37.6	88.2	191.1	162.5	142.3	23.6	0.0	0.0	797.0
1994	0.0	0.0	34.8	27.3	29.5	85.2	186.9	129.0	127.7	0.0	23.1	0.0	643.5
1995	0.0	28.0	65.7	48.9	30.0	67.6	240.3	169.9	48.9	0.0	0.0	82.1	781.4
1996	9.8	0.0	42.8	99.9	133.3	247.9	184.2	286.7	119.8	0.0	13.4	3.2	1141.0
1997	27.0	0.0	19.8	105.7	12.2	118.5	246.6	158.8	53.6	77.6	4.2	0.0	824.0
1998	22.4	69.6	1.6	48.0	96.5	56.8	265.1	280.5	118.9	112.8	0.0	0.0	1072.2
1999	0.0	0.0	12.1	6.1	59.3	109.9	208.6	273.8	79.5	150.8	0.0	0.0	900.1
2000	0.0	0.0	22.6	46.2	22.0	67.4	250.3	189.4	84.5	21.8	20.9	1.7	726.8
2001	0.0	6.8	116.9	20.3	113.4	80.2	226.1	176.1	97.5	9.0	0.0	0.0	846.3
2002	38.8	0.0	26.7	11.6	39.0	105.0	144.3	159.3	33.0	0.0	0.0	13.7	571.4
2003	25.2	44.8	66.5	149.0	19.5	107.2	310.4	175.5	36.7	0.0	0.0	63.4	998.2
2004	49.0	0.0	16.6	112.2	3.4	65.8	135.4	101.1	42.5	5.3	5.6	0.0	536.9
2005	62.9	0.0	79.7	94.9	72.1	97.7	256.2	57.6	125.8	3.0	3.6	0.0	853.5
2006	1.4	64.1	98.1	139.4	35.0	152.9	260.4	122.3	65.8	30.1	0.0	4.9	974.4
2007	41.0	6.1	54.0	24.8	65.5	75.8	302.1	188.0	136.9	23.8	0.0	0.0	918.0
2008	0.0	0.0	0.0	34.7	48.1	55.6	148.0	209.8	89.1	17.4	44.2	0.0	646.9
2010	0.0	75.4	60.4	87.2	0.0	0.0	60.0	135.6	92.9	0.0	0.0	0.0	511.5
2011	0.0	0.0	74.5	47.1	17.2	50.2	131.8	166.1	94.6	0.0	7.6	0.0	589.1
2012	0.0	0.0	0.0	23.8	34.4	70.6	110.6	105.4	53.2	0.0	3.8	0.0	401.8
2013	5.3	0.0	16.1	63.5	50.1	140.0	90.8	43.7	11.8	0.0	0.0	0.0	421.3
2014	0.0	20.9	54.7	30.9	40.4	93.3	93.3	232.1	135.2	17.5	0.0	0.0	718.3
2015	0.0	0.0	10.3	0.0	62.9	110.9	92.2	44.4	12.1	0.0	0.0	0.0	332.8
2015	34.7	5.5	7.5	29.5	52.7	110.9	92.2	49.2	26.0	4.7	0.0	0.0	412.8
2016	69.3	11	4.7	59	42.5	54	56.7	53.9	39.9	9.3	0	0	400.3
2017	0	22.2	36.4	59.6	47.6	82.45	74.45	51.525	32.95	6.975	0	0	414.2

**Addis Ababa University**  
**School of Earth Sciences**

**ANNEX 1: FORMAT FOR THESIS ORIGINALITY TEST REPORT**

Name of student	HABTAMU ATOMA FEDA
ID No	GSR/6769/09
Stream	Remote sensing and Geo-informatics
Thesis title	Assessment of Soil Erosion by RUSLE Model Using Remote sensing and GIS Techniques: A Case Study of Huluka Watershed, Central Ethiopia
Online site used for originality test	<a href="http://www.paperrater.com/plagiarism_checker">http://www.paperrater.com/plagiarism_checker</a>

No	particulars	Test I		Test II		Test II		Test IV		Test V		Average	Remark
		Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)	Originality (%)	Plagiarism (%)		
1	Abstract	100	-	-	-	-	-	-	-	-	-	100	
2	Introduction	100	-	100	-	100	-	-	-	-	-	100	
3	Literature review	91	9	99	1	100	-	100	-	100	-	98	
4	Methodology	100	-	100	-	100	-	100	-	100	-	100	
5	Results	100	-	100	-	-	-	-	-	-	-	100	
6	Discussion	100	-	-	-	-	-	-	-	-	-	100	
7	Conclusion	100	-	-	-	-	-	-	-	-	-	100	
	Overall Thesis											99.7	

	Name	Signature
Student	Habtamu Atoma Feda	
Advisor (1)	Dr. K. V. Suryabahagavan	
Advisor (2)	Prof. M. Balakrishnan	

## DECLARATION

I the undersigned declare that this thesis is my original work and has not been presented for a Degree in any other university and that all sources of materials used for the thesis have been duly acknowledged.

Habtamu Atoma Feda

Signature \_\_\_\_\_ Date \_\_\_\_\_

School of Earth Science

May, 2018

This thesis has been submitted for examination with my approval as university advisor.

Advisor:

Dr. K. V. Suryabahagavan

Signature \_\_\_\_\_ Date \_\_\_\_\_

Co-Advisor

Prof. M. Balakrishnan

Signature \_\_\_\_\_ Date \_\_\_\_\_