JIMMA UNIVERSITY

COLLEGE OF SOCIAL SCIENCES AND HUMANITIES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

ANALYSIS OF THE IMPACTS OF LAND USE/LAND COVER CHANGE IN TRIGGERING SOIL EROSION IN GILGEL GIBE SUB-CATCHMENT OF OMO-GIBE BASIN; SOUTHWEST ETHIOPIA.

BY: BERHANU ABERA TESEMA

A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (M.Sc.) IN GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING,

JULY, 2021

JIMMA UNIVERSITY, ETHIOPIA

JIMMA UNIVERSITY

COLLEGE OF SOCIAL SCIENCE AND HUMANITIES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

ANALYSIS OF THE IMPACTS OF LAND USE/LAND COVER CHANGE IN TRIGGERING SOIL EROSION IN GILGEL GIBE SUB-CATCHMENT OF OMO-GIBE BASIN; SOUTHWEST ETHIOPIA.

BY: BERHANU ABERA TESEMA

A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY, IN PARTIAL FULFILMENT OF THE REQUIRIMENT FOR THE DEGREE OF MASTER OF SCIENCE (M.Sc.) IN GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING.

MAIN ADVISOR: KEFELEGN GETAHUN (PhD)

CO-ADVISOR: Mr. KASAYE AMBAYE (M.Sc.)

JULY, 2021

JIMMA UNIVERSITY, ETHIOPIA

Declaration

I whom declare that, the thesis entitled "Analysis of the impacts of land use land cover change in triggering soil erosion in Gilgel Gibe sub catchment of Omo-Gibe Basin, Southwest Ethiopia" is a result of my own research investigations and findings. All the materials and methods used for this work other than my own have been acknowledged and a reference list has been appended.

Name --- Signature ……………... Date ……………

Approval Sheet

JIMMA UNIVERSITY COLLEGE OF SOCIAL SCIENCE AND HUMANITIES

Thesis Submission Request Form

Name of Student: Berhanu Abera Tesema

Program of Study: Degree of Masters of Science (MSc. Department of Geography and Environmental Studies (Specialization for GIS and Remote Sensing)

Title: **Analysis of the impact of land use land cover change in triggering soil erosion in Gilgel Gibe sub catchment of Omo Gibe Basin, Southwest, Ethiopia.**

I have completed my thesis research work as per the approved proposal and it has been evaluated and accepted by my advisors. Hence, I hereby kindly request the department to allow me to present the findings of my work and submit the thesis.

Name: Berhanu Abera Signature: ______ Date: 12/07/2021

We have evaluated the content of this thesis and found to be satisfactory executed according to the approved proposal, written according to the standard and format of the University and is ready to be submitted. Hence, we recommend the thesis to be submitted.

Kefelegn Getahun (PhD) (Main Advisor)	______ (Signature)	14/7/2021 (Date)
Kasaye Ambaye (MSc) (Main Advisor)	______ (Signature)	14/07/2021 (Date)

Decision/suggestion of Department Graduate Council (DGC)

____

____

______ (DGC)	______ (Signature)	__/__/__ (Date)
______ (Chairperson, CGS)	______ (Signature)	__/__/__ (Date)

i

Approval:

1. Main Advisor: Kefelegn Getahun (PhD) ____________ ____________
(Name) (Signature) (Date)

2. Co-advisor: - Mr. Kasaye Ambaye (MSc) ____________ ____________
(Name) (Signature) (Date)

3. Internal Examiner: - Kenate Worku (PhD) ____________ ____________
(Name) (Signature) (Date)

4. External Examiner: - Mersha A. (PhD) ____________ ____________
(Name) (Signature) (Date)

5. Chairperson__________________________ ____________ ____________
(Name) (Signature) (Date)

Acknowledgments

First of all, I would like to thanks to the Almighty GOD who made everything possible, not only to begin and finish this work successfully, but also for his protection and favor in my entire life.

I would like to express my special thanks to my advisor, Kefelegn Getahun (PhD) and Mr. Kasaye Ambaye who patiently read/edits the manuscript and provides me valuable comments and innocent advice throughout my thesis work.

I would particularly like to thanks Mr. Abdo Abdulkadir and Mr. Misbahudin Abdulmajid for providing me with the opportunity to work in the best conditions and also to all Jimma Zone Land Use and Administration office staff members who collaborated and supported me during my work. My deepest gratitude also goes to NMA/WOSC, Jimma Zone Agriculture & Rural Development office, four woredas rural land administration and Agriculture Development offices experts, Officials and community members for providing me the valuable data for this work.

I can’t find words powerful enough to express my profound feeling to my family (my daughter Heran Berhanu, my wife Tihitina Benti and brother-in-law Mr. Sabsibe Kumera) for their moral support and encouragement to mold me as what I am on the present state and without whom my life would not have been successful.

Lastly, I would like to convey my special thanks to my colleagues, for sharing wisdom and experiences as well as spending smart time in the course of three years graduate program.

Table of Contents

Contents **Page №**

Lists of Tables

Lists of Figures

List of Acronyms

ASTER -------- Advanced Space-borne Thermal Emission and Reflection Radiometer

CSA ------------ Central Statistical Authority

DEM ----------- Digital Elevation Model

EHRS ----------- Ethiopian Highland Reclamation Study

EGIA ----------- Ethiopian Geospatial Information Agency

EPA ------------ Environmental Protection Agency

ERDAS -------- Earth Resource Data Analysis System

ETM + -------- Enhanced Thematic Mapper Plus

FAO ----------- Food and Agricultural Organization

FDG ------------ Focus Discussion Group

GCP ----------- Ground Control Point

GIS ----------- Geographic Information System

GPS ----------- Global Position System

HWSD -------- Harmonized World Soil Database

LU/LC ------- Land use / Land cover

LULCC ------ Land use /Land cover change

NDVI -------- Normalized Difference Vegetation Index

NIR ----------- Near Infrared

NMA ---------- National Metrological Agency

OLI/TIRS ----- Operational Land sat Imageries Thermal Infrared

RUSLE ---------- Revised Universal Soil Loss Equation

SPSS ------------- Statistical Package for the Social Sciences

TM --------------- Thematic Mapper

UNCCD --------- United Nations Convention to Combat Desertification

USGS ----------- United State Geological Survey

USLE ------------ Universal Soil Loss Equation

UTM ----------- Universal Transverse Mercator

WGS ----------- World Geodetic System

WOMSC ------ Western Oromia Meteorological Service Center

Abstract

Recently, Land Use and Land Cover Change (LULCC) and their impacts on natural resources have gained increased attention. This study aimed at analyzing the impacts of LULCC in triggering soil erosion using GIS and remote sensing techniques integrating RUSLE model in Gilgel Gibe sub catchment of Omo Gibe basin, Southwestern Ethiopia. To analyze LULCC during study periods, Landsat images of 1991 (TM), 2005 (ETM+) and 2019 (OLI/TIRS) were used. Additionally, Digital Elevation Model (DEM), computed Land Use/Land Cover (LU/LC) maps, rainfall and soil data were used as sources of data to analysis LULCC impacts on soil erosion and to identify the most erosion prone areas. Accordingly, cultivated land, settlement area and water body were increasing at the expense of sharply reduction in forest, bush and grass lands. The high level of conversion to cultivated land at the expense of forest and bush land classes is confirmed in the area which implies that how much the area is prone to soil erosion hazard. Results from RUSLE factors determination indicated that the highest value in R-factor, K-factor and LS-factor were more of recorded in areas with steep slopes of the study area whereas the highest value in C and P-factors are recorded in cultivated land and the lowest were in water body. The result showed that the annual mean soil loss which was 24.81ton/ha/yr. in 1991 was increased to 56.67ton/ha/yr. in 2005 and 83.6ton/ha/yr. in 2019. This is due to the expansion of cultivated land without appropriate conservation measures, increment of settlement area, with other factors such as spares land cover and steep sloping terrain are the main causes for the increasing of mean soil erosion rate. The spatial distribution of soil erosion risk classes between 1991-2019 showed an increasing trend in the study area, that is, it increased from slight, moderate to severe and very severe classes while areas under very slight soil erosion risk class decreased sharply. Furthermore, results indicated that the trend of potential soil loss in the three study years indicates that a sharp increase for cultivated lands, settlement areas, forest and bush lands; whereas the reduction of forest and bush lands LU/LC classes and an increment of cultivatedl and settlement LU/LC areas are the main indicators of LULCC impacts on soil erosion. Particularly, about 0.01% of area in 1991, 0.04% area in 2005 and 4.12% area in 2019 of the study areas was subjected to erosion prone areas which needs prior intervention for implementation of the soil erosion controlling mechanisms and the other mitigation measures.

Key Words: *LULCC, Soil Erosion, RUSLE, Gilgel Gibe Sub-catchment, GIS, Remote Sensing*

CHAPTER - ONE

1. INTRODUCTION

1.1. Background

According to UNCCD (1994) Land Use/Land Cover (LULC) change is one of the most serious global environmental issues. Recently, land use/land cover change (LULCC) and their impacts on natural resources have gained increased attention (Lambin et al., 2003). Changes in land use have occurred at all times in the past, presently ongoing, and is likely continuing in the future producing a shift on earth surface for centuries. However, the current rates and magnitudes of LULCC are unprecedented and driving soil erosion and environmental change worldwide (Lambin et.al. ,2003). Similar study reveals that rapidly growing human population, expansion of agricultural land and natural factors have become the main factors causing Soil Erosion (Degbelo, 1996; Habtamu & Amare, 2016; Alemayehu et al., 2018).

In Ethiopia significant land-cover changes have occurred since the last century. These changes are primarily due to human induced factor, which is linked with the population increase and due to land use changes, including deforestation, over grazing, and improper cultivation of agricultural land which led to accelerated soil erosion and associate soil nutrient deterioration. Soil degradation in the form of plant nutrient depletion is the major environmental problems in the highlands of Ethiopia (Hurni, 1988; Eleni et al., 2013).

Currently in Ethiopia the concerns of energy, food security and environment with regard to LULCC which result soil erosion and deforestation are becoming very important issues (Gete and Hurni, 2001) and has become a central component in current strategies for managing natural resources and monitoring environmental changes.

In the study area LULCC is the major environmental problem causing soil erosion. This is mainly due to the development of Gilgel Gibe I Hydroelectric dam and rapid population growth attributed by expansion of agricultural land to meet food security (Bahiru, 2010). On the other hand, area with variety of physiographic features, deforestation, inappropriate agricultural practices such as over cultivation and overgrazing and inappropriate institutional and policy application is aggravating the problem (Mertens, 2013).

The studies done by Kasahun (2001); Bahiru (2010) has indicated that resettlement program conducted in the study area was the major factors changing LU/LC of the area. These changes and other related human induced factors such as increased demand for forests for construction and fuel, expansion of farm lands to steep and marginal areas have contributed to soil degradation. Area that was known with abundant forest covers especially the Gilgel Gibe watershed and other surrounding watersheds is almost become exhausted. The depletion of natural resource and environment has exacerbated accelerated soil erosion and the situation is still putting pressure the study area under risk.

To this extent there is not much established knowledge currently on the influence of LULCC on soil erosion in the area of intervention. This study tries to fill the gap of knowledge by bridging the LULCC analysis and its impact on soil erosion in the study area. Thus, investigation of the effect of LULCC on soil erosion using Geospatial technique were carried out to analyze the LULCC in relation to indicating soil erosion risk area.

Therefore, in this study, RUSLE model is used to estimate soil loss for Gilgel Gibe Sub Catchment and all factors map of the models are integrated in GIS environment. It is to be integrated with GIS to determine all parameters of these models for natural resources management and conservation response is very essential.

1.2. Statement of the Problem

Land use and land cover change through inappropriate agricultural practices and high human and livestock population pressure have led to severe land degradation in the Ethiopian highlands (Hurni et al., 2015; Tsegaye, 2019). This has led to further degradation such as biodiversity loss, deforestation, soil erosion and soil quality (Biniam,2012; Alemayehu et al., 2018). LULCC especially the conversion of forest to agricultural land and expansion of farm land to steep slope and marginal land are generating a wide scale soil erosion and land degradation in Ethiopia (Muleta, 2015; Ali, 2009). The expansion of cropland could increase the susceptibility of soils to erosion. Particularly, soil erosion would be more serious with the transformation of the steep mountain forest land, shrub land and wood land covers into cropland in Omo Gibe basin (Dagnachew et al., 2020).

In the last decades the development in the Gilgel Gibe catchment such as the construction of Gilgel Gibe I hydropower dam, the conducted resettlement program (Bahiru,2010), expansion of urban centers and the development of infrastructure have led to rapid changes in LULC. The diversification and intensification of socioeconomic development in the catchment over the last twenty years has increased the vulnerability of the population to environmental degradation. Land cover changes from natural to other land uses tend to disturb the natural ecosystem equilibrium (Dwivedi et al., 2005). Environmental degradation in the catchment has altered dramatically the social and ecological relationship between society and environment since activities attempting to make profit from the land have been going on for many years (Robin et al., 2000).

A strong potential for increased agricultural productivity is environmentally challenging south western Ethiopia and this is mainly due to deforestation, Poor land management practices coupled with the rugged topography, erosive rainfall regime in the area and nutrient depletions pose major threats both to the livelihood of the farmers and the life span of the Gilgel Gibe I dam (Negash and Mesfin, 2011). In addition, data obtained from the Jimma Zone environmental protection, forest and climate change authority, (2020) and field observation confirm that the amount of forest cover in the catchment is declining at an alarming rate. Most areas which were covered by the remaining forest during the previous government were converted to farm land and built-up areas few years ago and now some of these areas were made prone to extreme degradation. The expansion of farming on to the steep slopes has been observed while it is on the way of reaching an upper limit where it could no longer be expanded further.

The expansion of crop land and settlement into the dense forest areas to satisfy demand for food, charcoal sale and production, using firewood and other consumables in southwestern Ethiopia have resulted in widespread problems of deforestation and LULC changes (Getahun et al., 2017). On the other hand, Broothaerts et al. (2012) emphasis that removing the natural land resources, human land use practices were recognized as a driving force in initiating geo-environmental hazards such as the landslides occurred over the cleared and farmed hillside surfaces in Gilgel Gibe catchment. This implies that knowledge of the effects of LULCC on soil loss is important for effective and sustainable land resource monitoring and planning. Thus, the current study aimed to present the impacts of LULCC on soil erosion by identifying and indicating erosion risk areas for the study area using RUSLE model integrating with geospatial techniques.

Therefore, an attempt was made in this study to quantify and map the status of LULCC and its influence on soil erosion of Gilgel Gibe sub catchment of Omo- Gibe basin with a view of detecting soil erosion prone areas. This helps to predict possible changes that might take place in this status in the future by providing spatio-temporal information for decision maker and planners using both Geographic Information Systems and Remote Sensing technique by integrating RUSLE model.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this study is to analyze the impact of land use land cover change in triggering soil erosion between 1991 and 2019 in Gilgel Gibe sub catchment of Omo-Gibe River basin using both GIS and remote sensing techniques integrating RUSLE model.

1.3.2. Specific Objectives

- To quantify and map the magnitude and/or rate of land use land cover changes of the study area over the last three decades.
- To map and quantify the rate of soil erosion risk in the area by using RUSLE model over the specified time periods.
- To investigate the impacts of land use land cover change on soil erosion risk for the study sub-catchment.

1.4. Research Questions

Based on the above-mentioned specific objectives the following research questions was developed to guide the study.

- How the spatio-temporal magnitude and/or rate of LULCC occurred in Gilgel Gibe sub-catchment?
- How much rate of soil erosion risk recorded in the study area?

- How is it the LULCC dynamics affect soil erosion which area is at risk within the sub-catchment?

1.5. Significance of the Study

The study findings help different stakeholders including the Woreda and Zonal agricultural development officials, experts, civil societies, and development agents to design strategies that will bring positive synergies to restore land degradation, enhance food security and avert natural resource degradation in indicating key priority areas for conservation. In addition, it would have great role to manage and reduce the impact by providing spatial information on the status of LULCC and its direct influence on soil erosion by implying soil erosion prone area so as to indicate areas at risk. Thus, such information may guide the planners and decision makers to delineate closure area and effective watershed management and afforestation program for land resource management. Furthermore, the analysis contributes to knowledge on the potential impacts of land use and land cover changes on soil erosion. This is essential to long term progress because of the scarcity of information at sub-catchment level to address the problems of LULCC on natural resources. It may also help to propose and recommend mitigation measures to combat the negative impacts of LULCC on soil erosions.

1.6. Scope of the Study

The research deals with analyzing of the impact of LULCC in triggering soil erosion in Gilgel Gibe catchment of Omo-Gibe River basin from 1991 to 2019. Actually, the Gilgel Gibe catchment touch six administrative woredas (Seka Cokorsa, Dedo, Omo Nada, Sokoru, Kersa and Tiro Afeta) of Jimma Zone. But this study purposely concerns on the delineated sub catchment of Gilgel Gibe catchment which currently touch only four administrative woredas namely; Omo Nada, Kersa, Tiro Afeta and some partial part of Sokoru and covers 2,154.34 Km^2 (215,434 ha) area of land. The sub catchment delineation was done from ASTER DEM data by using Arc Hydro tool extension 10.3 in ArcGIS environment. This study has investigated land use/land cover change and its impact on soil erosion by identifying soil erosion risk area by using remote sensing data and GIS tools with integration of RUSLE model.

1.7. Limitations of the Study

This study was made with all possible efforts in acquiring all the necessary data collection and processing, interpretation, and analysis. However, the thesis work has encountered some restrictions. Google earth image resolution in 1991 and 2005 was one of the challenges in image classification of the study. So, the researcher selected images captured on a blue-sky day. In addition, poorly available input data related to practice and management factor (P-factor) and soil color were the greatest constraint faced by researcher. However, as an alternative, recommended P-factor values for each LU/LC category collected from previous studies with similar approaches in the area and in other parts of the country were reviewed and assigned. Additionally, soil color identified by Bahiru, (2010) in the area were used instead.

1.8. Organization of the Thesis

This thesis is organized in five chapters; chapter one introduces the general topic (research problem) by providing the background of the study, describing of the problem, and research objectives. It also addresses the significance of the research and scope of the study. Chapter two of this study discusses the literature review, where a general review of current knowledge relevant to the research topic was provided. Chapter three describes the description of the study area and the methodology used in the study and data collection techniques and in-depth analysis are explained as well. Subsequently, the fourth chapter presents the results and discussions of the study. Finally, the overall summary of the research findings, recommendations were given in chapter five.

CHAPTER - TWO

2. REVIEW OF LITERATURE

2.1. Concepts and Definitions

2.1.1. Land Use/Land Cover

According to Lambin et al (2003), Land Cover is defined as the biophysical attribute of earth surface and a key determinant of the state of physical and human environment and land use is the manipulation of land cover attribute by human to meet different need. Turner et al., (1995) defined land use as the purposes for which humans exploit the land and its resources (land use is the intended employment of land management strategy placed on land cover type by human agents or land managers. Forest, land cover, may be used for selective logging, for resource harvesting, such as rubber tapping, or for recreation and tourism. Land use change is the conversion of land use due to human intervention for various purposes, such as for agriculture, settlement, transportation, infrastructure and manufacturing, parks, recreation uses, mining and fishery (Lambin et al., 2003).

According to Alfred (2010), land use changes are mostly observed on deforestation, cropland expansion, dry land degradation, urbanization, pasture expansion and agricultural expansion. Land use change is the proximate cause of land cover change. The driving forces to this activity could be economic, technological, demographic and/or other factors (Turner et al., 1995). Hence, land use and land cover dynamics are a result of complex interactions between several biophysical and socio-economic conditions which may occur at various temporal and spatial scales (Robin et al., 2000). So, from this perspective conceptual definition given for LU/LC given by all of above studies were specifically considered in this study.

2.1.2. Land Use Land Cover Change

Land use and land cover change (LULCC) is commonly grouped into two broad categories: conversion and modification (Meyer and Turner, 1994). Conversion refers to a change from one cover or use category to another (e.g., from forest to grassland). Modification, on the other hand, represents a change within one land use or land cover category (e.g., from rain-fed cultivated area to irrigated cultivated area) due to changes in its physical or functional attributes. These changes in land use and land cover systems have important environmental consequences through their impacts on soil and water, biodiversity and microclimate (Lambin et al., 2003). Human activity on natural environment has transformed land cover (Mottet et al., 2006), resulting in ecosystem degradation and biodiversity loss worldwide (Green et al., 2005). An estimated 4.7million km^2 of grassland areas and 6 million km^2 of forest/woodland have been converted to cropland worldwide since 1850 (Lambin et al., 2003) and the main purpose for land use change is to obtain food and other essentials (Alfred, 2010).

In Ethiopia, land use can be seen from the perspective of human activities such as agriculture, forestry, building construction (Gete and Hurni, 2001) and since recently, industrialization (Eleni et al., 2013) which has led to increased human population within urban areas and depopulation of rural areas. The driving forces behind land use pattern include all factors that influences human activity, including local culture (food preferences), economics activity and environmental condition (Hamza and Iyela, 2012). So, definition for LULCC given by Gete and Hurni, 2001; Meyer and Turner, 1994 was considered in this study specifically.

2.1.3. Erosion

Erosion is the detachment of soil particles is due to raindrop impact, caused by its kinetic energy. It is the removal of soil (top soil) from the earth's surface by erosive agents such as water and wind. Water erosion involves the detachment, transport and deposition of soil particles by the erosive forces (Renard et al., 1997). The potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape), soil characteristics, local climatic conditions, and land-use and management practices implemented on the watershed (Suresh, 2000; Arora, 2003). It is accounted that loss of topsoil and terrain deformation due to soil erosion are the consequences of deforestation, removal of natural vegetation and overgrazing in the mountainous regions (Shrestha, 1997).

2.1.4. Catchment

A catchment can be defined as the area of land that drains to a point and may be subdivided into contributing sub catchments by considering relative elevations and subsequently flow directions in different areas which have size widely greater than 500,000ha (Ministry of Agriculture and Rural Development [MoARD], 2005).

2.1.5. Sub Catchment

A catchment can be defined as the area of land that drains to a point and may be subdivided into contributing watersheds by considering relative elevations and subsequently flow directions in different areas which have size widely vary from 200,000ha to 500,000ha (MoARD, 2005).

2.1.6. Watershed

A watershed is a surface area from which runoff is resulting from rainfall is collected and drained through a common outlet. 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. Watershed can be classified as micro-watershed, sub-watershed, broader or critical watershed, major watershed and have size widely vary from 2000ha to 200,000ha (MoARD, 2005).

2.2. Empirical Review

2.2.1. Causes of Land Use/Land Cover Dynamics

The exact factors that will drive land use and land cover changes in a given area are not perfectly itemized (Meyer and Turner, 1994). However, land use and land cover are never static and it constantly changes in response to the dynamic interaction between underlying drivers and proximate causes (Lambin et al., 2003). Proximate (direct) causes are immediate actions of local people in order to fulfill their needs from the use of the land (Geist and Lambin, 2002). These causes include agricultural expansion, wood extraction, infrastructure expansion and others that Proximate causes operate at the local level such as at individual farms, householders or communities (Lambin et al., 2003).

Underlying (indirect or root) driving forces are fundamental socio-economic and political processes that push proximate causes into immediate action on land use and land cover (Geist and Lambin, 2002). Underlying driving forces, i.e., including demographic pressure, economic status, technological and institutional factors, influence land cover/use in combination rather than as single causations (Turner and Meyer, 1994). The sources of underlying causes are at regional and national levels such as districts, provinces, or countries. Underlying causes are often external and beyond the control of local communities (Lambin et al., 2003).

2.2.2. Soil Erosion

The potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape), the soil characteristics, the local climatic conditions and the land use and management practices implemented on the watershed (Suresh et al., 2000).

Various human activities disturb the land surface of the earth, and thereby induce the significant alteration of natural erosion rates. Soil erosion by running water has been recognized as the most severe hazard threatening the protection of soil as it reduces soil productivity by removing the most fertile topsoil. It is accounted that loss of topsoil and terrain deformation due to soil erosion are the consequence of deforestation, removal of natural vegetation and overgrazing in the mountainous regions (Shrestha, 1997). Soil eroded from the up-land catchment causes depletion of fertile agricultural land and the resulting sediment deposited at the river networks creates river morphological change and reservoir sedimentation problems (George et al., 2013).

According to (Biniam, 2012; Eleni et al., 2013 and Muleta, 2015) the agricultural sector in Ethiopia is increasingly being confronted with the pressure from a rapidly growing population and diminishing natural resources. Agriculture faces the challenge of providing food for a growing population. Land use and land cover changes and socio-economic dynamics have a strong relationship as indicated by (Kebrom and Hedlund, 2000; Tedese et al., 2017 and Tsegaye, 2019) spatial and demographic changes in Ethiopia have an acute impact on agricultural land and the supply and amount of fuel in the surrounding areas.

In Ethiopia rates of soil erosion are being assessed since 1981 in the soil conservation project (Hurni, 1985). Soil erosion by water in Ethiopia is the most critical environmental problems particularly in the highland areas due to a high rugged topography, population pressure and cultivation on steep slope lands (Bewket & Teferi, 2009). In the highlands of Ethiopia, soil erosion by water is one of the main damaging and nonstop environmental problems (Gashaw et al., 2019). As mentioned by Hawando (1995), the recorded annual soil erosion in Ethiopia ranges from 16-300 tons/ha/yr. depending mainly on the slope, land cover, and rainfall intensities. According to the Ethiopian highland reclamation study (FAO, 1984), in middle 1980‘s 27 million ha or almost

50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation.

Accordingly, as mentioned to the above, similar to the study area has been severely affected by water erosion. Because of that the areal coverage of the study area has the diverse of topography/undulating land forms and changes LU/LC resulted from human induced factors are one of the major factors for soil erosion by water in Gilgel Gibe sub-catchment.

2.2.3. Studies of LULCCs and Its Impacts on Soil Erosion in Ethiopia

It is important to understand the past through conducting research on historical land use and land cover changes, which in turn helps to make projections for the future. Among the land use changes occurring, the most significant historical change in land cover has been the expansion of agricultural lands (Sherbinin, 2002), and the studies conducted in the previous times using remotely sensed data of different years with GIS, for some parts of Ethiopia indicate that croplands have expanded at the expense of natural vegetation, including forests and shrub lands (Gete and Hurni, 2001; Eleni et al., 2013) while Kebrom and Hedlund (2000) reported increases in the size of open areas and settlements at the expense of shrub lands and forests.

According to Amanuel and Mulugeta (2014), resource degradation due to unsustainable land resources management, removal of vegetation cover, population growth and the associated expansion of farming and increasing demand for resources are the main causes of LULC dynamics in Nada Asendabo watershed of Southwest Ethiopia. Demand for cultivable land, which mainly emanated from population growth, was also the fundamental driver of forest cover loss in Dembecha area (Gete Zeleke and Hurni, 2001).

Muleta (2015), reported a serious trend in land degradation resulting from the expansion of cultivated land at the expense of forestlands in Jimma Arjo Woreda of Western Ethiopia. In contrast, Muluneh (2003) and Woldeamlak (2002) have reported an increase in wood lots (eucalyptus tree plantations) and cultivated land at the expense of grazing land in both Sebat-bet Gurage land in south-central Ethiopia, and in the Chemoga River watershed in north-western Ethiopia. Land use/ Land cover changes that occurred from 1971/72 to 2000 in Yerer Mountain and its surroundings results an increase in cultivated land at the expense of the grasslands

(Kahsay, 2004). In the semi- arid areas of the central Rift Valley, in Keraru and GubetaArjo, during the period 1973-2000 cropland coverage has increased and woodland cover lost (Efrem, 2010).

In contrary Alemayehu et al. (2018), reported that during 1985-2005 period home garden agroforestry/settlement and grassland were increased, with a corresponding decline in the area of forestland and agriculture. But between 2005 and 2017 the result showed that expansion of agriculture and forestland because of implemented integrated and participatory forest management project in the country while reduction of grassland and home garden agroforestry with different rate in Somodo Watershed of Southwestern Ethiopia.

Human intervention in the natural condition of soils inevitably creates a considerable threat to the soil. Humans through alteration and reducing the vegetation cover naturally associated with the soil can contribute to nutrient and fertility depilation, carbon and biodiversity reduction and deterioration of the soil's physical properties and hence accelerate soil erosion. Soils of mountainous environments (as Ethiopian highlands) are very sensitive to such intervention (Muleta, 2015). Soil degradation in Ethiopia can be seen as a direct result of the past and present agricultural practices on the highlands. Furthermore, it is also assumed that insecurity of land and tree tenure has discouraged farmers from investing in soil conservation practices (Hurni, 1993). According to EPA (2012), land degradation is the major environmental problem in Ethiopia resulting in low and declining agricultural productivity in the country. Ethiopia has experienced food insecurity problems due to land degradation.

The soil erosion hazard is much higher for land under annual crops as compared to that under grazing, perennial crops, forest and bush. Research has shown that soil erosion is greatest on cultivated lands where almost half of the loss of soil comes from, even though they cover only 13 percent of the country (Hurni, 1993). Excessive land degradation, along with other climatic factors such unreliability and high intensity of rainfall could lead to reduced average crop yields per unit area (FAO, 2010).

Soil erosion estimates that were conducted some 18 years ago by the Ethiopian Highland Reclamation Study (EHRS) revealed that 20,000–30,000 hectares of cropland in the highlands were being abandoned annually by soil erosion and about two million hectares of land had been severely degraded to the extent of reaching point of no return for crop production (FAO, 1986).

During that time, about half of the highlands land area, close to 27 million hectares, was significantly eroded, and over one-fourth or nearly fourteen million hectares of arable land was seriously eroded (FAO, 1986).

Ethiopia has been described as one of the most serious soil erosion areas in the world with an estimated annual soil loss of about 42t/ha/yr. from croplands, resulting in an annual crop production loss of 1 to 2% (Hurni, 1993). It can be regarded as a direct result of past agricultural practices in Ethiopian highlands (Hurni, 1988).

The study by Yacob (2010), reported that because of land use/cover change, there was severe erosion has been observed on areas slope exceeding 5% and extreme severe erosion is observed on the escarpments of Tikur Wuha Watershed and this process is still very active. According to this study the increase in severity of soil erosion from 0.67t/ha/yr. in 1965 to 0.89t/ha/yr. in 2004 is resulted from the forest clearing and continuing search for farm land are the major one.

Shibiru et al., (2003) also reported the effect of land use and land cover changes in causing major gullies and quantified the expansion rate of these gullies and their effects on the livelihoods of people in eastern Ethiopia. Similarly, Selamyihun (2004) also indicated that increases in surface area of gullies in the central highlands of Ethiopia. All these studies will be identifying a strong influence of land use land cover changes on soil erosion.

Generally, land use/land cover changes are significantly impacted on crop production and soil degradation, forest resources degradation, loss of biodiversity, hydrological cycle, climate change and also land degradation and soil erosion, and others are the main impacts of environmental /ecological/ problems at global level, especial in the developing worlds like African Countries, and also involving Ethiopia is high significantly influenced.

2.2.4. Modeling Soil Erosion

Modeling in soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces to predict and evaluate soil erosion problem models which are the simplification of reality have effectively been developed and employed. Field studies for prediction and assessment of soil erosion are expensive, time-consuming and need to be collected over many years (Shi et al., 2004). Besides providing detailed understanding of the erosion processes, field studies have limitations because of complexity of interactions and the difficulty of generalizing from the results. Soil erosion models can simulate erosion processes in the watershed and may be able to take into account many of the complex interactions that affect rates of erosion. The reasons for soil erosion modeling are used because they are used as a tool: to predict and assess soil loss for conservation planning, project planning, soil erosion inventories, and for regulation. To predict where and when erosion is occurring and hence helping the conservation planner target efforts to reduce erosion and for understanding erosion processes and their interaction and for setting research priorities (Lal, 1994).

According to Petter (1992), the objective of soil erosion models is either predictability or explanatory. Several models were developed for the assessment of soil loss and numerous are in the process of development. In general, the models are categorized into three: namely conceptual, empirical and physically based models (Saavedra, 2005).

2.2.4.1. Conceptual Model

The Conceptual model method is based on the representation of physical erosion processes with empirical equations; SWAT, MMMF (Modified Morgan- Morgan- Finney) and CREAMS (Chemical, Runoff and Erosion from Agricultural Management System) are some of such models (Rapidel et al., 2011). Model includes only general description of catchment processes, without including the details occurring in the complex process of interactions (Renard et al., 1997).

2.2.4.2. Physical Based Model

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

2.2.4.3. Empirical Model

Empirical model refers to a simplified representation of a system or phenomenon which is based on experience or experimentation. Examples of these models are SLEMSA, MUSLE, USLE, RUSLE, etc. The computational and data requirements for such models are usually less than for conceptual and physically based models (Shi et al., 2004). RUSLE is the empirical model that has been most widely used and generally accepted by the natural resources community because it is relatively easy to use (Saavedra, 2005). By considering its ease of implementation, reliance on easily accessible data and its relatively accurate results, in this study RUSLE model was chosen and used rather to other methods.

2.3. Modeling Soil Erosion Using RUSLE Model

The Revised Universal Soil Loss Equation (RUSLE) is considered the alternative improved version of the proto USLE model (Renard et al., 1997). The RUSLE is a 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 (Wischmeier and Smith, 1978). Furthermore, the RUSLE can be combined with the Geographic Information System (GIS) in order to identify high soil erosion spots over a large watershed area in a quick, efficient and an acceptable accurate method (Shi et al., 2004). The RUSLE is an empirically based model that requires several variables to be measured and observed in order to estimate soil erosion.

The model needs data on rainfall, soil structure, soil texture, slope length, slope steepness as well as any crop management and erosion control practices (Morgan et al., 2005). Beside this, the model should be based on long-term average rainfall conditions for specific regions (Wischmeier and Smith, 1978).

Mathematically the Revised Universal Soil Loss equation (RUSLE) is denoted as:

$$\boldsymbol{A = R * K * LS * C * P} ---------------------- \boldsymbol{Equation\ 1}$$

Whereas A is the mean annual soil loss in tons per hectare per year, R is the rainfall erosivity factor, K is the soil erodability factor, L is the slope length factor, S is the slope steepness factor(degree), C is the Crop management factor and P is the erosion control practice or land management factor.

2.4. Application of GIS and RS in Soil Erosion Modeling

Several studies showed the potential utility of RS and GIS techniques for quantitatively assessing erosional soil loss (Saha and Mongkoisawat as cited in Israel, 2011). The advancement in the remote sensing and GIS technology provides an effective analytical tool in the modeling of soil erosion. Soil erosion is spatial phenomena, thus geo-information techniques play an important role in erosion modeling (Yazidhi, 2003). The potential utility of remotely sensed data in the form of aerial photographs and satellite sensors data has been well recognized in mapping and assessing landscape attributes controlling soil erosion, such as physiography, soils, land use/land cover, relief, soil erosion pattern (Pande et al., 1992).

The soil erosion process is influenced by biophysical environment comprising soil, climate, topography and ground cover and interactions between them. Soil erodability; susceptibility of soil to agent of erosion is determined by inherent soil properties e.g., texture, structure, soil organic matter content, clay minerals, and water retention and transmission properties. The most satisfactory methods of erosion hazard assessment are based on predicted soil losses by modeling the determinants of climate, soil, topography, vegetation or cover factors and management practices (Nill et al., 1996).

In a GIS environment, it is possible to link data generated from remote sensing with their spatial location (Beck as cited in Israel, 2011). In general, the use of geo-information techniques offers 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 (Israel, 2011). According to Yazidhi (2003), the use of digital elevation models and GIS offers possibilities to estimate topographical parameters that are useful in soil erosion modeling. Mapping soil erosion using GIS can easily identify areas that are at potential risk of extensive soil erosion and provide information on the estimated value of soil loss at various locations in the watershed (Shi et al., 2003).

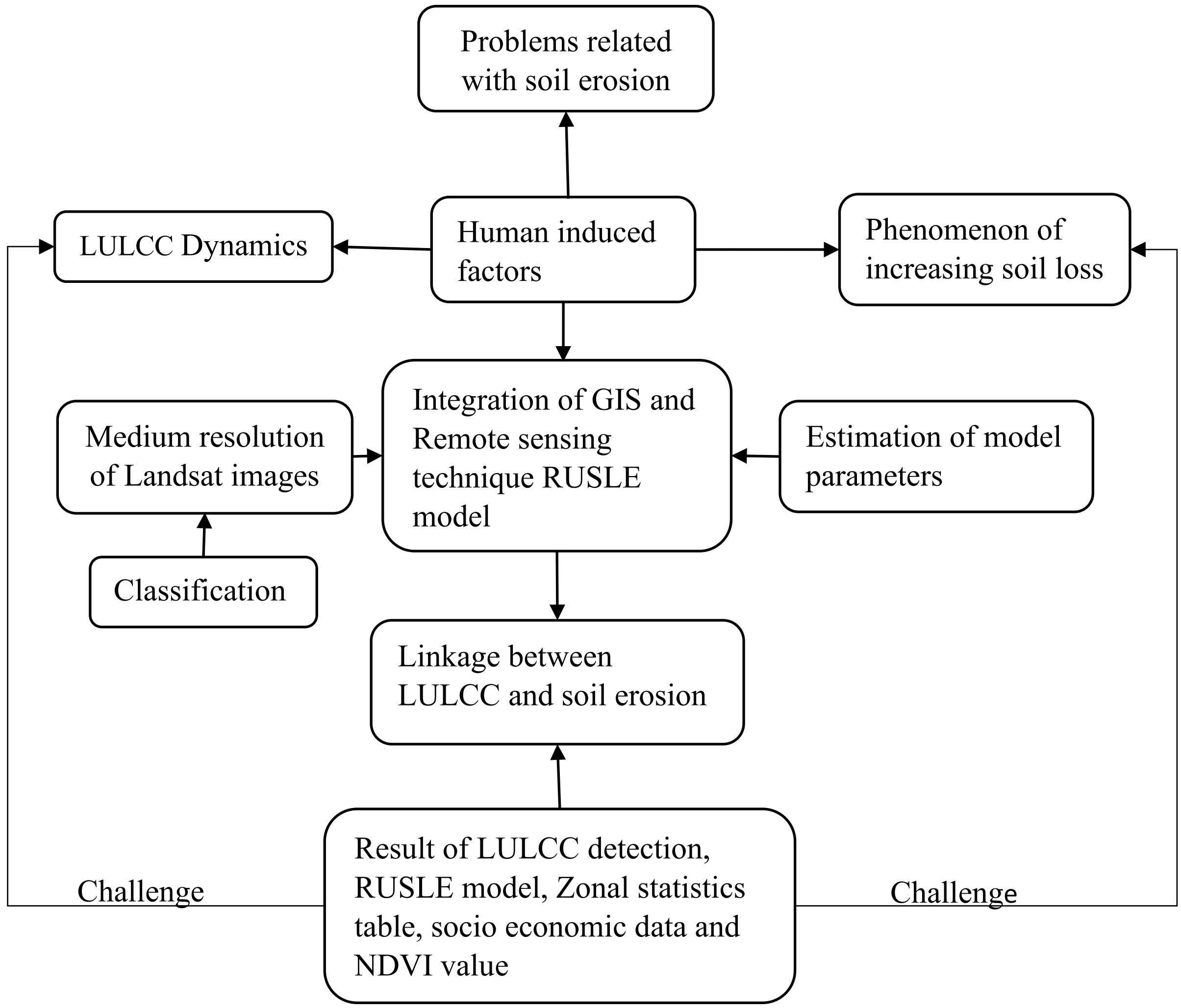


Figure 2:1 Conceptual framework.

CHAPTER - THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Geographically Gilgel Gibe sub-catchment is located in Omo-Gibe River basin of South western Ethiopia. According to the current structure of woreda, the area is enclosed with four woredas namely; Kersa, Tiro Afeta, Omo Nada and partially Sokoru. Geographically; the sub-catchment lies in 7^{0}30`00`` to $8^{0}$5`00``N latitudes and 36^{0}50`00`` to $37^{0}$25`00``E longitudes and has a total area of 2,154.34 Km^2 (215,434 hectares).

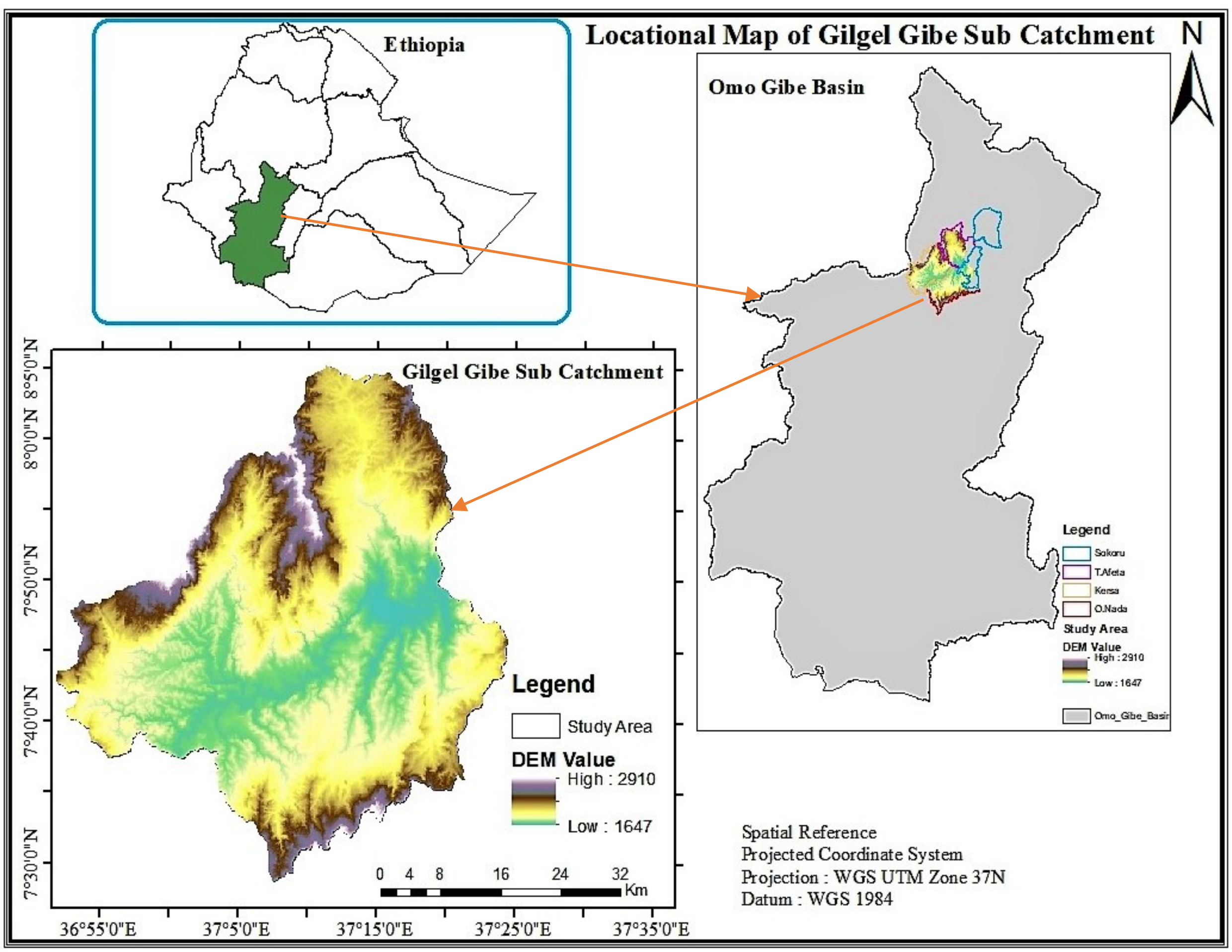


Figure 3:1: Location Map of the Study area.
Source: -Derived from DEM data and Ethiopian Geospatial Information Agency (EGIA), (2018).

3.1.2. Climate

According to data obtained from Jimma Zone Agriculture and Rural Development office the sub-catchment falls in between three traditional climatic types; Kola, Weina Dega and Dega. From the total area of the catchment, 0.17 % falls under Kola climate, 86.14 % falls in Weina Dega climate while the remaining 13.69 % of the catchment falls in Dega climatic condition.

The seasonal rainfall distribution takes a uni-modal pattern and it is maximum during the summer and minimum during the winter season, influenced by the intertropical convergence zone (ITCZ) (Demissie et al., 2013). The average rainfall of twenty-eight years (1991-2019) is 1438.9mm,1710.9mm,1763.9mm and 1104.5mm at Serbo, Nada, Dimtu and Asendabo station respectively. Rainfall decreases throughout the sub catchment with a decrease in elevation. The temperature of the study area ranges 8.2˚c to 27.2˚c in Asendabo station and 13.8˚c to 27.4˚c in Nada station with an average annual temperature of 17.7˚c and 20.5˚c, respectively. The hottest and coldest months are January and November at Asendabo station; while February and October at Nada station, respectively (Figure 3.3 & 3.4) (NMA/WOSC, 2020).

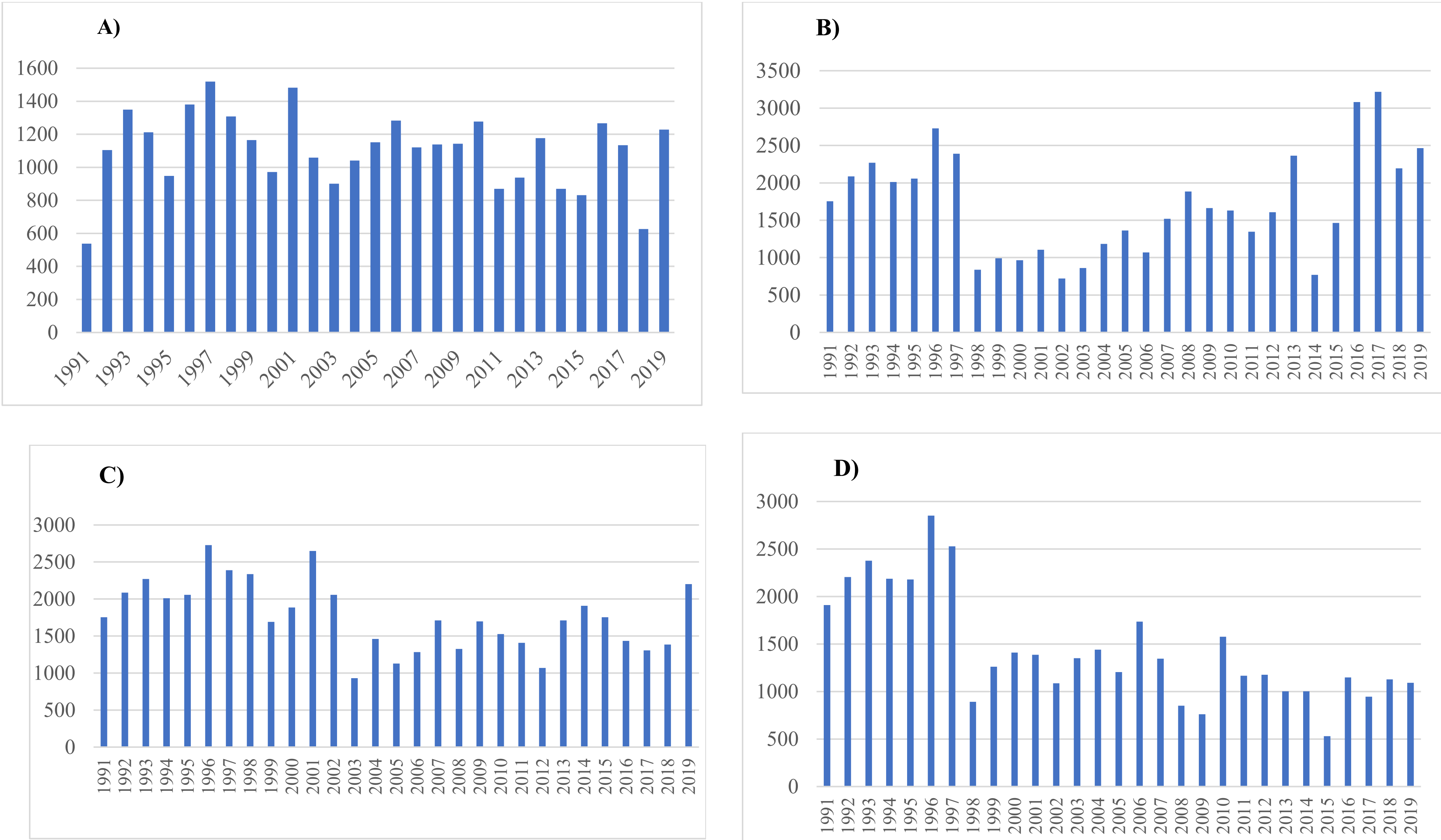


Figure 3:2: Rainfall distribution [mm]; A) in Asendabo station, B) in Nada station, C) in Dimtu station, D) in Serbo station. (Source; NMA/WOSC, 1991- 2019).

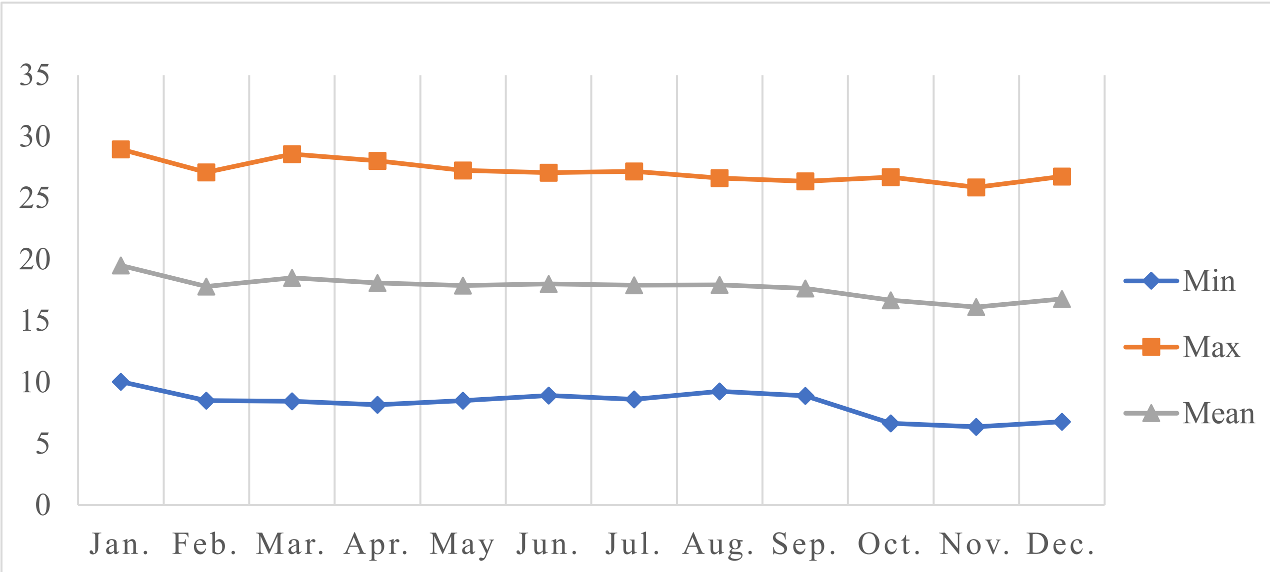


Figure 3:3: Temperature distribution at Asendabo station (Source; NMA/WOSC, 2020)

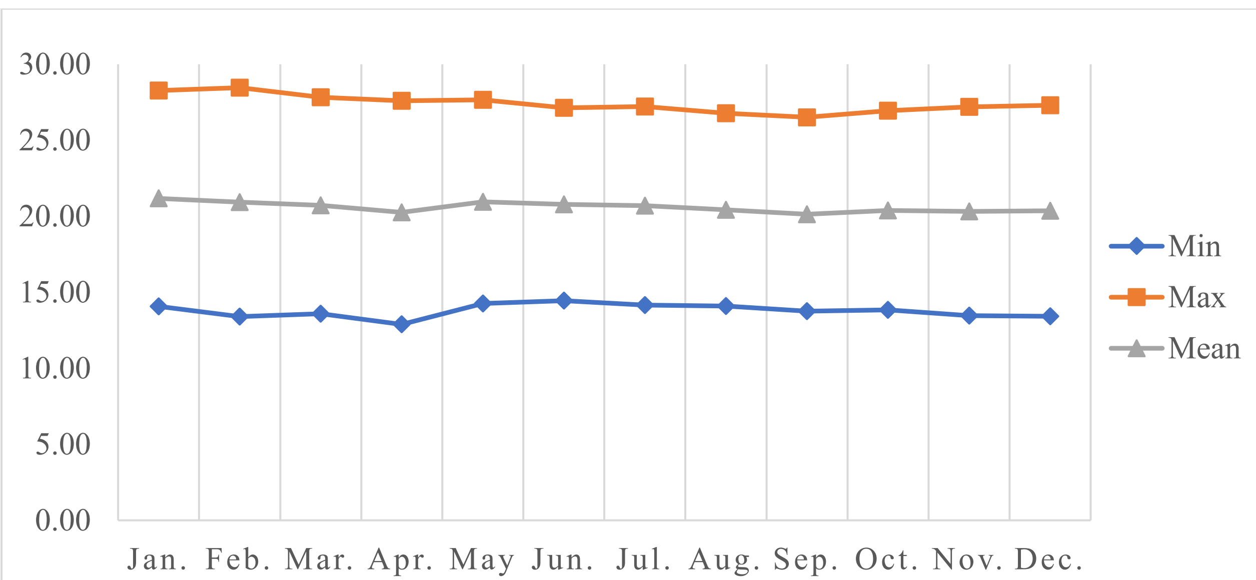


Figure 3:4: Temperature distribution at Nada station (Source; NMA/WOSC, 2020).

3.1.3. Topography

The physical landscape of Gilgel Gibe catchment is quite diversified. The major topographic features of the area are composed of hilly, flat to undulating rugged topography, plain, plateau and valley. Some of the relief forms identified in the landscape of the catchment are a well-defined conical or oval hill dissected by rivers, moderately steep to very steep hill side slopes, gently sloping flat terrains, deeply incised "V" shaped and steep valleys in the flanks and flat river terraces around the Gilgel Gibe River in the center of the catchment (Bahiru, 2010; Demissie et al., 2013). The altitude varying from 1647m to 2910 m.a.s.l. The upper part of the area is generally gentle slope and the lower part is with plain or flat (Figure 3.5).

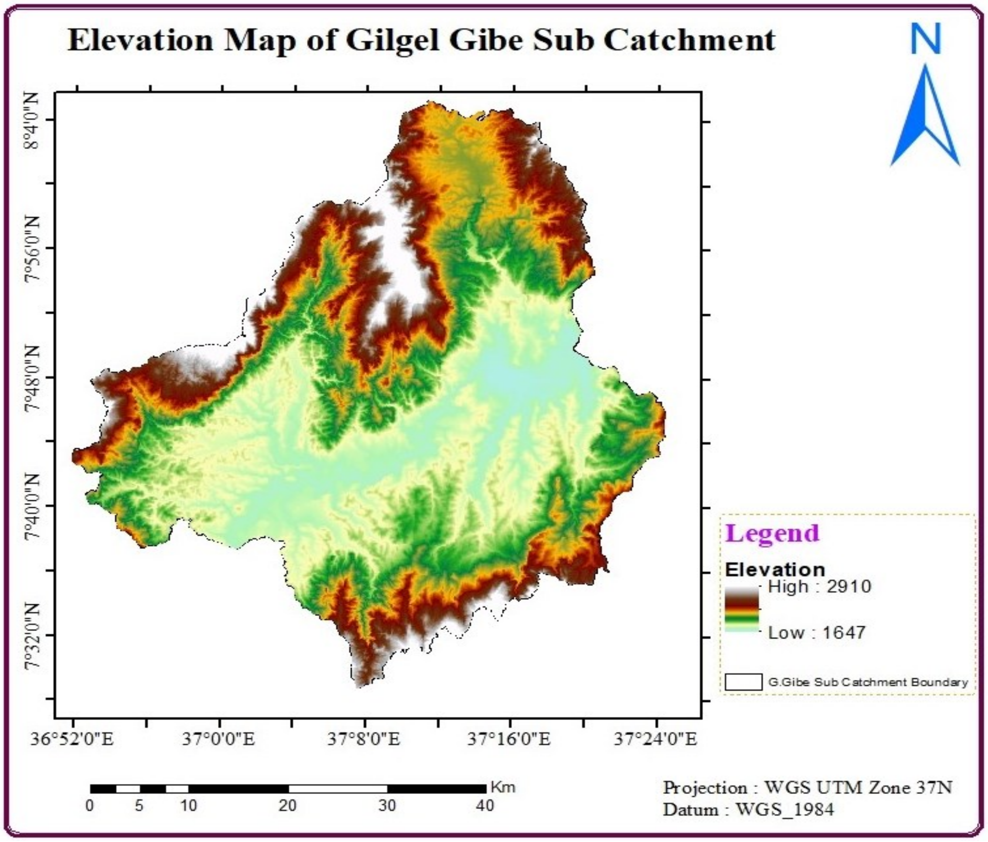


Figure 3:5: Elevation map of Gilgel gibe sub-catchment.
Source; Generated from ASTER DEM data, (2019).

3.1.4. Geology

The study area is situated on the southwestern Ethiopian plateau. The area is characterized by a series of basic and sub silicic effusive volcanic rocks, frequently inter-layered with reddish pale sols of tertiary age (Bahiru, 2010). According to Ethiopian Electric Power Corporation [EEPCO], (1999), the rocks of the area are tentatively ordered as following, beginning with the youngest rocks: Trachytictuff, Vesicular basalt, Aphyricaugite basalt, Weldedtuff (Rhyoliticignimbrite), Augitebasalt, Augitetrachyte, Augite basalt. In some locations, particularly in the area of the upper reservoir, these rocks are covered with fluvio -lacustr ine sediments. The entire volcanic sequence is frequently blanketed by thin, residual, subtropical later tic soils, which have been formed on hill and ridge foot slopes. As well, they are covered with thick, black, plastic clay deposits on the flatter areas and valley of Gilgel Gibe.

3.1.5. Soil Type

Gilgel Gibe Sub-Catchment possesses different soil types that are associated with the geomorphology and the geology of the area. Soil color varies from red and brown through to grey and black. The spatial distribution of the soil type shows that Dystric Vertisols (black) were located in the valley bottom (about 1,650 m a.s.l.), Lithic Leptosols (grey) and Humic Nitisols (red) in the hilly strip (1,660-1,760 m a.s.l.) and Humic Alisols (brown) at higher elevations (figure 3.6). The middle and high-altitude soils are less rich in nutrient elements due to the fact that they have been exploited by man and have been subjected to weathering and erosion (Bahiru, 2010).

According to FAO/IIASA/ISRIC/ISSCAS/JRC (2012) and Bahiru (2010), Dystric Vertisols the dominant soil types accounting for about 52.33% of the total land mass of Gilgel Gibe sub-catchment which is characterized by fine clay (Light) in topsoil texture and black in color. The second most dominant soil type in the area is Humic Alisols which covers about 41.70% of the total land mass of the sub-catchment and medium clay loam in topsoil texture and brown in color. Humic Nitisols soil type cover about 5.81% of the total area and fine clay in topsoil texture and brown in color. The least areal coverage belongs to Lithic Leptosols (0.03%) soil type which is characterized by medium clay loam in topsoil texture and grey in color (Table 3.1).

Table 3.1: Dominant soil types in Gilgel Gibe sub-catchment.

Soil Type	**Area Share (%)**	**Soil Color**	**USDA Textural Class**
Dystric Vertisols	52.33	Black	Clay
Humic Alisols	41.70	Brown	Clay loam
Humic Nitisols	5.92	Red	Clay
Lithic Leptosols	0.03	Grey	Clay loam

Source: - Bahiru, (2010) and computed from HWSD version 1.2, (2012).

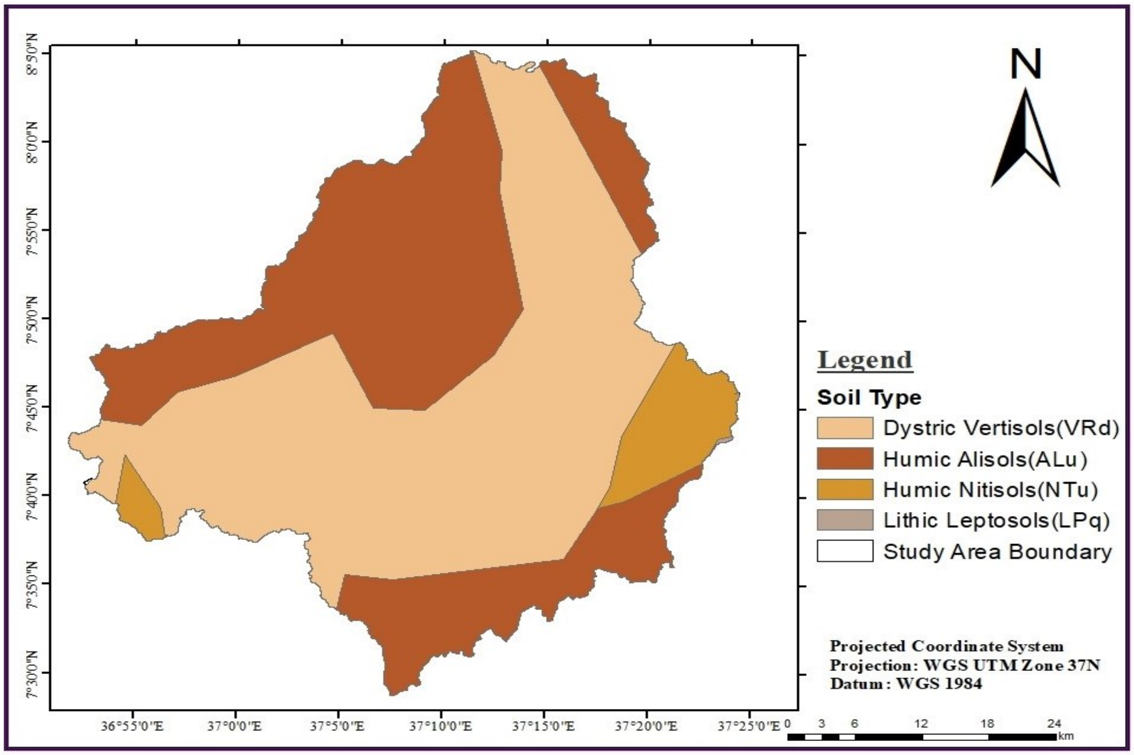


Figure 3:6: Soil map of Gilgel Gibe sub-catchment.

Source: - Extracted from HWSD version 1.2, (2012).

3.1.6. Water Resource and Drainage

Gilgel gibe sub-Catchment falls in the Omo-Gibe River basin. Water resource is abundant in the study area and a number of rivers and streams emanate from the hills and mountain sides and drain into the sub-catchment. Gilgel Gibe sub-catchment has endowed with enormous rivers and stream and occupies the largest surface area of the zonal drainage basin. Gibe, Kersa, Kewa, Anderacha, Nada kalo, Nada Guda, Bulbul, Doma, Busa and Nedi are remarkable perennial rivers flowing from the south western and eastern part and dendrite on the lower parts of the catchment that is the reservoir areas of Gilgel Gibe I hydroelectric dam.

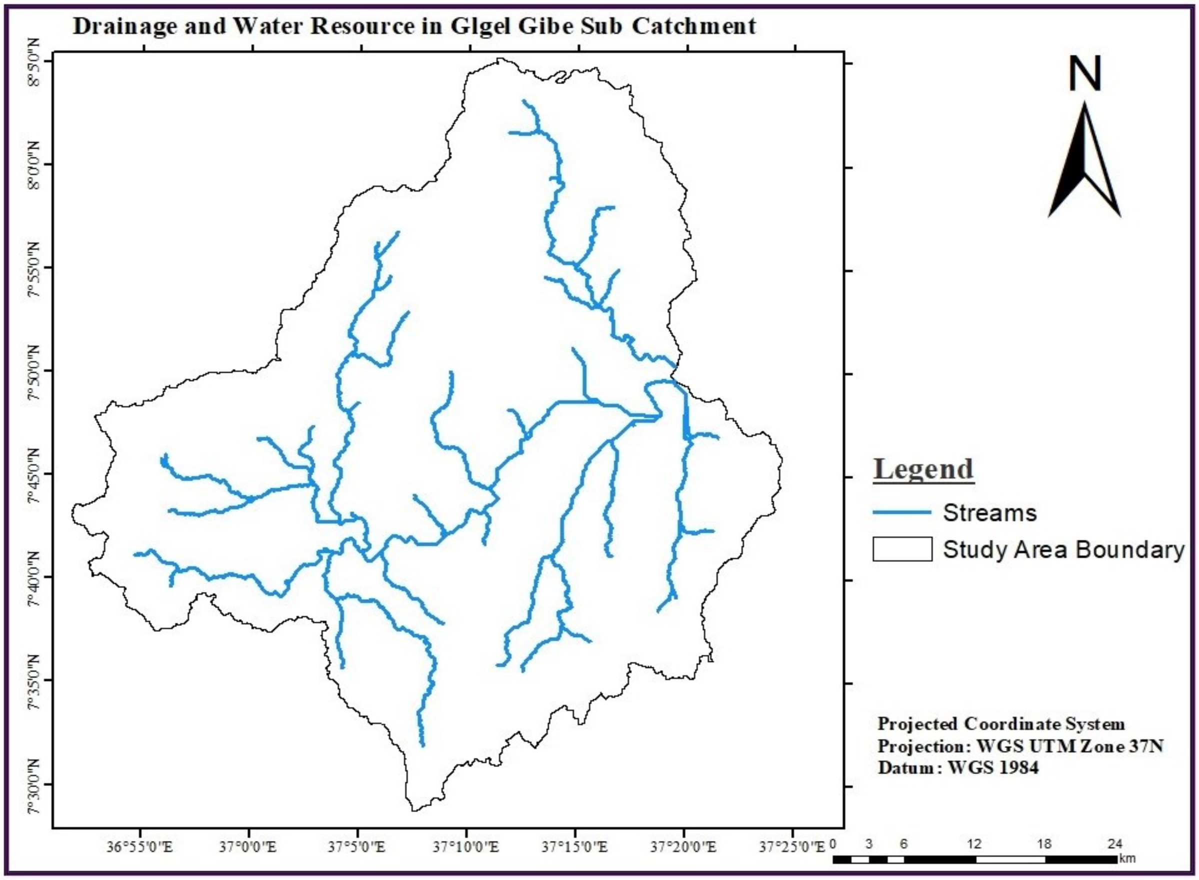


Figure 3:7: Drainage network with in Gilgel Gibe sub-catchment.
Source: - Generated from ASTER DEM data, (2019).

3.1.7. Land Use/Land Cover

The main land use type in the study area is agricultural cropping, mainly wheat, teff, barley, faba bean, sorghum and maize. Next to these cropping activities, the farmers keep certain plots as grazing land for their livestock. The plots are mostly small and enclosed by hedges or tree rows (Broothearts et al., 2012).

Six LU/LC classes such as forest, bush, grass, water body, cultivated land and settlement area were identified for three periods (1991, 2005 and 2019). Cultivated land accounted for more than 61% of the total sub-catchment area. This data shows clearly that agriculture plays an important role in the socioeconomic development of the sub-catchment. Table 4.1 and Figure 4.1 illustrate the LU/LC classification and distribution in the sub-catchment over twenty-eight years in three times series.

3.1.8. Population and Socio-economic Environment

The 1994 Population and Housing Census of Ethiopia indicated that there are a total of 531,010 people living in the sub catchment. According to CSA (2007), the total population of the four woredas which are found within the sub catchment area was about 681,420 (Male 342,178 and Female 339,242). Out of the total population, about 95.1% of the population lives in the rural Kebele while the remaining 4.86% of the population lives in urban areas. This indicates that the population of the sub catchment has been growing at the rate of 2.17% per annum during the period between the two censuses. According to the 2013 projected estimate figure of Ethiopian central statistical agency, the total population of the sub catchment was 818,257 with 3.34% annual growth rate.

According to Bahiru (2010), the dominant economic bases of the people are subsistence farming and livestock production. The most cultivated cereal crops include; Teff, Sorghum and maize. Pulses, onions, cabbage, banana, enset as well as coffee are grown in most highland parts of the study area. Due to primitive farming techniques the productivity of the crops is low.

3.2. Data Sources and Method of Collection

3.2.1. Primary Data

3.2.1.1. Field Survey and Observations

Field observations and field surveys was conducted in order to identify the land use/land cover types such as forest, grazing, shrubs, cultivated lands and settlement areas, conservation structures and to collecting sufficient GPS reading for validation of existing land use/land cover types of the study area. Furthermore, field observations were held to obtain insight knowledge about LU/LC practice in the area.

Field surveys were conducted using Global Positioning System (GPS Garmin 60) for accessible area instead of it google earth were used for inaccessible area to generate primary information regarding the ground truth for image classification and accuracy assessment. The surveys aimed at: (i) determining the land use and cover classes; (ii) associating the field data of specific land cover types with their image characteristics and; (iii) collecting sufficient field data for validation of Land Sat image.

3.2.1.2. Socio-economic Data

To obtain detailed information about the stated problems, Focus Group Discussion (FGD) and Key informant interviews (KII) with woredas experts like land management officers, agricultural and natural resources experts, government officials and elders were undertaken to collect socio-economic data.

Moreover, focus group discussions (FGDs) were also held to triangulate the reliability and validity of the data collected through other techniques. The discussions were held through interaction of a purposefully formed small group of people, often ranging from 6 to 10 people. The discussion was carried out with intentionally selected thirty-six (36) elders and experts. Twenty-eight (28) elders who live long period of time and know the long-term dynamic of LULCC in the area and eight (8) experts from the woredas land use and administration office and agricultural development office were participated in focus group discussion to acquire their deep and fertile views regarding the issues of land use land cover change.

In order to obtain in-depth information interviews were conducted with forty-eight (48) key informants from four intentionally selected kebeles based on their elevation categories (upper and downstream). Purposive types of questions were asked to get relevant information about impacts of land use/ land cover change on soil erosion risk in the study area. The interviews and the FGDs were conducted in Afan Oromo then it was translated back to English.

3.2.2. Secondary Data

Reviewing of different relevant published and unpublished literatures of the specific study area and related studies have been undertaken almost throughout the course of the research period. Necessary data including socio-economic, demographic, vegetation, physiographic, soil, hydrologic and rainfall was extracted from secondary data sources including CSA of Ethiopia, Jimma Zone Agricultural Development and Natural Resource Office, Harmonized World Soil Database (HWSD) version 1.2, National Meteorological Agency of Ethiopia/Western Oromia Meteorological Service Center (NMA/WOMSC), ASTER DEM, and three years Land sat images with different sensors of USGS (United State Geological Survey).

3.2.2.1. LU/LC Data

Landsat satellite image of 1991, 2005 and 2019 were used in this study. These Landsat satellite images of three different years (TM, ETM+ and OLI/TIRS) were obtained by visual interpretation of remotely sensed images in 169 path and 055 row at spatial resolution of 30m x 30m. Due to the problem of poor resolution of MSS sensor and data availability, the study period covered only from the year 1991 to 2019. Thus, the years 1991, 2005, and 2019 were selected for analysis with 14 years interval. These images were used in order to know and analysis the patterns and trends in LULCC which obtained by retrieved from USGS (United State Geological Survey) archive (http://www.earthexplorer.usgs.gov/). Table 3.2 below shows the LU/LC data source and their description. In addition to satellite and spatial layer google earth (2002-2019) , expert knowledge, preceding report by various institution and related literature survey was employed to help the validity the above data.

Table 3.2: Satellite images used for LULCC analysis and their description.

Satellite images	Periods	Path	Row	Sensor	Spatial resolution(m)	Date of acquisition	Cloud cover	Sources
Landsat-5	1991	169	55	TM	30X30	10 Jan,1991	< 10%	USGS
Landsa-7	2005	169	55	ETM+	30X30	05 Apr,2005	< 10%	USGS
Landsat-8	2019	169	55	OLI/TIRS	30X30	23 Jan,2019	< 10%	USGS

3.2.2.2. Soil Erosion Data

3.2.2.2.1. Rainfall Data

The rainfall data were collected from the NMA/WOMSC of four stations which found within the study area. For this study, the long-term records (1991-2019) of the four stations (Asendabo, Nada, Serbo and Dimtu) worked by NMA/WOMSC were taken as the basis for this study to generating erosivity factor maps. The mean annual rainfall of 28 years for each station was converted to raster format with 30m grid cell using IDW (Inverse Distance Weighted) interpolation techniques in ArcGIS environment by the spatial analyst tools and then, the analysis is done by using the raster data model to shown the erosivity factor map of the study area.

3.2.2.2.2. Soil Type Data

The soil data for this study was downloaded from Harmonized World Soil Database (HWSD) website (https://iiasa.ac.at) with spatial resolution of 1:1,000,000. The soil raster image file of the study area is obtained by masking the HWSD version 1.2 with the study area shapefile in the GIS environment. the extracted soil types of Gilgel Gibe sub-catchment were reclassified in Arc GIS 10.3.1 using reclassification geo processing tools based on their color by referring HWSD raster file and soil color which is identified by Bahiru (2010) which was used to estimate the soil erodibility factor in RUSLE model. For this study, erodability value (K-factor) is assigned for each of identified soil types based on their colors according to Hurni (1985) and Hellden (1987) (as cited in Habtamu and Amare, 2016).

3.2.2.2.3. Digital Elevation Model (DEM) Data

ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) Digital Elevation Model (DEM) for the study area at resolution of 30m by 30m was downloaded from the USGS website (http://www.earthexplorer.usgs.gov/). The DEM was used for automatic delineation of the sub catchment and also to define the stream network and determine slope of the area. Therefore, in this study, DEM serves as the primary input for calculating the slope length and slope steepness factors and help to generate the slope map of the study area.

3.2.2.2.4. P and C - Factor Data

In this study, 3 Landsat images acquired during dry seasons were used to determine the C-factor and P-factor value, respectively. The P-factor and C-factor data were derived from the classified LU/LC data of the respective study periods. In addition, NDVI value were employed to estimate the C-factor value of the RUSLE model. The thematic land use/land cover raster map of the study area were converted to vector format to assign the corresponding cover and management factor (C-factor) and erosion control practice (P-factor) value which obtained by reviewing different previous studies. Finally, raster map of C-factor and P-factor was produced.

Table 3.3: Description of data and its sources.

Type of data	Resolution	Source	Application/Purpose
Landsat image (TM, ETM+ & OLI)	30 m	USGS Website	For LU/LC classification & to generate C & P factor
ASTER DEM	30 m	"	To generate slope length and degree (slope factor) and drainage network, to delineate the study area.
Soil Data	1:1,000,000	HWSD Website	To generate soil erodibility factor
Rainfall Data	-	NMA/WOMSC	To generate rainfall erosivity factor
Field Survey & Observation		By author	To generate primary information for image classification and accuracy assessment, for identification & validation of existing LU/LC types.
Socio-economic Data		Experts, officials & elders	To obtain detailed information about the stated problems.
Ancillary Data	-	Google Earth/Previous Map	Ancillary data for classification, administrative boundary, road etc.

3.2.3. Materials and Tools

For the success of this research, the data processing tools included ArcGIS 10.3.1, ERDAS imagine 2015, Arc hydro tool extension, RUSLE model and MS excel was used. FGD and KII was tools used for collecting socio-economic related data. Materials such as computer with different image processing, GPS for collecting coordinate points for accessible area while google earth was used for inaccessible areas for ground truth and digital camera for taking pictures were used. GIS and RS analysis could help to analyze land degradation mainly soil erosion in cost effective, fast and accurate way. Those software and tools with their purpose are indicated below in Table 3.4.

Table 3.4: Software and tools used for the study

Software's, materials & tools	Purpose/Application
ERDAS Imagine 2015	For image pre-processing, Land use/land cover classification & Accuracy Assessment.
ArcGIS10.3.1	Vectorization, interpolation, reclassifying, change detection, area calculation and analyzing, displaying spatial data
Arc Hydro tool extension 10.3	Study area delineation, DEM generation & analysis
RUSLE model	To predict the long-term average annual soil loss
Handheld GPS	To collect GCP (accessible areas)
Google Earth	To collect GCP (inaccessible areas)
Digital Camera	For capturing the feature
DNR Garmin 5.4 Version	To download the GCP point from GPS
FGD & KII	To collect socio-economic data

3.3. Design of the Study

The research is based on method which encompasses technical quantitative and qualitative methods of research design. Quantitative and qualitative methods are combined and integrated to add value to the arguments from different perspectives, and enable to answer research questions more deeply. It is obvious that the study on land use land cover change in triggering soil erosion can encompass observational and mixed research methods to generate the required data for the research.

This study had three main methods. The first was LULCC analysis from Landsat satellite image of 1991(TM), 2005(ETM+), and 2019 (OLI). Second estimation of soil loss by using RUSLE model. Finally, zonal statistics were done for NDVI and to calculate mean annual soil loss with the change in corresponding LU/LC category. Impact analysis was done for LU/LC and NDVI, and LU/LC and estimated soil loss. The overall methods are presented in the methodological flow chart (Figure 3.8).

3.4. Data Analysis

3.4.1. Study Area Delineation

Delineation of a sub catchment were done using an area of interest from digital elevation model (DEM) and the Arc Hydro tool extension 10.3. DEM were used since it is a regularly spaced grid of numbers representing elevation which is the digital equivalent of a topographic map. Usually, the higher the resolution of the DEM is the more accurate, but for LU/LC dynamics studies and soil erosion modeling a DEM with a 30m resolution is enough.

The sub catchment under study was delineated by automatic delineation option using Arc Hydro tool extension with in Arc GIS 10.3.1. From ASTER 30m*30m resolution DEM, Fill Sink, Flow direction, flow accumulation, Stream Definition and Segmentation, Drainage line and point processing were generated respectively. In addition, the sub catchment was delineated by selecting outlet of the sub catchment and by increasing the threshold value in the stream definition. Once the delineation is completed, the result can be used to crop layers (land cover, area …) that are useful in hydrology.

3.4.2. LU/LC Data

Satellite data downloaded from official website of USGS were processed to enhance both spatial and spectral interpretability of the image. Thus, Image pre-processing is the initial processing of the raw data and normally involves processes like geometric corrections, image enhancement, radiometric correction, noise removal and image classification.

After collecting all necessary data, analysis and processing was done by classifying, vectorization (raster to vector conversion), calculating, zonal statistics and reclassifying the necessary information of each thematic layer using ERDAS IMAGINE 2015 and Arc GIS 10.3.1 software. Furthermore, some simple statistical methods, such as percentage, average and graphic tabulation was also employed for the analysis and interpretations.

A. Image Preprocessing

Image preprocessing were performed to extract meaningful information from satellite data so that they may become easier to interpret (Jensen, 2003). Image pre-processing is the initial processing of the raw data and normally involves processes like geometric corrections, image enhancement, radiometric correction, noise removal and image classification.

In the first step the acquired data were unzipped to stack into composite images. Layer stack technique was performed to group the all bands of each Landsat image together. This was followed by performing further image enhancement techniques. Then, geometric corrections are intended to compensate for the spatial distortions so that the geometric representation of the imagery will be as close as possible to the real world an image taken from any sensor system is a distortion of the real scene. In order to make the data compatible with each other, the projection transformation was carried out and assigned to the WGS 1984 UTM Zone 37N projection.

B. Image Enhancement

Image enhancement techniques improve the quality of an image as perceived by a human. These techniques are most useful because many satellite images when examined on a color display give inadequate information for image interpretation (Lillesand and Kiefer, 2000).

These techniques were applied to images in order to display more effectively or record the data for subsequent visual interpretation. Specifically, for this study resolution merge, fixing scanline error of ETM+, contrast stretching and histogram equalization were applied to enhance the visual interpretability of the image.

C. Image Classification

Image classification refers to the task of extracting information classes from a multi band raster image. The overall objective of the image classification is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand and Kiefer, 1994). In this study supervised classification technique were employed by using ground survey sample collected from field.

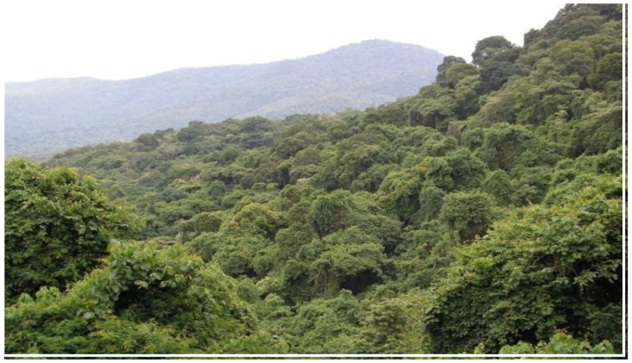
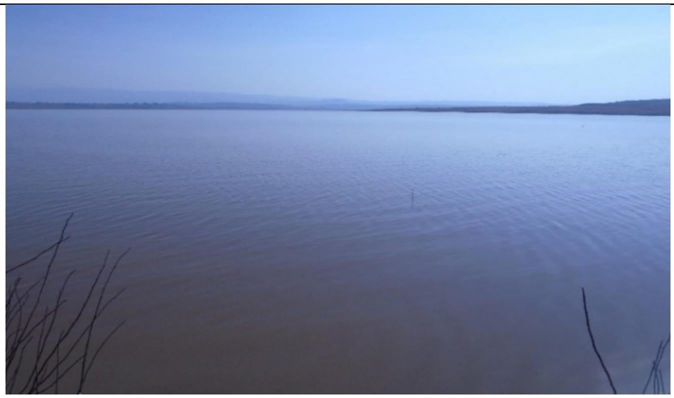
Supervised Classification

This technique requires a prior knowledge of the scene area in order to provide the computer with unique training classes. It is the job of the user to define the original pixels that contain similar spectral classes representing certain land cover class. During the image classification, 180 training sites were marked and used to determine various land use/land cover classes found in the Gilgel Gibe sub-catchment of Omo-Gibe River basin using GPS. Six land use/land cover classes were generated for the three corresponding periods; 1991, 2005 and 2019. The image classification was carried out to produce land cover layer through a supervised image classification method applying the training samples created using the field data and interoperation of the images (google earth and stacked images for the different years).

The classification system was developed by referring (Anderson et al. 1976) classification scheme and has been made to provide as much compatibility as possible with other classification systems currently being used by Ethiopian Geospatial Information Agency (EGIA, 2018). And also based on the prior knowledge of the study area and field survey with additional information from written material in the study area, a classification scheme was developed for the study area after (Anderson et al,.1976).

Classification was performed based on a supervised maximum likelihood classifier. The actual image classification was carried out after the training data had been established and the classification algorithm was designated. For training points, 30 training samples per each LU/LC classes were randomly assigned a total of 180 samples were generated for training and testing. This was done by identifying homogeneous representative training site of the major cover types based on prior knowledge, GCP (Ground Control Point), image interpretation and google earth. Then using ERDAS 2015 software each pixel in the image assigned to the class. In this typical classification all images were classified using the maximum likelihood classifier technique in ERDAS Imagine 2015 software. In total six land cover classes were identified and verified by field survey.

Table 3.5: Description and photo captured of Land use classes identified in Gilgel Gibe sub-catchment

No	Land Use class	Description of land use	Captured photo of each land use classes
1	Cultivated Land	This category involves both intensively and moderately cultivated agricultural lands.	
2	Forest Land	This land cover type is characterized by closed canopy vegetation and the riverine forests.	
3	Water body	Land with water-tables at or near the surface during the time the respective image as taken. It is Areas covered by man-made lakes, rivers, and streams in the catchment permanently and also it covers low lying and frequently in association with stretches of open water.	

4	Grass Land	In this study, an area in which grass is the primary natural vegetation or where an area is dominated by grasses and grassy areas used for communal grazing is categorized under this class.	
5	Bush land	These are areas where sparse trees are dominant and associated with sparse grass. The degraded forest land also categories under this class. The category is characterized by natural or semi natural sparse woody vegetation with opened canopy.	
6	Settlement Area	This is an area of a permanent residential (village) area, urban areas, service centers (as schools and health centers) and etc.	

Source: - By referring classification system by Anderson et al., 1976; EGIA, 2018; and Photos captured by author, 2020.

3.4.3. Accuracy Assessment for LU/LC Classification

According to Anderson et al (1976), the recommended standard of accuracy in the identification of LULCC mapping from the remote sensing data should be 85 to 90%. One of the most common means of expressing classification accuracy is the preparation of classification error matrix (Lillesand and Kiefer, 1994). In this study, the significant change patterns were identified based on the reference data derived by the ground survey, Land sat TM (1991)/ETM+(2005)/OLI (2019) images, and a high-resolution image (google earth). Some pixels were randomly selected and used for the reference data sets. The final number of samples are 125 pixels and each pixel have associated with a seasonal change or an actual change event regarding its location in the sets of Landsat images, high resolution image (google earth) and the 125-reference data derived from the ground survey points compared to randomly selected sample.

Based on 30m resolution of the land sat image data used to create map, it is important to keep in mind that the map was most accurate for viewing geographic patterns over larger areas. The result of an accuracy assessment was provided with an overall accuracy of the map based on an average of the accuracies for each class in the map.

$$Overall\ Accuracy = \frac{Number\ of\ Pixels\ Correctly\ Classified}{Total\ Number\ of\ Pixel} --------\ Equation\ 1$$

Three standard criteria have been used to assess the accuracy of the classifications: producer accuracy, user accuracy and kappa statistics were employed.

Kappa was used to measure the agreement or accuracy between the remote sensing derived classification map and the reference data as indicated by the major diagonals and the chance agreement, which is indicated by the row and column totals (Jensen, 2003). Producer's accuracy is the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data (column total). These statistics indicates the probability of a reference pixel being correctly classified and is a measure of omission error.

The kappa factor is given by the formula (Jensen, 2003):

$$Kappa(K) = \frac{Po - Pe}{1 - Pe} ----------------------------- Equation\ 2$$

Where: P_o = is the proportion of correctly classified cases,

P_e = is the proportion of correctly classified cases expected by chance.

Producer's accuracy gives how well a certain area can be classified (Jensen, 2003). User's accuracy is when the total number of correct pixels in a category divided by the total number of pixels that were actually classified in that category (row total), the result is a measure of commission error. The user's accuracy is the probability that a pixel classified on the map actually represent that category on the ground (Jensen, 2003).

3.4.4. LULC Change Detection and Rate of Change

Change detection is a method by which the process of changes that occur in land cover, over a certain number of years, can be observed (Tewelde & Cabra,2011). The LULCC were derived from comparison of classified Land sat images of the three study periods and the whole-time range was segmented into three; 1991 – 2005, 2005- 2019 and finally the overall change (1991 - 2019) was assessed over a period of about 28 years. This was detected using ERDAS imagine 2015 and the rate of change across the study period was also analyzed based on the statistical data derived from the images. This were done to see how the change in LU/LC is influencing soil erosion and which area is more rapidly changed and what so over. On the other hand, this task helps to determine the major loss of land cover especially forest and bush land losses were noticed and low vegetation cover whereas gains were noticed.

The rate of change was calculated for each land use/land cover using the following formula:

$$Rate\ of\ change(ha/year) = \frac{(A - B)}{C} ------------------- Equation\ 3$$

Whereas, A = Recent area of the land use and land cover in ha

B = Previous area of the land use and land cover in ha

C = Time interval between A and B in years

3.4.5. Analysis of Soil Erosion Using RUSLE Model

The Revised Universal Soil Loss Equation (RUSLE) is an empirical model developed by Renard et al. (1996) to estimate soil loss from fields. Based up on soil and water conservation research plots data, a modified USLE was adopted to Ethiopian condition by Hurni (1985). The revised RUSLE model by Renard et al. (1997) is the most intensively used empirical models for soil loss estimation. The RUSLE model is flexible, time and cost effective, and practical in areas of scarce measured data which can be used for watershed conservation.

The RUSLE model were applied in order to map the soil erosion potential areas and to estimate the annual rate of soil erosion on Gilgel Gibe Sub Catchment of Omo Gibe basin during the two study periods (1991-2005 and 2005-2019). All map layers were generated in a raster GIS environment (grid–based approach) based on the main soil erosion controlling factors, including climate (R-factor), soil characteristics (K-factor), topography (LS-factor), land cover and management (C-factor) and support practice for soil conservation (P-factor). These parameters derived from different data sources such as DEM (ASTER), soil map, climate (rainfall data) and remotely sensed data was used in the RUSLE model. The different data sources have different data formats, projections, data quality and spatial resolution. The use of GIS provides the tools to manage and analyze these data. Each layer was organized in a grid format with a cell size of 30x30 meters. Thus, in this study; RUSLE were applied at sub-catchment by incorporating the advanced LS factor estimation approach. The Revised Universal Soil Loss Equation (RUSLE) is empirically expressed as:

$$\boldsymbol{A = R * K * LS * C * P} ----------------------- \boldsymbol{Equation\ 4}$$

Whereas A is the average annual soil loss (in tons per area per year), R is the rainfall and run off erosive factor, K is the soil erodability factor, LS is the slope length–steepness factor, C is the crop/cover management factor and P is the erosion control practice or land management factor. This study, analyzes each process factor and equation was derived by GIS and Remote sensing techniques.

3.4.5.1. Estimation of RUSLE Factors

1. Rainfall Erosivity Factor (R)

The rainfall erosivity factor quantifies the effect of rainfall impact and also reflects the amount and rate of runoff likely to be associated with precipitation events. The rainfall erosivity factor (R) were analyzed based on Hurni (1985) as cited in Habtamu & Amare (2016), for Ethiopian condition is based on the available mean annual rainfall data (P) by employing the equation;

$$\boldsymbol{R = -8.12 + (0.562 * P)} ----------------------\boldsymbol{Equation\ 5}$$

Where, R= Rainfall erosivity and P is mean annual rainfall (mm/yr.) for its simplicity and possibility of using only precipitation data.

The mean annual rainfall data of 28 years (1991 to 2019) derived from 4 rainfall meteorological stations (Serbo, Omo Nada, Dimtu and Asendabo) were considered to estimate rainfall erosivity factor using the above formula. The mean annual rainfall of 28 years for each station was converted to raster format with 30m grid cell using IDW interpolation techniques. Table 3.6 shows the name, the location, elevation, duration of the data, mean annual precipitation and erosivity value of each of the metrological stations used in this study.

Table 3.6: Station's data considered within the study area and calculated rainfall erosivity

ID	Stations Name	Latitude	Longitude	Elevation	Period	MAP	Erosivity
1	Serbo	7.70867	36.974017	1802	1991-2019	1438.911	800.548
2	O.Nada	7.61671	37.25001	1838	1991-2019	1710.942	953.43
3	Dimtu	7.85067	37.235533	1786	1991-2019	1763.92	983.203
4	Asendabo	7.7605	37.231117	1764	1991-2019	1104.569	612.648

Source: Computed from NMA/WOSC, (2020).

2. Soil Erodibility Factor (K)

Morgan (1995) defined the soil erodibility factor (K) as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up-and-down with slope with no conservation practices and on a slope of 5 and 22 m length. Soil erodibility is the manifestation of the inherent resistance of soil particles for the detaching and transporting power of rain fall (Wischmeier and Smith, 1978). Morgan (1995) emphasis that erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic matter and chemical content of the soil.

The soil raster image file of the study area is obtained by masking the Harmonized World Soil Database (HWSD) version 1.2 FAO/IIASA/ISRIC/ISSCAS/JRC, (2012) with the study area shapefile in the GIS environment. The HWSD is composed of a raster image file and a linked attribute database. Each grid cell raster database is linked to commonly used soil parameters. HWSD allows soil compositions to be displayed or queried in terms of user-selected soil parameters. For modeling, the HWSD and its geographical layer can directly be read or imported by common GIS and Remote Sensing software (Chadli,2016). According to Bahiru (2010) and visual interpretation of the area soils in Gilgel Gibe valley are black in the valley bottom (about 1,650m a.s.l.), grey brown in the hilly strip (1,660-1,760m a.s.l.) and red at higher elevations. Soil color varies from red and brown through to grey and black.

Thus, the extracted soil types of Gilgel Gibe sub-catchment were reclassified in Arc GIS 10.3.1 using reclassification geo processing tools based on their color by referring HWSD raster file and soil color which is identified by Bahiru (2010) to determine the soil erodibility factor value (Table 3.7). Then, K value is assigned for each of the four soil types based on their colors according to the soil color class given by Hurni (1985) and Hellden (1987) (as cited in Habtamu and Amare, 2016).

Table 3.7: Soil types, textural class and their color with in Gilgel gibe sub-catchment and estimated soil erodibility (K) value.

Soil Type	Soil Color	Textural Class	Estimated K value (tons ha^{-1} MJ^{-1} mm^{-1})
Dystric Vertisols	Black	Clay	0.15
Humic Alisols	Brown	Clay loam	0.2
Humic Nitisols	Red	Clay	0.25
Lithic Leptosols	Grey	Clay loam	0.35

Source: - Derived from HWSD V. 1.2 and from related literature review.

3. Slope Length and Steepness (LS) Factor

The (LS) factor is the ratio of soil loss per unit area from a field slope to that from a 22.13 m length of uniform 9% slope under otherwise identical conditions (Wischmeier& Smith, 1978). For erosion hazard assessment at a scale of 1: 250,000 or larger slope length factor (L-Factor) could be adapted by Hurni, (1985) which is modified to Ethiopia local conditions with maximum L-factor of 3.8 for a slope length of 320m.

The effect of topography on erosion in RUSLE is accounted for by the LS factor. Erosion increases as slope length increases, and is considered by the slope length factor (L). Slope length is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or runoff becomes concentrated in a defined channel (Wischmeier and Smith, 1978). Accordingly based on the maximum slope length of the study area constant value were considered in the equation below (Gizaw & Degifie, 2018).

$$LS = (\text{flow length}/22.1)^{0.4} * (\text{Sin}\ (\text{slope} * 0.01745))/\ 0.09^{1.4} * 1.4 \quad ----- \textbf{Equation 6}$$

Where flow length is determined by multiplying flow accumulation with cell size of raster file, LS is combined slope length and slope steepness factor, cell size is size of grid cell (for this study 30 m) and slope is slope degree value.

4. Erosion Control Practice (P) Factor

In the RUSLE model, the P-factor is considered as the ratio of soil loss with a specific conservation practice to the corresponding loss with up and down slope cultivation (zero management), which has a value of one (Wischmeier & Smith 1978). Therefore, the effect of this factor depends upon the actual agricultural activities undertaken in the given area. Even though the effectiveness varies for different types of soil conservation practice, it reduces the amount and rate of runoff, increases infiltration and subsequently reduces the amount of erosion (Habtamu and Amare, 2016).

Therefore, for this study, the LU/LC classification map of the three study periods was used. The thematic LU/LC raster map of the respective study years were converted to vector format to assign the corresponding recommended p-factor values for different LU/LC classes as indicated in Table 3.8. These values were collected from previous studies and assigned for corresponding LU/LC types. Finally, raster map of p-factor of respective study periods was produced.

Table 3.8: Conservation practice factor value.

No	Land Use Land Cover Type	P-Factor Value	Source
1	Forest Land	0.7	Hurni (1985)
2	Cultivated Land	0.95	Hurni (1985)
3	Open Grassland	0.7	Hurni (1985)
4	Settlement	0.63	Hurni (1985)
5	Bush Land	0.8	Hurni (1985)
6	Water Body	0	OWWDSE (2014)

5. Crop Cover and Management (C) Factor

The cover and management (C) factor represent the ratio of soil loss from land with specific vegetation to the corresponding soil loss from a continuous fallow (Wischmeier& Smith, 1978; Morgan, 2005). It is the single factor most easily changed and is the factor most often considered in developing a conservation plan. land cover factor "C", is of vital importance in the determination of erosion hazard assessment because of the large difference between its minimum and maximum values and therefore slight mistakes in land cover mapping can easily result in large over- or under-estimations of soil loss (Nyssen et al., 2004). The thematic land use/land cover raster map of the study area were converted to vector format to assign the corresponding cover and management factor value obtained from different studies. Finally, raster map of C-factor was produced.

Table 3.9: Adopted C- Factor Value.

No	Land Use Land Cover Type	C-Factor Value	Source
1	Forest Land	0.01	Hurni (1985)
2	Bush Land	0.014	Wischmier & Smith (1978)
3	Cultivated Land	0.1	Hurni (1985)
4	Grass Land	0.09	Hurni (1985)
5	Settlement Area	0.05	Hurni (1985)
6	Water Body	0	Girma & Gebre (2020)

After the estimation of all RUSLE factors value and preparation of each factor in raster format, the raster layers were overlayed together (Figure 3.8) using the raster calculator of spatial analyst extension in the ArcGIS environment to drive the final soil erosion risk map. zonal Statistics as table tool of spatial analyst extension in ArcGIS 10.3.1 software was used to calculate the mean soil loss value of the sub catchment.

3.4.6. Analysis of Socio-economic Data

Descriptive data analysis has been used to analysis the information that was captured through observation, key informant interview, and focus group discussion. The qualitative data obtained from KIIs and FGDs were stated in narrative form alongside with the quantitative data.

3.4.7. Analysis of LULCC Impact on Soil Erosion

In order to evaluate the impact of the LULCC on soil erosion the RUSLE model was run for 1991, 2005 and 2019 separately. During each model run, all of those three parameters remained the same, except values of the C and P factors, which were changed according to the LU/LC of the respective year. The result was then compared with the deference in determined C and P-factor values of each LU/LC types. In addition, comparison was carried out to the deference in NDVI value of Land sat TM/1991, Landsat ETM+/2005 and Land sat OLI/2019.

The subsequent impacts of LULCC on soil erosion potential and the rate of soil loss of the sub catchment was evaluated through average annual soil erosion of the sub catchment using the

RUSLE model results of the corresponding study periods. Additionally, the annual mean soil erosion of study periods calculated corresponding with the change in LU/LC category using zonal statistics tool in ArcGIS environment. In RUSLE Model the C and P- factors were changed according to the LU/LC of the respective year. Since the C and P factor in the RUSLE model directly depends on land use/land cover, the change of land use type had a significant influence on soil loss potential.

The two factors are multiplied with the potential soil erosion to get soil loss risk area from the sub catchment by ArcGIS software spatial analysis raster calculator function using the following syntax:

Soil Erosion Risk = Potential erosion* C- factor (1991, 2005 and 2019) *P- factor (1991, 2005 and 2019)

The spatial pattern of potential erosion risk zone based on LULCC of the sub-catchment was analyzed and mapped. The estimated soil loss was reclassified and presented into five ordinal classes such as very slight, slight, Moderate, severe and very severe risk zone in the Gilgel Gibe sub-catchment of Omo Gibe basin.

3.4.8. Spatial Erosion Hazard and RUSLE Model Result Validation

Classification accuracy assessment of the results have been performed based on information from DEM derivative slope factor, Google Earth, deference in NDVI value of satellite image of the respective study periods and actual visit of randomly selected sites, overplayed with erosion hazard map.

In addition, the validity and consistency of the RUSLE model output was compared with the output of previously published study with similar approaches by reviewing of previous studies. Field observation was also conducted to check the model outputs in the study area.

3.5. Flow Chart of Methodology

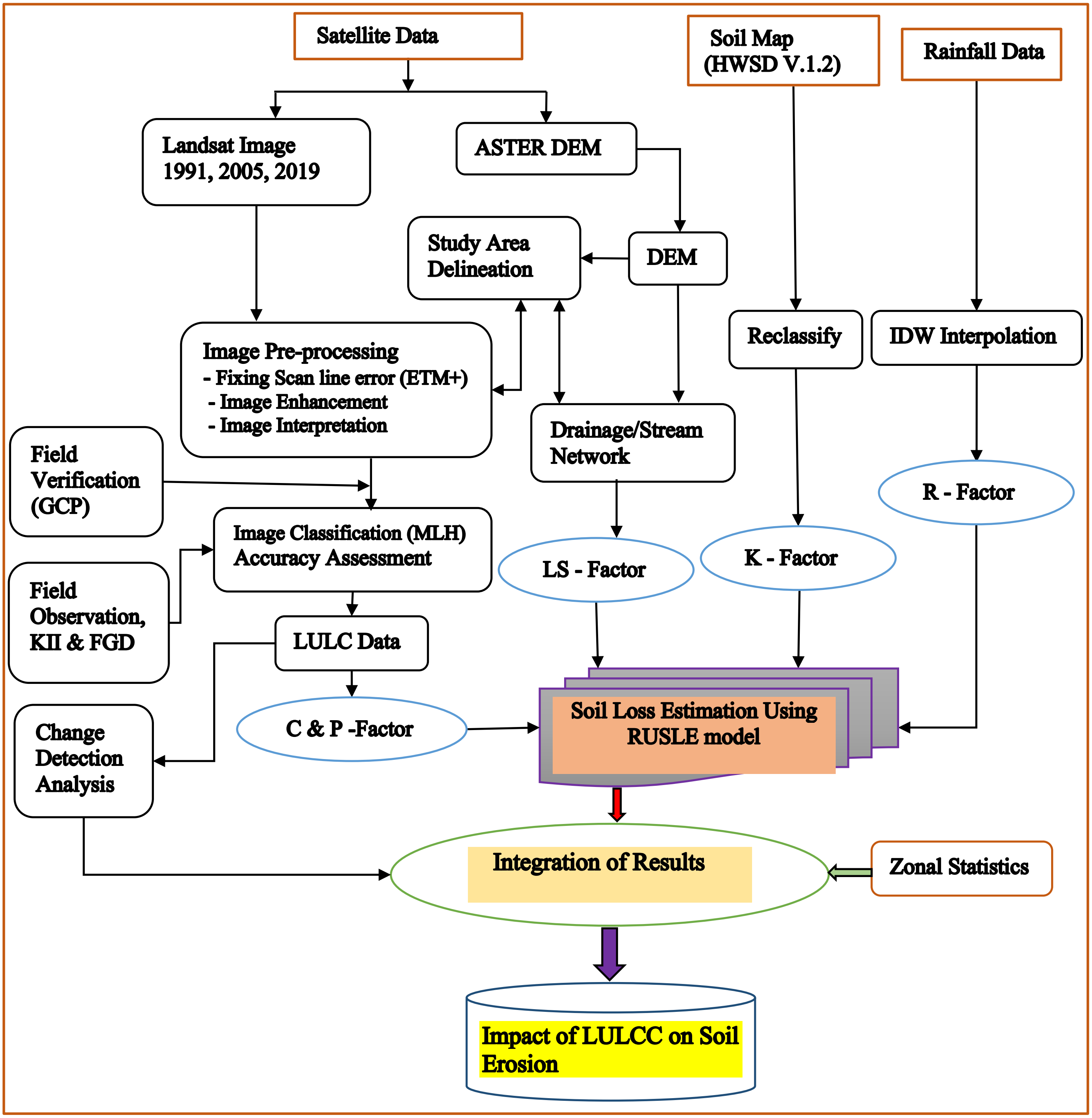


Figure 3:8: Methodological flow chart of the study.

Source: Developed by Author, 2020.

CHAPTER- FOUR

4. RESULTS AND DISCUSSIONS

4.1. Land Use/Land Cover of the Study Area

The result obtained from the classified Landsat image of 1991 show that; the dominant land cover of the study area within this period was cultivated land which account for 48.31% of the total study area. The other dominant land cover class was bush land, grass land and forest land which account for 32.03%, 10.43% and 8.84%, respectively. While; 0.23% and 0.17% of the area during this period was covered with settlement area and water body respectively which takes the lowest percentage share as compared to the other land cover classes in the study area (Figure 4.1 and Table 4.1).

Table 4.1: Areal extent of each land use/cover classes of the three periods.

LU/LC Classes	1991		2005		2019	
	Area(ha)	%	Area(ha)	%	Area(ha)	%
Forest Land	19042.9	8.84	6938.95	3.22	4509.1	2.09
Bush Land	68994.9	32.03	48541.27	22.53	47097.6	21.86
Grass Land	22464.7	10.43	34809.15	16.16	24322.5	11.29
Cultivated Land	104067.9	48.31	119484.94	55.46	132031.2	61.29
Water Body	369.6	0.17	4806.3	2.23	4645.5	2.16
Settlement Area	494.1	0.23	853.45	0.40	2827.6	1.31
Total	**215434**	**100**	**215434**	**100**	**215434**	**100**

Source: Computed from satellite imagery of study periods.

The classified Landsat image of 2005 shows that half of (55.46%) of the study area was covered with cultivated land. The forest cover, on the other hand, declined into 3.22%. Bush and grass land also cover 22.53% and 16.16% of the area respectively. Whereas, 0.40% and 2.23% of the area was under settlement and water cover respectively (Figure 4.1 and Table 4.1).

Furthermore, land use/land cover classification for 2019 from OLI/TIRS satellite image shows that forest land, bush land, grass land and water body a dramatic declined and they account for 2.09%, 21.86%, 11.29% and 2.16% respectively, whereas; cultivated land and settlement areas demonstrate a significant gain that accounts for 61.29% and 1.31% of areal coverage respectively within the period (see Figure 4.1 and Table 4.1).

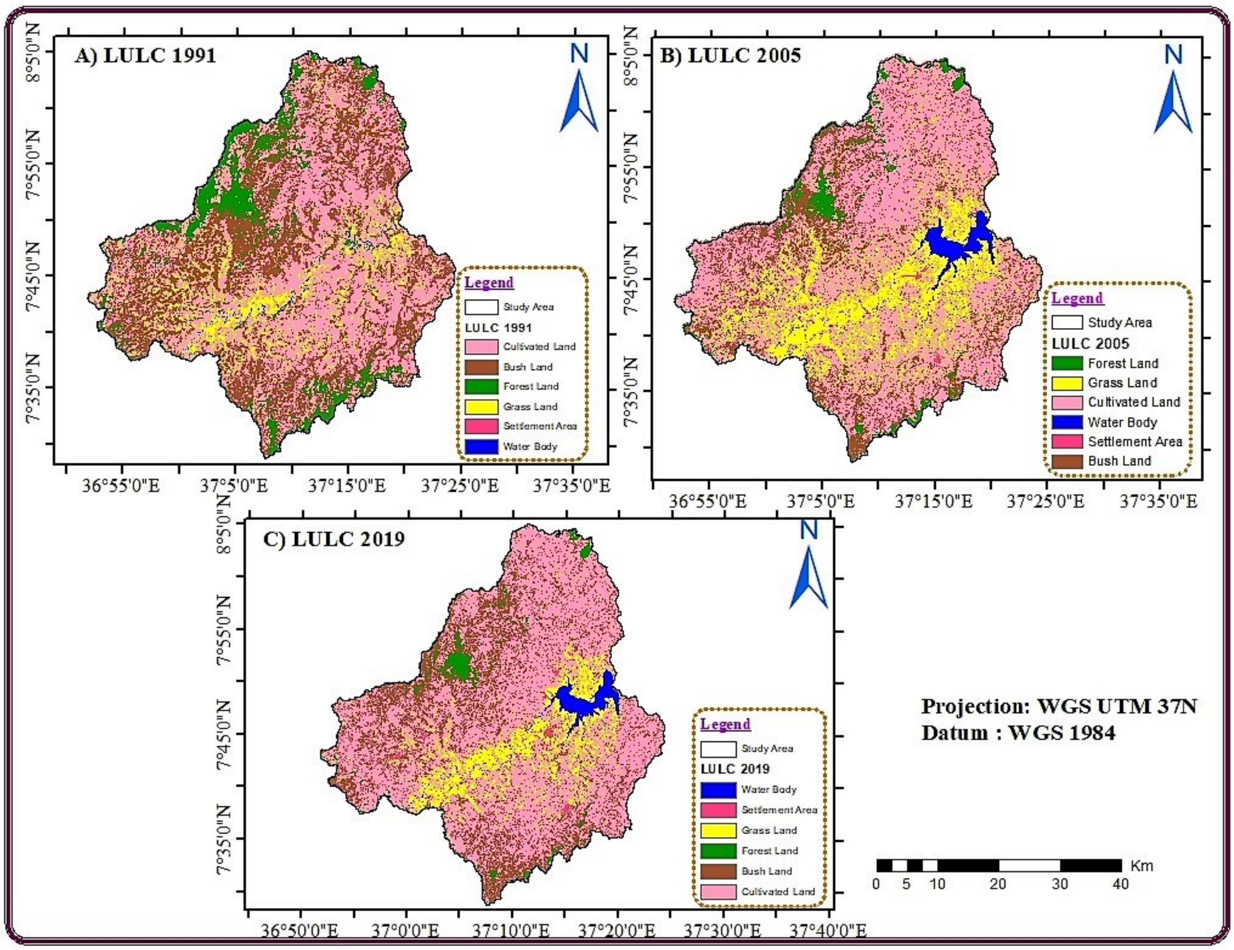


Figure 4:1: LULC map; A) LULC map of 1991, B) LULC map of 2005 and C) LULC map of 2019.

(Source: from satellite image interpretation)

4.2. Accuracy Assessment of Image Classification

After classification of satellite images, the accuracy of the classification derived from remote sensing sources is required to be assessed. One of such a method is the use of a confusion matrix which is produced from the random sample of individual pixels/clusters compared to known cover conditions over the same pixel areas (Lillesand and Kiefer, 1994; Tulu, 2017). In this regard, the accuracy of the classified Landsat images of 1991, 2005 and 2019 was evaluated by taking a total of 125 ground truth point from the field for accessible areas and from google earth for inaccessible areas from each LULC categories (Table 4.2).

The results of the accuracy assessment showed that the overall accuracies computed for each of the considered classified satellite images were 86.4%, 88.8% and 90.4% in 1991, 2005 and 2019 respectively with the kappa coefficient of 0.83, 0.86 and 0.88 in 1991, 2005 and 2019 respectively (Table 4.2). Thus, the kappa results of this study showed a strong agreement for each of the three classified images, and the overall accuracies were within the acceptable range for further LULCC analysis (Anderson et al., 1976) and there is a positive correlation between the remotely sensed classified samples and the reference data.

Results of user's accuracy in this study showed that in 1991 the maximum class accuracy was for bush land (92%) and the minimum was for water body (76.92%). In 2005, user's accuracy ranges from lowest accuracy (76.47%, settlement area) to relatively correctly classified (96.15%, cultivated land) whereas in the period 2019, it was ranges from 78.6% water body, 87.5% (settlement area) to 93.8% (forest land). Results of producer's accuracy showed that water body (90.91%) in 1991 and forest land (93.8%), settlement area (92.9%) and water body (100%) in 2005 whereas in 2019 forest land (93.8%), settlement area (100%) and water body (100%) are relatively correctly classified. The lowest producer accuracy was bush land (80.77%), cultivated land (80.6%) and bush land (84.6%) in 1991, 2005 and 2019, respectively.

Table 4.2: Accuracy evaluation result of classified satellite imagery.

Classification Accuracy of Landsat TM: 1991									
	LULC Class	CL	BL	FL	GL	S	WB	Row Total	User Accuracy
		Reference Data							
Classified in Satellite Image as	CL	26	1	0	2	0	0	29	89.66
	BL	1	23	1	0	0	0	25	92
	FL	0	1	14	1	0	0	16	87.50
	GL	2	0	1	23	1	0	27	85.19
	S	1	0	0	1	12	1	15	80.00
	WB	1	1	0	0	1	10	13	76.92
	Column Total	31	26	16	27	14	11	125	**OA = 86.4**
	Producer Accuracy	83.87	80.77	87.50	85.19	85.71	90.91		**KC =0.83**

Classification Accuracy of Landsat ETM+: 2005									
	LULC Class	CL	BL	FL	GL	S	WB	Row Total	User Accuracy
Classified in Satellite Image as	CL	25	0	0	1	0	0	26	96.15
	BL	1	23	1	1	0	0	26	88
	FL	0	1	15	0	0	0	16	93.75
	GL	2	1	0	24	1	0	28	85.71
	S	2	1	0	1	13	0	17	76.47
	WB	1	0	0	0	0	11	12	91.67
	Column Total	31	26	16	27	14	11	125	**OA = 88.8**
	Producer Accuracy	80.6	88.5	93.8	88.9	92.9	100.0		**KC =0.86**

Classification Accuracy of Landsat ETM+: 2005									
	LULC Class	CL	BL	FL	GL	S	WB	Row Total	User Accuracy
Classified in Satellite Image as	CL	27	0	0	2	0	0	29	93.1
	BL	1	22	1	0	0	0	24	91.7
	FL	0	1	15	0	0	0	16	93.8
	GL	2	0	0	24	0	0	26	92.3
	S	1	1	0	0	14	0	16	87.5
	WB	0	2	0	1	0	11	14	78.6
	Column Total	31	26	16	27	14	11	125	**OA = 90.4**
	Producer Accuracy	87.1	84.6	93.8	88.9	100	100		**KC =0.88**

NB: - CL =Cultivated land, BL=Bush land, FL=Forest land, S=Settlement area, WB=Water body

OA= Overall Accuracy, KC= Kappa Coefficient

4.3. Normalized Difference Vegetation Index

In this study, it has been observed that the vegetation cover was very high in 1991 than in 2005 and 2019 with maximum NDVI values of 0.95, 0.73 and 0.65, respectively. This indicates that there was high vegetation cover in 1991 than in 2003 and in 2019. The continuous expansion of cultivated land and settlement area at the expense of forest and bush land cover reduction in 2005 and in 2019 were responsible for decline of NDVI values (Figure 4.2).

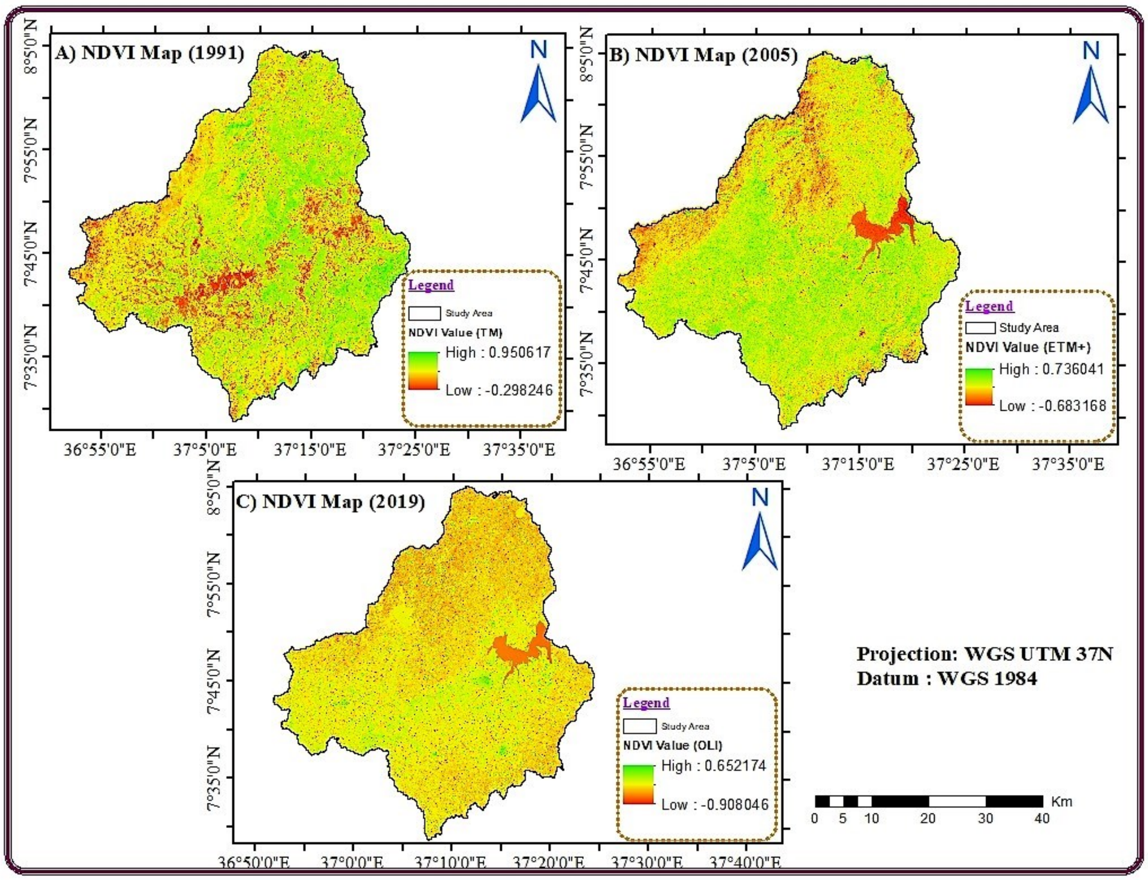


Figure 4:2: NDVI map; A) NDVI map of 1991, B) NDVI map of 2005 and C) NDVI map of 2019.

(Source: Calculated from satellite image).

4.4. Land Use Land Cover Change

4.4.1. LULCC Between 1991 and 2005

Within 14 years i.e., from 1991 to 2005 in the study area cultivated land and bush land showed maximum changes. More specifically, cultivated land was increased by 15,417.05 ha with 1,101.2 ha/yr. mean annual rate of change, whereas, bush land was decreased with 20,453.63 ha or 1,461 ha/yr. Forest land and grass land also showed significant changes the first one decreased by 12,103.99 ha (-864.6 ha/yr. negative rate of change). On the other hand; grass land was increased with 12,344.44 ha (881.7 ha/yr. rate of change) and within the same time period water body was raised by 4,436.73 ha with 316.9 ha/yr. rate of expansion. Obviously, the increase in water body was associated with the construction of Gilgel Gibe hydroelectric dam. Finally, as compared to other land use types of the study area settlement area showed the lowest rate of change (25.7 ha/yr.).

Table 4.3: Extent of land use/cover change in study periods.

LU/LC Classes	1991	2005	2019	Mean annual rate of change(ha/yr.)		
	Area(ha)	Area(ha)	Area(ha)	1991-2005	2005-2019	1991-2019
Forest Land	19042.9	6938.95	4509.13	-864.6	-173.6	-519.1
Bush Land	68994.9	48541.27	47097.58	-1461.0	-103.1	-782.0
Grass Land	22464.7	34809.15	24322.53	881.7	-749.0	66.4
Cultivated Land	104067.9	119484.94	132031.23	1101.2	896.2	998.7
Water Body	369.6	4806.3	4645.53	316.9	-11.5	152.7
Settlement Area	494.1	853.45	2827.63	25.7	141.0	83.3
Total	**215434**	**215434**	**215434**			

Source: Calculated from Table 4.1.

The change detection matrix in (Table 4.4) clearly indicates that there was a trend of each land category in the period. In this regard, bush and forest land which was the largest land cover category (32.03% and 8.84 respectively) in 1991 show significant reduction, i.e., about 49,994.67 ha and 13,548.21 ha of forest land and bush land was converted to other land unit respectively. Yet, the majority of forest lands at the initial period were transformed to bush lands (7465.95ha) and cultivated land (5448.21ha) and only small proportion of forest in the initial period was transformed to settlement area (8.37ha) and water body (261.45ha). Whereas, only 5494.32 ha area of forest land has been left unchanged during the final state. In contrast to this, small proportion of cultivated (286.78ha) and bush land (825.08ha) was the main land cover category which was changed to forest land.

In addition, bush land covers 32.08% of the study area in 1991 LU/LC classification. However, it was decreased to 22.53% in 2005 LU/LC classification. The change detection matrix showed that there was significant change owing to loosen and gains of bush land. The bush land lost significant amount of land to cultivated land (37,274.21ha) areas and grass land (10,630.96ha). There was insignificant portion of the bush land (8.37ha) has converted to settlement area.

Table 4.4: Land use/cover change matrix of 1991 and 2005 years.

LULC Category		Initial State in ha (1991)						Class Total
		CL	BL	FL	GL	SA	WB	
Final State in ha (2005)	CL	68174.47	37274.21	5448.21	8482.34	104.58	0.58	119484.39
	BL	11170.02	18999.96	7465.95	10886.33	19.00	0.00	48541.27
	FL	286.78	825.08	5494.32	326.11	0.00	5.24	6937.54
	GL	22351.84	10630.96	364.22	1373.14	23.69	64.46	34808.31
	SA	83.20	354.14	8.37	62.70	347.39	0.00	855.80
	WB	2001.58	910.29	261.45	1333.95	0.00	299.36	4806.63
Class Total		104067.89	68994.63	19042.52	22464.57	494.67	369.66	215434

Source: - Calculated from classification maps of 1991 and 2005.

NB: - CL=Cultivated land, BL=Bush land, FL=Forest land, SA=Settlement area, WB=Water body

Note: The Diagonals indicate areas that remained unchanged.

With regard to grass land cover, the change detection matrix of 1991 to 2005 LULCCs also indicates that there was an increase in grass land which was mainly gains from cultivated land and bush land 22,351.84ha and 10,630.96ha, respectively. This result is evidenced by the findings of Bahiru, (2010); Negash & Mesfin, (2011) whom indicated that this change was mainly related to creation of 1km buffer zone of Gilgel Gibe reservoir dam.

Cultivated land has shown significant changes (35,893.42ha). About 37,274.21 bush land, 8482.34 of grass land and 5448.21ha of forest land was the main land category of the period that was changed in to cultivated land. On the other hand, 11,170,02ha and 22,351.84 of cultivated land are also transformed in to bush land and grass land respectively. But within the period about 68,174.47ha of cultivated land remain unchanged.

Water body has the least areal coverage of the area during initial and the second areal coverage in final state. There is 1333.95ha of grass, 2001.58ha of cultivated, 910.29ha of bush land and 261.45ha of forest land are transformed into water body during early 2005. Settlement area owing to less contribution to transformation/conversion and the conversion of other land categories to it, due to increase in urban population there was an increased in a real extent. This also related to the creation of reservoir area of Gilgel Gibe hydroelectric dam which was created artificial lakes in the study area during early 2003. During the FGDs and KIIs, the participants described that, before the construction of dam (pre-2000) the area which is currently covered by the reservoir was covered with the riparian forest, bush land and cultivated land which was totally converted to other LU/LC (water body) at short period of time.

In this period the area has undergone different environmental and demographic changes that came due to the construction of Gilgel Gibe I hydroelectric power project which was completed in 2003 and the introductions of new resettlement of 10,000 people who were displaced due to the construction of the dam (Bahiru, 2010; Negash and Mesfin, 2011). The information acquired from FGD and KII also confirmed that the construction of Gilgel Gibe I hydroelectric power dam was expropriated nearly10,000 people, and resettled to the area with the riparian forest and bush land of Gello, Bulbul and waktola kebele of the study area. Obviously, these human induced factors combined with other factors contribute for forest land and bush land encroachment, and the rise of cultivated land, water body and settlement areas.

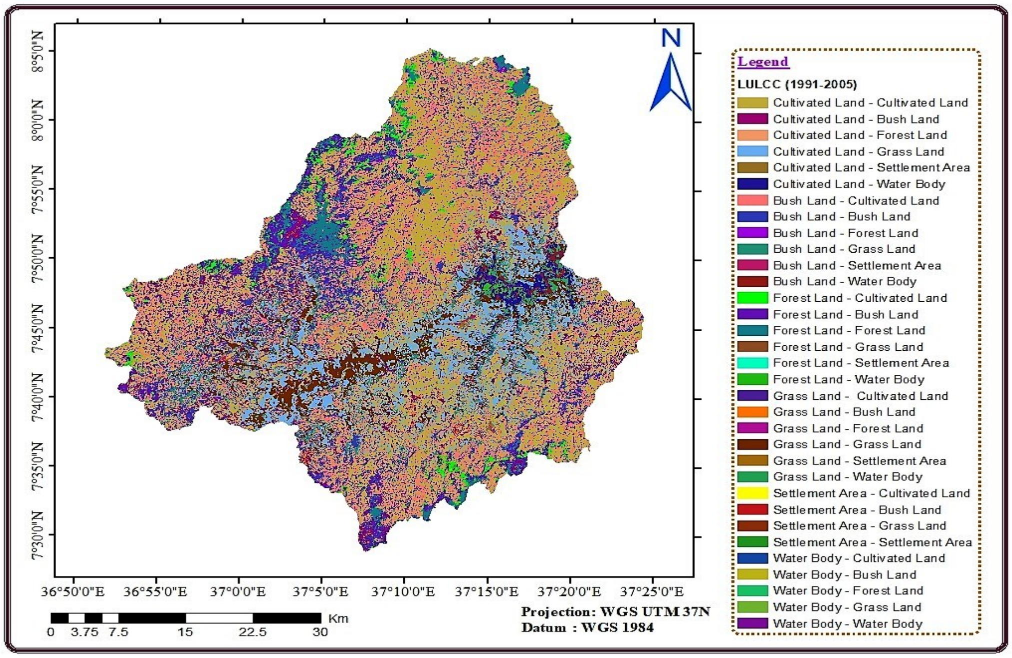


Figure 4:3: Land use land cover changes of the study area from 1991 to 2005.

Source: - Derived from LU/LC maps of 1991 and 2005.

4.4.2. LULCC Between 2005 and 2019

When comparing 2005 LU/LC classification with 2019 LU/LC classification, there are changes that showed decrease or increase in particular land use/land cover. The land use/land cover categories, which showed increase are only cultivated land and settlement area. In 2005, 55.46% of the study area covered by cultivated land which was increased to 61.29% in 2019 with average annual rate of change 896.2 ha/yr. and settlement area also show 141 ha/yr. average rate of changes. On the other hand, the land use/land cover categories like forest land, bush land, grass land and water body showed decreasing pattern with 173.6 ha/yr., 103.1 ha/yr., 749 ha/yr. and 11.5 ha/yr. average rate of changes respectively (Table 4.3). This is mainly related to human induced factors on existing natural resource of the area.

Forest land was diminished land category in this period and which was degraded and converted to other land category mainly into cultivated land and bush land. Within this period only 3219.74ha of forest land remain unchanged. The cultivated land (with over 61.29% coverage), has expanded throughout the period due to largely the conversion of the initial bush land (25,265.59ha) followed by grass land (12,757.40ha) and forest land (2,662.63ha). Bush land and grass land also showed significant reduction during the initial period, about 25,265.59ha of bush land and 12,757.40ha of grass land were transformed into cultivated land. From discussion made with selected focused groups and key informant interview, the expansion of cultivated lands and new settlement areas were exposed for deforestation for the purpose of fuel wood, for different construction purpose and farming activities.

This finding is in agreement with the finding of Bahiru, (2010) who reported that agricultural land and built-up area shows a continuous increment while forest land shows a decline trend between 1990-2008 in Gilgel Gibe watershed. Thus, agricultural land and built-up area expanded at the expense of forest cover. Similarly, the study by Amanuel and Mulugeta, (2014) reported that forest, bush land and riverine forest continuously declined by 22.64 ha/yr., 40.87ha/yr. and 35.71ha/yr. respectively between 1973 to 2004 in Nada Asendabo Watershed which found within the study area. Another finding of this study also agricultural and built-up area expanded at the expense of forest, bush land and riverine forest by 120ha/yr. and 19.19ha/yr. respectively in study periods. Another study by Yacob (2010), indicated that the growing demand of wood for fire, charcoal, construction materials, household furniture and pulp and paper industries has highly influenced the change in land use land cover condition of the Tikur Wuha watershed of Southern Ethiopia (Ethiopian Rift Valley) between 1965 and 2004.

Table 4.5 Land use/cover change matrix of 2005 and 2019 years.

LULC Category		Initial State in ha (2005)						Class Total
		CL	BL	FL	GL	SA	WB	
Final State in ha (2019)	CL	90886.26	25265.59	2662.63	12757.40	372.16	92.80	132036.83
	BL	21245.49	20668.00	992.31	3956.09	155.70	79.63	47097.22
	FL	210.27	1041.97	3219.74	33.46	3.58	0.00	4509.02
	GL	5906.61	1026.10	3.80	17069.51	56.48	260.28	24322.78
	SA	1197.55	483.10	59.42	814.83	265.79	5.59	2826.29
	WB	38.76	57.10	0.08	178.09	0.17	4368.61	4642.81
Class Total		119484.94	48541.87	6937.98	34809.38	853.87	4806.91	215435

NB: - CL=Cultivated land, BL=Bush land, FL=Forest land, SA=Settlement area, WB=Water body

Source: - Calculated from classification maps of 2005 and 2019. *Note: The Diagonals indicate areas that remained unchanged.*

Water body also shows of changes to other land category; the large proportion of water body (4368.61) remains unchanged during the final stages of the period. As indicated in (Table 4.5) the reservoir level of the dam was decreased, this is mainly related to the problem of siltation (Demissie et al., 2013) and the expansion of irrigation farm in the buffer zone and area covered by reservoir in the previous period (Negash and Mesfin, 2011) that was resulted from frequent LULCCs of the sub catchment. Although, settlement area LU/LC category expanded over the period this also mainly related to the fast population growths of the area.

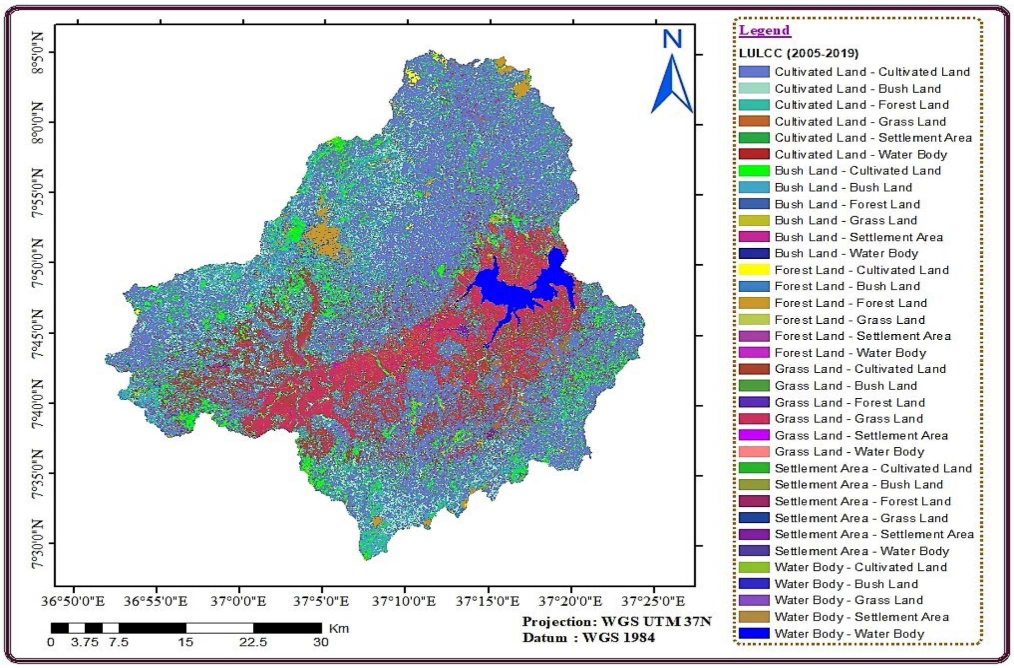


Figure 4:4: Land use land cover changes of the study area from 2005 to 2019.

Source: - Derived from LU/LC maps of 2005 and 2019

4.4.3. LULCC Between 1991 and 2019

Generally, the LU/LC types in the three study periods gradually changed with differing rates depending on the existing socio-economic, political, and environmental situation. Considering the overall study period (28 years), there was a remarkable increase in a real extent of cultivated land from 104,067.9 ha (48.31%) in 1991 to 132,031.2 ha (61.29%) in 2019. Grass land, settlement area and water body also showed relative increment of areal coverage of 66.4ha/yr., 83.3ha/yr. and 152.7ha/yr. average rate of increasement respectively. Within these 28 years; bush land was diminished at a higher rate, 782ha/yr. Forest land also showed a reduction in areal extent by mean annual rate of change 519.1 ha/yr. as showed in table 4.3.

Figure 4.5 and 4.6 clearly indicates that how much dynamic the land use/land cover of the study area. For instant; cultivated land was the greatest land cover category of the final period were increased in a real extent. About 43,867.95ha of bush land, 6201.67ha forest land, 11,369.04ha of grass land and 181.71ha of water body were converted to cultivated land. It was only the insignificant amount of settlement area (127.13ha) converted to cultivated land. Forest land has been transformed to cultivated land and bush land in greater amount and hence diminished greatly at the final state. Grass land were showed relative increase during the periods this was mainly from the conversion of bush land in to grass land (1,455.39ha). The bush land has increasingly decreased due to its conversion to cultivated land (43,867.95ha) in which the highest percentage of transformation recorded in. In addition to its conversion to grass land, water body and settlement areas.

Table 4.6: Land use/cover change matrix of 1991 and 2019 years.

	LULC Category	Initial State in ha (1991)						Class Total
		CL	BL	FL	GL	SA	WB	
Final State in ha (2019)	CL	70339.15	43867.95	6201.67	11369.04	127.13	181.71	132086.64
	BL	15058.87	21371.77	8720.57	1835.36	18.54	47.48	47052.58
	FL	142.64	545.10	3799.06	19.06	0.13	0.00	4505.99
	GL	15070.051	1455.39	81.46	7652.92	1.16	58.55	24319.54
	SA	1568.48	834.33	46.79	364.40	6.99	3.26	2824.25
	WB	1878.91	902.74	263.51	1221.52	0.00	378.40	4645.09
Class Total		104058.11	68977.26	19113.06	22462.30	153.95	669.41	215434

NB: - CL=Cultivated land, BL=Bush land, FL=Forest land, SA=Settlement area, WB=Water body

Source: - Calculated from classification maps of 1991 and 2019.

Note: The Diagonals indicate areas that remained unchanged.

In general, there were different magnitudes of changes has been recognized over the study period. Some of the land categories increased and thus has positive mean rate of change but others were diminished and thus have negative rate of change (Figure 4.5). Within 28 years of the study periods (1991 to 2019) there was an extreme degradation of original ecosystem over the area. This is evident in that as cultivated land has been increased dramatically, the forest and bush land has been declined extremely over the years. Both grass land and water body increased at the beginning and showed some reduction at the last. Settlement area and cultivated land increase continuously (Figure 4.6). The response from FGD and KII also indicated that the expansion of cultivated land and settlement area at the expenses of forest and bush land and cultivating along steep slope which causes changing LU/LC of the area. Hence, the major cause of forest land, bush land and grass land change are related to cultivation land expansion in the study land escape.

Figure 4:5 Observed cultivated land and settlement area expanded at steep sloping area.

Source: - Photo captured during field observation in southern part of the area in Omo Nada Woreda (Author, 2020)

Thus, this finding is in line with the study conducted by Bekele et al., (2017) in Dedo district of Southwestern of Ethiopia which revealed that forest land cover continuously degrading since 1987 to 2015 which were primarily changed in to farm land and water body with a high changing rate. Similarly, the research conducted in Jima Arjo Wereda (Western Ethiopia) by Muleta, (2015) reported that farm land increased from 43.62% to 63.4% while forest land reduced by 754.6ha/yr. between 1973 and 2001 and also indicated that the conversion of forest land was primarily to farm land. Likewise, the study by Gete and Hurni (2001), revealed cultivated land increased from 39%

in 1957 to 70% in 1982 and to 77% in 1995 in Dembecha area while the natural forest cover declined from 27% to 2% and to 0.3% over the course of these periods.

Research conducted by Dagnachew et al., (2020) in Gojeb River catchment of Omo Gibe Basin indicated that crop land increased from 29.56% in 1978 to 52.7% in 2015 while forest land declined from 18.6% to 8.78% in respective year and the expansion of crop land has largely been a result of the conversion of open grassland, shrub land, riparian vegetation and forest and dense trees. Another study conducted in Dessie zuria of central highlands of Ethiopia by Ali, (2009) reported that agricultural and bare land expanded while forest and bush land decreased by different rate at steep slope than gentler slope and this contributed to the land degradation between 1973 and 2000.

In general, based on the findings of this study and previous studies mentioned above cultivated land expanded at the expense of forest and bush land reduction. The conversion of forest and bush land to cultivated land especially at steep slopes in the area is confirmed with in the study periods. These implies how much the area is prone to erosion hazard (since sever erosion is expected over steep slopes than gentler slopes) and the consequent soil and land degradation.

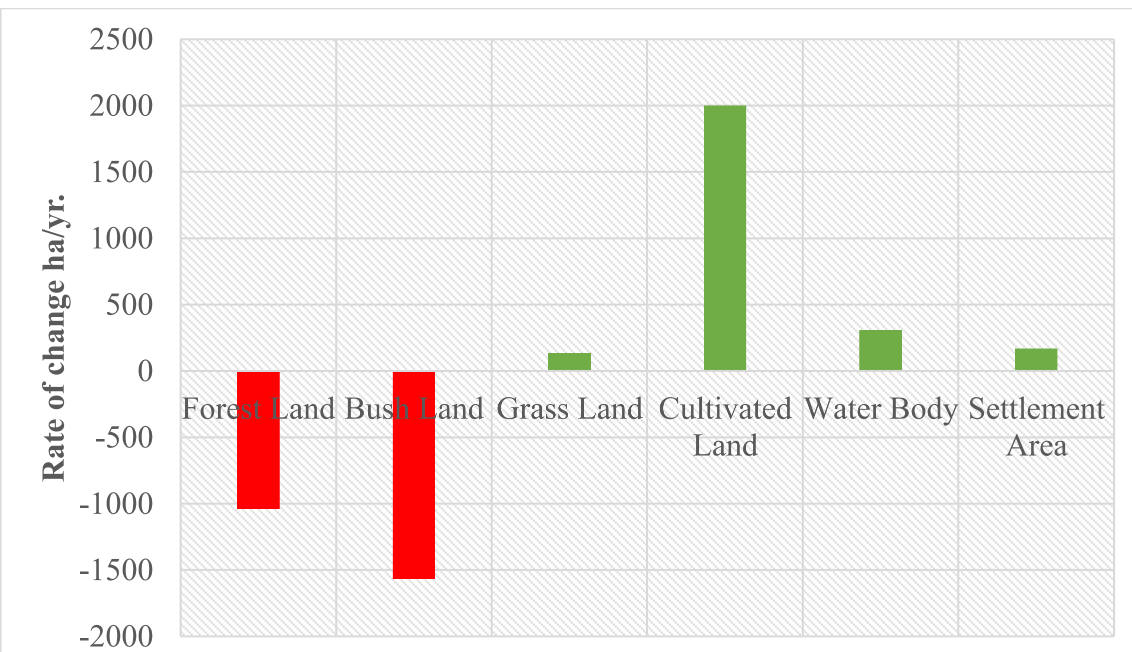


Figure 4:6: Rate of change of land use/cover across 1991- 2019.

(Source: Derived from Table 4.3)

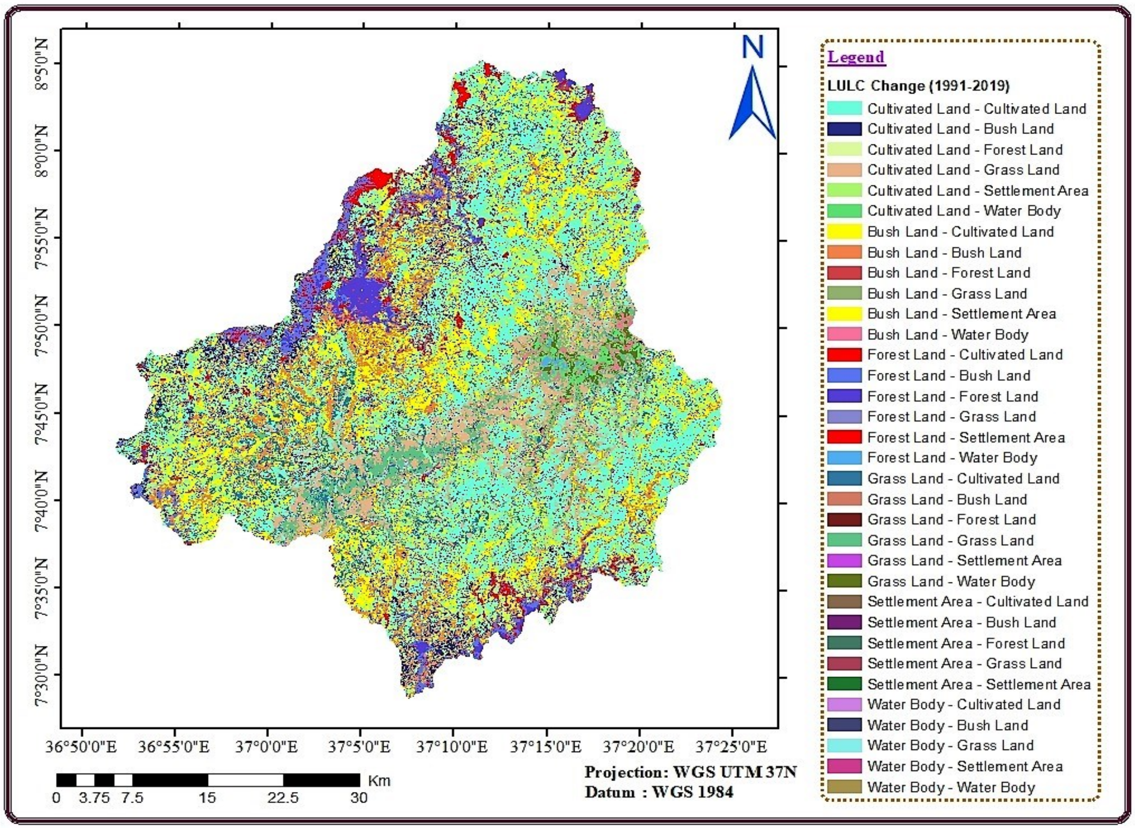


Figure 4:7: LULCC of the study area between 1991 and 2019.

Source: - Derived from LU/LC maps of 1991 and 2019

4.5. Determination Of RUSLE Factors

4.5.1. Rainfall Erosivity Factor (R)

As presented in Table 3.6, the long-term mean annual rainfall amount varied between 1104.56mm and 1763.92mm. The rainfall erosivity values estimated from mean annual rainfall of the selected rainfall stations varied from 612.64 MJ mm h^{-1} ha^{-1} yr^{-1} at Asendabo to 983.2 MJ mm h^{-1} ha^{-1} yr^{-1} at Dimtu. The calculated R-value of Omo Nada and Serbo station is 953.43 and 800.54, respectively. The calculated values show that, as the mean annual rainfall increases, the rainfall erosivity also increases. Following this, the study area faces highly erosive rainfall in the northern part of the study area around Dimtu and O.Nada and gradually a decrease towards the central, western and eastern parts of the study area around Asendabo and Serbo, respectively (Figure 4.7). Thus, this finding is in agreement with Gizawu and Degifie, (2018) whom reported that stations with high rainfall had resulted high rainfall runoff erosivity value which may cause high soil erosion. This study also revealed that the area with high rainfall and R-value were located in the upper part and lowest at the middle and near to outlet (where Gilgel Gibe dam constructed) of Gilgel Gibe catchment.

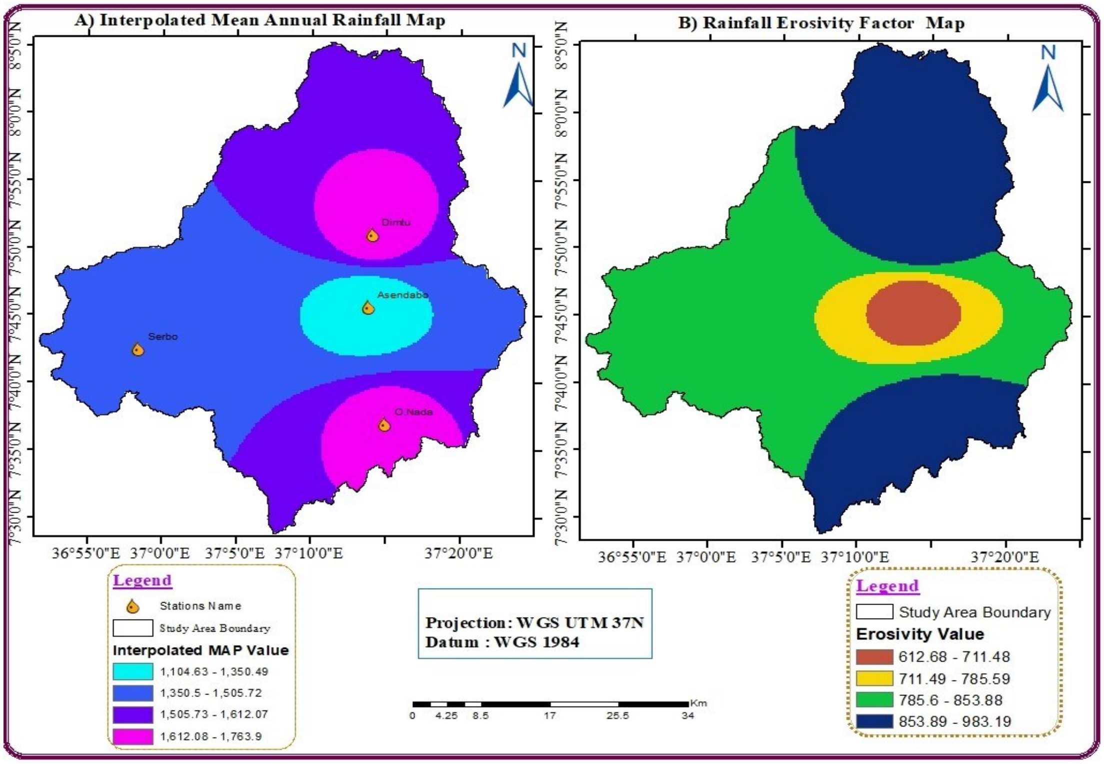


Figure 4:8: A) Interpolated mean annual rainfall map; B) Generated rainfall erosivity map.

4.5.2. Soil Erodibility Factor (K)

From the digital soil map of the study area, four different soil types with different characteristics were identified. The erodibility characteristics of the existing soils in the study area varied with the range of K-factor values of 0.15 - 0.35ton $h^{-1}ha^{-1}$ MJ^{-1} mm^{-1}. According to Chadli, (2016) K-factor is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff and higher k-value indicates more susceptibility to erosion while lower k-value indicates less susceptibility to erosion. Hence, Lithic Leptosols and Humic Nitisols which account for about 0.03% and 5.92% of the total area have the highest K-factor values of 0.35 and 0.25 respectively. Humic Alisols which covers 41.70% of total area have the moderate k-factor value of 0.2. Dystric Vertisols which cover about 52.33% of the total area have the lowest K-factor value of 0.15 (Table 3.7).

Generally, soil types have highest k-value were found mostly in the southeastern parts of the catchment with some coverage in the western part as well. Soils with low and moderate k-values are found in central, all portion of northern and southern parts of the sub catchment.

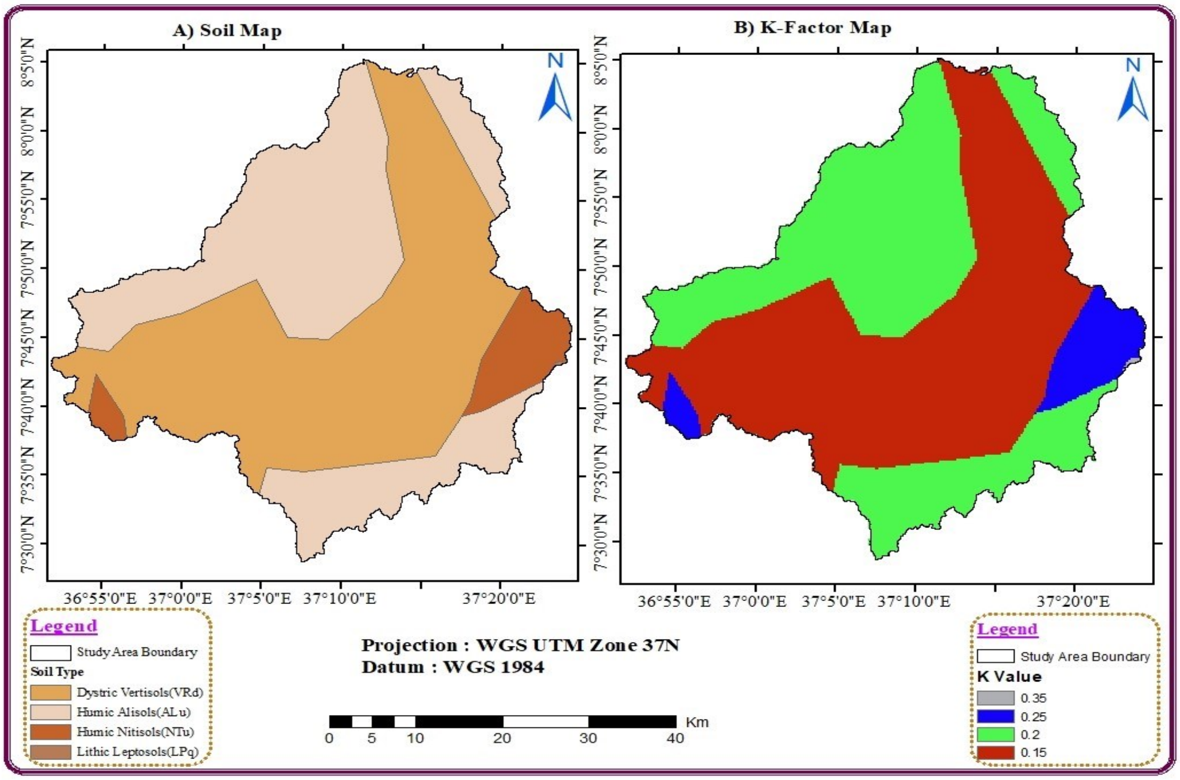


Figure 4:9: A) Soil map(left); B) Soil erodibility factor(K) map(right).

Source: Extracted from HWSD version 1.2.

4.5.3. Slope Length and Steepness Factor (LS)

The values of LS-factor in the study area vary between 0 (flatter and lower part) and 51.04 (steep and upper part). The higher LS-factor values of 9.4 to 51.04 were mostly observed in the mountainous and hilly region of northwestern, south, western and northeastern the study area. This is because, as the slope gradient increases, the value of the LS-factor also increases. Therefore, in the area where smaller LS-factor values existed, the expected soil erosion due to this factor would be less and, in the area where larger LS factor values existed, the expected soil erosion would be more. Most of the central and southeastern parts of the study area show a lower LS-factor value of 0 to 1.4. Majority of the study area has LS value less than 1.4 and some specific areas only showing values higher than 9.4 (Figure 4.10).

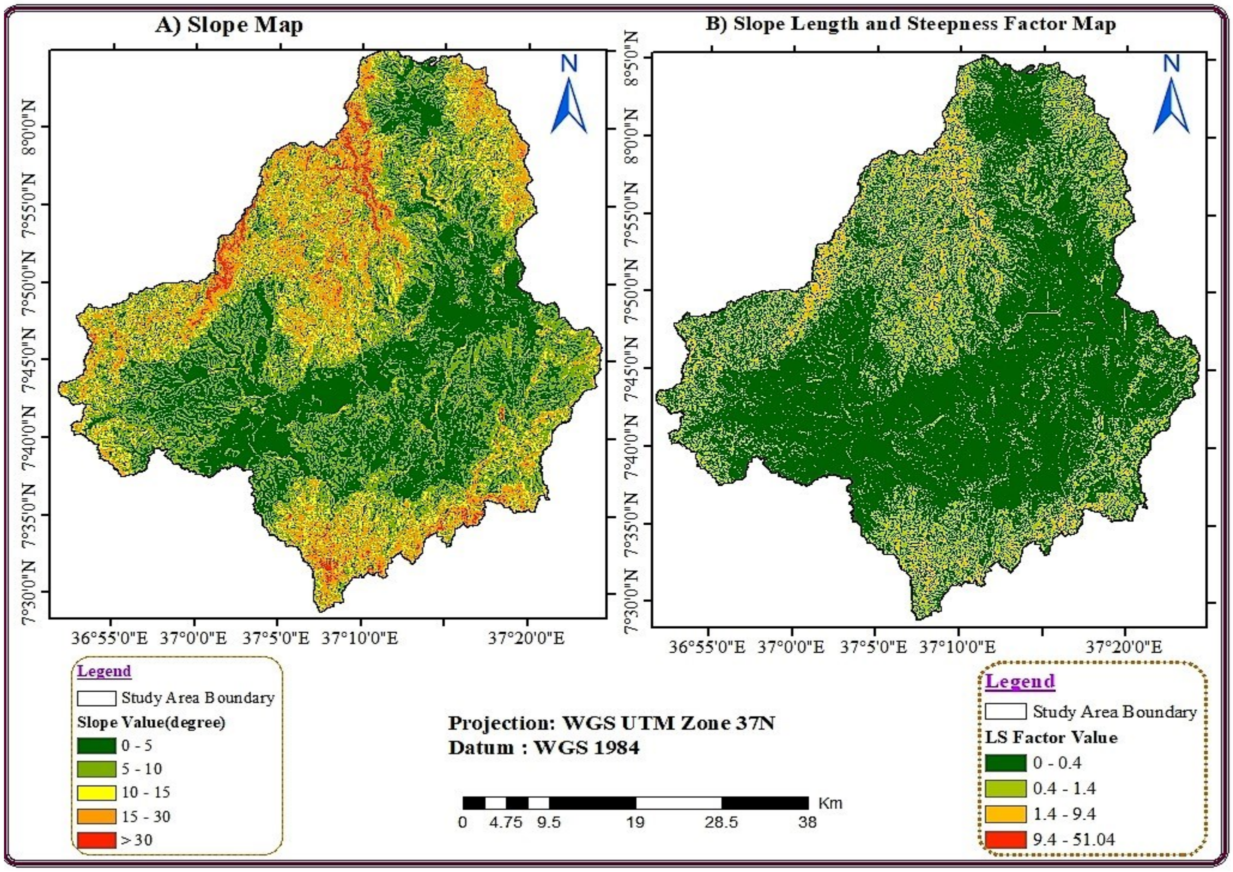


Figure 4:10: A) Slope map; B) Generated slope length and steepness(gradient) factor map
Source: - Generated from ASTER DEM.

4.5.4. Crop Cover and Management Factor (C)

Based on the recommended value of c-factor which is collected from previous studies and assigned for the corresponding LU/LC classes the bush and forest land have smaller values of C-factor 0.014 and 0.01, respectively, collectively cover an area of 40.87% in 1991, 25.75% in 2005 and 23.95% in 2019. About 48.31% in 1991, 55.46% in 2005 and 61.29% in 2019 of the study areas is covered by cultivated land that is exposed to direct rainfall during the time of crop preparation. Soil erosion from this area was expected to be high because the soil is exposed to the first rainfall events without any cover. In this area, the larger value of C-factor (0.1) was assigned next to settlement area and grass land, which has a C-factor value of 0.05 and 0.09, respectively. Water body have a C-factor value of 0.00 based previous study conducted with in the study area.

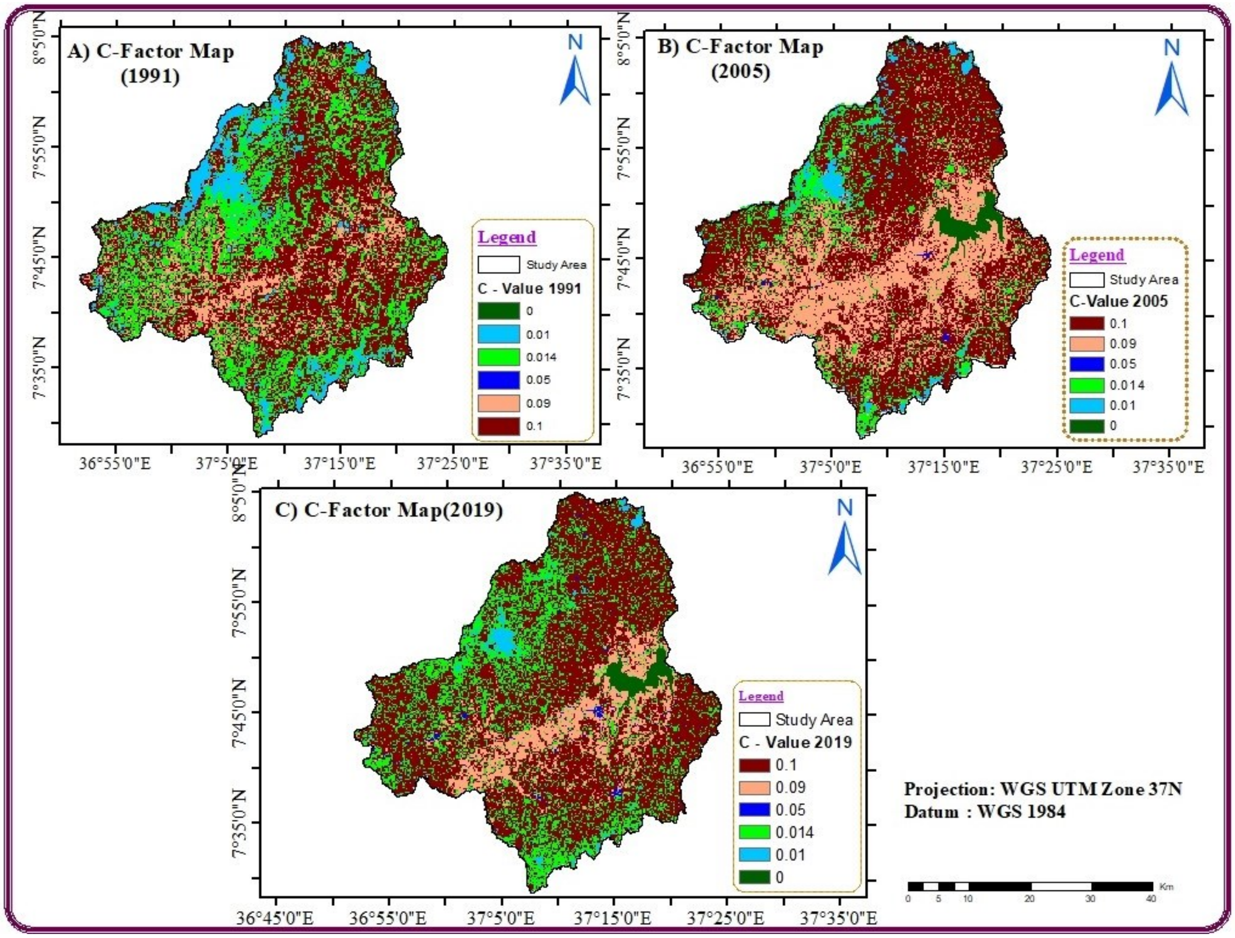


Figure 4:11: C-Factor map; A) 1991; B) 2005; C) 2019.

Source: - Derived from LU/LC maps of respective years.

4.5.5. Erosion Control Practice Factor (P)

Depending on the reviewed related previous studies, the value of P-factor ranges from 0 to 0.95. Based on the result, both forest and grass land have P-factor value of 0.7 while cultivated land, bush land and settlement area have P-factor value of 0.95, 0.8 and 0.63 respectively. Area covered with water body has a P-factor value of 0. Based on the result, the central part of the study area is characterized by lower P-factor values and the rest of the study area shows higher P-factor values. Because the P-factor values are highly influenced by slope steepness conditions (Habtamu and Amare, 2016), the area characterized with steep slope in the sub catchment (northwestern, southern, southeastern and some parts of northern and northeastern) parts of the study area have the higher values of P-factor. In this condition also, the lower values of P-factor were concentrated in the central part of the study area especially area following Gibe River and Gilgel Gibe I reservoir area.

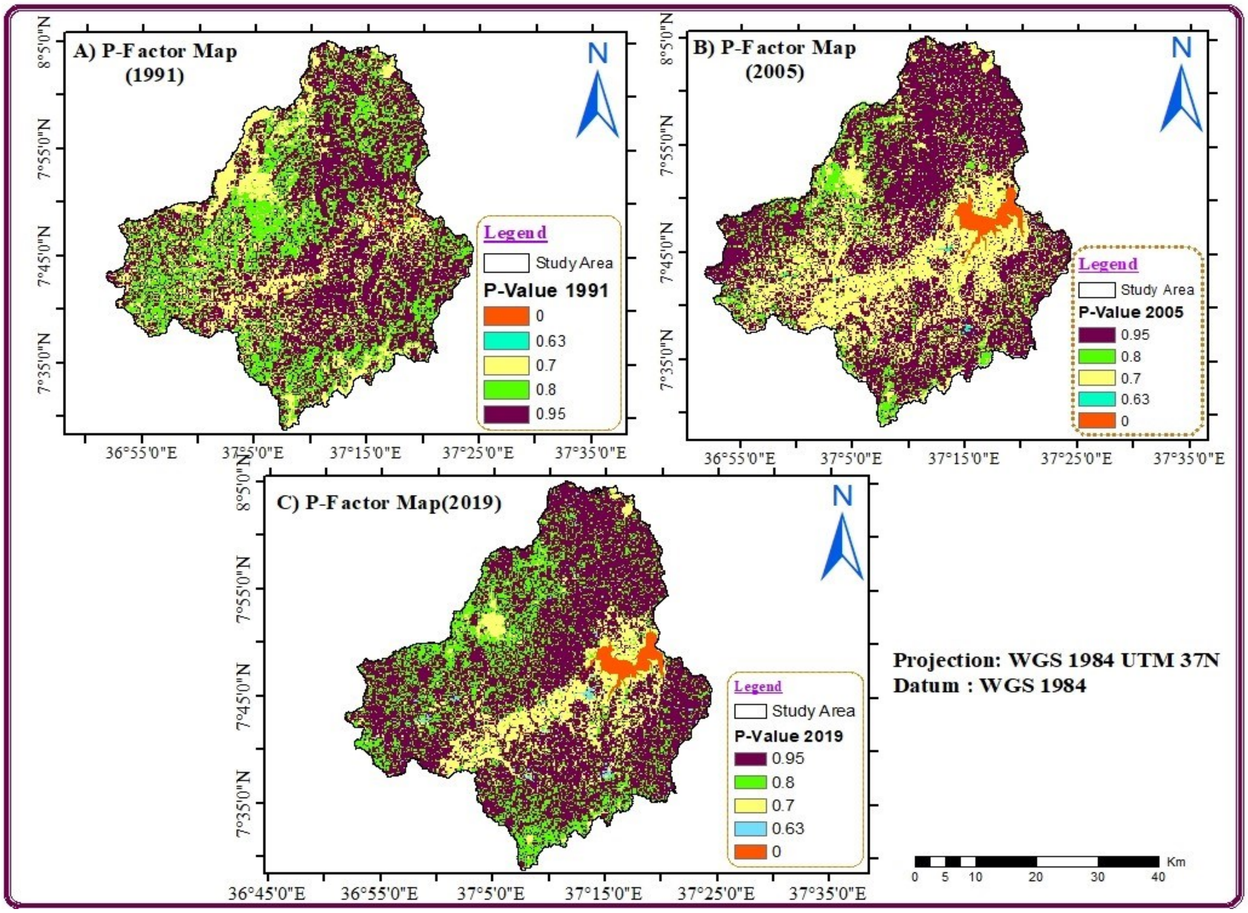


Figure 4:12: P-Factor map; A) 1991; B) 2005; C) 2019.
Source: - Derived from LU/LC maps of respective years.

4.6. Soil Erosion Assessment Using RUSLE Model Results

In order to evaluate the soil erosion potential in the Gilgel Gibe sub catchment, the RUSLE model was run for 1991, 2005 and 2019 separately. During each model run, all parameters remained the same, except values of the C and P factors, which were changed according to the LU/LC of the respective year. Based on the estimated rates of mean annual soil loss, erosion risk was grouped into five classes ranging from the very slight to very severe. Thus, the first two classes (very slight and slight) are considered in the range of soil loss tolerance values. Moderate and severe classes need conservation applications to maintain a sustainable productivity, while the last class (very severe), is very dangerous because it can be destructive in few years if no intervention is done and soil loss level is maintained constant in the future.

Table 4.7: Soil erosion severity classes and its areal coverage of the study periods.

Soil Loss(ton/ha/yr.)	Soil Erosion Risk Class	1991		2005		2019	
		Area(ha)	%	Area(ha)	%	Area(ha)	%
0 - 5	Very Slight	208823.96	96.93	202560.05	94.02	123499.80	57.33
5.1 - 15	Slight	5886.52	2.73	11225.26	5.21	44804.69	20.80
15.1 - 30	Moderate	619.33	0.29	1303.92	0.61	25774.23	11.96
30.1 - 50	Severe	86.82	0.04	249.42	0.12	12481.90	5.79
> 50	Very Severe	17.36	0.01	95.35	0.04	8873.39	4.12
Total		**215434.00**	**100.00**	**215434.00**	**100.00**	**215434.00**	**100.00**

As indicated in Table 4.7 and 4.8 during 1991 mean annual soil loss is 24.81ton/ha/yr. and generally falls in the range of 0-80.08 ton/ha/yr. The total soil loss in the area is found to be 5.3 million tons per year and most of erosion prone area has occurred in the highland and mountainous part of the area especially in North eastern, North western and Southern part of the study area. In this period about 0.01% (17.36 ha) of the area is fall under erosion prone areas i.e., area under very severe risk class (> 50 ton/ha/yr).

In 2005 the quantitative output of estimated actual soil loss from Gilgel Gibe sub catchment varied from 0 to 341.62 ton/ha/year with mean annual soil loss of 56.67 ton/ha/yr. The estimated total soil loss was increased to 12.2 mt/yr. Thus, the result obtained also shows that 94.02% of the study area is under very slight erosion risk, 5.21% of the study area is categorized under slight erosion risk and moderate, severe and very severe risk zones shares 0.61%, 0.12% and 0.04% respectively as showed in Figure 4.11 and Table 4.7. Thus, in this period area under erosion prone areas increased to 0.04% (95.35ha).

LU/LC transformation was widely occurred due to resettlement program undertaken in the study area especially in the lower stream of the central and north western part of the study area. In addition, in the central and some parts of north western tips of the study area which is mainly the resettlement area has started experiencing erosion.

Table 4.8: Estimated soil loss (ton/ha/yr.) result for three study periods.

Year	Min.	Max.	Mean soil loss(ton/ha/yr.)	Total Soil Loss (mt/yr.)
1991	0	80.08	24.81	5.34
2005	0	341.62	56.67	12.20
2019	0	481.9	83.6	18.01

Source: - Computed from RUSLE model result.

In 2019 the quantitative output of estimated actual soil loss from Gilgel Gibe sub catchment extends from 0(the lower and middle part following the gibe river, specifically on Gilgel gibe I reservoir) to 481.9 ton/ha/yr. The current mean soil loss in the sub catchment is 83.6 ton/ha/yr. with the estimated total annual soil loss of 18 mt/yr. for the entire 215,434ha of the study area. In the sub catchment about 61.29% of land is grouped under cultivated land use/land cover type (moderately and intensively cultivated land). The results show that, currently 4.12% of the study area is under erosion prone.

Accordingly, as presented in Table 4.7, 4.8 and Figure 4.13 about 4.12% (8,873.39 ha) of the study area is fall under erosion prone areas (very severe risk class) in 2019. While very slight, slight, moderate and severe risk zones share 57.33%, 20.80%, 11.96% and 5.79%, respectively.

Generally, the spatial distribution of soil erosion risk classes between 1991-2019 showed an increasing trend in the study area, that is, it increased from slight, moderate to severe and very severe classes while areas under very slight soil erosion risk class decreased sharply. Areas under very slight soil erosion risk class was reduced by 39.61% from 1991 to 2019, while areas under slight, moderate, severe and very severe increased by 18.07%, 11.68%, 5.75% and 4.11% respectively within 28 years.

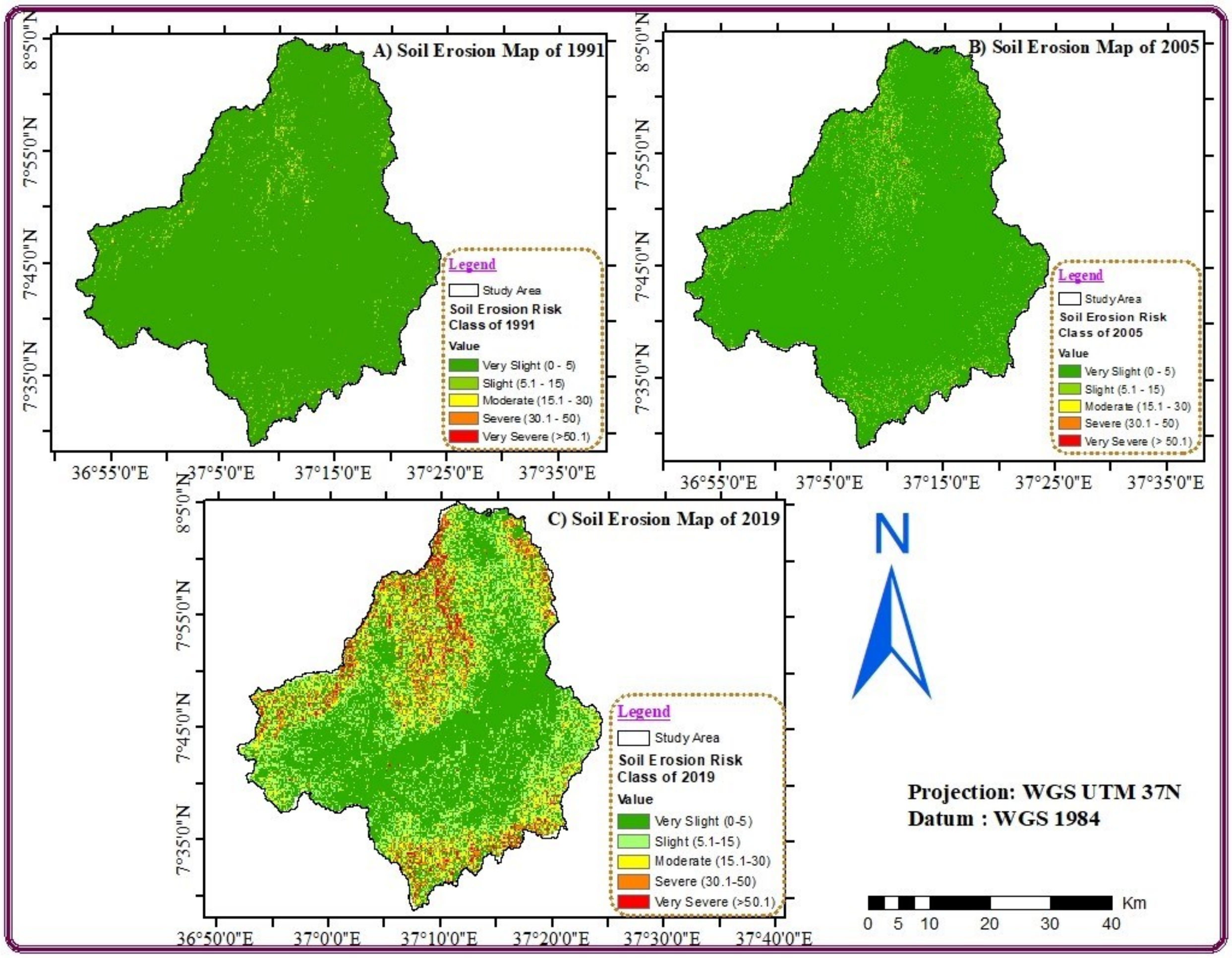


Figure 4:13: Soil erosion map; A) in 1991, B) in 2005 and C) in 2019.

Source: - Derived from LU/LC maps of respective years and computed from RUSLE model.

The mean annual soil loss range of this study in three study periods (1991, 2005 & 2019) is higher than the tolerable soil loss limit of Ethiopian highlands (2–18 ton/ha/yr.) which is suggested by Hurni (1985) but it is lower than the value reported by Gizawu and Degifie, (2018) and by Bewket and Teferi, (2009). Soil erosion modeling in Gilgel Gibe I catchment by Gizaw and Degifie (2018), using RUSLE model and GIS technique reported that the mean annual soil loss of 62.98ton/ha/yr. with a range of 0 to 938.14ton/ha/yr. for the entire catchment and 86.75ton/ha/yr. for sub-watershed which is found within this study area and prioritized it under severe class with ranking of number one in 2016. Similarly, the soil erosion assessment by Bewket and Teferi (2009), in Chemoga watershed of the northwestern highlands Ethiopia, reported the average soil loss of 93ton/ha/yr.

Another study in Omo-Gibe basin using the same method by Girma & Gabre (2020), come out with the result of mean annual soil loss 69 ton/ha/yr. for the entire basin and the high amount of soil loss rate was recorded in upper catchment and central parts of the basin where the study area found in 2018. They also reported that high amount of soil loss is due to deforestation, high population pressure, sparse land cover and steeply sloping terrain in these two parts of the basin and put under very severe erosion risks with first priority for soil conservation planning.

In addition, Beshir and Awdenegest (2015), reported annual mean soil loss in Jimma Zone 48.1 ton/ha/yr. and 60.9 ton/ha/yr. for the year 2001 and 2013 respectively and three woredas such as Tiro Afeta, Omo Nada and Sokoru (which is touched by Gilgel Gibe sub catchment) their respective 28% of area was under very high erosion risks class (> 50 ton/ha/yr.) in two study periods. Similarly, a study conducted in Koga watershed of Upper Blue Nile basin reported an average soil erosion rate of 47.4 ton/ha/yr. in 2013 (Gelagay, 2016). This variation on the reported soil loss record was because of LULCC and topography difference considered for each study (Kidane et al., 2019). Thus, based on the above studies by comparing with time series the result is comparable and relatively similar with the findings of this study.

4.7. Impacts of LULCC on Soil Erosion Risk

The subsequent impacts of LULCC on soil erosion potential and the rate of soil loss of the sub catchment was evaluated through average annual soil erosion of the sub catchment using the RUSLE model results of the corresponding study periods. Additionally, the annual mean soil erosion of study periods calculated corresponding with the change in LU/LC category using zonal statistics tool in ArcGIS environment. According to Renard (1997), in RUSLE model the C and P factors were changed according to the LU/LC of the respective year. Since the C factor in the RUSLE model directly depends on land use/land cover, the change of land use type had a significant influence on soil loss potential.

Table 4.9: Mean annual soil loss from each land use/land cover types for each study year and its rate of change over the study periods.

Class Name	Average Soil Loss(ton/ha/yr.)			Rate of change of soil loss (%)		
	1991	2005	2019	1991-2005	2005 -2019	1991-2019
Forest Land	0.63	1.18	9.74	86.61	727.03	1443.31
Bush Land	0.72	1.59	12.27	120.49	673.23	1604.89
Grass Land	0.59	0.61	2.32	2.78	280.92	291.50
Cultivated Land	1.29	6.97	15.39	441.40	120.91	1096.00
Water Body	0.11	0.07	0.05	-34.96	-28.57	-53.54
Settlement Area	0.39	0.64	4.59	61.55	619.74	1062.74

LU/LC change exerts negative impacts on ecosystem services, in general, and on biodiversity, climate, soil, water, and air, in particular (Biniam, 2012). Soil erosion is affected by LULCC despite other factors such as climate, soil characteristics, and topography. Land cover plays a significant role in controlling soil erosion by reducing the direct impacts of raindrops on the soil, enhancing the organic matter content in the soil, increasing the infiltration rate of water, reducing the velocity of runoff, and reducing the transportation of sediments on the surface (Chadli,2016; George et al., 2013). Hence, a change in LU/LC due to anthropogenic activities significantly affects the rate of soil erosion.

During the three study periods, the trend of soil loss in the study years indicates that a sharp increase for bush, forest, cultivated lands and settlement areas. The major source of increased erosion in the study sub catchment was the cultivated LU/LC classes. The average soil loss in the cultivated land area was 1.29 ton/ha/yr. in 1991 and this value was increased to 6.97 ton/ha/yr. and 15.39ton/ha/yr. in 2005 and in 2019, respectively (Table 4.9). Increased soil loss in the cultivated areas especially cultivated areas within steep slopes was not surprising because larger cultivated area meant larger areas are mostly disturbed and exposed to different erosion agents and therefore increased potential of soil erosion. In the case of the bush land areas, average soil loss was 0.72 ton/ha/yr. in 1991 and this value was increased to 1.59 ton/ha/yr. and 12.27 ton/ha/yr. in 2005 and in 2019, respectively (Table 4.9). Additionally, in forest land areas average soil loss in 1991 was

0.63 ton/ha/yr. and this amount of soil loss was increased to 1.18 ton/ha/yr. and 9.74 ton/ha/yr. in 2005 and 2019, respectively.

Accordingly, the most dominant rate of change in erosion potential was observed within four opposite LU/LC categories i.e., bush lands, settlement areas, forest and cultivated lands. The bush land areas erosion potential increased by 1604.89% from 1991 to 2019 while 1443.31%, 1062.74% and 1096% is for forest land, settlement and cultivated land areas, respectively. But cultivated land and settlement LU/LC areas increased by 38.38% (27,963.3ha) and 3.2% (2,333.57ha) respectively, whereas the reduction in forest and shrub land areas was 19.95% (14,533.81ha) and 30.05% (21,897.32ha), respectively which were predominantly changed to cultivated LU/LC land and settlement areas. This is an indicator of the impacts of LULCC on soil erosion potential in general and particularly in Gilgel Gibe sub-catchment. However, the total loss is greater on the cultivated land as it is the most dominant land use/land cover type in the study area.

Different studies undertaken nearby study area and other parts of Ethiopia indicated the impacts of land use and land cover change on soil erosion. Among these, a recent study made by Woldemariam and Harka (2020) at Erer Subbasin, Northeast Wabi-Shebelle Basin of Ethiopia, indicated that the expansion of cropland, bare land, and settlement from 47.92%, 8.03%, and 0.20%, respectively in 2000 to 64.36%, 9.71%, and 0.61%, respectively in 2018 and the decline of forestland, shrubland, and water body from 2.99%, 40.67%, and 0.18%, respectively in 2000 to 1.42%, 23.87%, and 0.03% respectively in 2018 increased the mean soil loss rate of the subbasin from 75.85 ton/ha/yr. in 2000 to 107.07 ton/ha/yr. in 2018. Similarly, Kidane et al., (2019) revealed that the expansion of cultivated land at the expense of forest and shrubland increased the mean rate of soil erosion from 25.8 ton/ha/yr. in 1973 to 28.7 ton/ha/yr. in 1995 and 30.3 ton/ha/yr. in 2015 and the total soil loss from 198 million ton/yr. in 1973 to 221 million ton/yr. in 1995 and 239 million ton/yr. in 2015 in Guder Sub watershed, Blue Nile basin of Ethiopia.

Another recent study by Aneseyee et al., (2020) in the Winike Watershed, Omo Gibe Basin of Ethiopia, reported that total soil loss of the watershed increased by 176.35 thousand tons over the periods between 1988 and 2018 due to the change in LU/LC. Another study in Andassa Watershed, upper Blue Nile Basin of Ethiopia, revealed that the rapid expansions of cultivated land and built-up area at the expense of forest, shrubland, and grasslands for three decades (1985–2015) have increased the average soil erosion rate of the watershed from 35.5 ton/ha/yr. in 1985 to 55 ton/ha/yr. in 2015 (Gashaw et al., 2019).

The research conducted by Tadesse et al., (2017) on land use and land cover changes and soil erosion in Yezat Watershed, Northwestern Ethiopia, showed that the expansion of cultivated land and decline of sparsely wooded land, grassland, and shrubland during the period between 2001 and 2010 have increased the estimated average soil loss from 7.2 ton/ha/yr. in 2001 to 7.7 ton/ha/yr. in 2010 in the study area. Another study by Mariye et al., (2020) in Legedadi Watershed, Berhe District of Ethiopia, reported the mean annual soil loss of the watershed has increased from 54.19 ton/ha/yr. in 1997 to 66.21 ton/ha/yr. in 2013 due to the increment of cultivated land and settlement area by 18.3% and 14.34%, respectively.

Study undertaken in Shashogo woreda of Southern Ethiopia by Shamebo, (2010) also revealed that the high reduction of forest land and vegetation areas predominantly caused by agricultural activities which led to dramatic increase of soil loss and which reduced the protective function of the land. A study in Didessa River Catchment, Southwest Blue Nile of Ethiopia, by Chimdessa et al., (2018) has shown that the average soil loss of the river catchment increased by 9.6 ton/ha/yr., 11 ton/ha/yr., and 20.9 ton/ha/yr. due to LULCC between 1986-2000, 2001-2015, and 1986-2015, respectively.

In general, from the results we can notice that rate of soil loss is highly dependent on the existing LULCC. The results also indicated that conversion of other LU/LC types to cultivated land especially from forest and bush lands was the most sever in terms of soil loss while forest lands acted as an effective barrier. Thus, the expansion of settlement areas and cultivated land without appropriate conservation measures and reduction of forest and bush lands, with other factors such as sparse land cover coupled with steep sloping terrain are the main causes for the increasing of mean soil erosion rate.

CHAPTER - FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Inappropriate use of land resources, coupled with a growing interest and reliance on various products and services from those resources poses a challenge for managing the natural resources in Gilgel Gibe sub-catchment. Inappropriate cultivation practices especially in highly steep sloping terrain, dynamics in LULCC coupled rugged topography have been reported as the main facilitators for having severe erosion. Thus, analyzing of LULCC is crucial to generate information and to understand its impact in triggering soil erosion using modern applications. Thus, the status of LULCC and soil erosion of study periods in the area were analyzed using GIS and remote sensing techniques by integrating RUSLE model.

This study revealed that LULCC is a widespread, accelerating and significant process in the study sub-catchment. There is a sharp increase in cultivated land and settlement area; while there was a sharp decrease in forest and bush lands between 1991 to 2019. On the other hand, the landscape experienced a high level of conversion to cultivated land at the expense of forest and bush land classes which implies that how much the area is prone to soil erosion hazard.

Results of determined RUSLE parameters indicated that as the mean annual rainfall increases the rainfall erosivity also increases while; the soil erodibility characteristics of the identified soils in the study area indicated that the highest k-value indicate higher susceptibility to erosion and vice versa. The calculated values of LS-factor in the study area indicated that the majority of the study area has LS value less than 1.4 and some specific areas only showing values higher than 9.4. RUSLE model results also indicated that the bush and forest land have smaller C-values while cultivated land have the highest value next to settlement area whereas; the highest P-factor value was for cultivated land while the smallest was for water body.

After consideration of C and P factor the estimated mean annual soil loss from the area (actual soil loss) for 1991, 2005 and 2019 were 24.81ton/ha/yr., 56.67ton/ha/yr. and 83.6ton/ha/yr., respectively. Accordingly, about 0.01% area in 1991, 0.04% area in 2005 and 4.12% area in 2019 of the study areas was fall under erosion prone areas (very severe risk classes). The spatial distribution of soil erosion risk classes between 1991-2019 showed that areas under very slight soil erosion risk class was reduced from 1991 to 2019, while areas under slight, moderate, severe and very severe was increased within 28 years.

Another result of this study also demonstrates that the overall LULCCs over these three decades has affected the sub catchment negatively by increasing soil erosion risks. The most dominant rate of change in erosion potential was observed within four opposite LU/LC categories i.e., bush lands, forest, cultivated lands and settlement areas. Also, conversion of other LU/LC types to cultivated land and settlement areas especially from forest and bush lands was the most detrimental of soil loss while forest acted as an effective barrier. This is an indicator of the impacts of LULCC on soil erosion potential. Thus, the expansion of cultivated land without appropriate conservation measures, with other factors such as sparse land cover coupled with steep sloping terrain are the main causes for the increasing of mean soil erosion rate.

5.2. Recommendations

This study focuses on the identification of the long term LULCCs and its impacts on soil erosion risks. Further this study would address what specific conservation structures are required and how the LULCC cause soil erosion in the study area. Based on the results of this study, the following recommendations were proposed for action.

- Successive efforts towards increasing vegetation covers are very important in order to reduce soil erosion. So, recent implementation of National tree plantation campaign called as "Green Legacy" should give the first priority to those areas under severe and very severe erosion risk classes.
- The LULCC that is mostly affected by agricultural activities needs to be projected to figure out where the LULCC leads in the future. Land use and administrator and agricultural development sectors experts and officials should prepare effective community-based land use planning and should implement as of planned to anticipate the possibility of erosion risk triggered by LULCCs.
- Awareness creation for community on optimum use of natural resources, sustainable land management, practicing appropriate land use planning and their respective benefits should done by those sectors incorporating government officials, NGOs and community leaders.
- Application of RUSLE model integrating with climatic, soil, topographic and remotely sensed data within a GIS environment was found very helpful in quantifying the past and present LULC and soil erosion status and the link between them from which an appropriate planning could be made for the future. Knowledge of cause effect relationships between LULCC and soil erosion modeling and their spatial patterns should be essential to plan integrated watershed management schemes and to design necessary management precautions.
- Further studies need to be done in order to prioritizing of watersheds/micro-watersheds based on their susceptibility to soil erosion risk and to assess the conservation measures required for different stages of erosion vulnerable watersheds under different factors.

References

Alemayehu, F., Motuma, T. M., & Gizaw, T.G., (2018). Land use land cover change trend and its drivers in Somodo Watershed, South Western Ethiopia. *African journal of agricultural*, Vol. 14(2), pp. 102-117, DOI: 10.5897/AJAR2018.13672.

Alfred, E. H., (2010). Land use change in the tropics and its effect on soil fertility. World congress of soil science. Soil solutions for a changing world 1–6 August 2010, Brisbane, Australia.

Ali, G., (2009). Assessment of land use land cover dynamics and soil erosion susceptible modeling in Amhara regional state: case study at Dessie zuria woreda using remote sensing and GIS. MSc thesis, Addis Ababa University, Ethiopia.

Amanuel, A., & Mulugeta, L., (2014). Detecting and quantifying land use/ land cover dynamics in Nadda Asendabo Watershed, South Western Ethiopia. *International journal of environmental sciences*, 3(1.), pp: 45-50.

Anderson, J. R., Hardy E.E., Roach, J.T., & Witmer, R.E., (1976). A land use and land cover classification for use with remote sensor data, USGS professional paper 964. Washington, DC: US Government Printing Office, p14.

Aneseyee, A.B., Elias, E., Soromessa, T., & Feyisa, G.L., (2020). Land use/land cover change effect on soil erosion and sediment delivery in the Winike watershed, Omo Gibe Basin, Ethiopia, *Science of the total environment*,728(138776).

Bahiru, G., (2010). Environmental impact monitoring for Gilgal Gibe I dam using an integrated method of Remote sensing and Geographic information system (GIS), MSc Thesis, Addis Ababa university, Addis Ababa, Ethiopia.

Bekele, T. A., Melaku, M., & Getinet, S., (2017). Analysis of land cover change of Dedo District, Jimma Zone, Oromia regional government, Southwestern Ethiopia. *International journal of scientific research in civil engineering*, 2(2): 52-59. http://ijsrce.com.

Beshir, K., Awdenegest, M., (2015). Identification of soil erosion hotspots in Jimma Zone, Ethiopia, using GIS based approach. *Ethiopian journal environmental studies and management*. 8(Suppl.2):926–938. https://doi.org/10.4314/ejesm.v8i2.7S.

Bewket, W., Teferi, E., (2009). Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga watershed, Blue Nile basin, Ethiopia. *Land Degrad*. *Dev*. 20 (6), 609–622.

Biniam, A., (2012). Carbon stock potentials of woodlands and land use and land cover changes in North Western Lowlands of Ethiopia. Msc thesis, Hawassa University, Wondogenet, Ethiopia. pp.79.

Broothearts, N., Kissi, E., Poesen, J., Rompaey, A.V., Getahun, K., Ranst,E.V., Deils , J.,(2012). Spatial patterns, causes and consequences of landslides in the gilgel gibe catchment, SW Ethiopia. *Catena* 97, pp.127-136.

Chadli, k., (2016). Estimation of soil loss using RUSLE model for Sebou watershed (Morocco). *Model Earth System Environment*, pp.3-5, DOI 10.1007/s40808-016-0105-y.

Chimdessa, K., Quraishi, S., Kebede, A., & Alamirew, T., (2018). Effect of land use land cover and climate change on river flow and soil loss in Didessa River Basin, South West Blue Nile, Ethiopia. *Hydrology*, 6(1).

CSA [Central Statistical Agency], (2007). Census data of the central statistical agency of Ethiopia. Addis Ababa, Ethiopia.

Dagnachew, M.A., Asfaw, K., Awdenegest, M., & Adane, A., (2020). Land use land cover changes and its drivers in Gojeb River Catchment, Omo Gibe Basin, Ethiopia. *Journal of agriculture and environmental for international development*, 114(1), 33-56. DOI: 10.12895/jaeid.20201.842.

Degbelo, S., (1996). Assessment of human impact on the physical environment using remote sensing.

Demissie, T.A., Saathoff, F., Sileshi, Y., Gebissa, A., (2013). Climate change impacts on the streamflow and simulated sediment flux to Gilgel Gibe 1 hydropower reservoir Ethiopia. *European international journal of science and technology* 2(2): 63-77.

Deore, S.J., (2005). Prioritization of micro-watersheds of upper Bhama Basin on the basis of soil erosion risk using remote sensing and GIS technology. PhD thesis, University of Pune, Pune.

Dwivedi, R.S., Sreenivas, K., & Ramana, K.V., (2005). Land-use/land-cover change analysis in part of Ethiopia using Landsat Thematic Mapper data. *International journal of remote sensing*. 26 (7), 1285-1287

Efrem, G., (2010). Land use and land cover dynamics and rural livelihood perspectives, in the semi-arid areas of Central RiftValley of Ethiopia,Faculty of forest sciences, Department of forest resource management, Umeå,Swedish University of Agricultural Sciences.

Eleni, Y., Wolfgang, W., Michael, E.K., Dagnachew, L., & Gunter, B., (2013). Identifying land use/cover dynamics in the Koga Catchment, Ethiopia, from multi-scale data, and implications for environmental change. Geo-Info, pp. 302-323.

Ethiopian Electric Power Corporation [EEPCO], (1999). Gilgel Gibe hydroelectric project; environmental impact assessment report. Addis Ababa, Ethiopia.

EPA [Environmental Protection Authority of Ethiopia], (2012). Ethiopian environmental and climate change policy brief, Ethiopia national report for Rio+20.

EGIA [Ethiopian Geospatial Information Agency], (2018). Ethiopian land use land cover classification and coding standard. Addis Ababa, Ethiopia.

FAO [Food and Agriculture Organization of the United Nations], (1984). Ethiopian highland reclamation study (EHRS). Final report, 1(2). Rome.

FAO, (1986). Ethiopian highland reclamation study. Final report, Vol. 1. FAO, Rome

FAO, (2010). Global forest resources assessment main report; FAO forestry paper 163, food and agriculture organization of the United Nations, Rome.

FAO/IIASA/ISRIC/ISSCAS/JRC, (2012). Harmonized world soil database (version 1.2). FAO, Rome, Italy and IIASA, Luxenberg, Austria. Retrieved from https://iiasa.ac.at.

Geist, H.J., & Lambin, E.F., (2002). Proximate causes and underlying driving forces of tropical deforestation, bioscience, 52(2), pp:143.

Gashaw, T., Tulu, T., Argaw, M., & Worqlul, A.W., (2019). Modeling the impacts of land use land cover changes on soil erosion and sediment yield in the Andassa watershed, Upper Blue Nile Basin, Ethiopia. *Environmental earth sciences*, 78 (24).

Gelagay, S., 2016. RUSLE and SDR model-based sediment yield assessment in a GIS and remote sensing environment, A case study of Koga watershed, upper Blue Nile basin, Ethiopia. *Hydrol. Curr. Res.* 7, 239–248.

George, A., Eric, K. F., Prosper, L., & Raymond, A., (2013). Modeling soil erosion using RUSLE and GIS tools. *International journal of remote sensing & geoscience* (IJRSG). 2:4.

Getahun, K., Poesen J., & Van Rompaey, A., (2017). Impacts of resettlement programs on deforestation of moist evergreen Afromontane forests in Southwest Ethiopia. *Mountain research and development*, 37(4):474-486. https://doi.org/10.1659/MRD-JOURNAL-D-15-00034.1

Gete, Z., & Hurni, H., (2001). Implications of land use and land cover dynamics for mountain resource degradation in the North Western Ethiopian high lands. *Mountain research and development*, 21 (2), pp.184-193.

Girma, R., & Gebre, E., (2020). Spatial modeling of erosion hotspots using GIS-RUSLE interface in Omo-Gibe river basin, Southern Ethiopia: implication for soil and water conservation planning. *Environmental systems research*, *9*(19), 1-14. DOI: 10.1186/s40068-020-00180-7.

Gizaw, T., & Degifie, T., (2018). Soil erosion modeling using GIS based RUSLE model in Gilgel Gibe-1 catchment, South West Ethiopia. *Int J Environ Sci Nat Res.* 15(5): 555923. DOI: 10.19080/IJESNR.2018.15.555923.

Green, R. E., Cornell, S. J., Scharlemann, J. P. W., & Balmford, A., (2005). Farming and the fate of wild nature science 307: pp. 550-555.

Habtamu, S. G., & Amare, S. M., (2016). Soil loss estimation using GIS and Remote Sensing techniques: a case of koga Watershed, Northwestern Ethiopia, *International soil and water conservation research,* http://dx.doi.org/10.1016/j.iswcr.2016.01.002.

Hamza, I., & Iyela, A., (2012). Land use pattern, climate change and its implication for food security in Ethiopia: A review; *Ethiopian journal of environmental studies and management*.5:1.

Hawando, T., (1995). The survey of the soil and water resources of Ethiopia. UNU/Toko.

Hurni, H., (1985). Erosion-productivity conservation systems in Ethiopia. paper presented at IV.

Hurni, H., (1988). Ecological issues in the creation of famine in Ethiopia. Paper presented to the national conference on a disaster prevention and preparedness strategy for. Addis Ababa, Ethiopia.

Hurni, H., (1993). Land degradation, famine and resource scenarios in Ethiopia. In world soil erosion and conservation. Cambridge. Cambridge University press.

Hurni, K., Zeleke, G., Kassie, M., Tegegne, B., Kassawmar, T., Teferi, E., … Hurni, H. (2015). Economics of land degradation (ELD): Ethiopia case study. Soil degradation and sustainable land management in the rainfed agricultural areas of Ethiopia: An assessment of the economic implications. Report for the economics of land degradation pp.94. https://tinyurl.com/y2vqcjd2.

Israel, T., (2011). Soil erosion risk assessment with RUSLE and GIS in dire dam watershed, MSc Thesis, Addis Ababa University, Ethiopia, Addis Ababa.

Jensen, J. R., (2003). Introductory digital image processing, A remote sensing perspective. 3rd Ed., pp. 505-508.

Jimma zone environmental protection, forest and climate change authority, (2020). Zonal annual report. Jimma, Ethiopia.

Kahsay, B., (2004). Land use and land cover changes in the central highlands of Ethiopia: The case of Yerer mountain and its surroundings, Addis Ababa University, Environmental Science.

Kassahun, K., (2001). Re-relocation and dislocation of communities by development projects: the case of Gilgal Gibe dam (1962-2000) in Jimma zone, Southwest Ethiopia. Master of Arts in Social Anthropology, Addis Ababa University.

Kebrom, T., & Hedlund, L., (2000). Land use and land cover change between 1958 and 1986 in Kalu district, southern Wollo, Ethiopia. *Mountain research and development*, pp. 41-51.

Kidane, M., Bezie, A., Kesete, N., Tolessa, T., (2019). The impact of land use and land cover (LULC) dynamics on soil erosion and sediment yield in Ethiopia. *A Cell Press Journal: Heliyon*, *5*(12),1 -13. doi: https://doi.org/10.1016/j.heliyon.2019.e02981.

Lal, R. (1994). *Soil erosion research methods (2nd ed.).* Washington DC, USA: pp.1293-1306.

Lambin, E., Geist, H., Lepers, E., (2003). Dynamics of land use and land cover change in tropical regions. Annual review of environment and resources, 28, pp. 205–241.

Lillesand, T., & Kiefer, R., (1994). Remote sensing and image interpretation. Third edition. Printed in the United States of America.

Lillesand, T., & Kiefer, R., (2000). Remote sensing and image interpretation (4th ed.). New York, USA: Wiley and Sons.

Mariye, M., Mariyo, M., Changming, Y., Teffera, Z.L., & Weldegebrial, B., (2020). Effects of land use and land cover change on soil erosion potential in Berhe district: a case study of Legedadi watershed, Ethiopia, *International journal of river basin management*, 18, pp. 1-13.

Meyer, W. B., & Turner, B. L., (1994). Changes in land use and land cover: A global perspective. Cambridge: Cambridge university press. New York.

Mertens, K., (2013). Land use dynamics in the planosol belt of the Gilgal Gibe catchment, South-West Ethiopia, Thesis submitted in the fulfilment of the requirements for the degree of Master (MSc) in Bioscience Engineering: *land and water management*. Ghent University, Belgium.

Ministry Of Agriculture and Rural Development [MOARD], (2005). A guide line for community based participatory watershed development. Addis Ababa, Ethiopia.

Morgan, R.P.C., (1995). Soil erosion and conservation. Edinburgh: Addison-Wesley Longman.

Morgan, R. P. C., (2005). Soil erosion and conservation (3rd ed.). National soil resources Institute, Cranfield University. Blackwell Science Limited.

Mottet, A., Ladet, S., Coque, N., & Gibon, A., (2006). Agricultural land use change impacts in mountain landscapes: A case study in the pyrenees. Agronomy, ecosystem environment, 114: pp. 296-310.

Muleta, E., (2015). Remote sensing and GIS based spatio-temporal land use/ cover study of Western Ethiopian highland –A case of Jima Arjo district, *science, technology and arts research*, 4(1), pp.139-148.

Muluneh, W. (2003). Population growth and environmental recovery: More people, more trees: Lesson learned from Western Gurage land. *Ethiopian journal of social sciences and humanities*, 1(1).

Negash, T., & Mesfin, K., (2011). Proceeding of the national workshop in integrated watershed management on Gibe -Omo Basin, Jimma University and Gilgel Gibe Site. PHE Ethiopia Consortium, Addis Ababa, Ethiopia.

Nill, D., Schwertmann, U., Sabel-Koschella, U., Bernard, M., Breuer, J., (1996). Soil erosion by water in Africa; Principles, prediction and protection. GTZ. pp 292.

NMA/WOSC [National Meteorological Agency/Western Oromia Service Center], (2020). Daily rainfall and temperature data of stations. Jimma, Ethiopia.

Nyssen, J. P. J., (2004). Human impact on the environment in the Ethiopian and Eritrean highlands. Earth-Science, pp. 273-320.

Pande, L.M., Prasad, J., Saha, S.K., & Subramanyam, C., (1992). Review of remote sensing applications to soils and agriculture. Proc. Silver Jubilee Seminar, IIRS, Dehra Dun.

Petter, P., (1992). GIS and remote sensing for soil erosion studies in semi-arid environments. PhD thesis. University of Lund, Lund.

Rapidel, B., DeClerck, F., Le Coq, J.F., & Beer, J., (2011). *Ecosystem services from agriculture and agroforestry: Measurement and payment*. Earthscan.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., & Yoder, D.C., (1996). Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). USDA agriculture handbook, pp.703:382, Washington DC.

Renard, K. G., Foster, F. G., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). Predicting soil loss erosion by water: A guide to conservation planning with the revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Washington, DC.

Robin, S., Reid, Russell, L., Kruska, Nyawira, M., Andualem, T., Sara, W., Cathleen, J., Wilson, & Woudyalew, M., (2000). Land-use and Land-cover Dynamics in Response to Changes in Climatic, Biological and Socio-political Forces: the case of southwestern Ethiopia; Landscape Ecology. 15: pp. 339–355.

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

Selamyihun, K., (2004). Using Eucalyptus for Soil and Water Conservation on the Highland Vertisols of Ethiopia. Ph.D. Thesis. Wageningen University, The Netherlands.

Shamebo, L.B., (2010). Assessment of Land Use Land Cover Dynamics and its Impact on Soil Loss: Using GIS and Remote Sensing, in Shashogo Woreda, Southern Ethiopia. MSc Thesis, Addis Ababa university, Ethiopia, Addis Ababa.

Sherbinin, A., (2002). A CIESIN Thematic Guide to Land-Use and Land-Cover Change (LUCC). Columbia University: Palisades, NY, USA.

Shibru, D., Rieger, W., & Strauss, P., (2003). Assessment of gully erosion in eastern Ethiopia using photogrammetric techniques. *Catena*, 50: pp. 273– 291.

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

Shrestha, D.P., (1997). Assessment of soil erosion in the Nepalese Himalaya, a case study in Likhu Khola Valley, Middle Mountain Region. Oxford & IBH publishing co. pvt. ltd, 2(1), 59-80.

Suresh, C. P, Chakravarty, S., Ghosh, S. K, Dey, A. N., & Shukla, G. (2000). Deforestation: causes, effects and control strategies. Global perspectives on sustainable forest management.

Tedese, L., Suryabhagavan, K.V., Sridhar, G., Legesse, G., (2017). Land use and land cover changes and soil erosion in Yezat Watershed, North Western Ethiopia. *International Soil and Water Conservation Research, 5*(2):85-94. https://doi.org/10.1016/j.iswcr.2017.05.004.

Tewolde, M.G., and Cabra, P., (2011). Urban Sprawl Analysis and Modeling in Asmara, Eritrea. Remote Sensing, 3 (10), pp. 2148–2165.

Tulu, T., (2017). Spatiotemporal land use/land cover change, driving forces and consequences in Ameya woreda, central Ethiopia. MSc thesis, Addis Ababa University, Ethiopia, Addis Ababa.

Turner, B. L., Skole, D., Sanderson, S., Fischer, G., Fresco, L., & Leemans, R., (1995). Land-use and land-cover change. *International Geosphere- Biosphere Programme*.

Tsegaye, B., (2019). Effect of land use and land cover changes on soil erosion in Ethiopia. *International Journal of Agricultural Science and Food Technology*. 5(1): 026-034. DOI: http://doi.org/10.17352/2455-815X.000038.

UNCCD, (1994). United nations convention to combat desertification in countries experiencing serious drought and/or desertification, particularly in Africa. Paris.: A/AC.

Warra, H.H., Mohammed, A.A., Nicolau, M.D., (2013). Spatio-temporal impact of socio-economic practices on land use/land cover in the kasso catchment, Bale mountains, Ethiopia. Scientific annals of "Alexandru Ioan Cuza" University of IAȘI, LIX (1), II, Geography series, 1–26.

Wischmeier, W. H., & Smith, D. D., (1978). Predicting rainfall erosion losses to conservation planning. Washington DC, USA: US Department of Agriculture.

Woldeamlak, B., (2002). Land cover dynamics since the 1950s in Chemoga watershed, Blue Nile Basin, Ethiopia. *Mountain Research and Development* 22, No. 3: 263–269.

Woldemariam G., & Harka, A., (2020). Effect of land use and land cover change on soil erosion in Erer sub-basin, Northeast Wabi Shebelle Basin, Ethiopia, *Land*, 9(4).

Wubie, Mohammed, A., & Melania, D.N., (2016). Patterns, causes and consequences of land use/cover dynamics in the Gumara watershed of Lake Tana basin, north western Ethiopia. Department of Geography and environmental studies, Bahir Dar University, Bahir Dar, Ethiopia.

Yacob, E., (2010). Evaluating the impact of land use land cover change on soil erosion and runoff using SWAT model at Tikur Wuha Watershed. MSc thesis, Addis Ababa University, Ethiopia, Addis Ababa.

Yazidhi, B., (2003). A comparative study of soil erosion modelling in Lom Kao-Phetchabun, Thailand. Unpublished MSc Thesis, ITC, Enschede.

Appendices

Appendix I – Ground Truth Points

FID	X - Cord.	Y- Cord.	Class Name	FID	X - Cord.	Y- Cord.	Class Name
1	299213	849660	Cultivated Land	69	308760	969227	Forest Land
2	307987	915502	Cultivated Land	70	300927	942071	Forest Land
3	308132	943233	Cultivated Land	71	315988	849541	Grass Land
4	302915	871605	Cultivated Land	72	308064	873486	Grass Land
5	350193	861527	Cultivated Land	73	315418	868676	Grass Land
6	306859	837789	Cultivated Land	74	310123	869796	Grass Land
7	320701	857132	Cultivated Land	75	310854	860135	Grass Land
8	270759	856335	Cultivated Land	76	308711	853376	Grass Land
9	323268	846781	Cultivated Land	77	307583	850655	Grass Land
10	310671	910400	Cultivated Land	78	355358	839399	Grass Land
11	292984	834506	Cultivated Land	79	295373	846256	Grass Land
12	300357	861919	Cultivated Land	80	296578	844766	Grass Land
13	300772	877741	Cultivated Land	81	314509	869682	Grass Land
14	300674	875719	Cultivated Land	82	348895	858619	Grass Land
15	312279	988164	Cultivated Land	83	340039	853817	Grass Land
16	305526	955001	Cultivated Land	84	278821	857885	Grass Land
17	301162	963522	Cultivated Land	85	273342	854578	Grass Land
18	296882	883789	Cultivated Land	86	353034	838962	Grass Land
19	303946	880097	Cultivated Land	87	306919	844137	Grass Land
20	273162	858182	Cultivated Land	88	302950	848417	Grass Land
21	309919	882841	Cultivated Land	89	310520	872399	Grass Land
22	293274	831428	Cultivated Land	90	307988	877131	Grass Land
23	299948	834937	Cultivated Land	91	334595	863945	Grass Land
24	293897	845551	Cultivated Land	92	300782	857875	Grass Land
25	307933	856655	Cultivated Land	93	336496	850888	Grass Land
26	389205	850044	Cultivated Land	94	303895	857775	Settlement Area
27	320402	853265	Cultivated Land	95	307500	844158	Settlement Area
28	319282	861701	Cultivated Land	96	294604	843384	Settlement Area
29	294088	865949	Cultivated Land	97	303336	917167	Settlement Area
30	299728	869762	Cultivated Land	98	308718	876599	Settlement Area
31	296242	882863	Bush Land	99	308541	876248	Settlement Area
32	298757	879676	Bush Land	100	305634	868398	Settlement Area

33	310201	865608	Bush Land	101	305666	867596	Settlement Area
34	298316	923262	Bush Land	102	298577	884454	Settlement Area
35	298887	959455	Bush Land	103	267504	848181	Settlement Area
36	311016	911599	Bush Land	104	279324	850272	Settlement Area
37	314072	873110	Bush Land	105	275494	861030	Settlement Area
38	307915	882866	Bush Land	106	277408	852910	Settlement Area
39	308487	880246	Bush Land	107	278038	853333	Settlement Area
40	322208	867696	Bush Land	108	383961	852840	Settlement Area
41	316202	862247	Bush Land	109	300192	858173	Settlement Area
42	294835	881636	Bush Land	110	303895	857775	Settlement Area
43	294365	878302	Bush Land	111	314269	867174	Water Body
44	381887	878518	Bush Land	112	314209	865453	Water Body
45	292634	871982	Bush Land	113	316245	864396	Water Body
46	270604	861447	Bush Land	114	316175	861802	Water Body
47	295288	857602	Bush Land	115	308434	858697	Water Body
48	308092	860496	Bush Land	116	307508	864959	Water Body
49	267190	852999	Bush Land	117	309811	861875	Water Body
50	276870	847968	Bush Land	118	307257	866388	Water Body
51	264782	853781	Bush Land	119	300913	858498	Water Body
52	298547	832561	Bush Land	120	300359	856559	Water Body
53	384825	838143	Bush Land	121	294765	850887	Water Body
54	319863	858552	Bush Land	122	366386	850544	Water Body
55	315858	876453	Bush Land	123	330541	848796	Water Body
56	310900	928061	Forest Land	124	306400	846535	Water Body
57	309111	954771	Forest Land	125	351858	843943	Water Body
58	311551	960989	Forest Land				
59	308868	964083	Forest Land				
60	354989	869894	Forest Land				
61	374800	867031	Forest Land				
62	300287	877466	Forest Land				
63	278493	848831	Forest Land				
64	300101	832399	Forest Land				
65	294540	832215	Forest Land				
66	299754	867811	Forest Land				
67	307019	877487	Forest Land				
68	310880	934229	Forest Land				

Appendix II – Long year rainfall data of meteorological stations with in the Gilgel Gibe sub-catchment

Station Name- Dimtu

Parameter – Rainfall(mm)

Lat.	Long.	Elevation	Year	Time	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
7.85067	37.2355	1786	1991	9:00	28.8	57.38	117.1	165.1	235.46	230.54	305.5	262.3	213.8	75.65	16.6	45.4
7.85067	37.2355	1786	1992	9:00	33.7	94.37	76.43	187.1	274.67	364.57	254.7	350	174.3	177.9	64.4	33.6
7.85067	37.2355	1786	1993	9:00	62.8	48.35	67.43	250.1	326.01	430.64	322.8	319.6	189.6	217.7	29.5	6.09
7.85067	37.2355	1786	1994	9:00	0.56	20.84	112.4	230.3	275.31	310.85	342.9	298.3	272.6	80.64	61.7	5.67
7.85067	37.2355	1786	1995	9:00	3.31	63.03	108	251.9	237.53	308.33	242.4	286.3	290.2	133.4	37.9	94.7
7.85067	37.2355	1786	1996	9:00	63.4	24.1	259.5	219.2	359.98	385.05	437.2	398.5	352.8	156.5	64.9	7.76
7.85067	37.2355	1786	1997	9:00	33.3	1.9	82.28	301.4	279.46	366.53	226.5	264.9	253.2	419.6	128	33.2
7.85067	37.2355	1786	1998	9:00	70.5	78.45	50.06	91.91	242.52	411.21	399	293.7	264.8	341.3	90.6	1.46
7.85067	37.2355	1786	1999	9:00	29.4	4.79	58.76	113.6	286.35	282.18	261.7	202.7	171.5	264.9	9.18	7.02
7.85067	37.2355	1786	2000	9:00	1.9	0	19.8	211.8	196.4	281.2	309.6	494	172.6	144.7	45.2	7.8
7.85067	37.2355	1786	2001	9:00	28.1	30.7	252.8	235.2	333.7	356.7	498.5	507.7	280.1	100.5	20.9	4.4
7.85067	37.2355	1786	2002	9:00	31.5	31.8	282	300.6	238.2	280.5	265	355	202.6	56.5	12.7	0
7.85067	37.2355	1786	2003	9:00	49.2	17.5	50.3	0	0	0	172.2	202.3	221	126.7	52.7	39.5
7.85067	37.2355	1786	2004	9:00	49.7	0	114.9	88.8	96.9	218	178.4	347.8	230.4	89.8	10.9	34.2
7.85067	37.2355	1786	2005	9:00	18.2	1	83.8	124.2	179.7	171.8	165.4	134.7	184.9	42.6	20.9	0
7.85067	37.2355	1786	2006	9:00	11	21.7	115.4	70.5	69.6	198.8	271.7	293.9	80.6	62.8	33.3	54.4

7.85067	37.2355	1786	2007	9:00	51	32	77	150.6	151	193	338.7	373	0	304.3	39.9	0
7.85067	37.2355	1786	2008	9:00	27.5	4.9	59.5	189	296.3	236.8	387.1	0	0	121.9	0	2.4
7.85067	37.2355	1786	2009	9:00	80.7	1.4	34	102.4	141.9	343.3	296.9	367.1	163.4	103.2	2.8	59.4
7.85067	37.2355	1786	2010	9:00	25	69.6	128.5	99.8	166.6	231.3	329.9	227	183.9	11.9	15.1	37.3
7.85067	37.2355	1786	2011	9:00	14.7	0	62.6	79.1	220.3	335.7	162.6	332.3	115.6	18.5	62.8	3.2
7.85067	37.2355	1786	2012	9:00	0	0	8.3	62.8	67.7	291.4	370.5	0	156.9	5.6	68.2	39
7.85067	37.2355	1786	2013	9:00	21.6	37.6	101.2	84.1	132.5	234.8	364.3	347.6	234.2	115.4	34.7	2.1
7.85067	37.2355	1786	2014	9:00	29.5	0	88.3	0	188.7	267	322.2	429.9	415.3	121.3	41	4.2
7.85067	37.2355	1786	2015	9:00	0	3.2	0	205.7	296.8	314.7	0	346.4	405.1	70.1	80.1	31.8
7.85067	37.2355	1786	2016	9:00	52.8	2.4	72.3	229.8	147.1	154	215.3	317	149.9	76.3	15.6	0.9
7.85067	37.2355	1786	2017	9:00	0	47.8	16.2	80.8	201.3	251	179	193.2	200.3	107.7	28.2	0
7.85067	37.2355	1786	2018	9:00	2.1	43.9	12.5	148.3	118.1	299.1	298	283.8	180.4	0	0	0
7.85067	37.2355	1786	2019	9:00	0	26.3	39.9	224.1	167.5	413.1	356.5	383.5	232.4	204	156	0

Station Name- Asendabo

Parameter – Rainfall(mm)

Lat.	Long.	Elevation	Year	Time	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
7.7605	37.2311	1764	1991	9:00	0.6	54.3	88.9	25.3	152.3	216	0	0	0	0	0	0
7.7605	37.2311	1764	1992	9:00	19.8	29.6	99	54.4	0	224	126.5	345.8	106.2	65.7	21.6	12.8
7.7605	37.2311	1764	1993	9:00	33.3	97.6	84	198	132.5	232	178.4	136.9	113.3	144.1	0	0
7.7605	37.2311	1764	1994	9:00	0	5.9	0	160	113.2	257	190.6	303.1	132.3	7	13.5	29
7.7605	37.2311	1764	1995	9:00	9.4	34.4	55.9	98.6	98.1	111	214.6	115	76.5	8.4	9.2	116.5
7.7605	37.2311	1764	1996	9:00	38.7	54.1	164.6	198	143.4	208	192.6	201.7	143.3	8.7	27.4	0
7.7605	37.2311	1764	1997	9:00	38.6	0	29.4	153	138	202	237.7	203.8	108.9	249.6	146.6	10.8
7.7605	37.2311	1764	1998	9:00	54.6	59.2	60.5	83.6	130.3	217	218.9	199.7	169.9	87.1	26.8	0
7.7605	37.2311	1764	1999	9:00	23.5	0	51.8	71.1	168.9	227	296.4	145.1	76.3	103.3	1.9	0.3
7.7605	37.2311	1764	2000	9:00	0	0.2	5.6	120	113.8	157	149.9	144.2	157.3	86.7	34.6	3
7.7605	37.2311	1764	2001	9:00	30.8	22	103.5	162	242.6	262	197	235.9	91.1	121.1	8.3	5.6
7.7605	37.2311	1764	2002	9:00	37.4	18.7	124.6	73.9	110.7	162	169.5	158.4	86.9	8.3	5.1	103.6
7.7605	37.2311	1764	2003	9:00	27.2	91.5	209.3	88.3	35.8	0	203.9	145.2	19.4	29.7	19.4	30.8
7.7605	37.2311	1764	2004	9:00	45.2	7.7	72.4	118	67.4	217	0	267.3	127	52.1	28.1	39.6
7.7605	37.2311	1764	2005	9:00	29.9	1.9	97.6	166	185.3	99.9	175.2	135.4	176.8	69.4	13.9	0
7.7605	37.2311	1764	2006	9:00	7.4	0	176.2	116	119.2	212	287.2	183.1	0	120	37.1	24.9
7.7605	37.2311	1764	2007	9:00	48.6	45.4	99.6	94.3	75.5	159	211.8	188.7	185.3	10.9	1.7	0

7.7605	37.2311	1764	2008	9:00	10.3	0	51.8	142	226.2	158	205.3	0	143.6	136.8	63.9	1.4
7.7605	37.2311	1764	2009	9:00	75.4	12.9	0	99.1	50.6	155	161.6	287.5	119.5	84.7	9.2	87
7.7605	37.2311	1764	2010	9:00	31.7	52.8	103.2	132	162.6	159	204.5	208.2	160.5	10.8	18.3	34.1
7.7605	37.2311	1764	2011	9:00	3.9	3.5	22.8	123	222.5	233	152.1	0	107.5	1	0	0.7
7.7605	37.2311	1764	2012	9:00	0	4.3	1.1	69.6	75.4	233	174.3	127.9	228.4	8	10.8	5.8
7.7605	37.2311	1764	2013	9:00	15.5	0.9	92.6	0	0	241	264.3	294.9	181.6	69.3	6.4	9.6
7.7605	37.2311	1764	2014	9:00	6.2	0	0	0	230.4	138	152	249.9	0	68.8	24.3	0
7.7605	37.2311	1764	2015	9:00	0	1.6	0	0	0	182	161.3	159.4	165.8	0	125	35.8
7.7605	37.2311	1764	2016	9:00	29.8	2	57.8	162	166.9	122	300	157.4	166	99.7	0	2.5
7.7605	37.2311	1764	2017	9:00	0	0	70.5	32.9	139.9	224	147.5	148.9	241.1	103.3	26.1	0
7.7605	37.2311	1764	2018	9:00	28.1	0	262.2	0	122.8	0	213.1	0	0	0	0	0
7.7605	37.2311	1764	2019	9:00	0	0	85	156	221.1	189	286.3	150.2	0	140.4	0	0

Station Name- Omo Nada

Parameter – Rainfall(mm)

Lat.	Long.	Elevation	Year	Time	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
7.61671	37.25	1838	1991	9:00	28.8	57.4	117	165	235	231	306	262	214	75.7	16.6	45
7.61671	37.25	1838	1992	9:00	33.7	94.4	76.4	187	275	365	255	350	174	178	64.4	34
7.61671	37.25	1838	1993	9:00	62.8	48.4	67.4	250	326	431	323	320	190	218	29.5	6.1
7.61671	37.25	1838	1994	9:00	0.56	20.8	112	230	275	311	343	298	273	80.6	61.7	5.7
7.61671	37.25	1838	1995	9:00	3.31	63	108	252	238	308	242	286	290	133	37.9	95
7.61671	37.25	1838	1996	9:00	63.4	24.1	259	219	360	385	437	399	353	156	64.9	7.8
7.61671	37.25	1838	1997	9:00	33.3	1.9	82.3	301	279	367	227	265	253	420	128	33
7.61671	37.25	1838	1998	9:00	0	0	0	0	0	143	258	160	221	21.6	34	0
7.61671	37.25	1838	1999	9:00	4.9	0	39.3	39.4	129	116	257	224	81.2	102	0	0
7.61671	37.25	1838	2000	9:00	0	0	10.6	80.4	113	0	118	117	221	137	171	0
7.61671	37.25	1838	2001	9:00	0	0	141	93	0	26.4	188	375	208	17.5	53.3	4.2
7.61671	37.25	1838	2002	9:00	57.5	68.4	104	28.6	86.6	92.6	128	141	15	0	0	0
7.61671	37.25	1838	2003	9:00	0	42.1	20	37.3	0	121	184	196	198	11.7	19	31
7.61671	37.25	1838	2004	9:00	33.8	0	62.5	71.9	55.1	202	220	253	131	80.1	29.3	44
7.61671	37.25	1838	2005	9:00	39.2	4.2	91.8	60	374	160	259	141	113	121	0	0
7.61671	37.25	1838	2006	9:00	3.9	0	123	151	94	170	219	0	112	57.8	60.3	80
7.61671	37.25	1838	2007	9:00	78.3	78.3	83.1	0	95.7	239	326	261	294	64.2	0	0

7.61671	37.25	1838	2008	9:00	4.2	0	32	0	152	190	150	580	454	273	51.6	0
7.61671	37.25	1838	2009	9:00	102	5.3	0	0	107	168	228	413	241	127	0	274
7.61671	37.25	1838	2010	9:00	58.4	85.6	88.4	105	206	193	263	236	370	0	16.6	8.5
7.61671	37.25	1838	2011	9:00	20.4	14.3	65.4	153	257	220	151	130	147	76.4	109	6.1
7.61671	37.25	1838	2012	9:00	1.43	2.27	40.3	190	192	137	248	325	274	103	57.1	36
7.61671	37.25	1838	2013	9:00	29.8	12.9	135	235	505	342	316	272	210	186	119	3.6
7.61671	37.25	1838	2014	9:00	0	0	0	248	332	190	0	0	0	0	0	0
7.61671	37.25	1838	2015	9:00	2.3	11	52.6	53.3	211	293	312	205	131	112	47.8	34
7.61671	37.25	1838	2016	9:00	27.7	95.7	74.8	391	421	218	456	575	720	85.9	17.3	0
7.61671	37.25	1838	2017	9:00	0	15.1	100	43	357	327	753	1012	343	204	63.7	0
7.61671	37.25	1838	2018	9:00	0	43.5	45.6	305	203	477	396	336	175	106	110	0
7.61671	37.25	1838	2019	9:00	0	0	98.1	0	234	263	457	445	333	45	175	416

Station Name - Serbo

Parameter - Rainfall(mm)

Lat.	Long.	Elevation	Year	Time	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
7.708667	36.974017	1802	1991	9:00	33.36	53.55	123.8	195.05	298.93	252.97	308.42	258.7	211.18	94.19	24.32	55.07
7.708667	36.974017	1802	1992	9:00	34.47	89.22	76.25	186.82	296.45	377.1	260.42	373.64	187.66	198.18	78.04	46.92
7.708667	36.974017	1802	1993	9:00	66.4	56.1	83.49	261.28	341.9	451.7	330.21	324.08	182.07	231.08	40.21	7.52
7.708667	36.974017	1802	1994	9:00	1.04	25.01	118.64	257.38	308.69	322.82	361.38	305.46	279.2	107.68	89.2	10.14
7.708667	36.974017	1802	1995	9:00	5.14	57.3	123.08	252.27	259.69	322.6	252.02	286.91	307.57	159.54	55.35	96.97
7.708667	36.974017	1802	1996	9:00	74.8	32.35	252.07	227.53	392.61	392.5	458.7	400.71	358.51	173.43	78.03	11.01
7.708667	36.974017	1802	1997	9:00	33.73	3.26	88.74	326.06	310.94	387.94	224.88	267.93	249.52	432.78	153.7	48.15
7.708667	36.974017	1802	1998	9:00	0	0	0	0	0	43.7	260.8	322.4	153	94.2	18.4	0
7.708667	36.974017	1802	1999	9:00	23.4	0	36.6	120.3	199.4	211.3	174.3	145.2	173.5	173.9	2.3	0
7.708667	36.974017	1802	2000	9:00	1.8	1.2	45.2	149.7	209.6	147.4	262.8	243.3	194.5	85.7	41.3	28.1
7.708667	36.974017	1802	2001	9:00	28.8	5.1	103.5	131.1	201.7	206.2	231.4	154.6	163.9	106.4	54.1	0
7.708667	36.974017	1802	2002	9:00	54.3	12.3	167.4	89.8	144.4	241.1	144.4	126.6	69.7	34.1	2.5	0
7.708667	36.974017	1802	2003	9:00	29.7	55.2	95.3	82.7	18.2	345.8	237	267.5	163.7	41.8	5.3	7.7
7.708667	36.974017	1802	2004	9:00	51.5	29.9	115.3	102.9	185.3	133.2	232.1	286.5	174.7	46.6	24.1	59.9
7.708667	36.974017	1802	2005	9:00	24.7	0.8	134	78.2	145.1	231.4	183.3	161.8	190.5	31.8	22	0
7.708667	36.974017	1802	2006	9:00	10.4	0	178.7	145	156.5	215.1	335.3	168	198.4	102	123.9	102.1
7.708667	36.974017	1802	2007	9:00	52.7	93.9	81.1	90.5	204.4	238.5	276.9	160.2	123.2	24.1	1.5	0
7.708667	36.974017	1802	2008	9:00	0	7.8	30	0	191	235.6	0	177.3	115.6	91.9	0	0.7
7.708667	36.974017	1802	2009	9:00	134.9	0	0	69.5	0	0	204.7	0	144.1	102	45.4	61.3

7.708667	36.974017	1802	2010	9:00	33.5	44	62.7	56.2	108.3	193.9	145.5	228.4	604.8	35.2	29	35
7.708667	36.974017	1802	2011	9:00	39.4	0	42.1	71.5	121.8	0	220.3	273.3	250	11.8	120.8	15.8
7.708667	36.974017	1802	2012	9:00	15.8	0	33.8	85.3	43.6	285.4	263.3	233.8	161.6	16.9	32.1	4.1
7.708667	36.974017	1802	2013	9:00	54.7	0	5.7	121.4	80.9	0	189.8	246.5	185.2	108	5.7	4.1
7.708667	36.974017	1802	2014	9:00	13.8	18.8	141.5	0	276	0	101	181.9	114	154.2	0	0
7.708667	36.974017	1802	2015	9:00	0	2.8	103.7	116.8	0	143.9	0	0	131.5	0	31.5	0
7.708667	36.974017	1802	2016	9:00	40.4	4.9	39.2	118.2	126.5	225	202.8	211.2	132.5	47.8	0	0
7.708667	36.974017	1802	2017	9:00	0	30.5	51.4	23.7	0	169.8	114.2	231.5	236.7	87.5	0	0
7.708667	36.974017	1802	2018	9:00	2.4	9.5	46.8	104.8	181.3	227.6	119.5	158.4	114.6	23.8	78.8	59.9
7.708667	36.974017	1802	2019	9:00	0	67.3	43.9	204.8	134.8	252.8	0	0	205.4	32.3	148	3.4

Appendix III – Focus Group Discussion and Key Informant Interview Checklist.

I. Focus Group Discussion Checklist

1. On what agricultural activity the community of your area is engaged?
2. Is there enough farm land for the farming community?
3. If farm land is not enough for the farming community in the area, what causes are prevailing?
4. What is the way of survival additionally and/or for those that do not have farmland?
5. What is the trend of land use/cover in the sub catchment?
6. If changes were recognized, which land cover has been made susceptible and why?
7. If there is farm land expansion in your area, in which area/slope category the highest expansion is observed and why?
8. What measures peasants take when the productivity of their farm declines?
9. What is the state of the soil erosion in the area?
10. On which land cover land use category, you face severe soil erosion risk? What are the reasons behind these?
11. Is there a difference of soil erosion rate based on slope category? At which slope category the highest rate of soil erosion recorded?
12. What measures were made to alleviate soil erosion and degradation problems in your area?
13. What is the implication of human activity and land resource interaction in the area? What would be its impacts on the soil erosion?
14. What attempts have been made to sustain land resources and to solve soil degradation problems in the sub catchment?

I. Key Informant Interview Checklist

1. What factor or factors do you think might have caused LULC changes of the area in the past 30 years? (You may give multiple answers)
   - o Population pressure
   - o Expansion of cultivated land
   - o Resettlement programs.
   - o Built-up area expansions
   - o Introduction of new development projects
   - o Fuel wood and charcoal production.
2. What is your present source of energy for household use?
   - o Fire wood
   - o Cattle dung
   - o if others, specify, ____________
3. If firewood, further comment on its source and its availability, both in the past and the present periods. ____
4. What are major environmental problems in your locality?
   - o Deforestation.
   - o Soil erosion
   - o Siltation problem
   - o Losses of biodiversity
   - o Reduction of productivity
   - o Land slide.
   - o other, specify __________________________
5. If soil erosion is the most common environmental problem considering land use land cover change as the casual factor. How severe is it?
   - Very slightly eroded
   - Slightly eroded
   - Moderately eroded
   - Severe
   - very severe
6. On which land section you face severe erosion?

- Cultivated land
- Forest land
- Bush land
- Grass land
- Water land
- Settlement area

7. In which slope category you face severe erosion risk?
   - Gentle slope
   - Moderate slope
   - Steep slope

Appendix IV – Field observation data

Undergone Cultivation activities and deforestation on the steep sloping areas

Photo captured from field in northern parts of the area (Tiro Afeta Woreda)

In South Eastern part of the area (Omo Nada Woreda)

Observed undergone soil erosion in Gilgal Gibe sub catchment.

Taken from the upper stream in Kersa Woreda

Photo captured from field in Sokoru Woreda

Observed undergone soil erosion in Gilgal Gibe sub catchment.

Photo from field in South Eastern part of the area (Omo Nada Woreda)