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

Assessing the Impact of Watershed Development Programs on Soil Erosion and Biomass Production Using Remote Sensing and GIS: The Case of Yezat Watershed, West Gojam Zone of Amhara Region, 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
Lemlem Tadesse Hishe
ID. No: GSR/0566/07

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Co-advisor: Dr. Sridhar Gummadi

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Abstract

Environmental problems are alarming all over the world. Land degradation, environmental and social problems associated with its use, calls for adopting appropriate policy measures and practical actions for the best land management practices. Integrated Watershed Development Program (IWSDP) was implemented for reducing soil erosion, improving water resources and reestablishing vegetation under the Sustainable land management (SLM) program. Consequently, this study was conducted in Yezat watershed with the objective of determining the trends and changes of soil erosion, vegetation cover and land-use/land-cover(LULC) that has changed during pre and post treatment periods (2001−2010 to 2010−2015) and evaluating the impact of watershed development program using remote sensing and Geographical information system(GIS) approach. The study was carried out time series satellite imageries (Landsat ETM+ 2001, TM 2010, and OLI 2015) together with other ancillary data covering the watershed. The satellite image was classified into different land-use/land-cover categories using supervised classification by maximum likelihood algorithm. They were also classified into different biomass levels using Normalized Difference Vegetation Index (NDVI) analysis. Revised Universal Soil Loss Equation (RUSLE) modeling is applied in a GIS environment to quantify the potential soil erosion risk. The modeling is carried out for the years 2001, 2010, and 2015, and is based on Landsat satellite imageries, rainfall, soil and DEM data. The results reveal significant modification and conversion of land-use/land-cover of the watershed. A significant portion of the watershed was continuously under intensively grass land, wood land and homesteads. The area covered with grassland, woodland and homesteads were increased by 610.69 ha (4%), 101.69 ha (0.67%) and 126.6 ha (0.83%) while cultivated land and shrub/bush land where decreased by 323.43(0.02%) and 515.44ha (3.41%), respectively during post treatment period (2010−2015). The estimated woody biomass considerably decreased during the period 2001−2010 (pre treatment) while in 2010 −2015 (post treatment), significant increase in the woody biomass area was observed. Based on the result, vegetation cover was decreased during pre treatment periods (2001−2010) which account for 91.1% of the land area. From 2010 −2015 (post-treatment) period, 88% of the land area was changed to increasing trend. The increasing of NDVI indicates better ground cover vegetation condition. The result derived from the estimated annual soil loss rate has shown the mean annual soil losses are 7.2 tons ha^{-1} yr^{-1} in 2001, 7.7 tons $ha^{-1}yr^{-1}$in 2010 and 4.8 tons $ha^{-1}yr^{-1}$in 2015. The study further shows that IWSDP decreased soil erosion, reduced sedimentation and run off, and rehabilitation of degraded lands. This study reconfirms the importance of IWSDP as a key to improve the status and utilization of watershed resources in response to sustainable land management interventions and sustainable livelihood. Thus, remotely sensed data using advanced techniques such as remote sensing and Geographic information system (GIS) can be useful to guide decision making process in evaluating the impact of IWDP on trends of soil erosion and biomass production.

Keywords: Biomass, watershed, GIS, NDVI, LULC, Remote Sensing, RUSLE, Soil erosion

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Table of Contents

List of Figures

List of Tables

List of Appendices

List of Abbreviations and Acronyms

DEM	Digital Elevation Model
ENVI	Environment for Visualizing Image
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced thematic mapper Plus
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GPS	Global Positioning System
Ha^{-1}	Per hectare
IWSDP	Integrated Watershed Development Programme
LS	Slope Length and Slope Steepness
LULC	Land-use/land-cover
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
MoWR	Ministry of Water Resources
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-Red
NMA	National Meteorological Agency
OLI	Operational Land imagery
RGB	Red, Green, Blue
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SLM	Sustainable Land Management
SLMP	Sustainable Land Management
SRTM	Shuttle Radar Topographic Mission
T/ha/yr	tons per hectare per year
TM	Thematic Mapper
TIFF	Tagged Image File Format
USGS	United State Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER I

INTRODUCTION

1.1 Background of the study

An environmental problem is alarming humanity all over the world. Its effects on ecosystem services challenge conservation, management and rehabilitation activities a matter of life and death. Land degradation and associated decline in the productive potential of agricultural lands are threatening economic and social well-being of the present and future generations. Land degradation is one of the major and widespread environmental threats that the planet earth has faced in the past and present years (Xu *et al.,* 2012). Soil erosion is one of the most serious environmental problems in the world today, which threatens agricultural and natural environments (Krishna, 2009). In order to meet their livelihoods, to address economic stress and to accelerate development, people in the developing countries utilize land and soil resources in an unsustainable way as evidenced by overgrazing, destruction of forest for urban expansion and high intensive and unscientific agricultural activities, improper land-use/land-cover changes (De Meyer *et al.,* 2011). In the recent past, soil erosion has become sever, which negatively affects the soil quality, decreasing agricultural efficiency, declining water quality, flooding, debris flow and habitat destruction (Park *et al.,* 2011).

According to Hurni (1985), degradation and loss of soil resulting from soil erosion was estimated to be about 20 tons per hectare. Ethiopia loses about 1.9 billion metric tons of fertile soil from the highlands every year and the degradation of land through soil erosion is increasing at a high rate (Hurni, 1989). Similarly, as reported by Ethiopian Highlands Reclamation Study (FAO, 1986), soil erosion had been forecasted to cost the country 1.9 billion USD between 1985 and 2010. According to Phillips (1989, as cited in Maria *et al*., 2009), the off-site effects of erosion such as reservoir sedimentation and water resources pollution are commonly more costly and severe than the on-site effects on land resources. Therefore, proper management of land and water resources could reduce the risks and negative impacts from erosion on-site and also downstream. Ethiopia is one of the most vulnerable countries facing severe environmental degradation. The ever increasing demand of land for food production from the rapidly growing population led to the loss of nearly 97 percent of Ethiopia's native forests, which resulted in rapid degradation of the soil and water resources. The soil degradation is felt through reduction of soil depth resulting in low capacity of soil to hold moisture and through loss of organic matter leading to soil fertility loss (Fitsum *et al.*, 1999).

Amhara region, in Ethiopia, is the region having diversified agro-climatic zones, topography, agricultural potential and natural resources. Extreme exploration of these resources through time, created a serious problem of land degradation. In spite of substantial progress in watershed management in the region, land degradation and unsustainable natural resource base is still continuing. Sustainable natural resource is essential for conserving water, land and biodiversity, enhancing local livelihoods, improving the economy of highland inhabitants and people living in downstream areas.

Land degradation, environmental and social problems associated with its use, calls for adopting appropriate policy measures and practical actions for the best land management practices. In the recent years, Government of Ethiopia started to pay attention to sustainable agriculture and development. As a result, many environmental and land degradation assessment policies are declared, which point out that soil erosion and land degradation in the highlands areas are increasingly regarded more serious than in other ecosystems. For example, one of the major reasons for this is the irregular terrain and topography in the highland areas, which means that the slope diversity and heterogeneity are significant factors for the intensity of soil erosion and conversion of the land-cover, which has negative impacts on the environment, especially replacement of forest area by agriculture fields.

1.2 Problem statement and justification of the Study

Understanding the implication of the past, present and future patterns of land-use for biodiversity and ecosystem function is increasingly important in landscape ecology (Turner *et al*., 2003). The alarming rates of land degradation, with which land management interventions are advancing and changes faced for having in place sustainable development in natural resources management entail that there is a need for sound strategies to be developed. Natural resource conservation and sustainable utilization is among the top priority development agendas of the Government of Ethiopia. Over the past two decades, Ethiopia has made concerted efforts to arrest land degradation and rehabilitate degraded lands under the flagship program Sustainable Land Management (SLM). The promoted erosion control interventions include construction of physical and biological structures such as cut-off drains and waterways to manage run-off, farm and community ponds to harvest and store runoff water and area enclosures to allow natural regeneration. Even though these interventions have resulted in improving the productive potential of land and water resources, monitoring and evaluation activities have been very limited and therefore it is very difficult to quantify and asses the changes, which have taken place not only in natural resources, but also in livelihoods of people due to these programmes. The need therefore arises to identify a quick and cost effective technique to monitor and to evaluate the impacts of such schemes before project – after project temporal scale as well as during project implementation stage.

The implementation has been based on integrated watershed development approach that contributes to creation of dynamic up-scaling process of proven SLM technologies and systems by introducing them into different agro-ecologies and livelihood systems since 2009/2010. Yezat watershed is one of the selected areas to implement SLM program starting from 2010 implementing by Ministry of Agriculture (MoA).

Since 2010, significant efforts were made to restore the watershed health under the SLM program. These efforts have helped in reducing erosion, improving water resources and reestablishing vegetation. These assessments were based on the field surveys by the watershed staff and were limited to areas treated with interventions. A comprehensive assessment of impacts of watershed management on the overall health and resilience of the entire watershed is very limited. On the other hand, there are land-use/land-cover changes in the study area so using this and related factors, the status and utilization of the watershed resources should be identified i.e. weather it is treated or not, in different development stages. Besides, the amount of soil erosion and vegetation covers could not be the same at different development stages. Therefore, this study is aimed at bridging this gap by developing an approach to assess the temporal changes in the watershed resources as multi-temporal change detection technique using remote sensing and Geographic Information Systems (GIS), which are powerful tools to quantify temporal changes in ecosystems.

1.3 Objective of the study

1.3.1 General objective

The main objective of this study was to assess the spatiotemporal changes in the status and utilization of watershed resources in response to sustainable land management interventions using remote sensing and Geographic Information Systems (GIS).

1.3.2 Specific objective

The specific objectives of this research are as listed below

- To assess temporal changes in land-use/land-cover that occurred between pre-treatment and post-treatment of the watershed.
- To estimate woody biomass productivity of the watershed area using remotely sensed data, ground truth and topographic maps.
- To adopt and apply RUSLE model for soil erosion assessment using remote sensing and GIS techniques.
- To analyze the trends and changes in soil erosion and vegetation covers in relation to land conservation and productivity enhancing practices promoted.

1.4 Scope of the study

The present study mainly deals with the assessment of temporal changes in the status of watershed and analyzes the trends and changes in soil erosion, vegetation covers and land-use/land-cover in relation to land conservation.

1.5 Significance of the study

The use of satellite data using advanced techniques such as remote sensing and Geographic information system (GIS) can assist for impact assessment of watershed development program on the spatiotemporal trends and changes of soil erosion and biomass production. Understanding the impacts of watershed development program on trends and changes of soil erosion, vegetation and land-use/land-cover change is an essential indicator for resource base analysis and development of effective and appropriate response strategies for sustainable land management. Thus, outputs produced from this study can be useful for assist policy analysis and decision making related to the sustainable development and management of the watershed resources. Moreover, it may be helpful for researchers to provide a scientific basis for understanding sustainability-related problems and solution options in the agricultural production systems. The methods and approaches developed will have wider application within and outside the country.

1.6 Organization of the thesis

This thesis is organized into five chapters: chapter one is introduction, where the background, statement of the problem, objectives of the study, research questions and significance of the study a discussed. In chapter two, review of related literatures is presented. Chapter three provides necessary background information about the study area in terms of location, topography, climate, soil, vegetation cover and land-use of the studied watershed. This section also elaborates the source of the data and software used and methodologies applied to achieve the desired objectives with details of the data sources and relevant parameters. In the fourth chapter, results are provided. In the fifth chapter interpretation and discussion of the results of the research from land-use/land-cover classification, woody biomass estimation, assessment of vegetation status using Normalized Difference Vegetation Index (NDVI) index and soil erosion modeling are given. Finally, in section; six, conclusions, recommendations and suggestions for further research work in the study area are provided.

1.7 Limitation of the study

The limitation of the study was lack of time series satellite data. Due to lack of the satellite data and cloud cover, the time series study was only carried out for three target years, 2001, 2010 and 2015. This research study is also limited on using high resolution satellite data for producing a more realistic estimated woody biomass of the past years.

CHAPTER II

LITERATURE REVIEW

2.1 Land degradation

Land degradation has already been treated as one of the most serious problems all over the world. As one of the most important basic natural resources relate to almost all human activities directly or indirectly, land and soil are crucial for sustaining livelihoods in many Sub Saharan African (SSA) countries. Rational utilization of the land and soil resource have been treated as the key factor in the development of many SSA countries. However, land degradation is one of the major and widespread environmental threats in the developing tropical nations (Xu *et al*., 2012).

Among the several land degradation process as, such as soil compactness, soil salinitation, soil acidity, and soil erosion, soil erosion directly affects environment and food production. Mitiku *et al*., (2006) defined soil erosion as the wearing away of the land surface by physical forces such as rainfall, flowing water , wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove surface soil or geological materials from one point on the earth surface to be deposited elsewhere. Water and wind are the main agents responsible for soil erosion. Sedimentation and soil erosion includes the processes of detachment, transportation and deposition of solid particles or sediments. The forms of water responsible for soil erosion are raindrops, runoff and flowing water (Wischmeier and Smith, 1978).

2.1.1 Soil erosion by water

Soil erosion by water can be described in two stages; detachment and transportation of sediments. The detachment of soil particles is due to raindrop impact, caused by its kinetic energy. Soil particle detachment is also caused by the scouring effect of over land runoff. The other is soil particles by water that caused by buoyancy of particles and turbulence of water. Soil erosion by water occurs in various forms (splash, sheet, rill, gullies) depending on the stage of progress in the erosion cycle and the position in the landscape.

Accelerated soil erosion by water can be divided in to the following categories:

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 through the ground (Van der Knijff *et al.,* 2000). 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.

Sheet Erosion occurs as a shallow 'sheet' of water flowing over the ground surface, resulting in the removal of a uniform layer of soil from the soil surface. (Van der Knijff *et al.,* 2000). The result of this action is detachment and transportation of the detached sediment by runoff. On slope areas, sheet wash can takes place to remove shallow layer of soil.

Rill Erosion is the removal of soil where small linear channels are formed due to concentrated runoff. This type of water erosion can occur during or suddenly after rainfall. Rills occur mostly on bare surfaces on sloping areas, they can be eliminated by tillage operation.

Gully erosion is developed by scouring effect of concentrated overland flow causing deeply incised channels. Sometimes they are initiated after surface collapse from piping. Definition of gullies is limited by 30 mm minimum depth. They can take place during or suddenly after heavy rainfall. Gullies bottom may have also continuous flow at gullies bottom due to seepage water.

2.1.2 Impacts of soil erosion by water

Soil erosion has been a problem ever since land was first cultivated. The consequence of soil erosion occurs both on-site and off-site. In Ethiopia, on-site impacts of soil erosion are most frequently studied, typically by estimating the productivity losses as economic cost of soil erosion. Less well known and documented are the off-site costs of soil erosion (May and Place 2005). Off-site effects are those which occur when runoff and sediments from one field, watershed or waterway enters to another. These downstream effects reduce the capacity of river and drainage ditches, enhance the hazard of flooding, blocking irrigation canals and shorten the designed life of reservoirs. Lal (1998, as cited in Israel, 2011) classified the off-site effects of soil erosion into three categories: (i) damage to present and future crop growth, (ii) adverse change in environment; and (iii) damage to civil structure.

2.1.3 Factors Affecting Soil Erosion by Water

The major factors affecting soil erosion are climate, soil properties, vegetation characteristics and topography (Renard *et al.,* 1997).

2.1.3.1 Climatic Factors

Soil erosion occurs when raindrops act upon the soil particles. Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. Potential ability of rain to cause erosion is known as erosivity (R) factor (Renard *et al.,* 1997). 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).

2.1.3.2 Soil Factors

The susceptibility of soil to erosion agents is generally referred to assoil erodibility (Renard *et al.,* 1997). 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). 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. That is, clay particles are more difficult to detach (low K values) than sand, but clay is more easily transported. The susceptibility of soil to erosion agents is generally referred to as soil erodibility.

2.1.3.3 Topographic Factors

Topographic features that influence erosion is slope length and steepness, shape (including concave, uniform, or convex) and size and shape of the watershed. The slope factors (LS) refer to topographic and/or relief factor. 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.

2.1.3.4 Ground Cover 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 and maintaining the roughness of the soil surface.

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.

2.1.3.5 Conservation Practice Factor

Especially in agricultural areas, conservation practices such as contouring, strip cropping, or terracing, reduce soil losses. For instance, in areas where there is terracing, runoff speed could be reduced with increased infiltration, ultimately resulting in lower soil loss and sediment delivery. The effectiveness of such practices is often analyzed with a support practice factor (P-factor) which is defined as the ratio of soil loss with the practice applied and up- and down slope cultivation (Wischmeier and Smith, 1978; Renard *et al.,* 1997). P-values have been assigned to land use classes using literature values and ranges from 0 to 1 (Kaltenrieder, 2007).

2.2 Watershed

A watershed is a surface area from which runoff which is resulting from rainfall is collected and drained through a common outlet. Most of the time, the term is similar with a drainage basin or catchment area. Hydrologically, it is an area from which the runoff drains through a particular point in the drainage system. It is made up of the natural resources in a basin, especially water, soil, and vegetative factors. Socioeconomically, a watershed includes people, their farming system and interactions with land resources, cropping strategies, social and economic activities and cultural aspects (MoARD, 2005).

2.2.1 Concept of Sustainable Watershed Management

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 disturbance 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). The success of watershed projects is determined by the environmental services offered by the poor people to the rich farmers who live downstream (Kerr, 2002). The term environmental service is defined as the conditions and processes through which ecosystems sustain and fulfill human life, including the provision of food and other goods (Rosegrant, 2002).

2.2.2 Watershed Management Practices in Ethiopia

The Ethiopian government has recognized the serious implications of soil erosion and to mitigate environmental degradation national programs were implemented in the 1970s and 1980s. However, the efforts of these initiatives were inadequate in managing the rapid rate of demographic growth within the country, widespread and increasing land degradation, and high risks of low rainfall and drought. Since the 1980^{s}, the government has supported rural land rehabilitation, aimed to implement natural resource conservation and development programs through watershed development programmes (MoARD, 2005).

Watershed projects in Ethiopia were very few in number. Institutional strengthening was implemented by Food and Agricultural Organization (FAO), which was principally aimed at capacity building of the Ministry of Natural Resources, in the highland regions of the country. The project used the sub-watershed as the planning unit and sought the views of local technicians and members of the farming community to prepare land-use and capability plans for soil and water conservation. This approach was tested at the pilot stage through FAO technical assistance under MoA during 1988 to 1991 (MoARD, 2005). This was the first step in the evolution of the participatory planning approach to watershed development in Ethiopia. By late 1990s, watershed development was considered the focal point for rural development and poverty alleviation.

2.3 Erosion Model

Every soil erosion model tries to simplify and represent the complexity of natural processes. Model building is based on defining the essential factors relating to erosion and soil loss through obtaining from methodology of field observation, measurement, experiment and statistical analysis. With increasing computation power of computers, several models were developed. However, only one model cannot cater and solves diverse problems. This is the reason why many models are available. Users need to understand the concepts behind the models before applying them. Some models are developed for particular conditions that cannot be directly applied to other locations.

Modeling in soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces. Erosion models allow users to ascertain temporal trends, examine spatial variations, identify critical processes and explore the possible impacts of remedial measures and the relative effectiveness of implementation strategies for erosion and sedimentation control (Baigorria and Romero, 2007). The objective of soil erosion models is either predictability or explanatory. Usually, erosion models can be categorized into three groups: conceptual, empirical and physically based models.

1. Conceptual models lie somewhere between empirical and physically based models, and aim at reflecting the physical processes governing the system, but describe them with empirical relationships (Deore, 2005). Conceptual models tend to include a general description of catchment processes, without including the specific details occurring in the complex process interactions. As parameter values are determined through calibration against observed data, conceptual models tend to suffer from problems associated with the identification of the parameter values (Saavedra, 2005).
2. Physically based models are based on an understanding of the physics of the erosion and sediment transport processes (Deore, 2005). 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 hydro meteorological records (Saavedra, 2005). Examples of physically based models are the Morgan-Morgan and Finney (MMF), Water Erosion Prediction Project (WEPP) and the Soil and Water Assessment Tool (SWAT).
3. Empirical models are based primarily on defining important factors through field observation, measurement, experimentation and statistical techniques relating erosion

factors to soil loss (Morgan, 1994). They are particularly useful as a first step in identifying the source of sediments. The Universal Soil Loss Equation (USLE) and its revised version RUSLE are two of the empirical models that have been most widely used and generally accepted by the natural resources community as they are relatively easy to use (Maria *et al.*, 2009).

2.4 Use of remote sensing and GIS in erosion modeling

The advancements in remote sensing and GIS technology provide an effective analytical tool in the modeling of soil erosion, mapping and assessing landscape attributes controlling soil erosion (Krishna, 2009). Remote sensing provides imagery data for identifying and analyzing necessary data layers.

In a GIS environment, it is possible to link data generated from remote sensing with their spatial location (Krishna, 2009). In general, the use of geo-information techniques offer the following advantages in erosion modeling: 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.

Soil erosion is influenced by the spatial heterogeneity in topography, vegetation, soil properties and land-use, among other factors. All too often, however, predictive soil erosion models do not examine the problem in a spatial context. Soil erosion prediction is relevant at a wide range of spatial scales, from the plot scale to the catchment scale, from the regional scale to the continental and global scales. At different scales, different processes tend to become dominant, so that the effective focus of the models also changes. At scales from the single erosion plot to the hill slope catena, for example, the timing and volume of overland flow hydrographs are essential, along with their distribution across rill and inter-rill areas. At the larger scales, topography, soil and vegetation patterns become more important. This is where remote sensing and GIS become valuable tools. Remotely sensed imagery and GIS have a long history in erosion modeling.

Numerous studies have shown the potential of remote sensing in soil erosion mapping (Haboudane *et al.,* 2002; Metternicht and Gonzalez, 2005; Prasannakumar *et al.,* 2012). At the most basic level, estimates of erosion risk can be derived by classifying pixels according to the percentage of bare soil (De Jong, 1994 and Haboudane *et al.,* 2002) improved this scheme by estimating vegetation parameters from Medium Resolution Imaging Spectrometer (MERIS), Landsat-TM and SPOT-4 imagery and combining them with slopes generated from a DEM to produce an erosion rate map. On the other hand, empirical soil erosion models in combination with soil, climate, vegetation and topography information have been implemented using remote sensing (Dwivedi *et al.,* 1997). Classification of Landsat-TM imagery has been used to estimate the crop management factor of the USLE (Millward and Mersey, 1999). Methods using satellite imagery to produce maps of vegetation-related variables for soil erosion studies have been compared by De Jong (1994), and Tateishi *et al.* (2004), who found that the normalized difference vegetation index (NDVI) was the most useful.

Geographical information system is thus an important tool for coping with the vast number of spatial data and the relation between data from various sources in the erosion modeling process. Advantages of linking soil erosion models with a GIS include the following:

- The possibility of rapidly processing input data to simulate different scenarios. A

GIS provides an important spatial and analytical function, performing the time consuming georeferencing and spatial overlays to develop the model input data at various spatial scales (Zhang *et al.,* 2002; Shi *et al.,* 2004).

- The ability to look at spatial variation; thus areas can be simulated at a user-defined resolution (Qinke *et al.,* 2002; Renschler and Flanagan, 2003).
- The facility of displaying the model outputs (i.e., visualization). Visualization can be used to display and animate a sequence of model output across time and space. Therefore, visualization enables objects to be viewed from all external perspectives, and suggests insight into the data.

2.4.1 Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is calculated as a ratio between measured reflectivity in the red and near infrared portions of the electromagnetic spectrum. These two spectral bands are affected by the absorption of chlorophyll in leafy green vegetation and by the density of green vegetation on the surface. Furthermore, in these two bands the difference between soil and vegetation is at maximum (CGIS, 2004). Generally, vegetated areas have high reflectance in the near infrared and low reflectance in the visible red. In this index, green vegetation is high values, water has negative values, and bare soil has value around 0.

For the middle value, they are indicator for difference in coverage with green vegetation. The NDVI algorithm takes advantage of the fact that green vegetation reflects less visible light and more NIR, while sparse or less green vegetation reflects a greater portion of the visible and less near-IR. NDVI combines these reflectance characteristics in a ratio so it is an index related to photosynthetic capacity. The range of values obtained is between −1 and +1.Only positive values correspond to vegetated zones; the higher the index, the greater the chlorophyll content of the target.

The last half of the 20^{th} century has seen the development and use of different remotely sensed vegetation indices. The basic assumption behind the development and use of these indices is that some algebraic combination of remotely-sensed spectral bands can reveal valuable information such as vegetation structure, state of vegetation cover, photosynthetic capacity, leaf density and distribution, water content in leaves, mineral deficiencies and evidence of parasitic attacks (Jensen, 2007). The algebraic combination of spectral bands should therefore be sensitive to one or more of these factors. Conversely, a good vegetation index should be less sensitive to factors that affect spectral reflectance such as soil properties, atmospheric conditions, solar illumination, and sensor viewing geometry (Jensen, 2007; Purkis and Klemas, 2011).

2.4.2 NDVI-based assessments of soil erosion

Erosion is the displacement of materials like soil, mud and rock by gravity, wind, water or ice. The most common agents of soil erosion are water and wind (Foth, 1991); their effects may be on-site (where soil detachment and transportation occurs), or off-site (where eroded soil is deposited). In soil erosion studies, the NDVI is commonly used in conjunction with soil-erosion estimation models such as the Fuzzy-based dynamic soil erosion model (FuDSEM), the Revised Universal Soil Loss Equation (USLE/RUSLE), the Water Erosion Prediction Project (WEPP), the European Soil Erosion Model (EUROSEM), and the Soil and Water Assessment Tool (SWAT) (Zhou *et al*., 2008; Prasannakumar *et al*., 2012). Ai *et al*., (2013) in China Terra-MODIS derived NDVI is used to characterize the state of the ecosystem (spatial and temporal heterogeneity of the vegetation conditions), and as one of the input parameters for estimating the potential of erosion using fuzzy-set theory. In a study of the effect of vegetation cover on soil erosion in the Upper Min River watershed in the

Upper Yangtze Basin, China, Zhou *et al.* (2008) used NDVI as a land-management factor (an input into the RUSLE model representing the effect of soil disturbing activities, land-cover and vegetation productivity on soil erosion. A similar study also using NDVI as a land-cover management factor to determine the vulnerability to erosion of soils was carried out in a forested mountainous sub-watershed in Kerala, India (Prasannakumar *et al*., 2012). In such studies, NDVI proved to be a useful indicator of land cover condition and a reliable input into models of soil dynamics.

In most soil erosion research, the NDVI data come from Landsat TM/ETM (Thematic Mapper/Enhanced Thematic Mapper) with a spatial resolution of 30m (Ai *et al*., 2013). These data are generally used in conjunction with a digital elevation model with a spatial resolution of 30m (Prasannakumar *et al*., 2012 and Ai *et al*., 2013).

2.4.3 Remote sensing-based biomass estimation

Biomass is the over-dried weight (Kilograms or tonnes per hectare) of organic matter that can be found in Ecosystem at any given time (Penner *et al*. 1997).The use of remote sensing technology has become the most effective approach to biomass estimation. According to Rawat and Singh (1988) biomass is one of the very important parameters affecting biosphere-atmosphere interactions. Estimation of woody biomass is a prerequisite for determining the state and flux for biological materials in an ecosystem and for understanding the dynamics of ecosystem. Information on biomass is not only important from the standpoint of fundamental ecology, but also relevant to planning for ecologically sustainable development of a region. Destructive techniques for biomass estimation procedures are time consuming and expensive in both conventional and short rotation forestry, due to large dimensions and amounts of biomass that have to be processed.

The measurement of field data is the most conventional method for estimating the forest biomass. Although, this method of forest biomass estimation is the most accurate method, it is strenuous, expensive, time consuming and destructive (which may not be very practical for those forest ecosystems with threatened or rare or protected plant species). Moreover, it is applicable for only a small sample of trees and small-scale analysis. Therefore, remote sensing technology is expected to provide a solution for the above mentioned challenges.

Remote sensing technology provides a synoptic view of the surface area of interest, thereby capturing the spatial variability in the attributes of interest. A major advantage of remote sensing technology is that it can obtain information about an area of interest that is difficult to access or inaccessible. Remote sensing has enabled us to monitor natural resources on a continental, even on a global scale. It is also the only realistic and cost-effective way of acquiring data over a large area.

Biomass estimation using remotely sensed data is an emerging technology and it is being increasingly used to inventory forest biomass. However, remote sensing data does not directly estimate the amount of biomass that is present in the forest. It only measures the parameters, which are correlated to biomass like the tree height, crown size, forest density, forest type, forest volume, leaf area index. Remote sensing data coupled with the field-based measurement of the forest is used to estimate the above-ground biomass. The field measurements are commonly used to develop predictive models or allometric equations for biomass and to validate the results obtained from the remotely sensed data. Once it is validated remotely sensed data can be used to estimate the forest biomass for wider area where there is very little or no field measurement data available.

Steininger (2000) conducted a study to examine the potential of Landsat TM images in estimating the above ground biomass of tropical secondary forests. Cutler *et al.* (2012) also conducted a study a combination of SAR image texture and Landsat TM data, for the estimation of tropical forest biomass. The result of this study suggested that inclusion of SAR texture with multispectral data can be successfully applied to a predictive relation at times and space other than for which it was developed. Although, texture measurements demonstrate a promising result for biomass estimation, it requires further investigation.

Estimation of forest carbon stocks will enable us to assess the amount of carbon loss during deforestation or the amount of carbon that a forest can store when such forests are regenerated. The principal element for the estimation of forest carbon stocks is the estimation of forest biomass. Although there has been numerous studies carried out to estimate the forest biomass and the forest carbon stocks, there is still a further need to develop robust methods to quantify the estimates of biomass of all forest components and carbon stocks more accurately.

2.5 Land-use/land-cover change

Land-cover is the observed (bio) physical cover on the earth's surface (Di Gregorio, 2005). Land-use/land-cover change is a general term used to refer to the human modification of Earth's terrestrial surface (Bajocco *et al*., 2012). Mankind has modified Land-use/land-cover change for thousands of years to obtain food, fuel, fibre and other materials, but current rates and intensities of land-use/land-cover are far greater than ever before (Mayaux *et al.* 2008). The quantity and quality of vegetation cover are important controls on the evolution of landscapes, their resilience or degradation (Symeonakis and Drake, 2004) and the quality of environmental services.

Human activities has directly or indirectly modified the natural environment this is due to the fact that production demands by human cannot be fulfill without modification or conversation of land cover. Human activities impacts on the topography such as changes in land-use/land- cover are often observed with synchronous changes in erodibility of soils, erosion patterns and suspended sediment concentration characteristics in rivers. Land use changes influence the soil properties such as bulky density, soil structure, and water retention characteristics (Zhou *et al.,* 2008).

Land-use/land-cover changes play a major role in the assessment of watershed conditions as most environmental problems are often related to the changes in land-use/land-cover patterns. Therefore, data on land-use/land-cover changes is a critical input in assessing the watershed conditions and to detect the direction and magnitude of changes over time. The land-use/land- cover changes can be unplanned or planned as in the case of SLM project areas. Remote sensing and GIS have the potential to provide accurate and timely information on the spatial and temporal distribution of land-use/land-cover changes over large areas.

CHAPTER III
MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted in Yezat watershed, West Gojam Zone, Amhara Regional State of Ethiopia. It falls in two Districts namely Gonji Kolla and Yilmana Densa districts. Geographically, it is situated from 37^{o}28'0" to 37^{o}45'30" E longitude and from 11^{o}05'30" to 11^{o}19'30" N latitude covering a total area of about 15085 ha. The surrounding area is accessible by all weather road and seasonal gravel roads (Figure 1). It is 430km from Addis Ababa and 70 km south of Lake Tana, Bahir Dar Town, capital of Amhara Regional State, Ethiopia.

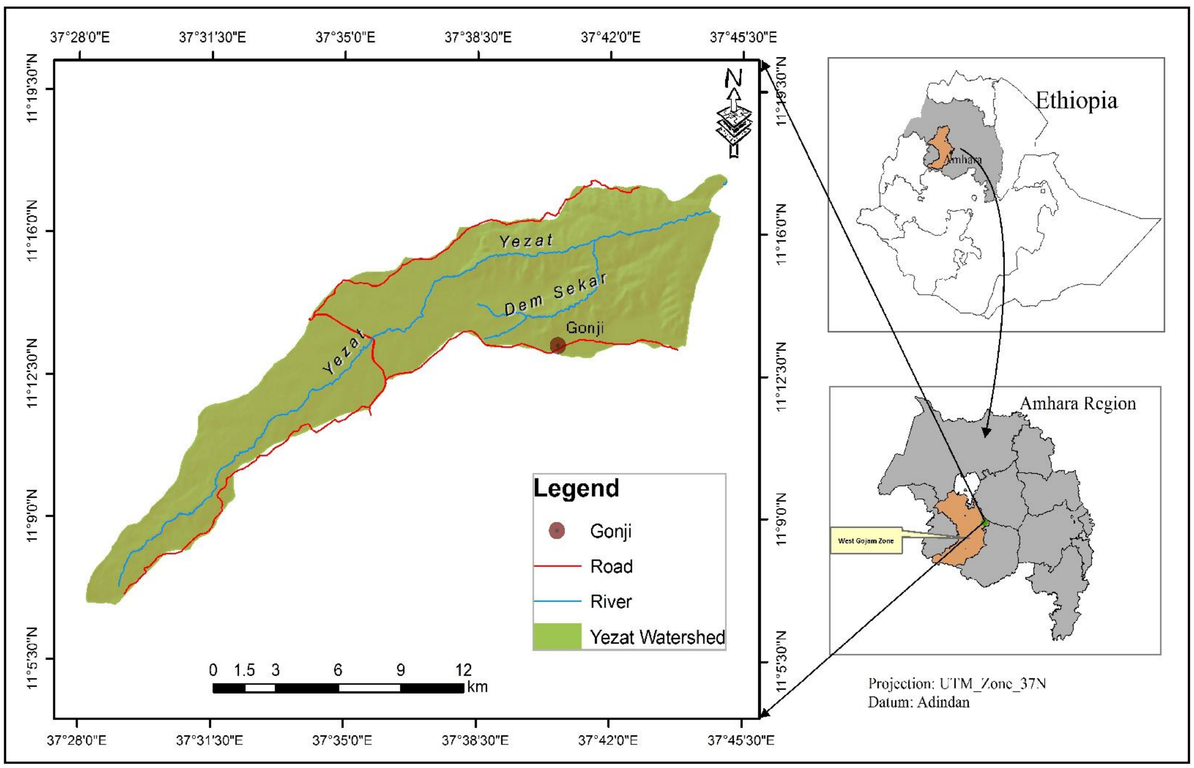


Figure 1: Location map of the study area

3.1.1 Climate

In Ethiopia, the climate varies with regard to its high extent of altitudinal and topographical features. Rainfall increases with rise in altitude (FAO, 1984). Based on the agro-climatic classification of Ethiopia (Hurni, 1985), the majority of the watershed falls in Woina Dega agro-climatic Zones (traditional climate classification) which is similar to dry sub-humid.

The main rainy season, rainfall is heaviest from June to mid of October. About 83.3% of the annual rainfall occurs during the main rainy season. The remainder 16.7% unevenly distributed throughout the rest of the year (Tibebu Checkol, 2014). Even though, the short rainy season is not used for growing crops, farmers use it for land preparation instead.

There is no metrological station within the watershed and based on long term climatic data from nearby meteorological station (Adet, Finote selam, Dembecha, Debrework and Zege), the study site receives 1352.9 mm of rainfall annually while 29.5^{o}C and 12.9^{o}C of average maximum and minimum temperatures, respectively. The mean monthly rainfall of the main rainy season is 246.92 mm (Figure 2).The highest mean monthly temperature was recorded in March and the lowest in December and January.

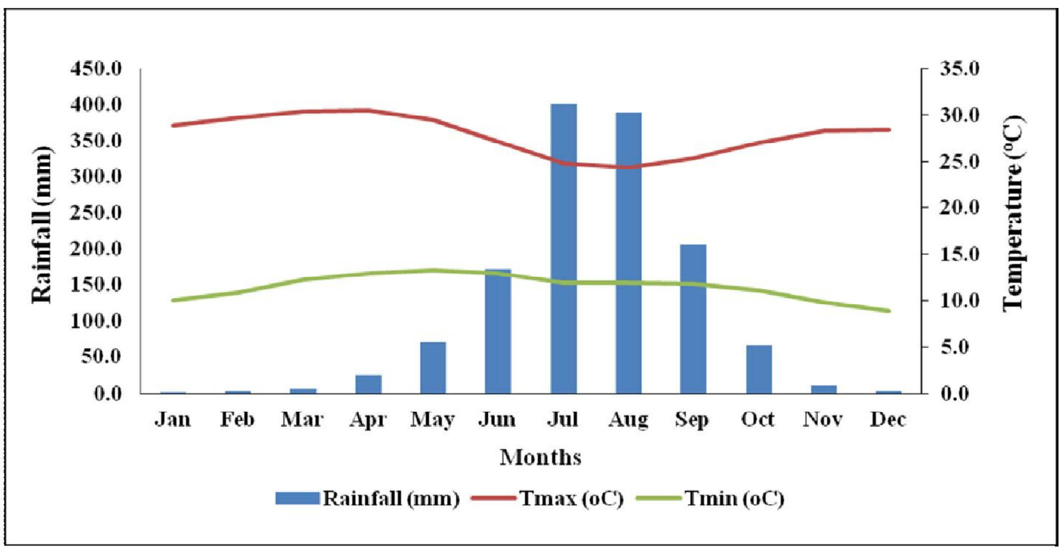


Figure 2: Average monthly rainfall (mm) and temperature (^{o}C) of the study area (1986−2013) (Source: Ethiopian Meteorology Agency)

3.1.2 Geology

The geology is dominated by the Precambrian basement rock underlying Mesozoic marine sediments and Teritary flood basalt (Mohr, 1971). An integral part of the present day geology of the study area fall into transitional basalts (rocks) forming shield in the tertiary highland volcanoes with minor trachyte and Ashenge formation deeply weathered alkaline and transitional basalt flows. It also falls into the late Paleozoic to early tertiary sediment and Cenozoic volcanic and associated sedimentary rocks.

3.1.3 Soil

According to the FAO-WRB (2006), soil map unit classification system, Vertisols are the predominant soil type with area coverage 7166.2ha, which located in moderately gentle sloping and very deep soil of the study area. This soil class can be characterized by heavy black clay, mostly water logged during the rainy season. It has high cation exchange capacity and base saturation content both in surface and subsurface horizons and decreases these quantities with increasing soil depth. The rest of the physiographic units are dominated by Cambisols, Regosols, Luvisols, and Leptosols. Moderately deep to very deep major soil types dominate the study area.

3.1.4 Topography

The altitude of the study area ranges 1485 to 3207m above sea level (Figure 3). The slope gradient of the watershed ranges from 4 to 66.5^{o}. The higher elevation ranges are located at the southwest and eastern part of the watershed.

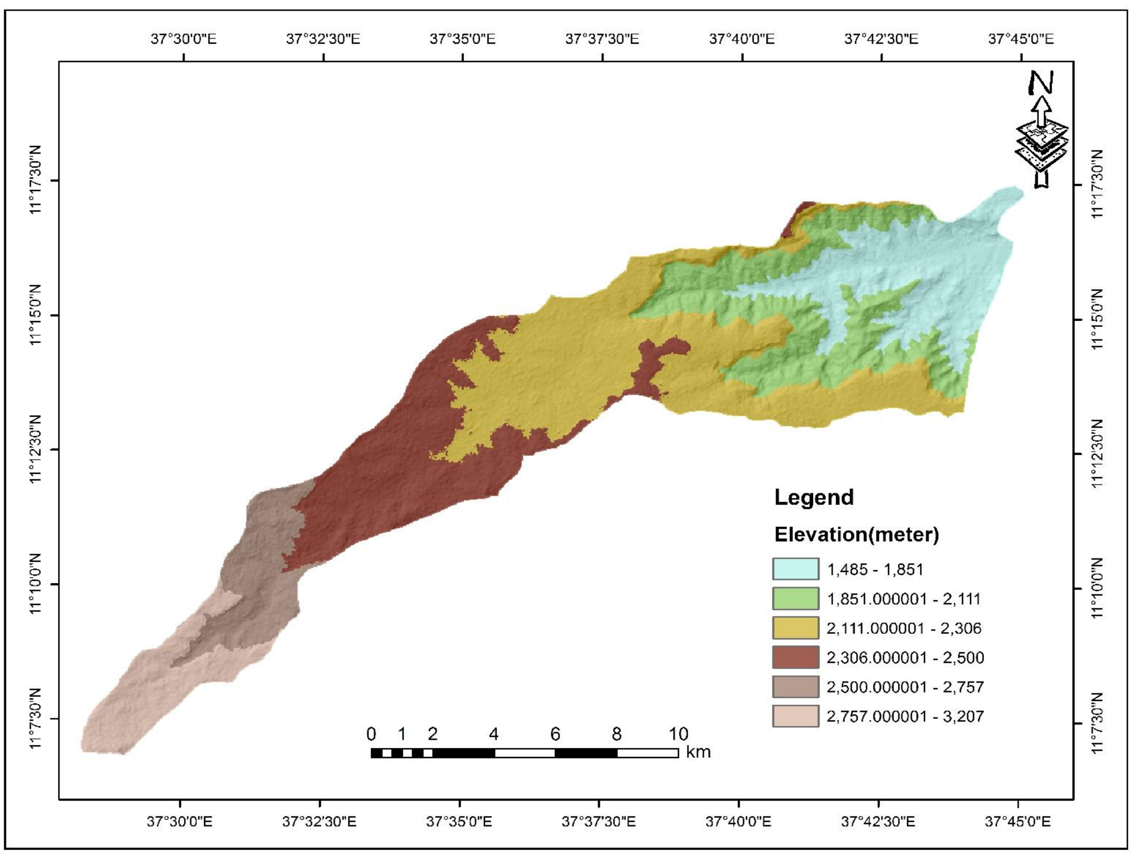


Figure 3: Elevation map of the study area

3.1.5 Vegetation and land cover

The main land-covers in the study area are: settlements surrounded by eucalyptus wood, cultivated land, grassland (grazing land), wood land, and shrub/bush land. Major crops grown in the area are wheat, barley, and sorghum. Few scattered trees such as *Acacia Albida*, *Cordia African* and *Croton sp*. are found in the farm land whereas, *Eucalyptus Camendulensis*, are grown around the homestead. The partial view of the study site is presented in Figure 4. According to the information from farmers the cultivated land has received UREA and DAP fertilizers in most of the past years for most crops. They usually use crop residues for livestock feed. In addition, animals are allowed to graze on the cultivated land after the crop has been harvested.

The vegetation consists of evergreen and semi–evergreen bushes, small trees and occasionally larger trees (Figure 5). Depending on the landscape and topography of the watershed, there are different types of indigenous vegetation existing in the area. Besides, different types of crops grow in this altitude. The remaining indigenous biomasses, which are common along ridges and rivers or very few protected areas, are good indicators of their degradation through time.

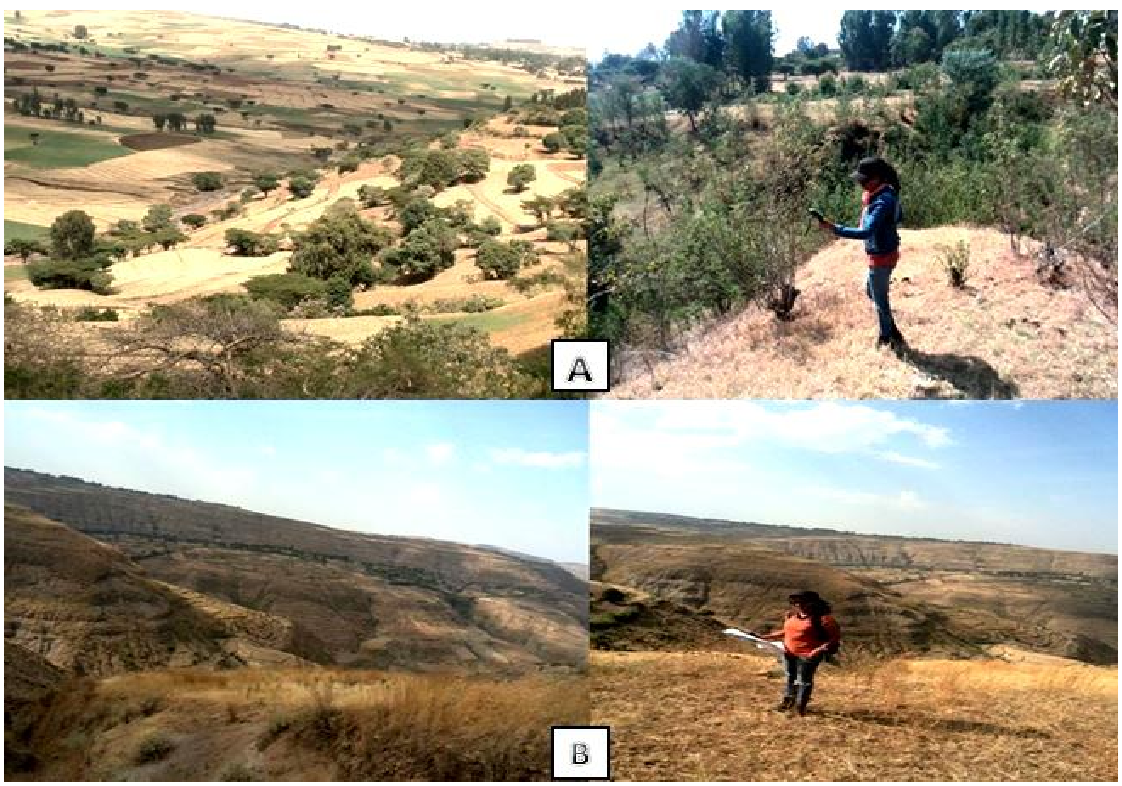


Figure 4: Partial view of land-use/land-covers of the study site (Southwest (A) Northeast (B) of the study area)

Figure 5: *Eucalyptus* trees, in the upper part of the watershed

3.1.6 Demographics and socioeconomics features

According to the 2007 National Population and Housing Census, the two Woredas has a total population of 321,508 of which 160,709 are men and 160,829 are women; out of which 19,169 or 8.92% are urban inhabitants. The majority of the inhabitants practiced Ethiopian Orthodox Christianity, with 98.19% reporting that as their religion, while 1.76% was Muslims. The dominant ethnic group of the Woredas is Amhara. Amharic is the dominant language spoken by the great portion of the population. Agriculture lands are the most common land use type across this area and agriculture activities are extremely frequent. Agriculture is the mainstay of economy. About 91.9% of the area is predominantly used for crop production and the population livelihood depends on mixed farming (Tibebu Checkol, 2014).

3.2 Data and software

3.2.1 Data Acquisition

To achieve the objectives outlined in the section 1.3, the following relevant information was collected / generated from various sources.

- **Digital Image data sets**

A time series landsat (TM, ETM+ and OLI) satellite data and Shuttle Radar Topographic Mission (SRTM) digital elevation data of 30 m resolution are used in 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

The details of remote sensing data used and Source, description of the data used in the study are summarized in Table 1.

- **Field Data**

Field work was carried out during the dry season in January 2016. Prior to the fieldwork, a detailed examination of False Color Composite of a Landsat image and a topographic map of the study area was conducted to get an overall view and to systematically identify and select sampling areas depending on the accessibility of each site. The field data collection were done randomly to verify the classified image and to collect the necessary land-use/land-cover data for accuracy assessment. A Global Positioning System (GPS) was used to locate and define the sampling areas. Meanwhile, information was collected about physical aspects of vegetation cover in the area. Interviewing of the nearby residents along with the various methods of data collection, informal interviews of the neighboring people good information about the past condition of the area, hence local people can interviewed as one method of data collection in this study.

- **Ancillary data**

Ancillary data were collected from different reports and departments in the study area. The soil map of the study area is 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 (1980−2013) were gathered from National Meteorological Agency (NMA) and well adopted for the analysis interpretation of the results. Topographic maps of the study area with scale 1:50,000 published by the Ethiopian Mapping Agency from Ethiopia Map Agency (EMA) were also used.

Table 1: The details of remote sensing data and description, Source of data used in the study

No	Data Type	Description	Source
1	Landsat image (ETM+ Jan 13,2001, TM Jan 30, 2010 and OLI Jan 28, 2015)	• 30m*30m Spatial resolution • 8 bit Spectral resolution • 16 days Temporal resolution • Path/raw - 169/52	USGS
2	DEM	Shuttle Radar Topographic Mission (SRTM) data of 30 m resolution	USGS
3	Digital Soil map	FAO (2012)	From Ministry of Agriculture (MoA),Ethiopia
4	Rainfall	15 years RF data from 5 stations near the study area	National Meteorological Agency, Ethiopia
5	Ground Control Points(GCPs)	Random coordinates from each land use using Garmin GPS model GARMIN etrex 12 channels	From fieldwork

3.2.2 Software package

Image processing and image classification is carried out by using ERDAS Imagine 2014 software. Image processing tasks and NDVI analysis are accomplished by using ENVI 5.1. GIS analysis is conducted by using ArcGIS 10.2. Stream Extraction, fill sinks and flow accumulation generation is performed using Arc Hydro 10.2 Software plug-in into ArcGIS software. The DEM for the study area is analyzed and processed using ArcGIS 10.2 software. Documentation and statistical analysis tasks are accomplished by using MS Office 2010 software. The software and its specific use are summarized in Table 2, see below.

Table 2: Software used and their respective tasks

Software	**Application**
ERDAS	Image pre-processing, LULC classification and Post Classification Change Detection
ENVI	Image processing and NDVI analysis
ArcGIS	Database creation, dataset preparation, raster calculation, Displaying and viewing Spatial data and map lay out preparation.
Arc Hydro extension	Stream Extraction, fill sinks, slope and flow accumulation Extraction
MS Office	Documentation, statistical analysis and presentation

3.3 Data processing and analysis methods

3.3.1 Image Processing

The standard image processing techniques, such as image extraction, rectification, restoration, and classification have been used for the analysis of the satellite imageries using ERDAS imagine software. Landsat imageries of three bands (4, 3, and 2) for Landsat TM and Landsat ETM+ whereas bands (5, 4, and 3) to Landsat-8 were used in image enhancement to identify changes in landuse/land-cover features. All satellite images had original format in TIFF. They were exported to img format in ERDAS Imagine 2014 software by using layer stack function. The images were georefrenced in to the same map projection of WGS (World Geodetic System) 1984 Zone 37N. All satellite images were sub-mapped (subset) for covering only the study area. In order to interpret and discriminate the surface features clearly, all satellite images were composed using the Red Green Blue (RGB) color composition. False Color Composites (FCC) of satellite imageries were prepared for the years 2001 and 2010 using band 4 (NIR), band 3 (Red), and band 2 (Green) and for the year 2015 Landsat 8 using band 5(NIR), band 4(Red) and band 3 (Green) combination.

3.3.2 Image classification

Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands, and attempts to classify each individual pixel based on this spectral information. 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. Notice that data are transformed into information.

As there was no prior knowledge about the study area, unsupervised classification method was done in order to get an idea of approximately land-use/land-cover of the study site and to use it in sampling planning 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. The computer uses these information located arbitrary vectors as the center points of the clusters. Then each pixel was assigned to a cluster by using minimum distance cluster centriod decision rule. The iteration stops when the cluster centers do not change anymore. The result from this process was a raster map, with each pixel had a class of the cluster.

3.3.3 Supervised Classification

In supervised classification process, "User-Defined Polygon" function reduces the chance of underestimating class variance since it involves a high degree of user control. A supervised classification was performed using the maximum likelihood algorithm methodology for the extraction land-use/land-covers map of the study site in ERDAS Imagine software. Supervised classification requires a prior knowledge of the scene 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 cultivated land, grass land, forest land, shrub/bush land and settlements (homesteads) were considered as training areas in image classification based on samples collected from fields (Table 3). In ERDAS Imagine software, signature editor was created for defining the classes. By using Area of Interest (AOI) tools, 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. Finally, land-use/land-cover maps for the year 2001, 2010 and 2015 were classified. Summary of major steps followed during satellite image analysis for land-use/land-cover change detection has been showed in Figure 6.

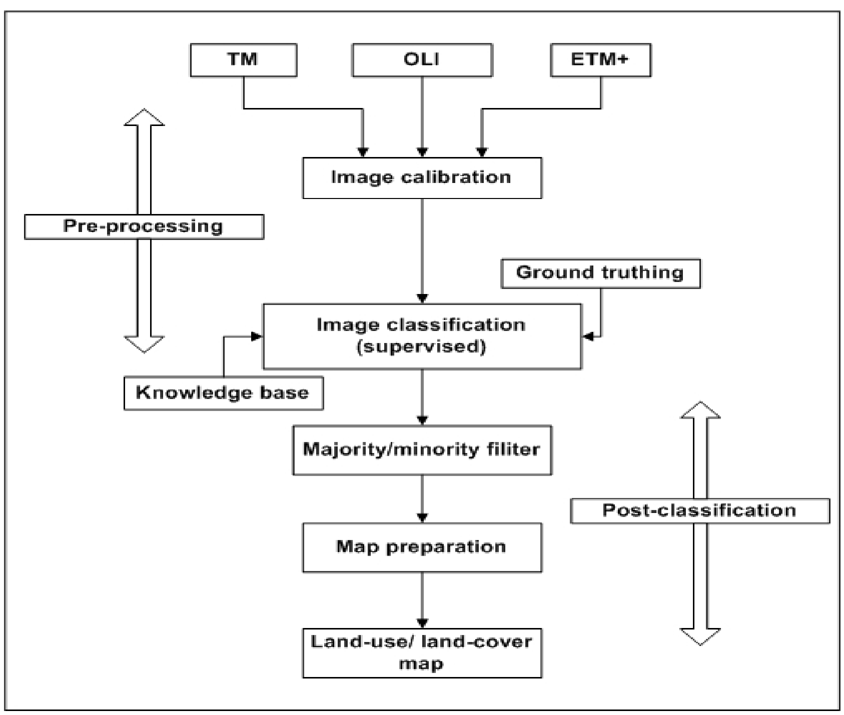


Figure 6: Major steps followed during satellite image analysis for LULC extraction

Descriptions of each of the land-cover categories of the study watershed are presented in Table 3.

Table 3: Descriptions of land-use/land-cover categories of the study area

Sr.No.	Land Cover Category	General description
1	Cultivated land	Areas of land ploughed and/or prepared for growing crops. The category includes most flat areas and also some steep slopes where various food crops were grown, either on a rain-fed basis or using irrigation.
2	Grassland	Land refers to those land units allocated as a source of animal feed, including privately and communally owned grazing areas and also those owned by various institutions (church and school).
3	Woodland	Areas covered with relatively tall and dense trees of *Eucalyptus globules* and other remnant trees forming closed canopies.
4	Shrub/bush land	This category includes areas covered with different species of shrubs and bushes with widely varying density from one locality to another, and often found in hilly areas.
5	Homesteads	Small rural communities and other manmade structures

3.3.4 Accuracy Assessment

Accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true, in order to determine the accuracy of the classification process. To assess the accuracy of the land-use/land-cover (LULC) maps, field collected data has been compared against the classified images. The reference pixels have been generated by user-defined options.

For each of the classified cover type's random sample points were established. Then, each random sample point visited in the field and the actual cover type verified (recorded as reference data). According to Jensen (1996) in order to perform classification accuracy assessment, it is necessary to compare two source of information that is the remote sensing driven classification map and what is called reference test information, which may in fact contain error. The relationship between the two sets of information is commonly summarized in an error matrix.

The data from fieldwork were used to validate the results of classification through confusion matrix (error matrix). The error matrix summarizes the relation between the remote sensing derived classification map and the reference information where columns represent the reference data and rows indicate the classification generated. The confusion/error matrix consists of rows and columns. The columns of the error matrix represent the actual ground truth from field verification of each random sample points, while the rows represent the predicted classes for random sample points. Using the ERDAS Imagine software accuracy assessment utility, reference random test pixels in the study area are located which are not used in the training of the classification algorithm to eliminate to the possibility of bias of training samples chosen in classification. These pixels chosen are referenced on the ground with field trip as well as high resolution Google earth imageries and used to assess the accuracy of classes in the remote sensing classification map. In ERDAS Imagine software, accuracy assessment function was selected. Validated points with coordinates and land-cover classes in text format were imported as true classes. Overall accuracy was computed from correctly classified pixel divided by total number of pixel checked. Based on this, the accuracy for all land-use/land-cover classification of 2001, 2010, and 2015 was performed.

3.3.5 Normalized Difference Vegetation Index (NDVI) Analysis

Several studies propose change detection techniques for monitoring land-use/land-cover change based on changes in NDVI. It is used in this study for gaining information about the seasonal growth of vegetation condition, vegetation dynamics and as input parameters for estimating the potential of erosion using RUSLE model. NDVI was also used to differentiate vegetation from other land-cover classes. It was estimated by the division of the difference between the near infrared and red reflection (visible wavelength observations) and the sum of these measurements using the formula:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \qquad \text{Eq (3.1)}$$

Where, NIR is the reflectance value in near-infrared band; Red is the reflectance value in visible red band.

For Landsat TM and ETM+, the formula can change into the following equation:

$$NDVI = \frac{(B4 - B3)}{(B4 + B3)}$$

Where, B4 is band 4 (0.76 – 0.90 μm) which represents infrared band; and B3 is band 3 (0.63-0.69 μm) which represents red band for Landsat TM or ETM+ imageries

For Landsat8 (OLI-TIRS) the formula can change in to the following equation:

$$NDVI = \frac{(B5 - B4)}{(B5 + B4}$$

Where, B5 is band 5 (0.85-0.88 μm) which represents infrared band and B4 is band 4 (0.64-0.67 μm) which represents red band for Landsat 8 imagery

The values for NDVI range from -1.0 to +1.0. Vegetated areas generally have high values of NDVI because of their relatively high NIR reflectance and low visible reflectance. Water, snow and clouds have negative IR radiation. Rocks and bare soil have NDVI values around zero as they have almost similar reflectance in both the bands and represent area without any vegetation cover. Only green vegetation has positive NDVI values and high values being associated with higher densities/ vigour of any given healthy biomass (Lilesand and Kefier, 2000).

3.3.6 Methods of woody biomass estimation

There are different types of methods to estimate biomass of an area. Including ground based estimation and applying remote sensing and GIS modeling. Remote sensing has opened an effective way to estimate forest biomass (Rosenqvist *et al.,* 2003). According to the Intergovernmental Panel on Climate Change, Good Practice Guidance (IPCC, 2003), remote sensing methods are especially suitable for verifying the national LULUCF (Land Use, Land-Use Change, and Forestry) carbon pool estimates particularly the aboveground biomass.

For woody type mapping, land use-/land-cover map of the study area were used. Land use-/land-cover map was prepared from time series landsat (TM, ETM+ and OLI) satellite data. During land-use-/land-cover classification, ground truth data and Google earth satellite data was used as reference. Preliminary interpretation of satellite data was done visually on false color composite in order to stratify woody types. Possible separability of various land-use/land-cover types with special reference to vegetation cover was studied using ground

collected data for land-use/land-cover map of study area. The ground truth sites, which could be identified on satellite imagery, were used as training sets for classification.
The process of biomass estimation and methodology of calculation is methodical in nature. In this study, the woody biomass available from tress can be estimated by applying the following formula used in Energy (2013) as:
Growing stock (tons/ha/yr) = Area under plantation or canopy (per ha) x productivity (m^3/ha (per year) Eq (3.2)

Productivity estimates made by Indicative estimates of hardwood volumes for the project "hardwood plantations in the tropics and subtropics" for indicative forest plantation yields by species and country for hardwood species grown in the tropical and subtropical zone are used. The productivity of *Eucalyptus* species in Ethiopia is 8.0 − 12.5 m^3/ha/year (Leech 1998). By using this source compiled by FAO, the most dominate species grown in the study area is *Eucalyptus* species. Therefore, an average 10.25 m^3/ha/year is used to compute sustainable yield. It is selected on the basis the assumption taken by the FAO. The time series landsat imageries were used for extraction the size of the woody stands.

3.3.8 Revised Universal Soil Loss Equation (RUSLE) model and GIS Parameters

Since the erosion process is gradual, there are difficulties in differentiating between the natural and accelerated rate of erosion, and the physical measurement of soil erosion is made worse by the complexities of temporal and spatial variations (Eaton, 1996). To overcome these, 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. The Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) is the most frequently used empirical soil erosion model worldwide. More recently, Renard *et al*. (1997) has modified the USLE into a Revised Universal Soil Loss Equation (RUSLE) by introducing improved means of computing the soil erosion factors.
Revised Universal Soil Loss Equation (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.*, 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. GIS can then be used to isolate and query these locations to identify the role of individual variables in contributing to the observed erosion potential value. 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 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:

$$A = R \times K \times LS \times C \times P \qquad \text{Eq (3.3)}$$

Where, A is the computed spatial annual soil loss (t $ha^{-1}y^{-1}$); R is the rainfall erosivity factor (MJ mm h^{-1} $ha^{-1}y^{-1}$); K is the soil erodibility factor (t $ha^{-1}MJ^{-1}mm^{-1}$); 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) to 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 10.2 to predict soil loss in a spatial domain. Each factor grid had a cell size of 30m by 30m 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 has been showed in figure 7.

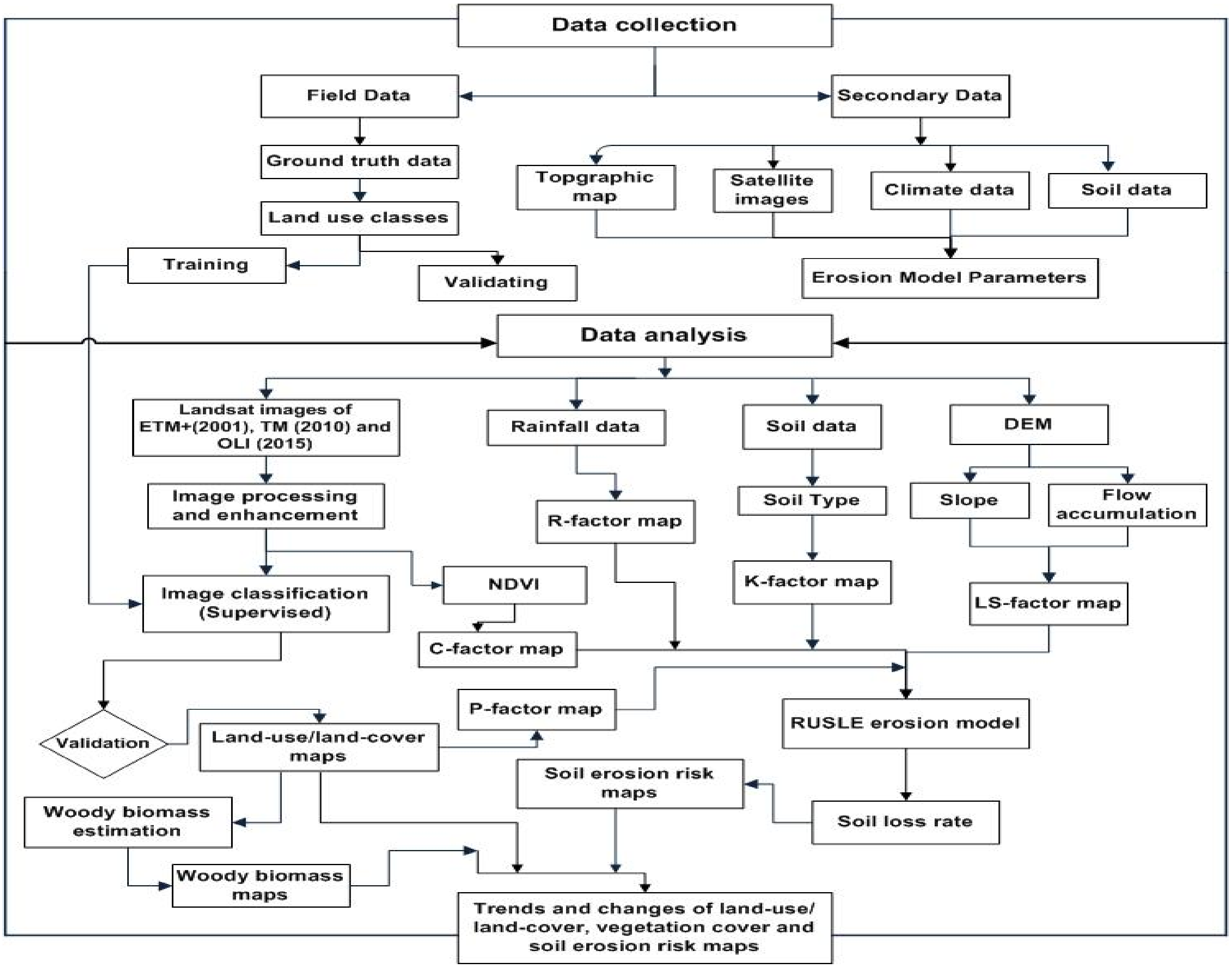


Figure 7: Flow chart of overall methodology

3.3.9 RUSLE Factor Generation

The following GIS layers were formed in raster format as input source for the RUSLE model.

3.3.9.1 Rainfall Erosivity (R) Factor

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1994). The rainfall erosivity factor indicates the erosive force of a specific rainfall (Prasannakumar *et al*., 2012). In the original equation of USLE, the value for R measures the kinetic energy of the rain and it requires measurements of rainfall intensity with autographic recorders. The energy of a given storm depends upon all the intensities at which the rain occurred and the amount of precipitation associated with each particular intensity value. Within the RUSLE, rainfall erosivity is estimated using the EI30 measurement (Renard *et al.,* 1997).That means R is the average annual sum of the event rainfall-runoff (erosivity) factor when this factor is given by the product of the kinetic energy of the rainstorm E and the maximum 30 minutes rainfall intensity I30.

Rainfall intensity data are not commonly available in data scarce developing and remote regions. There is, thus, a tendency to use intensity values available in roughly similar environments to estimate for locations where those data are available. Due to rainfall characteristics and absence of automatic hourly rain intensity records in many rainfall stations in Ethiopia, it is difficult to apply erosivity equation proposed by Renard *et al*. (1997) for Ethiopian condition. Therefore, the erosivity factor R was calculated according to the equation given by Hurni (1985), derived from a spatial regression analysis (Hellden, 1987) for Ethiopian conditions based on the easily available mean annual rainfall (P). The R-factor is given by a regression equation as:

$$R = -8.12 + (0.562 \times P) \qquad \text{Eq (3.4)}$$

Where, R is rainfall erosivity value in MJ mm $ha^{-1}h^{-1}y^{-1}$, P is the mean annual rainfall in mm In order to compute R factor using the relationship above, five rainfall stations randomly distributed around the study area were used in this study. The monthly amounts of rainfall for these stations were collected by the National Meteorological Agency. Monthly rainfall records from these five meteorological stations (Adet, Finote selam, Dembecha, Debrework and Zege) with mean annual rainfall of 15 years for the three target year 2001, 2010 and 2015 covering the period 1986 to 2013 were used to calculate the rainfall erosivity factor (R-value) (Appendix 2). The position of the stations and the corresponding rainfall depth values were imported to ArcGIS as point vector data. Afterwards, Inverse Distance Weighting (IDW) interpolation was applied to create rainfall depth maps for each of the target years. The Inverse Distance Weighted tool uses a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weight; it has in the averaging process.

Similar methods of determining R-values from rainfall totals have been used in previous studies from different countries (Morgan, 2005; Bewket and Teferi, 2009). The mean annual rainfall available from the National Meteorological Services Agency was first interpolated to generate continuous rainfall data for each grid cell. The R-value of each cell was then calculated using Equation 3.4 (Figure 8).

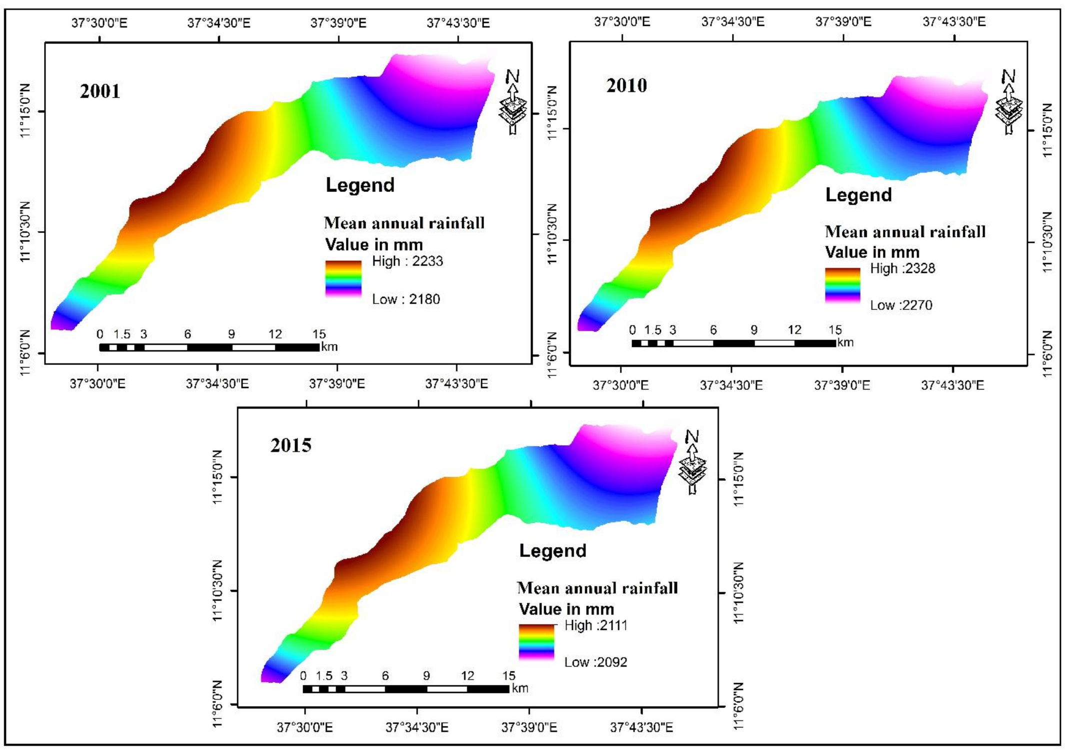


Figure 8: Spatial distribution of mean annual rainfall map

3.3.9.2 Soil erodibility factor (K)

Vulnerability of the soils to get eroded is referred to as erodibility of soils. The K-factor is defined as the rate of soil loss per unit of R-factor on a unit plot (Renard *et al.,* 1997). For Ethiopian condition an attempt was made to classify the soil types of the study area based on their color by referring the FAO soil database.

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 erodibility of a soil is an expression of its inherent resistance to particle detachment and transport by rainfall. It is determined by the cohesive force between the soil particles, and may vary depending on the presence or absence of plant cover, the soil's water content and the development of its structure (Wischmeier and Smith, 1978). Hellden (1987) proposed the K values for Ethiopian condition based on soil color by adapting different sources.

The higher erodibility value the soil has, the more erosion will be suffered when the soils are exposed to the same intensity of rainfall, splash or surface flow (Hudson, 1981). Based on this assumption, the soil types were assigned K-values according to the color of the soils. There are five different soil types classified in the study area, namely, Eutric Cambisols, Eutric Leptosols, Vertic Luvisols, Eutric Regosols and Eutric Vertisols (Figure 9).

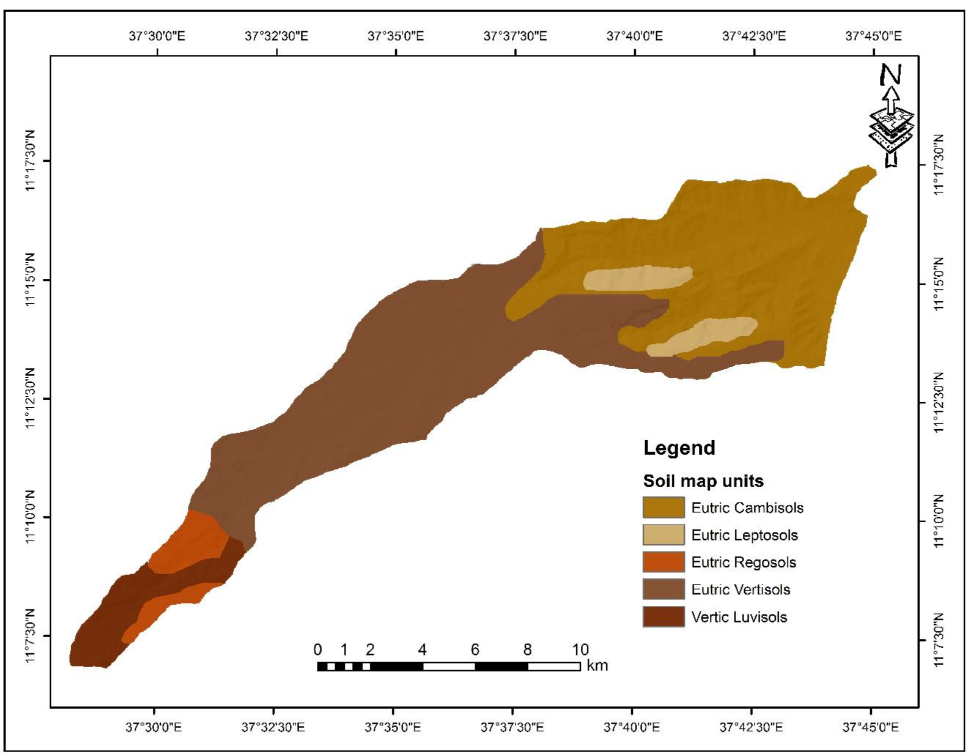


Figure 9: Soil map of the study area

The vector data were first rasterized and each raster (grid-cell) was assigned K-values (Table 4).

Table 4: K value based on their color

Soil Types	Color	K Value
Eutric Cambisols	Brown	0.2
Eutric Leptosols	Red	0.25
Vertic Luvisols	Grey	0.35
Eutric Regosols	Yellow	0.3
Eutric Vertisols	Black	0.15

Source: Adapted from Hellden (1987).

Figure 10 shows the resulting K- values map.

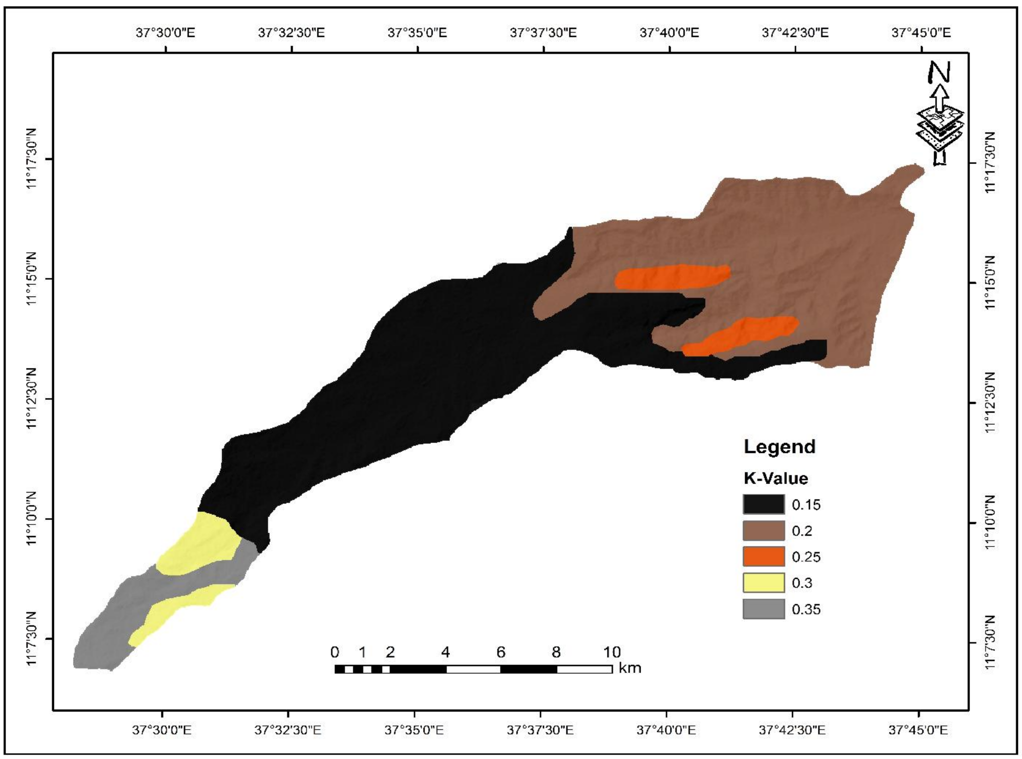


Figure 10: Spatial distribution of soil erodibility K factor map

3.3.9.3 Topographic (LS) factors

The influence of topography on erosion is complex. The local slope gradient (S sub-factor) influences flow velocity and thus the rate of erosion. Slope length (L sub-factor) describes the distance between the origin and termination of inter-rill processes. Termination is either the result of the initiation of depositional processes or the concentration of flow into rills (Wischmeier and Smith, 1978). In using RUSLE model, the effects of topography on soil erosion are estimated by the slope length (L) and slope steepness (S). Slope length is defined as the horizontal distance from the origin of overland flow to the point where deposition begins or where runoff flows into a defined channel (Renard *et al.,* 1997). However, in a real two-dimensional landscape, overland flow and the resulting soil loss do not really depend upon the distance to the divide or upslope border of the field, rather on the area per unit of contour length contributing runoff to that point. For this reason, the slope length unit should be replaced by the unit-contributing area (Shi *et al.,* 2004).

In erosion prediction, the factors L and S are usually evaluated together. In this study, Digital Elevation Model (DEM) dataset of 30m resolution were used generating LS factor. Depressions in the DEM are problematic for most flow routing algorithms and must be eliminated before calculating flow accumulation (Martz and Garbrecht, 1998; Rieger, 1998). As the first, any spurious single-cell sinks within the DEM were filled to produce a depression less DEM. In this process, individual sink elevations were flattened. Then by using filled DEM the flow directions of each DEM cell was calculated. From flow directions Flow accumulation was determined in ArcGIS10.2 software. Then the LS factor grid was estimated with the following equation using raster calculator which is proposed by Moore and Burch (1986a, b).

$$LS = ([FlowAccumulation] \times [cellsize] / 22.13)^{0.4} \times (\sin[localslopegradient(percent)] / 0.0896)^{1.3} \qquad \text{Eq (3.5)}$$

Where, LS is the combination of slope length and steepness; Flow accumulation is the accumulated upslope contribution to a cell; Cell size is the resolution of the raster image, and sin slope is the sin value of the slope in percent. The estimated LS values based on slope length and steepness is presented in Figure 11.

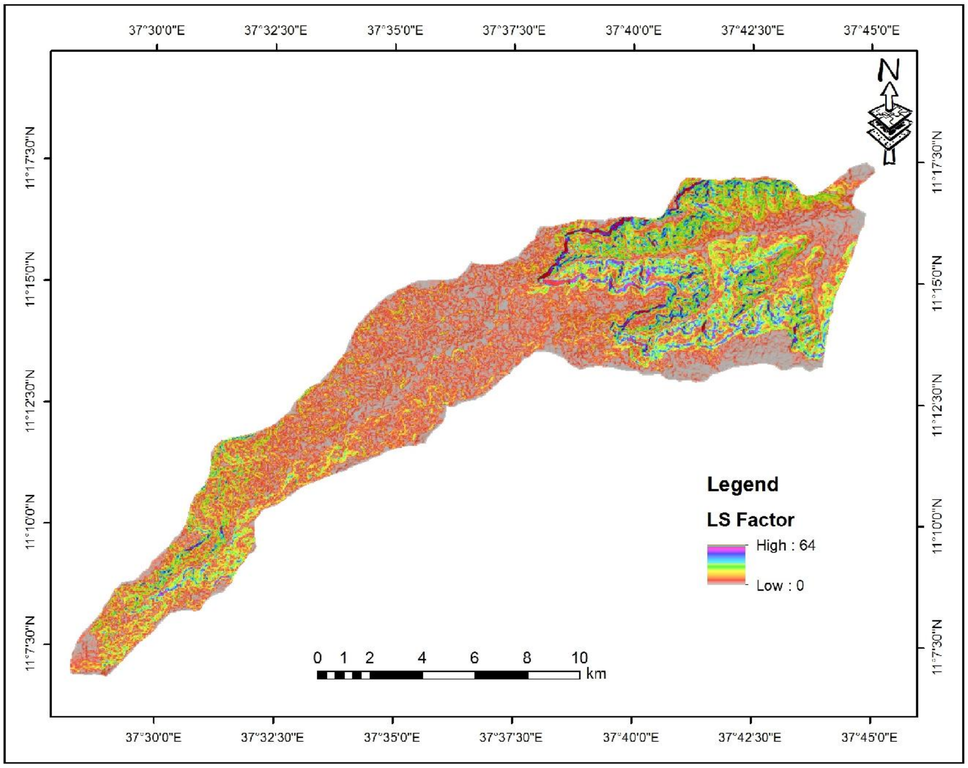


Figure 11: LS factor map

3.3.9.4 Cover management factor (C)

The cover management factor represents the effect of plants, crop sequence and other cover surface on soil erosion. 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).According to Prasannakumar *et al.* (2012), the NDVI can be used as an indicator of the land vegetation vigor and health. In addition, Karydas *et al.* (2009) state that due to the variety of the land cover patterns, satellite remote sensing data can act as an extremely important role to estimate the C-factor.

In this study, the original landsat imageries from the year 2001, 2010 and 2015 with the reflectance values in bands red and near-infrared, were converted to NDVI for the corresponding years. The NDVI calculation formula presented in section 3.3.5 using Eq (3.1).

From the calculated NDVI, the C-factor can be estimated by applying the relationship used in Zhou *et al.* (2008) and Kouli *et al*. (2009) as:

$$C = Exp(-\alpha \times \frac{NDVI}{\beta - NDVI}) \qquad \text{Eq (3.6)}$$

Where α and β are unit less parameters that determine the shape of the curve relating to NDVI and the C factor. Van der Knijff *et al*., (2000) found that this scaling approach gave better results than assuming a linear relationship and the values of 2 and 1 were selected for the parameters α and β respectively.

The values of C factor can vary from 0 for very well protected soils to 1.5 for finely tilled, ridged surfaces that produce much runoff, leaving it susceptible to rill erosion.

By running the formula with the raster calculator tool in ArcGIS software, C factor maps were obtained and the spatial variability is shown in Figure 12.

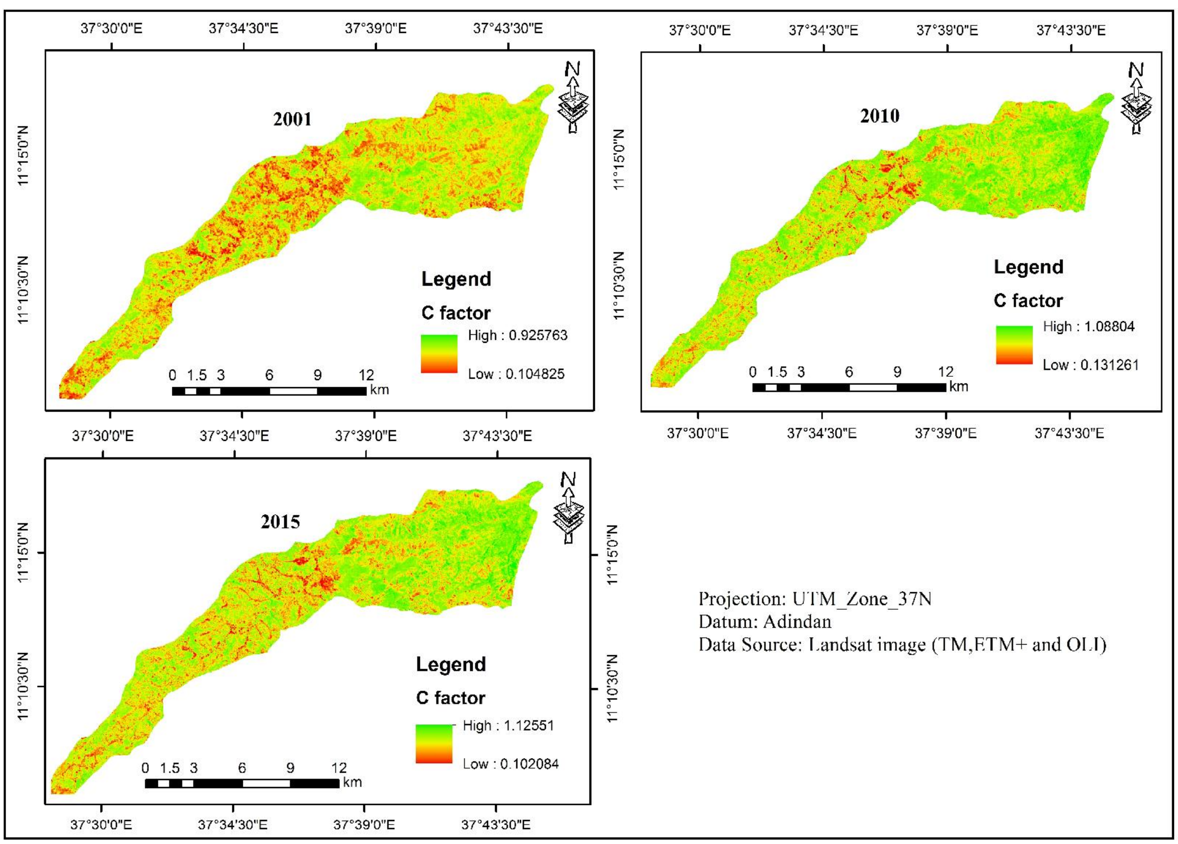


Figure 12: Spatial distribution of C factor map derived from NDVI years between 2001−2015

3.3.9.5 Conservation practice factor (P)

The conservation practices factor (p-values) reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. It depends on the type of conservation measures implemented, and requires mapping of conserved areas for it to be quantified. The P-value ranges from zero to one depending on the soil management activities employed in the specific plot of land. Therefore, erosion control practice factor is based on the soil conservation practices operated in a particular area. The support practices considered in this study for cultivated land includes contour plaguing, strip cropping, bunds, fanyajuu, drainage systems and others. On non cultivated land conservation practices considered includes hillside terraces, check dams and other practices that result in storage of moisture and reduction of runoff.

Even though, it is more suited for small-scale erosion hazard assessment mapping than regional or basin-wide, Hurni gives parameters for different land management practices on cultivated land. Studies conducted by Hurni (1985) have found P values for various support practices and land use cover. Hurni used P value range between zero and one.

In this study, during the years 2001−2010 (pre treatment), there was only a small area that has been treated with terracing through the agricultural extension programme of the government, and these are poorly maintained as implementation was performed without participation of the local people. The traditional conservation measure is a drainage ditch which is meant to drain excess runoff from croplands during rainstorms. The entire study area is therefore not treated with improved permanent soil and water conservation measures. Therefore, the conservation practice factor was assigned to the maximum value of one for the years 2001−2010 (pre treatment) for the entire study area for running the RUSLE model. As data were lacking on permanent management factors and there were no management practices, the P factor was assigned to be equal to one.

For the year 2015 (post treatment), the data related to management or support practices situations of the study area were collected during the field work through different techniques such as interview of the local community, site observation by transect walk and secondary information collected from Wereda and local agricultural offices. Therefore, values for this factor were assigned considering local management practices and based on values suggested in Hurni (1985).

The p value assigned for different land-use types presented in Table 5. Hence, the classified land-use/land-cover map format was changed into vector format and the corresponding P values were assigned to each land-use/land-cover classes and the P factor map was produced.

Table 5: Land-use/land-cover types and the corresponding P values

Land-use/land-cover Type	**P-Value**
Cultivated land	0.9
Wood land	0.53
Grass land	0.63
Shrub/bush land	0.53
Homesteads (Settlements)	0.63

Source: Adapted from Hurni (1985).

CHAPTER IV

RESULTS

4.1 Land-use/Land-cover Change Detection

Information about the any change in land-use/land-cover changes have become a key component in current strategies for managing natural resources and monitoring environmental changes. The land-use/land-cover maps were correctly classified independently according to the selected land use classes including cultivated land, woodland, grassland, shrub/bush land and homesteads for each periods (2001, 2010 and 2015). The land-use/land-cover classification maps for the study site are depicted in Figure 13.

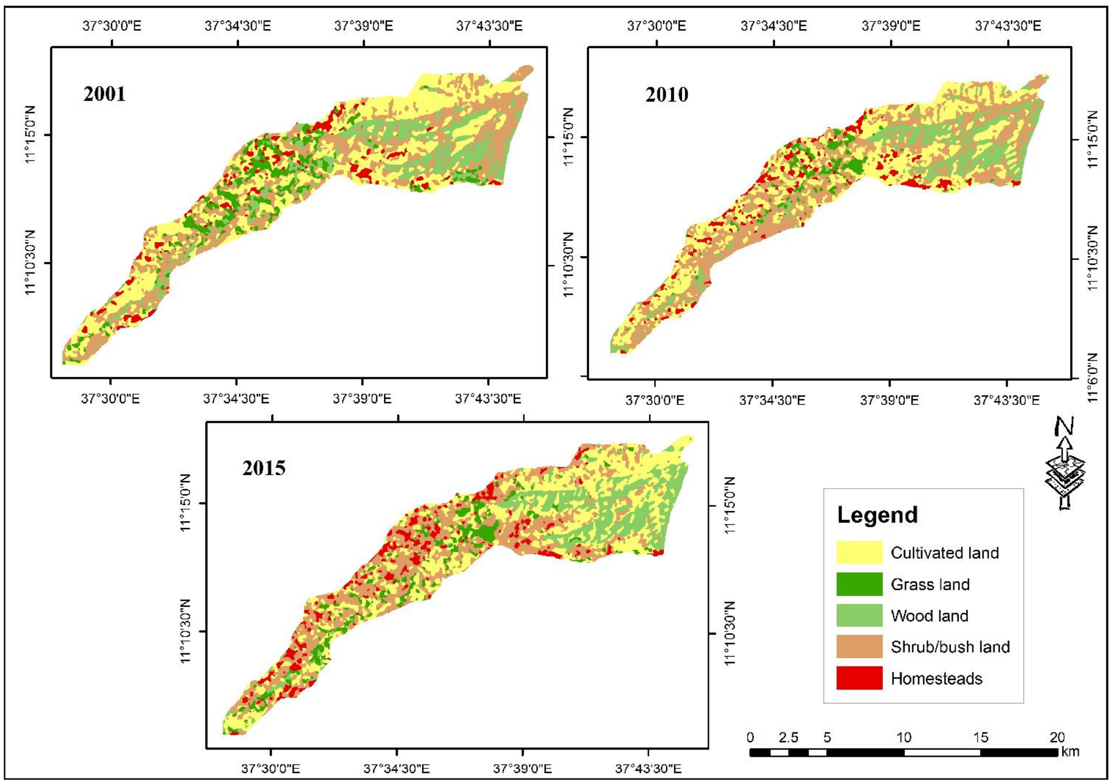


Figure 13: Land-use/land-cover maps 2001, 2010 and 2015

The spatial distribution of land-use/land-cover categories of the study area during the period 2001, 2010 and 2015 in Figure 14 shows that grass land, wood land, cultivated land, and homesteads area increased while, shrub/bush land declined continuously from 2001 till 2015. The comparison of different land-use/land-covers between those years is shown in table 6 as follows.

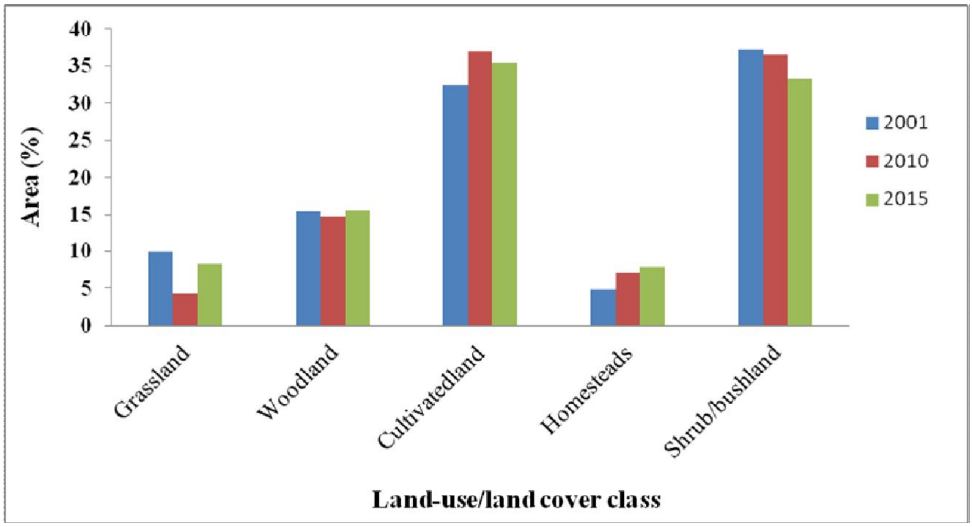


Figure 14: Land-use/land-cover change in the study area from 2001−2015

Table 6: Comparison of the areas of land-use/land-cover in year 2001, 2010 and 2015

Land use class	Pre-treatment				Post-treatment	
	2001		2010		2015	
	Area(ha)	(%)	Area(ha)	(%)	Area(ha)	(%)
Grass land	1509.17	10	643.98	4.3	1254.53	8.3
Wood land	2322.35	15.4	2228.77	14.8	2330.46	15.5
Cultivated land	4886.72	32.4	5589.69	37	5266.26	35
Homesteads	738.63	4.9	1075.65	7.12	1202.25	7.96
Shrub/bush land	5628.11	37.3	5546.85	36.7	5031.46	33.35
Total	15085	100	15085	100	15085	100

According to Table 6 and Figure14, land-use/land-cover classification map of 2001 showed that the highest area of the watershed is covered with shrub/bush land (37.3%), while cultivated land, woodland, grassland and homesteads covered 32.4%, 15.4%, 10% and 4.9%, respectively.

In the year 2010, the areal coverages of cultivated land and homesteads is increased to 37% and 7.12% respectively while, the areal coverage of shrub/bush land, woodland and grassland were decreased to 36.7%, 14.8% and 4.3%, respectively.

In the year 2015, the areal coverage of woodland increased by 15.5% followed by grassland 8.3% and homesteads 7.96%. While, the areal coverage of shrub/bush land still continues to decrease to 33.35%.

4.1.1 Trends of land-use/land-cover

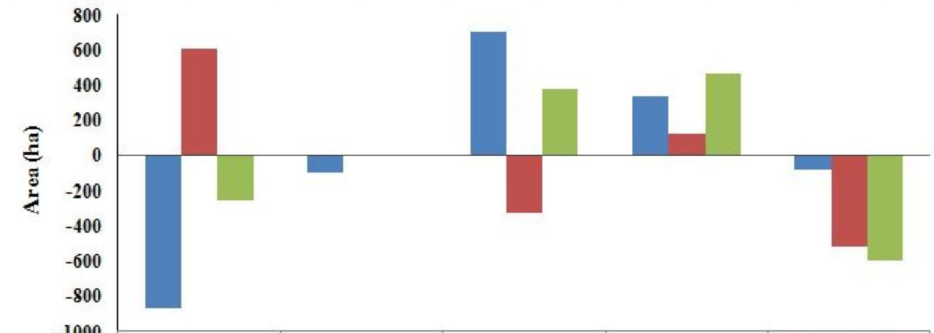
From the results of classification (Table 7) in the period's 2001−2010 (pre treatment), grassland, woodland and shrub/bush were dramatically decreased. Especially grassland areas decreased by 865.19ha (−5.73%) during theses 9 years. This could be due to lack of protection of communally owned grasslands, which are exposed to open grazing, and converted to cultivated lands and homesteads. Areas under woodland and shrub/bush land were also decreased by −93.58 ha (−0.62%) and −81.26 ha (−0.51%), respectively. Conversely, cultivated land and homesteads area were increased by 702.97ha (4.66%) and 337 ha (2.23%), respectively.

Detection of land-use/land-cover for a period of 2010− 2015 (post treatment), the area under grassland, woodland and homesteads were increasing by 610.69ha (4%), 101.69ha (0.67%) and 126.6ha (0.83%) while cultivated land and shrub/bush land where decreased by 323.43(0.02%) and 515.44ha (3.41%), respectively. The area under grassland increased dramatically.

The change detection from 2001−2015 showed, cultivated land, and woodland and homesteads areal coverage was increased by 379.54ha (2.51%), 8.11ha (3.1%) and 463.62ha (0.05%) while grass land and shrub/bush land slight decreases by 255ha (1.69%) and 596.65ha (3.4%), respectively. The change of land-use/land-cover areas in periods 2001−2010, 2010−2015 and 2001−2015 is shown in Table 7 and Figure 15 as follows.

Table 7: Land-cover classes and rates of change in the study area during 2001, 2010 and 2015

Land-cover class	**2001−2010**		**2010−2015**		**2001−2015**	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**	**Area (ha)**	**(%)**
Grassland	-865.19	-5.73	610.55	4	-255	-1.69
Woodland	-93.58	-0.62	101.69	0.67	8.11	0.05
Cultivated land	702.97	4.66	-323.43	-0.02	379.54	2.51
Homesteads	337	2.23	126.6	0.83	463.62	3.1
Shrub/bush land	-81.26	-0.51	-515.44	-3.41	-596.65	-3.4



	Grass land	Wood land	Cultivated land	Homesteads	Shrub/bush land
2001 – 2010	-865.19	-93.58	702.97	337	-81.26
2010 – 2015	610.55	10.55	-323.43	126.6	-515.44
2001 – 2015	-255	8.11	379.54	463.62	-596.65

Figure 15: Land-use/land-cover changes during 2001−2010, 2010−2015 and 2001−2015

4.1.2 Accuracy aassessment of land-use/land-cover mapping

The ground truth data were utilized in the classification report as the independent data set from which the classification accuracy was compared. An error report containing the error matrix and accuracy report summarizing the agreement and disagreement are produced (Appendix 3). The accuracy is essentially a measure of how many ground truth pixels were classified correctly. An overall accuracy of 85%, 91% and 93.2% was achieved with a Kappa coefficient of 0.80, 0.89 and 0.91 for the three Scenes (Landsat ETM+ 2001, TM 2010 and OLI 2015), respectively (Table 8). The overall accuracy is a similar average with the accuracy of each class weighted by the proportion of test samples for that class in the total training or testing sets. Thus, the overall accuracy is a more accurate estimate of accuracy. The Kappa coefficient represents the proportion of agreement obtained after removing the proportion of agreement that could be expected to occur by chance. The Kappa coefficient lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy.

Table 8: Overall classification accuracy and overall kappa coefficient

Year	Overall Classification Accuracy (%)	Overall kappa coefficient
2001	85.00	0.80
2010	91.00	0.89
2015	93.2	0.91

4.2 Estimation of spatial distribution of woody biomass production

Data on the spatial distribution of the estimated woody biomass production was analyzed and the result showed that the estimated woody biomass production was 5844, 5706 and 5972 tons/ha/yr during the periods of 2001, 2010 and 2015, respectively (Figure 16).

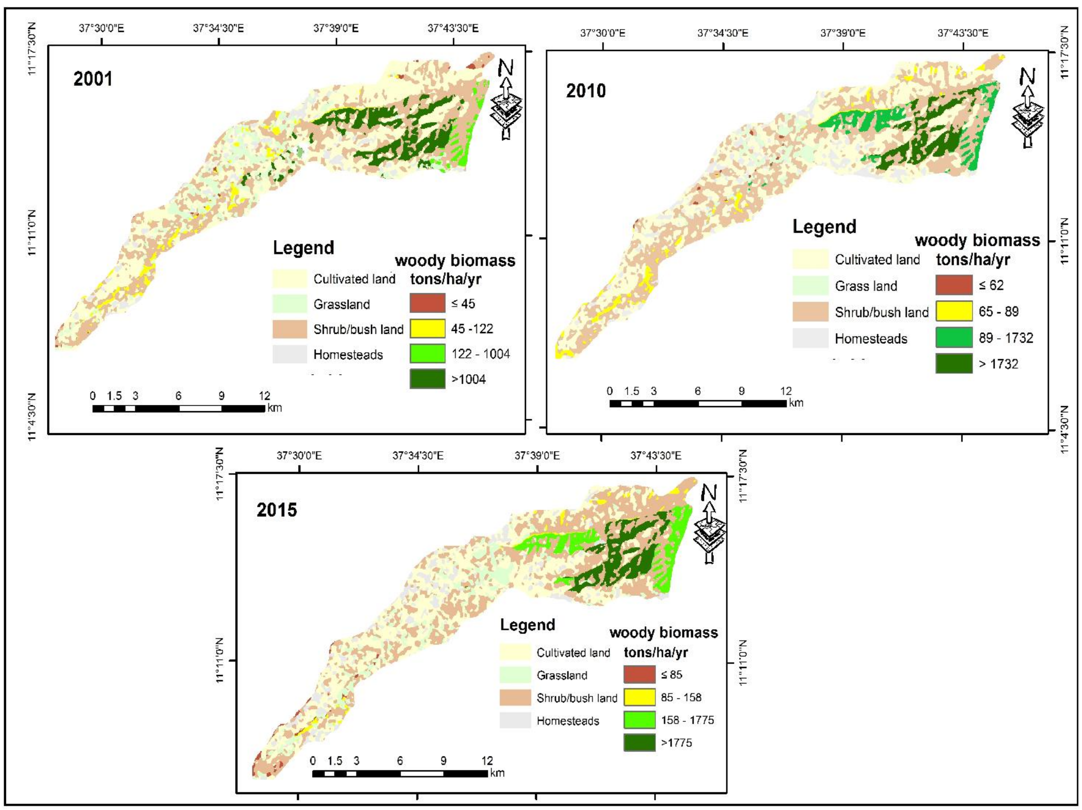


Figure 16: Spatial distribution of the aboveground biomass and estimation of woody biomass (2001, 2010 and 2015)

Figure 16 indicates that, the estimated woody biomass decreased during pre treatment period (2001−2010). During post treatment period (2010−2015), significant increase in the woody biomass area was observed.

4.3 Assessment of vegetation cover using Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is calculated for the Landsat images of the 2001, 2010 and 2015 using the NDVI formula to see how the vegetation cover of the watershed changes over the past periods. The NDVI values for vegetation range from a low of 0.0257125 to high 0.751822 for the year 2001, from a low of -0.0281265 to high 0.676855 for the year 2010 and low -0.0394121 to high 0.7606 for the year 2015, respectively. Non-vegetated surfaces have NDVI values of less than zero and the highest NDVI values represent the maximum vegetation at that period.

The NDVI map in Figure 17 indicates that the vegetation decreased dramatically during the period of 2001−2010 (pre treatment). The decrease may be due to inappropriate land use management. During post treatment period (2010−2015), there was significant increase observed in post-treatment.

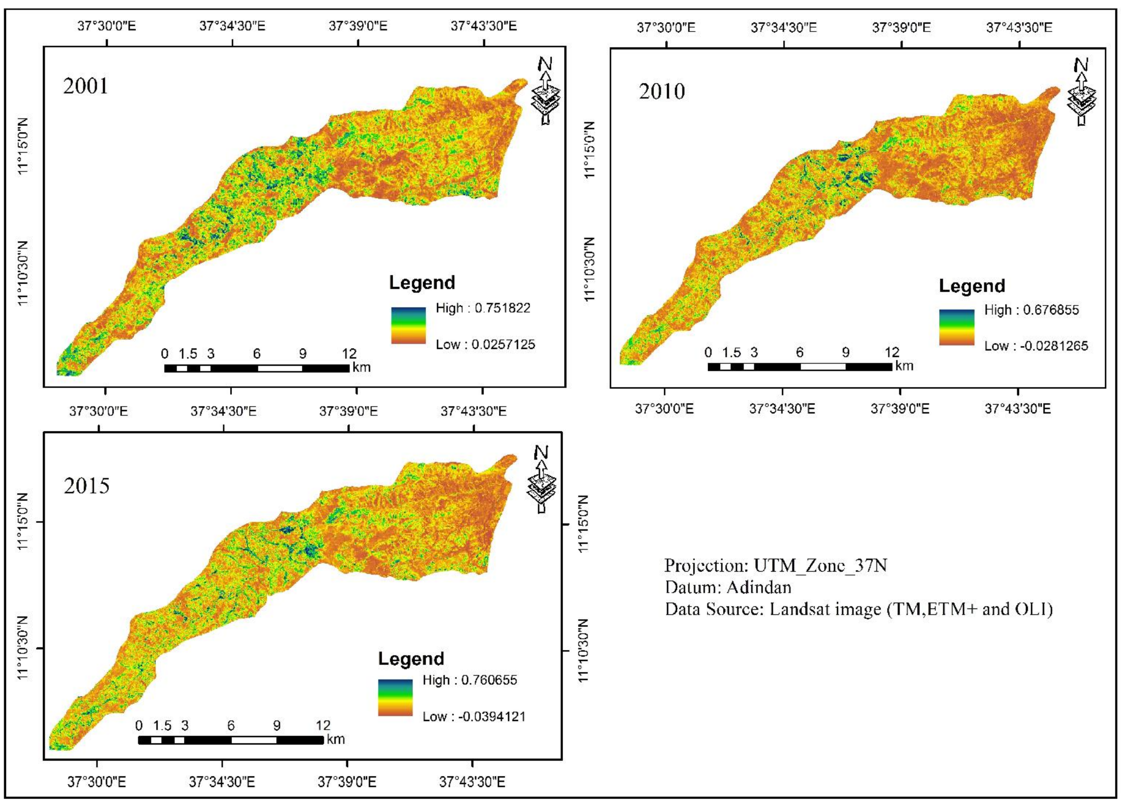


Figure 17: NDVI index based vegetation cover status (2001, 2010 and 2015)

It was also noticed that the NDVI values were higher in the central part of the watershed than the south and east during the study periods. Such indication could be of interest in understanding the hydrology of the area. The value of the NDVI indicates the absence or presence of groundwater assuming that vegetation response to presence of water in the soil. Areas with denser vegetation, i.e. higher NDVI, may indicate areas with higher rainfall and presence of ground water, However, in the northwest and west parts of the watershed the low NDVI indicates limited groundwater or low rainfall zones.

4.4 Assessment of soil loss rates

The annual soil loss rate was determined by a cell-by-cell analysis of the soil loss surface by multiplying the respective RUSLE factor values interactively by using Equation (3.3) in section 3.3.8. The estimated rates of soil loss in the watershed are developed as shown in Figure 18.

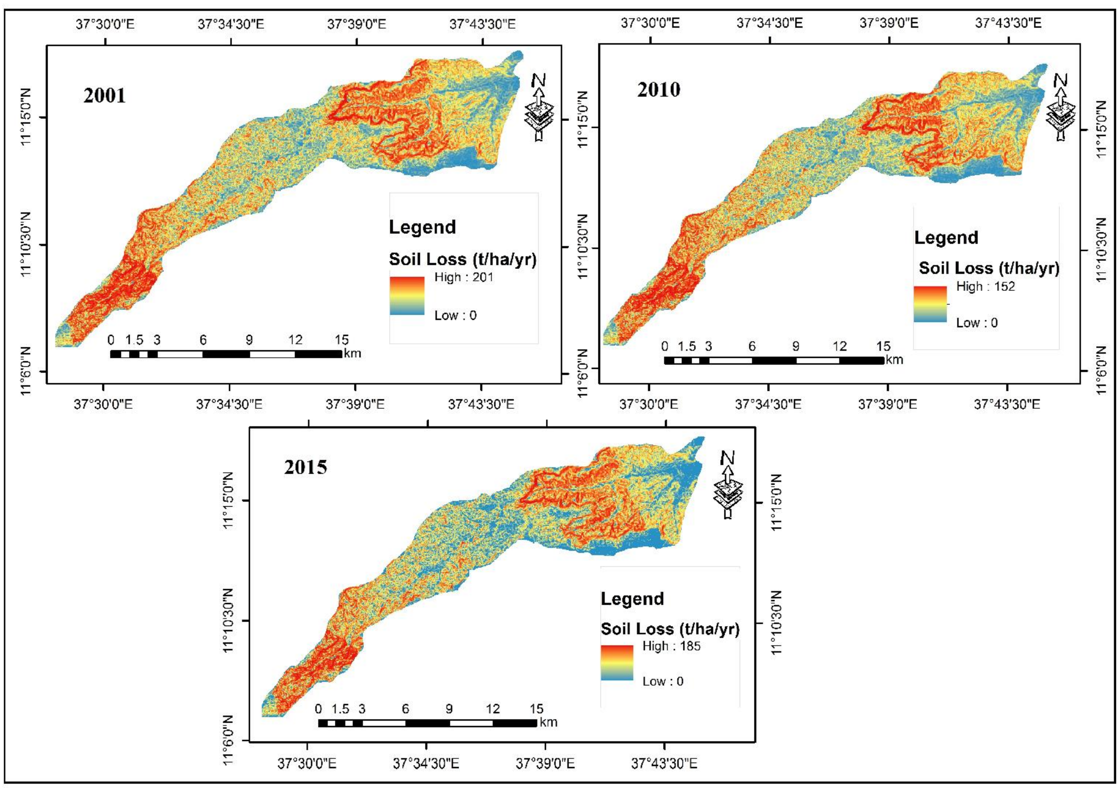


Figure 18: Predicted annual soil loss maps of 2001, 2010 and 2015

For the year 2001, annual soil loss ranged from 0 in the plain area to 201 tons ha^{-1}yr^{-1} in much of the steeper slopes of the banks of the tributaries in the selected watershed. The mean annual soil loss for the entire watershed was estimated at 7.2 tons ha^{-1}yr^{-1}.

For the year 2010, annual soil loss ranged from 0 in the plain area of the study watershed to 152 tons ha^{-1}yr^{-1} in much of the steeper slope banks of tributaries. The mean annual soil loss for the entire watershed was estimated at 7.7 tons $ha^{-1}yr^{-1}$ for 2010. For the year 2015, annual soil loss ranged from 0 in the plain area to 185 tons $ha^{-1}yr^{-1}$ in much of the steeper slopes of the banks of the tributaries in some areas of the study area. The mean annual soil loss for the entire watershed was estimated at 4.8 tons $ha^{-1}yr^{-1}$.

The results for the year 2001 presented in Figure 19 show that about 60.2% of the study area was of low potential erosion risk, while rest of the area was under moderate to high erosion risk. In terms of actual soil erosion risk, 15.7% of the area was of moderate risk, 20.5% was of high risk and 3.7% was of very high risk.In the year 2010, 57.4% of the area was of low potential for erosion risk, 22.7% was of modetare potantial for erosion risk, 15.8% was of high potential for erosion risk and 4.1% area of very high potential for erosion risk. There was an increasing in the area of very high and moderate erosion risk compared with year 2001. The result for 2015 (Figure 19) showed 70% of the area was under low potential erosion risk which was much higher than 2001 and 2010. Erosion risk 17.2% of the area has a moderate erosion risk, 11% a high risk and only 1.8% as very low risk of soil erosion.

The grouping of different soil erosion severity zones was carried out by considering the field conditions. The threshold for each of the risk level was presented in Table 8.

Table 9: Soil erosion severity zones with erosion rate and area covered

Threshold tons $ha^{-1}yr^{-1}$	**Severity Classes**	**Pre-treatment**		**Post-treatment**
		2001 Area (ha)	**2010 Area (ha)**	**2015 Area (ha)**
<5	Low	9022	8581	10452
10	Moderate	3052	3401	2558
25	High	2354	2368	1618
>50	Very high	552	607	269

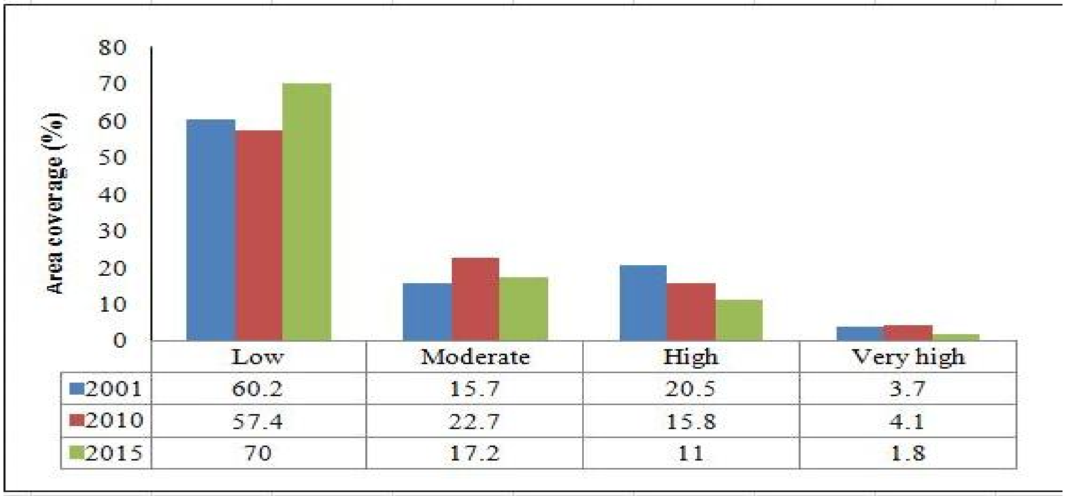


Figure 19: Area coverage for the erosion risk map 2001, 2010 and 2015

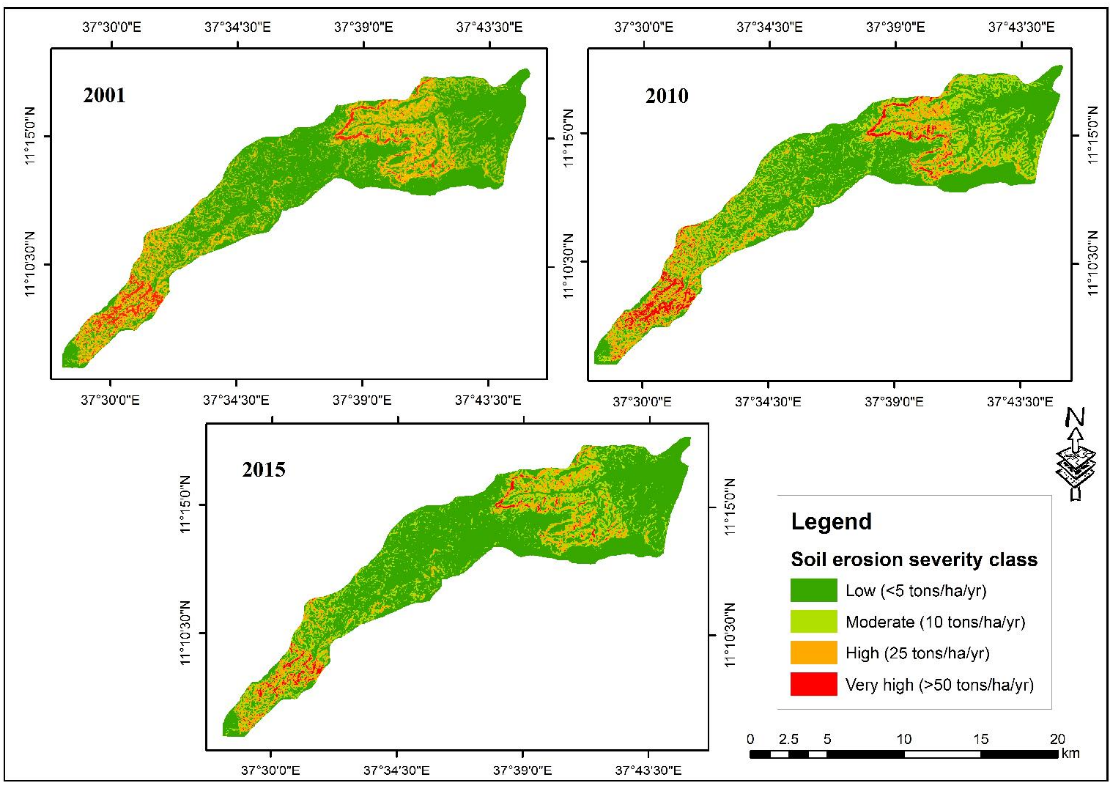


Figure 20: Spatial distribution of classified soil erosion risk maps of 2001, 2010 and 2015

4.5 Soil erosion trends related land-cover changes

Soil erosion trends in the study area were assessed in terms of Normalized Difference Vegetation Index (NDVI). Regarding land-cover, mean NDVI was used as the indicator for land-cover changes. The change detection methods used was NDVI Differencing. Normalized Difference Vegetation Index (NDVI) method is applied according to its charactercterstic like vegetation at different NDVI threshold values such as 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4 and 0.5.

As illustrated in Figure 21, mean NDVI values decrease from 0.25 to 0.15 during pre treatment periods (2001−2010) and increased from 0.15 to 0.23 during post treatment periods (2010−2015).

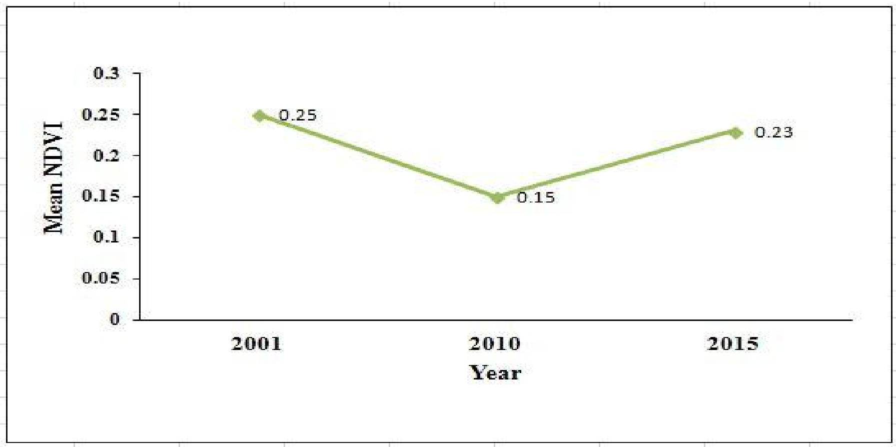


Figure 21: Vegetation cover trends using NDVI index (2001−2015)

The estimated soil erosion increased during 2001−2010, and decreased during 2010−2015. This trend was similar to the NDVI trend discussed before. The NDVI value in the year 2010 was much lower than the year 2001 and 2015. This indicates that soil erosion is more sensitive to changes in vegetation cover.

In more detailed, the histogram in Figure 22 shows a comparison of the NDVI increase and decrease among the three target years. The increasing NDVI indicates better ground cover vegetation condition. The maps showing NDVI changes during the years 2001, 2010 and 2015 are presented in Appendix 4. Vegetation cover in the study area was decreased during the years 2001−2010, which account for 91.1% of the land area. This area was dispersed throughout the watershed. Only 8.9% increase was observed mainly in the central part of the watershed. From 2010 to 2015, 88% of the land area was changed to increasing trend. An increase in NDVI was observed across the watershed. However, 12% of the land coverage area has decreasing. Comparing the year 2001 and 2015, 36% of the land has an increasing trends in vegetation cover.

This indicated that the most of the central part of the study area has got more vegetation cover during post treatment period (2010−2015). However, a regular polygon located in the southwest and east corner had decreased in vegetation cover.

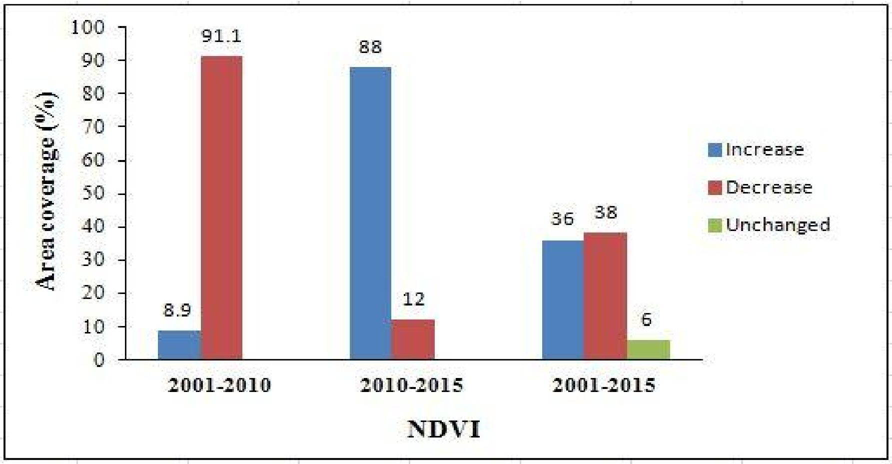


Figure 22: NDVI index based Coverage percentage change in vegetation coverage during the period 2001−2015

The result in soil loss trend indicated that there was an increasing and decreasing trend in mean annual soil loss among the year 2001, 2010 and 2015 (Figure 23).

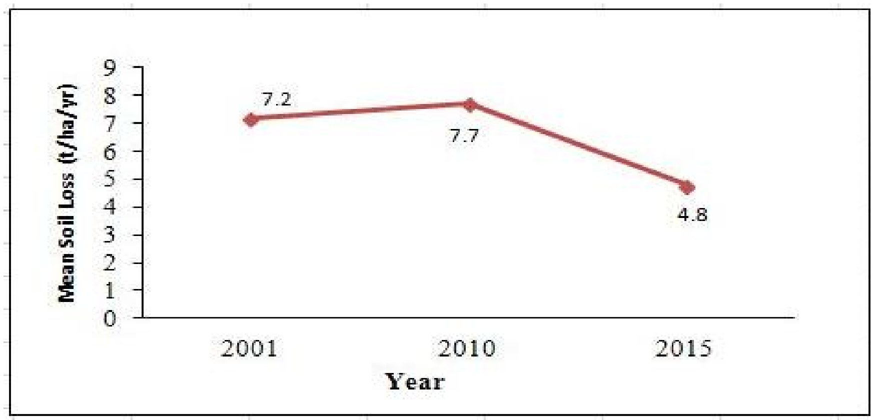


Figure 23: Mean annual soil loss trend from the year 2001−2015

There were an increasing and decreasing trends in the mean annual soil loss during the year 2001, 2010 and 2015 (Figure 23). During pre treatment period (2001−2010), 0.5 metric tons per $ha^{-1}yr^{-1}$ of the study area had an increasing trend of annual soil loss especially in the southwest and eastern parts of the watershed. In the period of post treatment (2010−2015), there was a general decrease in soil erosion risk by 2.9 metric tons $ha^{-1}yr^{-1}$. Areas with higher risk for soil erosion were located in the southwestern and eastern parts of the study area. When comparing the periods 2001 and 2015, soil loss through erosion had significantly decreased by 2.4 metric tons $ha^{-1}yr^{-1}$.

CHAPTER V

DISCUSSION

5.1 The impacts of watershed development program on soil erosion and biomass production

Watershed management implies the wise use of natural resources like land, water and biomass in a watershed to obtain optimum production with minimum disturbance to the environment. Remote sensing and GIS based assessment of natural resources and spatiotemporal change detection studies have predominantly focused on providing the knowledge of how much, where, what type of land-use/land cover change has occurred (Weng, 2002). Proper utilization and management of natural resources depends on the development of effective resource information database. Remote sensing and GIS are one of the key tools which have capability to provide real time information that makes it possible to have meaningful repetitive surveys which can show that changes that have taken place. Satellite image interpretation has enabled to use an objective assessment of monitoring and evaluating of an integrated watershed development program.

There was an expansion of the area of cultivated land during the period 2001−2010. During this period, sparsely wooded land, grass land and shrub grass land have vanished. This was due to the human population pressure, which resulted in the expansion of agricultural activities and settlements. The evidences collected from the survey have revealed that lack of adequate soil and water conservation practices, overgrazing, deforestation and repeated tillage practices were the major problems that pose challenges for natural resource during the study periods. This led to heavy soil erosion from severe flooding. Detection of land-use/land-cover changes for the period 2010−2015 had revealed, the area under grassland, woodland and homesteads has increased. The area under grassland increased dramatically. This improvement in vegetation cover could be attributed to the better soil and water conservation practices through SLM interventions. It was also observed that the area under homesteads was increased. This was because of the increase in human population and construction of new houses (building, water harvesting and storage structures etc).

A similar land-use/land-cover study made by Solomon (1994) in the southern Ethiopia indicated that the influence of land-use /land-cover changes depends very much on the nature of the land and the level of management techniques used. The rapid change in land-use/land-cover of the study area has been driven by factors such as population pressure, expansion of rural towns, large-scale overgrazing, and recurrent drought and poor land management.

Biomass estimation using remotely sensed data is an emerging technology and it is being increasingly used to inventory forest biomass. From the estimation of spatial distribution of woody biomass result maps for the year 2001, 2010 and 2015; it has been observed that the estimated woody biomass decreased during the period 2001−2010 (pre treatment). During the period 2010−2015 (post treatment), significant increase in the woody biomass area was observed after the intervention. This increase may be due to the interventions (transformation of degraded land to plantation, due to adoption of soil and water conservation practices, better utilization of surface and groundwater). Similar study by Sheikh *et al.,* (2011) estimated the carbon storage in India's forest biomass for the years 2003, 2005 and 2007 using secondary data of growing stock data and satellite data and revealed that there was a continuous decrease in the carbon stock in India's forest biomass since 2003, despite a slight increase in forest cover (India State of Forest Report, 2003, 2005 and 2009). Lu D (2005) also conducted a study to estimate the above-ground biomass in the Brazilian Amazon using Landsat TM data. These studies showed that the use of Landsat TM image for estimating forest above-ground biomass was more successful for successional forest rather than mature forests.

Normalized Difference Vegetation Index was calculated for the Landsat images of the 2001, 2010 and 2015 to understand how the vegetation cover of the watershed changed over time and used as a land-management factor (an input into the RUSLE model) representing the effect of soil disturbing activities, land-cover and vegetation productivity on soil erosion. The change in vegetation cover status of watershed was assessed using NDVI for the year 2001, 2010 and 2015. There was an improvement in the vegetation cover owing to implementation of various soil and water conservation measures, which was reflected in the NDVI images of the present investigation.

The rehabilitation of vegetation in many places of the watershed has improved the vegetation cover. Farmers also confirmed during focus group discussions, that the vegetation cover has increased and the change that has been observed at present was the result of the intervention i.e. the establishment of area enclosures. This increase may be due to adoption of soil and water conservation practices, better utilization of surface and ground water. A similar study also using NDVI as a land-cover management factor to determine the vulnerability to erosion of soils was carried out in a forested mountainous sub-watershed in Kerala, India (Prasannakumar *et al.,* 2012). In such studies, NDVI proved to be a useful indicator of land cover condition and a reliable input into models of soil dynamics.

Revised Universal Soil Loss Equation (RUSLE) is a straightforward and empirically based model that has the ability to predict long-term average rate of soil erosion. In the present research, annual soil erosion rate map was generated for study area. The estimated soil loss rate and the spatial patterns are generally realistic and in agreement with results from previous studies. In the Highlands of Ethiopia and Eritrea soil losses are extremely high with an estimated average of 20 metric tons $ha^{-1}yr^{-1}$(Hurni, 1985a) and measured amounts of more than 300 tons $ha^{-1}yr^{-1}$on specific plots. Hurni (1993) estimated mean soil loss from cultivated fields as 42 tons $ha^{-1}yr^{-1}$. A similar soil loss estimation study made by Bewket and Teferi (2009) in the Blue Nile Basin, Ethiopia indicated that the estimated average annual soil loss for the entire Chemoga watershed was 93 tons $ha^{-1}yr^{-1}$ and also the average annual soil loss estimated by USLE from the entire medego watershed of northern Ethiopia was also 9.63 tons $ha^{-1}yr^{-1}$(Gebreyesus and Kirubel, 2009). Revised Universal Soil Loss Equation (RUSLE) model was critically applied using an integrated remote sensing and GIS approach in a raster environment so as to obtain maps for each RUSLE factor. Its simplicity and statistical relationships between input and output variables make it adaptable to other environments (Morgan, 1986 and Soil and Water Conservation Society, 1994).

The positive impact of the integrated watershed development program (IWSDP) in the study area could be explained in terms of reduced soil erosion rates, and increased soil moisture availability, which resulted in the increased in crop production, reduced sedimentation and flooding problems in the lower parts of the watershed, stabilized gullies and river banks, rehabilitation of degraded lands and improved ecological balance in the area. This could be associated with watershed management practices implemented by SLM project.

Similar studies elsewhere in northern Ethiopia (Woldeamlak, 2003; Liu *et al.,* 2008; Nyssen *et al.,* 2008) also reported the effectiveness of sustained conservation efforts in catchments in controlling soil erosion and in improving hydrology and land productivity of the area.

The present investigation has demonstrated that the estimation of soil loss rate using RUSLE modeling, land-use/land-cover change detection, and estimation of woody biomass and assessment of vegetation cover using Normalized Difference Vegetation Index (NDVI) is a good agreement with those obtained by other studies.

CHAPTER VI

CONCLUSTION AND RECOMMENDATIONS

6.1 Conclusion

This study attempts to assess the impact of watershed development program on soil erosion and biomass production from 2001 to 2015 (pre-treatment to post-treatment) using remote sensing and GIS approach in Yezat watershed, west Gojam zone, Amhara region, Ethiopia. The use of satellite data using advanced techniques such as remote sensing and geographic information system (GIS) can assist for evaluating the spatiotemporal changes and trends of soil erosion and biomass production. Spatiotemporal variation of soil erosion, vegetation cover, land-use/land-cover patterns and estimation of spatial distribution of woody biomass are detected and mapped with the help of remote sensing and GIS techniques. The obtained results are agreement with the ground surveyed information and with some of the recent previous studies. Hence, assessment the impact of watershed development program using satellite data are paramount importance in order to evaluate the pre and post watershed intervention conditions and generate baseline information that helps to monitor and evaluate real time situation in the future for different adaption options within relatively large geographical area and repetitive time scale coverage.

The major changes in the watershed due to implementation of integrated watershed development programs are having reflections in the development of vegetation cover, agricultural land use, reduced soil erosion and rehabilitation of degraded lands. This improvement in reducing erosion, improving water resources and reestablishing vegetation cover could be attributed to the better soil and water conservation practices through SLM interventions. Farmers are satisfied with the status of their current land holding. Based on the interview, field observation and the obtained results, the major observed changes after the implementation of integrated watershed development are: reduced soil erosion, and increased soil moisture availability which could be explained by the increase in crop production, reduced sedimentation and run off problems in the lower parts of the watershed, stabilized gullies and river banks, rehabilitation of degraded lands and improved ecological balance. This study reconfirms the importance of IWDP as a key to improve the status and utilization of watershed resources in response to sustainable land management interventions and sustainable livelihood.

It was observed that the monitoring and evaluation of watershed development program using remote sensing data is cheap, rapid, and accurate and release with the repetitive coverage. Thus, the remotely sensed data potentially offers a rich source of information for planning, management and development on the earth's surface that change cover time. Thus, it is hoped that the findings of this research will contribute to developing future watershed resources management strategies in response to sustainable land management.

6.2 Recommendations

Based on the findings of the study, the following recommendations are suggested.

- As this study indicated, satellite data proposes an ideal solution to impact assessment of integrated watershed development programs on soil erosion control and biomass production. Therefore, for enhanced results, it is recommended that high resolution satellite data such as IKONOS, Quick Bird and GeoEye coupled with advanced digital image processing techniques and to study the success and progress of the implementation of such watershed development programs.

- For future studies working on this field, more target years are suggested to be treated on.

- The methods as well as results of evaluation of watershed development program in soil erosion control and biomass production area believed to be highly important for decision makers and stakeholders, who have a stake in the study area. However, it is recommended that the future studies can build up on this work by including ground water recharge and socio-economic importance to evaluate overall impacts so as to make decision and draw important lessons.

- Ecological changes caused by the destruction of natural vegetation, removal of soil by erosion and drying out of rivers as the result of mismanagement of land-use has been reversed as a result of the integrated watershed development interventions. While, the IWDP intervention researched shows encouraging results for both vegetation cover and soil erosion control. Therefore, the study highly recommends the up-scaling of such intervention in similar agro-ecologies across Ethiopia.

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Appendices

Appendix1. Questionnaire

This questionnaire is prepared to collect data about soil erosion, vegetation cover and land-use/land-cover changes, their impacts and implications for assessing the impact of watershed development Programs on soil erosion and biomass production from the study area (Yezat watershed), West Gojam Zone of Amhara Region, Ethiopia. It is expected to generate and provide helpful information for policy makers and development practitioners about trends and changes in soil erosion, vegetation cover and land use in relation to land conservation and productivity enhancing practices. Therefore, your inputs as a stakeholder to fill this questionnaire is highly appreciated and information provided will stay confidential and your right to involve or not is also respected.

Part I-General background information

1. Region …………………..Wereda………………… Kebele …………………………..

2. Date of Interview ……......................Data Entry by ……………

3.Name of interviewee………………Age……..Position in the Household ……………

4. Total land owned................. (‘Kada’).................

Type of land	Approximate Size of each parcels of land		
	Before the program	Now	Reason
Cropland – rainfed			
Cropland – irrigated			
Grazingland (private, Communal)			
Forest / woodland			
Plantation			
Homestead			
Gully, Closed area/hill			

Part II-Soil and Water related issues

5. What are the major problems associated with land and water resources?

6. What are the practices that you were using to address the same?

7. What are the interventions that the SLM program has introduced?

8. How do you evaluate their effect in reducing the problem?

Technology/practices	**Benefits**[1]	**Drawbacks**[2]	**Overall assessment**[3]

[1] 1: Low; 2: moderate; 3: high; 4: very high

[2] 1: None; 2: Few; 3: Many and [3] 1: not beneficial; 2=beneficial; 3: Highly beneficial

9. List the major trees/shrub species found on your farmland before and after the program.

S/N	**Local name**	**Before**	**After**	**Use**[4]
1				
2				
3				
4				

[4] 1: construction; 2: firewood; 3: fodder; 4: shelter; 5: fruits; 6: conservation; ….

10. What major shifts in land use occurred during the period 2001─2015 G.C? (Provide qualitative description; +, - & No change)

11. Did the total area you cultivate have a change from year to year?

12. Describe land lost[1] or additional land gained[2] during the last 14 years and associated factors?

[1] *it may include land provided to new weds, taken by government, abandoned due to degradation or others.*

[2] *it may include those gained through redistribution, conversion of hillsides, transferred from relatives*

13. How do you evaluate the trend of land degradation the last 14years?

Appendix2. Meteorological data used for Soil erosion modeling

Table 2.1: Average monthly rainfall (mm) data of five stations (1986−2001)

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adet	7.3	2.6	25.8	51.4	100.2	153.5	308.8	254.9	179.8	115.5	33.4	5.5
Dembecha	9.4	6.8	37.2	58.7	107.0	219.5	330.4	259.1	191.5	112.1	46.6	11.1
Debrework	0	0.8	6.9	34.4	64.7	192.9	343.3	203.8	165	53.9	11.8	5.2
Finote selam	7.6	9.1	31.5	55.3	105.4	178.9	293.3	210.4	142.8	87.2	24.4	12.6
Zege	3.0	0.8	12.6	32.6	93.0	195.4	417.8	398.5	218.7	69.6	5.6	0.4

Table 2.1: Average monthly rainfall (mm) data of five stations (1995−2010)

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adet	0.7	2.5	6.0	25.4	71.0	171.3	400.5	388.9	207.1	66.8	9.8	2.9
Dembecha	8.0	4.1	44.3	53.5	100.0	218.8	333.6	288.3	193.1	115.6	40.2	12.5
Debrework	8.0	4.1	44.3	53.5	100.0	218.8	333.6	288.3	193.1	115.6	40.2	12.5
Finote selam	7.4	8.3	24.3	69.7	138.5	190.0	293.0	226.9	144.7	82.6	35.4	18.8
Zege	3.2	0.1	11.4	24.6	83.2	228.4	479.4	444.0	248.6	92.7	8.0	0.3

Table 2.3: Average monthly rainfall (mm) data of five stations (2000−2013)

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adet	8.3	4.1	17.8	54	94	153.5	337.9	253.9	175.1	95.6	15.9	11.4
Dembecha	5.0	4.7	48.6	41.3	82.6	194.3	312.5	294.5	195.7	109.7	36.2	11.0
Debrework	2.5	0.8	6.9	35.4	74.7	192.9	303.3	203.8	155.9	53.9	11.8	5.2
Finote selam	7.4	8.8	24.3	68.8	131.8	181.0	302.2	226.6	131.3	84.9	34.8	19.5
Zege	0.3	0.1	8.1	35.5	68.7	205.5	476.9	457.3	272.4	77.2	5.7	0.1

Table 2.4: Climatic Stations in Proximity to study site and erosivity (R) value

Station Name	Lat	Long	Elevation	Erosivity (R) Value		
				2001	2010	2015
Adet	11.26645	37.495035	2118	805.72	904.51	895.52
Dembecha	10.571873	37.313485	2117	687.47	752.1	678.36
Debrework	10.64963	38.169363	2508	642.96	691.29	678.36
Finote selam	10.717113	37.495035	1840	772.67	785.48	742.92
Zege	11.68192	37.313485	1801	599.41	631.72	580.35

Appendix3. Confusion matrix of the Land-use/land covers classification accuracy assessment

Table 3.1: Confusion matrix of the Land-use/land cover Classification in year 2001

		Reference Data						
Classification Data		CL	H	GL	WL	S/BL	Total	User Accuracy (%)
	CL	10	0	0	0	0	10	100
	H	4	5	1	0	0	10	50
	GL	0	0	10	0	0	10	100
	WL	0	0	1	9	0	10	90
	S/BL	0	0	0	0	10	10	100
	Total	14	5	12	9	10	50	
Producer accuracy (%)		71.43	100	83.33	100	100		

Table 3.2: Confusion matrix of the Land-use/land cover Classification in year 2010

		Reference Data						
Classification Data		CL	H	GL	WL	S/BL	Total	User Accuracy (%)
	CL	15	1	1	2	0	19	78.95
	H	0	19	1	0	0	20	95
	GL	1	0	19	2	0	22	86.36
	WL	1	0	0	18	0	19	94.74
	S/BL	0	0	0	0	20	20	100
	Total	17	20	21	22	20	100	
Producer accuracy (%)		88.24	95	90.48	81	100		

Table 3.3: Confusion matrix of the Land-use/land cover Classification in year 2015

		Reference Data						
Classification Data		CL	H	GL	WL	S/BL	Total	User Accuracy (%)
	CL	18	1	3	0	1	23	78.26
	H	0	20	0	0	0	20	100
	GL	0	0	15	0	0	15	100
	WL	0	0	0	20	0	20	100
	S/BL	0	0	1	1	23	25	92
	Total	18	21	19	21	24	103	
Producer accuracy (%)		100	95.24	78.95	95.24	95.83		

Users accuracy = number correct/classified total

Producers accuracy = number correct/reference total

Note: CL= cultivated land, H=homesteads, GL= grassland, WL= woodland and S/BL=shrub/bush land

Appendix4. NDVI index based change in vegetation coverage during the period 2001−2015

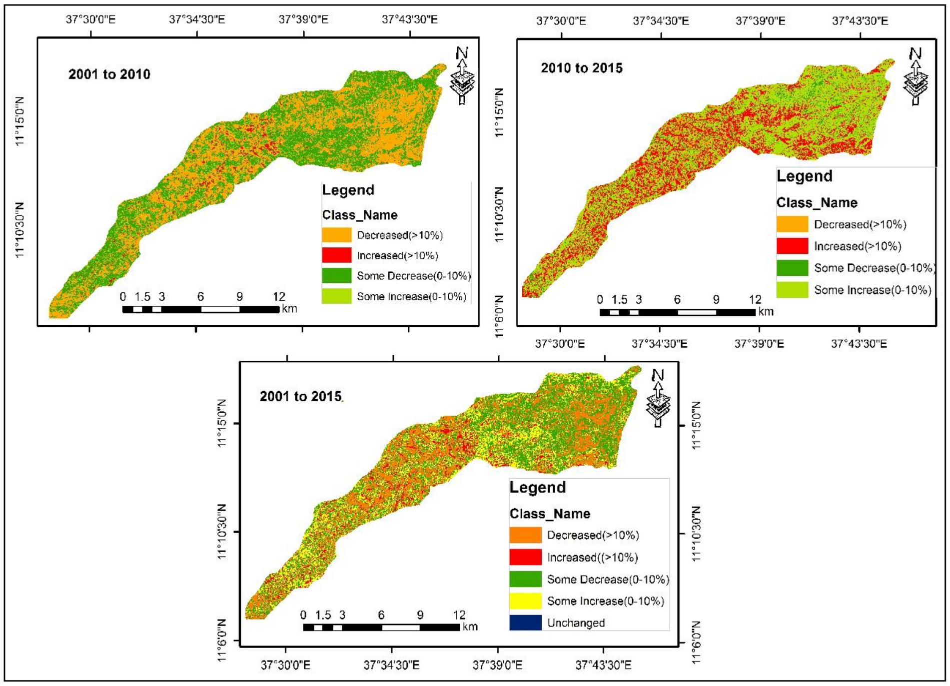

Figure 4.1: NDVI change detection map of the study area during the period 2001−2015

Appendix5. Partial view of physical soil and water conservation structures part of the watershed

Figure 5.1: Physical soil and water conservation structures part of the improved land management in the Watershed

Figure5.2: Pictures showing rehabilitated gullies

D E C L A R A T I O N

I hereby declare that the thesis entitled "Assessing the Impact of Watershed Development Programs on Soil Erosion and Biomass Production Using Remote Sensing and GIS: The Case of Yezat Watershed, West Gojam Zone of Amhara Region, Ethiopia" has been carried out by me under the supervision of Dr. K.V. Suryabhagavan, Associate Professor, School of Earth Sciences, College of Natural and Computational Sciences, Addis Ababa University, Addis Ababa during the year 2015−2016 as a part of Master of Science program in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Lemlem Tadesse

Signature: ___________________

Addis Ababa University

Addis Ababa

Date: Jun, 2016

C E R T I F I C A T E

This is certified that the thesis entitled "Assessing the Impact of Watershed Development Programs on Soil Erosion and Biomass Production Using Remote Sensing and GIS: The Case of Yezat Watershed, West Gojam Zone of Amhara Region, Ethiopia" is a bonafied work carried out by Lemlem Tadesse under my guidance and supervision. This is the actual work done by Lemlem Tadesse for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University. Addis Ababa, Ethiopia.

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Date: Jun, 2016