THESIS

ABEBAW WUDU ABIYE
MSc in Agricultural Water Management Engineering

Gödöllő, Hungary

2023

HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCE (MATE)

Szent Istvan Campus

Spatiotemporal Dynamics of Soil Erosion Response to Land Use Land Cover Dynamics and Climate Variability in Maybar Watershed, Awash Basin, Ethiopia

Supervisors:

Primary Supervisor: Dr. István Waltner (PhD)

Associate Professor

Co-Supervisor: Dr. Hailu Kendie (Ph. D)

Senior Researcher

Abebaw **Wudu** Abiye

Neptune ID: QBTP7R

Institute of Environmental Science

Department of Water Management and Climate Change Adaptation

GODOLLO, HUNGARY

2023

TABLE OF CONTENTS

TABLE OF CONTENTS **iii**
LIST of TABLES **v**
LIST OF FIGURES **vi**
LIST OF ABBREVIATIONS AND ACRONYMS **viii**
1. INTRODUCTION **1**
1.1Background and Justification 1
1.2Statement of Problem 3
1.3Objectives 4
1.3.1 General Objectives 4
1.3.2 Specific Objectives 4
1.4 Research Questions 4
2. LITERATURE REVIEW **5**
2.1 Land Use and Land Cover Dynamics 5
2.2 Factors Driving Land Use and Land Cover Change 7
2.3 Methods for Analyzing Land Cover and Use Change **7**
2.3.1. Remote Sensing 8
2.3.2 Image Classification 9
2.4. Land Use and Land Cover Change and its Implications 10
2.5Land Use Land Cover Change and Soil Erosion 10
2.6Watershed Management and Soil Erosion 12
2.7 Soil Erosion in the World 13
2.8 Soil Erosion in Ethiopia 15
2.9 Soil Erosion Modeling 16
2.10 Revised Universal Soil Loss Equation (RUSLE) 17
2.11 Modeling Soil Erosion Using GIS and Remote Sensing 21
3.MATERIALS AND METHODS **22**
3.1Description of Study Area 22
3.1.1 Location 22
3.1.1 Geology and Soil 23
3.1.2 Climate 23
3.1.3Agricultural activities of the watershed 24
3.2 Data Collection Method and Source 25
3.2.1 Data Type and Collection Methods 25

3.2.2 Data Type and Collecting Methods 25
3.2.3 Materials and tools used 26
3.2 Data Analysis Methods 26
3.3.1 Land Use and Land Cover Change (LULC) Analysis 26
3.3.2 Soil Erosion Estimation 27
3.3.2.1. Rainfall erosivity (R) factor 28
3.3.2.2. Soil erodibility (K) factor 28
3.3.2.3. Estimating slope (S) and gradient length (L) factors. 29
3.3.2.4. Cover Management Factor (C) 29
3.3.2.5. Conservation or Supportive Practices(P) 30
4. **RESULT AND DISCUSSION** **32**
4.1 Trend of Land Use and Land Cover (LULC) 32
4.1.1. Land Use Land Cover (LULC) 2004 32
4.1.2. Land Use Land Cover (LULC) 2012 33
4.1.3. Land Use Land Cover (LULC) 2020 34
4.2. Land Use Land Cover Change (LULC) 35
4.3 RUSLE Parameter for Soil Loss Estimation 36
4.3.1. Rainfall erosivity(R) 36
4.3.2. Soil Erodibility (K) Factor 36
4.3.3. Slope and Gradient Length (LS) Estimation 38
4.3.4. Land cover/management(C) factor 40
4.3.5 Conservation Practice Factor (P) 42
4.4 Soil loss Estimation 43
4.4.1 Impacts of Land Use Land Cover Dynamics on Soil Erosion 45
4.5. Prioritization of the Watersheds for Conservation Planning 49
5.**CONCLUSIONS AND RECOMMENDATIONS** **53**
5.1 Conclusion 53
5.2 Recommendations 53
6.SUMMARY **54**
7.ACKNOWLEDGEMENTS **55**
8. REFERENCE **56**
9.APPENDIX **63**
10.DECLARATION **64**

LIST of TABLES

Table 1: The type of input data, sources of data, analysis tools utilized, and the data's purpose 26
Table 2: Land use and land cover classes identified in the study watershed 27
Table 3: C-factor value based on (Hurni 2008) and Nigussie etal 2022) 30
Table 4: Land use type in Maybar Watershed for 2004, 2012, and 2020 32
Table 5: Trend Analysis of Land Use and Land Cover Change 35
Table 6: Mean Annual Rainfall and Erosivity factor of the Study Area 36
Table 7: Statistically Summary of Soil Parameters in the watershed 37
Table 8: Soil type and corresponding erodibility factor of the watershed 38
Table 9: Estimated soil loss with slope gradient in 2004 and 2020 40
Table 10: Support Practices (P) factor Based on (Wischmeier & Smith, 1978) 42
Table 11: Temporal variation of soil erosion with land use dynamics 45
Table 12: Distribution of annual and mean soil loss between different types of land use 46
Table 13: Soil erosion across different soil types during 2004, 2012, and 2020. 48
Table 14: Soil Erosion Classification based on Morgan (2005) 49
Table 15: Prioritized part of watersheds for conservation planning purposes. 51

LIST OF FIGURES

Figure 1: Location map of Maybar Watershed 22
Figure 2: Soil types of Maybar Watershed, Ethiopia 23
Figure 3: Mean annual rainfall and maximum/minimum/mean temperatures for the study area 24
Figure 4: Mean monthly rainfall and maximum/minimum/mean temperatures for the study 24
Figure 5: Flow Chart of the analysis 31
Figure 6: Slope class of the study area 31
Figure 7:Land Use and Land Cover of the Study Area (2004) 33
Figure 8: Land Use and Land Cover of the Study area (2012) 34
Figure 9: Land Use and Land Cover of the Study area (2020) 34
Figure 10: Soil Sample Distribution (Left) and Soil Erodibility (K) Factor Map (Right) 37
Figure 11; Slope in degree (left) and Ls _factor value (right) 39
Figure 12: Cover Management factor (C-Value) for the three study years 41
Figure 13 : P _factor Map for Maybar Watershed for the Years 2004,2012 and 2020 42
Figure 14: Annual Soil Loss Map in 2004, 2012 and 2020 of the Watershed 44
Figure 15: Variation in mean soil loss in different land use classes and years 47
Figure 16: Trend of Soil Erosion Severity Map (2004-2020) 50
Figure 17:Annual Soil Loss and Severity Class Map of Maybar Watershed 51
Figure 18: Current Priority Class of the Watershed for Soil and Water Conservation 52

LIST OF TABLES IN THE APPENDIX

Table 1: Soil Parameter Analysis Result--63

LIST OF ABBREVIATIONS AND ACRONYMS

A	Annual Soil loss
ARARI	Amhara Agricultural Research Institute
C	Cover Management Factor
CCME	Canadian Council of Ministers of the Environment.
Co2	Carbon dioxide
DEM	Digital Elevation Model
DSMW	Soil Map of the World
EPIC	Erosion Productivity Impact Factor
ESDB	European Soil Data Base
ETB	Ethiopian Birr
EUROSEM	European Soil Erosion Model
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GIZ	Gesellschaft für Internationale Zusammenarbeit,
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
IWMI	Integrated Water Management Institute
K	Erodibility of the Soil
LS	Length of Slope and Steepness
LULC	Land Use and Land Cover
MUSLE	Modified Universal Soil Loss Equation
NGO	Non-Governmental Organization
OC	Organic Carbon
OM	Organic matter
P	Erosion Control Practices Factor
R	Rainfall Erosivity factor
RS	Remote sensing
RUSLE	Revised Universal Soil Loss Equation
SCRP	Soil Conservation Research Project
SSA	Sub -Saharan Africa
SW	Sub-Watershed
SWAT	Soil and Water Assessment Tool
SWC	Soil and Water Conservation
T	Ton
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
USDA	United States Department of Agriculture.
USGS	United States Geologic Survey
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project
WFP	World Food Program
WLRC	Water and Land Resource Center
Yr	Year

1. INTRODUCTION

1.1 Background and Justification

Land and land cover dynamics have been recognized as critical factors in influencing soil erosion rates across the globe. Ethiopia, a country with a diverse landscape and fragile ecosystem, is not an exception. Soil erosion is a major environmental problem in Ethiopia, leading to the loss of fertile soil, decreased agricultural productivity, and degraded land quality (Asfaw et al. 2021).

Soil erosion is a significant environmental problem that can adversely impact agricultural productivity, land quality, and water resources. Land use and land cover change (LULC) are the primary drivers of soil erosion in many world regions. Ethiopia, a country with a complex topography and diverse ecosystems, is particularly susceptible to soil erosion (Moges et al. 2021)

Land Use land Cover Change (LULC) refer to alterations on the Earth's surface caused by natural or human factors, as stated by Berhane and Mekonen (2009) and (Terefe et al. 2019). Replacing natural vegetation with cultivated land can significantly impact the environment (Tolessa et al. 2019). Expansion of cultivated land has been found to contribute significantly to land degradation, posing a considerable risk to soil fertility. In Ethiopia, many scholars have searched into how land use and land cover changes affect the world's soil resources (Haregeweyn et al. 2017, Zerihun et al. 2018, Ebabu et al. 2019). Determining soil loss, especially in spatiotemporal variation, remains a global threat to soil resources (Waltner et al .2020).

Erosion-caused ecological degradation is an increasing global environmental concern. Loss of soil productivity, habitat destruction, and flooding pose significant risks to food security, water resources, biodiversity, and sustainable development (Ebabu, K et al. 2019, Wang et al. 2016). Various factors, such as land use and land cover changes, rainfall, and catchment surface features, contribute to soil erosion (Ochoa p.a et al. 2015, Wang Z et al. 2016). However, human activities primarily cause soil erosion (Wang, N et al. 2020). The abandonment of land, deforestation, and afforestation are among the most critical factors influencing the occurrence and intensity of soil erosion (Liu, Lc et al.2007). These activities alter land use and vegetation cover, significantly impacting soil erosion (Wang et al. 2016). According to Pimentel etal 1998, agricultural systems lose approximately 75 billion tons of productive soil annually. Erosion is viewed as a significant global productivity issue. Unplanned agricultural practices brought on by human activity start the process of soil erosion. Agriculture without soil conservation practices accelerates this process, especially in sloped locations (Aytop and Enol, 2022).

Soil erosion is a significant issue that impacts the environment, economy, and social factors. It also contributes to climate change and human migration problems. Soil erosion is a widespread concern, especially in agriculture, with up to six million hectares of fertile land lost annually due to water erosion and other related factors. The productivity of crops reduces by 17% each year due to soil loss, which ranges from 22 to 100 tons per hectare per year (Oldman et al 1990. According to Morgan (2005) and Pimentel et al. (1995), soil loss rates in agricultural land vary from 0.5 to 400 tons per hectare, with an average speed of 30 tons per hectare per year. The depletion of soil quality is a pressing issue that can impede sustainable agricultural practices and economic development, particularly in developing nations (Arekhi 2008). Sub-Saharan African (SSA) nations, including Ethiopia, are particularly susceptible to land degradation concerns due to high soil runoff rates and crop nutrient depletion that threaten Agricultural production and farming methods that are good for the environment (Menale et al 2007). The situation is particularly Dire in Ethiopia, where severe soil degradation problems have led to the loss of topsoil and a decline in soil functions, depleting its deteriorating soil resources (Addis and Klik 2015). Soil degradation reduces agricultural productivity by stripping essential nutrients, organic matter, and colloidal fractions from the fertile topsoil (Kebede et al. 2011, Wubet et al. 2013).

Understanding the spatiotemporal dynamics of soil erosion in response to land use and land cover change (LULC) is also crucial for developing effective soil conservation and management strategies in Ethiopia. The country has experienced significant changes in land use and cover, resulting in increased soil erosion rates in some regions. Analyzing the spatiotemporal dynamics of soil erosion in response to land use land cover change makes it possible to identify areas more susceptible to soil erosion and prioritize them for soil and water conservation interventions. This knowledge will also help to evaluate the effectiveness of current soil conservation measures and identify areas where additional interventions are needed. Developing effective soil conservation and management strategies can reduce soil erosion rates, increase soil fertility, and improve agricultural productivity in Ethiopia. Therefore, understanding the spatiotemporal dynamics of soil erosion in response to land use land cover is essential for promoting sustainable land management practices and ensuring food security in the country. This study investigated the impact of land use and land cover change (LULC) between 2004 and 2020 on soil erosion. The Revised Universal Soil Loss Equation (RUSLE) erosion model was used to examine trends of soil loss at the sub-watershed level to determine the mean and total soil loss for different periods. Furthermore, the study examined the spatial distribution of erosion severity to evaluate the overall trends of soil erosion.

1.2 Statement of Problem

The alterations humans have made to land use and land cover have substantially impacted the environment and natural resources. These modifications have brought about unfavorable consequences such as soil erosion, a reduction in flora and fauna, desertification, the regular occurrence of dry spells and heavy inundations, and the contamination of water and air (Shiene 2012). Accurately modelling land-use changes is crucial for predicting soil erosion and degradation, as land-use changes directly affect soil erosion (Leh et al.2013). Assessing the effects of changes in land use on soil erosion at the watershed scale is of great importance (IPCC 2007). Furthermore, identifying the different categories and consequences of alterations in land use and land cover can assist in the formulation of efficient strategies for the sustainable conservation of natural resources (Geist 2002).

Numerous investigations have been carried out worldwide to determine the possible impacts of land use and land cover (LULC) alterations on soil erosion across various spatial and temporal dimensions (Leh et al.2013, Alfred et al.2010). Several research projects were conducted in the Ethiopian highlands (Eleni et al.2013; Tsegaye 2007, Zeleke and Hurni 2001, Tukura and Akalu 2019). Despite this, the research has not been conducted in the watershed of Ethiopia's lowlands. Land Use Dynamics have been found to impact soil erosion in Ethiopia's highlands significantly (Geist 2002). While several studies have been conducted on the impact of land-use change on soil erosion, the hot and humid lowlands have not been adequately studied (Nyssen et al.2018).

The primary objective of this study was to measure the extent to which land use changes have influenced the risk of soil erosion in the Maybar sub-watershed, located in the South Wollo district of Ethiopia. The significance of this research lies in the fact that this region has suffered from severe land degradation, caused mainly by deforestation, improper land and soil use, and resettlement. The main objective of this study was to address a significant gap in knowledge regarding the influence of land use and land-cover changes on soil erosion potential. The study's focus was on identifying the areas with the highest level of degradation in the watershed, with the intention of proposing specific conservation measures to address these areas' issues. Moreover, the findings of this research provided valuable insights into the long-term effects of implementing watershed management practices to mitigate soil erosion rates. Overall, this study holds tremendous importance in understanding the consequences of land use changes on soil erosion in the Maybar sub-watershed and can serve as a basis for future research and policy decisions.

1.3Objectives

1.3.1 General objectives

The main objective of this study was to evaluate the spatiotemporal changes of soil erosion, in response to the variations in land use and cover and climate variability, in the Maybar Sub-Watershed in the South Wollo Zone of Ethiopia.

1.3.2 Specific Objectives

1. To analyze the trend of Land Use and Land Cover (LULC) changes in the study area over the past few decades
2. To assess the soil erosion rate in the years 2004, 2012, and 2020 due to changes in land use and land cover (LULC) and to estimate the soil erosion with different land use and land cover type
3. To assess the potential risk of soil erosion in various regions of the study watershed and prioritize them for Soil and Water Conservation (SWC) interventions based on their current status.
4. To evaluate the impact of climate variability on soil erosion rate in the study watershed.
5. To evaluate the effectiveness of soil conservation measures in reducing soil erosion.

1.4 Research Questions

1. Can the dynamic land use and cover changes lead to soil erosion?
2. How has the spatial and temporal distribution pattern of soil erosion changed from 2004 to 2020?
3. What is the long-term average annual rate of soil loss?
4. Which area of the Watershed has the highest risk of soil erosion and should be prioritized for conservation planning and implementation?
5. Is there a correlation between climate variability and soil erosion trend?
6. Which factor(s) has had the most significant impact on the rate of soil erosion in the study area?

2. LITERATURE REVIEW

2.1 Land Use and Land Cover Dynamics

Land use pertains to how humans exploit the land for specific objectives, shaped by production and consumption dynamics across diverse sectors like industrial zones, residential neighborhoods, agricultural fields, grazing areas, mining locations, etc. Other way affects the earth's surface's physical state, including features like forests, croplands, topography, soil, and water. Land-use change occurs when a physical, biological, or chemical alteration results from land management practices (Quentin et al. 2006). Land Use dynamics refers to transforming land use from one kind to another, significantly altering the earth's surface. Population growth, economic development, and the demand for agricultural land are the primary drivers of these land-use changes. Land use also plays a crucial role in determining soil erosion rate in a watershed and contributes significantly to soil, water, and air pollution (Ellis and Roberts 2007, Schulze 2000 and Tena et al. 2019).

Understanding the impact of land use and land cover alterations is essential for effectively managing land and water resources over a sustained period (Kiros et al. 2015). The change in land use and the cover is primarily driven by the urgent need for natural resources to satisfy the requirements of human society (Meyer and Turner 1992, Vitousek et al.1997). The condition to supply food, fibre, water, and shelter for more than six billion people is causing global changes in forests, farmlands, rivers, and air, which has led to an expansion of croplands, pastures, plantations, and urban areas in recent decades (Foley et al. 2005). This expansion has been accompanied by significant energy, water, and fertilizer usage increases and a substantial loss of biodiversity. In the context of environmental change, comprehending the dynamics of land use and land cover alterations has become increasingly critical for analyzing the current resource status and devising sustainable resource management options. It is imperative to have an in-depth understanding of the direction and underlying causes of these changes, as well as their potential impacts on the natural environment and humans. Ongoing human activities have resulted in continuous land cover and land use modifications, significantly transforming the environment and its associated services. Therefore, investigating the dynamics of land use and land cover change has become a fundamental aspect of environmental research, providing valuable insights into the complex interactions between human activities and the environment. Deforestation and other land cover changes have become a global issue with significant impacts on human livelihood systems (Woldmak and Solomon 2013).

Human activities have significantly impacted Ethiopia, mainly through changes in land use and land cover. One of the most urgent environmental concerns is the conversion of natural vegetation into cultivated land, leading to considerable modifications in the landscape. This transformation process can have far-reaching impacts on various ecological and socio-economic aspects, such as changes in soil fertility, hydrological regimes, biodiversity loss, and land-use conflicts. Moreover, it can also affect the livelihoods of local communities who depend on natural resources for their survival. As such, understanding the underlying causes and impacts of this transformation process is crucial for formulating effective land-use policies and management strategies that promote sustainable development and environmental conservation (Ajanaw 2021). Ethiopia's highland regions, which comprise 40% of the country's total area, are characterized by high population and livestock pressure, extensive cultivation, and high land fragmentation, leading to severe land degradation (Essays 2011). The expansion of rain-fed agriculture is responsible for annual deforestation estimates ranging from 80,000 to 200,000 hectares (Temesgen et al. 2014). The rate of land use and land cover changes and degradation is accelerating at an alarming pace in Ethiopia's highlands (Yohannes et al. 2017), causing the loss of natural habitats to other land uses (Gelet et al.2010). Farmers frequently cultivate crops on steep slopes, leading to soil erosion and water resource degradation. The rapid population growth in Ethiopia has led to the rapid expansion of agriculture at the expense of forest resources and the free grazing system, further exacerbating ecosystem depletion. Land use and land cover (LULC) change refers to the human modification of the Earth's terrestrial surface from one land management or land cover type to another (Hailemariam et al .2016).

Ethiopia's dominant characteristic of land use and land cover (LULC) change is transforming natural vegetation into agricultural land. This phenomenon has been extensively studied and documented by scholars and researchers, who have highlighted the significant impact of this process on the country's natural resources and environment (Gashaw et al. 2018, Bewket and Abebe 2010). According to the report of FAO (2020) that Ethiopia has experienced a reduction in forest cover from 13.3 percent (14.69 million hectares) of the country's total area in 1993 to 11.4 percent (12.54 million hectares) in 2016. This trend is expected to continue, with an anticipated annual rate of change of 0.8 percent (104,600 hectares per year). Studies conducted in Ethiopia have revealed significant changes in land use and land cover across different regions and periods (Gete 2000).

2.2 Factors Driving Land Use and Land Cover Change

Understanding the causes of land use and land cover change is often oversimplified, leading to ineffective environment-development policies (Lambin et al.2001). To better understand the current state of land use and land cover and predict future changes, it is vital to identify and describe the factors that drive these transformations, along with their effects and feedback mechanisms (Baulies and Szejwach 1998).Land use and land cover changes can be influenced by a variety of socioeconomic forces, including agricultural intensification, urbanization, globalization, population growth, demand for fuelwood and construction materials, agricultural expansion, and policies, as well as tenure insecurity(Lambin et al. 2001). The causes of land use and land cover change can be categorized as either proximate or underlying. Proximate causes refer to immediate, direct, or local actions that directly impact land use and cover, such as agricultural development or urban expansion. On the other hand, underlying causes refer to broader social, economic, or political processes that indirectly influence land use and land cover change at a national or global level. These include factors such as population dynamics, agricultural policies, or global economic forces, which can shape patterns of land use and cover change over long periods. Recognizing and understanding the complex interplay between these proximate and underlying causes is vital for designing effective policies and management strategies that can promote sustainable land use and cover change. (Geist and Lambin 2002). Effective land use and land cover change policies must consider both causes.

Land use and land cover change is often driven by a complex web of factors at multiple scales. While proximate causes of change are generally linked to local activities, underlying causes can originate from regional or global levels, with intricate interplays between them. These underlying causes are typically complex and involve social, political, economic, demographic, technological, cultural, and biophysical variables considered fundamental factors. In contrast, proximate causes tend to operate at a more limited scale. Understanding the interrelationships between these different factors and their impact on land use and land cover change is crucial to developing effective strategies for managing and mitigating the effects of these changes (Lambin et al .2003).

2.3 Methods for Analyzing Land Cover and Use Change

Detecting changes in land use and land cover involves observing a phenomenon or object to identify any alterations in its condition (Smith 2023). This information is crucial for effective land management, sustainable development, conservation, and quantitative analysis of population distribution (Tewabe and Fentahun 2018). Four key aspects of change detection include recognizing the occurrence of changes, categorizing the nature of the change, estimating the magnitude, and analyzing the spatial distribution of the change (Pathak 2014). Remote sensing data is frequently used to identify changes in land use and land cover, relying on the ability to measure radiance values remotely, which reflect changes in the land cover. With advancements in digital processing and computer power, the accuracy and efficiency of change detection methods using satellite imagery have significantly improved (Zubair. A 2006).

Methods based on remote sensing and geographic information systems have been applied worldwide to investigate and examine land use and cover modifications. These techniques have proven useful for analyzing a range of surface features, such as vegetation and air pollution, with increasing accuracy over time, thanks to the progress of geographic information systems and remote sensing technology (Chavare.S et al. 2015). Geographic Information Systems (GIS) are computer-based systems that use geographic data to quickly collect, store, modify, analyze and display data with a geographical component (Dangemond 1992).

2.3.1. Remote Sensing

Remote sensing is acquiring data on an object, location, or phenomena by analyzing information obtained via a device that does not directly contact the examined object (Coburn and Roberts 2004). Remote sensing can gather information about the surface of the Earth by detecting and recording reflected or emitted energy from the terrain's surface (Sohl and Sleeter 2011). Remote sensing satellite data has several advantages including large area coverage at once, a synoptic view of a given area, and regular coverage at consistent intervals (Pramanik 1993). Despite the advantages, remote sensing has some limitations such as the inability to acquire adequate data and information through clouds, the similarity in appearance of different phenomena by the sensor, and the coarse resolution of satellite imagery for detailed mapping (Fonji and Taff 2014). Nonetheless, remote sensing data can be highly useful in managing, assessing, and monitoring natural resources, such as agriculture, forestry, water, and geology (Berlanga and Ruiz 2002). Remote sensing is an important tool in land change science for observing and researching landcover changes in underdeveloped and developing regions. Many LULC scientists use it for resource evaluation (Patil M.B et al.2012). Tewabe and Fentahun (2020) to estimate LULC changes in the Lake Tana Basin of Northwest Ethiopia and by Fonji and Taff (2014) to track LULC changes in northern Latvia. Remote sensing is an essential technique in land change science as it enables observing large areas of the Earth's surface that ground-based observations cannot achieve. The use of remote sensing technology has become a valuable tool for monitoring and analyzing land cover changes, allowing for a better understanding of land use patterns on both a local and global scale (Shanwad 2008). Remote sensing can detect and record electromagnetic radiation emitted or reflected from the Earth's surface, which can be used to identify changes in land use and land cover over time. With its multi-spectral and temporal resolution capabilities, remote sensing has proven to be a powerful tool for analyzing LULC dynamics.

Remote sensing technology provides a vast amount of data, ranging from highly detailed photos to broad regional datasets updated regularly, to low-resolution images captured daily from across the globe. Satellite-based remote sensing's synoptic image of the Earth's surface has become a key tool for monitoring land use and cover changes over time. These changes may be due to natural or artificial causes and result in altered reflectance patterns in the incident radiation, caused by variations in soil moisture, vegetative cover, or other modifications to the Earth's surface (Sharma et al .2001).

2.3.2 Image classification

The process of image classification is a challenging task that requires the translation of statistical spectral information into distinct categories or labels that portray the characteristics of terrain ((Mather and Tso 2016). Numerous factors influence this procedure, and it involves algorithms aimed at categorizing every pixel in an image into various land use and land cover categories or themes (Lillisand and Kiefer 1994).

Remote sensing data can extract important thematic information from the Earth's surface. Multispectral categorization is a commonly used method for extracting information from remote sensing data (Jensen 1996). Image processing technology is used to gather and manipulate digital images, and image classification is typically carried out in four stages: preprocessing, training sample selection, target comparison, and accuracy evaluation.

A process known as image classification is used to classify a digital image's pixels into various land use and land cover categories (Huang 2005). This categorization has traditionally been based on remotely sensed data. The process can be performed visually or digitally, utilizing different types of image data such as single or multiple image datasets, or image data containing additional information such as altitude values or expert knowledge of the location. Various algorithms are involved in this process, and several factors influence it.

There are two methods of image classification, namely supervised and unsupervised classification. In supervised classification, the analyst has prior knowledge of the study area and selects representative samples for each land cover class. The output is classified into different classes based on these samples. On the other hand, unsupervised classification is used when prior knowledge of the study area is not available and the computer algorithm identifies groups of pixels with similar spectral characteristics and assigns them to classes.

2.4**. Land Use and Land Cover Change and its Implications**

Tegegne (2002) suggests that land use and land cover changes significantly affect rural livelihoods. The impacts include negative effects on land resources, the environment, livestock, and ecosystem products and services. Land degradation, soil erosion, and reduced production are among the impacts on land resources. Rural areas are subject to various changes that can affect their resilience to climate change, such as alterations in rainfall patterns, water availability, and access to clean water. Converting grazing land into agricultural land can also negatively impact livestock, especially cattle raising. Furthermore, land use and land cover modifications can negatively impact the provision of ecosystem services and goods, particularly concerning deforestation.

In the domain of global ecosystem dynamics, land use and land cover (LULC) change are key factors affecting biogeochemical, nutrient, and hydrological cycles. The change of land use land cover has significant implications for regional, social, economic, and environmental development. Given the extensive impact that land use and land cover change have on Earth-atmosphere interactions and biodiversity loss, it is essential to incorporate these factors into integrated models and assessments of environmental challenges to promote sustainable development and inform human responses to global change (Chen and Stow 2002).

The modification and alteration of land use and land cover can profoundly affect different environmental factors. Soil depletion is a significant consequence of these changes, regardless of other factors like climate, soil properties, and terrain. The state of land cover plays an essential role in mitigating soil erosion by minimizing the direct effect of rainfall on the soil, enhancing the organic content in the ground, facilitating water infiltration, reducing runoff velocity, and preventing sediment transportation on the surface. Anthropogenic activities that alter land use and land cover significantly impact the speed of soil erosion (Qiang et al.2016).

2.5 Land Use Land Cover Change and Soil Erosion

The relationship between land use, land cover alterations, and soil erosion is a widely recognized phenomenon. The type of land cover significantly impacts the amount of soil loss caused by erosion, according to studies conducted by Gete and Hurni (2001) and (Gashaw et al.2014). Belay (2002) recommends implementing effective management strategies for land use and land cover changes to address the issue of soil erosion caused by agricultural practices. The effects of land use and land cover changes are extensive and can impact various socioeconomic and environmental systems. These changes can create trade-offs between food security, sustainability, biodiversity, and human vulnerability (Hailslasie 2005).

According to Belay (2002), Ethiopia's main reason for the transformation of land use and land cover is the substitution of forest and shrub lands with agricultural lands. This change in land cover leads to increased soil erosion due to the removal of soil particles and reduction of soil cover protection against decay. Over the past century, the highlands of Ethiopia have undergone substantial alterations in land cover, largely forced by agricultural activities and human settlements (Gete 2000, Woldeamlak and Sterk 2002). The changes in land use and cover have led to higher population pressure, unsustainable land management practices, and the depletion of vital natural resources like soil. These changes have resulted in adverse environmental consequences, such as soil degradation and the loss of crucial natural resources. Land use and land cover modifications profoundly influence ecosystem services, including biodiversity, climate, soil, water, and air. Although other factors such as climate, soil qualities, and topography play a role, land use and land cover changes can impact soil erosion rates. The land cover is vital in reduction soil erosion by decreasing the direct effect of rainfall on soil, boosting soil organic matter content, intensifying water infiltration, mitigating runoff velocity, and reducing sediment movement on the surface. Anthropogenic activities that result in changes to land use and land cover substantially affect soil erosion rates. Therefore, it is crucial to employ integrated management practices to maintain sustainable development and reduce human vulnerability to environmental challenges (Ajanaw 2021).

Scholars have studied the impact of changing land use and land cover on soil erosion across various regions in Ethiopia. For example, a recent investigation carried out in the Erer Subbasin, Northeast Wabi-Shebelle Basin of Ethiopia (Woldemariam and Harka 2020) discovered that the percentage of cropland, bare land, and settlements escalated from 47.92% to 8.03%, and 0.20%, respectively, in 2000 to 64.36%, 9.71%, and 0.61%, in 2018. Furthermore, forest land, shrubland, and water bodies reduced from 2.99%, 40.67%, and 7.55% in 2000 to 2.13%, 36.61%, and 6.05%, respectively in 2018. Similarly, (Kidane et al. 2019) exposed that the average rate of soil erosion increased from 25.8 tha^{-1} $year^{-1}$ in 1973 to 28.7 tha^{-1} year1 in 1995 and 30.3 $that^{-1}$ $year^{-1}$ in 2015. Consequently, total soil loss escalated from 198 million t/year in 1973 to 221 million t/year in 2015 due to the rapid expansion of cultivated land, which has led to the depletion of forest and shrubland.

2.6 Watershed Management and Soil Erosion

Watershed management practices such as afforestation, terracing, and soil conservation structures can reduce soil erosion by controlling surface runoff, preserving soil structure, and improving vegetation cover. One study found that these practices decreased soil erosion rates from 31.2 to 12.2 tons per hectare per year. Similarly, the use of contour bunds and stone terraces reduced soil erosion rates by 85% and 80%, respectively, while improving soil quality. These practices can mitigate the negative impacts of soil erosion on agriculture, water quality, and ecology (Zehtabian et al.2017, Gebresamuel et al.2019)

The Ethiopian government, NGOs, and communities have taken action to counter the negative impacts of land degradation by implementing environmental restoration measures. Several methods can be used to promote sustainable land use practices and manage watersheds effectively. These include implementing soil and water conservation techniques, utilizing enclosures to minimize human and livestock interference, and adopting integrated watershed management (IWM) approaches. The latter involves a coordinated and adaptive management process that addresses both human and ecological systems at the watershed scale, defined as a significant sub-drainage area within a river basin. (Gebregziabher et al. 2016, CCME 2016).

The collaborative effort between the Irish development cooperation program and northern Ethiopia began the integrated watershed management (IWM) strategy in 1997. According to GIZ (2015), this initiative aimed to achieve six main objectives. The first goal was to enhance food security by improving the production of food and cash crops. To enhance soil and water conservation, soil fertility, and land management, the second goal aimed to utilize suitable biological and physical measures and agricultural inputs. This objective recognized the significance of maintaining healthy soil and water resources and improving agricultural practices to ensure sustainable land management. The third objective was to improve access to multiple water sources for irrigation, livestock, and domestic purposes. Diversifying agricultural and non-agricultural activities to increase household incomes was the fourth goal, while the fifth was to promote sustainable development of local resources by empowering communities. Finally, the IWM strategy aimed to promote adopting sustainable agricultural practices by providing incentives. Overall, the IWM strategy aimed to better people's daily lives and economies in northern Ethiopia by promoting sustainable agriculture, enhancing food security, and building resilience to climate change.

Scholars such as Herweg and Ludi (1999) and Gebremichael et al. (2005) have conducted separate studies to evaluate the effects of different integrated watershed management strategies, such as stone bunds and exclosures, on mitigating soil erosion and runoff. However, it is worth noting that the combined impact of all watershed activities, whether positive or negative, determines their overall effect on the watershed (Chiang et al. 2012). In Ethiopia's highlands, establishing exclosures has emerged as an integral approach to combat land degradation (Descheemaeker et al. 2006). It is projected that such exclosures can reduce soil loss by 26-123 tons per hectare per year by reducing the volume and speed of runoff.

Herweg and Ludi (1999) have suggested that applying soil and water conservation techniques may decrease the runoff by 10 to 60%. Likewise, Gebremichael et al. (2005) reported that using soil and water conservation practices could reduce soil erosion by as much as 68%.

Expanding terraces is a helpful way to enhance onsite soil resources and increase crop productivity. This approach can positively impact onsite natural resources by improving soil macronutrients, reducing soil erosion, and boosting crop yields (Tilahun et al. 2021).

2.7 Soil Erosion in the World

The soil degrades rapidly, and this issue broadly impacts many regions. Soil erosion is a primary factor in this degradation, leading to a decline in soil fertility and land quality. This is a significant environmental concern as it affects the availability of essential resources such as water. According to El-sway (1994), approximately 55% of the world's damaged soils, covering almost 2 billion hectares, are caused by water erosion. Recent research by van Biggelaar et al. (2004) found that the annual production losses for selected crops worldwide could amount to up to US$400 million. Lal (1994) found that water erosion destroyed approximately 915 million acres of land in tropical regions. In Africa, Lal (1995) reported that crop production had declined between 2% to 40% due to erosion, with an average loss of around 8% across the continent. He also found that soil erosion in Africa has caused yield reductions of about 9%, and if the current trend continues, the yield loss by 2020 may reach almost 16%. Additionally, Dregne (1990) identified several African regions where erosion could lead to yield reductions as high as 50%.

Soil erosion is the loss of fertile topsoil from the earth's surface caused by water, wind, or tillage. According to Lal and Stewart (1990), soil degradation occurs when human activities harm the soil, decreasing soil quality. Soil deterioration disrupts ecosystem function and affects global and local climate by interfering with the water balance, energy, nitrogen, carbon, sulfur, and other element cycles. The most valuable component of topsoil, which includes organic matter and fine mineral particles, is preferentially eliminated by wind and water erosion. The erosion of soil that contains two to five times the organic matter and colloidal percentage of the original ground has significant on-site and off-site consequences, as per Brady and Weil (2003) and Lal and Stewart (1990).

The local and global effects of soil erosion make it a major environmental problem (Shiferaw 2012). Over the last ten years, soil erosion has increased globally, with developing countries being the most affected. This rise can be attributed to population growth and limited resources (Bayramin et al. 2003). Soil erosion occurs faster than soil development in many areas, and previous research has shown that this is more than just a theory. According to FAO (2015), soil loss on cultivable or unlimited grazing pastures is projected to be 100 to 1000 times greater than natural erosion, less than 1 ton ha-1yr-1. The main difference between natural and accelerated soil erosion is that in the latter, the soil is manipulated and exposed to make it easier for detaching and carrying forces to attach and transfer (FAO 2015).

Agricultural land degradation is a common problem, and soil erosion is a primary cause (Stocking and Murnaghan 2001). Soil erosion occurs when water or wind erodes the surface, decreasing soil productivity due to physical topsoil loss, reduced rooting depth, nutrient removal, and water loss (Yesuf et al. 2007). Climate, plants, parent material, and topography are only a few factors that might affect soil erosion. Since soil erosion can lead to various environmental problems, including loss of organic matter and nutrients, decreased landscape production, and poor downstream water quality, evaluating the impacts of soil erosion on land degradation is necessary (Newcombe and MacDonald 1991). In some cases, soil erosion may result from previous soil quality loss, particularly if the soil's structural components have been damaged. In other situations, erosion can cause soil and land degradation (Lal 2001).

Soil erosion can have significant impacts not only on the eroding site but also downstream. Upstream or on-site effects of soil erosion can be particularly severe, particularly in agricultural areas. It can lead to soil degradation, including reduced soil depth in the root zone, loss of organic matter, and nutrient depletion. These factors can significantly decrease soil fertility and affect crop productivity. This reduces available soil moisture content, limits crop growth, and increases fertilizer expenses needed to maintain yields (Holdsworth and Morgan 2005). Off-site effects are caused by downstream soil deposition, which reduces the capacity of drainage ditches and rivers, increases flood risks,

blocks/fills irrigation lines, and shortens reservoir lifespan. Many irrigations and hydropower generation projects have been damaged by sedimentation caused by soil erosion. In addition to its negative impact, the carried sediment contains compounds like nitrogen and phosphorus that increase nutrient levels in water bodies and contribute to eutrophication (Morgan 2005, Nigatu et al. 2016). Erosion breaks down soil aggregates and clods into their constituent clay, silt, and sand particles. This process has the potential to release CO2 into the atmosphere. Thus, erosion contributes to climate change, and increasing the CO2 level of the atmosphere amplifies the greenhouse effect (LAL 1995, 2004, 2005). Soil erosion can have severe economic consequences that reduce agricultural productivity and cause loss of farm revenue. The impacts of soil erosion on productivity can occur both on-site and off-site. Three primary factors contribute to on-site production loss: long-term effects on productivity, short-term effects on productivity, and soil quality deterioration. In soils with a restrictive root layer, the reduction of topsoil depth has the most severe impact. Soil erosion also leads to the pollution of natural waterways, which can have negative ecological consequences (Lal 2001).
The process of soil erosion leads to adverse effects on the environment and agriculture, such as the depletion of soil nutrients, surface water pollution, reduced productivity, and contributions to global climate change (Zuazo and Pleguezuelo 2008). The issue of soil erosion and its negative impact on the environment and food production is a longstanding one that has persisted since the advent of agriculture. Several factors influence soil loss, such as the terrain, rainfall, soil erodibility, vegetation cover, and land management practices. To track erosion levels caused by various crops, the University of Missouri initiated the first experimental plots as early as 1917 (Foth 1990).

2.8 Soil Erosion in Ethiopia

Soil erosion is a major environmental issue with both local and global consequences. In developing countries like Ethiopia, where the ability to prevent soil erosion and restore lost nutrients is limited, the economic impact of soil erosion is particularly severe. These countries are also grappling with rapid population growth, which increases demand for already depleted resources and drives production onto marginal and vulnerable lands. This, in turn, exacerbates erosion and reduces productivity, creating a cycle of poverty, population growth, and land degradation. Ethiopia's primary causes of soil erosion are farming on steep slopes, vegetation removal, overgrazing, and rapid population growth. Every year, Ethiopia loses around 1.5 billion tons of topsoil from its highlands, which is more than its annual production rate, posing a grave threat to its food security. To mitigate this issue, there is a need to assess the extent of the problem and the factors contributing to erosion and identify high-risk areas that require tailored management interventions. The efficacy of different soil conservation methods can also vary depending on the governing variables and existing erosion processes, making it necessary to evaluate the soil conservation potential of various management techniques. (Luelseged and Paul 2008).

The agricultural sector in Ethiopia is heavily reliant on the Land and supports more than 85% of the population. However, unsustainable land management practices and soil erosion have led to a reduction in soil productivity. The average agricultural production in Ethiopia is low compared to international standards, mainly due to topsoil loss through erosion (Sertsu 2000). Reports indicate that soil loss due to cultivated field erosion in Ethiopia amounts to around 42 t ha1 year1 (Hurni 1990, 1993). In the mid-1980s, FAO (1986) estimated that 50% of Ethiopia's highlands were already "seriously degraded," leading to a 2.2% decrease in land productivity. The Amhara region in Ethiopia's northwest highlands is mainly affected by severe soil erosion, with estimates ranging from 19.2 to 25 tons ha-1yr-1 (Yeshaneh et al. 2017, Mekuriaw 2017). Furthermore, it has been estimated that the yearly average soil loss from farmland is 200-300 tons per hectare. The cost of soil erosion between 1985 and 2010 is estimated at around $1.5 billion. This information has been reported by several studies, including Tiruneh and Ayalew (2016), (Gessese et al. 2015), and (Setegn et al. 2009). Erosion in Ethiopia is caused primarily by topographic and climatic factors. However, clearing forests for agricultural expansion, cultivating marginal lands, and overgrazing communal lands exacerbate the problem, making the ecosystem more sensitive to rainfall-driven erosion in the northwest Highlands (Addis et al.2016). Deforestation, uncontrolled grazing, and intensive crop production systems reduce vegetation cover, leaving the Land more susceptible to water erosion (Brady and Weil 2003, Hurni 1988). There is a need to carry out additional studies that can enhance our comprehension of the harmful impacts of soil erosion on crop production, sustainability, and food security in Ethiopia.

2.9 Soil Erosion Modeling

One approach to studying soil erosion is modelling, which involves using mathematical equations to describe the processes of Separation, Movement, and Surface Deposition of Soil (Renschler et al.1999). This allows for estimating soil erosion over time, which can be more efficient than measuring the decline in the field. However, developing a comprehensive database to analyze the impact of factors such as land-use change and climate change can be time-consuming. Nonetheless, modelling techniques can provide valuable insights into soil erosion and sediment output in different scenarios.

Several models are currently available for assessing soil erosion, such as SLEMSA, EUROSEM, SWAT, USLE, RUSLE, and MUSLE, with many more under development. These models can be categorized as empirical, conceptual, or physical based on their representation of biological processes and data requirements (Fantaye 2022).

Models used to assess soil erosion have different strengths and limitations. While physical-based models effectively calculate sediment outputs from basins, they require large datasets and have certain restrictions (Renschler and Harbor 2002). Nonetheless, simplistic models such as the Universal Soil Loss Equation (USLE) can be utilized with limited datasets (Bartsch et al. 2002) to estimate soil erosion and sediment yield resulting from inter-rill and rill erosion. Additionally, empirical models can efficiently predict erosion quantities under different management options. However, it's important to remember that each model has unique features and applications.

One commonly used soil erosion prediction model worldwide is the USLE, including its modified versions, such as the RUSLE. These models are popular due to their user-friendliness and compatibility with GIS (Millward and Mersey 1999). Although RUSLE is comparable to its predecessor empirical model (USLE), numerous changes have been made. RUSLE is now a simple and generally recognized model for estimating soil loss at the watershed scale (Renard et al. 1997).

Improving soil-erosion modelling is a challenging task, and one of the obstacles is the lack of baseline information on how models are utilized.

2.10 Revised Universal Soil Loss Equation (RUSLE)

The RUSLE is a technique used to approximate the yearly average amount of soil eroded by water runoff on various agricultural terrains while accounting for particular agricultural and management practices. It is constructed upon empirical data and was initially inspired by the USLE model, which was first proposed by Wischmeier and Smith in 1978; it has more extensive capabilities and incorporates a database that was not available when USLE was initially developed (Renard et al .1997).

The RUSLE model is a versatile computer program continuously being enhanced and adjusted based on feedback from users worldwide. The RUSLE can be used in any land use type where the soil material is subjected to raindrop impact and overland flow caused by rainfall intensity greater than infiltration rate. Generally, the RUSLE model is an empirical model that calculates soil erosion within each pixel, considering all six parameters of the previous USLE model (Renard et al. 1997). This model can be represented as a function of six factors, as shown in equation (1) below.

$$A= R x K x LS x C x P .... (1)$$

The six factors in the RUSLE model are denoted as follows: A is used to determine the average soil loss per year over the study period (ton $ha^{-1}y^{-1}$); R represents the erosivity factor driven by rainfall (MJ mm ha^{-1} h^{-1} y^{-1}); K denotes the soil erodibility factor (Mg ha ha^{-1} MJ^{-1} mm^{-1}); LS is the topographic factor; C represents the cover factor, and P refers to the support practices (SWC) factor.

Rainfall erosivity Factor (R)

Farhan et al. (2013) established a way to measure the erosive force of soil erosion caused by local average annual precipitation and runoff, known as the R-factor. This factor precisely gauges the erosive capacity of rainfall. A more suitable way to express the erosivity of rain is through an indicator that considers the precipitation's kinetic energy.

The volume, intensity, energy, length, pattern, and size of raindrops from precipitation and associated runoff all play a role in the multidimensional erosion process caused by rainfall (Farhan and Nawaiseh 2015). To determine the rainfall erosivity parameter in the RUSLE model (Renard et al. 1997), one can use the formula that involves dividing the total energy of a storm by the intensity of the rainfall within a 30-minute interval. However, this equation cannot be effectively utilized in countries such as Ethiopia, where there is insufficient data.

Hurni (1985) modified it in the actual situation of Ethiopia to be practical using widely accessible mean annual rainfall data empirical equation, represented as

$$R = -8.12 + (0.562 * P) \text{-------------------(2)}$$ Where P is the annual precipitation

Soil Erodibility (K) Factor

The capacity of soil particles to detach and be carried away by rain and runoff is determined by a soil attribute known as the erodibility factor (K). Several factors, such as permeability, organic matter content, texture, and structure, can influence the soil erodibility factor (Erencin et al.2000).

The impact of soil parameters on soil loss during storm events in highland regions can be assessed using the soil erodibility value (Wischmeier and Smith 1978). This value represents the soil's susceptibility to erosion, the ease of silt removal, and the estimated quantity of runoff for each rainfall input (Kayet et al.2018). The K-factor measures the soil's characteristics and vulnerability to detachment and transportation by rainfall runoff (Haile and Fetene 2012). Soil texture, drainage quality, soil depth, soil structure, and organic matter content are important soil characteristics that affect erodibility (Prasanna Kumar et al. 2012).

The erodibility factor allocated to a specific type of soil is the amount of soil expected to be lost for each unit of erosive rainfall energy relative to bare soil, assuming a standard research plot under the USLE model with a length of 22.1 meters and a slope of 9% (Renard et al.1997) and (Wischmeier and Smith 1978). The two most crucial and related soil characteristics that affect erodibility are infiltration capacity and structural stability. The amount of water that may be concentrated for runoff decreases as soil infiltration capacity increases, and there won't be any more standing water at the surface. Stable soil clumps withstand the rain's splashing and detaching effects. Certain tropical clay soils with high levels of iron- and aluminum-containing hydrous oxides are renowned for having highly stable aggregates that withstand heavy rain (Brady and Weil 2003).

Hurni (1985) states that the soil erodibility factor value was created for Ethiopian conditions by adopting many sources and recommended the K values of the soil based on their colour. The range of the K values is 0 to 1. It is also possible to determine erodibility-related parameters using the soil's physical and chemical characteristics.

The following equation, given by, expresses the most significant soil characteristics that affect the K factor, including Organic matter content, particle size distribution, soil structure, and permeability classes (Wischmeier and Smith 1978).

$$K = [2.1 * 10^{-4} M^{1.14}(12 - a) + 3.25(b - 2) + 2.5(c - 3)] * (\frac{0.1317}{100}) \ldots\ldots\ldots\ldots\ldots (3)$$

Slope length-steepness (LS) factor

This factor affects the volume and speed of runoff in combination (Prasanna Kumar et al. 2012). Gashaw et al. (2017) indicate that the steepness and length of a slope have a prominent influence on the rate of soil erosion caused by water due to the accumulation of runoff (Wischmeier and Smith 1978). The velocity of the runoff water can become more erosive as it increases, and water tends to flow more rapidly down steeper slopes. This acceleration raises the surface shear force and causes the stream to carry a more significant amount of silt (Wischmeier and Smith 1978) and (Haile and Fetene 2012). The potential for runoff water collection and concentration increases with slope length, and slope steepness accelerates runoff velocity (Brady and Weil 2003, Wischmeier and Smith 1978). The

RUSLE software program creates more site-specific values, including values for non-uniform slopes, although such generic LS factor values for easy slopes can be employed with the USLE. The LS factor in the original USLE can be computed manually using equation 4 (Wischmeier and Smith 1978).

$$LS = \left(\frac{\lambda}{22.1}\right)^{m} \; (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where: λ = horizontal slope length; θ= slope angle; and the value of "m" is an exponent varies from 0.2 – 0.5 depending on slope gradient then the m value equals to 0.2, 0.3, 0.4 and 0.5 for the slope steepness of <1%, 1-3%, 3-5% and >5% respectively.

To calculate soil loss in a specific watershed, the RUSLE model calculates the S and L values separately and then combines the two with additional variables. Now a days, LS can be calculated using a raster calculator in a GIS context. The L factor is computed in the GIS interface using flow accumulation and cell size, and the S factor is calculated from DEM using slope angle.

Cover management factor (C) estimation

When evaluating conservation plans, the C factor is frequently utilized to assess the influence of various management alternatives on erosion rates (Renard et al. 1997). This factor is an essential indicator of how farming and management approaches can impact the erosion rate.

When calculating soil loss, the C factor is the soil loss ratio from a particular farmland to the corresponding erosion from clean-tilled, continuous fallow fields. The C factor value varies from 0.001 for the deep forest to 1.0 for bare land (Arekhi 2008, Wischmeier and Smith 1978).

This variable tracks the effects of all the linked management and cover factors. Different kinds of vegetative cover or cropping systems have a noticeable impact on raindrop impact, runoff velocity, and erosion. The most efficient method for protecting soil is provided by dense grasses and unaltered woodlands (Brady and Weil 2003). Direct drainage rates of up to 80% of rainfall are caused by degraded vegetation and soil, whereas well-covered soils can retain 90% or more rain (Hurni 1993). Slight increases in surface cover can lead to significant reductions in soil erosion, particularly inter-rill deterioration. The C factor values vary from region to region depending on the type of vegetation cover and soil management practices implemented.

Support practices factor (P factor)

(Renard et al.1997) The support practices factor (P) measures the relative soil loss caused by a particular support practice versus the loss triggered by upslope and downslope tillage. In addition, the P factor map and the land use map are interconnected.

The P factor measures how much soil erodes with specific erosion control measures compared to the corresponding soil loss when cultivating along a slope (Wischmeier and Smith 1978). Erosion control barriers help lower the P-value of soils without support techniques, almost down to zero. By slowing down the runoff velocity and reducing soil erosion, various support/erosional control measures such as contour strip-cropping, tillage on the contour, terrace systems, and grassed rivers function as a barrier, leading to a reduction in the P factor (Arekhi et al. 2010).

2.11 Modeling Soil Erosion Using GIS and Remote Sensing

The use of remotely gathered aerial and satellite data can provide significant contributions to mapping and evaluating soil erosion conditions. The identification of soil erosion-prone areas can be facilitated by analyzing soil properties, land cover, and drainage systems using a combination of visual interpretation of analogue satellite images and digital analysis of remote sensing satellite data (Rao 1999). Remote sensing and GIS techniques are essential for quantitatively assessing soil erosion in susceptible regions (Saha etal 1991). They enable the estimation of soil erosion and its distribution across regions with greater precision and reasonable costs (Wang et al. 2003). Models that take into account relevant factors for different soil erosion processes can be applied at various spatial scales, ranging from the plot level to the planetary level. GIS is an effective tool for managing spatial and non-spatial georeferenced data, facilitating data preparation, input, output presentation, and model interaction. GIS's capacity to handle spatial data is crucial for soil erosion inventory in risk assessment and modelling. In a GIS setting, USLE is frequently used to assess soil loss, highlighting the importance of GIS in managing vast quantities of spatial data and relationships between data from different sources in the erosion modelling process. Geographical elements are employed to store and process data in GIS databases, enabling the creation and storage of maps and various evaluations of potential outcomes, such as model simulations (Djokic et al. 2000).

Utilizing GIS technology for soil erosion mapping facilitates the identification of areas that are at risk of significant soil erosion, as well as obtaining information on how land use and land cover dynamics impact soil loss in various watershed areas (Shi et al. 2003).

3. MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Location

Maybar Watershed is situated in the Dessie Zuria district of the South Wollo Zone in the Amhara National Regional State in Ethiopia. The Place is located about 20 km southeast of Dessie, and is situated approximately 422 km north of Addis Ababa. The basin covers an area of roughly 113.41 ha and has been a site for research conducted by the Soil Conservation Research Project (SCRP) since 1981.The digital elevation model (DEM) used for the watershed delineation was at a 2m resolution, and the process was carried out in ArcSWAT.The watershed's coordinates range from 10^0 59’ 45” N to 11^0 30’ 45” N and 39^0 39’ 15” E to 39^0 39’ 45” E, as described in Figure 1. The catchment area features a highly uneven topography, with an elevation range between 2530 and 2858 a.m.s.l. The Kori Sheleko sub-catchment feeds Lake Maybar, which ultimately flows into the Borkenna and Awash rivers.

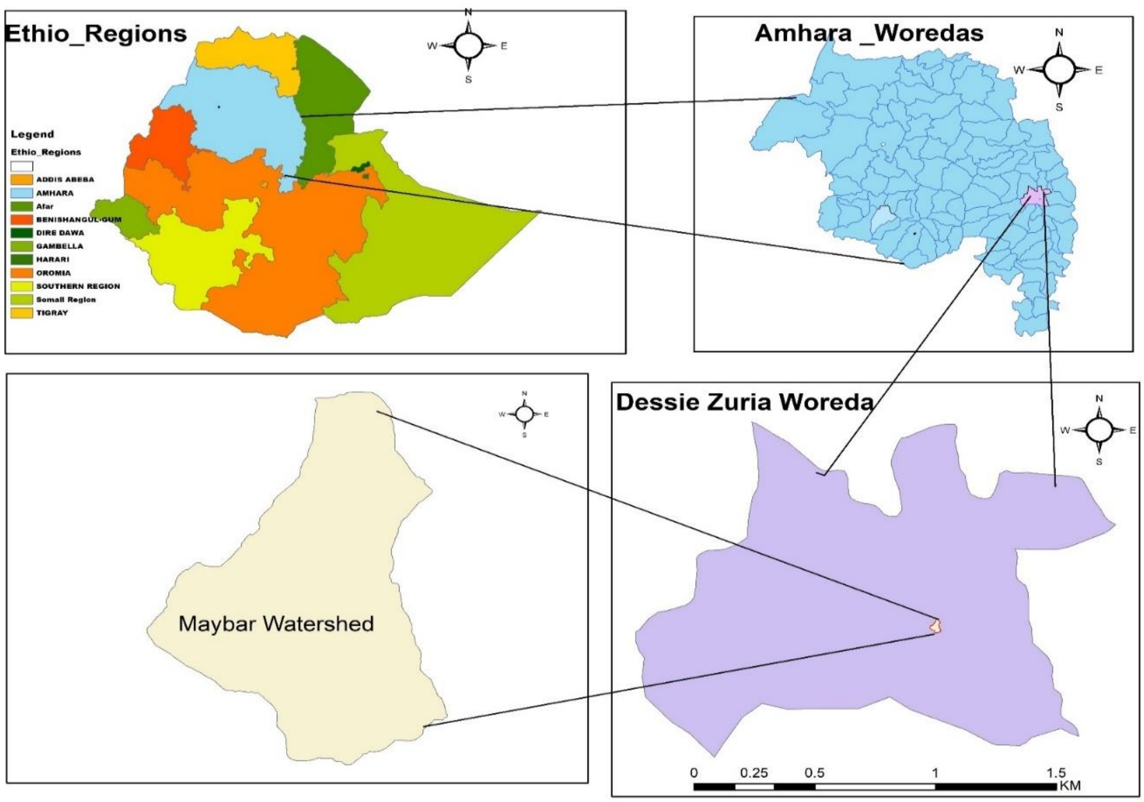

Figure 1: Location map of Maybar Watershed

3.1.1 Geology and Soil

Shallow Phaeozems, usually associated with Lithosols, are the predominant soil type in the Maybar watershed. These soils are dark brown and stony, with a clay loam texture, and are generally well structured, although they can be excessively drained. The depth of the soils ranges from 0 to 50 cm, with an average depth of approximately 15 cm. Due to their low moisture and nutrient retention capacity, most of the soils in the area are unsuitable for permanent crop cultivation. In addition to these soils, there are also hydromorphic soils known as mollic Gleysols. Due to a high-water table, these soils are regularly saturated with water and muddy. The primary soil texture classes in the catchment are sandy clay loam, comprising 80% of the watershed, while the remaining 20% is clay loam (SCRP 2000).

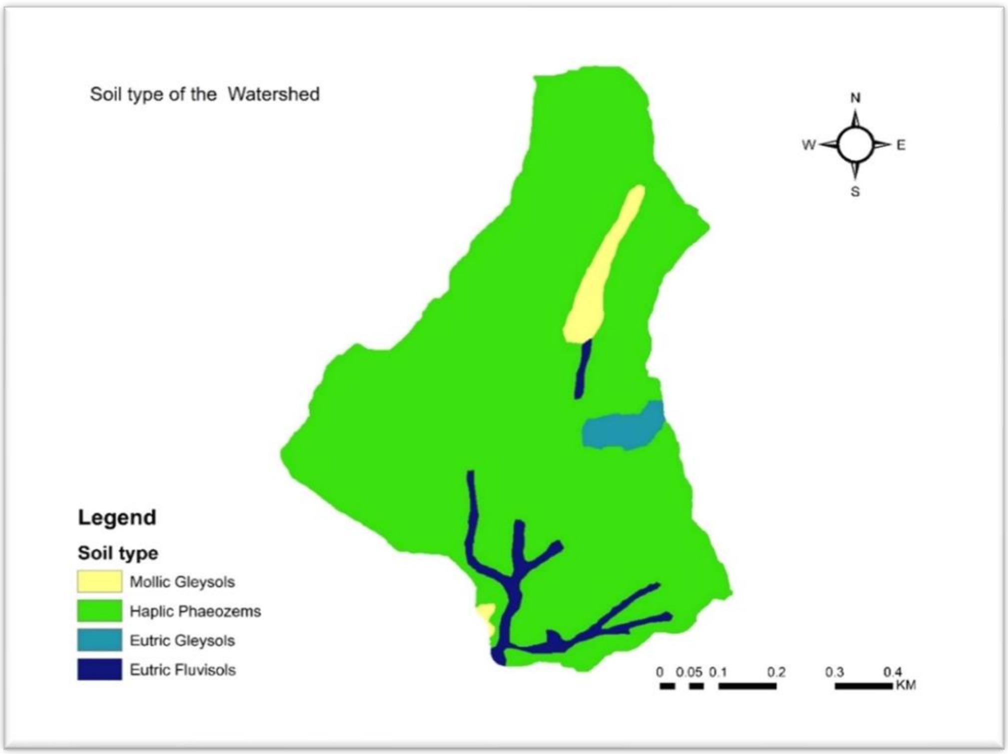

Figure 2: Soil types of Maybar Watershed, Ethiopia

3.1.2 Climate

The study watershed typically receives an average annual precipitation of 1275.4 mm. The study area experiences a range of temperatures throughout the year, with annual mean, minimum, and maximum temperatures ranging from 10.39 to 21.90 °C, as shown in Figure 4. The precipitation in the Maybar Area follows a bimodal pattern with an unpredictable distribution. The first rainy season, Belg, is typically observed from March to May. The primary rainy season, Kiremt, occurs from June to September, with a dry season from October to February. The Moist Woina Dega agroecological zone classification is used to characterize the climate in the area, according to Hurni et al. (2016).

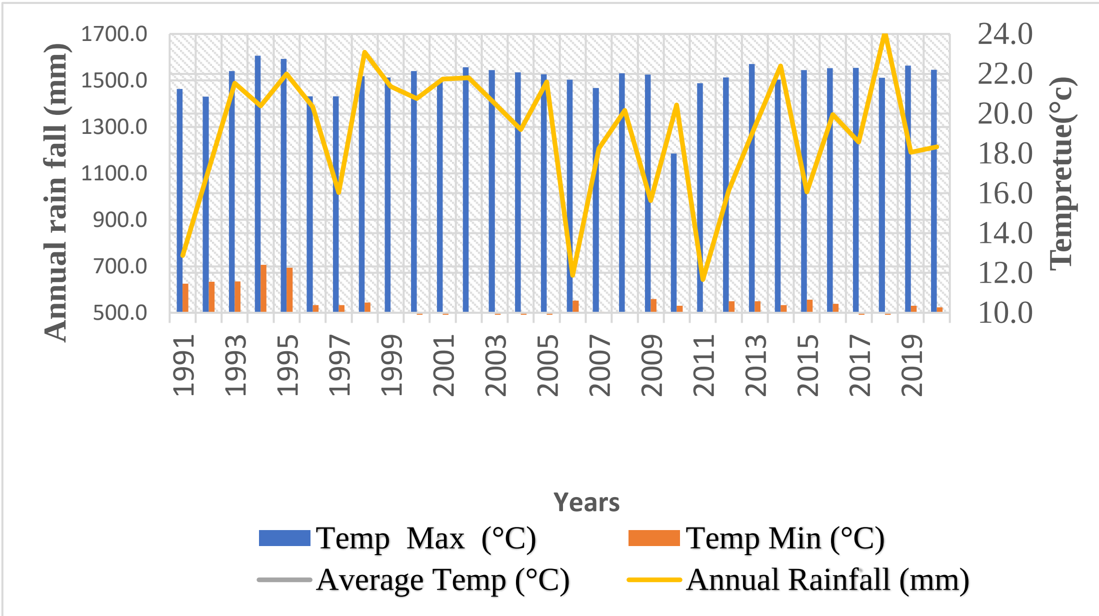

Figure 3: Mean annual rainfall and maximum/minimum/mean temperatures for the study area

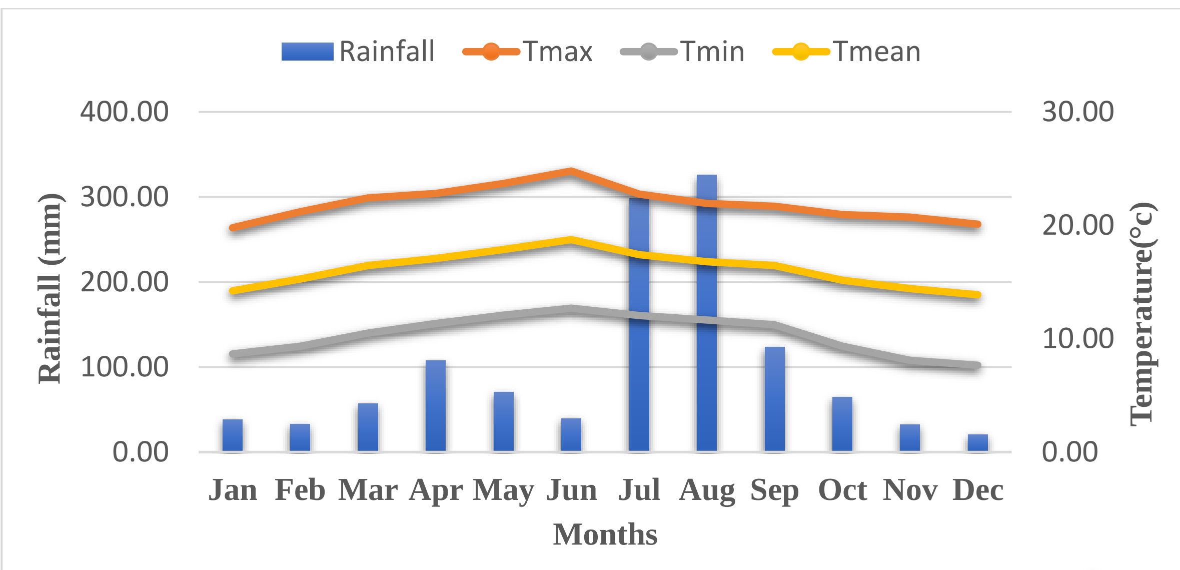

Figure 4: Mean monthly rainfall and maximum/minimum/mean temperatures for the study

3.1.3 Agricultural activities of the watershed

The study area is situated on the northeastern side of the Ethiopian highlands and is known as a cereal belt with extensive cultivation. However, the site has a low potential, is prone to erosion, and is ploughed by oxen (SCRP 1982 and Bosshart 1997). Approximately 60% of the Maybar catchment is used for cultivation, with cereals and maize being the primary crops, covering around 30% of the total catchment area. Maybar has two distinct cropping seasons, namely Belg, the short spring season, and Kremt, the primary rainy season. Due to lower precipitation levels, cereals are primarily planted during the Belg season, whereas the Kremt season is dominated by pulses that require more water (Tilahun and Awdenegest 2021).

3.2 Data Collection Method and Source

A range of data from various sources was collected during the study to accomplish the research aims. Both primary (field) and secondary data sources were used, including satellite images from different years (2004, 2012, and 2020) obtained from Google Earth, a soil sample from the study area, rainfall data from meteorological stations (specifically from the Sirinka Agricultural Research Center), and a 2m DEM from SCRP and WLRC.

3.2.1 Data Type and Collection Methods

To determine the soil erodibility factor (K) and fulfil the research objectives, soil samples were collected using augers in the study catchment area. Their geographic coordinates were recorded with GPS. A gridding technique was employed to collect the soil samples, where sample plots were identified at 250-meter intervals along the longitudinal and latitudinal axes, as shown in Figure 2. 17 soil samples were collected at each field at a depth of 0-20 cm and later tested in the laboratory.

3.2.2 Data Type and Collecting Methods

Data from various sources were utilized in this study to achieve the research objectives. Rainfall, temperature, and agricultural system data were obtained from secondary sources, specifically from the Sirinka Agricultural Research Center. The study area's watershed was identified, and slope maps were created using the Water and Land Center Digital Elevation Model. In addition, three periods of land cover maps were used to determine C and P variables in the RUSLE model. These maps were obtained from https://www.google.com/earth/versions/ provided by the USGS. The images were chosen based on the need to minimize the impact of seasonal variations on vegetation patterns and distribution. The collection of soil samples was done using an auger, and the position of the samples was recorded using GPS technology. The soil samples were tested in the laboratory. The gridding method was used to collect soil samples at 250m intervals along the longitudinal and latitudinal axis, as shown in Figure 2. Soil samples were collected at 0-20 cm depth at each plot. The soil erodibility factor (K) was then calculated using the collected soil samples.

3.2.3 Materials and tools used

The study used various equipment and materials, including a computer with image processing software, augers for collecting soil samples, GPS for tracking locations, and geographic information systems and remote sensing for analyzing land degradation. In addition, RUSLE models and Google Earth were employed for data analysis, with the latter utilized for evaluating land use and cover before conducting fieldwork. The data required for RUSLE input parameters were sourced from diverse sources detailed in Table 1.

Table 1: The type of input data, sources of data, analysis tools utilized, and the data's purpose

No	Input data	Source	Tool for analysis	Purpose
1	Climate (Rainfall)	Water and Land Resource Center (WLRC)	Microsoft Excel	To calculate the R-factor from mean annual RF data
2	Soil data	Field survey	ArcGIS 10.8.2	To calculate the Soil erodibility factor and other maps (LULC, study area)
3	Google image	Google earth	Arc Map	Land use land cover classification and C _factor determination
4	DEM_2m	WLRC	ArcGIS 10.8.2	To delineate the Watershed and to calculate the Length and Slope factor

3.2 Data Analysis Methods

3.3.1 Land Use and Land Cover Change (LULC) Analysis

LULC maps were created using ArcGIS 10.8 software to digitize images from Google Earth with great attention to detail. The Google Earth image used was from the same year as the simulation periods to ensure a more accurate representation of the system. Former research has suggested that pixel-based classification on Google Earth imagery to identify land use and land cover may decrease accuracy due to its high level of detail and acceptable spatial resolution. To address this issue, on-screen digitization was utilized instead of pixel-based classification. On-screen digitization has been found to provide an accurate representation of land use mapping, albeit a more time-consuming process for larger areas (Myint et al.2011, Shalaby 2012).

ArcGIS software was used to create a 20-meter buffer around the watershed boundary. That data was then imported into Google Earth Pro as a shapefile for use in the study's image digitization. Small land cover areas were also delimited and overlaid on the ArcGIS environment once the primary land use/land cover types were determined. The catchment's land features and covers were mapped on Google Earth and imported into a geographic information system. We engaged a senior hydrologic observer with over a decade of experience in the watershed while digitizing to guarantee precision. While "land cover" referred to the ground's covering, "land usage" referred to the land's intended function.

Table 2: Land use and land cover classes identified in the study watershed

Land Use type	Description of Land Use type
Cultivated land	This category refers to land areas that have been tilled and made ready for the cultivation of crops, whether through rain-fed or irrigation methods
Forest Area	Natural forests and woodlands with a diverse tree species composition.
Settlement	Human-made constructions and small rural settlements
Bare land	Areas with degraded lands and bare ground.
Shrub land	This land type is characterised by perennial woody shrubs and bushes with varying densities across different locations. It is typically found in hilly areas.
Grazing land	Land designated for grazing purposes
Water body	This category pertains to areas covered by bodies of water, such as ponds, lakes, and rivers.

3.3.2 Soil Erosion Estimation

Three different periods of soil erosion in the watershed were analyzed using the RUSLE model in this research (2004, 2012, and 2020). The model considers various factors such as climate, soil type, topography, land cover and management, and soil conservation practices, mapped using GIS software. Data sources for these parameters were gathered from various sources, including DEM, soil samples, and remotely sensed data, each with different formats, projections, quality, and resolution. ArcGIS software was used to manage and analyze the data, allowing for the creation of detailed maps and accurate analysis. The mathematical equation for RUSLE is:

$$A = R \times K \times LS \times C \times P \text{-----------Equation (5)}$$

where: A = average annual soil loss (in tons per acre or tons per hectare per year) R = rainfall erosivity factor K = soil erodibility factor LS = slope length and steepness factor C = cover management factor P = support practice factor

The RUSLE method was employed to simulate soil erosion at three different time intervals, specifically in 2004, 2012, and 2020, with dynamic parameters being assigned correspondingly. While the LS-factor, K-factor, and erosion control remained constant, the R-factor, P-factor, and C-factor were treated as varying parameters across the years.

3.3.2.1. Rainfall erosivity (R) factor

The index, known as the R-factor, measures precipitation's capacity to remove and transport soil particles. To calculate this factor, the intensity and maximum rainfall duration in a specific region are examined based on experimental data obtained from prior studies. The R-factor is a gauge of the relationship between rainfall and the potential for erosion, as determined by the quantity and rate of runoff. The computation of the R-factor involves multiplying the kinetic energy of each rainfall event with the maximum 30-minute rainfall intensity. By summing up the erosivity factor of multiple rainfall events recorded over a given period, the cumulative rainfall erosivity factor can be determined. When dealing with an unmeasured watershed, the R-factor can be approximated by employing average annual rainfall data from nearby weather stations. For this particular investigation, the R-factor was computed using precipitation information gathered from a weather station located inside the watershed between 1991 and 2020, overseen by the National Meteorology Agency (NMA) of Ethiopia. The calculation of the R-factor in this study was executed via equation 6, developed by Wischmeier and Smith (1978).For Ethiopia, modified by and utilized by Hellden (1987):

$R = (0.56 * P)-8.12$ ….. (6)

R implies erosivity (MJ mm ha^{-1} $h^{-1}y^{-1}$), and P = mean annual precipitation (mm/year).

3.3.2.2. Soil erodibility (K) factor

Soil erodibility refers to the degree to which the soil or surface material is prone to erosion (Mhaske S etal 2012). It is strongly associated with the physical characteristics of the soil (Shabani F etal 2014), such as the percentage of sand, silt, clay, and soil organic matter (Millward, A and Mersey J 1999). Additionally, it describes the soil's resistance to detachment and transport. The topographic position, slope gradient, and degree of tillage disturbance can influence soil erosion resistance, but the primary factors are the soil properties themselves.

The erodibility of a particular soil is determined by its texture, structure, permeability, and organic matter content (Deniz et al.2008). Organic matter reduces soil erodibility and susceptibility to detachment but increases infiltration. The area's primary soil classification is haplic phaeozems, with K-factor values varying from less than 0.1 for the soil least prone to erosion to nearly 1.0 for the most susceptible soil.

$\text{KUSLE} = \text{Fsand} * \text{Fclay} * \text{Foc} * \text{Fsilt} * 0.1317$ ………………………………………….... (7)

Where each fraction of soil has its formula:

$$\text{Fsand} = \left[0.2 + 0.3 \exp\left(-0.0256 * \text{Ms}\left(1 + (\text{Msilt}/100)\right)\right)\right] \text{……………………. (7.1)}$$

$$\text{Fclay} = \left[\frac{\text{Msilt}}{\text{M clay} + \text{Msilt}}\right]^{0.3} \text{.. (7.2)}$$

$$\text{Forgc} = [1.0 - (0.256 * \text{orgC} + \exp[(3.72 - 2.95\text{orgC})])] \text{ .... (7.3)}$$

$$\text{Fsilt} = [1.0 - (0.70(1 - \text{Ms}/100)/\ (1 - \text{MS}/100 + \text{Exp}(5.51 + 22.9(1 - \text{ms}/100))]\ldots \text{ (7.4)}$$

The variables in the equation are defined as follows: Ms represents the percentage of sand content (0.05-2.00 mm diameter particles), Msilt represents the percentage of silt content (0.002-0.05 mm diameter particles), Mc represents the percentage of clay content (<0.002 mm diameter particles), and organic represents the percentage of organic carbon content in the layer.

3.3.2.3. Estimating slope (S) and gradient length (L) factors.

The LS factors are commonly used to quantify the impact of slope gradient on soil erosion. Kaltenrieder (2007) computed the soil loss rate using a standard slope length of 22 meters and a slope steepness of 9%, adjusted according to the site-specific conditions. It has been observed that soil erosion rises as the slope gradient increases and the slope length becomes longer.

The LS factor was derived from a 3-arc-second SRTM DEM with a 2-meter resolution. The origin of this data is the (SCRP 2000), located in the (WLRC) in Addis Ababa, Ethiopia. It has a resolution of 2 meters by 2 meters.

The study watershed shapefile was used to extract the DEM, which underwent raster calculation to determine the L and S factors. Prior to the computation of LS factors, the slope angle and flow accumulation had to be pre-processed. The DEM was utilized as an input to process the slope angle and flow accumulation in ArcGIS Spatial Analyst with the arc hydro tools extension. The L factor was calculated using equation 10 based on the improved RUSLE equations described by Wischmeier and Smith (1978).

$$\text{LS} = \text{Power}(\text{flow accumulation} * \frac{\text{Cell size}}{22.13}, 0.4 * \text{ Power}(\frac{\text{Sin(slope in dgree}*0.01745}{0.0896}, 1.3 \text{ .... (10)}$$

3.3.2.4. Cover Management Factor (C)

Determining the crop management factor (C) is essential in evaluating the effectiveness of support strategies. The C value approximates the soil loss ratio using support techniques to conventional up and down-slope farming (Ganasri and Ramesh 2016). C values range from 0 to 1, where a value closer to 0 indicates good conservation practices and a value approaching 1 suggests poor conservation practices. The C factor in the RUSLE formula ranges from 0.001 for dense forests to 1.0 for bare land

(Arekhi 2008; Wischmeier and Smith 1978), reflecting the level of soil protection under specific land cover management. As the land use and land cover (LULC) type changes, so does the C factor, which was calculated after determining the LULC type of the specified area. The C factor was computed from the LULC map, and values were assigned to all the LULC classes based on related literature on C-factors in the tropics (Table 3). A field was added in the attribute table, and the ArcGIS raster calculator was used to convert these values to a raster, producing C-factor maps for successive years. These maps were then used as inputs in the RUSLE model.

Table 3: C-factor value based on (Hurni 2008) and Nigussie etal 2022)

Land Use Type	C_factor value
Cultivated land	0.18
Forest land	0.001
Grazing land	0.05
bare land	1
Settlement land	0.15
Water body	0.0
Shrub land	0.014

3.3.2.5. Conservation or Supportive Practices(P)

The conservation management factor (P) determines the soil loss ratio using a particular support technique, unlike tillage practices that are either upslope or downslope (Renard et al. 1997). The P factor modifies the RUSLE for soil conservation tillage methods. The P value ranges from 0 to 1, with 0 indicating excellent mechanical erosion resistance practices and 1 indicating no natural erosion resistance practices. The P factor represents the ratio of soil loss with a specific erosion control practice to the soil loss without any erosion control measures (Wischmeier and Smith 1978). In the absence of any erosion control, the P value is 1, while it is close to zero when practical erosion control measures are implemented. Erosion control techniques such as contour strip-cropping, tillage on the contour, terrace systems, and grassed waterways act as barriers for runoff velocity, reduce soil erosion, and tend to decrease the P factor (Arekhi et al. 2010).

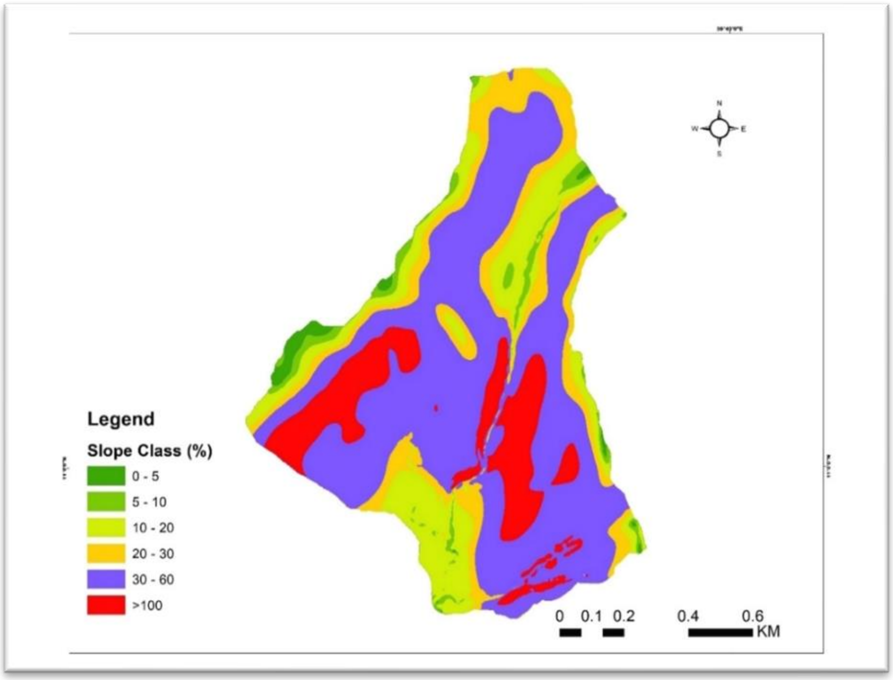

Figure 5*:* Slope class of the study area

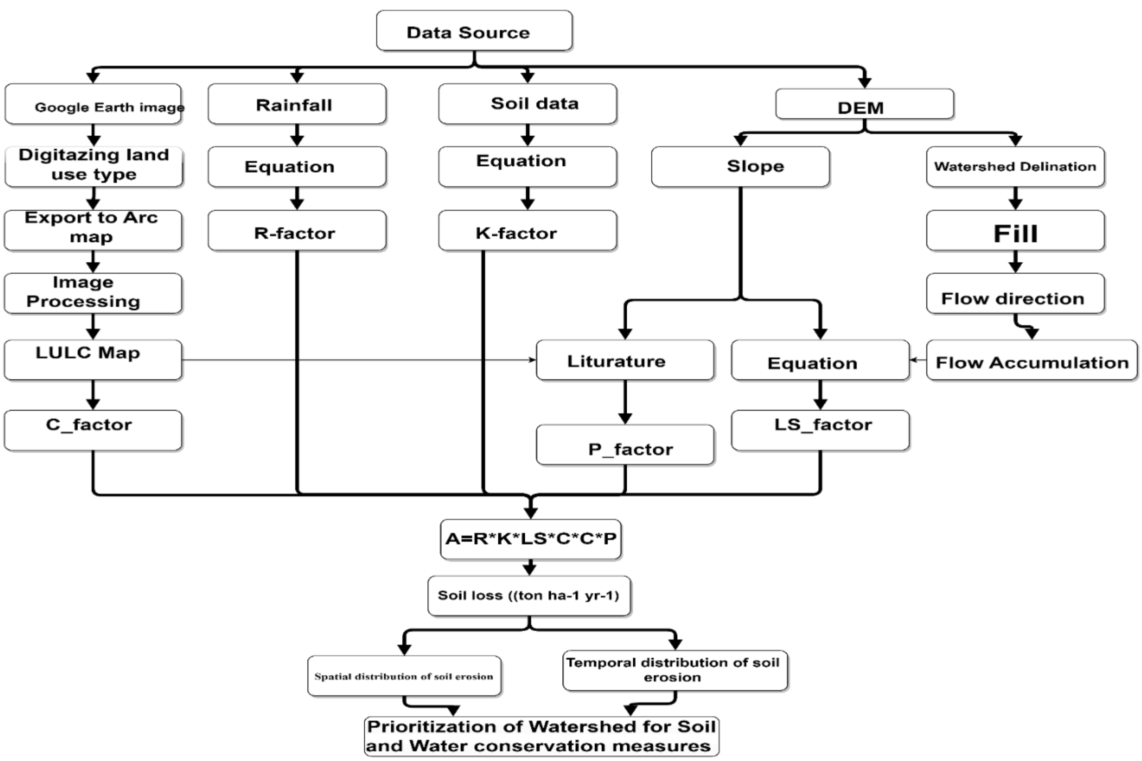

Figure 6: Flow Chart of the analysis

4. RESULT AND DISCUSSION

4.1 Trend of Land Use and Land Cover (LULC)

This study identified six different land use and land cover types in the study area, which include forest, shrub, grazing, cultivated, bare, and settlement lands. However, an additional land use type, water body land use, was existed between 2012 and 2020, resulting in seven land use types. Accurately classifying these categories was vital to analyze the effects of land use changes on the environment and could help establish sustainable land management practices. The results of this study could have significant implications for land-use planning and management, natural resource conservation, and biodiversity preservation in the study area.

Table 4 displays the classification results for Google Earth images from 2004, 2012, and 2020 and also provides comprehensive statistical information for each land use class, including the land use and land cover (LULC) map for the study duration. The primary land use types in the study area were cultivated land (49.8%), forest land (36.1%), and bare land (33.6%) in 2020, 2012, and 2004, respectively. Accurately classifying these categories was vital to analyze the effects of land use changes on the environment and could help establish sustainable land management practices. The results of this study could have significant implications for land-use planning and management, natural resource conservation, and biodiversity preservation in the study area.

Table 4: Land use type in Maybar Watershed for 2004, 2012, and 2020

Land use type	Year					
	2004		2012		2020	
	Area(ha)	Area (%)	Area(ha)	Area (%)	Area(ha)	Area (%)
Cultivate Land	36	31.9	56.4	49.8	40	35.3
Forest land	18	15.9	26	22.9	40.9	36.1
Bare land	38	33.6	14.4	12.7	9.1	8.1
Grazing land	4	3.5	4.2	3.7	11.8	10.4
Shrub land	13	11.5	7.8	6.9	6	5.3
Settlement	4	3.5	4	3.5	4.2	3.7
Waterbody	0	0.0	0.6	0.5	1.3	1.1
Total	**113.4**	**100**	**113.4**	**100.0**	**113.4**	**100**

4.1.1. Land Use Land Cover (LULC) 2004

The findings from the land use and land cover (LULC) classification analysis conducted for 2004 reveal a comprehensive picture of the study area. The research shows that the study area was predominantly characterized by bare and cultivated land, accounting for 33.6% and 31.9% of the area, respectively. Forest land and shrubland followed closely, with 15.9% and 11.5% coverage, respectively. Additionally, grazing land and water body land use constituted only 3.5% of the study area each. Figure 5 visually presents these outcomes, highlighting the dominant LULC types in the watershed for 2004.

Notably, barren lands were also prevalent in the watershed, although not as dominant as bare and cultivated lands. In contrast, grazing and settlement land had the least coverage among all LULC types, indicating their limited impact on the study area.

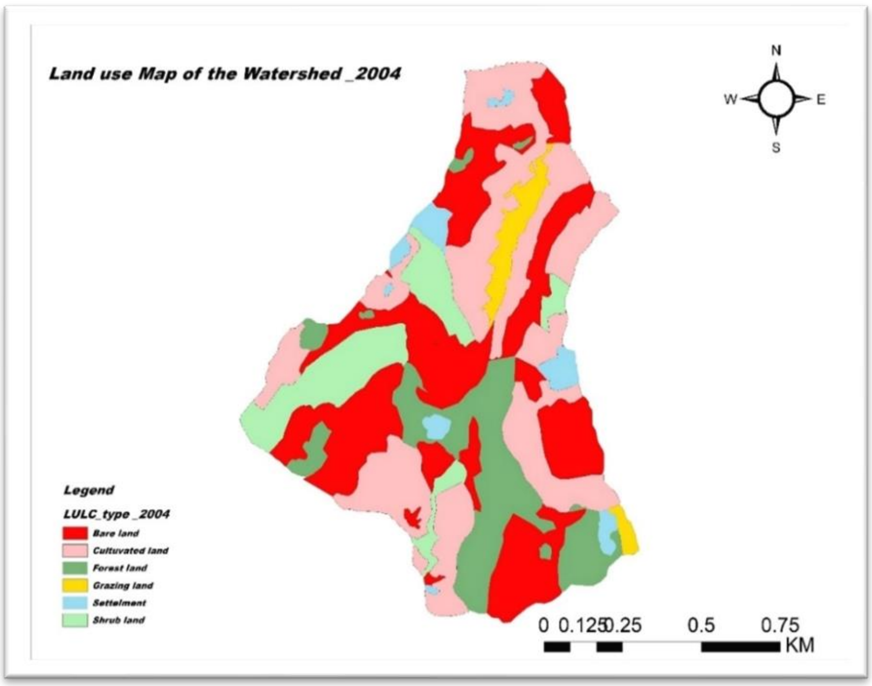

Figure 5:Land Use and Land Cover of the Study Area (2004)

4.1.2. Land Use Land Cover (LULC) 2012

The examination of the image classification conducted in 2012 showed that the dominant land use type in the study region was Cultivated land, which covered about 49.8% of the total area, while forest was the second-largest land use type, accounting for 22.9%. The remaining land use/land cover types, including shrubland, forest, and barren lands, collectively occupied 27.3% of the total area. According to Table 8, water bodies had the least coverage area among all other classes, making up only 0.5% of the area.

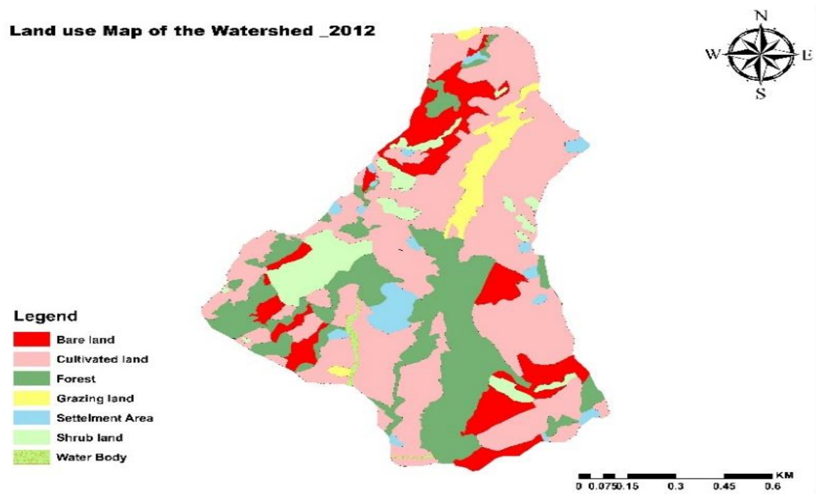

Figure 6: Land Use and Land Cover of the Study area (2012)

4.1.3. Land Use Land Cover (LULC) 2020

After conducting the land use/land cover (LULC) classification of the 2020 image, the results showed that forest land and cultivated land were the most dominant categories, covering a combined 71.4% of the study area. Specifically, forest land covered 36.1% of the area, while cultivated land occupied 35.3%, indicating equal prevalence. The remaining land use/land cover types, including grazing land (10.2%), barren lands (6.5%), water body (1.1%), shrubland (0.5%), and settlement (0.3%), collectively accounted for 28.6% of the total area, as shown in Figure *7*.

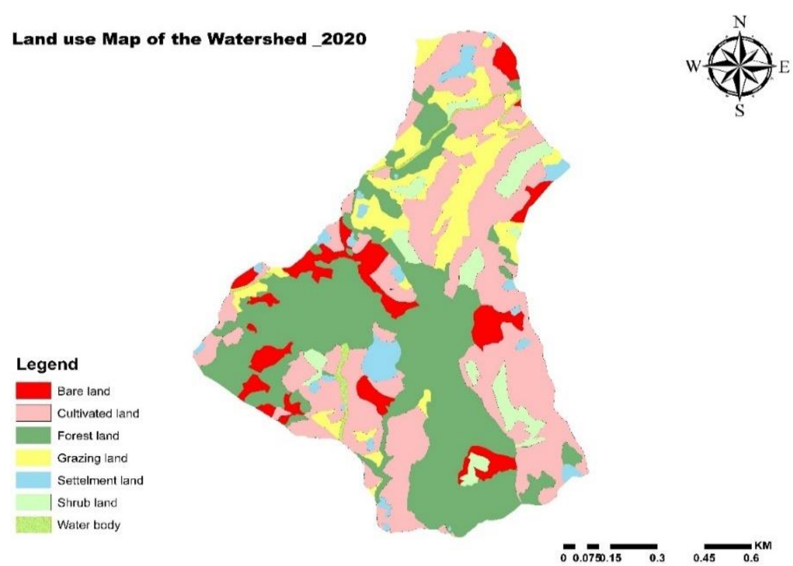

Figure 7: Land Use and Land Cover of the Study area (2020)

4.2. Land Use Land Cover Change (LULC)

This research investigated land use and cover changes in the study area from 2004 to 2020. The study analyzed satellite images for 2004, 2012, and 2020 to assess land use and cover changes over different periods. The analysis indicated that the study area's most dominant land use and cover types were cultivated land, bare land, and forest land. At the same time, water bodies were less prominent and only appeared in 2012 and 2020. To further examine the changes, the study compared the data from different years and summarized the findings in Table 5. From 2004 to 2020, cultivated land and forest land areas increased by 49.8% (56.4 ha) and 36.9% (40.9 ha), respectively. Conversely, the bare land and shrubland area decreased by 25.5% (28.9 ha) and 6.2% (7 ha), respectively. During 2004-2012, the reduction in shrubland and bare land was more significant, while the decrease in settlement land was lower.

Table 5: Trend Analysis of Land Use and Land Cover Change (2004-2012, 2012-2020, and 2004-2020)

LULC type	Year								
	2004		2012		2020		2004-2012	2012-2020	2004-2020
	Area(ha)	Area (%)	Area(ha)	Area (%)	Area(ha)	Area (%)	Area(ha)	Area(ha)	Area(ha)
Cultivated land	36	31.9	56.4	49.8	40	35.3	-20.4	16.4	-4
Forest land	18	15.9	26	22.9	40.9	36.1	-8	-14.9	-22.9
Bare Land	38	33.6	14.4	12.7	9.1	8.1	23.6	5.3	28.9
Grazing land	4	3.5	4.2	3.7	11.8	10.4	-0.2	-7.6	-7.8
Shrub land	13	11.5	7.8	6.9	6	5.3	5.2	1.8	7
Settlement	4	3.5	4	3.5	4.2	3.7	0	-0.2	-0.2
Waterbody	0	0	0.6	0.5	1.3	1.1	-0.6	-0.7	-1.3
Total	**113.4**	**100**	**113.4**	**100**	**113.4**	**100**			

*- sign indicates that there is land use change (the specific land use is increasing)

Over the 24-year period from 2004 to 2020, there were significant changes in the land use and land cover of the study area. The forest land area increased from 18 ha in 2004 to 26 ha in 2012 and reached

40.9 ha in 2020. The increase in the area of cultivated land resulted in the reduction of forest, shrubland, and grazing land. Bare land and shrubland experienced the most significant reduction in area, declining by 28.9 ha (25.5%) and 7 ha (6.2%), respectively, between 2004 and 2020. This decrease in bare land may have led to a reduction in surface runoff in the study area. Additionally, a new land use class, water bodies, emerged after 2012, which could be accredited to the impact of watershed management practices.

4.3 RUSLE Parameter for Soil Loss Estimation

4.3.1. Rainfall erosivity(R)

The study area had an average annual rainfall of 1402mm, 1097.4mm, and 1322.8mm for 2004, 2012, and 2020, respectively. Using the Hans Hurni method and the regression equation developed by Hurni (1985) for Ethiopian conditions, the R-factor values were computed for the respective years and found to be 776.99, 606.42, and 732.6 MJ mm ha^{-1} h^{-1} $year^{-1.}$ The calculated values of rainfall erosivity are presented in a Table 6, which indicates that the R-factor values varied between 606.42 and 776.99 MJ mm ha^{-1} h^{-1} $year^{-1}$, with an average value of 705.348 MJ mm ha^{-1} h^{-1} $year^{-1}$. This implies that the mean annual precipitation impacts the value of the R-factor since changes in the mean yearly precipitation result in changes in the R-factor value.

Table 6: Mean Annual Rainfall and Erosivity factor of the Study Area

Year	Mean Annual Precipitation(mm)	R_factor		Source
1996- 2004	1402.0	776.987		
2005-2012	1097.4	606.42		
2013- 2020	1322.8	732.64	R=(0.56*P)-8.12	(Hans Hurni,1985)

4.3.2. Soil Erodibility (K) Factor

A research study was conducted in the watershed area to analyze the physical and chemical properties of soil samples collected from various points. The laboratory tests included analyzing the soil's texture characteristics and organic matter content, and the results are presented in an appendix table. The study showed that the K-factor values in the study area ranged from 0.053 to 0.11, with an average value of 0.099. This value falls within the range of K-values for Ethiopian soils reported by FAO in 1984, which is between 0.05 and 0.6. These findings suggest that the soil in the study area is prone to erosion, and appropriate soil conservation measures should be taken to prevent soil loss. However, the soil erosion trend is decreasing because of the soil and water conservation measures implemented there.

Table 7: Statistically Summary of Soil Parameters in the watershed

Soil Parameter	Minimum	Maximum	Mean	STDEV	CV
Organic of Matter	2.66	3.45	3.2	0.3	0.1
Percentage of Clay	27	43.25	35.05	6.56	0.2
Percentage of Silt	22.5	31.5	27.82	3.67	0.14
Percentage of Sand	27.75	47.75	37.1	9.86	0.29

*CV-Coefficient of Variation, STDEV-Standard Deviation.

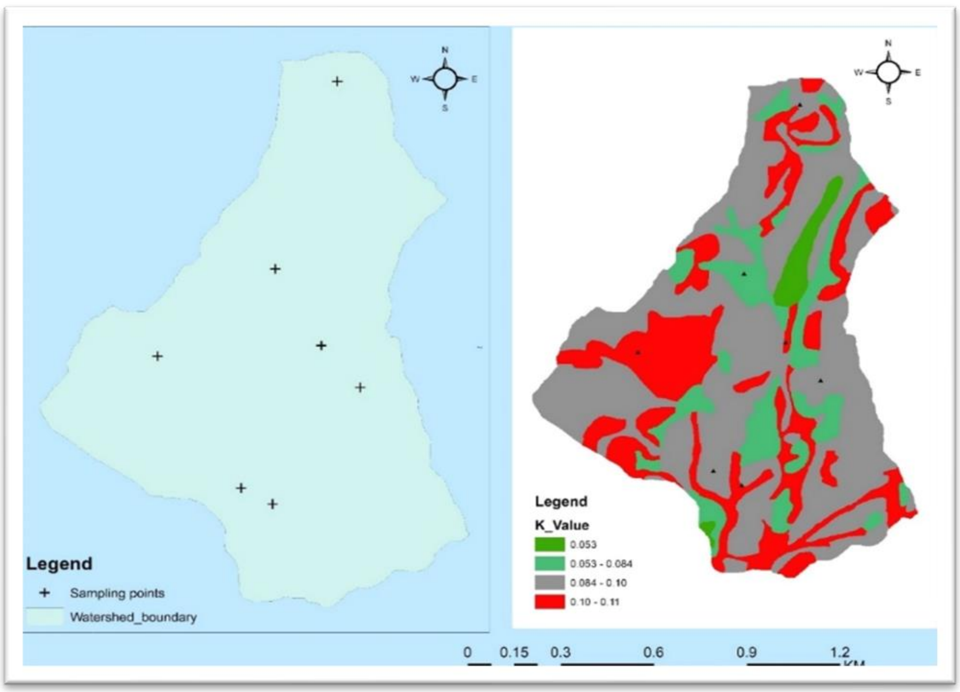

Figure 8: Soil Sample Distribution (Left) and Soil Erodibility (K) Factor Map (Right)

Table 8 provides the distribution of soil types and their erodibility values in the Maybar watershed. The identification of soil types was accomplished by using a soil map of the Maybar watershed created by Weigel (1986). Seven distinct soil types were identified, including Mollic gleysols, Haplic phloeozems, eutric fluvisols, and eutric Regosols, commonly used in categorizing environmental soil types. Shallow Phaeozems were found to be the most common soil type in the watershed, covering 91.6% of the catchment area with a depth of approximately 15 cm. Gleysols, Eutric Fluvisols, and Eutric Regosols covered the remaining 8.4% of the watershed's land area. The erodibility values of these soil types fall within the range of what is typically reported for Ethiopian soil K values, with a mean value of 0.099.

Table 8: Soil type and corresponding erodibility factor of the watershed

Soil mapping code	**Soil Name**	**Description**	**Textural Class**	**K_factor**	**Area coverage (ha)**	**(%)**
GM	Mollic Gleysols	Within shallow water table	Clay	0.053	3.03	2.7
Hh1	Haplic Phaeozems	very shallow (10–25 cm deep)	Sandy clay loam	0.098	46.41	40.9
Hh2	Haplic Phaeozems	shallow (25–50 cm deep)	Clay loams	0.114	25.6	22.3
Hh3	Haplic Phaeozems,	moderately deep (50–100 cm)	Sandy clay loams	0.850	16.89	14.9
Hh4	Haplic Phaeozems,	deep to very deep (>100 cm)	Sandy clay loams	0.098	15.29	13.5
Je	Eutric Fluvisols,	>100 cm deep	Clay loams	0.114	4.43	3.9
Re	Eutric Gleysols	10-100 cm deep	Clay	0.101	2.08	1.8
Total					113.4	100

*Where K value is in Mg ha^{-1} MJ^{-1} mm^{-1}

4.3.3. Slope and Gradient Length (LS) Estimation

In studying erosion's impact on topography, slope length is a significant factor that interacts with slope gradient (S). Slope length (L) accounts for the proportionality of erosion with slope length and its increase as the slope becomes steeper. The horizontal distance that separates the origin of overland flow from the point where the slope gradient decreases, allowing for deposition or runoff to become concentrated in a channel, was the flow length factor. Meanwhile, the slope gradient factor (S) assessed the impact of slope gradient on erosion. The LS factor is an essential component of the Revised Universal Soil Loss Equation (RUSLE), which determines the topography's impact on soil erosion. To generate the LS factor, digital elevation models (DEM) with a 2m resolution were created from contour maps obtained from the Water and Land Resource Center Project. The slope and flow accumulation maps were also produced using ArcGIS with the DEM.

The interplay between slope angle and slope length significantly impacts the extent of erosion, and therefore, both should be considered jointly (Edward 1987). Our study area showed that the LS factors ranged from 0 in flat regions to 7.25 in the watershed's steeper and longer slope areas. The incremental increase in LS factors from 0 to 7.25 indicates potential erosion as slope steepness increases.

Approximately 34.8% of the study area comprises slopes with a gradient ranging from 30-50% (steep slope).

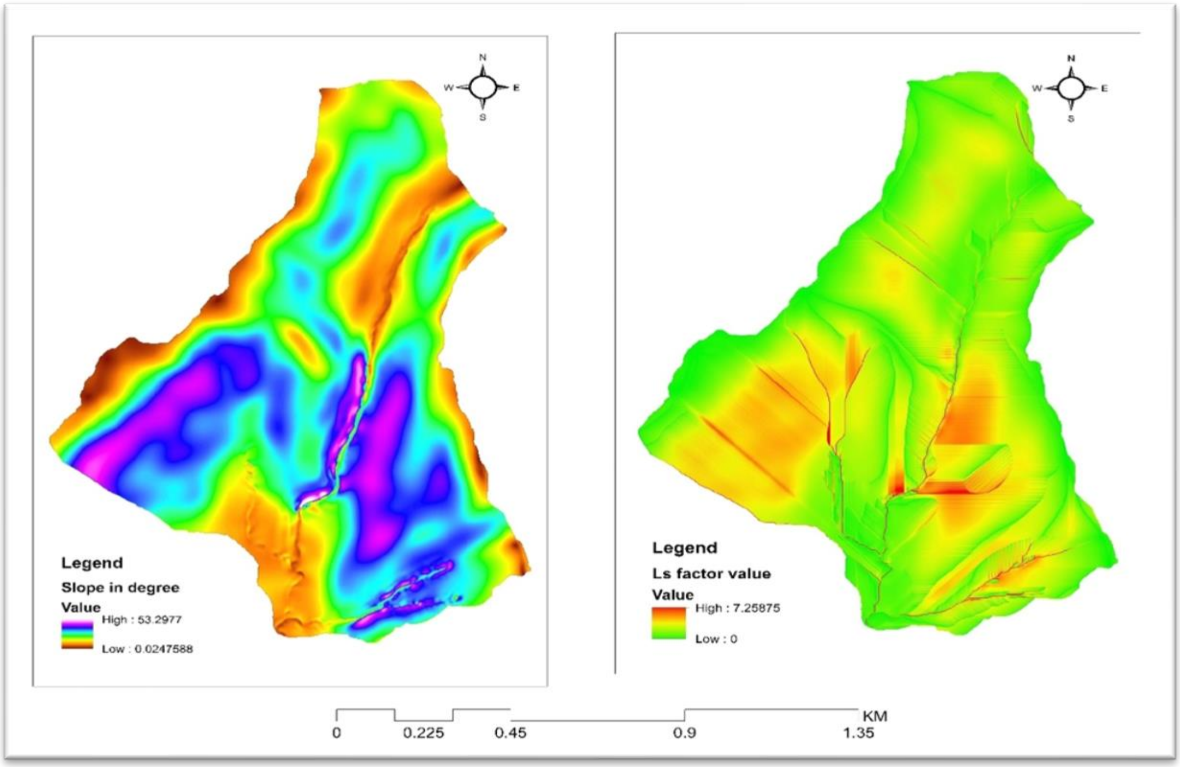

Figure 9; Slope in degree (left) and Ls _factor value (right)

According to the data presented in Table 9, soil loss rates varied depending on the slope gradient. An increase in slope gradient corresponded with an increase in soil erosion rates. For slopes less than 5 degrees, the rate of soil loss was the lowest, with values of 0.04 t ha-^{1} yr-^{1} in 2004, 0.03 t ha-^{1} yr-^{1} in 2012, and 0.1 t ha-^{1} yr-^{1} in 2020. Soil loss rates for 5-10 degrees slopes were 1.5 t ha-^{1} yr-^{1} in 2004, 0.38 t ha-^{1} yr-^{1} in 2012, and 0.4 t ha-^{1} yr-^{1} in 2020. The soil loss rates for 10-20 degrees slopes were 2.5 t ha-^{1} yr-^{1} in 2004, 0.79 t ha-^{1} yr-^{1} in 2012, and 0.8 t ha-^{1} yr-^{1} in 2020. Similarly, soil loss rates for 20-30 degrees slopes were 8.09 t ha-^{1} yr-^{1}in 2004, 1.7 t ha-^{1} yr-^{1} in 2012, and 3.0 t ha-^{1} yr-^{1} in 2020. For 30-50 degrees slopes, soil erosion rates were 15.7 t ha-^{1} yr-^{1} in 2004, 6.0 t ha-^{1} yr-^{1} in 2012, and 3.1 t ha-^{1} yr-^{1} in 2020. The rate of soil loss for slopes of 50-100 degrees was 21.9 t ha-^{1} yr-^{1}in 2004, 8.25 t ha-^{1} yr-^{1} in 2012, and it is expected to be 6.0 t ha-^{1} yr-^{1}in 2020. Lastly, the soil erosion rates for slopes greater than 100 percent were 1.4 t ha-^{1} yr-^{1} in 2004, 0.079 t ha-^{1} yr-^{1} in 2012, and 0.1 t ha-^{1} yr-^{1} in 2020. These findings suggest the slope gradient strongly influences soil loss within the watershed. Soil erosion rates increase as the slope angle increases.

Table 9: Estimated soil loss with slope gradient in 2004 and 2020

Slope Class (%)			Soil loss in 2004		Soil loss in 2012		Soil loss in 2020		Net change
	Area(ha)	Area (%)	t ha^{-1} $year^{-1}$	t $year^{-1}$	t ha^{-1} $year^{-1}$	t $year^{-1}$	t ha^{-1} $year^{-1}$	t $year^{-1}$	%
0-5	1.5	1.3	0.04	5.13	0.03	3.5	0.1	8.9	-0.09
5-10	3.5	3.14	1.5	167.6	0.38	43.9	0.4	39.83	0.72
10-20	17.9	15.8	2.5	281.2	0.79	88.6	0.8	95.3	0.91
20-30	16.08	14.18	8.09	918.02	1.7	192.3	3.0	334.6	3.39
30-50	39.5	34.8	15.7	1775.9	6.0	688.7	3.1	347.01	6.6
50-100	34.85	30.7	21.9	2485.7	8.25	936.07	6.0	683.73	7.65
>100	0.027	0.024	1.4	162.7	0.079	9.0	0.1	9.73	1.22

*-sign indicates soil erosion is reducing within this slope

4.3.4. Land cover/management(C) factor

The impact of land management practices on soil erosion can be evaluated by utilizing the C-factor, a numerical value ranging from 0 to 1. A lower value of the C-factor represents lower soil erodibility, while a higher value indicates higher erosion potential. The spatial distribution and magnitude of the C-factor throughout the watershed can be visualized in Figure 9.

In 2004, the land cover of the watershed consisted of forests (15.9%), grassland (3.5%), cropland (31.85%), shrubland (11.5%), and settlements (3.5%), as revealed by supervised classification. By 2012, the percentages had changed to bare land (12.7%), shrubland (6.9%), cultivated land (49.55%), forest land (22.95%), grazing land (3.6%), water body (0.5%), and settlements (3.5%). By 2020, the distribution of land use had further altered to bare land (48.05%), shrubland (5.26%), cultivated land (35.36%), forest (36.11%), grazing land (10.42%), water body (1.10%), and settlements (1.10%). After analyzing the land use classifications, specific C-factors were assigned to each land use type in the watershed. The C-factor is a metric that measures the impact of land cover management practices on soil erosion. It is expressed as a numerical value that ranges from 0 to 1, with lower values indicating less erodible soil and higher values indicating a greater potential for erosion. A C-factor closer to 0 indicates a lower tendency for soil erodibility, while a value closer to 1 indicates a higher tendency for erosion. Vegetative cover, habitation, grassland, and arable land were assigned C-values of 0.015, 0.03, 0.04, and 0.16, respectively. Additionally, protected land was given a value of 0, and unprotected land was given a value of 1 according to the C-factor categorization system (Hurni and Hellden 1998).

The suitability of the northern highlands for human settlement led to the widespread removal of vegetation cover for agricultural lands. This practice, along with intensive farming practices, exacerbated soil erosion, resulting in the loss of fertile topsoil and essential nutrients. This left shallow and infertile soils with poor water retention capacity (Hurni 1998, Hurni et al. 2010). Croplands were particularly vulnerable to erosion since they were frequently tilled, vegetation was removed before planting, and the land remained bare between two seasons (Pimentel 2006).

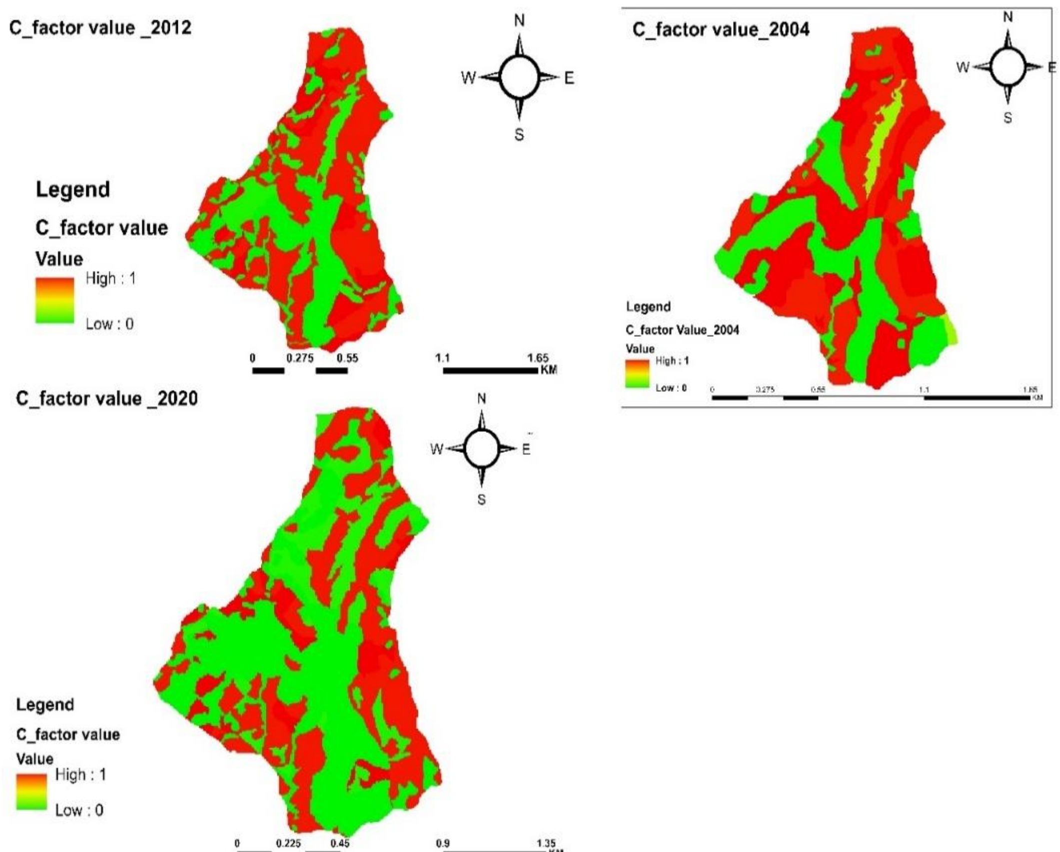

Figure 10: Cover Management factor (C-Value) for the three study years

The distribution of the C-factor, which characterizes the degree of land cover management and its impact on soil erosion, varies significantly across land use types and periods. Forest and shrubland exhibit the lowest C-values, while bare land and cultivated fields (associated with poor land cover management) show the highest values, implying that increased C-factors correspond to more severe soil erosion in the study region. The representation of the C-factor in Figure 10 displays how it varies over time and space. The data indicate a decrease in soil erosion over time and space, suggesting that the measures taken to reduce erosion have been effective.

4.3.5 Conservation Practice Factor (P)

The P-factor represents the conservation measures implemented to control surface runoff velocity and minimize soil loss (Wischmeier and Smith 1978). In this study, data were utilized as inputs to compute and generate the P-factor map due to the lack of comprehensive information on the different protection measures employed in the research area, land use, and slope gradient. Based on the RUSLE analysis, agricultural lands had P-factors ranging from 0.1 to 0.33, while other land uses were assigned a P-value of 1, as presented in Table 10.

Table 10: Support Practices (P) factor Based on (Wischmeier and Smith, 1978)

Land Use	Slope (%)	P Factor
Agricultural Land	0-5	0.1
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	>50	0.33
Nonagricultural land use	All	1

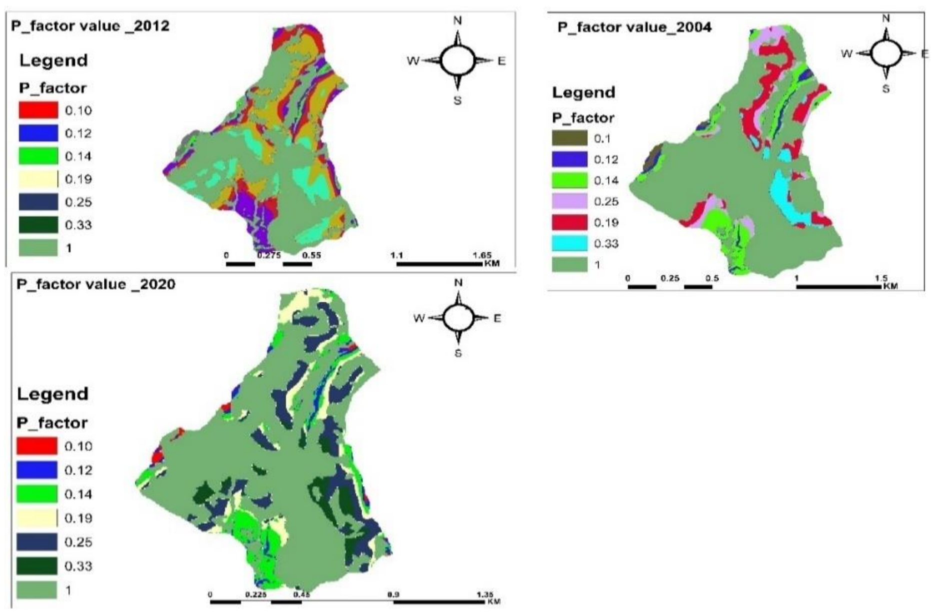

Figure 11 : P _factor Map for Maybar Watershed for the Years 2004,2012 and 2020

4.4 Soil loss Estimation

Using GIS software, the annual soil loss in a study watershed was calculated based on five input parameters of the RUSLE model. These parameters were organized in a grid format with a cell size of 2m * 2m and some parameters varied spatially and temporally. The resulting map layers of soil erosion controlling factors were used to generate a raster map of soil erosion risk for 2004, 2012, and 2020. A potential annual soil loss map for the watershed was developed in the study, and the findings indicate that the mean annual soil loss for the entire watershed was roughly 12.8 t ha $^{-1}$ yr^{-1} in 2004. The study period in 2004 resulted in a total loss of 99728.4 tons of soil from the entire watershed.

The study found that in 2012, the mean annual soil loss for the entire watershed was approximately 4.8 t ha-^{1} yr-^{1}. Furthermore, the total yearly soil loss for the entire watershed during the study period in 2012 was approximately 19167.3 tons. The average soil erosion rate in 2012 decreased by 8.0 t ha-^{1} yr-^{1} compared to 2004, primarily due to changes in land use and land cover, such as the conversion from bare land to forest and shrubland. The study analyzed the annual soil loss in the watershed for 2020 using the RUSLE model. The results showed that the annual soil loss varied from 0 to 295.4 t ha^{-1} yr-^{1} in areas with high erosion vulnerability. The average annual soil loss for the entire watershed was estimated to be 3.21 t ha-^{1} yr-1. Compared to the average rate in 2012, the average rate of soil erosion decreased by 1.59 t ha-^{1} yr^{-1}, which can be attributed to the long-term management of the watershed and the implementation of physical and biological soil and water conservation measures. These efforts led to an increase in forest land use in 2020 and a decrease in the general trend of soil erosion.

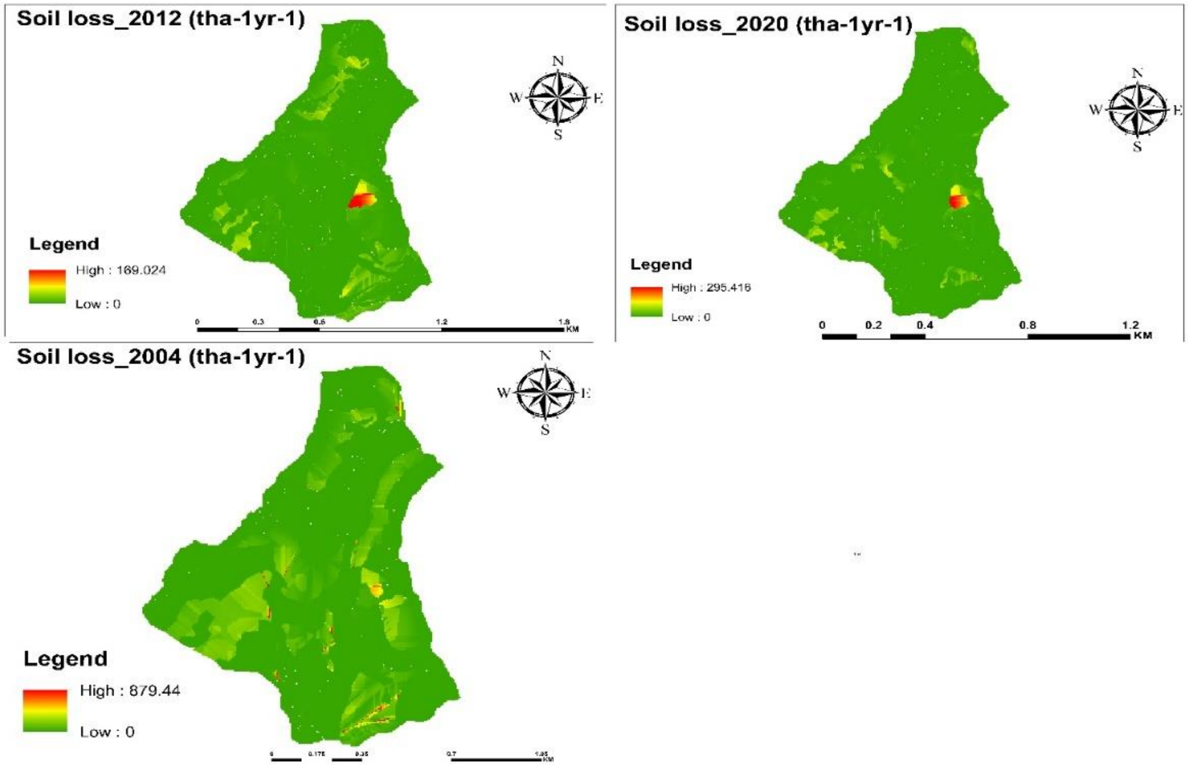

Figure 12: Annual Soil Loss Map in 2004, 2012 and 2020 of the Watershed

The loss of soil annually in a particular watershed was calculated to be between 3.21-12.8 t ha-^{1} yr-^{1,} which falls within the tolerable soil loss level of 2-16 t ha-^{1} yr-^{1} (Hurni 1983). This finding aligns with earlier research in Ethiopia's upper Blue Nile basin and other areas.

Habtamu et al (2020) reported that the average annual soil loss in the Huluka area of Central Ethiopia's Oromia region ranged from 14.4 to 27 t ha–^{1} year–^{1} between 1998 and 2018. Similarly, Ajanaw etal (2021) found that the mean annual soil loss was between 6.2 to 25.07 t ha-^{1} yr-^{1} in the Chereti watershed of North Eastern Ethiopia. However, other studies have reported higher soil erosion rates than the present study. For instance, Meseret and Habtamu (2021) observed 76.5 t ha-^{1} yr -^{1} in the Fincha Catchment of Ethiopia, Tadele B et al. (2022) observed 62.5 t ha-^{1} yr -^{1} in the Coka watershed of Southern Ethiopia, and Zerihun et al. (2018) found 49 t ha-^{1} yr-^{1} in the Dembecha district of Northwestern Ethiopia. The implementation of soil and water conservation measures in the study watershed since 1990, as well as proper watershed management, may have contributed to the relatively low average annual soil loss observed in the area. Furthermore, the dominant soil type in the watershed is Phaeozems, which contains iron oxides that act as a binding agent, resulting in increased aggregate stability and resistance to erosion.

4.4.1 Impacts of Land Use Land Cover Dynamics on Soil Erosion

The contribution of land use and land cover to soil erosion hazards is well known (Rozos D etal 2013). Physical factors are crucial for land-use planners to consider when engaging in spatial planning (Bathrellos etal 2013). Therefore, integrating spatial and temporal variations in land use, land cover, and soil erosion hazard maps is essential for effective land-use planning (Tsegaye D et al. 2010). In Ethiopia, soil erosion hazard rates have significantly increased due to land use and land cover changes (Tsegaye D et al. 2010, Mariye M et al. 2022, Weldu and Haraka 2020). Thus, it is crucial to manage land use and land cover effectively to mitigate soil erosion hazards and ensure sustainable land resource utilization in Ethiopia.

Tsegaye et al. (2010) estimated that soil loss in the highlands of Ethiopia ranged between 1,248 and 23,400 million tons per year across 78 million hectares. This represents a range of 16 to 300 tha^{-1} yr^{-1} for pasture, ranges, and cultivated fields across the country. A study conducted by Melese D et al. (2021) estimated that Ethiopia has an average annual soil loss of 12 tha^{-1} yr^{-1}. Soil erosion rates are higher on steep slopes with minimal vegetation cover, where soil loss can exceed 300 tons ha-1 yr-1. However, the study found that the mean annual soil loss decreased gradually over the study period, with rates of 12.8, 4.8-, and 3.21 tha^{-1} yr^{-1} in 2004, 2012, and 2020, respectively (Table 11). This decrease in soil erosion is due to long-term watershed management practices. The study also observed a decrease in bare land use and an increase in forest land use, contributing to the decreasing trend of soil erosion. Changes in land use dynamics are among the factors that contribute to soil erosion hazards, and physical factors play a critical role for land-use planners in spatial planning. Thus, it is important to integrate spatial and temporal variations in land use, land cover, and soil erosion hazards into hazard maps for effective land-use planning. These findings are consistent with those of previous studies and suggest that soil erosion rates can vary over time.

Table 11: Temporal variation of soil erosion with land use dynamics

Result descriptions	Soil loss in different years		
	2004	2012	2020
Soil loss Range (tons ha−1 yr−1)	0-879.44	0-169.02	0-295.4
Total soil loss (tons/yr.)	99728.4	19167.3	33500.1
Mean soil loss (tons ha−1 yr−1)	12.8	4.8	3.21

Using zonal statistics analysis in ArcGIS, we examined the effects of land use and land cover on soil erosion. Our findings indicate significant variation in mean annual soil loss rate values across land use and cover classes. Specifically, bare lands had the highest mean value of soil loss (ranging from

28.0 to 37.34 that-^{1} yr-1) followed by cultivated land (ranging from 2.6 to 3.34 t ha-^{1} yr^{-1}) and grazing land (ranging from 0.33 to 1.12 t ha^{-1} yr^{-1}) (Table 12 and Figure 13).

In contrast forest land had the lowest value, followed by shrubland (ranging from 0.17 to 0.42 t ha^{-1} yr^{-1}) and (from 0.6 to 0.755 t ha^{-1} yr-^{1}), respectively.

These results indicate that land use and land cover dynamics significantly impact soil erosion rates, with bare and cultivated land more susceptible to soil erosion. Additionally, we observed that as the trend of bare land decreases and forest coverage increases, watershed soil erosion decreases from 2004 to 2020.

Table 12: Distribution of annual and mean soil loss between different types of land use during (2004, 2012, and 2020)

LULC type	2004				2012				2020			
	Soil loss (t/y)	Mean soil loss (t/ha/yr)	Area (h)	(%)	Soil loss (t/yr)	Mean soil loss (t/ha/y)	Area (ha)	(%)	Soil loss (t/y)	Mean soil loss (t/ha/y)	Area (ha)	(%)
Bare land	4234	37.34	38	33.6	3176.8	28.0	14.4	12.7	3429.2	30.2	9.1	8.1
Shrub land	85.7	0.755	13	11.5	87.24	0.8	7.8	6.9	67.17	0.6	6	5.3
Cultivated land	380.6	3.35	36	31.9	311.79	2.7	56.4	49.8	300.3	2.6	40	35.3
Forest land	48.37	0.42	18	15.9	36.74	0.3	26	22.9	20.17	0.17	40.9	36.1
Grazing land	127.0	1.12	4	3.5	42.86	0.4	4.2	3.7	37.75	0.33	11.8	10.4
Settlement	11.42	0.10	4	3.5	13.74	0.1	4	3.5	17.42	0.15	4.2	3.7
Waterbody	0	0	0	0	73.59	0.6	0.6	0.5	124.87	1.10	1.3	1.1

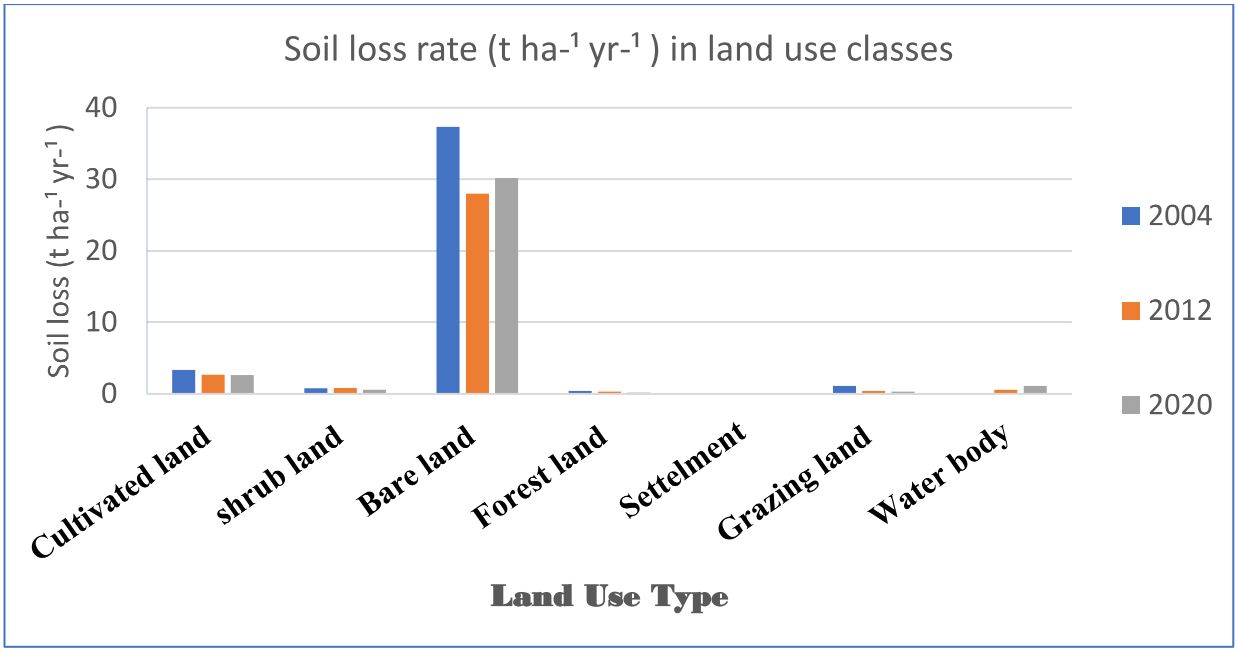

Figure 13: Variation in mean soil loss in different land use classes and years

The study area covered four different soil types, with Haplic Phaeozems being the most dominant, covering more than 91% of the site (Table 13). Analysis of soil loss rates across these soil types revealed varying erosion rates (Table 13). Particularly, the highest risk of soil erosion was observed in Eutric Gleysols, Eutric Fluvisols, and Haplic Phaeozems. Erosion rates in Eutric Gleysols (2.1 ha or 2.6%) were 37.3 t ha $^{-1}$ yr^{-1} in 2004, 51.0 t ha $^{-1}$ yr^{-1} in 2012, and 41.0 t ha $^{-1}$ yr^{-1} in 2020. Similarly, erosion rates in Fluvisols (4.4 ha or 3.9%) were 26.3 t ha $^{-1}$ yr^{-1} in 2004, 3.4 t ha $^{-1}$ yr^{-1} in 2012, and 3.1 t ha $^{-1}$ yr^{-1} in 2020. In contrast, erosion rates in Phaeozems (103.9 ha or 91.6%) were lower, at 13.3 t ha $^{-1}$ yr^{-1} in 2004, 4.4 t ha $^{-1}$ yr^{-1} in 2012, and 6.1 t ha $^{-1}$ yr^{-1} in 2020.

Table 13: Soil erosion across different soil types during 2004, 2012, and 2020.

Soil type	Area		2004 Total annual soil loss(ton/year)		2004 Soil loss ($t\ ha^{-1}\ yr^{-1}$)	2012 Total annual soil loss(ton/yr)		2012 Soil loss ($t\ ha^{-1}\ yr^{-1}$)	2020 Total annual soil loss(ton/yr)		2020 Soil loss ($t\ ha^{-1}\ yr^{-1}$)
	(ha)	(%)	(t)	(%)		(t)	(%)		(t)	(%)	
Mollic Gleysols	3	2.6	58.2	0.7	0.5	19.7	0.3	0.2	18.1	0.3	0.2
Haplic Phaeozems	103.9	91.6	1508.9	17.2	13.3	493.5	7.4	4.4	325.1	6.1	2.9
Eutric Fluvisols	4.4	3.9	2987.4	34.0	26.3	388.7	5.8	3.4	354.8	6.6	3.1
Eutric Gleysols	2.1	2.6	4231.0	48.2	37.3	5785.4	86.5	51.0	4652.3	87.0	41.0
Total	113.4	100									

The severity class was adjusted based on the average erosion rate in each sub-watershed and the specific characteristics of the watershed. This study created six severity classes to generate the severity map for the sub-watersheds, ranging from highly severe (I) to low erosion class (VI). These categories were defined as follows: low erosion severity (<5 tons $ha^{-1}yr^{-1}$), moderate erosion (5-10 $t\ ha^{-1}\ yr^{-1}$), high erosion category (10-50 $t\ ha^{-1}\ yr^{-1}$), severe (50-100 $t\ ha^{-1}\ yr^{-1}$), very severe (100-500 $t\ ha^{-1}\ yr^{-1}$), and extremely severe (>500 t $ha^{-1}\ yr^{-1}$).

Based on the severity class categories, 62.2%, 82.6%, and 88.5% of the watershed were classified as low severity class, 6.2%, 5.3%, and 3.9% of the watershed as moderate severity class, 22.3%, 9.4%, and 5.4% of the watershed as high severity class, 7.0%, 0.9%, and 0.6% of the water as severe class, 0.7%, 0.6%, and 0.4% of the watershed as very severe class, and 0.1%, 0%, and 0% of the watershed as a highly severe class in the years 2004, 2012, and 2020, respectively Table 14.

The findings in Table 14 indicate that there has been no extreme soil erosion class since 2004, most likely due to the long-term watershed management strategies employed in the study area. The results show that 88.5% of the Maybar watershed is now classified as low-risk for soil erosion. However, it is essential to note that this does not mean conservation measures are no longer necessary in this area. Immediate soil and water conservation measures are still required for the remaining parts of the watershed at higher risk of erosion. Additionally, it is essential to ensure that even the low-risk areas continue to improve their conservation measures to prevent future erosion.

Table 14: Soil Erosion Classification based on Morgan (2005)

Soil erosion rate (t ha^{-1} $year^{-1}$)	Coverage of the erosion-affected area (%)			
	2004(%)	2012(%)	2020(%)	Severity Class
0-5	62.2	82.6	88.5	Low
5-10	6.2	5.3	3.9	Moderate
10-50	22.3	9.4	5.4	High
50-100	7.0	0.9	0.6	Severe
>100	0.8	0.6	0.4	Very severe
Total	100	100	100	

4.5. Prioritization of the Watersheds for Conservation Planning

The RUSLE model is an essential tool for conservation planning that enables a comparison of soil erosion risk across a study area. This information is critical for identifying areas within a watershed that are at high erosion risk and require prioritization for intervention. In this study, the watershed was divided into five classes based on soil erosion severity, with the area coverage ranging from 0.5 ha (SW5) to 100.3 ha (SW2). The soil loss class for each part of the watershed was determined based on the information provided in Table 15 and

Figure 15. Based on Figure *14*, it can be inferred that the number and extent of hotspot areas in the watershed have decreased. The changes observed range from a reduction in severity class (e.g., from very severe to medium) to a shift from low to medium severity class. These findings suggest that some highly degraded areas have been improved due to soil and water conservation measures implemented by the community in the watershed with the assistance of various non-governmental organizations.

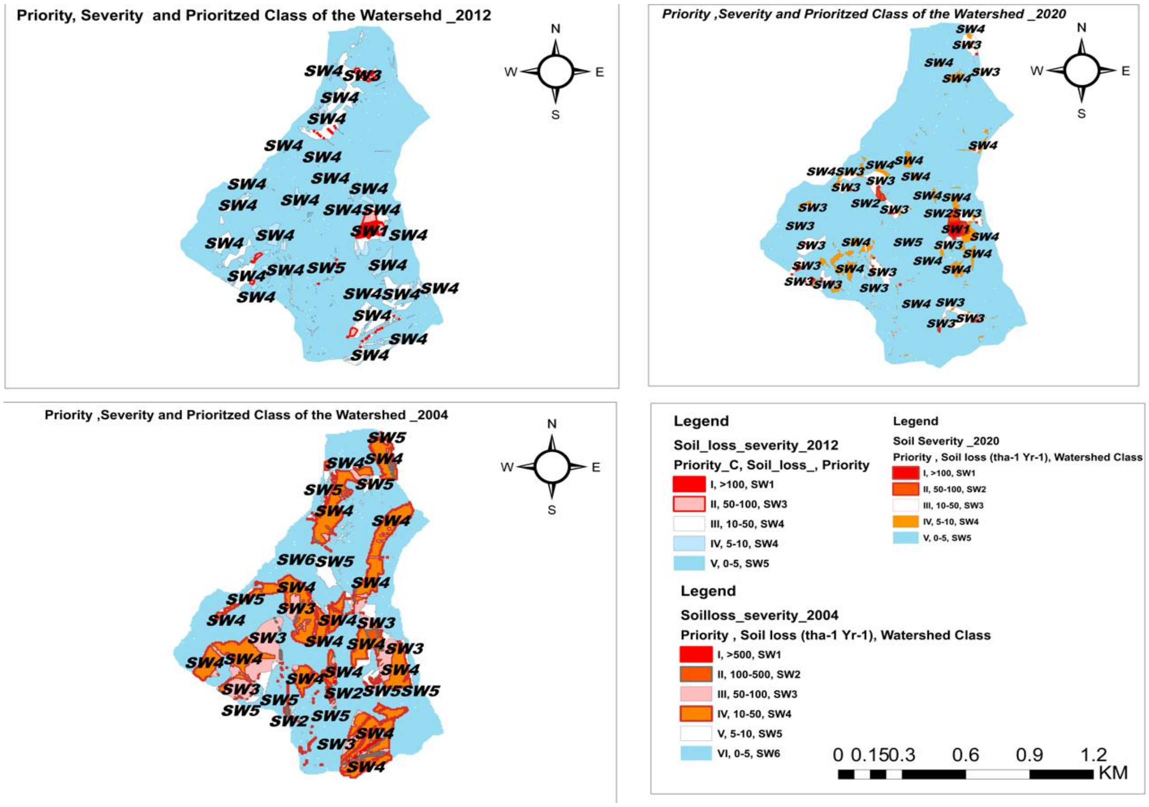

Figure 14: Trend of Soil Erosion Severity Map (2004-2020)

According to the data presented in Figure 14, there has been a decreasing trend in the severity of soil erosion from 2004 to 2020. This suggests that changes in land use and land cover have had a positive significant impact on reducing soil erosion. Additionally, there has been a reduction in soil loss per hectare of land over the same period, and the area requiring immediate soil and water conservation measures also shows a decreasing trend. According to (Table 15) the percentage of the severe soil erosion class has decreased over time. Specifically, the rate of the severe class was 7.8% in 2004, 1.5% in 2012, and further decreased to 1% in 2020. In 2004, the catastrophic severity class was identified, but this class was not observed in the 2012 classification and 2020 classication. This suggests that efforts to reduce soil erosion, such as changes in land use and conservation measures, have positively impacted the severity of soil erosion over time.

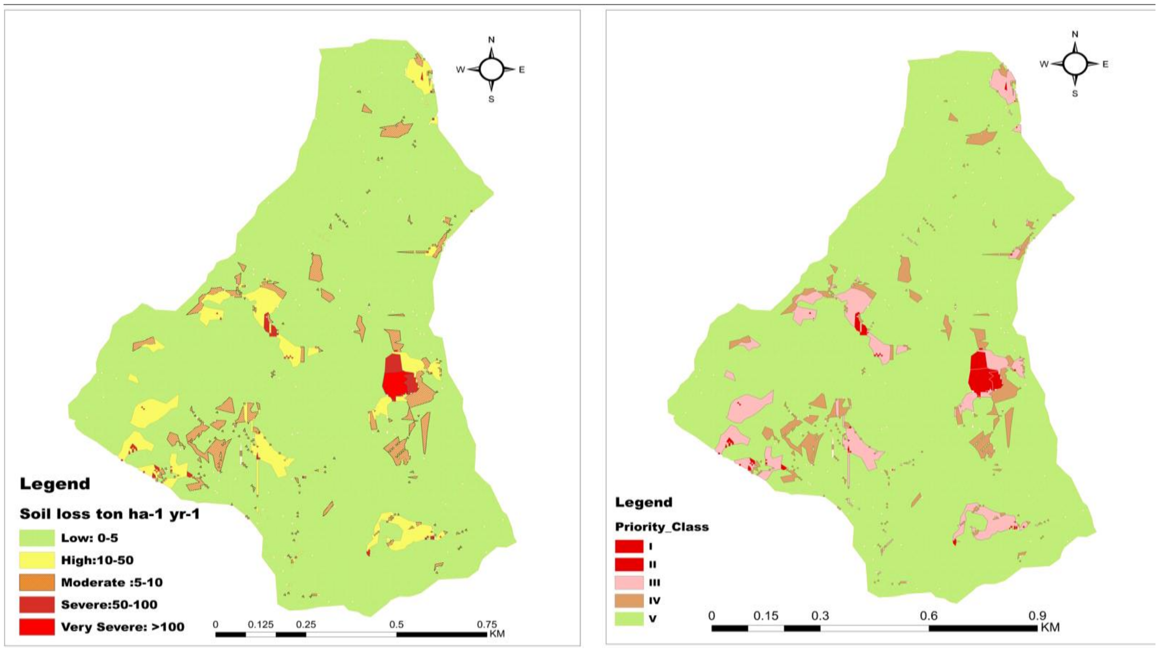

Figure 15:Annual Soil Loss and Severity Class Map of Maybar Watershed

Table 15: Prioritized part of watersheds for conservation planning purposes.

Soil loss t ha $^{-1}$ yr^{-1}	Area coverage (ha)	Area (%)	Priority Class	Class of Watershed	Description
		2020			
0-5	100.3	88.5	V	SW5	Low
5-10	4.4	3.9	IV	SW4	Moderate
10-50	6.2	5.4	III	SW3	High
50-100	0.6	0.6	II	SW2	Severe
>100	0.5	0.4	I	SW1	Very Severe
		2012			
0-5	93.7	82.6	V	SW5	Low
5-10	6.0	5.3	IV	SW4	Moderate
10-50	10.6	9.4	III	SW4	High
50-100	1.0	0.9	II	SW3	Severe
>100	0.6	0.6	I	SW1	Very Severe
		2004			
0-5	70.5	62.2	VI	SW6	Low
5-10	7.0	6.2	V	SW5	Moderate
10-50	25.2	22.3	IV	SW4	High
50-100	8.0	7.0	III	SW3	Severe
100-500	0.8	0.7	II	SW2	Very severe
>500	0.1	0.1	I	SW1	Catastrophic

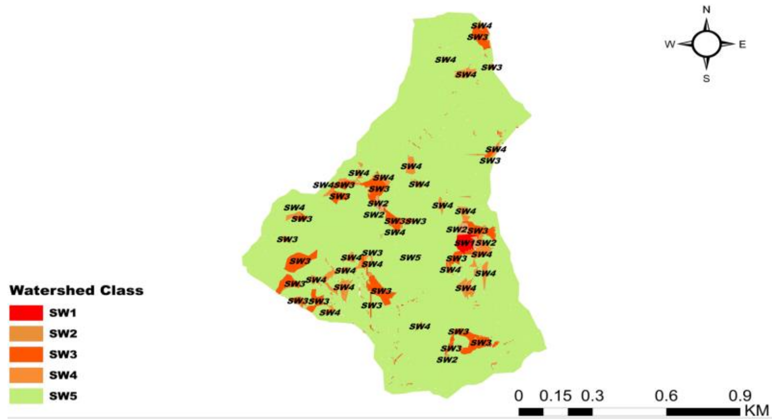

Figure 16: Current Priority Class of the Watershed for Soil and Water Conservation

The identification of priority areas for conservation planning in the watershed was determined by evaluating the mean annual soil loss rates during the study period of 2020, and also by taking into consideration the average annual soil loss for each of the respective watershed categories. The classification of soil erosion severity classes was based on the yearly average soil erosion rates, which were divided into five priority classes according to Morgan (2005) Low (0-5), Moderate (5-10), High (10-50), Severe (50-100), and Very Severe (>100) t ha-1 yr-1. The watersheds were grouped into five severity classes based on their mean soil loss rates. Out of the 52 watershed classes, one was classified as having low soil loss severity, 24 as having moderate soil loss severity, 26 ranged from high to severe soil loss severity class, and one as extremely powerful soil loss severity. Effective implementation of soil and water conservation strategies is crucial to ensure sustainable land use practices in the entire watershed, as demonstrated by the mean annual soil loss rates of all the watershed classes in Table 15. Prioritizing conservation efforts is crucial for successful outcomes and identifying areas that require immediate attention for appropriate remedies. Severity classifications based on soil loss amounts can help identify vulnerable watershed areas. The more sensitive a watershed is to erosion; its higher priority is developing management strategies to prevent soil and nutrient losses.

Watershed classes have been ranked based on average soil loss per hectare per year. As described in Figure 14, the largest watershed class (SW5) covering 100.3 ha (88.5% of the watershed) was classified as having low soil loss rates, likely due to high C and P factors and land cover types resulting from watershed management efforts as shown in Figure 10 and Figure 11. In the middle of the watershed, there were three classes of watersheds (SW1, SW2, and SW3), accounting for 6.4% of the research area and ranging from high soil erosion to extremely severe erosion classes. 3.9% moderate erosion, 0.4% highly severe erosion in watershed (SW4).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study has shown the increasing threat of soil erosion to land and water resources in the highlands of Ethiopia due to changes in land use and land cover dynamics. The study used GIS and remote sensing techniques and the RUSLE model to map soil erosion risk and estimate soil loss rate. The results showed that land use and land cover change significantly impacted soil erosion, with bare land, cultivated land, and grazing land having the highest annual loss and forest land, shrub land, and water body having the lowest. From 2004 to 2020, there was a decreasing trend in soil erosion, as demonstrated by our results, with the rate decreasing from 12.8 to 3.2 $tha^{-1}\ y^{-1}$. The study identified priority areas for soil and water conservation interventions based on the severity of soil erosion, with the watershed class SW1 being the most severely affected and needing urgent conservation measures. The study concludes that effective planning and management of land use, land cover dynamics, and soil and water conservation practices are critical to reducing soil erosion, conserving water resources, and sustaining agricultural productivity.

5.2 Recommendations

- ✓ Encourage afforestation and reforestation programs: Since an increase in forest area is shown to have a positive impact on reducing soil erosion, there should be a focus on afforestation and reforestation programs in the region. This will not only reduce soil erosion but also provide multiple benefits, such as carbon sequestration, biodiversity conservation, and sustainable livelihoods for local communities.
- ✓ Develop policies to promote sustainable land use: The study highlights the importance of sustainable land use practices in reducing soil erosion. Therefore, policies should be in place to encourage sustainable land use practices such as agroforestry, conservation agriculture, and integrated watershed management.
- ✓ Strengthen soil conservation measures: The study shows that terracing, contour ploughing, and soil bunds reduce soil erosion. Therefore, there should be efforts to strengthen and scale up these measures in the region.
- ✓ Improve monitoring and evaluation of land use change to identify areas needing intervention and ensure sustainable practices. The study's findings offer recommendations for sustainable land use to reduce soil erosion and improve environmental quality.

6. SUMMARY

Soil erosion is currently the most significant threat to land and water resources, particularly in Ethiopia's highlands. Land use changes, land degradation, and soil erosion are increasing, resulting in annual losses of fertile soil and declining crop yields. The objective of this study was to examine how changes in land use and land cover affected soil erosion dynamics and determine which areas should receive priority for soil and water conservation interventions. The study employs GIS and remote sensing techniques to assess the impact of land use and land cover change on soil erosion between 2004 and 2020. The RUSLE model maps soil erosion risk and estimates soil erosion rates. Mean annual rainfall, soil data, 2m DEM, and satellite images are used to input data into the model to determine soil erosion. The study identifies six land use and cover types and shows that significant changes have occurred in bare land and shrubland, decreasing by 25.48% and 6.17%, respectively, over 24 years. On the other hand, forest land increased by 20.19%, and cultivated land increased by 3.52%. Additionally, the study evaluated the response of soil erosion to land use and land cover changes, showed that bare land, cultivated land, and grazing land have the highest annual loss. In contrast, forest land, shrubland, and water body have the lowest. The analysis of soil erosion risk indicated a decline in the mean annual soil loss rate at the watershed scale, with rates decreasing from 12.8t ha^{-1} yr^{-1} in 2004 to 3.21t ha-^{1} yr-^{1} in 2020. The watershed is classified into five severity classes, and the study area was divided into five priority categories based on their average annual soil losses. The study emphasized that prioritizing interventions for watershed types with high erosion risks is crucial for reducing on-site soil loss and off-site effects and conserving water resources. The findings support the importance of long-term watershed management in reducing soil erosion. To effectively reduce soil erosion and improve environmental quality, it is recommended to encourage afforestation and reforestation, develop sustainable land use policies, strengthen soil conservation measures, and improve monitoring and evaluation of land use changes.

Keywords: Soil Loss, Land use dynamics, Hydrology, GIS and Remote Sensing, RUSLE

7. ACKNOWLEDGEMENTS

Firstly, I express my gratitude and thank the Almighty God for His blessings, limitless care, and love throughout my life. I would like to extend my sincere appreciation to my supervisors, **Dr István Waltner**, associate professor at the Hungarian University of Agriculture and Life Science in Hungary, and **Dr Hailu Kendie**, a senior researcher at Amhara Regional Agricultural Research Institute (ARARI), for their vital help, immense encouragement, professional guidance, and direct support from the initial stages of proposal development to the final thesis write-up, which enabled me to complete this work meaningfully. It was a great privilege and honor to work and study under their genuine advice, comments, and guidance. I would also like to thank all my teachers and classmates at the Hungarian University of Agriculture and Life Science (MATE) and express my appreciation to the Amhara Agricultural Research Institute (ARARI), particularly the Sirinka Agricultural Research Center (SARC), for granting me admission to the graduate school and for providing financial support.

I am delighted to express my gratitude to the Scholarship for FAO Hungarian Government Scholarship for giving me the opportunity to pursue my master's degree at the Hungarian University of Agriculture and Life Science in Hungary and for providing financial sponsorship. I would like to extend my special acknowledgment to **Mr Muluken Lebay**, who provided the necessary data on the research work subject matter and encouraged my efforts in various aspects. I offer my heartfelt thanks to my family and my spouse, **Mahider Wodaje, and my son, Nathan Wudu**, for providing me with love, support, and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. Without these people, this thesis accomplishment would not have been possible.

Thank you.

Wudu Abiye

8. REFERENCE

1. Addis, H. K., And Klik, A. (2015). Predicting the spatial distribution of soil erodibility factor using USLE nomograph in Ethiopia's agricultural watershed. International Soil and Water Conservation Research, 3(4), 282-290. https://doi.org/10.1016/j.iswcr.2015.11.002
2. Alemayehu, F., Taha, N., Nyssen, J., Girma, A., Zenebe, A., Behailu, M And Poesen, J. (2009). The impacts of watershed management on land use and land cover dynamics in Eastern Tigray (Ethiopia). Resources, Conservation and Recycling, 53(4), 192-198. https://doi.org/10.1016/j.resconrec.2008.11.007
3. Arekhi, S And Rostamizad, G. (2011). Sediment yield estimating from three micro-watersheds by integrated KW-GIUH and MUSLE models. Advances in Environmental Biology, 1346-1359.
4. Arekhi, S. (2008). Evaluating long-term annual sediment yield estimating the potential of GIS interfaced MUSLE model on two micro-watersheds. Pakistan J. Biol. Sci, 11, 270-274. https://www.academia.edu/download/31094522/270-274.pdf
5. Asfaw Alemayehu, Taye Bekele, Yohannes Gebremichael and Asmamaw Tadege. (2021). Impacts of land use/land cover dynamics on soil erosion rate: A Hare Watershed, Ethiopia case study. Environmental Systems Research, 10(1), 1-19.doi:10.1186/s40068-021-00212-4 .
6. Batjes, N. H., Van Engelen, V. W. P., Kauffman, J. H. and Oldeman, L. R. (1994). Development of soil databases for global environmental modelling. In Trans. 15th World Congress of Soil Science (Acapulco, us, 10-17 July, 1994) (Vol. 6, pp. 40-57).
7. Baulies, X., and Szejwach, G. (Eds.). (1998). LUCC Data Requirements Workshop: Survey of Needs, Gaps and Priorities on Data for Land-use/land-cover Change Research, Barcelona, 11-14 November 1997 (No. 3).
8. Bayramin, I., Dengiz, O., Başkan, O. and Parlak, M. (2003). Soil erosion risk assessment with ICONA model; case study: Beypazar area. Turkish Journal of Agriculture and Forestry, 27(2), 105-116
9. Berlanga-Robles, C. A and Ruiz-Luna, A. (2002). Land use mapping and change detection in the coastal zone of northwest Mexico using remote sensing techniques. Journal of Coastal Research, 514-522.
10. Bewket, W and Abebe, S. (2013). Land-use and land-cover change and its environmental implications in Ethiopia's tropical highland watershed. International journal of environmental studies, 70(1), 126-139. https://doi.org/10.1080/00207233.2012.755765
11. Biggelaar, C. D., Lal, R., Wiebe, K And Breneman, V. (2004). The global impact of soil erosion on productivity. I. Absolute and relative erosion-induced yield losses.https://pubag.nal.usda.gov/catalog/47818
12. Biro, K., Pradhan, B., Buchroithner, M. and Makeschin, F. (2013). Land use/land cover change analysis and its impact on soil properties in the northern part of Gadarif region, Sudan. Land Degradation & Development, 24(1), 90-102. https://doi.org/10.1002/ldr.1116
13. Borrelli, P., Alewell, C., Alvarez, P., Anache, J. A. A., Baartman, J., Ballabio, C., and Panagos, P. (2021). Soil erosion modelling: A global review and statistical analysis. https://doi.org/10.1016/j.scitotenv.2021.146494
14. Brhane, G. and Mekonen K. (2009). Estimating soil loss using Universal Soil Loss Equation (USLE) for soil conservation planning at Medego watershed, Northern Ethiopia. Journal of American Science, 5(1), 58-69. http://www.sciencepub.org/
15. BURAKA, T., ELIAS, E., SURYABHAGAVAN, K. V., & LELAGO, A. (2022). Assessment of soil erosion risks in response to land-use and land-cover changes in Coka watershed, Southern Ethiopia. https://doi.org/10.1080/24749508.2022.2109825
16. Campbell, D. J. (2003). Globalization and Local Heterogeneity: An overview of diversity in land use and development issues in the Loitokitok Division, Kajiado District, Kenya. LUCID Project, International Livestock Research Institute.
17. CCME (Canadian Council of Ministers of the Environment) (2016). Summary of Integrated Watershed Management Approaches across Canada. Canadian Council of Ministers of the Environment. https://doi.org/10.1016/j.iswcr.2020.06.007
18. Cerdan, O., Govers, G., Le Bissonnais, Y., Van Oost, K., Poesen, J., Saby, N And Dostal, T. (2010). Rates and spatial variations of soil erosion in Europe: A study based on erosion plot data. Geomorphology, 122(1-2), 167-177. https://doi.org/10.1016/j.geomorph.2010.06.011

19. Chavare, S. D., Karande, K. M., Aloorkar, N. H., Kulkarni, A. S and Majumdar, S. H. (2015). Formulation of novel herbal mosquito repellent: A new approach in antimalarial management. Int J Med Pharm Res, 1, 78-85.
20. Chen D and Stow D. (2002). The Effect of Training Strategies on Supervised Classification at Different Spatial Resolutions. November.
21. Chiang, L.C., Chaubey, I., Hong, N.M., Lin, Y.P. and Huang, T. (2012). Implementation of BMP strategies for adaptation to climate change and land use change in a pasture-dominated watershed. International journal of environmental research and public health, 9(10), pp.3654-3684. https://doi.org/10.3390/ijerph9103654
22. Chisholm, N. And Woldehanna, T (2012). Managing watersheds for resilient livelihoods in Ethiopia.
23. Coburn, C A and Roberts, AC (2004). A multiscale texture analysis procedure for improved forest stand classification. International journal of remote sensing, 25(20), 4287-4308. https://doi.org/10.1080/0143116042000192367
24. Dangermond, J (1992). What is a Geographic Information System (GIS)? ASTM International.
25. Di Gregorio, A and Jansen, L (2000). Land Cover Classification System (LCCS): Classification Concepts and User. FAO Corporate Document Repository.
26. Dregne, H. E. (1990). Erosion and soil productivity in Africa. Journal of soil and Water Conservation, 45(4), 431-436. https://www.jswconline.org/content/45/4/431.short
27. Ebabu, K., Tsunekawa, A., Haregeweyn, N., Adgo, E., Meshesha, D. T., Aklog, D. and Yibeltal, M. (2019). Effects of land use and sustainable land management practices on runoff and soil loss in the Upper Blue Nile basin, Ethiopia. Science of the Total Environment, 648, 1462-1475. https://doi.org/10.1016/j.scitotenv.2018.08.273
28. Ellis, E and Pontius, R. (2007). Land-use and land-cover change. Encyclopedia of earth, 1, 1-4.
29. Erencin, Z., Shresta, D. P and Krol, I. B. (2000). C-factor mapping using remote sensing and GIS. Case study Lom SakLom Kao Thail Geogr Inst Justus-Liebig-Univ Giess Intern Inst Aerosp Surv Earth SciITC Enschede Netherland. https://core.ac.uk/download/pdf/56347214.pdf
30. Essaysu.K., 2013. Land Use and Land Cover in Ethiopia Environmental Sciences Essay. Link: https://bit.ly/3t6amR9.
31. Fantaye, T. (2022). Impact of land use land cover change on soil erosion, watershed prioritization and farmer perception: the case of mitka watershed in Ethiopia (Doctoral dissertation, Hawassa University). http://dlib.hu.edu.et//handle/123456789/3044
32. FAO and ITPS. (2015). Status of the world's soil resources (SWSR)–main report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, 648.
33. Fonji, S. F and Taff,Gn(2014). Using satellite data to monitor land-use land-cover change in North-eastern Latvia. Springer plus, 3(1), 1-15. http://www.springerplus.com/content/3/1/61
34. Gashaw, T., Bantider, A and Mahari, A. (2014). Evaluations of land use/land cover changes and land degradation in Dera district, Ethiopia: GIS and remote sensing-based analysis. International Journal of Scientific Research in Environmental Sciences, 2(6), 199. http://dx.doi.org/10.12983/ijsres-2014-p0199-0208
35. Gashaw,T., Tulu, T., Argaw, M and Worqlul, A.W.(2018). Modeling the hydrological impacts of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. Science of the Total Environment, 619, 1394-1408. https://doi.org/10.1016/j.scitotenv.2017.11.191
36. Gebregziabher, G., Abera, D.A., Gebresamuel, G., Giordano, M. and Langan, S. (2016). An assessment of integrated watershed management in Ethiopia (Vol. 170). International Water Management Institute (IWMI).
37. Gebrernichael, D., Nyssen, J, Poesen, J., Deckers, J., Haile, M., Govers, G. and Moeyersons, J,2005. Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray Highlands, northern Ethiopia. Soil use and management, 21(3), pp.287-297. https://doi.org/10.1111/j.1475-2743.2005.tb00401.x
38. Geist, H. J and Lambin, E. F (2002). Proximate Causes and Underlying Driving Forces of Tropical Deforestation Tropical forests are disappearing as the result of many pressures, both local and regional, acting in various combinations in different geographical locations. BioScience, 52(2), 143-150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2
39. Gelet, M., Suryabhagavan, K. V and Balakrishnan, M. (2010). Land use and landscape pattern changes in Holeta-Berga watershed, Ethiopia. Int J Ecol Environ Sci, 36(2–3), 117-132.

40. Gessese, B. H. (2018). Impact of land use/land cover change on rural communities' livelihood of Ethiopia. J Ecol Environ Sci, 6(1).
105. Gho. Lamreza Z, Abdolhossein .R, Seyed S and Jafar N (2017)Impacts of watershed management practices on soil erosion and sediment yield in the Zayandehrud River basin, Iran. International Soil and Water Conservation Research, 5(1), 19-26.
41. Gidey, E., Dikinya, O., Sebego, R., Segosebe, E And Zenebe, A. (2017). Modeling the Spatio-temporal dynamics and evolution of land use and land cover (1984–2015) using remote sensing and GIS in Raya, Northern Ethiopia. Modeling Earth Systems and Environment, 3(4), 1285-1301.
106. Girmay G, Amanuel Z, and Wubalem T (2019). Effects of soil and water conservation practices on soil erosion and soil quality: A case study from Tigray, Ethiopia. Land Degradation & Development, 30(1), 91-103.
42. GIZ (Deutsche Gesellschaft International Zusammenarbeit GmbH), 2015. GIZ Ethiopia: lessons and experiences in Sustainable Land Management.
43. Haile, G. W and Fetene, M. (2012). Assessment of soil erosion hazard in Kilie catchment, East Shoa, Ethiopia. Land Degradation and Development, 23(3), 293-306. https://doi.org/10.1002/ldr.1082
44. Hailemariam, S. N., Soromessa, T and Teketay, D. (2016). Land use and land cover change in the bale mountain eco-region of Ethiopia during 1985 to 2015. Land, 5(4), 41. https://doi.org/10.3390/land5040041
45. Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D and Lesschen, J. P. (2005). Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. Agriculture, ecosystems & environment, 108(1), 1-16. https://doi.org/10.1016/j.agee.2004.12.010
46. Hardegree, L.C. (2006). Spatial characteristics of the remotely-sensed surface urban heat island in Baton Rouge, LA: 1988-2003.
47. Haregeweyn, N., Berhe, A., Tsunekawa, A., Tsubo, M. and Meshesha, D.T (2012). Integrated watershed management as an effective approach to curb land degradation: a case study of the Enabered watershed in northern Ethiopia. Environmental management, 50, pp.1219-1233.
48. Haregeweyn,N, Tsunekawa,A.,Poesen, J., Tsubo, M., Meshesha, D. T, Fenta, A.A. and Adgo, E.(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. https://doi.org/10.1016/j.scitotenv.2016.09.019
49. Hartemink, A E. (2010). Land use change in the tropics and its effect on soil fertility. In Proceedings 19th World Congress of Soil Science, Brisbane, Australia, 01-06 August, 2010 (pp. 55-58). https://library.wur.nl/WebQuery/wurpubs/fulltext/174757
50. Herweg, K. and Ludi, E (1999). The performance of selected soil and water conservation measures: Case studies from Ethiopia and Eritrea. Catena, 36(1-2), pp.99-114. https://doi.org/10.1016/S0341-8162(99)00004-1
51. Holdsworth, C and Morgan, D. (2005). Transitions in context: Leaving home, independence and adulthood: leaving home, independence and adulthood. McGraw-Hill Education (UK).
107. Hurni, H., & Hellden, U. (1998). Watershed management, soil conservation and slope stability in high mountains: a case study from the Ethiopian Highlands. Mountain Research and Development, 18(2), 135-148.
52. Hurni, K., Zeleke, G., Kassie, M. Tegegne, B., Kassawmar, T., Teferi, E and Hurni, H. (2015). Economics of Land Degradation (ELD) Ethiopia Case Study: Soil degradation and sustainable land management in the rainfed agricultural areas of Ethiopia: An assessment of the economic implications. http://eld-initiative.org/fileadmin/pdf/ELD-ethiopia_i_06_72dpi-D.pdf
53. Jones, K. B.,Neale, A.C.Nash,M.S.Van Remortel,R.D.Wickham, J. D., Riitters, K. H.and O'neill, R.V.(2001). Predicting nutrient and sediment loadings to streams from landscape metrics: a multiple watershed study from the United States Mid-Atlantic Region. Landscape Ecology, 16(4), 301-312. https://link.springer.com/article/10.1023/A:1011175013278
54. Kassie, M, Pender,J.Yesuf, M. Kohlin, G., Bluffstone, R.and Mulugeta, E. (2007). Impact of soil conservation on crop production in the Northern Ethiopian Highlands. Intl Food Policy Res Inst.
55. Kidane, M., Bezie, A., Kesete, N and Tolessa, T(2019). The impact of land use and land cover (LULC) dynamics on Ethiopia's soil erosion and sediment yield. Heliyon, 5(12), e02981. https://doi.org/10.1016/j.heliyon.2019.e02981
56. Lal R. (1994). Soil erosion research methods. CRC Press.

57. Lal, R. and Stewart, B.A. (1990). Soil degradation: A global threat. Advances in soil science, 2.
58. Lal, R.A.T.T.A.N.(2001). Soil degradation by erosion. Land degradation & development, 12(6), 519-539. https://doi.org/10.1002/ldr.472
59. Lal,R (1995). Erosion-crop productivity relationships for soils of Africa. Soil Science Society of America Journal, 59(3), 661-667. https://doi.org/10.2136/sssaj1995.03615995005900030004x
60. Lambin, E. F and Geist,H. J. (Eds.). (2008). Land-use and land-cover change: local processes and global impacts. Springer Science & Business Media. https://scholar.google.com/citations?user=kH_t7-MAAAAJ&hl=en&oi=sra
61. Lambin, E. F, Turner, B. L,Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W and Xu, J. (2001). The causes of land-use and land-cover change: moving beyond the myths. Global environmental change, 11(4), 261-269. https://doi.org/10.1016/S0959-3780(01)00007-3
62. Leh, M., Bajwa, S and Chaubey, I. (2013). Impact of land use change on erosion risk: an integrated remote sensing, geographic information system and modelling methodology. Land Degradation & Development, 24(5), 409-421. https://doi.org/10.1002/ldr.1137
63. Liu, L. C. Dong, X. F and Wang, J.H. (2007).Dynamic analysis of eco-environmental changes based on remote sensing and geographic information system: an example in Longdong region of the Chinese Loess Plateau. Environmental geology, 53(3), 589-598. https://link.springer.com/article/10.1007/s00254-007-0674-1#article-info
64. Lu, D.and Weng, Q. (2007). A survey of image classification methods and techniques for improving classification performance. International Journal of Remote sensing, 28(5), 823-870. https://doi.org/10.1080/01431160600746456
65. Mather, P and Tso, B.2016. Classification methods for remotely sensed data. CRC press. https://doi.org/10.1201/9781420090741
66. Meyer, W. B and Turner, B. L. (1992). Human population growth and global land-use/cover change. Annual review of ecology and systematics, 39-61. https://doi.org/10.1146/annurev.es.23.110192.000351
67. Millward, A. A and Mersey, J. E. (1999). Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena, 38(2), 109-129.https://doi.org/10.1016/S0341-8162(99)00067-3
68. Moges, M. A., Dagnew, D. C and Tilahun, S. A. (2021). Spatiotemporal dynamics of soil erosion response to land use and land cover change in Ethiopian highland: a review. Environmental Systems Research, 10(1), 1-17. doi:10.1186/s40068-021-00216-0
69. Negese, A. (2021). Impacts of land use and land cover change on soil erosion and hydrological responses in Ethiopia. Applied and Environmental Soil Science, 2021. https://doi.org/10.1155/2021/6669438
70. Newcombe, C.P and Macdonald, D.D. (1991). Effects of suspended sediments on aquatic ecosystems. North American journal of fisheries management, 11(1), 72-82.https://doi.org/10.1577/1548-8675(1991)011%3C0072:EOSSOA%3E2.3.CO;2
71. Nyssen, J., Fetene, F., Dessie, M., Alemayehu, G., Sewnet, A., Wassie, A.and Adgo, E. (2018). Persistence and changes in the peripheral Beles basin of Ethiopia. Regional Environmental Change, 18(7), 2089-2104. https://doi.org/10.1007/s10113-018-1346-2
72. Ochoa, P.A.A.,Fries, A., Mejía, D., Burneo, J. I., Ruíz-Sinoga, J. D and Cerdà, A.(2016). Effects of climate, land cover and topography on soil erosion risk in a semiarid basin of the Andes. Catena, 140, 31-42. https://doi.org/10.1016/j.catena.2016.01.011
73. Oldeman,L.R. (1992). Global extent of soil degradation. In Bi-Annual Report 1991-1992/ISRIC (pp. 19-36). ISRIC. https://library.wur.nl/WebQuery/wurpubs/fulltext/299739
74. Pathak, S. (2014). New Change Detection Techniques to monitor land cover dynamics in mine environment. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(8), 875. https://pdfs.semanticscholar.org/969f/f4bb0825dc86c9c3d3df267796ffbfcff9bb.pdf
75. Patil, M. B., Desai, C. G. and Umrikar, B. N. (2012). Image classification tool for land use/land cover analysis: A comparative study of maximum likelihood and minimum distance method. International Journal of Geology, Earth and Environmental Sciences, 2(3), 189-196. (IJCSEIERD), 4(2), 157-170. http://www.cibtech.org/jgee.htm
76. Pimentel, D and Kounang, N. (1998). Ecology of soil erosion in ecosystems. Ecosystems, 1(5), 416-426. https://doi.org/10.1007/s100219900035

77. Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., Mcnair, M.and Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. Science, 267(5201), 1117-1123. https://doi.org/10.1126/science.267.5201.1117
78. Pimentel, D., Terhune, E. C., Dyson-Hudson, R., Rochereau, S., Samis, R., Smith, E. A. and Shepard, M. (1976). Land degradation: effects on food and energy resources. Science, 194(4261), 149-155. https://doi.org/10.1126/science.194.4261.149
79. Qiang, F. E. N. G., Wenwu, Z. H. A. O., Jun, W. A. N. G., Zhang, X., Mingyue, Z. H. A. O., Zhong, L and Xuening, F. A. N. G. (2016). Effects of different land-use types on soil erosion under natural rainfall in the Loess Plateau, China. Pedosphere, 26(2), 243-256. https://doi.org/10.1016/S1002-0160(15)60039-X
80. Quentin, F. B., Jim, C., Julia, C., Carole, H. and Andrew,S. (2006). Drivers of land use change, final report: matching opportunities to motivations. ESAI project, 5116.
81. Rasid, H. and Pramanik, M.A. H (1993). The areal extent of the 1988 flood in Bangladesh: How much did the satellite imagery show? Natural Hazards, 8(2), 189-200. https://link.springer.com/article/10.1007/BF00605441
82. Rawat, J.S K and Umar, M (2015). Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. The Egyptian Journal of Remote Sensing and Space Science, 18(1), 77-84. https://doi.org/10.1016/j.ejrs.2015.02.002
83. Renard, K.G. (1997). Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). United States Government Printing.
84. Renschler, C. S and Harbor, J. (2002). Soil erosion assessment tools from point to regional scales—the role of geomorphologists in land management research and implementation. Geomorphology, 47(2-4), 189-209.https://doi.org/10.1016/S0169-555X(02)00082-X
85. Renschler, C. S., Mannaerts, C and Diekkrüger, B. (1999). Evaluating spatial and temporal variability in soil erosion risk—rainfall erosivity and soil loss ratios in Andalusia, Spain. Catena, 34(3-4), 209-225. https://doi.org/10.1016/S0341-8162(98)00117-9
86. Rientjes, T. H. M., Haile, A. T., Kebede, E., Mannaerts, C. M. M., Habib, E. and Steenhuis, T. S. (2011). Changes in land cover, rainfall and stream flow in Upper Gilgel Abbay catchment, Blue Nile basin–Ethiopia. Hydrology and Earth System Sciences, 15(6), 1979-1989. https://doi.org/10.5194/hess-15-1979-2011
87. Scholes, R. J., Montanarella, L., Brainich, E., Barger, N., Ten Brink, B., Cantele, M., .and Willemen, L. (2018). Ipbes (2018): Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://research-repository.uwa.edu.au/en/publications/summary-for-policymakers-of-the-assessment-report-on-land-degrada
88. Schulze,R.E.(2000). Modelling hydrological responses to land use and climate change: a southern African perspective. Ambio, 12-22. https://www.jstor.org/stable/4314988
89. Shanwad, U. K., Patil, V. C., Gowda, H. H and Dasog, G. S. (2008). Application of remote sensing technology for impact assessment of watershed development programme. Journal of the Indian Society of Remote Sensing, 36(4), 375-386. https://link.springer.com/article/10.1007/s12524-008-0037-8
90. Sharma, T., Kiran, P. S., Singh, T. P., Trivedi, A. V. and Navalgund, R. R. (2001). Hydrologic response of a watershed to land use changes a remote sensing and GIS approach. International Journal of Remote Sensing, 22(11), 2095-2108. https://doi.org/10.1080/01431160117359
91. Shiene, S.D. (2012). Effectiveness of soil and water conservation measures for land restoration in the Wello area, northern Ethiopian highlands (Doctoral dissertation, Universitäts-und Landesbibliothek Bonn). https://nbn resolving.org/urn:nbn:de:hbz:5n-30171
92. Shiferaw, A. (2011). Estimating soil loss rates for soil conservation planning in the Borena Woreda of South Wollo Highlands, Ethiopia. Journal of Sustainable Development in Africa, 13(3), 87-106. https://www.cabdirect.org/cabdirect/search/?q=sn%3a%221520-5509%22
93. SOLOMON, S. (2007). IPCC (2007): Climate change the physical science basis. In Agu fall meeting abstracts (Vol. 2007, pp. U43D-01). https://doi.org/10.1007/978-3-031-15501-7_7

94. Solomon, S. (2007). The physical science basis: Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change (IPCC), Climate change 2007, 996. https://cir.nii.ac.jp/crid/1574231874770091776
95. Stocking, M and Murnaghan,N. (2001). Land degradation. International Encyclopedia of the Social & Behavioral Sciences, 8242-8247. https://pubs.iied.org/sites/default/files/pdfs/migrate/7283IIED.pdf
96. Tadesse, L Suryabhagavan, K.V., Sridhar, G and Legesse, G (2017). Land use, land cover changes, and Soil erosion in Yezat Watershed, North Western Ethiopia. International soil and water conservation research, 5(2), 85-94. https://doi.org/10.1016/j.iswcr.2017.05.004
97. Tamene, L and Vlek, P. L.(2008). Soil erosion studies in northern Ethiopia. In Land use and soil resources (pp. 73-100). Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-6778-5_5
98. Taye, T, Moges, A., Muluneh, A., Lebay, M. and Abiye,W., 2021. Implication of Long-Term Terracing Watershed Development on Soil Macronutrients and Crop Production in Maybar Sub watershed, South Wello Zone, Ethiopia. Air, Soil and Water Research, 14, p.11786221211004220. https://doi.org/10.1177/11786221211004220
99. Tegene, B. (2002). Land-cover/land-use changes in the derekolli catchment of the South Wello Zone of Amhara Region, Ethiopia. Eastern Africa Social Science Research Review, 18(1), 1-20. https://doi.org/10.1353/eas.2002.0005
100. Tena, T. M., Mwaanga, P. and Nguvulu, A. (2019). Impact of land use/land cover change on hydrological components in Chongwe River Catchment. Sustainability, 11(22), 6415. https://doi.org/10.3390/su11226415
101. Teshome T.(2007). Assessment of Land use/Land covers Dynamics and Soil Erosion Estimation for Sustainable Management of Land Resources. A Case study in Gozamin Woreda, Amhara Region, North Central Ethiopia. http://etd.aau.edu.et/bitstream/123456789/7935/1/1.WORKYE%20TSIGE.pdf
102. Tewabe, Dm and Fentahun, T. (2020). Assessing land use and land cover change detection using remote sensing in the Lake Tana Basin, Northwest Ethiopia. Cogent Environmental Science, 6(1), 1778998. https://doi.org/10.1080/23311843.2020.1778998
103. Tufa, D. F., Abbulu, Y. E. R. R. A. M. S. E. T. T. Y. and Srinivasarao, G. V. R. (2014). Watershed hydrological response to changes in land use/land covers patterns of river basin: A review. International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development. https://www.academia.edu/download/33647084/18
104. Tukura, N. G. and Akalu, M. M. (2019). Soil erosion risk assessment due to land use. Journal of sedimentary environments, 4(4), 379-386. https://doi.org/10.12957/jse.2019.46538
108. Vitousek, P. M., Mooney, H. A., Lubchenco, J And Melillo, J.M. (1997). Human domination of Earth's ecosystems. Science, 277(5325), 494-499. https://doi.org/10.1126/science.277.5325.494
109. Wagari, M. and Tamiru, H. (2021). RUSLE Model Based Annual Soil Loss Quantification for Soil Erosion Protection: A Case of Fincha Catchment, Ethiopia. Air, Soil and Water Research, 14, 11786221211046234. https://doi.org/10.1177/11786221211046234
110. Waltner, I., Saeidi, S., Grósz, J., Centeri, C, Laborczi, A. and Pásztor, L. (2020). Spatial assessment of the effects of land cover change on soil erosion in Hungary from 1990 to 2018. ISPRS International Journal of Geo-Information, 9(11), 667. https://doi.org/10.3390/ijgi9110667
111. Wang, N., Jiao, J., Bai, L., Zhang, Y., Chen, Y., Tang, B and Wang, H. (2020). Magnitude of soil erosion in small catchments with different land use patterns under an extreme rainstorm event over the Northern Loess Plateau, China. Catena, 195, 104780. https://doi.org/10.1016/j.catena.2020.104780
112. Wang, X., Zhao, X. Zhang, Z. Yi, L. Zuo,L, Wen, Q and Liu, B.(2016). Assessment of soil erosion change and its relationships with land use/cover change in China from the end of the 1980s to 2010. Catena, 137, 256-268. https://doi.org/10.1016/j.catena.2015.10.004
113. Wang, Z. J.Jiao, J.Y., Rayburg, S., Wang, Q. L and Su, Y.(2016). Soil erosion resistance of "Grain for Green" vegetation types under extreme rainfall conditions on the Loess Plateau, China. Catena, 141, 109-116. https://doi.org/10.1016/j.catena.2016.02.025

114. Weil, R. R., Islam, K. R., Stine, M. A., Gruver, J. B and Samson-Liebig, S. E. (2003). Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. American Journal of Alternative Agriculture, 18(1), 3-17. https://doi.org/10.1079/AJAA200228
115. Weng, Q. Lu, D and Schubring, J. (2004). Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. Remote sensing of Environment, 89(4), 467-483. https://doi.org/10.1016/j.rse.2003.11.005
116. Wischmeier, W. H. and Smith, D (1978). Predicting rainfall erosion losses: a guide to conservation planning (No. 537). Department of Agriculture, Science and Education Administration. https://books.google.com/books?hl=en&lr=&id=rRAUAAAAYAAJ&oi=fnd&pg=PA1&dq
117. Yeneneh, N., Elias, E.and Feyisa, G. L.(2022). Quantify soil erosion and sediment export in response to land use/cover change in the Suha watershed, northwestern highlands of Ethiopia: implications for watershed management. Environmental Systems Research, 11(1), 1-19. https://doi.org/10.1186/s40068-022-00265-5
118. Yeshaneh, E., Wagner, W., Exner-Kittridge, M., Legesse, D and Blöschl, G.(2013). Identifying land use/cover dynamics in the Koga catchment, Ethiopia, from multi-scale data, and implications for environmental change. ISPRS International Journal of Geo-Information, 2(2), 302-323.https://doi.org/10.3390/ijgi2020302
119. Yesuf, M., Mekonen, A., Kassie, M. and Pender, J. (2005). Cost of land degradation in Ethiopia: A critical review of past studies. Addis Ababa, Ethiopia: EDRI/EEPFE. https://www.researchgate.net/profile/MenaleBerresaw/publication/252336871
120. Yohannes, H., Mohammed, A and Elias, E (2017). Land use/land cover dynamics and its impact on biodiversity resources in the Abijata Shalla National Park, central rift valley Lakes Region, Ethiopia. Environ Sci Ind J, 13(5), 152. https://www.researchgate.net/profile/HamereYohannes/publication/321134110
121. Zeleke, G and Hurni, H. (2001). Implications of land use and land cover dynamics for mountain resource degradationinthenorthwesternethiopianhighlands.https://doi.org/10.1659/0276-4741(2001)021[0184:IOLUAL]2.0.CO;2
122. Zeleke, G. (2000). Landscape dynamics and soil erosion process modelling in the north-western Ethiopian highlands. https://www.cabdirect.org/cabdirect/search/?q=bn%3a%223906151476%22
123. Zerihun M, Mohammedyasin Ms, Sewnet D, Adem Aa, Lakew M (2018). Assessment of soil erosion using RUSLE, GIS and remote sensing in North Wollo Ethiopia. Geoderma reg 12:83–90. Https://doi.org/10.1016/j.geodrs.2018.01.002
124. Zubair, a. O. (2006). Change detection in land use and Land cover using remote sensing data and GIS (A case study of Ilorin and its environs in Kwara State). Department of Geography, University of Ibadan, 176.

9. APPENDIX

Table 1: Soil parameters analysis result

Soil Analysis Result Delivery Sheet

Requested by: **Wudu Abiye** Signature: ---Sample type: **Soil**

Lab No-	Sample Location		Organic Carbon (%)	Bulk Density (g/cm3)	Soil Texture (%)			Textural Class
	Easting	Northing			Sand	Clay	Silt	
1	571664	1216360	2.00	1.18	29.75	39.25	31.00	Clay Loam
2	571664	1216360	1.14	1.17	32.25	39.25	28.50	Clay Loam
3	572140	1216393	2.00	1.08	31.25	37.75	31.00	Clay Loam
4	572140	1216393	0.81	1.40	33.00	38.50	28.50	Clay Loam
5	572140	1216393	0.50	1.45	29.75	39.25	31.00	Clay Loam
6	571998	1215904	2.00	1.38	47.25	28.25	24.50	Sandy clay loams
7	571998	1215904	1.15	1.56	48.50	23.75	27.75	Sandy clay loams
8	571998	1215904	0.74	1.67	46.75	30.25	23.00	Sandy clay loams
9	571998	1215904	0.54	1.66	45.75	29.75	24.50	Sandy clay loams
10	571907	1215953	1.81	1.28	27.75	43.25	29.00	Clay
11	571907	1215953	0.99	1.48	28.75	40.25	31.00	Clay
12	572253	1216263	1.80	1.41	47.75	29.75	22.50	Sandy clay loams
13	572253	1216263	0.56	1.48	46.25	30.25	23.50	Sandy clay loams
14	572253	1216263	0.56	1.29	45.25	30.50	24.25	Sandy clay loams
15	572006	1216629	1.54	1.11	28.25	40.25	31.50	Clay
16	572186	1217207	1.96	1.38	47.75	27.00	25.25	Sandy clay loams
17	572186	1217207	1.14	1.60	45.75	29.75	24.50	Sandy clay loams

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of Abebaw Wudu Abiye (Student's name) QBTP7R (Student's NEPTUN ID), I here declare that the master's thesis has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I recommend/don't recommend[1] the final essay/thesis/master's thesis/portfolio to be defended in a final exam.

The document contains state secrets or professional secrets: yes no*[2]

Place and date: 2023 year 05 month 02 day

Internal supervisor

[1] Please underline applicable.
[2] Please underline applicable.

DECLARATION

on authenticity and public assessment of final essay/thesis/master's thesis/portfolio[1]

Student's name: Abebaw **Wudu** Abiye

Student's Neptun ID: QBTP7R

Title of the document: Spatiotemporal Dynamics of Soil Erosion Response to Land Use Land Cover Dynamics and Climate Variability in Ethiopia

Year of publication: 2023

Department: MSc in Agricultural Water Management Engineering

I declare that the submitted final essay/thesis/master's thesis/ is my own, original individual creation. Any parts taken from another author's work are clearly marked, and listed in the table of contents.

If the statements above are not true, I acknowledge that the Final examination board excludes me from participation in the final exam, and I am only allowed to take the final exam if I submit another final essay/thesis/master's thesis.

Viewing and printing my submitted work in a PDF format is permitted. However, the modification of my submitted work shall not be permitted.

I acknowledge that the rules on Intellectual Property Management of the Hungarian University of Agriculture and Life Sciences shall apply to my work as an intellectual property.

I acknowledge that the electric version of my work is uploaded to the repository system of the Hungarian University of Agriculture and Life Sciences.

Place and date: Godollo,2023. 05. 02.

Student's signature

[1]Please select the one that applies, and delete the other types.