



SEEK WISDOM, ELEVATE YOUR INTELLECT AND SERVE HUMANITY!

Addis Ababa University

አዲስ አበባ ዩኒቨርሲቲ



ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
SCHOOL OF EARTH SCIENCE
REMOTE SENSING AND GEO-INFORMATICS STREAM

LAND DEGRADATION ASSESSMENT USING GEO-SPATIAL MODELING
APPROACH, THE CASE OF DEGA DAMOT DISTRICT: NORTH-WESTERN
ETHIOPIA

A thesis submitted to the school of graduate studies of Addis Ababa University in
partial fulfillment of the requirements for the degree of masters of Science in
Remote sensing and Geo-informatics

By: Yismaw Aregaw

ID: GSR/ 8953/12

Advisor: Tibebu Kassawmar (PhD)

June 2021

Addis Ababa, Ethiopia



ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
SCHOOL OF EARTH SCIENCE
REMOTE SENSING AND GEO-INFORMATICS STREAM

**LAND DEGRADATION ASSESSMENT USING GEO-SPATIAL
MODELING APPROACH, THE CASE OF DEGA DAMOT DISTRICT:
NORTH-WESTERN ETHIOPIA**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF
ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN
REMOTE SENSING AND GEO-INFORMATICS**

By

YISMAW AREGAW DESTA

June, 2021

Addis Ababa University

Addis Ababa University

School of Graduate Studies

This is to certify the thesis prepared by **Yismaw Aregaw Desta** entitled “*Land degradation assessment using geo-spatial modeling approach, the case of Dega Damot district, North-Western Ethiopia*” and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Remote Sensing and Geo-informatics complies with the regulations of the university and meets the accepted standards to originality and quality.

Signed by the Examining Committee:

Dr. Tibebe Kassawmar	_____	_____/_____/_____
Advisor	Signature	Date
Dr. Dagnachew Legesse	_____	_____/_____/_____
Examiner	Signature	Date
Dr. Biniyam Tesfaw	_____	_____/_____/_____
Examiner	Signature	Date
Dr. K.V. Suryabhagavan	_____	_____/_____/_____
Chairman	Signature	Date

DECLARATION

I hereby declare that the dissertation entitled “Land degradation assessment using geo-spatial modeling approach, the case of Dega Damot district, North-western Ethiopia” has been carried out by me under the supervision of Dr. Tibebe Kassawmar, Remote Sensing and Geo-Informatics, School of Earth Sciences, Addis Ababa University during the year 2019-2021 as a part of Master of Science programme in Remote Sensing and Geo-informatics. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Addis Ababa, Ethiopia

Date: June, 2021

Yismaw Aregaw

ACKNOWLEDGMENTS

First and for most, I would like to thank “**Almighty GOD**” who made it possible and for the strength and patience that he gave me the successful completion of my study.

I am extremely grateful to my advisor to Dr.Tibebu Kassawmar, for his constructively critical and invaluable comments, generous support, guidance, feedback, and follow-up throughout the research work.

I also want to thank The Ethiopian Ministry of Agriculture and Addis Ababa University College of Natural and computational science allowed me to pursue my postgraduate study. Moreover, I acknowledge different government organizations that support and provide data like the national Metrological Agency of Ethiopia, Dega Damot District Agriculture office.

I wish to express my deepest gratitude to my friends in the remote sensing and Geo-Informatics stream for their collaboration, assistance, and creating a wonderful environment through working together.

Finally, I want to extend warmest thanks to my family members for their emphatic support helpful nature, and love throughout this study

Table of contents

ACKNOWLEDGMENT	I
List of figures	v
List of Tables	vi
List of Appendices	vii
Acronyms and Abbreviations	viii
Abstract	ix
CHAPTER ONE	1
1. INTRODUCTION	1
1.1.BACKGROUND	1
1.2. Statement of the Problem	3
1.4. Research question.....	4
1.5. Significance of the study	5
1.7. Limitation of the study	5
1.8. Organization of the thesis.....	6
CHAPTER TWO	7
2. Literature Review	7
2.1. Land degradation an overview	7
2.2. The extent, Forms, and impacts of Land degradation in Ethiopia	8
2.2.1. Forms of Land degradation	8
2.2.1.1. Soil erosion	9
2.2.1.2 Forms of soil Erosion	10
2.2.1.4. Vegetation Biodiversity Decline	13
2.2.2. Impacts of Land degradation	14
2.3. Land Degradation Assessment Approaches.....	15
2.2.2. Soil erosion Modeling.....	16
2.3.1. Spatial Multi-criterial Evaluation.....	18

2.3.2. Analytical Hierarchy Process (AHP).....	18
2.3.3. Weighted overlay analysis	19
2.4. The role of Geospatial Technologies for Land degradation Modeling	19
CHAPTER THREE	21
3. MATERIALS AND METHODS.....	21
3.1. Description of the Study Area.....	21
3.1.1. Location.....	21
3.1.2 Physiographic Background	22
3.1.2.1. Topography.....	22
3.1.2.2. Soil.....	23
3.1.3. Climate and Agro-ecological zones	25
3.1.3.1. Agro-ecology	25
3.1.3.2. Climate	28
3.1.3.2. Drainage system	30
3.1.3.3. Natural Vegetation.....	30
3.1.4. Population and settlement	30
3.2. Research design.....	31
3.2.1. Data description.....	31
3.2.2. Software used.....	32
3.3. Methods.....	32
3.3.1. Land-use and land-cover	32
3.3.2. Vegetation degradation hotspot mapping.....	36
3.3.3. Soil erosion Modeling.....	37
3.3.3.1. Estimation of soil erosion risk caused by sheet and rill and erosion using RUSLE .	37
3.3.3.2. Processing of RUSLE parameters.....	38
3.3.4. Gully erosion assessment	42
3.4.1.1. Consistency check.....	45

CHAPTER FOUR	47
4. Results	47
4.1. Land-use/Land-cover mapping and change analysis	47
4.1.1. Land-use and land-cover maps of 1990, 2005, and 2020 periods	47
4.1.2. Accuracy Assessment	50
4.1.3. land-use and land-cover change detection	50
4.1.4. Spatiotemporal Transition of land-use and land-cover	51
4.2. Soil erosion assessment.....	53
4.2.1. Sheet and rill erosion assessment.....	53
4.2.1.6. Model result.....	60
4.2.2. Gully erosion assessment	62
4.3. Soil erosion status due to sheet, rill and gully.....	64
4.4. Biodiversity degradation Vulnerability	67
4.4. Composite land degradation map.....	73
CHAPTER FIVE	75
5. DISCUSSION	76
5.1. Land-use/ land cover change.....	76
5.2. Soil erosion Assessments.....	76
5.3. Biodiversity degradation hotspot assessment	77
5.4. Composite land degradation mapping	78
CHAPTER SIX	79
6. CONCLUSION AND RECOMMENDATIONS	79
6.1. CONCLUSION.....	79
6.2. Recommendations	80
References	82
Appendices	94

List of figures

Figure 2. 1. The photo was taken from Gully land in Dega Damot District	11
Figure 3. 1: Location map of the study area.....	21
Figure 3. 2. Elevation map (a) and Slope map (b) of the study area	23
Figure 3. 3. Soil Map of the Study Area (Source: Water and land Resource Center).....	25
Figure 3. 4. Agro-ecological zones of the study area (MOA, 2014)	27
Figure 3. 5. Monthly average Rainfall (1990 – 2020) of the study area	28
Figure 3. 6. Mean maximum temperature (1990 – 2020).....	29
Figure 3. 7. Mean minimum temperature (1990 – 2020)	29
Figure 3. 8. Vegetation degradation flowchart.....	37
Figure 3. 9. Flow chart for estimating soil erosion.....	41
Figure 3. 10. Methodological flow chart	46
Figure 4. 1. The land-use and land-cover map of 1990 (A), 2005(B) and 2020 (C).....	49
Figure 4. 2. Vegetation Degradation hotspots in the study area.....	53
Figure 4. 3. Rainfall erosivity of 1990(A), 2005 (B) and 2020(C) of the study area.....	55
Figure 4. 4. Soil erodibility (k) (A) and Topographic (B) factor of the study area.....	56
Figure 4. 5. Cover management (C-factor) 1990(A), 2005(B), 2020(C)	59
Figure 4. 6 . Conservation support practice (P) factor 1990(A), 2005(B), 2020(C)	59
Figure 4. 7. Annual soil loss 1990(A), 2005(B) and 2020(C) for the study area.....	60
Figure 4. 8. Reclassified annual soil loss 1990 (A), 2005 (B) and 2020 (C)	61
Figure 4. 9. Gully erosion map of the study area	63
Figure 4. 10. The photo was taken from gully hotspot areas	64
Figure 4. 11. Soil erosion risk map of the study area	66
Figure 4. 12. Distance to (A) settlement, to road (B), LULC and Slope gradient (D).....	70
Figure 4. 13. Biodiversity degradation hotspot map of the study area.....	72
Figure 4. 14. Composite land degradation hotspot map of the study area	75

List of Tables

Table 3. 1. Slope class of the study area	22
Table 3. 2. Major soil Types of the study Area.....	24
Table 3. 3. Traditional agro-ecological zone of the study area.....	26
Table 3. 4. Description of satellite images used for this study	31
Table 3. 5. Data types and sources.....	32
Table 3. 6. Land-use and land-cover types	34
Table 3. 7 The LULC along with their C value	41
Table 3. 8. P factor value on different LULC types.....	41
Table 3. 9 Paramaters used for biodiversity degradation mapping.....	43
Table 3. 10. Scale of relative importance of constraints.....	44
Table 4. 1. Land-use and Land-cover of three periods.....	48
Table 4. 2. Net Changes of LULC.....	50
Table 4. 3. Land-use and land-cover transformation over the year three decades.....	53
Table 4. 4. Areal distribution hotspot of Vegetation Degradation.....	54
Table 4. 5. Table 4.4. Soil erosion risk class of 1990, 2005 and 2020	62
Table 4. 6. Accuracy assessment of gully occurrence	60
Table 4. 7. Degree of soil erosion risk levels of the study area	65
Table 4. 8. Pairwise comparison matrix of soil erosion.....	67
Table 4. 9. Pairwise comparison matrix for determining biodiversity degradation mapping.....	71
Table 4. 10. Statistics of biodiversity degradation in Dega Damot District	73
Table 4. 11. Pairwise comparison matrix of composite land degradation	73
Table 4. 12. Composite land degradation status of Dega Damot District.....	74

List of Appendices

Appendix 1. Statistical information of accuracy assessment for 1990, 2005 and 2020.....	94
Appendix 2. Land/use and land/cover change between 1990 and 2020.....	96
Appendix 3. Stream Power index (SPI) and Topographic wetness index (TWI).....	97
Appendix 4: Accuracy assessment points 1990(A),2005(B) and 2020 (C.....	98
Appendix 5: Two False Color Composite (FCC) scenes of Landsat 5(1990) and one scene Landsat 8(2020) (A&C) and after mosaic clipped FCC image of Dega Damot district for 1990 (B) and clipped 2020 (D).....	99

Acronyms and Abbreviations

AHP	Analytical Hierarchical process
CHRS	Climate and hydrological remote sensing
CLD	Composite land degradation
ENVI	Environment for visualizing image
ERDAS	Earth Recourse Data Analysis system
ETM+	Enhanced Thematic Mapper
FAO	Food and Agricultural organization
GLASOD	Global Assessment of human Induced Soil degradation
GIS	Geographic Information system
GPS	Global Positioning System
HWSD	Harmonized World Soil Data Base
LADA	land degradation assessment in drylands
LULC	Land-Use Land-Cover
LULCC	Land-Use Land-Cover Change
MCA	Multi criteria analysis
MOA	Ministry of agriculture
RUSLE	Revised Universal Soil loss Equation
USLE	Universal Soil loss equation
USGS	United states Geological survey
WGS	World Geodetic System

Abstract

Land degradation is an increasing problem in Ethiopia. Combating in land degradation needs an improvement in awareness on causes, impact, and degree of degradation. Therefore, land degradation assessment is the main aim in a decision support system for reversing degradation. The main objective of this study is to asses land degradation through modeling of land use and land cover, soil erosion, and biodiversity Status. Land/use and land cover classification were made from Landsat 5, Landsat 7ETM+ and Landsat 8 OLI for the years 1990, 2005, and 2020 through supervised classification in ENVI 5.3. Seven different types of and/use and land/cover were identified. Using the post-classification method accuracy assessment was computed for each study period resulted in an overall accuracy of 87%, 86%, and 87% respectively. The change detection was analyzed and validated with the aid of field data coupled with Google Earth. The findings of the study show land use/ Land cover change 1990, 2005, and 2020 crop land, urban settlement, and grass land increase in expense of other land use while forest and shrub land vanished seriously for the last 30 years. Soil erosion estimation was done by compiling RUSLE model results and gully erosion maps with multi-criteria evaluation methods. The study area found that nearly 75% has been moderate to severe levels of soil erosion severity. Moreover, biodiversity degradation hotspot of the study area was computed with the combined proxy factors of road, settlement, slope, and land/use and/cover. And the result revealed that about 0.5%, 21.2%, 54.3%, 20.4%, and 3.6% of the district experienced very low, low, moderate, high, and very high levels respectively. To produce the final composite land degradation map of the study area, vegetation, soil erosion, and biodiversity degradation levels have been standardized and normalized with analytical hierarchy and pairwise comparison techniques. Therefore, the combined multi-criteria analysis result showed that about 20%, 44%, 32%, and 4% exhibits low, moderate-high, and very high levels of land degradation levels. The study area comes up with biodiversity followed by soil erosion severity as critical levels of land degradation. Thus, the study suggests afforestation programs, soil, and water conservation, and different sustainable land management practices should start by identifying the hotspot areas.

Key words: Composite Land degradation, MCA, Dega Damot District, Soil erosion

CHAPTER ONE

1. INTRODUCTION

1.1. BACKGROUND

Land resource is a delimited area of the earth's terrestrial surface, encompassing all attributes of the atmosphere just above or below this surface including those of the near-surface climate the soil and terrain forms, the surface hydrology near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement and physical results of past and present manmade actions which include terracing, water storage or drainage structures, roads, buildings, etc.(FAO, 1995). Land is the primary means of production used to generate a livelihood for rural residents of most developing countries. It is the main asset that farmers have to accumulate wealth and, equally importantly, what they transfer in the form of wealth to future generations (Nega et al., 2003; Debrie, 2018). However, the unwise use of land resources tends to the degradation of lands.

Land degradation is the reduction and loss of the biological or economic productivity and complexity of land ecosystems resulting from land uses or from a combination of processes arising from human activities and habitation patterns (UNCCD, 2015). Moreover, it is also the long-term diminishing of ecosystem function and productivity caused by disturbances from which land cannot recover unaided (Bai et al. 2008a, 223). Moreover, Land degradation comprises all processes that diminish the capacity of land resources to perform essential functions and services in these ecosystems, i.e. deforestation, loss of biodiversity, soil degradation (Hurni, et al., 2010). It is caused by a combination of various causes. It includes such types of land degradation such as soil degradation (e.g. Soil erosion), biological degradation (e.g. loss of biodiversity), and water scarcity among others (Ahmed, 2012).

Among the various factors of land, degradation is deforestation extractions of firewood, livestock farming, absence of using shifting cultivation, industrialization, urbanization mainly around the main towns (Mahala, A. 2019).

The understanding of land degradation processes, including their causes and consequences on ecosystem functioning also because identification of affected areas and regions in danger, are a prerequisite to developing strategies to combat and diminish land degradation (Stellmes *et al.*, 2015). Most of the land degradation is because of extensive soil degradation caused by erosion, salinization, compaction, and nutrient depletion (GEF, 2013), biodiversity loss, water shortages (Nachtergaele & Petri, 2010), global climate change associated biophysical and manmade driven factors. It has been a significant global issue during the 20th century and can remain higher with in the international agenda in the 21st century, owing to its impact on world food security and quality of the environment (Eswaren *et.al*, 2001). Land degradation could be a serious global environmental problem and may be a matter of great concern. Wide of all land everywhere in the world has been converted into unproductive and degraded lands (Dogo, 2014).

Ethiopia is also one of the most strictly affected countries by land degradation a high level of soil loss (FAO, 2011; World Bank, 2012). The major environmental problem in the Eastern African highlands is land degradation, manifested mainly in the sort of soil erosion, gully formation, soil fertility loss, water scarcity, and reductions in crop yield, which has been more visible in the Ethiopian (Yiheneu & Tilahun, 2014). A short-term increase in agricultural production is often obtained through increased pressure on the land visible in the northern part of Ethiopia (Dagim , 2020).

Although various soil and water conservation interventions have been introduced across Ethiopia, land degradation, mainly in the form of soil erosion, continues to be a significant problem (Amdihun, A.*et al.*, 2014). The evaluation of land degradation ranges from the population or social terms to that of erosion or physical terms. It has different controversies like magnitude, scale, reliability, relevance problem of land degradation data, which has both temporal and spatial scale of dimension (Mahala, A. 2019).

This study demonstrated the utilization of an integrative, spatially explicit procedure, using an integrated geospatial approach of various land degradation agents which governments and relevant stakeholders can adapt for assessing and validating local-level land degradation.

1.2. Statement of the Problem

Land degradation manifested in terms of soil erosion, nutrient depletion, gully erosion, water scarcity, and reduction in yield production is highly observed in the highlands of Ethiopia especially in the Amhara region. It accounts for 45% of the total land area of the country and 66% of the total land area in the Amhara region (Lakew *et.al*, 2002). Land degradation is an alarming problem in the Amhara region where soil erosion leaving 20,000-30,000 hectares of land unproductive (Taffa, 2009).

According to CSA (2007), the total populations of Dega Damot District were increased by 26.48 percent in the 10-year interval; this phenomenon has caused cropping and grazing activities to be shifted to a hillside and ecologically fragile areas. Moreover, people are forced to use crop residues and dung for fuel rather than using them as sources of organic fertilizer to improve soils and have led to a reduction in land management activities such as fallowing, planting trees, and investing in conservation structures. On the other hand, deforestation is severe in the study area. Forest cover is declining from day to day due to population growth and the lack of strong forest protection and management strategies in the District. This leads to loss of biodiversity vulnerability to soil erosion, which in turn results in land degradation. To address the problem Most of the GIS-based land degradation assessments are on a basis of a single agent, for instance, soil erosion. However, a land degradation assessment that involves a wide range of factors responsible for degradation could be more informative.

Abebaw (2015) specifically assessed land degradation by RUSLE model of soil erosion considering limited input variables, which affects sustainable land management.

Due to a lack of well-developed research methodology, in many cases, planners take only one or a few of them, commonly soil erosion maps. The application of remote sensing and geographic information system (GIS) techniques gives land degradation estimation and its spatial distribution

feasible with reasonable costs and better accuracy in larger areas (Reddy G.P.O., *et al*, 2018). However, to halt the problem, often requires, a well-integrated application of geospatial technology along with the intensive land degradation hotspots should be addressed. Studies conducted (Mengie *et al.*, 2019) specifically only soil erosion assessment at Gumara watershed excluding other attributable factors. This study was conducted to fill the gap by accompanying other variables such as gully, biodiversity with the popular methodology of MCA. assessing the land degradation at Dega Damot district using geospatial modeling approach combining with ground truth data calibration and validation, in which the output may help as an input information future land use and sustainable land management approaches and planning's for planners and decision-makers.

1.3. Objectives

1.3.1. General objective

The overall objective of the study is mapping and quantifying land degradation by using geospatial modeling approach that allows developing an effective land management plan.

1.3.2. Specific objectives

The specific objectives of the study are:

- To quantify and asses land use land cover change dynamics from 1990 to 2020 using multi-temporal images
- To asses and map the Spatio-temporal change of soil erosion
- To map and quantify biodiversity degradation hotspot in the study area.
- To map and quantify composite land degradation in the study area

1.4. Research question

- What is the trend of land use land cover change over three decades?
- How to assess the spat-temporal rate of soil erosion estimation of the study area?
- What is the status of biodiversity degradation hotspot?
- What are the areal dynamics of composite land degradation?

1.5. Significance of the study

In many studies, assessment of land degradation studies has been done taking only one aspect of it, like soil erosion. However, such information has limited contribution in developing an appropriate intervention that could halt land degradation. Therefore, this study provides assessment of land degradation that considers the various land degradation types that could allow planners and land resources managers to get the required information for the purpose to develop an effective management plan.

1.6. Scope of The study

The scope of the research study was spatially bounded in Dega Damot District, Amhara Regional State of Northwestern Ethiopia. The study was conducted on the Assessment of land degradation, which mainly concerned with investigation of vegetation, biodiversity, and soil degradation hotspot areas with the aid of different geospatial modeling perspectives. It was used to evaluate the degraded lands within the use of land use land cover dynamics analysis, modeling Soil erosion, which consists of gully mapping and the biodiversity hotspot modeling to come up with the overall land degradation assessment in the study area.

1.7. Limitation of the study

Any research would not be free from limitation but the degree of challenges varies depending up on the nature and the type of research problem and the study area. Thus, the courses of this study the most challenging and facing some types of problems.

Since the study covers a large area, that challenges the analysis and validation of data. Moreover, this study also deals with assessing land degradation, which required the collection of different volumes of data, and there was a lack well-structured of the desired types of data. In addition, there are no enough meteorological gauging stations in the study area, and even the Consistency of record of the rainfall data had some gaps, which was a challenge for showing the long climate trends.

1.8. Organization of the thesis

This thesis is organized into five chapters to achieve the designed objectives. The first chapter deals with the background, statement of the problem, research objectives, and scope of the study, and limitation of the study. Chapter Two gives an overview of land degradation studies with remote sensing and GIS technology, soil erosion modeling, land-use, and land-cover dynamics, and biodiversity degradation. Chapter Three focused on the description of the study area including Martials methodologies applied for the achievement of the research objective. Chapter Four explains the results, which mainly introduces the results and findings primarily leading to a map of land use/cover, Accuracy assessment, Soil Erosion, and biodiversity degradation hotspot, and composite land degradation of the study area. Finally, Chapter Five Discussions presents main works related to previous findings. Chapter Six deals with drawing conclusions and recommendations of the study area.

Chapter Two

2. Literature Review

2.1. Land degradation an overview

Land is a non-renewable resource, which is a basis for human survival, and development that provides a crucial material foundation and space guarantee for human development (Xie *et al.*, 2020). Land is the highest valuable resource for the survival and prosperity of humankind and the existence of life. It helps for the production of food, fiber, fuel, and many other vital goods require to meet human and animal needs. However, it is facing serious threats of degradation because of unrelenting human pressure and utilization incompatible with its carrying capacity (Bairagi *et al.*, 2012).

Land degradation is the reduction and loss of the biological or economic productivity and complexity of land ecosystems resulting from land uses or from a combination of processes arising from human activities and habitation patterns (UNCCD, 2015). It is not only one of the most serious environmental problems within the world, but also one of the major social and economic issues (Xie *et al.*, 2020). Land degradation is closely related to the sensitivity, resilience, and carrying capacity of the land, as well as to the vulnerability of people living on and from these lands. It may be defined as the loss of utility or potential utility, or reduction, loss, or change of features or organisms that cannot be replaced (Zorn M; Komac B., 2013).

Land degradation manifests itself in many ways for which includes land abandonment, declining populations of wild species, loss of soil and soil health, reduction of rangelands and fresh water, and deforestation (IPBES, 2018). It is an ecological and environmental sensation that disturbing arable lands and affects the economic and natural excellence of an agronomic land which is a continuing deterioration of the production capacity of lands (Muhammad D T, 2020). Additionally, Coxhead and Oygard,(2007) give a more specific and detailed definition for land degradation as land degradation is a loss or reduction of biological or economic productivity and complexity of

rain-fed crop land, irrigated crop land, or range, pasture, forest and wood lands resulting from land uses or from a process of combination of process, including process arising from human activities and habitation patter. Moreover, land degradation can also be defined in terms of actions taken which increase the reduction soil loss from agricultural lands affecting crop productivity and increasing sediment loss to rivers and reservoirs. Land degradation, in general, implies temporary or permanent recession from a higher to a lower status of productivity through the decline of physical, chemical, and biological aspects. A complex ensemble of surface processes is facilitated by erosion, soil compaction, Stalination, and soil water logging. These can ultimately lead to severe land degradation and loss of productivity (Bairagi *et al.*, 2012).

Globally, land degradation becomes a serious environmental issue in the context of anthropogenic pressure and climate change in the twenty-first century (Sandeep, P *et al.*, Jegankumar, R. *et al.*, 2020). Land degradation is a critical global environmental problem and is a matter of serious concern. It occurs in all kinds of landscapes over the world (Wassie, S.B., 2020).

2.2. The extent, Forms, and impacts of Land degradation in Ethiopia

The highland of northwestern Ethiopia is highly vulnerable to land degradation. Moreover, the problem that is more pronounced within the highlands of northern Ethiopia is related to ancient human settlements and age-old farming activities relative to other parts of the country (Kassahun & Yitbarek, 2018).

2.2.1. Forms of Land degradation

Different Scholars have identified various causes of land degradation. Berry (2003) specifically identifies the sources of land degradation, that involve two linked complex systems: the natural environment and therefore the human activity over the ecosystem. The extended causes of land degradation can be viewed as biophysical factors like unsuitable land use (land use for the goal for which environmentally unsuited for sustainable use), socioeconomic factors such as poor land management activity, land issuing, marketing, institutional support, income, and human welling, and political determinants such as lack of security issues (Temesegen Gashaw, 2017).

2.2.1.1. Soil erosion

Soil erosion as "soil cancer" could be a multifarious process and its multiple obvious and unknown social and environmental influences are an increasing hazard for the human being (Ownegh, 2003). It is one part of land degradation that affects the physical and chemical properties of soil and leading to on-site nutrient loss and off-site sedimentation of water resources in Ethiopia (Hurni, 1993b). Soil degradation caused by water erosion in Sub-Saharan Africa (SSA) is of concern mainly due to its impact on hand-to-mouth agriculture, of which 75% of the population generates their income (Zerihun Nigussie, *et al.*, 2017). The Rapid population increase and growing demand posed a greater pressure on land resources, resulting in severe soil erosion (Gezahegn and Arus, 2020.) The extent and severity of the problems differ in spatial variations in altitude, ecology, settlement, topography, and land-use system (Kefale Munye, 2020). Nevertheless, the Ethiopian highland, which covers about 44% of the country's total geographic area and sustains the livelihood of about 87% of the population, is that the foremost-eroded physiographical region within the country (Gezahegn and Arus, 2020). Every year, Ethiopia loses over 1.5 billion tons of topsoil from the highlands to erosion that could be added about 1.5 million tons of grain to the country's production (Lulseged and Vlek, Paul. 2008). Approximately 39 percent of the land within the Amhara region is estimated to be used for grazing and browsing and 27 percent is under cultivation, much of it is cultivated for three millennia or longer. Many of the soils, which shrink and swell have severe drainage and waterlogging problems during the rainy season. A majority of the land is steep, infiltration rates are low, and the little surface cover is left after extensive cropping or grazing (<https://www.ctahr.hawaii.edu/sm-crsp/phase1/pdf/amhara.pdf>).

2.2.1.2 Forms of soil Erosion

The forms of soil erosion depend on the process and agent of erosion drivers, considering the erosion cycle and the position in the landscape, there are various forms of soil erosion by water. Sheet, rill, and gullies are the most important ones (Mitiku *et al.*, 2006).

Sheet erosion: it is the removal of a thin uniform covering of top productive/surface soil from large areas, often from the field, more or less, during every rain, which produces a run-off. This is a type of erosion that is harmful since it keeps the cultivator almost ignorant of its ill effect. It is also known as the death of farmers (Telkar, S. and Pote, 2018).

Rill erosion: When runoff starts, channelization begins and erosion is not any longer uniform. The raindrop effect does not directly erode any particles below the flow line in rills, however, increases the detachment and transportation capacity of the flow. Rills are small channels, which might be removed by timely normal tillage operations (Telkar, S. and Pote, 2018). Researches in the highlands of Ethiopia revealed that Splash, sheet, and rill erosion have been studied in the laboratory and at the plot scale irrespective of district level, which comprises different agro-ecological settings (Birara Chekol, 2012).

Gully Erosion: it is the removal of soil by runoff water and sometimes persists in narrow ditches and, over a short time, removes the soil from this narrow area to reasonable depths. Gully is the worst stage of all kind of erosion and it is a highly visible form of erosion, which affects many types of soil functions that includes food and other biomass production, water containing, filtering and transformation, habitat and gene pool, physical and cultural environment for mankind, and source of raw materials and hence soil qualities (Hailu Kendie, *et al.*, 2015). In Ethiopia, soil erosion is a typical part of the landscape, particularly in the highland area for which the loss of top soil via gully erosion (Iulseged and Vlek, 2008). Attempts have been made to use spatially distributed models to study gully erosion in the country, mainly in small watersheds (Nigussie Haregeweyn *et al.*, 2016). In the study area ephemeral gully is more pronounced in most parts of agricultural and grazing lands (Figure 2.1).



Figure 2. 1. The photo was taken from Gully land in Dega Damot District

2.2.1.3. Land use Land Cover change

Land use and land cover have some basic differences. Kaul, H.A. & Ingle, Sopan. (2012), defines two terms; Land cover refers to the physical characteristics of Earth's surface, captured in the distribution of vegetation, water, soil, and other physical features. Land use refers to how the land has been used by humans and their habitats such as agriculture, settlements, industry.

Vegetation cover functions as an integrated indicator of vegetation responses to environmental factors. This including rainfall, temperature, soil, and topography, as well as factors related to human activities, which are typically derived from land cover and land use (LULC) information. However, Changes and modifications of vegetated land surfaces, such as habitat loss and LD, are considered as the primary cause for global environmental change particularly land degradation as they reduce ecosystem services and impair ecosystem function (Olena, 2017). Vegetation plays an

important role in stabilizing the global environment. Reliable information on the status of vegetation using different techniques is necessary for solving environmental problems particularly land degradation (Nurhussen Ahmed. (2016). Land use/land cover changes (LULCC) have become a major issue for natural resource management and environmental change monitoring (Biniyam, *et al.*,2019). A quantitative and qualitative alteration of LULC mostly with the interference of humans is called Land-use and land-cover changes (Samson, *et al.*,2020). Land-use and land-cover changes (LUCC) increasingly have been regarded as a primary source of global environmental change such as global climate change, loss of biodiversity, and loss of soil resources (Maina J., *et al.*,2020).

Scholars in the field of social and earth system sciences hypothesized that LULC changes are triggered by the interaction of anthropogenic and biophysical driving forces and Studies have shown that LULCC has been severe in the highlands of Ethiopia. (Berhan and Woldeamlak,2014). The overgrowing of the population in Ethiopia, consequently inducing many effects on the natural resources such as very dynamic land use and land cover (Abdata, 2020). Similarly, the changes in the population growth, overgrazing, and agricultural expansion in the highland areas have caused a drastic increase in the rate of LULC changes (Alemayehu and Chakma S., 2019).

Ethiopia highlands are considered the most degraded lands in Africa (El-Swaify and Hurni 1996). Moreover, LULCC occurs due to the combination of factors of the rapid expansion of urbanization, high demand for production, land shortage which is attributable to management including conversion of grazing and forest land into farming land, pollution and land degradation, removal of vegetation, and conversion to non-agricultural uses (Tesfa *et al.*,2016). Previous studies reported that there have been considerable LULC changes in different parts of the country over different periods (Birhan and Assefa, 2018). Recently (Sabiela *et al.*, 2020) studied land use land cover dynamics and Properties of Soils in Tejibara Watershed Estie showed that the forest and grazing lands have been reducing consistently for the three decades due to the demand for cultivated lands and settlement by the ever-increasing population residing in the watershed that leads to LULCC. As a result, Removal of surface vegetation decreases infiltration in the soil and results in increased runoff which intern leads to deforestation and LULC changes.

Likewise, (Wakjira *et al.*, 2020) studied that land use land cover was changing in alarming rate for 30 years onward in Fincha Catchment, Northwestern Ethiopia; which is exhibited by expansion in agriculture, commercial farm, and urban and built-up showed endless increase whereas forestland, grazing land, rangelands, and swampy area showed a continuous decline. Similarly, (Temesgen *et al.*, 2017), studied land use land cover change changes in the Andassa watershed around Dembecha district and showed that Cultivated land was expanding from 62.7% in 1985 to 73.1% in 2000 and 76.8% in 2015. The area of built-up also slightly increased (0.1–1.1%) between the 1985 and 2015 periods. In contrast, forest, shrub land, and grassland were reduced alarmingly.

2.2.1.4. Vegetation Biodiversity Decline

According to (Muchin L., *et al.*, 2014) biological diversity is that the richness among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and also the ecological variabilities of which they are among; this contains diversity within species, across species and of ecosystems. Genetic resources, species or parts of organisms, populations, or any other biotic component of ecosystems having present or potential use or value for humankind constitute biological resources. African ecosystems have a diverse biodiversity, with a high number of native and endemic plant species, making them biologically distinctive and providing a variety of ecosystem services. (Catarino L. and Romeiras M.,2020).

Ethiopia is endowed with diverse ecosystems within which diverse flora and fauna also microbial resources are found. The main ecosystems include Afro-alpine and sub-afro-alpine, Montane dry forest and scrub, Montane moist forest, Acacia-Commiphora woodland, Combretum-Terminalia woodland, Lowland humid forest, Aquatic, wetland, Montane grassland, and Desert and semi-desert ecosystems (<https://www.ebi.gov.et/biodiversity/ecosystems-of-ethiopia/> accessed on 20/01/2021).

Although some success in conserving biodiversity at the local level, the biodiversity continues to decline due to continued increase in human population, resource consumption, market factors, and policies. Ethiopian biodiversity, being having a unique combination of gene/genotypes, are well selected against the environment for ages. However, these resources are gradually decreasing in sustenance and will have serious ecological, social and economic implications in Ethiopia. (Azamal *et al.*, 2012). Moreover, this biodiversity, the biological resources of Ethiopia are

currently under critical threat mainly due to rapid population growth. The livelihood of the population mainly depends on natural products and lands, and the demand for these is consistently growing (Mengesha *et al.*, 2020). Human actions have resulted in multiple changes on a global scale that often drive contemporary biodiversity declines. In particular, land-use changes, exotic species invasions, nutrient enrichment, and climate change are often considered some of the most ubiquitous and influential global ecosystem changes (Isbell, 2010).

2.2.2. Impacts of Land degradation

Land degradation is a serious problem in Ethiopia, with more than 85 % of the land degraded to various degrees. Recent estimates using satellite imagery show that land degradation hotspots over the last three decades cover about 23 % of the land area in the country (Samel *et al.*, 2016). Moreover, Land degradation is a major threat to biodiversity, ecological sustainability, and ecosystem stability. It interrupts the regulating and provisioning services of ecosystems, in particular nutrient cycling, the global carbon cycle, and the hydrological cycle. Even though the

Amhara region has wide biodiversity of flora and fauna, the quality and quantity of biodiversity are diminishing due to significant depletion of forest resources, soil erosion, loss of soil fertility, and degradation of water resulted from an increase in the population, livestock pressure, and increased demand for arable land (Desalew, 2014). The immediate impact of land degradation is lower crop yields, leading to higher poverty rates among agricultural households. Land degradation is also a widespread problem in Ethiopia with over 85% of the land moderately to very severely degraded (Gashu and Muchie 2018), and about 75% affected by desertification (Simachew, 2020). Land degradation also adversely affects and seriously influences the situation of, temporary or permanent decline in the productive capacity of the land for rain-fed agricultural practices. This impact can be seen through a loss of biomass, a loss of actual productivity, or in potential productivity, on a loss or change and vegetation cover and soil nutrients (Yilkal, 2018).

Land degradation is also altering hydrological conditions where vegetative cover is removed and the soil surface is exposed to the impact of raindrops. It deteriorates the quantity and quality of water resources. Many perennial springs and streams of the region had become seasonal (Lakew *et al.*, 2000). Generally, the effects of land degradation are a serious phenomenon in northwestern Ethiopia of the Amhara region.

2.3. Land Degradation Assessment Approaches

Assessment of the problem of land degradation and desertification is very difficult because this phenomenon includes several complex processes (Masoudi *et al.*, 2018). Due to this the types of degradation and the method used to address them vary accordingly (Sileshi, 2016). Land degradation has been a global development and environmental issue that affects mostly developing countries regarding the economic impact and food security (Ahmed *et al.*, 2014). The quantification and monitoring frameworks developed to provide information about land degradation have been very valuable; however, there are some opportunities to improve and test methodologies according to regional and country needs.

The Global Assessment of Soil Degradation, GLASOD was the first global assessment of land degradation attempt, which was mainly concerned, with human-induced soil degradation assessment (Oldman, 1994 *et al.*, 1990). In this study the status of soil degradation was mapped by defining physiographic units, themselves based on expert judgment, in which type, and degree, extent, rate, and main causes of degradation were characterized. The assessment was undertaken through a network of regional correlator's institutes and individual experts who were requested to prepare draft regional soil degradation maps on supplied topographic base maps following general guidelines and in recommendation with national soil and GIS experts within the region. The findings of GLOSAD show that human-induced soil degradation affects about 15% of the worldwide area. This approach was recently upgraded by a new worldwide project 'Land Degradation Assessment in Drylands' (LADA,2002) Withe retaining the original GLASOD categories of soil degradation, LADA takes a step forward by attempting at delivering quantitative results, formally including socio-economic drivers and enlarging its scope to carbon balances and biodiversity as components of the functional land system and its degradation process (Juan *et al.*,2009). Moreover, land degradation assessment employed more using Soil erosion modeling for the vulnerability of the area for degradation.

Since then, some approaches were conducted and tested. for instance, The analysis of Land Use Land Cover Changes on Land Degradation Dynamics that shows an increasing land degradation sensitivity was associated with the subsequent land cover transitions; Change in LULC can also

negatively affect the potential use of an area and may ultimately lead to land degradation (Bajocco *et al.*,2012; Binyam, 2015).

2.2.2. Soil erosion Modeling

Soil erosion modeling is the process of describing soil particles and processes of detachment, transport, and deposition mathematically on land surfaces (Kefale, 2020). Because a model is a simplification of reality, it has been practically developed and applied to solve soil erosion problems (Gebrat Shiferaw, 2018). Soil erosion modeling is used to:

- Predict and quantify soil loss for conservation planning,
- Predict where and when erosion is occurring and hence helping the conservation planner target to reduce erosion and
- Understanding erosion processes and their interaction for setting research priorities (Lal,1994).

To understand and estimate the amounts of soils eroded in an area, several erosion models have been developed where most of them were formulated in the U.S, relying on different equations (Patrick, 2015). One of the major advancement in soil and water conservation during the last century was the establishments of The Universal soil loss equation (USEL), which is an empirical model designed to predict the longtime average soil losses in runoff from specific field areas in specified cropping and management systems and Widespread field use has substantiated its usefulness and validity for this purpose (Wischmeir and Smith, 1978). The USLE was originally applied to the assessment of soil losses from agricultural land in the USA, which is to preserve soil resources, however has been extended for use in various countries (Sadeghi *et al.*, 2014). The model was developed based on the data collected from the specific rotation, slope length, slope steepness, row direction, soil erodibility, and support practice. Empirical models are easy to implement, reliance on easily accessible data, and produce relatively accurate results than others (Patrick, 2015).

Lots of consecutive attempts were done by researchers over the last three decades to improve into a better version of USEL. Because, USLE predicts the annual soil loss, as a result, only annual sediment yield can be quantified by this equation, which is less important for the design of water

storage structures. To overcome the drawbacks of USLE regarding the prediction of sediment yield, Williams in the year 1975 made an effort to modify the USLE suitable for computation of sediment yield, either monthly or seasonal values. He modified the USLE by replacing the rainfall energy factor (R) with another factor called the ‘runoff factor’. e determined by this equation, which is less important for the design of water storage structures (https://www.soilmanagementindia.com/soil-loss-measurement/soil-loss-equation/modified-universal-soil-loss-equation-musle-soil_management/15504). Therefore by including the runoff as an independent factor in modeling erosion, MUSLE has improved the accuracy of soil erosion prediction over USLE (Arekhi *et al.*, 2012). In general, MUSLE can be expressed as,

$$Y=11.8(Qqp) 0.56(K) (L) (S) (C) (P) \text{-----} (2.1)$$

Where,

Y = sediment yield in tones;

Q = volume of runoff in cubic meters;

q p = peak flow rate in cubic meters per second, and

K = the soil erodibility factor, which is the erosion rate per unit of erosion index for specified soil in cultivated continuous fallow,

LS = the slope length and gradient factor, which is the ratio of soil loss from the field slope length and gradient,

C = the cropping management factor defined as the ratio of soil loss from a field with specified cropping and management to that from the fallow condition for which the factor K is evaluated;

P = the erosion control practice factor, which is the ratio of soil loss with contouring, strip cropping, or terracing to that with straight row farming, up and down a slope.

Over time, The Revised Universal Soil Loss Equation (RUSLE) is an upgrade of USLE that is land use independent had been developed. The RUSLE model was first introduced in the USDA Soil and Water Conservation Service in 1993. RUSLE maintains the same empirically based equation as USLE to compute sheet and rill erosion but unable to gully erosion (FAO, 2001).

2.3.1. Spatial Multi-Criterial Evaluation

Multi-criteria evaluation involves multiple steps from statement of the problem, setting and formulating objectives developing criteria to the final analysis of the result (Silshi, 2016). The main elements of any multi-criteria decision problem include decision-maker(s), alternatives, and criteria. The procedures for tackling multi-criteria decision problems involve three main concepts: value scaling (or standardization), criterion weighting, and combination (decision) rule (Malczewski, 2015). The spatial multi-criteria evaluation method follows various indicators for producing a land degradation map these indicators of land degradation are categorized into three groups as biophysical degradation indicators, chemical degradation indicators such as soil acidity and alkalinity, and socio-economic indicators and the biophysical degradation indicators used include land use and land cover, vegetation index (Silshi,2016).

2.3.2. Analytical Hierarchy Process (AHP)

The most popular use for MCDM is the (AHP) method, introduced by Thomas Saaty in the early 1980s. The AHP technique was used as a method for consensus building in circumstances involving a committee or community decision-making. The AHP is more than a criteria-weighting method, as it provides an additive hierarchical aggregation of criteria. It assesses the viability of every factor in a complex system, which includes multiple factors and uses “pairwise comparisons” and matrix algebra to weight criteria, basing its decision on the weights from the evaluation criteria. It also differentiates the factors into different levels that are related to each other based on the judgment of relative importance among the factors on the same level while using the calculated weights of every factor. The AHP has many advantages, such as integrating the tangible and intangible aspects of questions, focusing on group objectives rather than objectives, and constant brainstorming to get better answers. The approach also has some drawbacks, however, such as the presentation of the environmental uncertainty issue, the deuce deficiency resulting from hierarchies and the possibility. Moreover, rank reversal is due to the modification of the relative values between the local priorities, which is a deferent and independent cause of rank reversal due to the right and left inconsistencies.

Therefore, the phenomenon of rank reversal is independent of the accuracy of the priority matrix and the method of derivation. While AHP is common and often used in MCDA, it is not enough

to remove all data uncertainty because the data characteristics used play a role in whether the data is certain or uncertain. Certain (deterministic) data are expressed in discrete forms whereas the (non-deterministic) uncertain data are represented by distributions (continuous or discrete). When applying WOA, the method of analytical hierarchy (AHP) is used as a comprehensive logical and structural framework that allows the understanding of complex decisions to be strengthened through decomposing the problem into a hierarchical framework. The incorporation of all relevant decision criteria and their comparison with Pairwise allows the decision maker to determine the tradeoffs among objectives (Satty, 1980).

2.3.3. Weighted overlay analysis

Weighted Overlay Analysis is one the components of the methods of spatial modeling using spatial Multi-criteria evaluation. Weighted Overlay Analysis assigns more importance to some criteria over the others. It has been used by several authors (Sileshi, 2016; Misganaw, 2020; Alelgn et al., 2021). They have adopted the Weighted Overlay Analysis method in undertaking spatial modeling for several purposes. The ArcGIS/IDRISI software's are commonly used to generate the weight factors for each criterion in the context of analytical hierarchy process. These authors have adopted the Weighted Overlay Analysis method for a comparison of expert systems and weighted overlay analysis for land degradation vulnerability mapping; Spatio-temporal assessment of land degradation, for cross traffic-ability suitability modeling and mapping and quantifying land degradation.

2.4. The role of Geospatial Technologies for Land Degradation Modeling

Geospatial technology refers to equipment used in visualization, measurement, and analysis of Earth's features, typically involving such systems as remote sensing, Geographical Information systems, and global positioning system (Dwivedi, 2019). The application of geospatial techniques particularly remote sensing and GIS technologies have proved successful in many fields of natural resources management. Its synoptic and large area extent as well as the ability of GIS to collect store and manipulate various types of data in a unique spatial database helps to perform various kinds of analysis and thus, extracting information about spatially distributed phenomena (Salem,2000). Furthermore, these technologies, including GPS (Global Positioning System), Satellite imageries, and GIS hold great promising for improving the quality and quantity of

information on degradation trends over large areas as well as provide for more effective management of that information which includes Processing of time series of geo-information products allows reliable detecting and mapping of landscape changes at local, regional and even global level (Badapalli, *et al.*, 2020).

Over the application of remote sensing and GIS environmental studies has become very important for mapping and monitoring land degradation and various natural hazards over broad spatial and spectral resolution using multi-temporal satellite images. To obtain more reliable and accurate data, it is better to use as many temporal images as possible with a certain interval of generation including images older than the degradation process. (Sileshi, 2016). Moreover, in studying, monitoring, and degradation, remote Sensing provides a cost-effective evaluation over extensive areas, whereas in situ process studies are resource demanding, and thus, are usually conducted at a field level (Olena, 2017). Remote sensing technology in general satellite imagery in particular provides imagery data for identifying and analyzing necessary data layers. Besides this, in a GIS environment, it is possible to integrate the preprocessed data that are generated from a different data source with their spatial location for further analysis and interpretation (Krishna, 2009).

At the larger scales, topography, soil, and vegetation patterns become more important. This is where remote sensing and GIS become valuable tools. Remotely sensed imagery and GIS have a long history in erosion modeling. This is where remote sensing and GIS become vital tools. Remotely sensed imagery and GIS have a long history in erosion modeling. Numerous studies have shown the potential of remote sensing inland degradation modeling and mapping (Prasannakumar *et al.*, 2012). As an indicator of land degradation and improvement, is preferred to NDVI – in its own right as a direct measurement of an important biophysical parameter, it is related to biophysical variables that control vegetation productivity and land/atmosphere fluxes (Bai, *et al.* 2008b). A geographic information system is so an important tool for coping with the vast number of spatial data and the relation between data from various sources in the land degradation modeling process. Moreover, the application of remote sensing and GIS technologies has provided great opportunities to provide evidence of degradation over large areas at relatively low cost and time investment (Alelgn *et al.*,2021).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Dega Damot District is found in Amhara Regional State, Northwestern Ethiopia. The study area is far from 110km from regional Capital Bahir Dar and 404km from Addis Ababa. It is bordered on the south by Dembecha, on the southwest by Jabi Tehnan, on the west by Kuarit, and the north by Hulet Eju enbsie and in the east by the Bibugn District. Geographically, its absolute location extends between $10^{\circ} 45' 00''$ and $11^{\circ} 05' 00''$ N Latitude North and $37^{\circ} 45' 00''$ and $35^{\circ} 50' 00''$ E Longitude east with a total area of 83,331 hectares of land (Figure 3.1.)

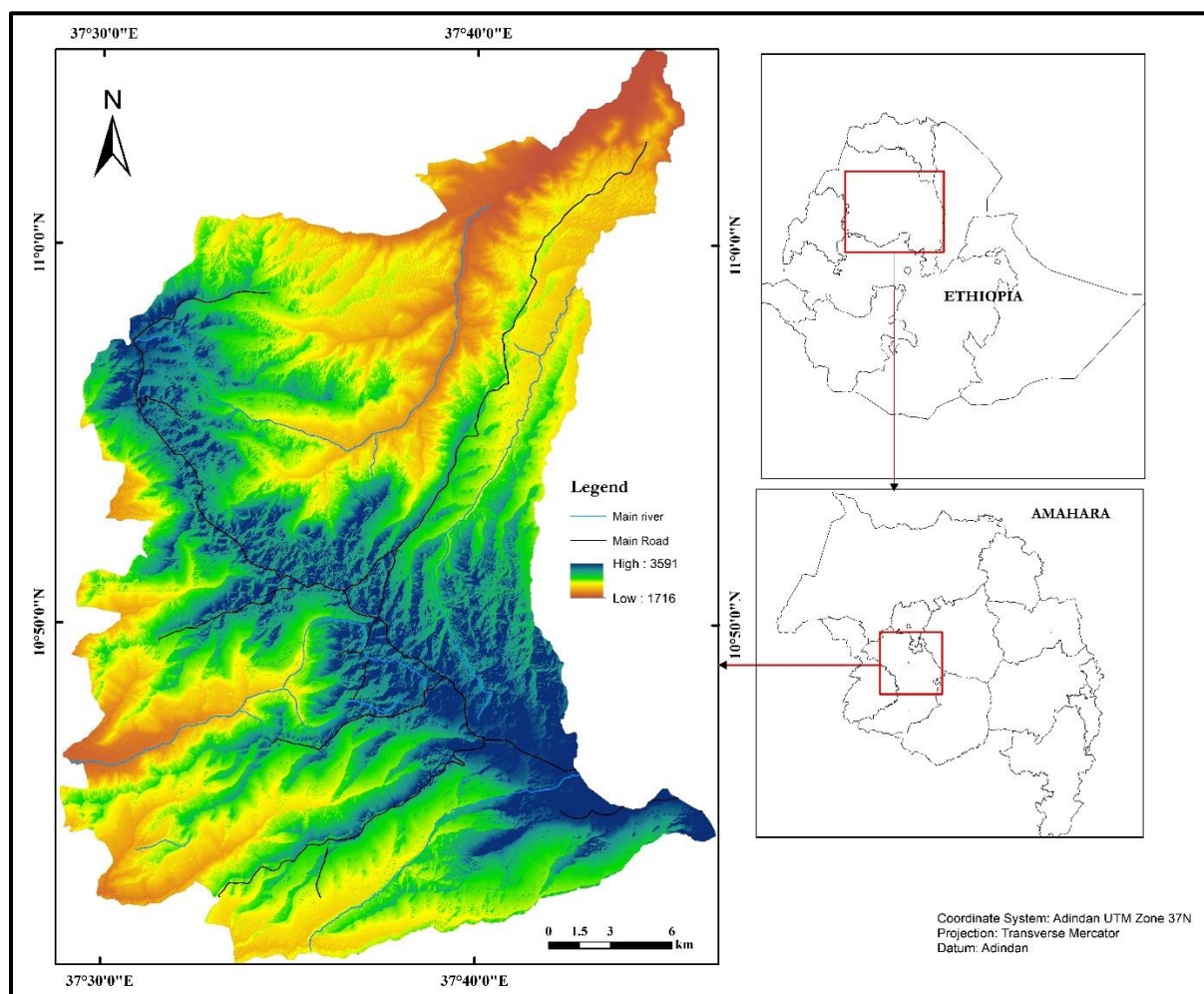


Figure 3. 1: Location map of the study area

3.1.2 Physiographic Background

3.1.2.1. Topography

Topography is the study of the shape and feature of the surface of the earth and other observable phenomenon or it is an integral part of the land surface. It contains mountains, hills, creeks, and other bumps and lumps on a specific hunk of the land.

The study area is characterized by rugged topography which contains, mountains plateau and rugged topography. While north and southern tip of the District has a broad flat area in between the western and eastern escarpment. The topography varies from low land (1716 m) in the northern part of the district which lays between the western, eastern, and central highlands and undulating rugged topography. Besides that, the central and some parts of northern and southern starts of the escarpments in the study area is range from above 2000 m to the highest being 3591 meters above sea level (Figure3.2A). This big elevation difference related to topographic variation within a short distance contributes a lot for micro-climate anomalies and plays an enormous role in controlling factors on the surface and sub-surface hydrological conditions and have a significant contribution to land degradation. This abrupt elevation difference brought variation in weather conditions in the high lands and the lowland areas.

Table 3. 1. Slope class of the study area

Slope Gradient (%)	Area (ha)	Area (%)
0 - 2	971	0.7
2 -5	2651	3.2
5- 10	8629	10.4
10 - 15	11136	13.4
15-25	29240	35.2
25-35	16215	19.5
>35	14489	17.5
Total	83331	100

Source: Computed from DEM (30 m)

The topography of the study area is mountainous, undulating plains, hills, and gullies that consist of flat to very steep slopes (Figure 3.2, B). As indicated in table 3.1 the largest part of the study area (35.4%) ranges from 15 – 25 %, which is strongly sloping whereas the smallest portion of the area (0.7%) ranges from 0-2%, falls in a flat plain. The largest proportion of the study area around 80% is characterized by steep and very steep slopes.

Steep slope areas are highly susceptible to land degradation especially soil erosion and most parts of the study area is characterized by steep slope area and most likely vulnerable to land degradation.

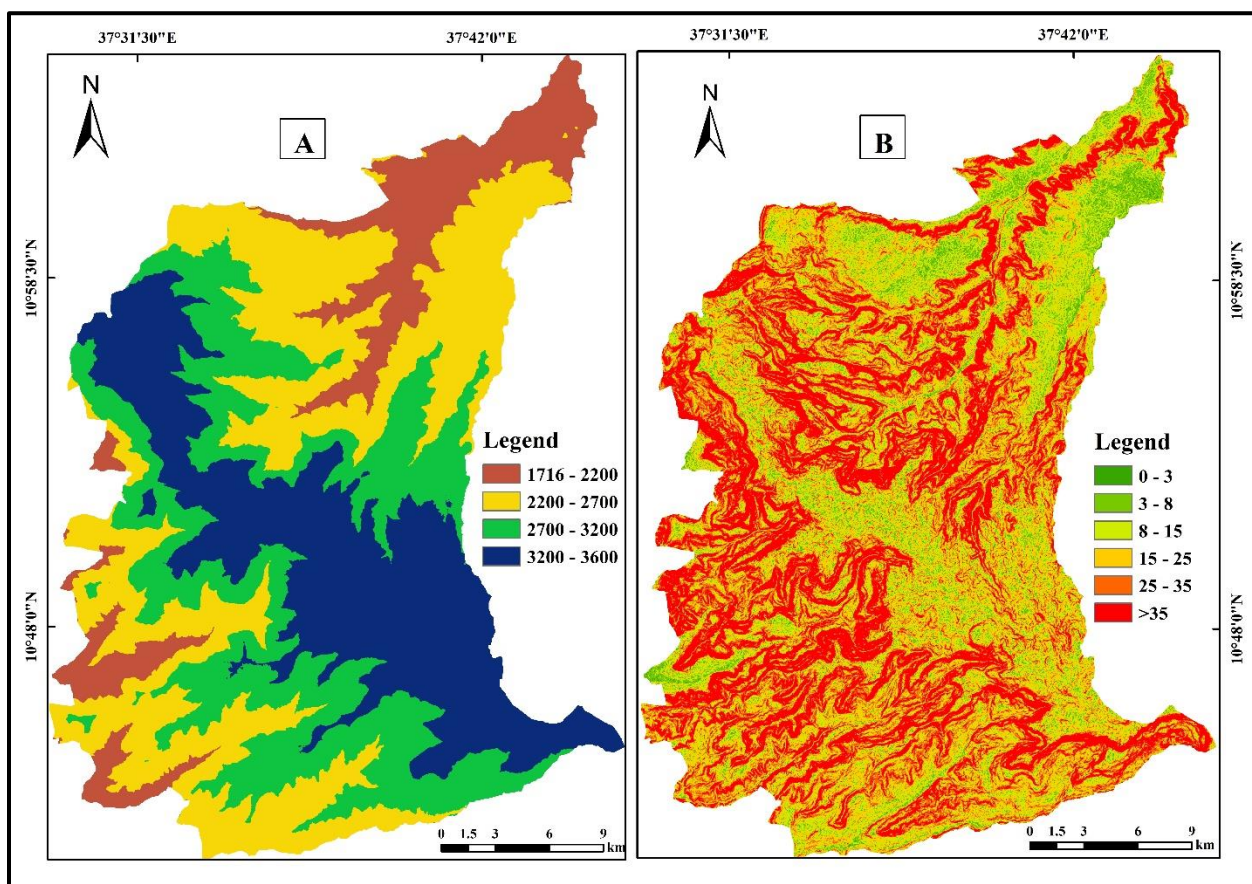


Figure 3. 2. Elevation map (A) and Slope map (B) of the study area

3.1.2.2. Soil

Soil is a mixture of organic matter, minerals, gasses, liquids, and organisms that together support life. Soil formation is a factor of climate, parent rock material, the nature of the landform, soil

organisms, and time. Soil comprises horizons near the Earth's surface that, contrary to the underlying parent material, have been altered by the interactions of climate, relief, and living organisms over time. Soil distribution and characteristics vary by their parent materials, climate, vegetation, and interaction among these factors and time. According to the data obtained from the Water and land resource center of Ethiopia, the study area generally constitutes six major types of soils (Figure 3.3). Among them, Luvisols which is characterized by low nutrient retention highly weathered with a subsurface accumulation of clay highly vulnerable to erosion hazards facilitates soil degradation (<https://www.britannica.com/place/Ethiopia/Soils>) is the dominant types of soils that account for half of the study area which is about 42264 ha (50.9%) of the total area of the landscape. The second major soil types in the study are Nitisols 19722 ha (23.7%), followed by Leptosols, Acrisols, Vertisols, and Lixisols which covers about, 17489 ha (21.1%), 2398 ha (2.9%), 1222 ha (1.5%) and 22 ha (0.1%) of the total area of the landmass respectively (Table 3.2). Soil is one of the parameters that affect the rate of soil degradation and thus contribute to land degradation. Soil texture, water holding capacity, and gravel content are major soil components that can determine the level of land degradation.

Table 3. 2. Major soil Types of the study Area

No	Soil Type	Area (ha)	Area (%)
1	Acrisols	2398	2.9
2	Leptosols	17489	21.1
3	Lixisols	22	0.1
4	Luvisols	42264	50.9
5	Nitisols	19722	23.7
6	Vertisols	1222	1.5
Total		831.16	100

Source: Water and land resource center, Addis Ababa

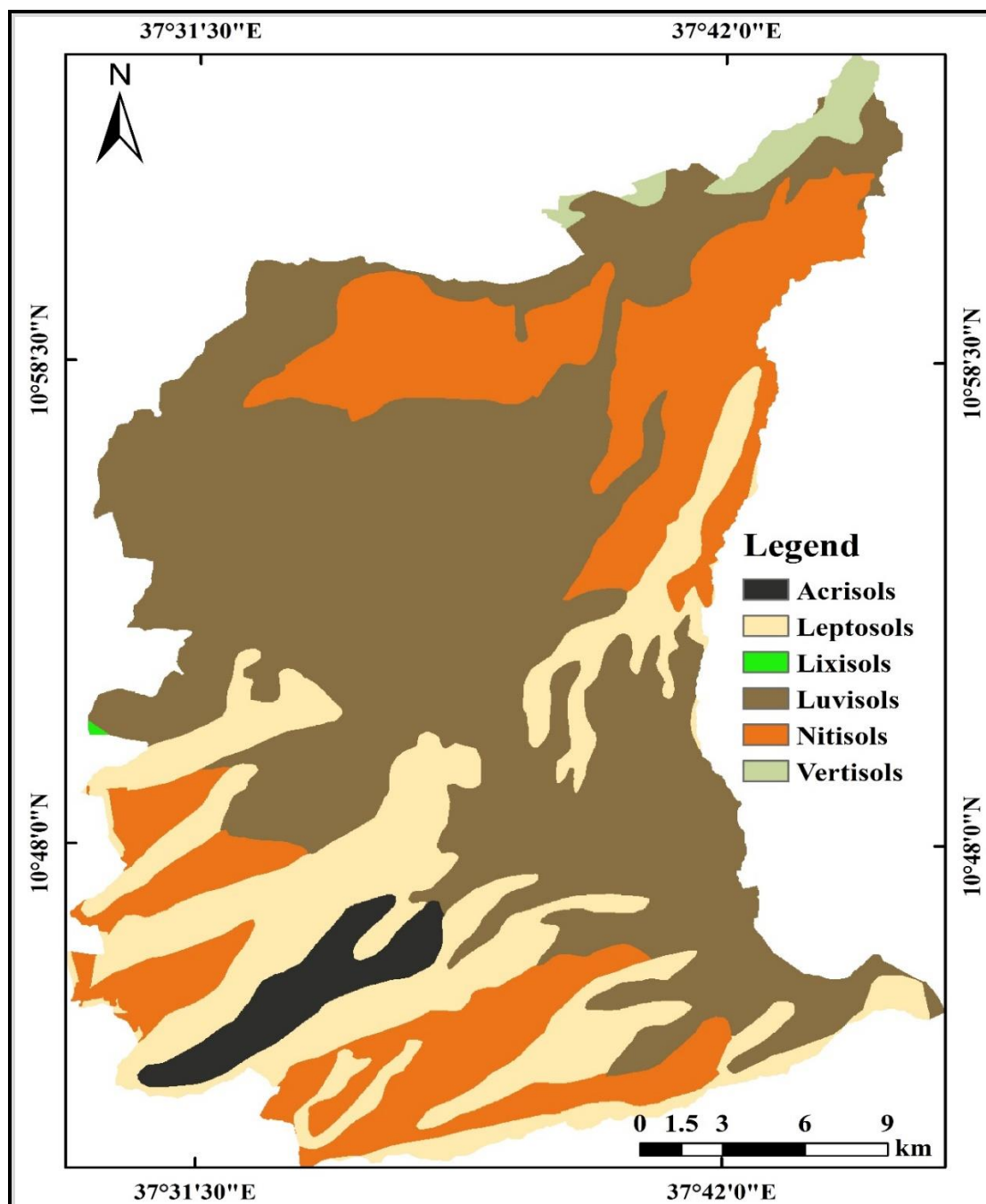


Figure 3. 3. Soil Map of the Study Area (Source: Water and land Resource Center)

3.1.3. Climate and Agro-ecological zones

3.1.3.1. Agro-ecology

According to the study conducted by the Ministry of Agriculture (1998), The diversity in topographic features represents varied elevations and slopes with the lowest point at Danakil

depression at about 126m below sea level and the highest on the top of Ras Dashen in the Semien mountain which is about 4,620m a.s.l. Mainly based on the relation between elevation and temperature, the traditional agro-ecological zones are classified from Berha to Wurch which ranges from 500 m to over 3700 m a.s.l. in altitude and from below 500 mm to over 1400 mm annual rainfall.

These presently identified, described, and defined Agro-ecological Zones (AEZ) reveal the qualities, potential, and restraint of the agricultural resources to help plan studies at different levels for specific purposes coped with the zones. Moreover, give various indications for delineating areas requiring resource conservation programs for the agricultural lands, forest areas, degraded lands, and natural vegetation and wildlife areas (MOA, 1998). These have a major influence on what crops farmers grow, how they keep their livestock, how they manage their land. In particular, the study area is characterized by altitude ranges from 1716m to 3590 m above sea level.

Table 3. 3. Traditional agro-ecological zone of the study area

No	Agro-ecology	Area(ha) ¹	Area (%)
1	Weyena Dega	50371	60.7
2	Dega	32482	39.2
3	Upper Dega	83	0.1
Total		8333.00	100.00

As indicated in (Table 3.3). The study area is dominantly demarcated by Weyna Dega traditional Agro- ecological zone that accounts for 50371ha and covers 60.7% whereas; Dega is the second AEZ that covers 32482 ha with 39.2%. The remaining is the smallest unit with 83 ha that covers of 0.1% the area. Woyena dega comprises the northern and southern most parts of the study area, Dega covers the central parts and Dega agro-ecological zone covers very small parts of Dega Damot district (Figure3.4).

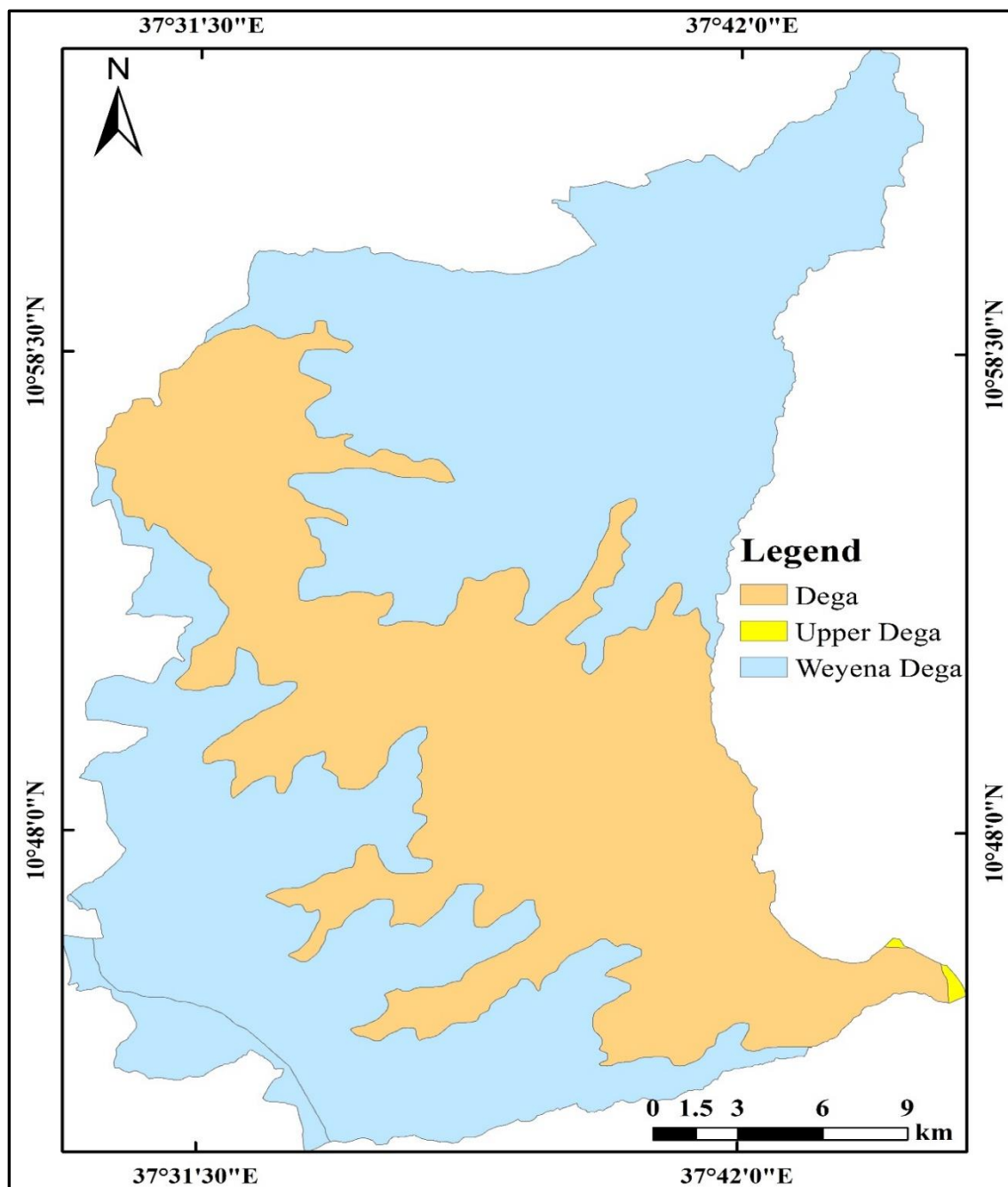


Figure 3. 4. Agro-ecological zones of the study area (MOA, 2014)

3.1.3.2. Climate

Rainfall and temperature are the two most important climatic factors that play a vital role in the development and distribution of plant life, but the variability and extreme determine areas at risk of land degradation and potential vulnerability for desertification (Sivakumar and Stefanski,2007). Based on the National metrological agency of Ethiopia, 30 years of recorded data (1990-2020) from 8 within and near weather stations indicate that the study area is characterized by receiving high annual rainfall ranging from 800 mm to 1800 mm (Figure3.5). Moreover, the study area gets 8°C and 27°C minimum and maximum average temperature per month. The summer season of June, July, August, and September received a small amount of rain thus becomes dry months. Whereas, the winter season months October, November, and December dry. Concerning temperature, the warmest months are April, June, and July while December, January, and February are cooler months. The mean monthly maximum and minimum temperature of the study area for thirty years is given in detail in (Figure 3.6) and (Figure3.7).

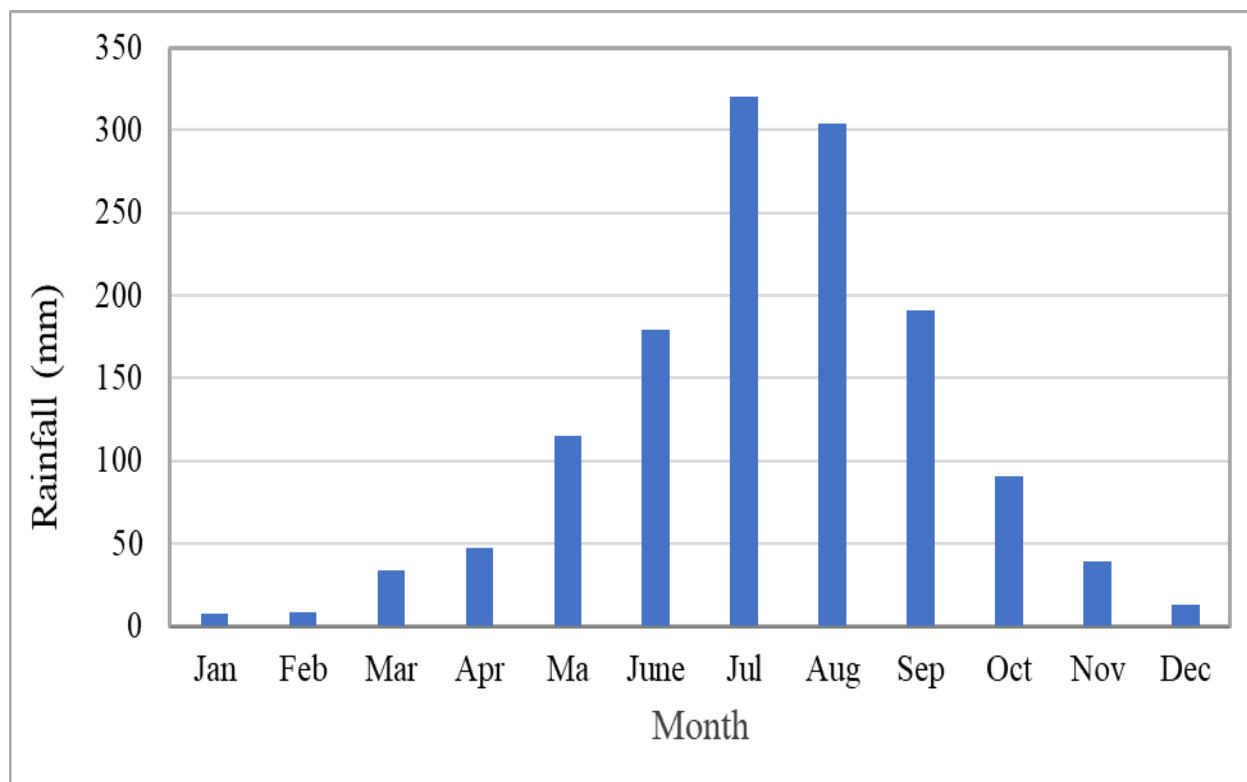


Figure 3. 5. Monthly average Rainfall (1990 – 2020) of the study area

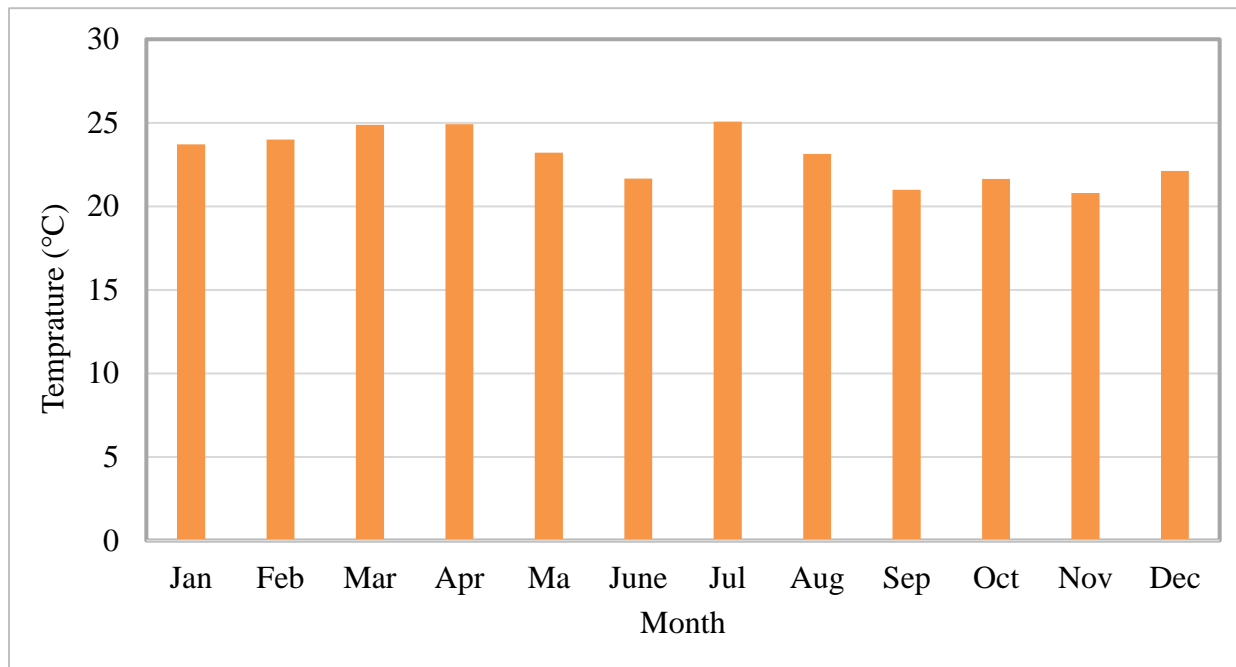


Figure 3. 6. Mean maximum temperature (1990 – 2020)

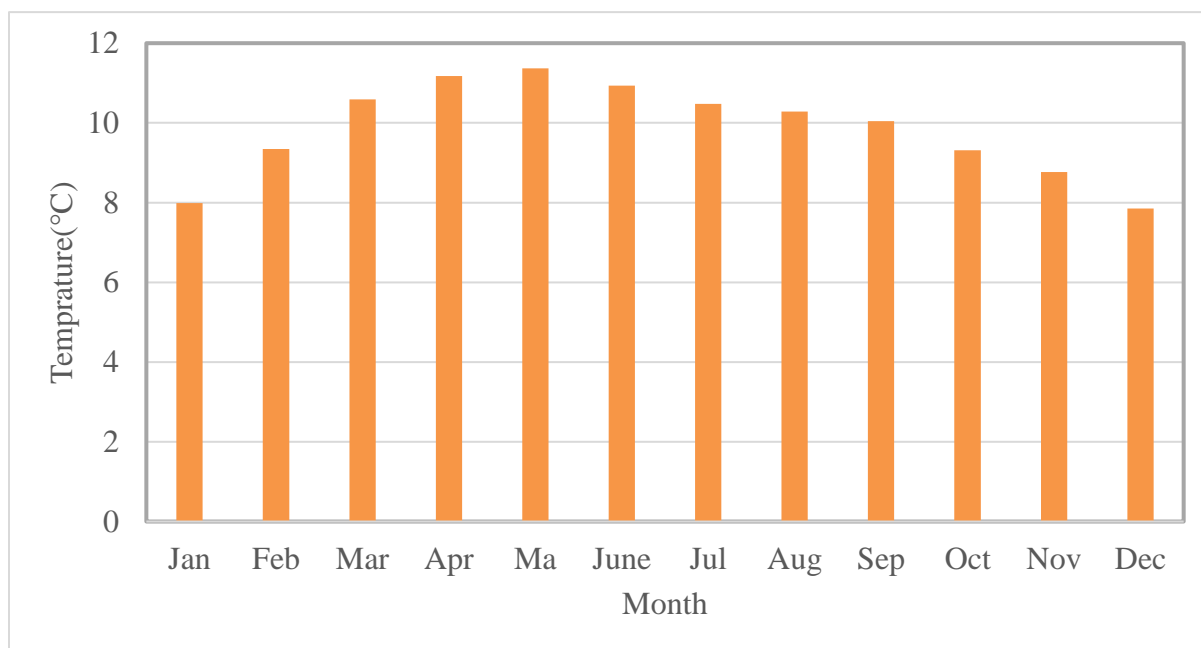


Figure 3. 7. Mean minimum temperature (1990 – 2020)

3.1.3.2. Drainage system

According to Dega Damot District Agricultural and Rural Development Office, five major streams along with their tributaries drain across the study area. The biggest streams, which flow throughout the year, are locally named “Gumara”, “Mutadin”, “Bere”, “Fendika” and “Gimbera”. All of these rivers start from different directions of the area of the western high land and flow towards relatively flat areas of the east. “Gumara and Gimbera” rivers have a large volume of water and drains to lower Gumara, which connects to finally Abay River. Recently small parts of this river are used for irrigation purposes.

3.1.3.3. Natural Vegetation

Ethiopia has eight major vegetation types classified mainly by elevation and climate namely Afro-alpine and sub-afro-alpine vegetation, Dry evergreen Afromontane Forest and grassland complex, Moist-evergreen Afromontane Forest vegetation, Acacia-Commiphora woodland vegetation, Combretum-Terminalia woodland vegetation, Lowland semi-evergreen forest vegetation, Desert and semi-desert scrubland vegetation, and Aquatic vegetation (Friis *et al.*, 2010). According to the elevation and climate, the study area vegetation includes Afroalpine, sub-afro-alpine, dry evergreen montane, and grassland complex types (Assefa *et al.*, 2020). The main vegetation types of forests are found in monasteries and churches and protected areas of the district. From this remnant vegetation the common types of trees are “Tid” (*Juniperus procera*), “Woirra” (*Olea Europaea* subspecies *cuspidate*), and bamboo (*Bambusoideae*) Girar (*Acacia*), “Kitkitas” (*Dodonia viscosa*), “Shembeko” (*arundodonx*), Agam (*Carissa edulis*), “Kulkual” (*Euphorbia candelabrum*) and “Eret” (*Erica arborea*).

Moreover, the eucalyptus tree is the dominant tree species in the study area used for various purposes and found in every residential area.

3.1.4. Population and settlement

According to the national census conducted by the Central statistical agency (2007), the study area has a total population of 151,121 of whom 74,383 are males and 76,738 females. From the total population, 144,428, or 95.5% are rural dwellers. The remaining 6,693 or 4.5% of the population resides in urban areas.

Moreover, according to CSA (2017), projection the total population is about 179,966 lived in different agro-ecological zones of the study area of whom 88,361 are males and 91,605 female population. The study area has a population density of 183.27, which is greater than the Zone average of 158 persons per square kilometer. 33,336 households were counted resulting in an average of 5 persons to a household, and 32,497 housing units. The majority of the inhabitants practiced Ethiopian Orthodox Christianity, with 99.92% reporting that as their religion. The district is structured by 31 rural and 3 urban kebele administrative of which the capita Fereabet is the most densely populated.

3.2. Research design

The research employed a mixed approach that integrated both qualitative and quantitative data. The qualitative approach was used to analyze non-spatial data that comes from qualitative data sources and a quantitative approach was used to quantify spatial data.

3.2.1. Data description

To achieve the desired objective both Primary and secondary and secondary data were collected from different sources. The primary geospatial data were information extracted from Landsat satellite time series sensors of 1990, 2005, and 2020 imageries at a different season of acquisition. Which is freely available at United States geological survey (USGSearthexplorer.usgs.gov), used mainly for Land-use and land-cover processing (Table3.4).

Table 3. 4. Description of satellite images used for this study

Landsat type	Path and row	Resolution	Acquisition date
Landsat TM	169/052 and 169/053	30 m	01 Jan1990
Landsat ETM+	169/052 and 169/053	30 m	03 Feb 2005
Landsat OLI	169/052	30 m	03 Feb 2020

**The images were downloaded at the same season of January, February and March when the cloud cover condition is minimized.*

Apart from this, the secondary data obtained from different organizations published and unpublished books magazines, and reports. The general description of the data and their possible sources used for this study are provided in (Table 3.5).

Table 3. 5. Data types and sources

No.	Types of Data	Resolution	Data Source
1.	Landsat 5 TM, Landsat 7 ETM, Landsat 8 (OLI)	30x30m	USGS, Earth explorer
2.	DEM	30m	USGS, Earth explorer
3.	Rainfall and temperature		Ethiopian meteorological agency, CHRS
4.	Population data		CSA
5.	GPS		Field data
6.	Soil		Water and land resource center, Addis Ababa

3.2.2. Software used

Data management, manipulation, analysis, and interpretation of spatial and none spatial data used to manage by using different software The software packages used for this study were ArcGIS 10.5 for data analysis, storage visualization and map preparation, ENVI 5.3 for classification and post-classification of satellite images, IDRISI SELVA 17.0 for multi-criteria decision support and Microsoft office is also used for documentation statistical analysis and presentation.

3.3. Methods

The method starts from collecting all the necessary data, organizing preprocessing and classification of the data to produce the composite land degradation map of the study area.

3.3.1. Land-use and land-cover

Satellite image preprocessing

To produce land-use and land-cover for 1990, 2005, and 2020, six bands from the visible to short wave infrared from Landsat 5 TM, Landsat 7ETM+, and Landsat OLI were used. After downloading and extracting the Landsat image (Level 1), preprocessing activities have taken

place. These include layer stacking/merging, atmospheric correction, gap filling (Landsat 7), image mosaic (Appendix 4) and to improve the quality and interpretability of the image so that the image become applicable and ready for further analysis. Remotely sensed data often comprises types of distortions due to less-than-optimal atmospheric conditions, rotation of the Earth, satellite or aircraft motion, the curvature of the Earth, and the exact location of a given point within an image, hence It needs to be reduced before image processing (Khorram, *et al.*,2013). To obtain the required quality Land-use and land-cover data from Landsat, image processing is mandatory. These include atmospheric correction, stacking, mosaicking which helps to improve the quality and interpretability of images for further processing and extract crucial information. Image Enhancement was applied on row images of Landsat 5, 7, and 8 to restore geometric and radiometric distortion. Top of Atmosphere (TOA) reflectance was calculated by using the following procedures and equations given in U.S. Geological Survey (2019).

Spectral radiance of Landsat 5 TM image was calculated using Equation

$$L\lambda = \left(\frac{Q_{calmax\lambda} - L_{MAX}L_{MIN}\lambda}{(Q_{cal} - Q_{calmin})} \right) - (Q_{cal} - Q_{calmin}) \dots\dots\dots (3.1)$$

Where: $L\lambda$ = Spectral radiance at the sensor's aperture [W/ (m² sr μ m)]

Q_{cal} = Quantized calibrated pixel value [DN]

Q_{calmin} = Minimum quantized calibrated pixel value corresponding to $L_{MIN}\lambda_{final}$ [DN]

Q_{calmax} = Maximum quantized calibrated pixel value corresponding to $L_{MAX}\lambda$ [DN]

$L_{MIN}\lambda$ = Spectral at-sensor radiance that is scaled to Q_{calmin} [W/ (m² sr μ m)]

$L_{MAX}\lambda$ = Spectral at-sensor radiance that is scaled to Q_{calmax} [W/ (m² sr μ m)]

For Landsat 8 (OIL), the digital numbers (DN) of the images converted to the Top of Atmosphere reflectance using the formula given in U.S. Geological Survey (2019)

$$\rho\lambda = \left(\frac{M_p * Q_{cal} + A_p}{\sin(\theta)} \right) \dots\dots\dots (3.2)$$

Where: $\rho\lambda$ = Top of Atmosphere Planetary Reflectance

Mp = Reflectance multiplicative scaling factor for the band.

Ap = Reflectance additive scaling factor for the band.

Qcal = Level 1-pixel value in DN, θ = Solar Elevation Angle

Image classification

Image classification is the process used to produce thematic maps from imagery. The themes can range from general categories to specific classes (Robert, 2007). In this study, classes are identified from processed images and applied to supervised classification, which often requires human skills and understanding of distinct features. It is a pixel-based classification system based upon the spectral signature of features.. Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed, and calculates the probability that a given pixel belongs to a specific class (Bosoon Park, 2008).The number of training sites varied from one LULC class to another depending on the case of identification and the level of variability. The Maximum Likelihood Classification is the most widely used per-pixel method by taking into account spectral information of land cover classes (Cheruto, et al., 2015). The selected Training samples from each land class type were employed and finally generate seven types of land-use and land-cover types namely: waterbody, forest, grassland, settlement, bare-land, shrub-land, and cropland (Table3.6).

Table 3. 6. Land-use and land-cover types

LULC Class	Description
Waterbody	Includes ponds,streams and major and minor rivers
Forest	Natural and plantation forests and trees
Grassland	Includes grazing lands grasses and wetlands
Settlement	Contains town residential areas
Bareland	Open space lands which has no activities and sand areas
Shrub-land	Bushes scrubs and sparsely distributed trees
Cropland	Main agricultural activities and rural settlement areas

Source: USGS (2019).

Change Detection

Change detection is used to determine which land-use class is changing to the other. The most commonly used land change detection methods consist of an image overlay, classification comparisons of land cover statistics, change vector analysis, principal component analysis and image differencing (Dires and Temesgen,2020). It is important for overall LULC change calculation while performing “from” to operation applications, subsequently identifying where the major conversion of land-use and land-cover is noticed. The detection is operated in two or more different periods of images classified. After classifying the study period into three time intervals; 1990 – 2005, 2005 – 2020, and 1990 – 2020, the percentage change of each interval was calculated using the equation applied by (Kiros and Desalegn, 2019).

$$\text{Percentage of LULC change} = \frac{\text{Final year area LULC} - \text{Initial year area LULC}}{\text{Initial year area LULC}} \text{-----} (3.3)$$

The positive value shows an increase in the area while the negative value indicated that there was a decrease meant for an area of LULC.

Accuracy Assessment

Accuracy assessment is the final step in the analysis of remote sensing data that helps us to verify how accurate our results are. It was carried out once the interpretation/classification has been completed. Here, the study used in assessing the accuracy of thematic maps or classified images, which is known as thematic, or classification accuracy (Mohan and Anand, 2012). It was conducted to obtain better data from sample points (ground control points) using the Global positioning system (GPS) and comparing this data with the map classification to improve the uncertainty. The advantage of accuracy assessment using GCP for improving the uncertainty of classification is accentuation (Samson, *et al.*, 2020). One of the commonly used accuracy assessment methods is the Classification error matrix, also known as a confusion matrix, which encouraged the assessment of the accuracy of the output of image classification. This confusion matrix is the difference between the collected reference data and the results of the classification (Semahbizu, 2020). The reference data collected from the field and assisted by Google earth was mapped application regarding classified data to measure the accuracy of the result (Appendix3).

Using the following formula suggested by (Amit, 2018) the accuracy assessment of each category has been computed.

$$\text{User accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of classified pixels in that category row total}} \times 100$$

$$\text{Producer Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of classified pixels in that category column total}} \times 100$$

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixels diagonal}}{\text{Total number of reference pixels}} \times 100$$

$$\text{Kappa Coefficient (T)} = \frac{(\text{Total Sample} \times \text{Total Corrected Sample}) - \sum(\text{Column total} \times \text{Row total})}{\text{Total Sample}^2 - \sum(\text{Column} - \text{total Row total})}$$

3.3.2. Vegetation degradation hotspot mapping

The land-use and land-cover hotspot mapping was quantified after the LULC transition change has been done. By Taking 1990 and 2020 images and performing an image differencing. Subsequently, areas distinguished dominantly by high conversion, for example, conversion of forest to cropland, grassland to cropland are classified as high change hot spot areas. Moderately changed areas are dominantly characterized by modification than conversion example shrub land to grassland (<https://pheethiopia.org/pdf/6.%20Hotspots%20of%20Environmental%20Degradation%20in%20the%20BER.pdf>). The rest with no change or slightly changed areas are areas where change is not detected or minor changes are observed. According to the result gained the hotspot areas are reclassified into high, moderate and no change or slightly changed areas based on change intensity. The overall vegetation degradation hotspot mapping process is given in (Figure 3.8).

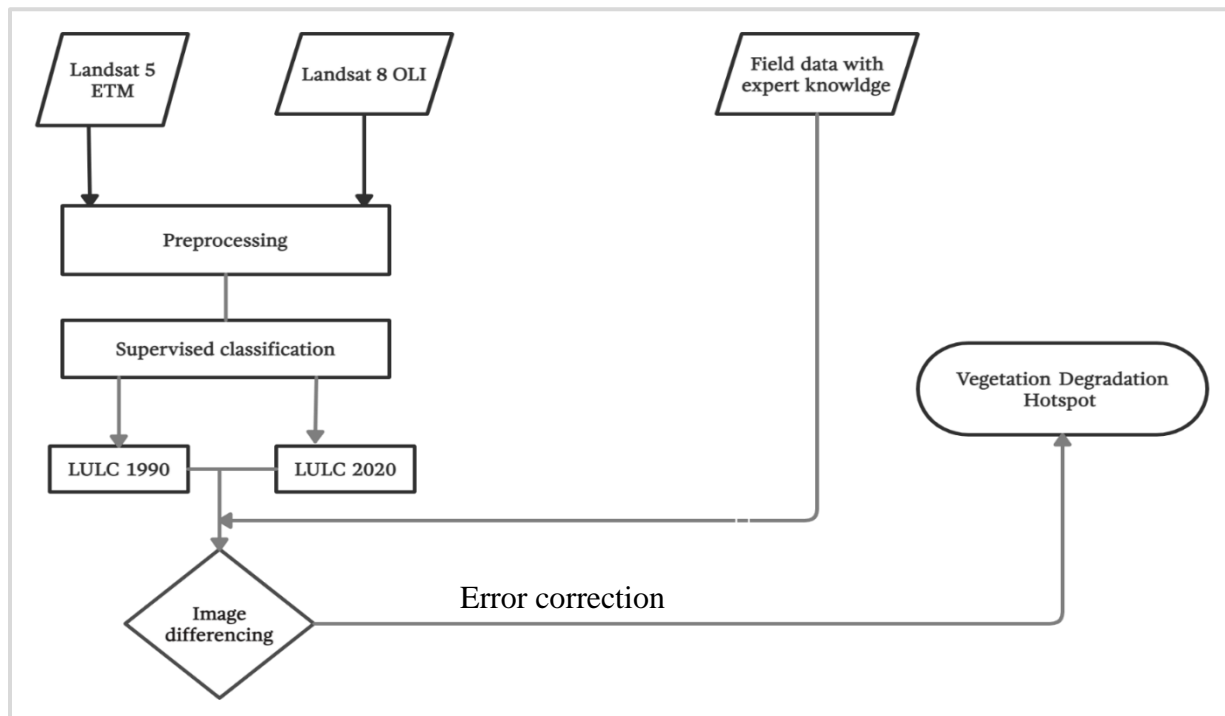


Figure 3. 8. Vegetation degradation hotspot flowchart

3.3.3. Soil erosion Modeling

3.3.3.1. Estimation of sheet and rill erosion risk using RUSLE

The RUSLE model has been widely used for the prediction of average annual soil losses caused by sheet and rill erosion and to display the spatial distribution of potential erosion risk (Andrew and Brigitta, 2020). The model is good to estimate in areas where different geographical and topography variability. It was adapted and most of the variables modified calibrated by Hurni (1985) in the Ethiopian highland condition. Therefore, it was applied for this study by considering its merit of simplicity, compatibility, applicability in limited data conditions, and its adoption in Ethiopian highland conditions annual soil erosion risk mapping induced by sheet and rill erosion.

RUSLE model is used to quantify by integrating parameters of cover management factor (C), Rainfall erosivity (R), Soil erodibility (K), slope steepness and length factor (LS) and Conservation (P) factor in Dega Damot District. All the five parameters are combined by using the equation provided below.

$$A = R * K * LS * P * C \text{ ----- (3.4)}$$

Where, A is the computed spatial average soil loss rate (t ha⁻¹yr⁻¹), R is the rainfall-runoff erosivity factor (MJ.mm.ha⁻¹yr⁻¹), K is the soil erodibility factor (Mgh MJ⁻¹mm⁻¹), L is the slope length factor (dimensionless), S is the slope steepness factor (dimensionless), C is the cover management factor (dimensionless), and P is the conservation support practice factor.

3.3.3.2. Processing of RUSLE parameters

Rainfall Erosivity (R) factor

The rainfall erosivity factor (R) describes the erosivity of rainfall in an area based on the rainfall amount and intensity and reflects the effect of rainfall intensity on soil erosion. It quantifies the effect of raindrop impact and explains the amount and rate of runoff associated with rainfall (Koirala, *et al.*, 2019). Rainfall was one of the dynamic layers used for model input. It has a direct relationship with average annual rainfall values. Therefore, Rainfall erosivity (R) was calculated by the equation given by Hurni (1985) calibrated for Ethiopian conditions based on the available mean annual rainfall data

$$R = (0.562 \times P) - 8.12 \text{ ----- (3.5)}$$

Where; P is the mean annual rainfall of the study area, in this study the mean annual rainfall for 30 years from (1990-2020) was employed from CHRS gauging stations

Soil erodibility (K) Factor

The soil erodibility factor (K) reflects the characteristics of the soil. Soil erodibility is a measure of the susceptibility of the soil particles to detachment and transport by rainfall and runoff (Habtamu *et al.*, 2020). It also reflects the resistance of the soil to both detachment and transport, the unit based on the amount of soil occurring per unit of erosivity and under specified conditions (Desale, 2021). This factor is quantitatively determined for a specific area soil type and shows the physical and chemical properties of the soil, which contribute to its erodibility potential and for soil loss estimation as well. For the analysis of the K factor, the soil map that collected from Water and land resource center and then estimated the value by using a formula (3.6) adapted from Williams (1995, as cited by Yonas, 2020).

Topographic (LS) factor

The slope factor is a combination of slope length and slope steepness. The length and steepness of a slope affect the total sediment yield from the area and is accounted by the LS-factor in RUSLE model (Habtamu *et al.*, 2020). It was derived from the 30m high-resolution Digital Elevation Model (DEM) with multiple flow algorithms that can divide flow between several output cells (Ahadu, 2020). To calculate LS factor for the study area, the formula (equation 3.6) recommended by (Moore and Burch, 1986) was used. Flow accumulation was an input for LS calculation, which is generated in the ArcGIS environment. The modified equation for computing the topographic factor (LS factor) was also adopted by different studies (Tadesse, 2014; Ajanaw *et al.*, 2021).

$$LS = \text{pow}[(\text{Flow Accumulation}) * \text{cell size} / 22.13]^{0.4} * \text{pow}[\sin(\text{slope} * 0.01745 / 0.0896)]^{1.3} - (3.6)$$

Where; LS is slope steepness length factor,

Cell size is the resolution of DEM 30m of the study area,

Flow accumulation: represents the accumulated upslope area for a given cell,

Slope: the steepness of the study area in degree

Cover management (C) factor

The cover and management (C) factor reflect the effect of LULC, cropping, and management practices on the rate of soil erosion, and it is the ratio of soil loss from land covered by vegetation to the corresponding loss from continuous fallow (Ajanaw, *et al.*, 2021). According to different studies the values of LULC were assigned where the C-factor value ranges between 0 implies very strong cover effects and 1 indicates no cover present and the surface treated as barren land. In this study LULC for three periods from covers of the three periods of 1990, 2003, and 2020 coupled with C values compiled from different sources (Table3.7).

Table 3. 7 The LULC along with their C value

LULC Type	Value	Source
Cropland	0.24	Birehanu et al., 2020
Forest (Dense)	0.01	Hurni,1985
Grassland	0.05	Tiruneh & ayalew 2015
Shrubland	0.2	Tiruneh & ayalew 2015
Bare land	0.6	Alelgn et al.,2021
Waterbody	0	Erdogan et al., 2006
Settlement	0.15	Hurni 1985

Support practice (P) factor

Support practice factor indicates the rate of soil loss according to the various land-use and land-cover types on the surface of the earth. There are considerable practices strip cropping, contour, and terracing that can implement to control soil erosion. The conservation practices factor (p-values) reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion, which depends on the type of conservation measures implemented, and requires mapping of conserved areas for it to be quantified (Hanna, 2014). P-value ranges from 0 to 1, whereby the value 1 indicates there is poor or no soil erosion conservation practice implemented and the value 0 shows very good manmade soil erosion resistance.

Studies conducted by (Tessema *et al.*, 2020), determine the P factor by different land-use and land-cover classification types. In this study area there are no significant and well-adjusted permanent soil and water conservation practices, however, there are some practices of terracing implemented annually by the community mobilization program, thus it is a seasonal and marching ways. Therefore, to estimate support practice (P) values of the area the classified LULC along with slope gradient (Shin, 1999; as cited by Balabathin *et al.*, 2020) determine the value from contouring, strip cropping, and terracing; considering the practice of terracing in the study area the estimation of P-value has been adopted (Table 3.8).

Table 3. 8. P factor value on different LULC types

LULC	Slope gradient	P values
	0-5	0.1
	5-10	0.12
Cropland	10-20	0.14
	20-30	0.19
	30-50	0.25
	>50	0.33
Other lands	All	1

The detail process of sheet and rill erosion risk by RUSLE is given detail in (Figure3.9).

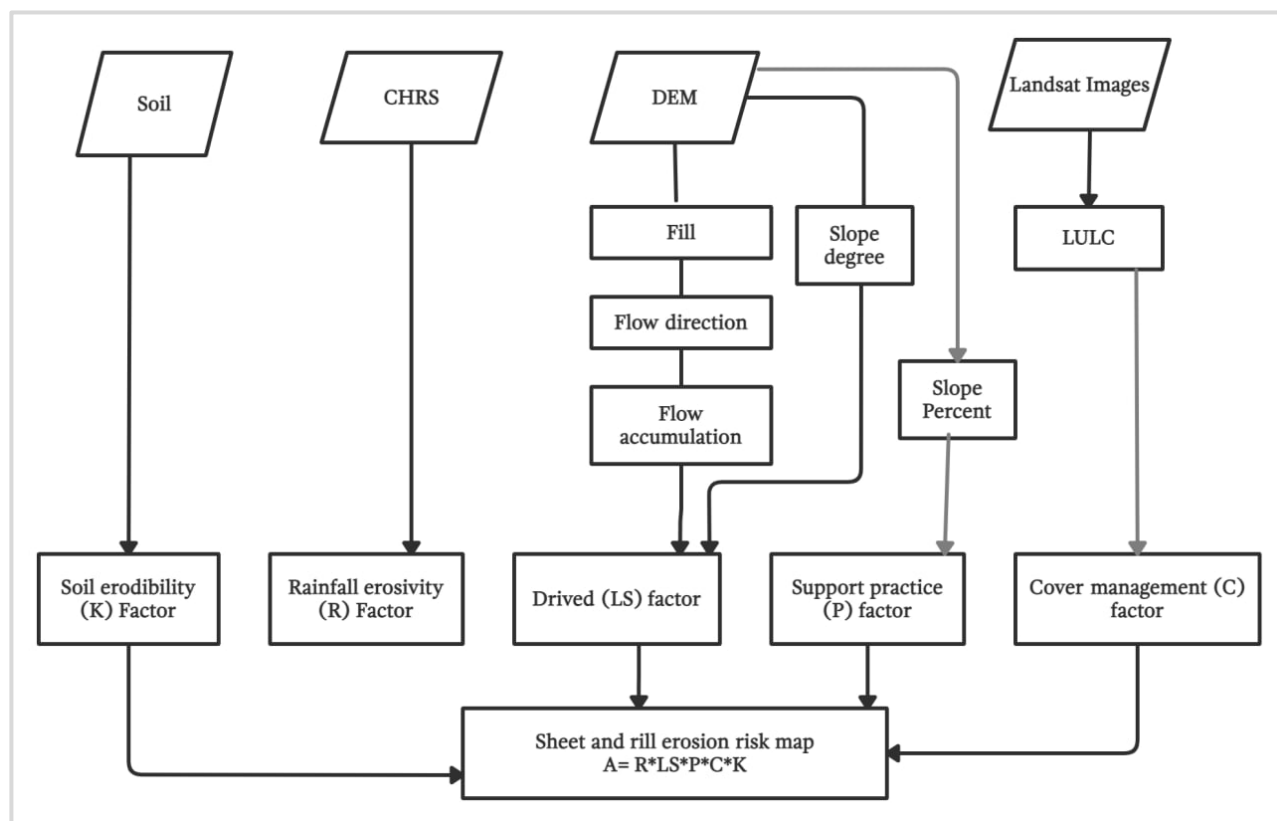


Figure 3. 9. Flow chart for estimating sheet and rill erosion

3.3.4. Gully erosion assessment

For assessing the gully erosion spatial patterns of gullies in the study area, the method proposed by Thorne et al., (1986) and Moore *et al.*, (1988) was used. Upslope contributing area or flow accumulation (As) and local slope (β) were generated from the DEM of the study area. Using As and β as in input, stream power index and wetness index were then determined (Appendix 3) in ArcGIS 10.5 Spatial Analyst raster.

Stream Power Index (SPI): The product of District area and slope indicates a possible source of erosion by concentrated flow detachment risk and used to identify suitable locations for soil conservation measures to reduce concentrated surface runoff.

$$\text{Stream power index (SPI)} = \ln (As/\tan\beta) \text{ ----- (3.7)}$$

Where; is As local upslope contributing area from flow accumulation raster and $\tan\beta$ is local slope angle (degree).

Topographic wetness index map (TWI)

The effect of topography on soil erosion is multifarious because the local slope gradient influences flow velocity and the rate of soil erosion. Erosion would normally be expected to raise with slope steepness and slope length increments because of respective increases in velocity and volume of surface runoff (Kefale, 2020). Topographic Wetness Index was used to define the effect of topography based on the saturated excess runoff mechanism. It characterizes the spatial distribution of surface saturation and surface runoff that were very important parameters for soil erosion analysis. Topographic wetness index and soil moisture increases as contributing area increases and slope gradient decreases; this implies that TWI has a high correlation with saturation. The wetness of the catchment or topographic wetness index was Topographic wetness index (TWI) = $\ln (As/\tan\beta)$ ----- (3.8)

Where; is As local upslope contributing area from flow accumulation raster and $\tan\beta$ is local slope angle (degree) predicted based on flow accumulation and slope of the particular pixel of the study area. Finally, accuracy assessment was calculated from 32 Ground truth points of which 12 collected by GPS and the remaining 22 points was from google earth pro.

3.3.5. Biodiversity degradation hotspot Mapping

To estimate biodiversity several factors identified as land use management classes, species richness, patch size, shape and level of fragmentation but also vulnerability to biodiversity degradation afro-alpine and sub-afro-alpine ecosystem was forwarded (Demissie, 2020). To assess biodiversity degradation hotspots different driving factors or parameter thematic layers were prepared. In this study proximity to the road, Land-use and land-cover, slope, and settlement were identified (Table3.9).

Table 3. 9.Parameters used for biodiversity degradation hotspot mapping

Parameter	Range	Reference
Road	0-5,5-10,10-15,15-25 and >25 km	Demissie, 2020
Settlement	0-1,1-2, 2-4,4-7 and >7km	Amare and Semegn, 2021
Slope	0-5,5-10,10-15,15-25 and >25 km	Kiros and Desalegn ,2019
LULC		Geparaju <i>et al.</i> (2017);Amare and Simgn (2021)

3.4. Producing composite land degradation

3.4.1. Spatial Multi-Criteria Analysis (MCA)

Quantifying comprehensive land degradation is not an easy task, since it comprises multiple factors that can be challenging to combine into a single output. To solve this challenge, multi-criteria can be applied with a combination of geospatial datasets (Alelgn *et al.*, 2021). To determine the factors were determined using (Satty, 1988) relative importance of constraints (Table3.10). The Multi-Criteria Analysis (MCA) addresses the analysis of a variety of decision alternatives and land-use options that aids the identification of the most suitable management solution for a given purpose and the effects of alternative options (Belal *et al.*, 2015). Moreover, The MCA process includes several steps: describe objectives, select the criteria to measure the objectives, identify alternatives, renovate the criterion scales into commensurable units, assign weights to the criteria that reveal their relative importance, choose and apply a mathematical algorithm for ranking alternatives, choose an alternative, and combine criteria into a single index (Alelgn *et al.*, 2021).

To model complex problems, in the MCA literature, there is a wide range of decision-making techniques. This study employed the AHP method with integrated geospatial models which is a powerful approach to identify the hotspot areas for land degradation. This study applied MCA in integration with an AHP that allows pairwise comparison and applies weights to each factor when merging to a single composite output (Alelgn *et al.*, 2021). For determining, the final output three major stages levels were processed. In the first level, vegetation degradation hotspot maps were prepared from LULC data inputs based on standard values. In the second stage, soil erosion risk level maps derived from RUSLE model and gully map were prepared. In the third stage from proximity to the road, settlement, LULC and slope yielded vegetation biodiversity degradation status has been produced. Finally, all the three major inputs were processed using the weighted overlay technique to combine the criteria maps. Each standardized criterion was multiplied by its weight in the overlay process (Selshi, 2016) and produced single composite land degradation map.

Table 3. 10. The scale of the relative importance of constraints.

Degree of Importance	Definition	Explanation
1	Equal importance	Two values contributing equally to the objectives
3	Weak importance of one over another	One variable has slightly more importance
5	Strong importance	Strongly favorable over the other
7	Demonstrated importance	Dominance importance
9	Absolute importance	The highest possible overtake over the other variables
2,4,6,8	Intermediate values between adjacent judgments	When compromise is needed
1/3,1/5,1/7,1/9	Values for inverse comparison	

Source: (Satty, 1988 cited by Munye, 2020)

3.4.1.1. AHP approach

The criteria were weighted through the pairwise comparison of individual parameters which derived from raster data (maps) following AHP approach. In this case, the two criteria were compared, the less important criterion gets a reciprocal value of the most important. And used the principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix to provide the relative importance of the criteria being compared. The elements of the normalized eigenvector were weighted with respect to the criteria or sub-criteria and rated with respect to the alternatives (Alelgn *et al.*, 2021). The evaluation of consistency of the matrix of order was done. When the consistency index failed to reach a threshold level, the comparisons were re-evaluated. Lastly, the weighted overlay technique was used to combine/aggregate the criteria maps, and each standardized criterion was multiplied by its weight in the overlay process.

3.4.1.2. Consistency check

The consistency of subjective judgment of each variable for producing one single output can be checked by estimating consistency ratio, which is the comparison between consistency index and random consistency index. After converting the comparison matrices pairwise matrices, the consistency of each matrix is checked by the method in crisp AHP. For this, first, multiplying together the entries in each row of the matrix and then taking the n th root of that product. The n th are summed and that sum is used to normalize the Eigen value. The next stage is to calculate, multiply total value of each column to Eigen value. The consistency index for a matrix is calculated from $(\lambda_{max} - n) / (n - 1)$. Some randomly generated consistency index (R.I) values are shown in Table 3.49. Acceptability of alternative or attribute is measured terms of Consistency Ratio (CR). The consistency check is

$$CR = CI/R \dots\dots\dots (3.9)$$

Where, CI is the consistency index and RI is the random consistency index. After calculation, the consistency ratio of each comparison matrix is found to be under 0.10. Thus, it concluded that the consistency of pairwise judgments in all matrices is acceptable. The overall research process flow chart is given detail in (Figure3.10).

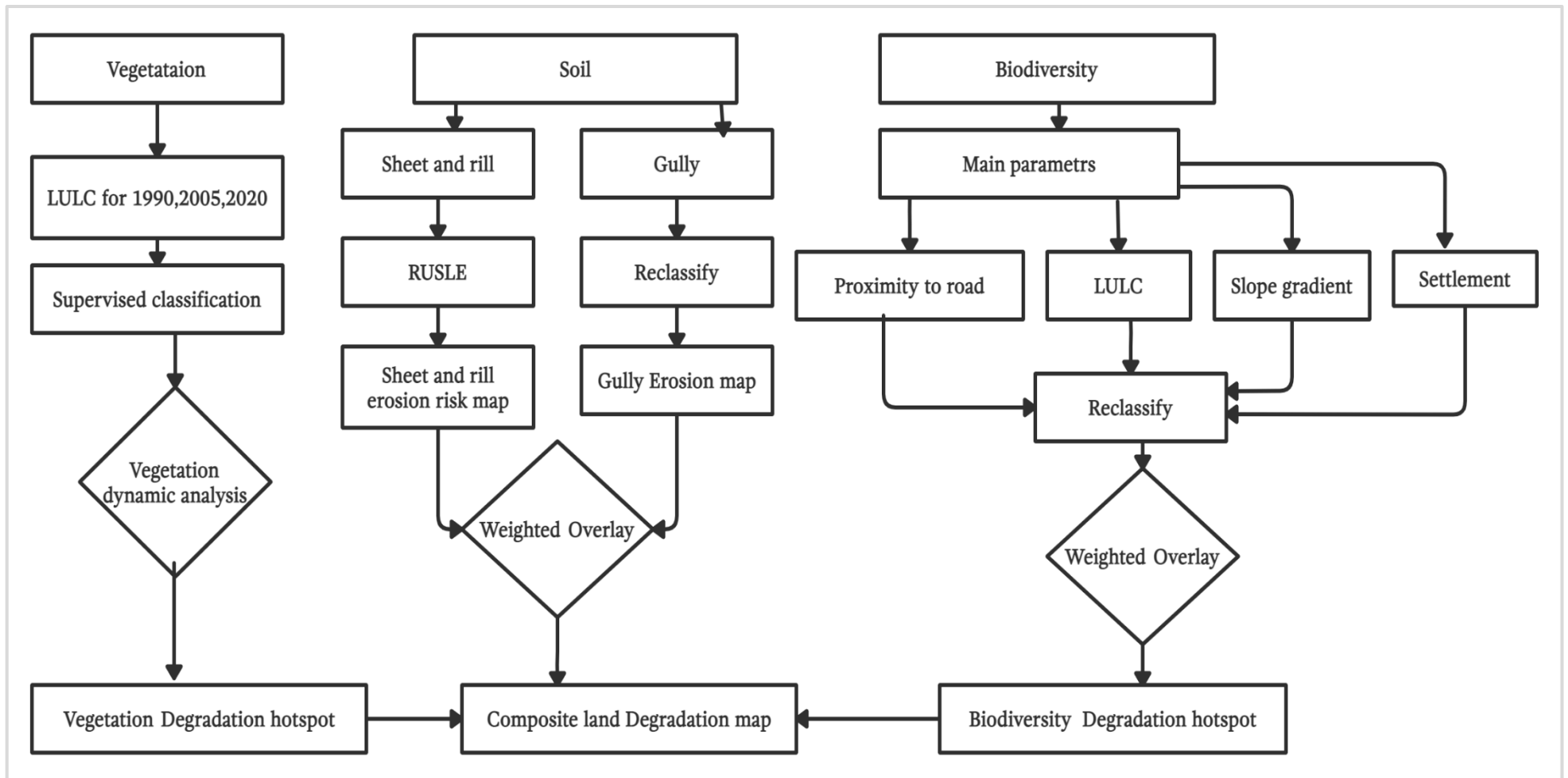


Figure 3. 10. Methodological flow chart

CHAPTER FOUR

4. Results

4.1. Land-use/Land-cover mapping and change analysis

Land-use/Land-cover is used to show the effect of each land use type on land degradation. The land use/cover pattern of the study area was the result of natural and socio-economic factors and their utilization by man in time and space. The LULC of Dega Damot district has been classified into seven land-use classes for assessing the vegetation degradation status of the study area. These land uses are forest, cropland, grassland, shrub land, settlement, water body, and settlement.

Classification of land use and many classes from remote sensing data can be dependent on the purpose, satellite resolution, and nature of the study area. For example, rural settlements have been classified as cropland, because rural hut with a roof of grass and surrounded by cultivation land makes it difficult to discriminate settlement from cropland. So, rural settlements are categorized under croplands. The land cover class of shrub includes both bush and perennial crops. The other land use layer is grassland and which incorporates annual crops and grassland.

4.1.1. Land-use and land-cover maps of 1990, 2005, and 2020 periods

Figure 4.1. Depicts Spatio-temporal pattern of different LULC types of the year 1990. The areal extents of the land-use and land-cover types are presented in table 4.1. The result shows that the study area is dominated by cropland and shrub land. Cropland covers 66.6% of the total area. The second major land-use and land-cover type is shrub land that accounts for 21.8% of the study area. The remaining land-use and land-cover types are grasslands, forest, waterbody, and bare land, a settlement that covers 5.7%, 4.6%, 0.8%, 2.6%, and 0.1% respectively. This figure shows that 80% of the total area of the study area was covered by Cropland and shrub land. In 2005, there was an increase in cropland expansion, and forest cover of the area decline within fifteen years of interval. From the seven LULC classes, cropland covers 60733.6 ha and 72.8%, shrub land 15316.5 ha and 18.4, Grassland 3484.6 and 4.18%, Forest 2800 ha and 3.4%, Bare land 793 ha and 0.9%, Waterbody 357 ha and 0.4% and Settlement accounts the smallest portion in the study area of 14.4 ha and 0.2 %. In this period, there was a considerable increment in settlement expansion especially

in the study area capital Feresbet and adjoining small rural towns. This results in deforestation of major forest areas found in the central and western parts of Dega Damot District.

Table 4. 1.Land-use and Land-cover of three periods

LULC Type	Year					
	1990		2005		2020	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Waterbody	553.2	0.7	357.3	0.4	161.7	0.2
Forest	3811.9	4.6	2800.4	3.3	2655.3	3.2
Grassland	4735.9	5.7	3484.6	4.2	2343.5	2.8
Settlement	5.7	0.1	14.4	0.2	186.8	0.2
Bare land	585.2	0.7	793.7	0.9	288.2	0.4
Shrub land	18184.2	21.8	15316.5	18.4	5921.5	7.1
Cropland	55483.8	66.6	60733.6	72.8	71802.9	86.1
Total	83360	100	83360	100	83360	100

Land use land cover change is one of the common phenomena on the earth and it is none stoppable event due to the interaction of anthropogenic and natural factors. In the study area, a considerable LULC change had happened since 1990. Particularly, in the land-use and land-cover unit of 2020, a magnificent increment in cropland was noticed. On the other hand, vegetation coverage especially in the forest of the study area was a decline from the previous period. The LULC map of 2020 shows that out of the total area of Dega Damot District, Cropland, Shrubland, Forest, Grassland, bare land, settlement and Waterbody accounts about 71802.9ha (86.14 %), 5921.5 ha (7.1 %), 2655.3 ha (3.2%), 2343.4 ha (2.8%), 288.2 ha (0.4%), 186.84 ha (0.2 %) and 161.7 ha (0.2 %) respectively. This figure indicates that forest cover in the study area was critically extracted out due to massive deforestation for the expansion of agricultural land, energy source and construction of houses. Major forest areas were plantations and done by reforestation programs especially Tid (*Juniperus procera*) was the dominant one. Since then, those and other similar plantations became cleared and used for household purposes and turned the area for agricultural activities.

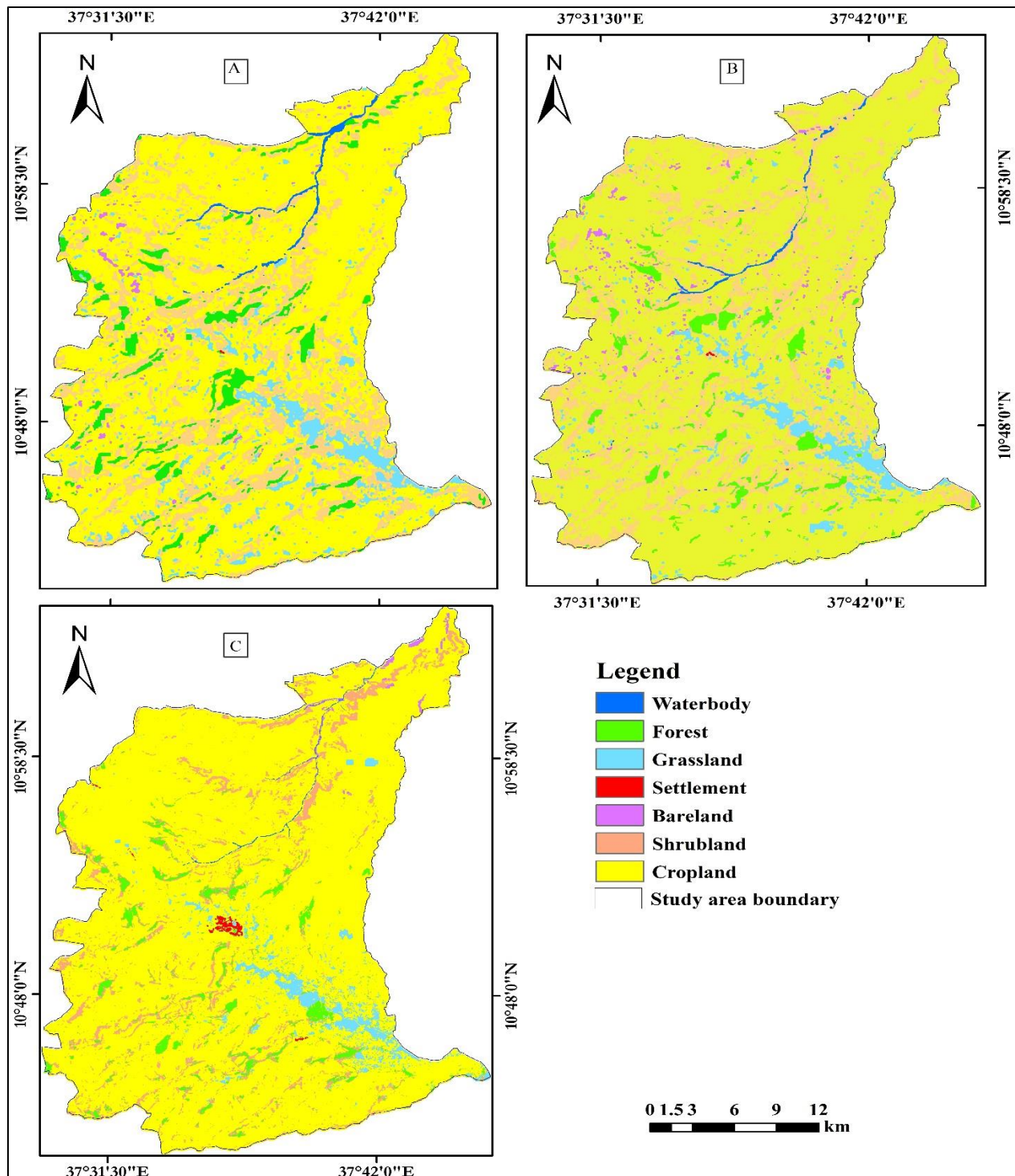


Figure 4. 1. The land-use and land-cover map of 1990 (A), 2005(B) and 2020 (C)

4.1.2. Accuracy Assessment

The process of producing a land use land cover classification from remotely sensed data could take lengthily. After the classification algorithm the accuracy assessment used for this work, and which has recorded the larger set of spectral classes into a reduced set of information classes, it is tempting to publish the resulting land cover map and then move on to other work.

The accuracy assessment result of Land-use and land cover indicated that the years 1990, 2005, and 2020 showed an overall accuracy of 87%, 86%, and 87% respectively. The kappa statics for the year 1990 is 88%, 84% for 2005, and 83% for 2020 (Appendix1). According to (Kiros and Desalegn, 2019) the Kappa statistics of a value greater than 0.80 indicates a strong agreement whereas there exists a substantial agreement between the ground truth and classified LULC types if the value ranges from 0.60 and 0.80.

4.1.3. land-use and land-cover change detection

This study aimed to understand better-taking detail and long-year LULC change. After classification has been done on every three images separately, using the post-classification method change detection was calculated.

Table 4. 2. Net Changes of LULC

No	LULC Type	Period					
		1990 - 2005		2005 - 2020		1990 - 2020	
		Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
1	Waterbody	-196.1	-35.4	-195.3	-54.7	-391.4	-70.7
2	Forest	-1011.8	-26.5	355.1	12.6	-656.6	-17.2
3	Grassland	248.7	5.2	-2641.1	-52.9	-2392.3	-50.5
4	Settlement	8.6	150	172.4	1197.5	181.1	3143.7
5	Bare land	208.5	35.6	-505.5	-63.6	-297	-50.7
6	Shrub land	-2867.7	-15.7	-9395.1	-61.3	-12262.8	-67.4
7	Cropland	5249.8	9.4	11069.1	18.2	16319.1	29.4

In this study 15 year time span, and two phases of change detection have been made one from 1990 to 2005, second from 2005 to 2020 which is moderately enough in showing the long history of land use and land cover. Land cover change status of Dega Damot District from 1990 to 2020 has been discussed in two segmented periods. The first period has 15 years of the gap from 1990 to 2005 and the second period is from 2005 to 2020. The cover dynamics discussed the rate of land cover change from 1990 to 2005 and 2005 to 2020 (Table 4.2). Depicts the land cover change rate for the past 30 years in Dega Damot District.

The dynamics of land use and land cover for three periods have been shown at different rates and trends. From 1990 to 2005 waterbody, shrub land, and forest diminished by 196.1 ha, 2867.7 ha, and 1151.8 ha respectively. On the other hand, the remaining land-use and land-cover units; cropland Grassland Settlement bare land has been increased at an alarming rate of 5249.8 ha, 248.7 ha, 8.64 ha, and 208.5 ha. Starting from the second period 2005-2020, shrub land, forest, grassland waterbody, and bare land were converted to cropland and settlement whereas Forest, settlement, and cropland were expanded over 15 years. The overall land-use and land-cover change in 1990-2020 indicated that settlement and cropland were increased dramatically.

4.1.4. Spatiotemporal Transition of land-use and land-cover

As shown in the LULC transition matrix (Appendix 2.) and (Figure 4.4.) in the last 30 years, shrub land the largest converted (13539.75 ha) and grassland (2849.20 ha) both converted to cropland. The transition matrix reveals that cropland was increased dramatically due to the demand for agricultural land was increased from time to time in the study area. Moreover, forested areas were cleared and converted into agricultural land. The study area is dominated by cropland; thus, the major unconverted land is. On the other hand, 1387.19 ha of forested areas were converted to cropland. In addition, forestland diminished magnificently from the base year to recent a period that was attributed by converted to other lands. Some of the noticed changes in the LULC could have been given an indicator for vegetation degradation that leads to land degradation in the study area. One of the most important changes, which may have a significant impact on land degradation, is the expansion of cultivated land (Table 4.3).

Table 4. 3. Land-use and land-cover transformation over the year three decades

	LULC 2020 (ha)								
	Bare land	Crop land	Forest	Grass land	Settle ment	Shrub land	Waterbody	Total	
LULC 1990 (ha)	Bare land	0.8	559.4	0.7	6.5	3.7	1.8	0.00	572.9
	Cropland	189.9	53374.7	195.9	472.1	104.5	1163.8	55.2	55556.1
	Forest	2.1	1387.2	1225.7	13.8	1.8	1169.9	0.2	3800.8
	Grassland	13.9	2849.2	168.7	1486.4	26.2	145.7	0.0	4690.2
	Settlement	0.1	2.5	0.00	0.00	3.2	0.00	0.0	5.7
	Shrub land	28.7	13539.7	1020.9	304.5	47.4	3170.8	9.2	18121.4
	Waterbody	45.2	343	1.5	0.00	0.00	78.3	90.7	558.7
	Total	280.6	72055.7	2613.6	2283.4	186.9	5730.5	155.3	83305.9

*Bold values in the diagonal matrix are unchanged LULC types

4.1.5. Vegetation degradation hotspot mapping

Based on the LULC change results, the vegetation degradation hotspot of Dega Damot district has been varied from this transition, by taking significant changes the vegetation degradation hotspot map has been classified into four hotspot zones high, medium, low and very low (Figure 4.2). The hotspot area contains 22.5%, 2.4%, 11.6% and 63.5% for high, medium, and low zones respectively (Table 4.4).

Table 4. 4. Areal distribution hotspot of Vegetation Degradation

Vegetation Hotspot Category	Area (ha)	Area (%)
High	18584.9	22.5
Medium	1943.7	2.4
Low	9518.1	11.6
Very low	53278.2	63.5
Total	83324.8	100

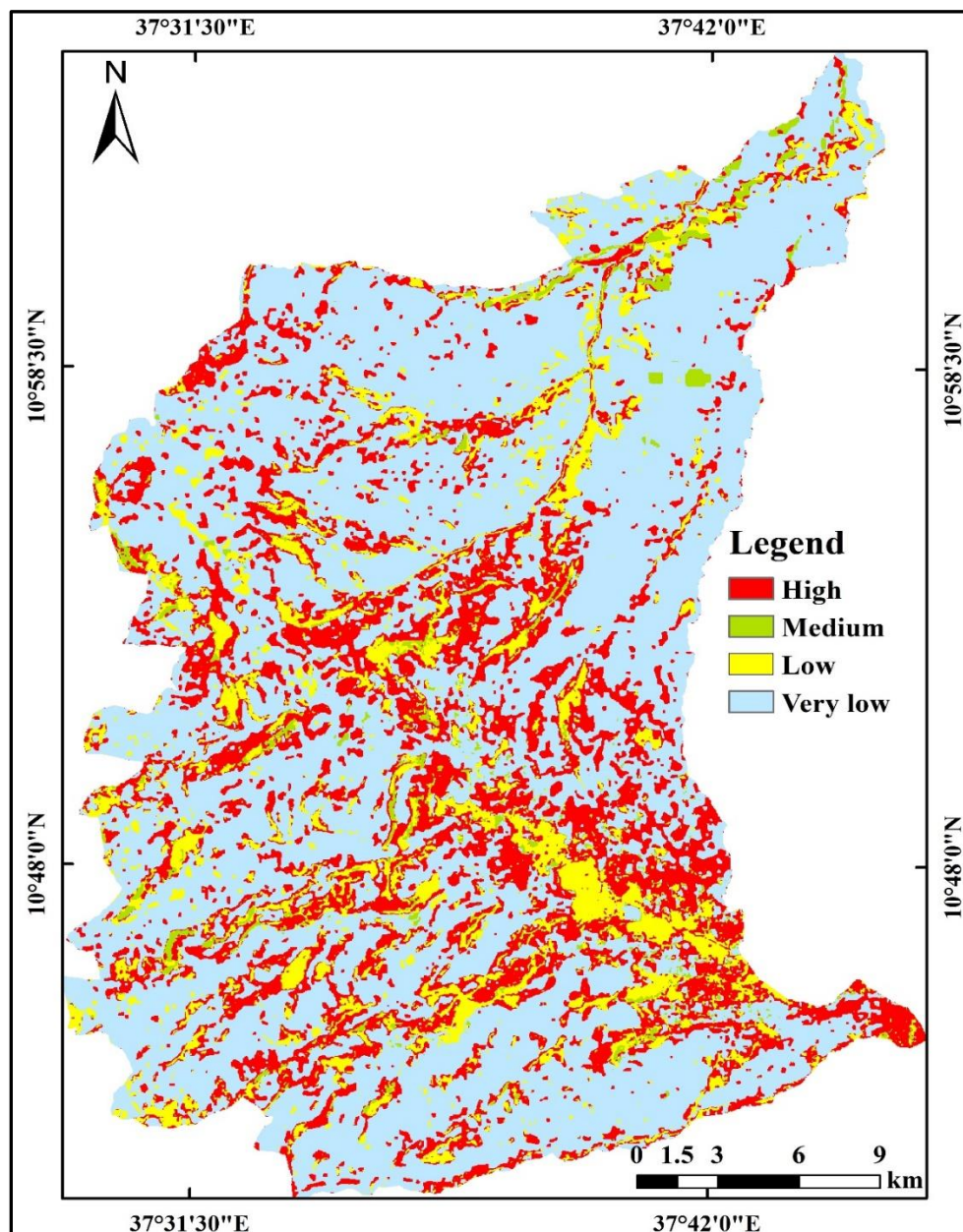


Figure 4. 2. Vegetation Degradation hotspots in the study area

4.2. Soil erosion assessment

4.2.1. Sheet and rill erosion assessment

The present study applied RUSLE to assess soil erosion. Parametrization of the factors used in the model was done before running the model.

4.2.1.1. Rainfall Erosivity (R) factor

Rainfall erosivity factor (R-factor) determines the sheet and rill, erosion processes, by detaching power of a raindrop striking the soil surface and for the incidence of runoff on the soil surface (Alelgn *et al.*,2021). The processed mean annual rainfall from CHRS data and the computed erosivity result map of the study area for each study period-depicted (Figure 4.3). The distribution of the Rainfall erosivity value of 1990 (A) ranges from 590.064 to 832.256 MJ mm ha⁻¹h⁻¹yr⁻¹. The result Indicated that the southwestern; southeastern part of the study area was characterized by high to very high erosivity. Northern and some parts of central high land part of the District were dominantly covered with low erosivity.

This shows that, area with high erosivity have a probability to face high amount of soil erosion and vice versa. Rainfall erosivity of 2005(B) also shows that, central plain, the Southeastern and northeastern high lands of the study area were characterized by high rainfall erosivity. Some parts of Northeastern and northern tips of the study area have low rainfall erosivity. The rainfall erosivity ranges from 597.07 to 821.89 MJ mm ha⁻¹h⁻¹yr⁻¹. In 2020 rainfall, erosivity has been declined compared to the last fifteen years as indicated on the map. Most of the study area northern and central part was under low erosivity and the southeastern part was characterized by high rainfall erosivity.

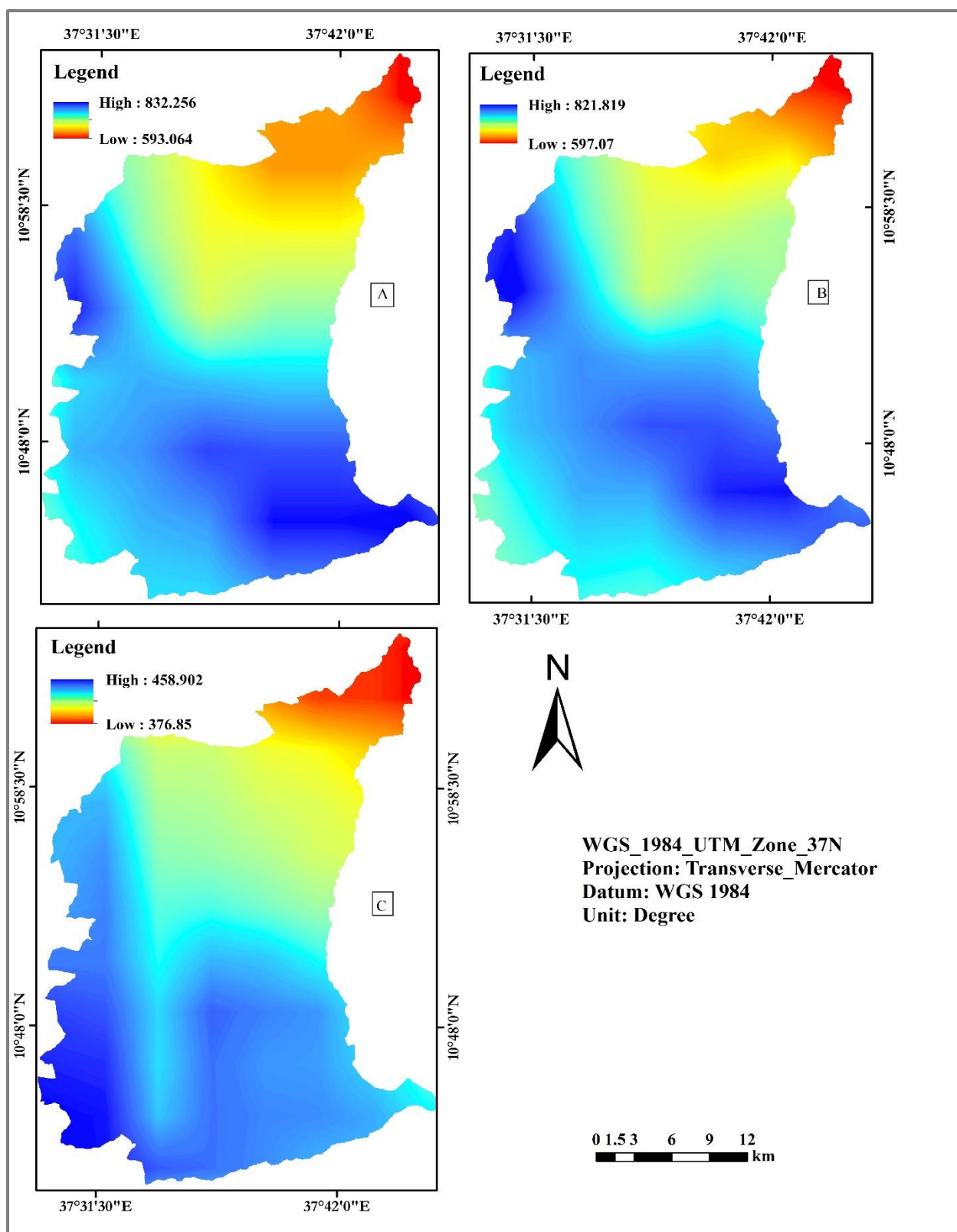


Figure 4. 3. Rainfall erosivity of 1990(A), 2005 (B) and 2020(C) of the study area

4.2.1.2. Soil erodibility (K) Factor

When physico-chemical properties of soil determine detachment and transportation of by the water that have great impact on the erodibility of the soil across an area. The result indicated that the Soil erodibility (K) Factor value of Dega Damot district ranges from 0.1 to 0.25 t ha MJ-1mm-1(Figure4.4). The dominant soil type in the study area is Haplic Luvisols 0.2 to 0.24 t ha MJ-1

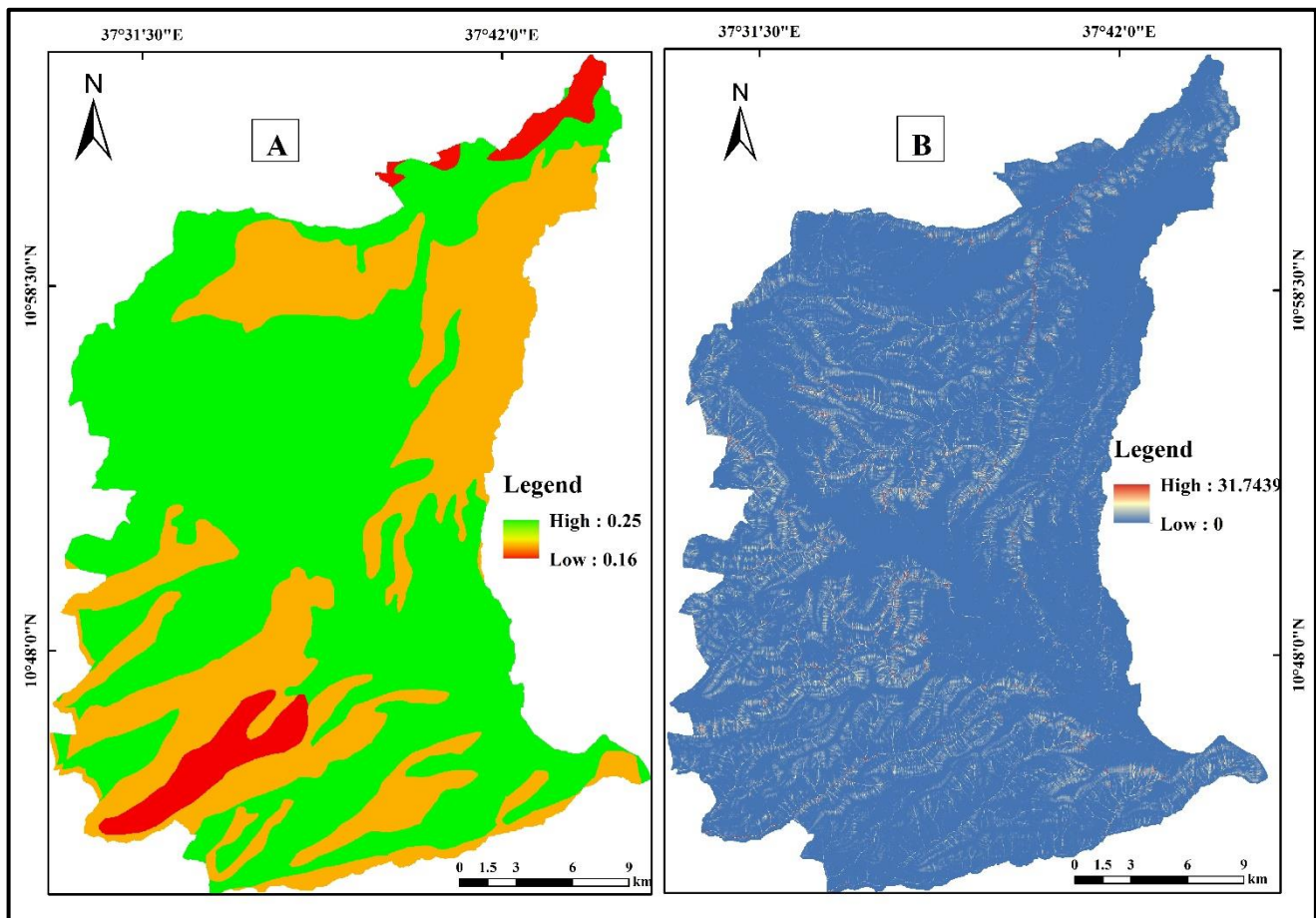


Figure 4. 4. Soil erodibility (k (A) and Topographic (LS) (B) factor of the study area

4.2.1.3. Topographic factor (LS)

The value of the LS-factor determines the relative erodibility of the specific slope length and steepness (Desale Kidane, 2021). The result revealed that the slope length and slope steepness (LS) factor of the study rea ranges from 0 to 31.7439. The increase in the LS factor tends to increase in erosion due to the runoff will be faster and then its energy will increase. As it is shown in figure (4.4B) northern and most parts of

southern parts of Dega Damot district where the topography is steepest and more undulating landscapes, has been denoted with medium to high LS value. This value indicated that these areas are more likely vulnerable to soil erosion. On the other hand, most parts of the study area are characterized by low slope length and steepness (LS) factor.

4.2.1.4. Cover management (C-factor)

As shown in (Figure 4.5) Cover management factor value of the Dega Damot district ranges from 0 to 0.6. The small value in the C factor indicates that the specified area is dominantly covered by vegetation and less susceptible to soil erosion (Sileshi, 2016). This indicates that the higher the value of cover management factor(C) the more vulnerability to soil erosion. Vegetation reduces soil erosion by protecting the soil against the action of falling raindrops, increasing the degree of infiltration of water into the soil, reducing the speed of the surface runoff, binding the soil mechanically, maintaining the roughness of the soil surface, and improving the physical; chemical and biological properties of the soil (Habetamu, *et al.*, 2020).

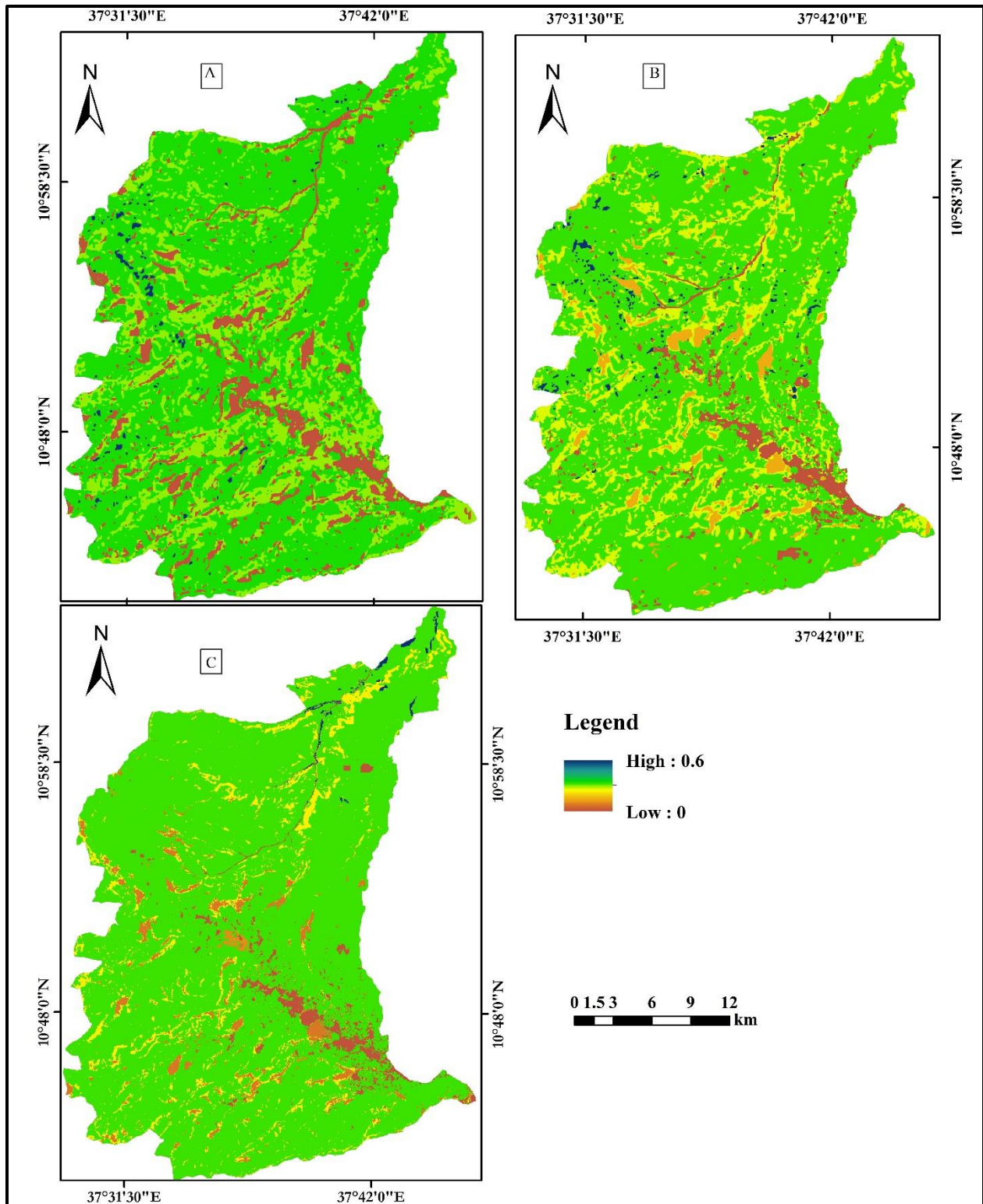


Figure 4. 5. Cover management (C-factor) 1990(A), 2005(B), 2020(C)

4.2.1.5. Conservation support practice (P) factor

The Conservation support practice (P) value of Dega Damot district ranges from 0 in croplands to 1 in other land-use types specifically in forests (Figure 4.6). This is because forests and dense shrublands have a high contribution in reducing the quantity and rate of runoff and the amount of soil erosion (Ajanaw *et al.*, 2021).

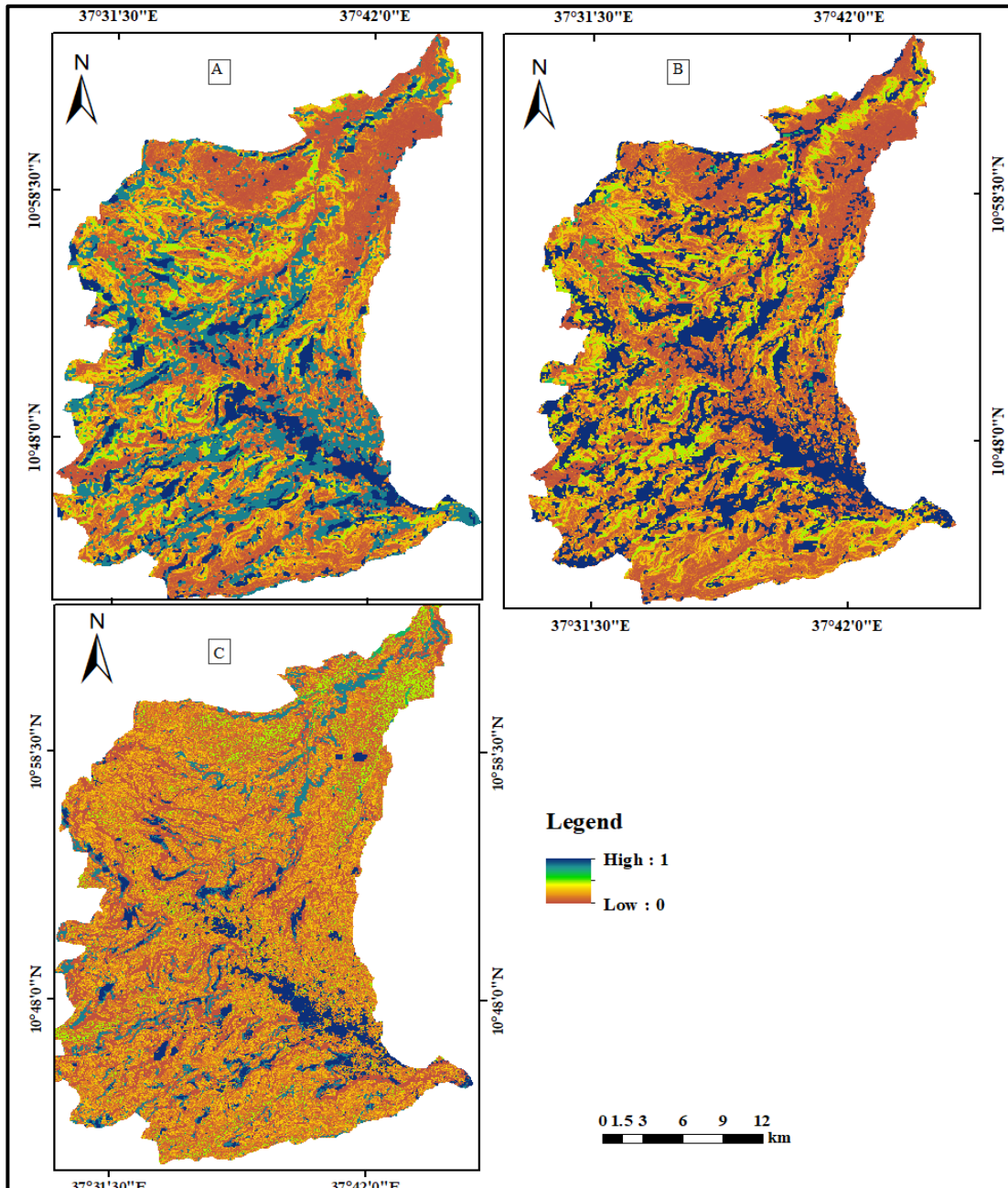


Figure 4. 6. Conservation support practice (P) factor 1990(A), 2005(B), 2020(C)

4.2.1.6. Model result

The RUSLE model indicated that annual soil loss for the study period 1990, 2005 and 2020 has been ranges from 0 to 428; 0 to 586; and 0 to 753 t /ha–1yr–1 respectively (Figure 4.7).

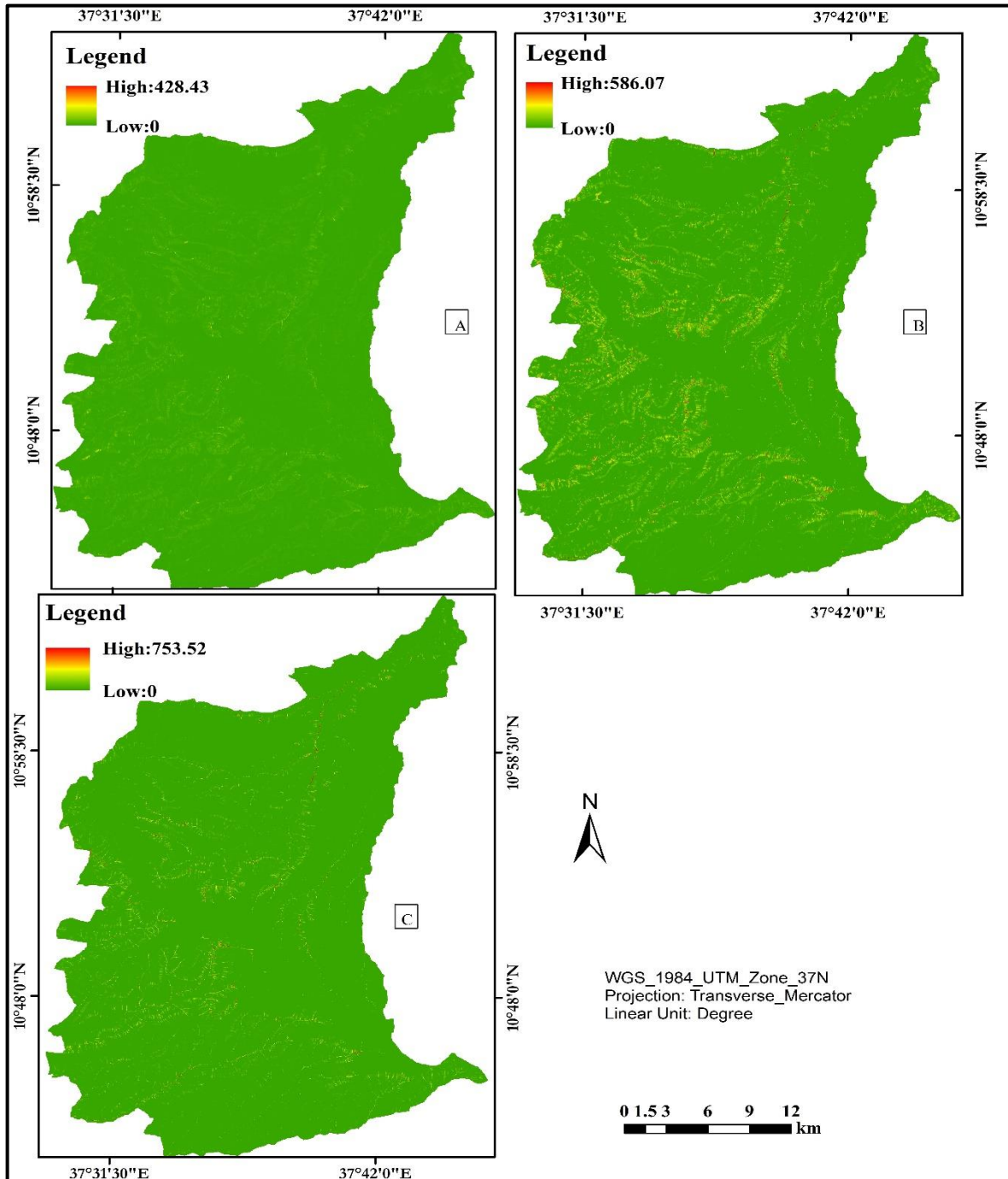


Figure 4. 7. Annual soil loss 1990(A), 2005(B) and 2020(C) for the study area

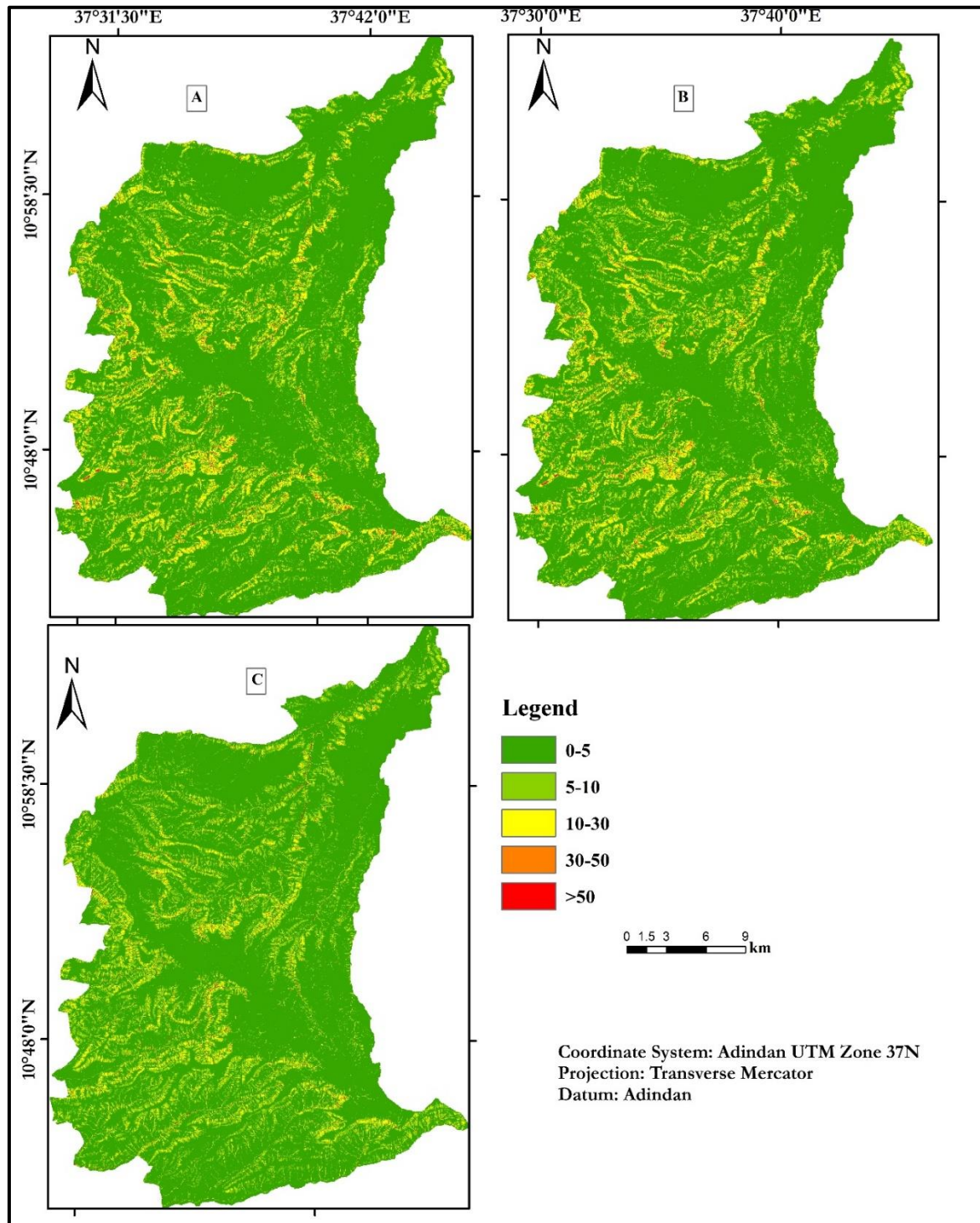


Figure 4. 8. Reclassified annual soil loss 1990 (A), 2005 (B) and 2020 (C) for the study area

As it is depicted in (Figure 4.8) annual soil loss of the study, area ranges from different levels of severity classes slight (0-5) to severe (>50) t/ha/yr.

Table 4.5. Soil erosion risk class of 1990, 2005 and 2020

1990			2005		2020		
Soil loss (t/ha/yr.)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Severity level
0 - 5	63656.4	77.8	60814.2	73.9	51215.4	62.6	Slight
5 - 10	15749.2	19.3	17912.1	21.8	26340.3	32.2	Moderate
10 - 30	1885.4	2.5	2760.9	3.4	3430.9	4.2	High
30 -50	369.1	0.6	571.9	0.7	652.7	0.8	Very high
>50	124.6	0.2	220.2	0.3	218.3	0.4	Severe

The mean rate of soil loss in the study area is 193.89, 247.4 and 589.5 t/ha/yr in the years 1990, 2005 and 2020 respectively. The highest mean rate of soil erosion was observed in the year 2020, which was 589.4t/ha/yr. The result shows the mean rate of soil loss increased magnificently from the beginning 1990) to 2020(Table4.5).

4.2.2. Gully erosion assessment

For the assessment of gully erosion in the study area, mapping and quantifying gully occurrences is crucial. Because, gully erosion contributes significantly effect to soil degradation in different landscapes (Karydas and Panagos, 2020), a comprehensive land degradation assessment shall not escape the gully erosion estimation. There is no direct, clear, and robust gully erosion assessment technique for large areas. However, some literature suggests that the topographic threshold approach is a potential technique to indicate gully erosion. A topographic threshold for gully initiation and location has been explained mainly in terms of soil surface gradient (β) and critical drainage area (A_s) relations (Kiflue, 2010). Based on the method proposed by (Thorne *et al.*, 1986) and (Moore *et al.*, 1988), SPI and WI maps were generated as described in section 3.3.4. To map potential spatial patterns of gullies occurrence in the study area, SPI and TWI above threshold values were estimated and crossed with “AND” Boolean operation in ArcGIS 10.5 raster calculator using the expression: “SPI > 12 AND WI > 6.8”. The resulted map shows areas with values 0 and 1 indicating areas with non-gully and with gully erosion respectively.

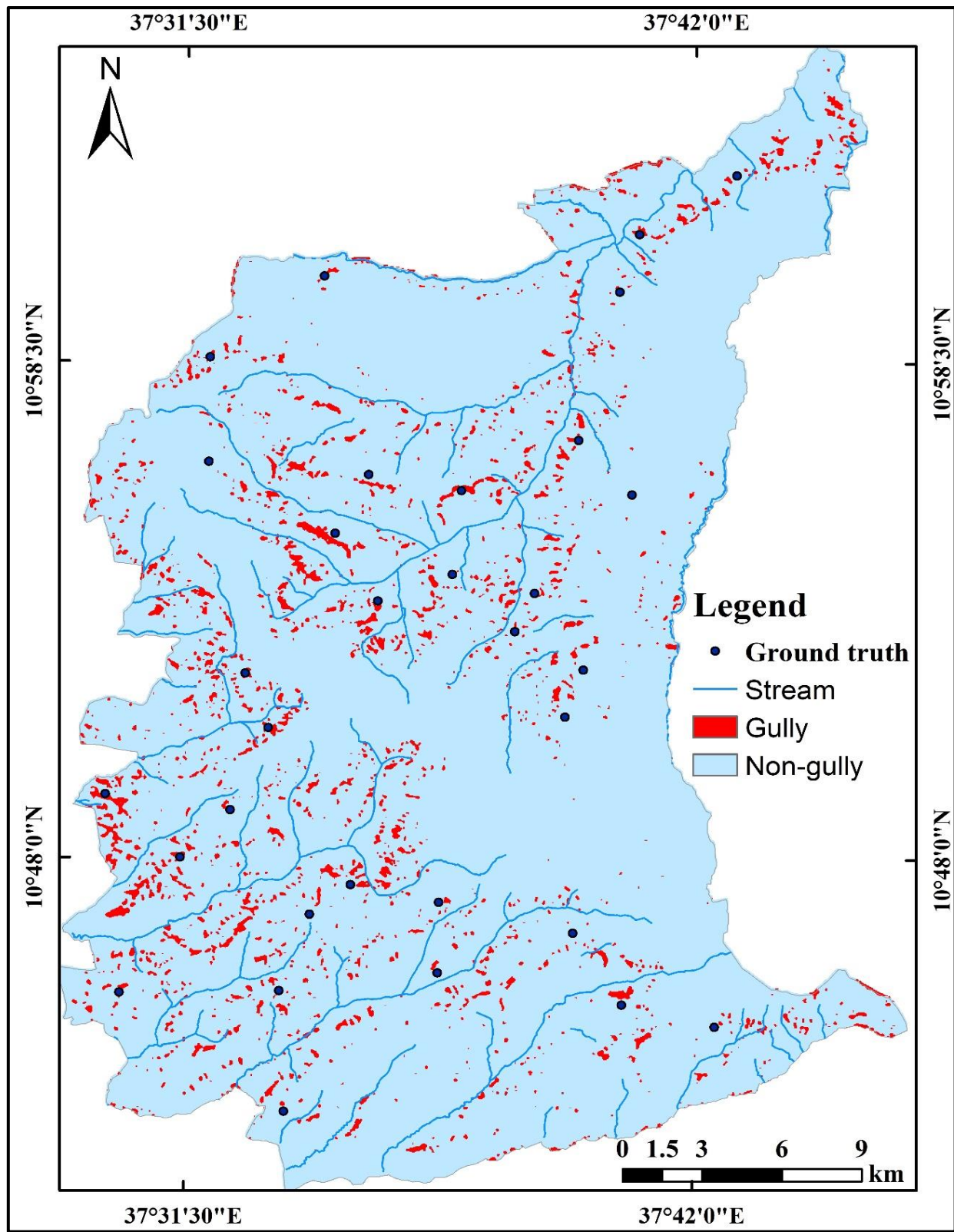


Figure 4. 9. Gully erosion map of the study area

The reclassified map (Figure 4.9) portrayed the spatial distribution of gully occurrences within different parts of the study area. The result revealed that 5,236 ha (5.9%) of the study area is covered by gully and the rest area 78,094 ha (94.2%) is non-gully areas.

According to the finding, gully formation is accompanied along natural streams and rivers in which are the caustic condition factors. As clearly shown, the gully occurrences are more pronounced in southern and northern parts of the study area where drainages Rivers and other associated intermittent streams have been. To validate the gully occurrence location, ground truth and polygons digitized from google earth have been used field point data was collected as shown in Figure 4.10., and validated by cross-checking with the result obtained from SPI and TWI prediction. The accuracy assessment result of gully occurrence shows 80%, which was relatively good. Ephemeral gullies were noticed during field visit in the study area (Figure 4.10).



Figure 4. 10. The photo was taken from gully hotspot areas of Dega Damot district

4.3. Soil erosion status due to sheet, rill and gully

The overall soil erosion status of the study area was calculated from the result obtained from sheet and rill erosion computed by RUSLE and gully erosion based on the pairwise comparison of criteria weighting (Table 4.6). The weights have been given based on the influence of each sub-class for

soil erosion. As presented in table 4.6, soil annual soil erosion was a more influential indicator than gully erosion for mapping and quantifying soil erosion assessment of the study area. The computed pairwise comparison consistency ratio was 0.003, which implies the comparison was nearly perfect which is less than the standard ratio of 0.1, which is acceptable.

Based on the weight overlay analysis portrayed in Figure 4.11, the northern and southern parts of the study area are characterized by moderate, high, and very high soil erosion risk. on the other hand, the central and other parts of the area are dominated by very slight to slight levels. Statistically, 12984.6 ha (23%), 2992.5 ha (9.5%), and 2149.6 ha (7.3%) of the study area fall under moderate, high, and very high levels of soil erosion risk level. In addition, 2595.9 ha (3.1%) of land is very slight and 40133.4 and 40133.4 ha (57.1%) falls in slight levels.

Table 4. 6.Degree of soil erosion risk levels of the study area

No	Soil erosion class	Area (ha)	Area (%)
1	Very slight	2595.9	3.1
2	Slight	40133.4	57.1
3	Moderate	12984.6	23
4	High	2992.5	9.5
5	Very high	2149.6	7.3

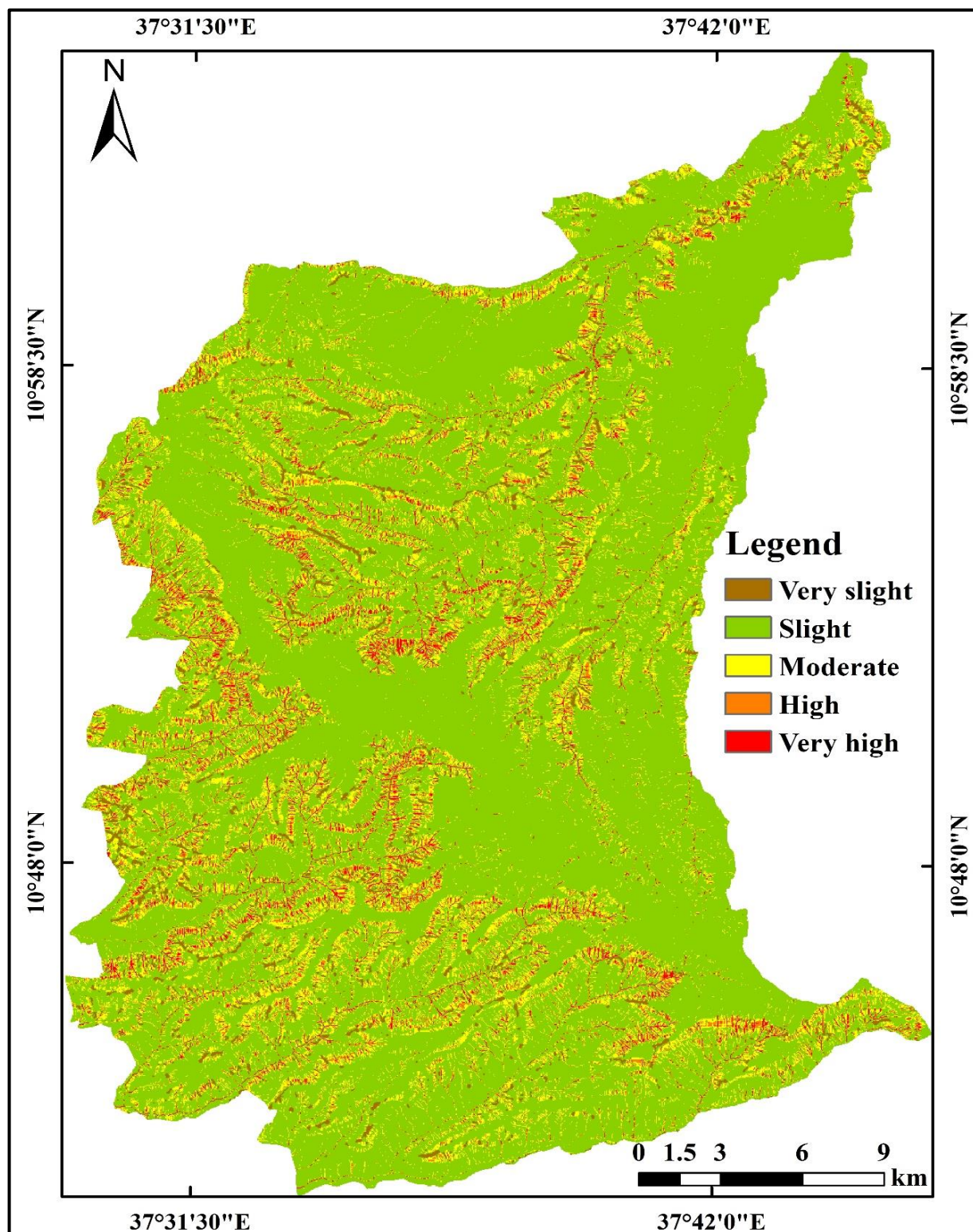


Figure 4. 11. Soil erosion risk map of the study area

Table 4. 7. Pairwise comparison matrix of soil erosion

criteria	Annual soil loss by RUSLE	Gully erosion	Weighting
Annual soil loss by RUSLE	1	2	66.7
Gully erosion	0.5	1	33.3

4.4. Biodiversity degradation hotspot

4.1.9.1. Proximity to Road

Distance from roads is one of the factors for biodiversity deterioration. The vegetation biodiversity of different plant communities and composition resources nearby access roads is more vulnerable to be exploited than the less accessible ones (Amare and Semegn, 2021). This entails that the more road density in the area, the more prone to biodiversity disturbance and degradation.

4.1.9.2. Proximity to settlement

The settlement patterns of the study area as shown in figure 4.12 in almost all parts of the landscape especially in northern and southwestern areas. The livelihoods of the district predominantly depend on energy sources such as fire, charcoal, and other household activities. These activities are mainly increasing deforestation and clearing of other plant and tree communities. The areas where settlements are clustered tend to be prone to biodiversity degradation.

4.1.9.3. Land management practice

Biodiversity contains and valuable habitats that contain species related to ecosystem functionalities. These functions are prone to anthropogenic disturbance of the ecosystem. The land use and land cover types of the study area were classified into seven categories (Table 4.8) for evaluating the expose to biodiversity diminishing. The land use and land cover types have a different level of vulnerability as a forest is the least vulnerable and grassland and cropland are more prone to degradation due to the expansion of settlement and agriculture. This result coincides with the study conducted by (Amare and Semegn, 2019), at Senawuha watershed and (Demissie, 2019) showed that biodiversity vulnerability is low in dense forests and high on agricultural lands

and settlements. Hence, most parts of the study area are dominated by croplands, the more visible biodiversity degradation.

4.1.9.3. Slope gradient

The topographical setup of a particular area has an influence on distribution and pattern on the quantity and function of plant communities and forest biodiversity (Zhang et al., 2018). Altitude and aspect are closely related to vegetation richness in a deciduous forest. In this study, the slope ranges from flat to very steep where disturbance of biodiversity is high in flat to gentle slopes due to easily accessible to settlement and farming.

The vulnerability of each parameter for mapping biodiversity hotspot degradation mapping is given in (Table 4.8) and the overall Biodiversity degradation hotspot parameters mapping is given in detail in (Figure 4.12)

Table 4.8. Parameters for Biodiversity degradation hotspot mapping

Parameter	Class	Scale	Weight	Rank
Settlement (km)	0-1	Very high vulnerability	14	1
	1-2	High vulnerability		2
	2-4	Moderate vulnerability		3
	4-7	Low vulnerability		4
	>7	Very low vulnerability		5
Distance road (km)	0-5	Highly vulnerable	36	1
	5-10	Moderately vulnerable		2
	10-15	Less vulnerable		3
	15-25	Least vulnerable		4
	>25	Not vulnerable		5
LULC	Settlement	Very high vulnerability	41	1
	Bare land	High vulnerability		2
	Cropland	Moderate vulnerability		3
	Grassland	Slightly vulnerable		4
	Shrub land, water body and forest	Very low vulnerability		5
Slope (%)	0-5	high vulnerability	9	1
	5-10	Moderate		2
	10-15	Low vulnerability		3
	15-25	Least vulnerable		4
	>25	No vulnerability		5

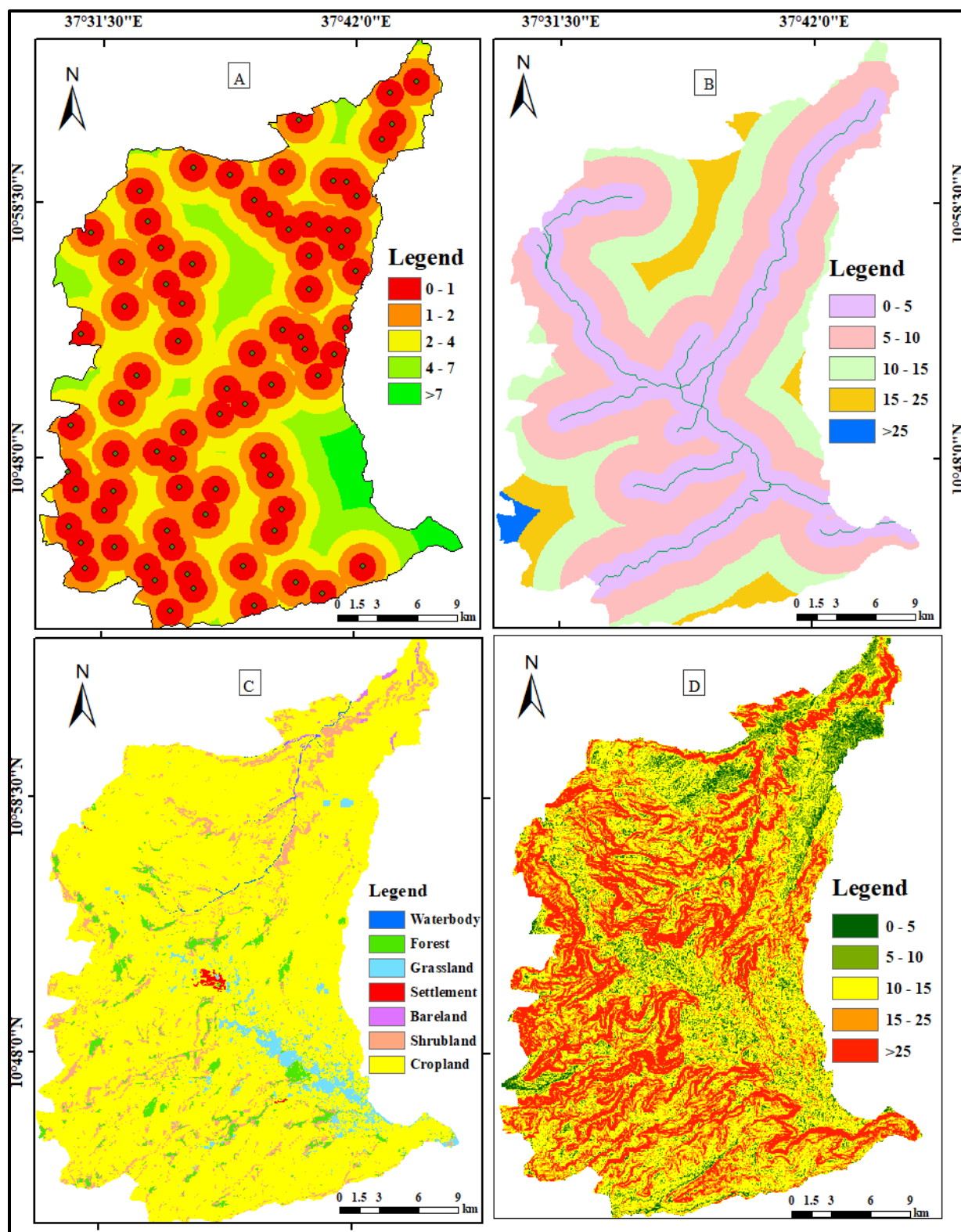


Figure 4. 12. Distance to settlement (A), distance to road (B), land use land cover(C) Slope (D)

Table 4. 9. Pairwise comparison matrix for determining biodiversity degradation mapping

Criteria	Land use land cover	Proximity to road	Settlement	Slope	Weighting
Land use land cover	1	2	3	3	41
Proximity to road	0.5	1	4	5	36
Settlement	0.33	0.25	1	5	14
Slope	0.33	0.2	0.5	1	9

Consistency ratio = 0.07

The consistency ratio < 0.1 is acceptable and as a result, the weight calculated is acceptable to proceed for determining biodiversity degradation in multi-criteria analysis.

The result in (Figure 4.13) revealed that the intensity of biodiversity degradation vulnerability of the study area ranges from very high around central parts of the study area where there are urban expansion and settlements to bare areas. High status of degradation found along with areas where there is road accessibility. Generally, moderate to very high status of biodiversity degradation dominantly characterizes the study area.

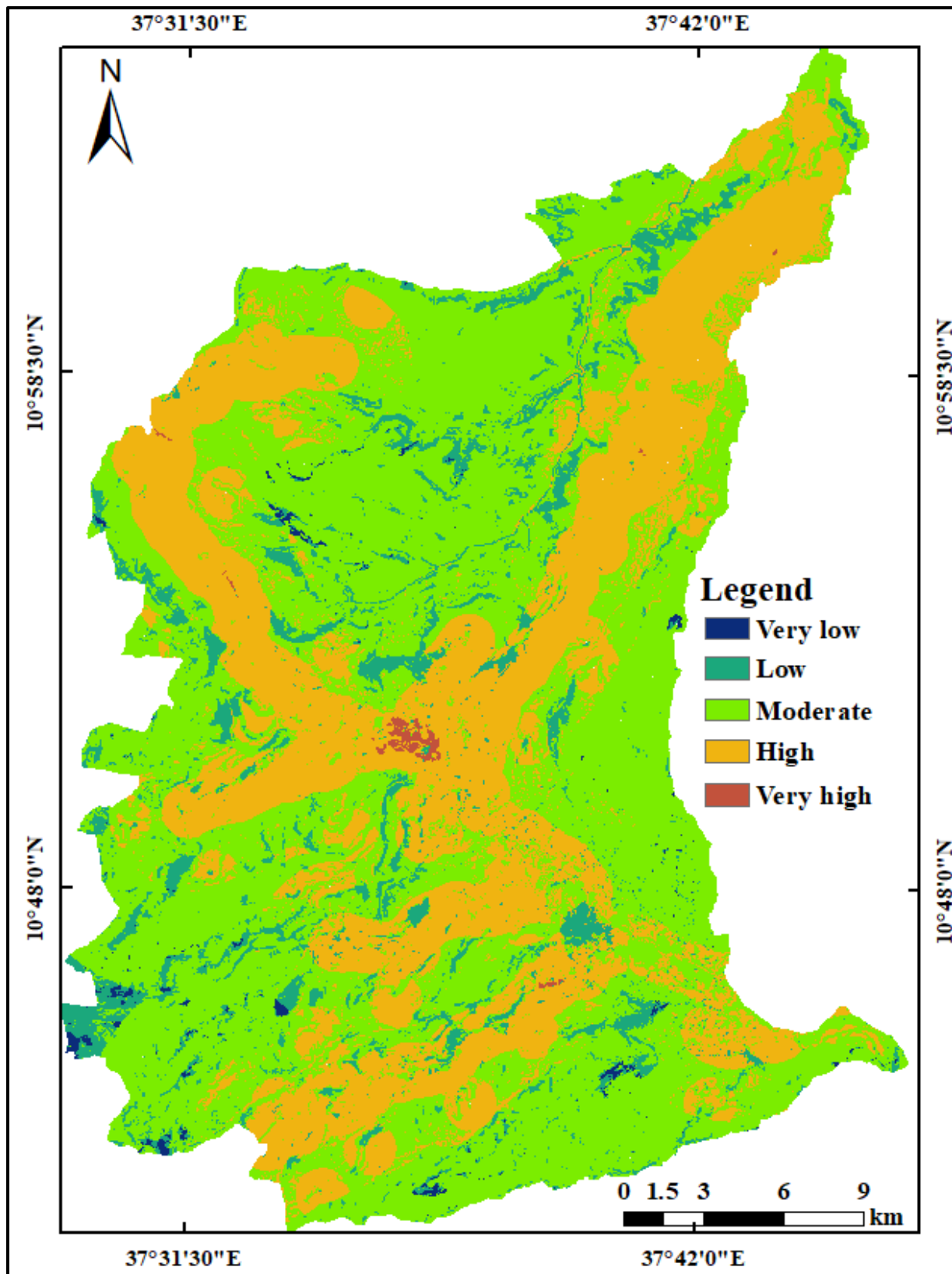


Figure 4. 13. Biodiversity degradation hotspot map of the study area

The spatial distribution of the biodiversity degradation level of the study area is presented in (Table 4.10.). The result revealed that 2979.7 ha (3.6%) of the study area is critical of characterized by a very high biodiversity degradation level in which the area is highly hotspot for biodiversity loss like a natural forest. This was observed in settlement bare areas where plant communities present in the lower composition. The study area 17049.4ha (20.4%) falls under high biodiversity degradation hotspot associated with grasslands due to overgrazing and easy way of expansion of farmlands. The remaining study area is described as moderate, low, and very low levels 45228.5 ha (54.3%) and 17780.6 ha (21.2%), 291.8 ha (0.5%) respectively.

Table 4. 10. Statistics of biodiversity degradation in Dega Damot District

Area (ha)	Area (%)	Status of degradation
291.8	0.5	Very low
17780.6	21.2	Low
45228.5	54.3	Moderate
17049.4	20.4	High
2979.7	3.6	Very high

4.4. Composite land degradation map

A final composite land degradation map was developed with the integration of different thematic layers of vegetation degradation, soil erosion vegetation and finally biodiversity degradation. As indicated in (Table 4.11), Soil erosion, biodiversity degradation and vegetation were the most to the least important components for composite land degradation in the study area. The weighted comparison consistency ratio was 0.02, and thus, the comparison was acceptable as the values is less than 0.1.

Table 4. 11. Pairwise comparison matrix of composite land degradation in Dega Damot District

Criteria	Soil erosion	Biodiversity	Vegetation	Weighting
Soil erosion	1	3	5	63.5
Biodiversity degradation	0.33	1	3	25.8
Vegetation Degradation	0.2	0.33	1	10.7

The result in (Table 4.12) shows that about 16492.4 ha (20.1%) of the study, area experienced low-level degradation while 35872.8 ha (43.4%) is moderately degraded. In addition, 26097.2 ha (31.8%) and 3364.9 ha (4.7%) were high to very high land degradation levels the result also shows that very high and high degraded areas of the study area were geographically distributed sparsely distributed over the area.

Table 4. 12. Composite land degradation status of Dega Damot District

No	Land degradation level	Area (ha)	Area (%)
1	Low	16492.4	20.1
2	Moderate	35872.8	43.4
3	High	26097.2	31.8
4	Very high	3364.9	4.7

As depicted in (Figure 4.14), the most highly degraded areas are located in the northern southern part of the study area. This is a result of a number of factors: steep slopes, poor land management, and continued cultivation, rugged topography, population pressure, and erratic rainfall. The moderately degraded areas were located in the middle elevation portion of the study area, where the area is characterized by flat to gentle topography and low vulnerability to soil erosion. Local land users confirm these factors. Local communities explained that a combination of soil erosion, low vegetation cover, and continued deforestation and overgrazing contributed to land degradation in the study area.

Overall, the combined degradation analysis shows that more than half of the study area was moderately to highly degrade. This implies that land degradation is a serious environmental and economic problem in Dega damot district.

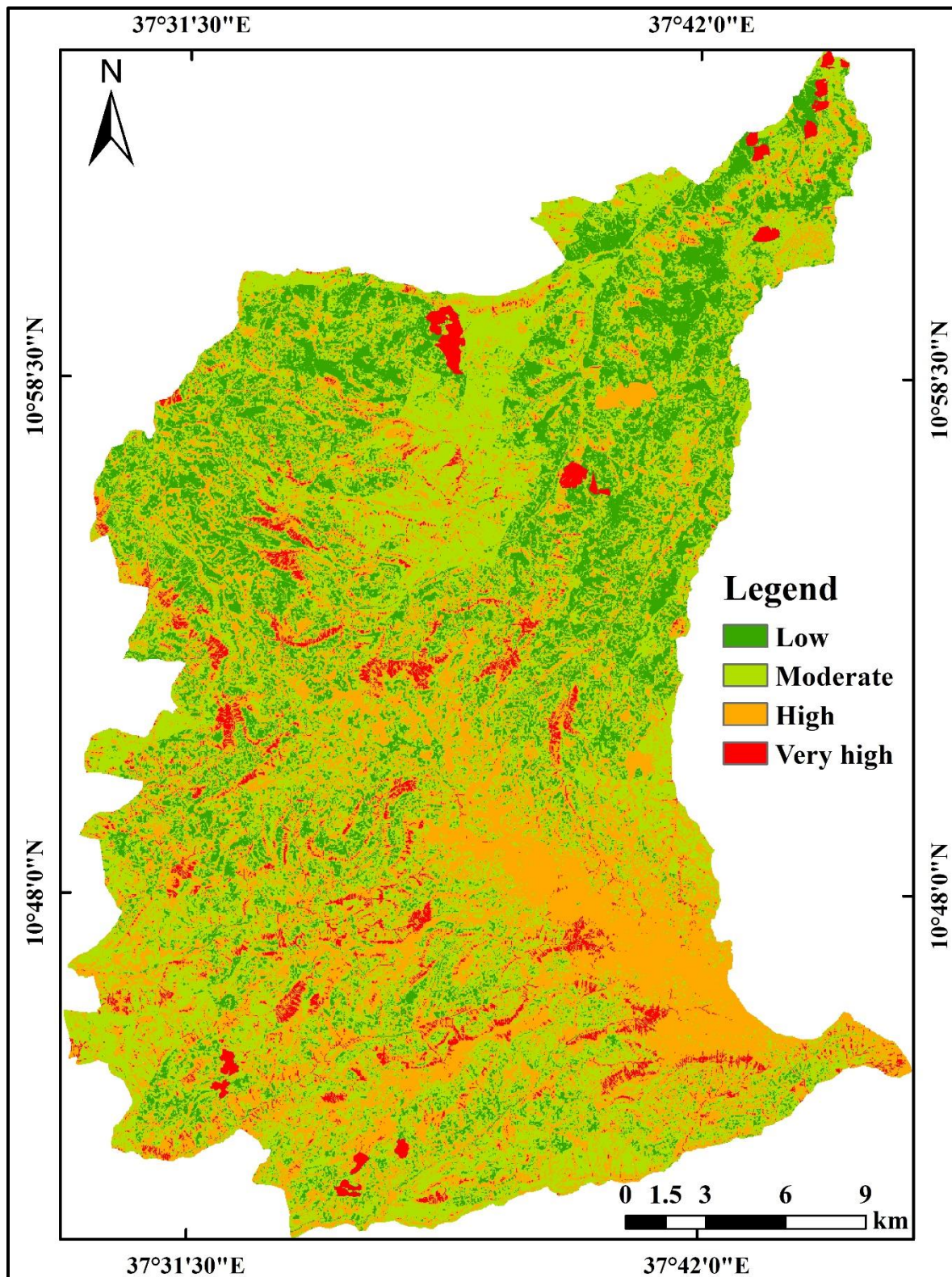


Figure 4. 14. Composite land degradation hotspot map of the study area

CHAPTER FIVE

5. DISCUSSION

5.1. Land-use/ land cover change

The land-use land-cover dynamics is essential to know the main indicator for levels of land degradation of an area (Samson, 2019). Land-use/cover of the Dega Damot district was frequently changing through the year 1990 to 2020. This study using GIS and remote sensing in which gives a great opportunity for examining larger areas like district level analyzed LULC. LULC was classified into seven thematic layers, where the result revealed that cropland was magnificently increasing over thirty study periods. During classification, identification of rural settlements was very challenging and only the District capital and other rural towns were considered for settlements. This agreed with Samson (2019) who classified rural huts and houses under the above-mentioned categories unlike cropland-forested areas was continuously declined in the study period. As to the information gathered from elder peoples, the major reason for the expansion of farmlands and the decrement of forest lands was population pressure which caused much of the forest land used for cultivation and also fall off the Derg Government in 1991 that led to the illegal destruction of protected forests such as well known “Berk forest” for agriculture by farmers (personal communication). Moreover, the study area was highly influenced by local people with poor land-use planning systems.

This study result is coinciding with previous findings of LULC studies in adjacent areas. Temesgen *et al.*, (2017), shown that the trend of LULC was multi-dimensional. Thus, some LULC types such as grassland were changed to settlement and forested areas were to cropland. Because of appropriate management of land use systems, such loss of vegetation cover happened in the study area. Other studies conducted by Semibuze (2020) agricultural land has been expanded by 22.3% between 1986 and 2019 in Enbsie samider woreda due to the population pressure and high demand for farming land.

5.2. Soil erosion Assessments

Soil erosion is the most serious cause of land degradation, which has influenced tremendous pressure on productivity and environmental stability of arid and semiarid areas. Sheet and rill

erosion are the major types that cause land degradation. To study the magnitude of different methods employed in different studies to conduct soil erosion. However, RUSLE is the most reliable model, which accompanies topographical rainfall as well as land cover and management practices. Moreover, the output was the combination of these factors in which the result is depend on the quality of the input data. In the present study, rainfall data acquired from CHRS data portal to overcome data gaps when applied metrological gauging data. Generally, RUSLE is used for estimating average annual soil loss based on available geospatial data.

The estimated soil erosion severity risk of and spatial distribution patterns is usually good what was observed in the field and past studies. Based on the parameters the spatial pattern of soil erosion is quite different from (1990-2020). In 1990 the result ranges from 0 to 428 t/ha/yr.in the same way in the final study period of 2020 the highest erosion rate increased magnificently to 753 t/h/yr. this implies rill and sheet erosion increased over the study period. This study agreed with previous findings, for instance, [Mengie et al \(2019\)](#), showed that the annual soil loss due to sheet and rill erosion extends to 442 t/ha/yr in Gumara watershed, Northwestern Ethiopia.

The full impact of soil erosion is not only captured by the sheet and rill erosion rather it must consist of gully erosion to present full of soil erosion risk of the study area. For instance, gully erosion was assessed based on the topographic wetness index (TWI) and stream power index (SPI) which is a good indicator for the prediction of ephemeral gully in the study area. Nearly 5% of the total area of land was affected by gully erosion. This result agreed with [Kefale \(2020\)](#) who reported that 10% of Dengora and 7% of Meno watershed were affected by gully erosion. The overall soil erosion severity of the area was computed by combining gully with sheet and rill erosion with multi-criteria decision analysis methods (MCDA) methods of pairwise comparison where nearly half of the total area of the study land is slight to high-level risks of erosion.

5.3. Biodiversity degradation hotspot assessment

The biodiversity is vulnerable if there are disturbances nearby and upon it. Disturbances mainly result from the influences of human activities. For various human activities, the role of natural features like elevation, slope and stream, and anthropogenic features such as road networks are inevitably important. To this effect, the biodiversity degradation vulnerability map of the study

area was generated from parameters of land use land cover, road network, settlement, slope, and stream network (Geparaju *et al.*, 2017; Demissie 2019; Amare and Semegn, 2020). The weighted overlay result showed the higher vulnerability of biodiversity resources based on pairwise comparison of the results of the above parameters in one-third of the study area exhibits series loss of vegetation biodiversity. In line with this, various studies reported that highland areas of Ethiopia are under serious biodiversity degradation (Demissie *et al.*, 201) central Ethiopia (Kiros, 2019).

5.4. Composite land degradation mapping

Composite Land degradation is often the result of a wide range of factors. In GIS, these factors usually are represented at different measurement scales. One of the challenges in modeling land degradation vulnerability is the integration of these factors into a single index. GIS-based multi-criteria analysis is an important method to deal with such problems. This follows a pairwise comparison of criteria weights of Soil erosion, vegetation, and biodiversity degradation. . Due to this reason, calculating weights or relative importance of each factor in Dega Damot district through pairwise comparison method is necessary to develop Composite land degradation.

The weights of the three major layers were calculated through pairwise comparison. Thus, the final composite land degradation map was produced through a weighted overlay. The overall composite land degradation result indicates that over 31% of the study area is affected by very high levels of degradation. This result also agreed with Sileshi (2016), the land degradation vulnerability result shown that 41% of the Beshalo basin was highly susceptible. In addition, Alelegn *et al* (2021) studied in North-Gojjam basin reported that 32% of the sub-basin area exhibits low-level degradation while about 35.4% is moderately and 30.5% is highly degraded. This clearly shows that the results of composite land degradation in the present study coincided with other similar studies.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

Remote sensing and GIS techniques were commonly used in spatial assessments and spatial decision-making, and were found to perform well in spatial data modeling. Thus, MCE has been incorporated into combining the out of best suit factors by these techniques. AHP, which is a comprehensive, logical and structured multi-criteria decision-making technique, has been widely used in land degradation assessment. In spite of the common way of combining different parameters, this study produced composite land degradation map, which applied standardizing each parameter like to quantify soil erosion. Hence, this study proposed incorporating relatively wide phenomena for comprehensive land degradation assessment. It integrates biodiversity degradation vulnerability including vegetation degradation and soil erosion estimation. Weights were assigned to the factors using a series of pairwise comparison judgments.

Land degradation is a major environmental and economic problem in countries where the proper land use plan is not available and implemented. Land degradation is taking place in all agro-ecological zones and has long-lasting impacts on people and the environment. To assess comprehensive land degradation in Dega Damot District, several tasks have been carried out by identifying the major tasks are land use/ Land cover classification and change detection, soil erosion assessment, and biodiversity degradation mapping each thematic layer contains several factors. Over the last thirty years, the study area passed in multi-dynamic LULC modification and transition levels.

The findings of the study show that there is series of land use/ Land cover changes and cropland was a major land-use type in Dega Damot District. The main change observed in 1990-2020 was the expansion of grassland by 124.16 square km by the expense of other land uses and to the reverse 104.4 square km of forestland were vanished and changed to different land uses. Moreover, erosion assessment using GIS and remote sensing is vital since it is important for comprehensive

land degradation assessments. The sheet and rill erosion computed by the RUSLE model shows the spatial distribution of erosion risk of which 428 t/ha/yr. in 1990 to 753 t/ha/yr. in 2020, this implies that the study area vulnerability to erosion was increased from time to time. As gully is not captured by, the model the topographic and stream concept was applied and found nearly 5% of the study area is affected by gully erosion. The other component of producing a composite land degradation map was biodiversity assessment using proxy methods of road, settlement slope, and land use and land cover which shows a considerable loss of biodiversity in the area. As settlements expand, the demand for road accessibility jeopardizes biodiversity for overexploitation. The results of the composite land degradation map have shown the spatial variation in land degradation severity in the study area. The medium to very high land degraded areas were found within the northern and southern parts of the study area.

Generally, the integration of GIS and Remote sensing, and multi-criteria analysis provides a great utility to assess land degradation. The overall assessment result of land degradation helps to suggest the need for sustainable land management practices by integrating indigenous knowledge, especially in highly degraded areas.

6.2. Recommendations

Following land degradation modeling and assessment, the study draws the following recommendations to be used by different stockholders who are engaged in environmental protection and rehabilitation:

- ❖ Land degradation is the manifestation of different phenomena, assessing it requires considering quite different geospatial methodological approach. It can therefore composite assessment approach through AHP method, where a capable of answering which factor is more important.
- ❖ Due to the increment of population growth that leads to high demand for farmlands which causes deforestation and clearing of vegetation. Therefore, appropriate methods of keeping the natural environment by increasing the livelihood of the people for producing enough food from a small plot of land

- ❖ Afforestation program, soil and water conservation, and different sustainable land management practices should start by identifying the hotspot areas.
- ❖ Develop collaboration of all stockholders such as Governmental, NGOs, researchers Development agents, and farmers to play a leading role in the rehabilitation of land degradation
- ❖ A sustainable land management plan should be strengthened through community mobilization and major soil conservation techniques that include improving farming practices.
- ❖ Develop integrated land management practice to cope with land degradation, enhance vegetation cover biodiversity rehabilitation, and protect soil erosion.
- ❖ Since land degradation is manifestation of different factors, the future reasrecher consider the chemical indictors of land degradation such as soil acidity and alkalinity.

References

- Abdata.Galata. (2020). Analyses of land use/land cover changes and their causes using landsat data in hangar watershed, Abay basin, Ethiopia. *Journal of Sedimentary Environments*. 5. 10.
- Aboytu Sisay Golla. (2019). “Soil Acidity and its Management Options in Ethiopia: A Review”, *International Journal of Scientific Research and Management*, 7(11), pp. 1429-1440.
- Ahmed Amdihun, Ephrem Gebremariam., Lisa M.R., & Gete Zeleke. (2014). Suitability and scenario modeling to support soil and Water Conservation interventions in the Blue Nile Basin, Ethiopia. *Environmental Systems Research*, 3:23.
- Ajanaw Negese, Endalkachew Fekadu, & Getnet .(2021). Potential Soil Loss Estimation and Erosion-Prone Area Prioritization Using RUSLE, GIS, and Remote Sensing in Chereti Watershed, Northeastern Ethiopia. *Air, Soil and Water Research*.
- Alelgn Ewunetu, Belay Simane ,Eremias Teferiand Zaitchik BF.(2021). Mapping and Quantifying Comprehensive Land Degradation Status Using Spatial Multicriteria Evaluation Technique in the Headwaters Area of Upper Blue Nile River. *Sustainability*. 2021; 13(4):2244.
- Azamal Husen, Mishra, Vinod, Semwal, Kamal & Kumar, Dinesh. (2012). Biodiversity Status in Ethiopia and Challenges. P10-13.
- Alemayehu Shawul & Chakma, Sumedha. (2019). Spatiotemporal detection of land use/land cover change in the large basin using integrated approaches of remote sensing and GIS in the Upper Awash basin, Ethiopia. *Environmental Earth Sciences*.
- Al-Hussein S., (2000). GIS modelling of land degradation in northern Jordan using satellite imagery: University of Leicester.
- Amdihun, A., Gebremariam, E., Rebelo, LM. et al. Suitability and scenario modeling to support soil and water conservation interventions in the Blue Nile Basin, Ethiopia. *Environ Syst Res* 3, 23 (2014). <https://doi.org/10.1186/s40068-014-0023-9>

- Amhara national regional state food security research assessment report. (2000). <https://www.ctahr.hawaii.edu/sm-crsp/phase1/pdf/amhara.pdf> accessed on 20/01/2021.
- Amit Sarkar. 2018. "Accuracy Assessment and Analysis of Land Use Land Cover Change Using Geoinformatics Technique in Raniganj Coalfield Area, India," International Journal of Environmental Sciences & Natural Resources, Juniper Publishers Inc., vol. 11(1), pp 25-34.
- Asefa, Mengesha , Cao, Min & Yunyun, He . Ewuketu Mekonnen, Song. Xiaoyang, Jie. Yang. (2020). Ethiopian vegetation types, climate and topography. Plant Diversity. 42PP.
- Badapalli Pradeep, K Raghu, M., Rajasekhar G. Sakram & M.Ramachandra. (2020). An Innovative Approach for the Assessment and Monitoring of Land Degradation and Desertification in Semi-Arid Regions Using Remote Sensing and GIS Techniques.
- Bai Z. G., Dent D. L., Olsson L., & Schaepman M. E. (2008a). Proxy global assessment of land degradation. *Soil Use and Management* 24(3), 223-234. Bairagi, G., Sharma, R., & Bhelawe, S. (2012). Mapping of Degraded Lands Using Remote Sensing and GIS Techniques.
- Bai Z.G., Dent David, Olsson Lennart & Schaepman M.E. (2008b). Global assessment of land degradation and improvement: 1. Identification by remote sensing.
- Balabathina, Veera & Raju, R. & Wuletaw Muluaem, & Gedefaw Tadele. (2020). Estimation of Soil Loss Using Remote Sensing And GIS-Based Universal Soil Loss Equation In Northern Catchment of Lake Tana Sub-Basin, Upper Blue Nile Basin, Northwest Ethiopia.
- Belal, A.B.; Sciences, S.; Abu-hashim, M. (2015). Land Evaluation Based on GIS-Spatial Multi-Criteria Evaluation (SMCE) for Agricultural Development in Dry Wadi, Eastern Desert. *Int. J. Soc. Sci.* pp100–116.

- Birara Chekol Tarekegn. (2012). A Case Study of Gully Erosion in the Ethiopian Highlands. Retrieved from http://soilandwater.bee.cornell.edu/publications/Birara_MPS_2012.pdf on 1/16/2021.
- Binyam Alemu. (2015). The Effect of Land Use Land Cover Change on Land Degradation in the Highlands of Ethiopia.
- Berhan Awoke & Woldeamlak Bewket. (2014). Drivers and Implications of Land Use and Land Cover Change in the Central Highlands of Ethiopia: Evidence from Remote Sensing and Socio-demographic Data Integration. 10. 1-23.
- Birhan Miheretu and Assefa Abega .(2018). Land use/land cover changes and their environmental implications in the Gelana sub-watershed of Northern highlands of Ethiopia. *Environ Syst Res* 6, 7 (2018).
- Bosoon Park. (2008). Supervised classification, Computer Vision Technology for Food Quality Evaluation. *Food Science and Technology*, Amsterdam. PP157-187.
- Catarino L. & Romeiras M. (2020). Biodiversity of Vegetation and Flora in Tropical Africa. *Diversity*. 12. 369.
- Cheruto, Mercy & Kauti, Matheaus & Kisangau, Patrick & Kariuki, P.(2016). Assessment of Land Use and Land Cover Change Using GIS and Remote Sensing Techniques: A Case Study of Makueni County, Kenya. *Journal of Remote Sensing & GIS*.
- Dagim A. (2020). Assessing the effect of land degradation on farmer's livelihood options at Choke Mountain, *South Asian Journal of Development Research*, 2(2): 114-129.
- Dwivedi, R.S. (2018). *Geospatial Technologies for Land Degradation Assessment and Management* (2nd Ed.). CRC Press.
- CSA, (2007). Summary and Statistical Report of the 2007 population and Housing Census of Ethiopia. Addis Ababa, Ethiopia.

- CSA, (2017). Population Projection of Ethiopia for All Regions at Wereda Level from 2014 – 2017. Addis Ababa, Ethiopia
- Desale Kidane. 2021. Remote Sensing and GIS-Based Soil Loss Estimation Using RUSLE in Bahir Dar Zuria District, Ethiopia.
- Desalew Meseret, (2016). Land Degradation in Amhara Region of Ethiopia: Review on Extent, Impacts and Rehabilitation Practices. *Journal of environment and earth science*, 6, 120-130.
- El-Swaify SA and Hurni H. (1996) .Trans-boundary effects of soil erosion and conservation in the Nile basin. *Land Husb* 1:6–21.
- Ethiopian soils(<https://www.britannica.com/place/Ethiopia/Soils>) accessed on 3/22/2021.
- Eswaran, H., R. Lal and P.F. Reich. (2001). Land Degradation: An Overview. In: Bridges, E.M., I.D, Hannam, and L.R. Oldeman, F.W.T penign de vries, S.J. Scherr, and S.Sompat panit (eds.). *Responses to land Degradation. Proc. 2nd International Conference on Land Degradation and Desertification*, Khon Kaen, Thailand. Oxford Press, New Delhi, India.
- Ethiopian Biodiversity Institute. <https://www.ebi.gov.et/biodiversity/ecosystems-of-ethiopia/> accessed on 20/01/2021.
- FAO. 2011. Sustainable Land Management in Practice Guidelines and Best Practices for Sub-Saharan Africa. Rome, 2011.
- FAO, (1995). Planning for Sustainable Use of Land Resources: Towards a New Approach, Issue 2 of FAO land and water bulletin. ISBN 9251037248, 9789251037249.
- Friis, I. B., Sebsebe Demissew, and Paulo van Breugel. (2010). Atlas of the potential vegetation of Ethiopia. Det Kongelige Danske Videnskabernes Selskab.
- Habtamu Atoma, Suryabhadgavan Karuturi & Balakrishnan, M. (2020). Soil erosion assessment using RUSLE model and GIS in Huluka watershed, Central Ethiopia. 6. 10.

- Hana Mekonnen. (2014). Assessment of soil erosion risk with RUSLE and GIS in Geffersa Watershed, West Shewa Zone Oromiya Region Addis Ababa University. Unpublished MSC thesis, Addis Ababa, Ethiopia.
- Hailu Kendie Addis, Belayneh Adugna, Muuz Gebretsadik, Baye Ayalew, "Gully Morphology and Rehabilitation Measures in Different Agroecological Environments of Northwestern Ethiopia", Applied and Environmental Soil Science, vol. 2015, Article ID 789479, 8 pages, 2015. <https://doi.org/10.1155/2015/789479>
- Hurni H. (1985). Erosion-productivity-conservation systems in Ethiopia. In: Paper presented at the 4th international conference on soil conservation, 3–9 Nov. 1985, Maracacy, Venezuela.
- Hurni, K., Zeleke, G., et al 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. Water and Land Resource Centre (WLRC); Centre for Development and Environment (CDE); Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).
- Hurni, H. (1993). Land degradation, famine and land resource scenarios in Ethiopia: World Soil Erosion and Conservation, edited by Pimentel, D., Cambridge University Press, Cambridge, UK. pp 27-61.
- <https://www.soilmanagementindia.com/soil-loss-measurement/soil-loss-equation/modified-universal-soil-loss-equation-musle-soil-management/15504> accessed on 13/02/2021.
- Gezahegn Weldu, & Arus Edo. (2020). Effect of Land Use and Land Cover Change on Soil Erosion in Erer Sub-Basin, Northeast Wabi Shebelle Basin, Ethiopia. Land. 9. 111. 10.3390/land904011
- Kassahun Gashu and Yitbarek Muchie (2018). Rethink the interlink between land degradation and livelihood of rural communities in Chilga district, Northwest Ethiopia. *J ecology environ* 42, 17.
- Kefale Munye. (2020). Identifying Soil Erosion Hotspot Area Using GIS and MCDA Techniques, Case Study of Dengora and Meno Watersheds in Belesa Woredas, Amhara Region, Ethiopia, 11 PP.

- Karydas, Christos & Panagos, Panos. (2020). Towards an Assessment of the Ephemeral Gully Erosion Potential in Greece Using Google Earth. *Water*. Pp 2.
- Kaul, H.A. & Ingle, Sopan. (2012). Land Use Land Cover Classification and Change Detection Using High Resolution Temporal Satellite Data. *The Journal of Environment*. 1. 146-152 PP.
- Kifelu Gudeta (2010). Soil Erosion and priority identification In Mojo watershed. Unpublished Thesis. Addis Ababa University. Addis Ababa E,thiopia.
- Kiros Deribew & Desalegn Wana. (2019). Land use and forest cover dynamics in the Northeastern Addis Ababa, central highlands of Ethiopia. *Environmental Systems Research*. pp 8.
- Koirala Pooja, Thakuri Sudeep, Joshi Subesh, Chauhan Raju. (2019). Estimation of Soil Erosion in Nepal Using a RUSLE Modeling and Geospatial Tool. *Geosciences* 9, no. 4: 147.
- IPBES. (2018). *Summary for policymakers of the thematic assessment of land degradation and restoration*. Bonn, Germany: Author. Retrieved from <https://www.ipbes.net>.
- Isbell, F. (2010). Causes and Consequences of Biodiversity Declines. *Nature Education Knowledge* 3(10):54.
- Ivits, E., & Cherlet, M. (2013). Land-productivity dynamics towards integrated assessment of land degradation at global scales (EUR-Scientific and Technical Research Reports). Publications
- IUCN 2015. Land Degradation Neutrality: implications and opportunities for conservation, Technical Brief 2nd Edition, November 2015. Nairobi: IUCN. 19p. Office of the European Union. JRC80541. Doi: 10.2788/59315.
- Lulseged Tamene && Vlek, Paul. (2008). Soil Erosion Studies in Northern Ethiopia. *Land Use and Soil Resources*. 10.1007/978-1-4020-6778-5_5.
- Mahala, A. (2019). Identifying the factors and status of land degradation in a tropical plateau region. *GeoJournal* 84: 1199–1218.
- Malczewski J. & Rinner C. (2015). Multi-attribute Decision Analysis Methods. In: *Multi-criteria Decision Analysis in Geographic Information Science*. Advances in Geographic Information Science. Springer, Berlin, Heidelberg.

- Maina J., Shem Wandiga, & Benjamin Gyampoh & Charles KKG. (2020). Assessment of Land Use and Land Cover Change Using GIS and Remote Sensing: A Case Study of Kieni, Central Kenya. *Journal of Remote Sensing & GIS*.
- Masoudi M., Jokar P., and Pradhan B. (2018). A new approach for land degradation and desertification assessment using geospatial techniques. *Nat. Hazards Earth Syst. Sci.*, 18, 1133–1140
- Mensah, F., Adanu, S., & Adanu, D. (2015). RESEARCH ARTICLE: Remote Sensing and GIS Based Assessment of Land Degradation and Implications for Ghana’s Ecological Zones. *Environmental Practice*, 17(1), 3-14.
- Millennium Ecosystem Assessment. 2005. Dryland systems. In: Hassan R, Scholes R, Ash N, editors. *Ecosystem and well-being: current state and trends*. Washington, DC: Island Press; p. 623–662.
- Million, T., Belay, K. 2007. Factors influencing adoption of soil conservation measures in s Muluneh, W. 2003. *Population Growth and Environmental Recovery: More People, More Trees; Lesson from Western Gurage Land: Ethiopian Journal of the Social Science and Humanities*, Vol. 1, December, 2003. Addis Ababa University. Southern Ethiopia: The Case of Gununo Area. *Journal of Agriculture and Rural Development in the Tropics and Subtropic* 105(1):49-62.
- Ministry of Agriculture. (1998). “Agro-Ecological Zones of Ethiopia on 1:2,000,000 scale,” Natural Resource Management and Regulatory Department, Addis Ababa.
- Mitiku, H., Herweg, K. G. & Stillhardt, B. 2006. Sustainable land management: A new approach to soil and water conservation in Ethiopia. Centre for Development and Environment (CDE) and NCCR North-South.
- Mohan, B & Anand, Anupam. . (2012). Processing and classification of remotely sensed images. Indira Gandhi National Open University School of Sciences. 60PP.
- Moore, I. D., & Burch, G. J. (1986). Physical basis of the length-slope factor in the universal soil loss equation. *Soil Science Society of America Journal*, 50(5), 1294-1298.
- Mucina, L., Price, J.N. & Kalwij, J.M. (2014), *Biodiversity and vegetation: patterns, processes, conservation*, p. 84. Kwongan foundation Perth AU.

- Foundation, Perth, AU. Muhammad D T, Muhammad A, Ali R, Rehan A, Anosha A, et al. (2020) Land Degradation and its Management: A Review. *Int J Environ Sci Nat Res.* 25(2): 556157.
- Gebrat Shiferaw. (2018). Soil loss estimation and source areas using RUSLE and MCE technique in Chemoga watershed, Blue Nile Basin, 11 PP.
- Nigussie Haregeweyn. & Tsunekawa, Atsushi & Poesen, J. & Tsubo, Mitsuru & Derege Tsegaye Meshesha & Ayele Almaw Fenta & Nyssen, Jan & Enyew Adgo. (2017). Comprehensive assessment of soil erosion risk for better land use planning in river basins: Case study of the Upper Blue Nile River. *Science of the Total Environment.* 574. 95-108.
- Nurhussen, Ahmed. (2016). Application of NDVI in Vegetation Monitoring Using GIS and Remote Sensing in Northern Ethiopian Highlands. 1. 12-17.
- Ojo Olumuyiwa & Ilunga Francois. (2018). Geospatial Analysis for Irrigated Land Assessment, Modeling and Mapping.
- Olena Dubovyk. (2017). The role of Remote Sensing in land degradation assessments: opportunities and challenges. *European Journal of Remote Sensing.* 50:1/ 601-613.
- Oldeman L. R., Hakkeling R. T. A., & Som. (broek, W. G. (1990). World map of the status of human-induced soil degradation: an explanatory note. International Soil Reference and Information Centre.
- Ownegh, M. (2003). Land use planning and integrated management of natural hazards in Golestan Province. International Seminar on flood hazard prevention and mitigation 15-16 January. (2003). Gorgan, Iran. Abstract.
- Patrick Ndolo. (2015). GIS-based soil erosion modeling and sediment yield of the N'djili river basin, Democratic Republic of Congo, 13PP.
- Prasannakumar V., H. Vijith & Abinod S. & Geetha, N. (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geoscience Frontiers.* 3. 209–215.
- Puigdefabregas Juan, Barrio Gabriel & Hill Joachim. (2009). Ecosystemic approaches to land degradation. *Avances en estudios sobre desertificación,* pags. 77-84.

- Rabia, A.H. (2012). GIS Spatial Modeling for Land Degradation Assessment in Tigray, Ethiopia.
- Reddy G.P.O., Kumar N., Singh S.K. (2018) Remote Sensing and GIS in Mapping and Monitoring of Land Degradation. In: Reddy G., Singh S. (eds) Geospatial Technologies in Land Resources Mapping, Monitoring and Management. Geotechnologies and the Environment, vol 21. Springer, Cham. https://doi.org/10.1007/978-3-319-78711-4_20.
- Robert, A. Schowengerdt. (2007). Remote sensing: models and methods for image processing. Department of Electrical and Computer Engineering, College of Optical Sciences, and Office of Arid Lands Studies University of Arizona. Tucson, Arizona., USA. pp. 387–394.
- Samson Mekasha, Suryabhadgavan, Karuturi & Mersha Gebrehiwot. (2020). Geo-spatial approach for land-use and land-cover changes and deforestation mapping: a case study of Ankasha Guagusa, Northwestern, Ethiopia. *Tropical Ecology*. 550–569PP.
- Samuel Gebreselassie, Kirui O.K., Mirzabaev A. (2016). Economics of Land Degradation and Improvement in Ethiopia. In: Nkonya E., Mirzabaev A., von Braun J. (eds) Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Springer, Cham. https://doi.org/10.1007/978-3-319-19168-3_14.
- Semahubizu Melise. (2020). Application of RS and GIS to Land Degradation Assessment in Enebsie Sar Midir micro watershed, western Ethiopia. Unpublished MSC thesis, Addis Ababa University, Addis Ababa, Ethiopia
- Sandeep, P., Reddy, G.P.O., Jegankumar, R. et al. (2020). Modeling and Assessment of Land Degradation Vulnerability in Semi-arid Ecosystem of Southern India Using Temporal Satellite Data, AHP and GIS. *Environ Model*.
- S.H.R. Sadeghi, L. Gholami, A. Khaledi Darvishan & P. Saeidi. (2014). A review of the application of the MUSLE model worldwide, *Hydrological Sciences Journal*, 59:2, 365-375.
- Sileshi Tadesse. (2016). Land degradation vulnerability Assessment using GIS and remote sensing in Beshilo River basin, Ethiopia: Norwegian university of Science and Technology, Trondheim.

- Simachew Bantigegn. (2020). Natural resource degradation tendencies in Ethiopia: a review. *Environ Syst Res* 9, 33.
- Siro Ali A. (2016). Use of geospatial techniques in modelling land degradation Case study of Kenya's Lake Victoria basin: University of Nairobi, Kenya.
- Sivakumar M. and Stefanski Robert. (2007). Climate and Land Degradation — an Overview. PP105-135.
- Stone, R.P., and Hilborn, D., (2000). Universal Soil Loss Equation (USLE), Agricultural and Rural Ministry of Agriculture, Food and Rural Affairs, Ontario, Canada
- Taffa, T. (2009). Characteristics of Property Units in Ethiopia the Case of Two Pilot Projects in Amhara National Regional State. *Nordic Journal of surveying and Real Estate Research*, 6(2),7-24.
- Telkar, Shivkumar & Pote, Neha. (2018). Soil Erosion: Types and Their Mechanism.
- Temesgen Gashaw, Worqlul, Abeyou & Dile, Yihun, Addisu, Solomon, Amare Bantider & Zeleke, Gete. (2020). Evaluating potential impacts of land management practices on soil erosion in the Gilgel Abay watershed, upper Blue Nile basin.
- Tesfa, A. and Mekuriaw, S. 2014. The effect of land degradation on farm size dynamics and crop livestock farming system in Ethiopia: A Review. *Open Journal of Soil Science* 4:1-5.
- Tesfa Worku, Tripathi, S.K. & Khare, D. Analyses of land use and land cover change dynamics using GIS and remote sensing during 1984 and 2015 in the Beressa Watershed Northern Central Highland of Ethiopia. *Model. Earth Syst. Environ.* 2, 1–12
- UNCCD (2015), Desertification and Land Degradation and their impact on natural ecosystems and food security: 2nd meeting of the 4th session of SED on the 2013-2015 review (SED 4–2) Geneva.
- Stellemas et al.(2015). Land degradation assessment and monitoring of dry lands. In Thenkabail, P.S. (Editor), *Remote Sensing of Water Resources, Disasters, and Urban Studies*, CRC Press, pp. 417–451. ISBN 978148221791 9.
- Temesgen Gashaw. (2017). *Land Degradation in Ethiopia: Causes, Impacts and Rehabilitation Techniques*.

- U.S. Geological Survey. (2019). Landsat 8 (L8) data users handbook. Document Number LSDS-1574. Version 5.0. <https://www.usgs.gov/media/files/landsat-8-data-users-handbook.pdf> (accessed January 2021).
- Wakjira , Tamene & Miegel, Konrad. (2020). Drivers and Implications of Land Use/Land Cover Dynamics in Finchaa Catchment, Northwestern Ethiopia. *Land*. 9. 113
- WMO (World Meteorological Organization) (2005). *Climate and Land Degradation: Climate Information–Resource Conservation – Sustainable Management of Land*. No. 989.
- World Bank (WB). 2012. *Managing land in a changing climate: an operational perspective for Sub-Saharan Africa*. Draft version Report No.: 54134-AFR. WB, Washington D.C.
- Xie, Hualin; Zhang, Yanwei; Wu, Zhilong; Lv, Tiangui. 2020. "A Bibliometric Analysis on Land Degradation: Current Status, Development, and Future Directions" *Land* 9, no. 1: 28.
- Wassie, S.B. (2020). Natural resource degradation tendencies in Ethiopia: a review. *Environ Syst Res* 9, 33.
- Williams JR .1995. Chapter 25. The EPIC model. In *computer models of watershed hydrology*. Water Resources Publications, Highlands Ranch, pp 909–1000.
- Wischmeir, W. H., and Smith, D. D. (1978). *Predicting rainfall erosion losses: a guide to conservation planning*. USDA Agricultural Handbook No. 537. Washington, DC: U.S. Department of Agriculture.
- Worku Nega, Binyam Hailu & Aramde Fetene. (2019). An assessment of the vegetation cover change impact on rainfall and land surface temperature using remote sensing in a subtropical climate, Ethiopia. *Remote Sensing Applications: Society and Environment*. 16. 100266.
- Yared, Jasińska Justyna, Lemma Tiki, Świtoniak, Marcin & Puchałka, Radosław & Eyob Gebrehiwot . (2020). Soil Loss Estimation for Conservation Planning in the Welmel Watershed of the Genale Dawa Basin, Ethiopia. *Agronomy*. PP10. 777.
- Yilkal Abebe. (2018). The impacts of soil degradation on the rained agriculture: the case of Dembia woreda, central Gondar zone, Amhara region, Ethiopia.
- Yonas Gebresilasie .2020. *Estimating Landscape Vulnerability to Soil Erosion by RUSLE Model Using GIS and Remote Sensing: A Case of Zariema watershed, Northern Ethiopia*.

Zerihun Nigussi, et al. (2017). Farmers' Perception about Soil Erosion in Ethiopia. *Land Degradation and Development*. Pp.28.

Zorn M., Komac B. (2013) Land Degradation. In: Bobrowsky P.T. (eds) *Encyclopedia of Natural Hazards*. *Encyclopedia of Earth Sciences Series*. Springer, Dordrecht.

Appendices

Appendix 1: Statistical information of accuracy assessment for the year 1990, 2005 and 2020.

Confusion matrix for 1990

		Validation data								User accuracy
		Waterbody	Forest	Grassland	Settlement	Shrubland	Bareland	Cropland	Total	
Classified data	Waterbody	28	1	0	0	0	0	1	30	93
	Forest	2	27	0	0	0	2	1	30	90
	Grassland	1	2	42	0	3	1	1	50	84
	Settlement	0	0	0	10	0	0	0	10	100
	Shrubland	1	2	3	0	53	0	1	60	88
	Bareland	0	0	2	0	1	26	3	32	81
	Cropland	1	2	4	0	3	1	79	90	88
	Total	33	34	51	10	60	30	86	302	
	Producer accuracy	84.85	79.41	82.35	100.00	88.33	86.67	91.86		

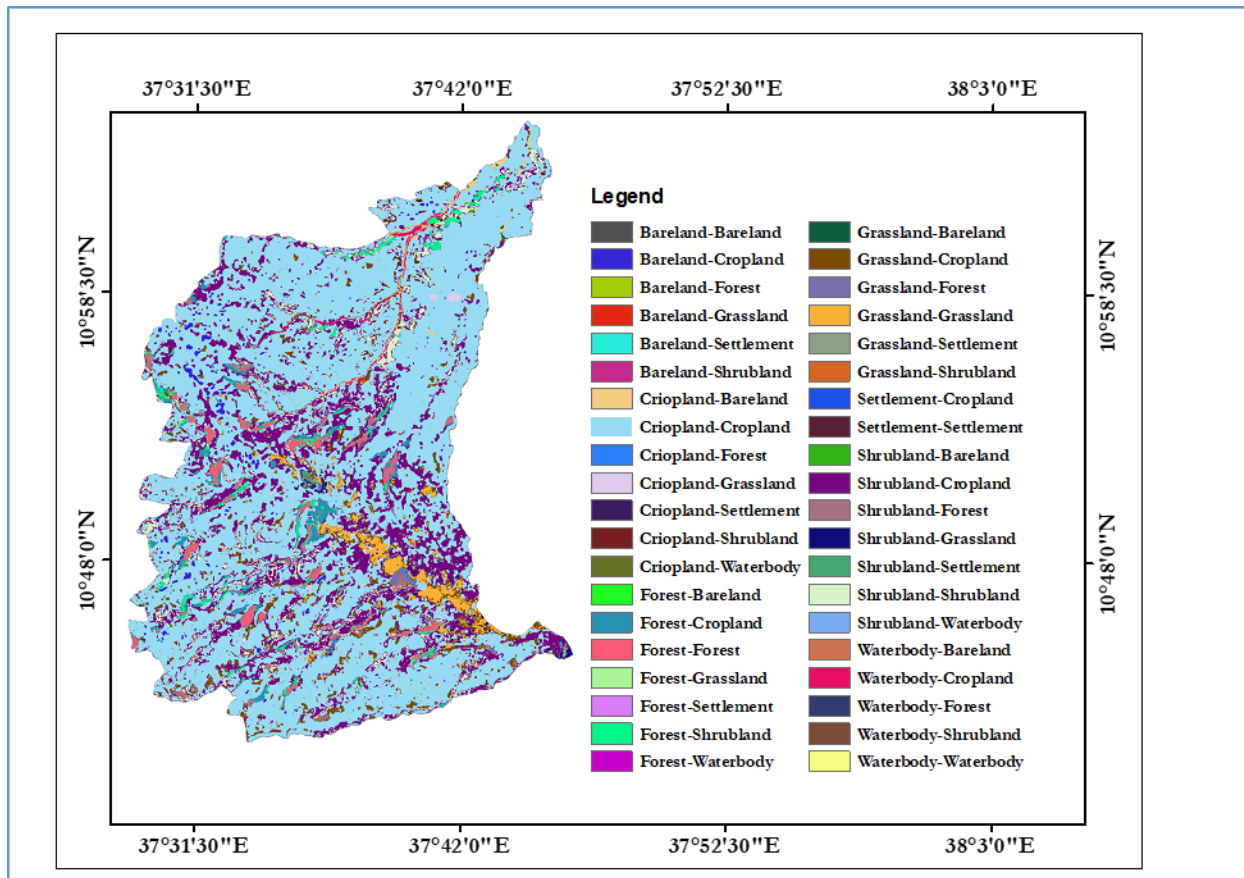
Confusion matrix for LULC map of 2005

		Validation data								User accuracy
		Waterbody	Forest	Grassland	Settlement	Shrubland	Bareland	Cropland	Total	
Classified data	Waterbody	23	1	0	0	0	0	1	25	92
	Forest	1	21	0	0	0	2	1	25	84
	Grassland	1	2	38	0	3	1	1	46	83
	Settlement	0	0	1	18	1	0	0	20	90
	Shrubland	1	1	3	0	49	0	1	55	89
	Bareland	0	0	2	0	1	21	3	27	78
	Cropland	1	1	4	0	3	1	73	83	88
	Total	27	26	48	18	57	25	80	281	
Producer accuracy	85.19	80.77	79.17	100.00	85.96	84.00	91.25			

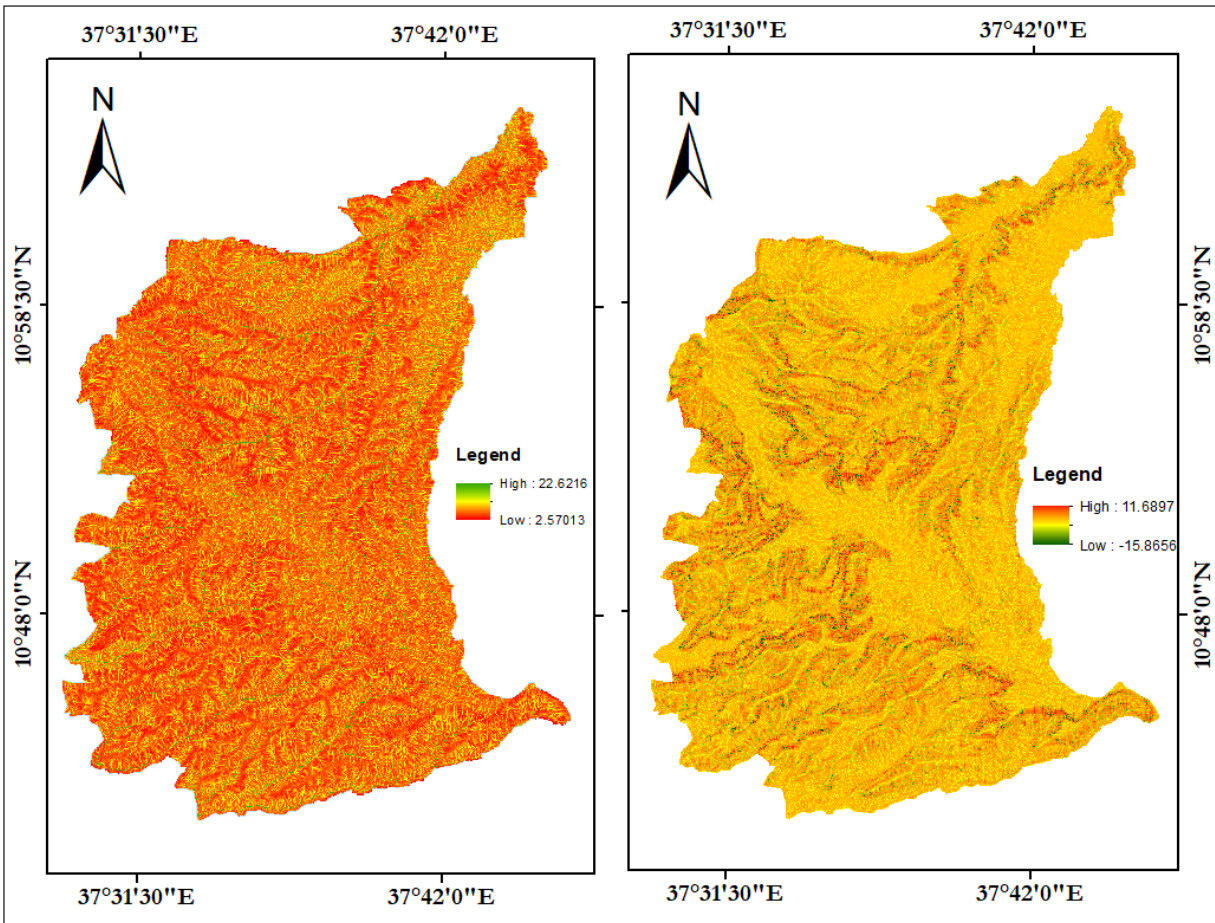
Confusion matrix for LULC map of 2020

		Validation data								User accuracy
		Water body	Forest	Grassland	Settlement	Shrub land	Bare land	Cropland	Total	
Classified data	Waterbody	17	0	1	0	1	0	1	20	85
	Forest	0	13	0	0	0	1	1	15	87
	Grassland	0	0	39	0	1	0	0	40	98
	Settlement	0	1	1	20	1	0	2	25	80
	Shrub land	0	0	3	1	38	0	3	45	84
	Bare land	0	1	1	0	1	15	2	20	75
	Cropland	2	1	5	0	3	1	113	125	90
	Total	19	16	50	21	45	17	122	290	
	Producer accuracy	89.47	81.25	78.00	100.00	84.44	88.24	92.62		

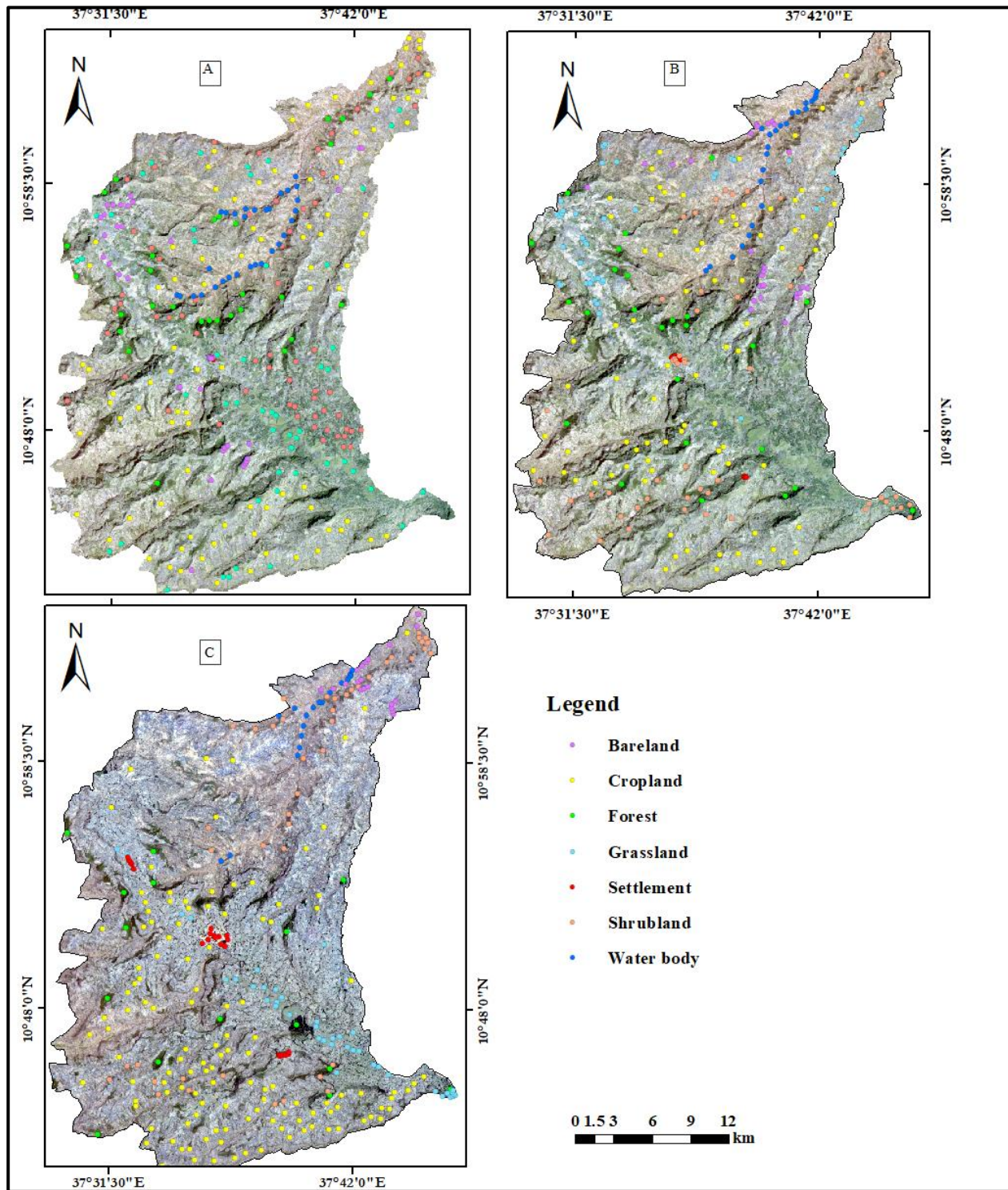
Appendix 2. Land/use and land/cover change between 1990 and 2020



Appendix 3. Stream Power index (SPI) and Topographic wetness index (TWI)



Appendix 4: Accuracy assessment points 1990(A),2005(B) and 2020 (C)



Appendix 5: Two False Color Composite (FCC) scenes of Landsat 5(1990) and one scene Landsat 8(2020) (A&C) and after mosaic clipped FCC image of Dega Damot district for 1990 (B) and clipped 2020 (D).

