LAND USE/COVER CHANGE DYNAMICS AND ITS EFFECT ON GULLY EROSION IN THE MITIKE WATERSHED, BELES SUB-BASIN, ETHIOPIA

MSc. THESIS

BY: DESSALEGN MOREDA

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LAND USE/COVER CHANGE DYNAMICS AND ITS EFFECT ON GULLY EROSION IN THE MITIKE WATERSHED, BELES SUB-BASIN, ETHIOPIA

By: Dessalegn Moreda

A Thesis

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We, the undersigned, member of the Board of Examiners of the final open defense by **Dessalegn Moreda** have read and evaluated his/her thesis entitled **"Land Use/Cover Change Dynamics and Its Effect on Gully Erosion In the Mitike Watershed, Beles Sub- Basin, Ethiopia"** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree Master of Science in **Watershed Management**

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DEDICATION

This thesis is dedicated with love and much respect to my beloved family and my wonderful wife Mareme Melaku for their constant support and unconditional family love.

STATEMENT OF THE AUTHOR

First, I, Dessalegn Moreda, declare that this thesis is my work and that all source of material used for this thesis have been acknowledged. This Thesis has been submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Natural resource Management Specialization in Watershed management at Jimma University, and it can be deposited at the University Library to be made available to borrowers under the rules of the library. I declare that this thesis is not submitted to any other institutions anywhere for the award of academic degree, diploma or certificate. Brief citations quotations from this article are allowable without any special permission provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the dean of the school of graduate studies when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

Dessalegn was born on 21 May 1985 at Debati Wereda zone of Metekel, Benishangul gumuz regional state. He attended his elementary school from 1995 to 2002 at Debati elementary school and then joined Debati secondary school from 2003 to 2004. He then joined Assosa ATVET College of Agriculture at 2006 and graduated with diploma in Natural Resource Management in 2009. After graduation he worked in office of agriculture of Metekel Zone, Mandura Woreda as a Natural Resource Management as expert for four years. He joined the Bahir Dar University, College of Agriculture and Environmental Sciences in 2013 and graduated with Bachelor Natural Resource Management in 2015.

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LIST OF ACRONYMS AND ABREVATIONS

ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
ENVISAT	Environmental Satellite
ERS	European Remote Sensing
ETM	Enhanced Thematic Mapper
GIS	Geographic Information Systems
IRS-LISS	Indian Remote Sensing- Linear Imaging Self Scanning
JERS SAR	Japanese Earth Resources Satellite Synthetic Aperture Radar
MLA	Maximum Likelihood Algorithm
MODIS	Moderate Resolution Imaging Spectroradiometer
MSI	Multispectral Instrument
NIR	Near-Infrared
NDVI	Normalized Difference Vegetation Index
NOAA/AVHRR	National Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer
KML	Keyhole Markup Language
RADARSAT	Radar Satellite
SARVI	Soil and Atmospheric Resistant Vegetation Index
SPOT (HRV/HRG)	Satellite Pour observation Terre (High Resolution Visible/High Resolution Geometric)
SRTM	Shuttle Radar Topography Mission
SWIR	Short-Wave Infrared
TM	Thematic Mapper

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ABSTRACT

Gully erosion is one of the main causes of land degradation, especially in human-induced activities in the warm humid lowland of Mitike watershed, Beles River Basin, Ethiopia. However, regarding this, conversion land use/ cover relation to gully formation have not been well studied in this watershed. Therefore, the objective of this study was to assess spatio-temporal changes in gully length and density due to land use/cover (LULC) changes in the Mitike watershed of the Beles sub-basin of Ethiopia. Landsat 5TM (1985), 7ETM$^+$ (2005), and 8OLI-TIRS (2023) images were used to evaluate the LULC changes over the past 38 years. All images were classified using the supervised classification technique of a Maximum Likelihood Algorithm (MLA), along with field survey results. Accuracy assessments were performed using simple random sampling techniques for each reference year. Gullies were mapped by visual image interpretation in the QGIS environment. The LULC types were classified with an overall accuracy ranging from 89.3% to 92.1% and a Kappa coefficient of 0.89 to 0.99. The classification result revealed that bamboo forests (42.6%), natural forests (25.6%), and woodlands (31.1%) were the dominant LULC types in 1985. In 2023, croplands (57.1%) were the major LULC types, followed by forest (15.3%), woodland (13.8%), and grassland (13.8%). The results showed that the bamboo forest was totally destroyed in the period (1985 and 2023). A rapid natural forests and woodland decreased by 40.1 and 53.7% respectively in study period (1985 and 2023). On the contrary, cropland and grazing land increased by 9.6% and 18.5 folds, respectively. The number of gully formation increased by 13 to 20 in study period (1985 -2023). Similarly, the gully density increased by 6.1–12 m ha^{-1} between 1985 and 2023.The highest gully formation in cropland, followed by grazing land woodland and natural forests in number of 24,14,7 and 3, respectively. Gully distribution was directly relation to land use type and its changes. Gully density was higher in cultivated areas where slope gradients were also gentle due land use dominated cropland. The findings this study indicate that was main factor gully formation and development. Therefore. Human induced land use (cropland and grazing land) crucial appropriate management strategies should be develop for sustainable utilize land resources maintained agricultural productivity this watershed.

Keywords: Land Use, Gully Density, QGIS, Gully Erosion, Watershed

1. INTRODUCTION

1.1. Background of study

Land degradation in the form of soil erosion by water is one of the major challenges in agricultural development (Setargie, Tsunekawa, Haregeweyn, Tsubo, Rossi, *et al.*,, 2023; Tamene *et al.*,, 2022; Wolka *et al.*,, 2018; Zingore *et al.*,, 2015), rapid sedimentation of reservoirs (Ayele *et al.*,, 2021; Haregeweyn *et al.*,, 2006; Haregeweyn, Tsunekawa, *et al.*,, 2013; Lemma *et al.*,, 2018; Tamene *et al.*,, 2006), and ecosystem services decline (Biratu *et al.*,, 2022; Kindu *et al.*,, 2016; Mekuria *et al.*,, 2021; Shiferaw *et al.*,, 2019) in Ethiopia. Due to erosive rains, landscape physiography nature with the synergic effects of human induced activities such as deforestation (Bishaw, 2009; Lemenih *et al.*,, 2005), overgrazing and overstocking (Gebremedhin *et al.*,, 2004; Sonneveld *et al.*,, 2010), urbanization (Haregeweyn *et al.*,, 2012; Kindu *et al.*,, 2020) and inappropriate agricultural activities (Diro *et al.*,, 2022; Hurni, 1986; Zerssa *et al.*,, 2021). As a result, nation-wide annual soil loss by water erosion was estimated at 1.9 billion tons, or 16.5 tons $ha^{-1}yr^{-1}$ (FAO, 2019; Fenta *et al.*,, 2021), which is greater than the mean soil loss tolerance range (10 tha^{-1}), as suggested by Hurni (1983) for Ethiopian conditions In addition, it was estimated that the rates of important plant nutrient depletion for C, N, P, and K were 3700, 122, 13, and 82 kg ha^{-1}, respectively (Haileslassie *et al.*,, 2005; van Beek *et al.*,, 2018). Injudicious uses of land resources also causes of socio-economic aspects, for example, Gebreselassie *et al.*,(2016) estimated annual cost of land degradation to be about US$ 4.3 billion in Ethiopia. As a result, Ethiopian agriculture productivity is generally low as compared to global and regional standards, as mentioned by Anteneh & Asrat, 2020) Tamene *et al.*, (2017).

Gully erosion is one of the most severe types of water erosion and has gotten a lot of attention because of how devastating land resources it is. Gully erosion has both off-site rapid siltation of reservoirs and on-site removal of fertile soil (Lemma *et al.*,, 2020; Pimentel & Burgess, 2013). As a result, agricultural production and river and reservoir sedimentation are affected (Poesen, 2011) consequently reducing water holding capacity and quality. For example, De Villiers & Basson (2007) observed in South Africa that sedimentation had reduced the storage capacity of the Welbedacht Dam by nearly 90% over a 30 years.

In Ethiopia, reports, gullies are progressively harming agricultural lands, causing an estimated soil loss range of 1248-23400 million tons per year from 78 million acres of pasture, rangelands, and cultivated fields across Ethiopia (Daba *et al.*,, 2003).

Land use and land cover (LULC) changes due to human-induced activities (agriculture, deforestation, urbanization)are primarily cause of soil erosion and eroded 35.5 billion ton per year in global level (Borrelli *et al.,* 2017). Among these, agricultural land use responsible for 75% of global soil erosion, affecting 80%of the world's cultivated soils (Pimentel *et al.*,, 1995)and adversely impacting food production on 40% of the agricultural land (Bossio *et al.*,, 2010).

Depending on the geographical location, gully erosion contributes 10-94% to the total generation of eroded soil by water erosion (Poesen *et al.*,, 2003).It is also altering the catchment hydrology, as results in a wide range of on- and off-site impacts including loss of soil, land, infrastructure, and even lives (Vanmaercke *et al.*,, 2021).Despite the environmental importance of gully erosion, most studies examining soil erosion by water have focused on a sheet(inter-rill) and rill erosion (Poesen *et al.*,, 2003; Valentin *et al.*,, 2005; Vanmaercke *et al.*,, 2021)while only around 10% of the studies have been dedicated to gully erosion (Castillo & Gómez, 2016).

Several factors involving in the formation and expansion of gullies depend on the dominant gully development processes and mechanisms. A wide range of factors that can influence the occurrence and distribution of gully erosion have been reported so far (Poesen *et al.*,, 2003; Valentin *et al.*,, 2005; Vanmaercke *et al.*,, 2021).These include topographic, hydraulic and hydrologic, weather and climatic, petrologic and lithological, and LULC related factors (Asamin *et al.*,, 2023).Among various factors, LULC is the most significant factors that affected gully erosion distribution in spatial and temporal (Li *et al.*,, 2021b).The relationship between land use change and gully erosion dynamics that direct proportional to cultivated land use and conversion while inversely with forest land use and conversion (Li *et al.*,, 2021b).It leads to the destruction of agricultural land and infrastructure, changes the hydraulic potential of soils, and affects water availability. With climate change, the problem of gully erosion is expected to worsen, particularly in low-income agricultural regions (Khan *et al.*,, 2023).

The measurement and monitoring of the spatial distribution of gullies is critical for effectively addressing the problem of gully erosion. Remote sensing technology has the ability to give a synoptic and immediate study of the severity of soil erosion in this scenario. Remote sensing is a powerful tool for assessing and monitoring spatio-temporal variations in soil erosion over large areas (Le Roux & Sumner, 2012; Liberti *et al.*,, 2009).Remote sensing provides low-cost, time-efficient tools for precisely mapping erosion, which frequently overcome the constraints of standard soil erosion assessment approaches (Liberti *et al.*,, 2009; Lu & Weng, 2007). Gully erosion maps, which may be created rapidly and cheaply using widely available data, are a useful tool in regional erosion management planning (Taruvinga, 2009).As a result, one of the current goals of this research is to provide a strong, dependable, and accurate method of mapping gullies. According to the literature, traditional mapping approaches such as manual digitization of aerial images and satellite data have been widely employed for gully erosion mapping and monitoring. However, because they are limited to a local scale, these procedures are time expensive, and the datasets rarely provide enough information for gully mapping and monitoring (Poesen, 2011).

As fine-resolution sensors like Quick Bird, IKONOS, and Worldview become more common, remote sensing technologies have brought significant capabilities for mapping gully erosion(Setargie, Tsunekawa, Haregeweyn, Tsubo, Fenta, *et al.*,, 2023). Although these datasets have been shown to provide accurate results for gully mapping (Kuanar *et al.*,, 2015), their application at a larger scale is limited due to their small swath width and high acquisition costs, which become a challenge in resource-constrained regions. These drawbacks have turned focus to the use of freely available multispectral sensors, such as Landsat records, which have a global footprint and continuous coverage(Kuanar *et al.*,, 2015).Seutloali *et al.*, (2017) for example, highlighted the utility of the freely available multispectral Landsat 8the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) in measuring the spatial variability of soil erosion at the regional scale, where comprehensive fieldwork is still lacking.

1.2. Statement of the problems

Mitike Watershed located in the dawn stream Abay Basin, was an unoccupied area until the resettlement villagization program, since 1984/85 Ethiopia hit by dreadful famine and drought (Kuls, 1986; Woldemeskel, 1989). To alleviate the food scarcity and ensure food self-sufficiency for resstelers, the removal of forests and transferred to mechanized agricultural production (excess chemical fertilizer, pesticides, herbicides) until the Italian group specialized Tana Beles Project phased out (Woldemeskel, 1989). Subsequently, the resettlers continued their livelihoods by practicing a mixed crop and livestock farming system, with dominant lands allocated for cultivation and grazing. Yibeltal *et al.,* (2019) have done so recently in the high lands of Upper Blue Nile Basin. Most of these studies consider the occurrence of gully erosion under different land use types, but not have attempted to examine the effects of land use conversion on gully erosion in the low lands of Blue Nile. The best exemplary is Mitike watershed in the Beles sub basin.

1.3. Objectives

1.3.1. General Objective

Assessing land use / cover changes effects on gully erosion in Mitike watershed

1.3.2 Specific objectives

- To asses land use and cover dynamics of Mitike watershed variation over the past four decades
- To assess gully erosion relation to land use and cover change dynamics watershed
- To assess spatio-temporal changes of gully length and density in the study watershed
- Here are some research questions to answer the objectives

1. What are the specific land use and land cover changes observed in the Mitike watershed over the past four decades, and what are the underlying drivers of these changes?
2. How has gully erosion within the Mitike watershed been influenced by variations in land use and land cover dynamics over the studied period?
3. What are the spatio-temporal patterns of gully formation and development in the Mitike watershed, and how do these patterns correlate with changes in land use and land cover?
4. What are the main factors contributing to the variation in gully length and density within different land use and land cover types across the Mitike watershed?

1.3.3. The significance of study

Gully erosion is significant of soil loss as the concentrated flow of water removes large volumes of soil from the landscape (Yibeltal., *2019*). The erosion process rapid and lead to the loss of fertile topsoil, which is rich in organic matter and nutrients (Khan *et al.*,, 2024). Gully erosion is render large areas of land unsuitable for agriculture or other productive uses. Studies in Moldavia and Romania showed the aerial distributions of gullies are mainly dominated by hillslope orientations (Radoane *et al.*,, 1995). The steep slopes enhance gully processes, accelerate sediment transfer from uplands to bottoms, and generate natural hazards, such as mudflows, overflowing of heavily loaded floods, and silting up of reservoirs. It results in the loss of fertile soil from cultivation land and damage to agricultural land and agricultural infrastructure (Parkner *et al.*, 2006).

2. LITERATURE REVIEW

2.1. Land Use and Land Cover Change

Land use and land cover change (LULCC) refers to the transformation of the Earth's surface due to human activities, resulting in alterations in the way land is used and the vegetation cover. It involves the conversion of natural ecosystems, such as forests, grasslands, or wetlands, into agricultural land, urban areas, industrial sites, or other human-made land uses. Land use and land cover change is driven by various factors, including population growth, urbanization, agricultural expansion, infrastructure development, and economic activities. These changes can have significant impacts on the environment, biodiversity, climate, and ecosystem services. It helps identify areas at risk, assess the impacts on ecosystems and biodiversity, and develop strategies for conservation and sustainable development (Steffen *et al.,*, 2018).

Cause of land use land cover changes are various natural and human factors within social, economic and political contexts (Garedew *et al.,*, 2009). Land use change is the land use transformation from one type to another land use type and land cover modification through land use management, has altered a large proportion of the earth’s land surface. The main aim of LULCC is to satisfy mankind” mankind’s immediate demands from natural resources(Rahman *et al.,*, 2012). In the worldwide changes of forests, farmlands, waterways and air are being driven by the need to provide food, fiber, water, and shelter to more than six billion people. In recent decades the Global the croplands, pastures, plantations and urban areas have expanded. This expansion for the reason of large increases in energy, water, and fertilizer consumption, along with considerable losses of biodiversity (Foley *et al.,*, 2005).The factors that contribute to land use and land cover changes include: Climate change, natural disasters, soil erosion, natural resource availability, population growth, urbanization, agricultural expansion, infrastructure development and industrialization (Steffen *et al.,*, 2018). Land cover can be altered not only anthropogenic activity it has another force that altered land cover. For instance, Natural events like weather, flooding, fire, climate fluctuations and ecosystem changes can also initiate modifications upon land cover. Human activities also incidental impacts on land cover such as forest and lakes damaged by acid rainfall from fossil fuel combustion and crops near cities damaged by tropospheric ozone resulting from automobile exhaust (Foley *et al.,*, 2005).

2.2. Land Use and Land Cover Identifies Using Remote Sensing and GIS Techniques

Remote sensing and Geographic Information System (GIS) techniques are widely used to identify and analyze LULCC. Here's how these techniques are applied. Data Acquisition: Remote sensing involves the collection of data about the Earth's surface from a distance, usually using satellites or aerial sensors. These sensors capture images and data in various wavelengths, such as visible, infrared, and microwave(Reddy, 2018; Zhu *et al.*,, 2018).The acquired remote sensing data is processed to enhance the images and extract relevant information. This includes preprocessing steps like radiometric and geometric corrections, atmospheric correction, and image calibration(Jakob *et al.*,, 2017). One of the key steps in land use and land cover analysis is image classification, where the processed remote sensing imagery is classified into different land cover classes. This is done using various classification algorithms, such as Maximum Likelihood, Support Vector Machines, and Random Forest (Basheer *et al.*,, 2022).

To perform image classification accurately, ground truth data is collected. This involves visiting the study area and collecting samples of different land cover types, which are then used to train the classification algorithm(Thapa & Murayama, 2009).Once the image classification is complete, land cover maps are generated, which represent the spatial distribution of different land cover types in the study area. These maps provide valuable information about the current land use and land cover patterns(Zhang & Li, 2022).By comparing land cover maps from different time periods, land use and land cover changes can be detected. Change detection techniques involve analyzing the differences between the land cover maps to identify areas that have undergone changes, such as urban expansion, deforestation, or agricultural encroachment (Civco *et al.*,, 2002).GIS techniques are used to analyze and visualize the land use and land cover data. Spatial analysis tools can be used to calculate the area and proportion of different land cover types, assess landscape fragmentation, identify hotspots of change, and analyze the relationship between land use patterns and other spatial datasets.

LULCC detection process of identifies the differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Change detection is an important process in monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution of the population of interest. (Pathak, 2014) list four aspects of change detection which are important when monitoring natural resources. They include; firstly, detecting the changes that have occurred; secondly, identifying the nature of the change; thirdly, measuring the area extent of the change and lastly, assessing the spatial pattern of the change. The basis of using remote sensing data for change detection is that changes in land cover result in changes in radiance values which can be remotely sensed. Techniques to perform change detection with satellite imagery have become numerous as a result of increasing versatility in manipulating digital data and increasing computer power by combining remote sensing and GIS techniques, land use and land cover changes can be accurately identified, monitored, and analyzed over time. This information is crucial for land management, urban planning, environmental assessment, and decision-making processes.

2.3. Impact of Land Use Land Cover Change on What?

LULCC can have significant impacts on the environment, society, and the economy. One of key impact is Biodiversity loss LULCC can lead to the destruction and fragmentation of natural habitats, resulting in the loss of biodiversity. This can negatively impact ecosystems and lead to the extinction of plant and animal species(Haines-Young, 2009) .Changes in land use, such as deforestation and urbanization, can contribute to climate change. Deforestation releases carbon dioxide into the atmosphere, a major greenhouse gas, while urbanization increases energy consumption and heat island effects. Alterations in land use can affect water availability and quality Deforestation can lead to reduced water infiltration and increased runoff, causing soil erosion and flooding. Changes in land cover can also impact the water cycle and water availability for human activities.

Conversion of agricultural land for other purposes, such as urban development, can reduce the availability of fertile land for food production. This can lead to decreased agricultural productivity and food security issues. LULCC can impact human health through various pathways. Deforestation can lead to the spread of vector-borne diseases by altering ecosystems and disrupting natural habitats. Urbanization can contribute to air and water pollution, leading to respiratory and other health issues. Changes in land use can have economic implications.

Deforestation can affect the livelihoods of communities dependent on forest resources, such as indigenous populations. Urbanization can drive economic growth but also lead to increased demand for infrastructure, services, and resources. LULCC can alter the provision of ecosystem services, such as pollination, water purification, and climate regulation. Changes in land use can disrupt these services, affecting human well-being and the functioning of ecosystems.

It is important to consider the impacts of LULCC and implement sustainable land management practices to minimize negative effects and promote the conservation and restoration of natural ecosystems(Kindu *et al.,*, 2013, 2016; Munthali *et al.,*, 2022; Rotich *et al.,*, 2022). Furthermore, land cover change has ecological, physical, and socio-economic consequences. Agricultural expansion, for example, can increase food production, but it can also have negative impacts such as deforestation and soil degradation.

The major impact of LULC changes in the livelihood of rural communities indicated in (Pathak, 2014) include: its impact on land resources with related to land degradation, soil erosion, and productivity decrement; its impacts on environment thereby rural communities vulnerability to climate vagaries; vulnerability of rural communities towards erratic rain fall and water sources problem with related to the change; impact on access to quality water; its negative impact on livestock rearing which related with grazing land shrinkage for agricultural land expansion, and also its impacts on ecosystem goods and services especially related with deforestation (Fenta *et al.,*, 2020; Temesgen *et al.,*, 2022; Tolessa, Senbeta, & Kidane, 2017).

The study utilizes satellite imagery, digital elevation models, climate data, and stream flow records to analyze the impact of LULCC on hydrological processes. The findings indicate an increase in surface runoff and evapotranspiration, as well as changes in wet and dry season flows, highlighting the need for effective land use management and water resource utilization in the region (Belihu *et al.,*, 2020). Changes in land cover also have an impact on weather and climate patterns. Alterations in land cover can affect the flow of energy, water, and greenhouse gases between the land and the atmosphere, thereby impacting local to global-scale weather and climate.

Getachew and Melesse (2012) conducted a study in northwestern Ethiopia, specifically in the Angereb watershed, and found that there was a significant increase in surface flow between 1985 and 2011 due to the conversion of forest and grassland into urban settlements and cultivated land. Another study by Roth *et al.*, (2016) in the Gerda catchment of central highland Ethiopia showed that surface runoff had a notable impact on the entire watershed, resulting in more than a 10% deviation in both stream flow and sediment loss. Additionally, a recent study by Welde and Gebremariam (2017) in the Tekeze watershed of Northern Ethiopia demonstrated the influence of land use and climate change on stream flow and sediment yield.

Therefore, information on land use/land cover changes, its ultimate impact and possibilities for their optimal use is essential for the selection, planning and implementation of land use schemes to meet the increasing demands for basic human needs and welfare. In Ethiopian condition there is an urgent need to design and implement appropriate land management options, coupled with population control and sustainable natural resource use and conservation that meet the need of both present and future generations ((Tamene & Vlek, 2008).

According to Teshome *et al.,*(2022a)the study found that the increase in cultivated land and the decline in conservation practices were the primary factors contributing to soil erosion and sediment yield in the study area. To address this issue, it is crucial to implement conservation strategies, particularly afforestation and re-afforestation programs, to mitigate environmental risks and reduce soil erosion and sediment loss. Effective prevention of soil erosion and sediment yield loss requires collaboration across multiple sectors. Overall, the impacts of LULCC are far-reaching and can affect biodiversity, climate, agriculture, and human well-being. It is crucial to consider these impacts and implement sustainable land management practices to mitigate the negative effects and promote the conservation of natural ecosystems.

2.4. Effects of Land Use and Land Cover Change on soil erosion

Soil erosion caused by LULCC can result in the loss of topsoil, which is rich in organic matter and essential nutrients for plant growth. This loss can reduce soil fertility and agricultural productivity. Also, eroded soil particles can be transported by runoff and deposited in rivers, lakes, and other water bodies. This sedimentation can impair water quality, reduce water storage capacity, and disrupt aquatic ecosystems. LULCC can lead to increased runoff of nutrients and chemicals from agricultural fields and urban areas. Excessive nutrient runoff, such as nitrogen and phosphorus, can cause water pollution and eutrophication, leading to harmful algal blooms and oxygen depletion in aquatic systems. Alterations in land cover can affect the hydrological cycle, including changes in infiltration rates, surface runoff, and groundwater recharge. These changes can influence the availability and distribution of water resources.

LULCC can contribute to soil degradation, including soil compaction, loss of organic matter, and reduced soil structure. These changes can negatively impact soil health and its ability to support plant growth. Soil erosion caused by LULCC can release carbon stored in the soil into the atmosphere, contributing to greenhouse gas emissions and climate change. Additionally, eroded sediments can bury and disrupt carbon sinks such as wetlands and coastal ecosystems. It is crucial to implement sustainable land management practices, such as conservation agriculture, reforestation, and erosion control measures, to mitigate the negative impacts of LULCC on soil erosion and maintain soil health and productivity.

Human-dominated landscapes, particularly agricultural land, are more vulnerable to soil erosion compared to forest and grassland cover1. This is because the removal of natural vegetation cover exposes the soil to erosive forces.

LULCC and land degradation are indeed highly interrelated phenomena that have significant implications for both environmental and socio-economic systems. The intricate connection between these two processes necessitates a comprehensive understanding of their interactions and impacts in order to effectively address the challenges they pose. Gashaw *et al.*,(2014) because usually the changes are associated with deforestation, biodiversity loss and land degradation (Langyintuo & Mekuria, 2005). Land cover is one of the factors that determine the rate of soil loss due to erosion. Belay (2002) stated that When land is converted for cultivation, the natural vegetation cover is often removed, leaving the soil exposed to the elements. This makes it more susceptible to erosion by wind and water. A study Ludi & Hurni, 2000 also reveals that human land use around the Simen Mountains National Park has accelerated the degradation of vegetation and soils. LULCC have significant impacts on the socioeconomic and environmental systems.

Functioning with tradeoffs for sustainability, food security, biodiversity and the vulnerability of people (Council & Committee, 2014).Most of LULCC in Ethiopia is in the form of changing forest and shrub lands to cultivation (Belay *et al.*,, 2002).Removal of vegetation cover means exposing the land to soil erosion because process accelerates removal of soil particles and increased sheet, rill and gully erosions by reducing the protection of soil cover. In the highlands of Ethiopia, significant land cover changes have been observed since the last century due to a long history of agricultural practices and human settlement that recently resulted in high population pressure including unsustainable practices and depletion of the natural resources including soil (Tilahun *et al.*,, 2014). This resulted in the soil degradation, mainly in the form of soil erosion, to be in worse sate.

The estimate in mid 1980s by FAO, indicated as about half of the highlands land area of Ethiopia was significantly eroded" and over one-fourth was "seriously eroded" and over two million hectares of farm lands had reached the "point of no return" in the sense that they are unlikely to sustain economic crop production in the future. There are different watershed and basin-based studies reported the impact of LULCC in erosion. The study report before few years indicated as Gojam area has undergone dramatic LULCC, with the result that almost all land units have been converted to cultivated land (Zegeye *et al.*,, 2014).

In developing countries, LULCC are very high, variable and dynamic. Different reports in Ethiopia show that, over the last 41 years agricultural land areas expanded extremely at the cost of natural vegetation (Chukwueze *et al.*,, 2022; Kiros-Meles & Abang, 2008) significant declination of woodland area 28% to 3% from 1964 up to 2005 in the highland of Ethiopia. In Ethiopia there are different studies that documented for land use land cover change in time and space, primarily an increase in agricultural land at the expense of natural vegetation in Southwestern Ethiopia (Kindu *et al.*,, 2013; Teshome *et al.*,, 2022; Tolessa, Senbeta, & Abebe, 2017).These findings highlight the importance of sustainable land management practices to mitigate the negative impacts of LULCC on soil erosion. Implementing measures such as conservation agriculture, reforestation, and erosion control can help maintain soil health and productivity while preserving natural ecosystems.

2.5. Effects the Gully Erosion on Soil Loss

Gully erosion is a severe form of soil erosion that occurs when concentrated water flow creates deep channels or gullies in the landscape (Khan *et al.*,,2024). Gully erosion significant soil loss as the concentrated flow of water removes large volumes of soil from the landscape (Yibeltal., 2019). The erosion process rapid and lead to the loss of fertile topsoil, which is rich in organic matter and nutrients (Khan *et al.,*, 2024). Gully erosion is render large areas of land unsuitable for agriculture or other productive uses. Studies in Moldavia and Romania showed the aerial distribution of gullies are mainly dominated by hillslope orientations (Radoane *et al.,*, 1995). The steep slopes enhance gully processes, accelerate sediment transfer from uplands to bottoms, and generate natural hazards, such as mudflows, overflowing of heavily loaded floods, and silting up of reservoirs. It results in the loss of fertile soil from cultivation land and damage to agricultural land and agricultural infrastructure (Parkner *et al.,*, 2006). Climate (Valentin *et al.,*, 2005), (Zhang *et al.,*, 2007), lithology, soils (Vandekerckhove *et al.,*, 2001), relief and land use/cover characteristics (Mitiku *et al.,*, 2006 and Martinez, 2003) mainly affect gully erosion. In most cases, gullies are formed due to intensification of human activities resulting from rapid population growth in developing countries and expansion of agriculture and grazing lands into forest areas. (Pathak *et al.,*, 2005) reported that in semi-arid tropics (SAT) watersheds of Africa, most migrants cut trees, burn litter and grasses and cultivate annual crops on hillsides or marginal lands without using appropriate conservation measures, which has been increasing gully erosion processes. Gully erosion can result in the degradation of the landscape, with the formation of deep scars and loss of vegetation cover. This can further exacerbate erosion processes and contribute to the loss of habitat for plants and animals. Gully erosion can have significant economic consequences, particularly for agricultural communities that rely on the land for their livelihoods. It can lead to reduced crop yields, loss of grazing land, and increased costs for soil conservation measures.

Land use changes in many landscapes result in upland erosion and gully formation, reducing land productivity, carving up agricultural land, and filling up downstream reservoirs (Haregeweyn, Poesen, *et al.,*, 2013). In the Ethiopian highlands where gully extension rates refer to the rate at which gullies, which are erosion channels formed by water flow, expand or grow over time. These rates can vary significantly depending on various factors such as climate, topography, land use practices, and geological characteristics.(Tebebu *et al.,*, 2015). The main drivers and dynamics of gully erosion including rainfall patterns, land use changes, slope characteristics, soil properties, and human activities such as deforestation and improper agricultural practices. Gullying is a threshold-dependent process controlled by a wide range of factors (Valentin *et al.*,, 2005), including rainfall and flowing water, soil properties, and drainage area. According to Hassen and Bantider (2020).

The study conducted in the Upper Blue Nile basin, Ethiopia, using a method called Random Forest to assess the susceptibility of gully erosion in different agro-ecologies and identify areas at high risk of gully erosion, providing valuable information for conservation planning and land management strategies in the region pay attention (Setargie, Tsunekawa, Haregeweyn, Tsubo, Fenta, *et al.*,, 2023). Another study also carried upper Blue Nile, the area covered by gullies in the watershed increased from 1.84 hectares to 3.43 hectares between 2005 and 2013, indicating that the proportion of the watershed affected by gullies nearly doubled during that period. In 2016, the soil loss increased to 7 tons per hectare per year in the main watershed and 9 tons per hectare per year in the gullies catchment (Bogale *et al.*,, 2020).

In the black soil region of Northeast China study, researchers utilized eight topographic attributes derived from different digital elevation model (DEM) resolutions and applied four machine learning methods to assess gully erosion susceptibility. The results indicate that elevation, plan curvature, and slope aspect are the most influential factors in the spatial distribution of gully erosion. The optimal pixel size for each machine learning method was determined to be 20.0 m, providing the highest prediction performance, and the random forest (RF) algorithm outperformed other methods in mapping GES(Huang *et al.*,, 2023).

2.6. Erosion Controlling Factor

2.6.1. Topography

The topography factor for gully erosion refers to the influence of the land's slope and shape on the formation and development of gullies. Steep slopes and irregular landforms are more prone to gully erosion as they increase the speed and volume of water runoff, leading to the erosion and deepening of gullies. The topography factor is an important consideration in assessing and predicting the potential for gully erosion in a given area. The topography factor for gully erosion is influenced by various factors such as elevation and slope gradient1. These topographic conditions significantly control vegetation density, climatic conditions, surface runoff, and drainage intensity, all of which contribute to the occurrence and development of gullies(Valipour *et al.*,, 2021).

Topographic factors play a crucial role in exploring gully occurrence and predicting gully erosion susceptibility. They are widely applied in studies to identify and model the spatial distribution of gullies, particularly in regions with black soil (Huang *et al.*,, 2022). The topography factor for gully erosion refers to the influence of the land's slope and shape on the formation and development of gullies. Steep slopes and irregular landforms are more prone to gully erosion as they increase the speed and volume of water runoff, leading to the erosion and deepening of gullies. The topography factor is an important consideration in assessing and predicting the potential for gully erosion in a given area (Huang *et al.*,, 2022).

The degree of slope is one topographic element that frequently contributes to erosion; a steeper slope causes runoff to move more quickly, which starts erosion (Valentin *et al.*,, 2005). For instance, (Seutloali *et al.*,, 2016)study discovered that soil erosion occurs on steeper slopes that are longer than 30m. The lower and middle portions of the slope typically have shallow gullies that are 0.3-2 m deep, whereas the higher and intermediate portions typically have rill erosion, according to Guanglu *et al.,* (2004).

Spatial erosion models often require a Digital Elevation Model (DEM) to extract topographic data, such as slope characteristics. Traditionally, DEMs are constructed using contour lines from topographic maps or from aerial photographs stereo pairs(Betts & DeRose, 1999; García-Ruiz, 2010; Martınez-Casasnovas, 2003) and more recently from high-resolution digital aerial imagery. For example, a study by Huete Huete(1988)monitor ed soil surface change of rangeland erosion using a DEM obtained from a high-resolution aerial imagery and successfully identified surface elevation change.

The advancement of remote sensing technologies set precedence for satellite data to offer good quality DEM of less than 20mresolution provided by the SPOT stereo optical imagery or Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER)(Toutin & Cheng, 2002). For example, Haboudane *et al.,* (2002) generated slope and topographic curvature from a Satellite Pouro bservation Terre High Resolution Visible (SPOT HRV) derived DEM while Payette *et al.*,(1995) also used a DEM derived from SPOT HRV for the visual interpretation analysis of erosion features.

On the other hand, interferometry Synthetic Aperture Radar (SAR) imagery with spatial resolution of 30m, such as the European Remote Sensing satellite (ERS), Environmental Satellite (ENVISAT), and TerraSAR-X have also been used for erosion detection. For example, Nanni *et al.*, (2012) were able to study erosion processes by performing a morphometric analysis based on slope aspect, flow accumulation, stream network and lithology derived from the ERS SAR interferometric DEM of 20m. Bouaziz *et al.*,(2011)on the other hand, recently used geomorphologic factors derived from Shuttle Radar Topography Mission (SRTM) and ASTER DEMs to describe the geomorphologic setting and shapes of gullies. The study found that ASTER derived DEM of 15 m improved the accuracy in identifying gullies over small scales as opposed to the 90m SRTM data DEM. Hence, the use of remote sensing demonstrates the feasibility of providing information for soil erosion vulnerability.

2.6.2. Soil characteristics in relation to remote sensors

The soil factor plays a significant role in gully erosion control. The characteristics of the soil, including its composition, structure, permeability, and erodibility, can influence the susceptibility of an area to gully erosion. Here are some soil factors that contribute to gully erosion control: Soils with finer particles, such as clay and silt, have a higher potential for erosion compared to soils with coarser particles, such as sand. Coarser soils allow water to infiltrate more easily, reducing surface runoff and the likelihood of gully formation. The composition of the soil, including the proportions of sand, silt, and clay, affects its erodibility(Huang *et al.*,, 2023).. Soils with a higher percentage of sand and low clay content are generally less prone to erosion. Well-structured soils with good aggregation and stability are more resistant to erosion. A strong soil structure helps to maintain soil cohesion and reduces the risk of soil detachment and transport. Soils with higher organic matter content tend to have better structure, water-holding capacity, and resistance to erosion(Huang *et al.*,, 2023). Organic matter improves soil stability and reduces surface runoff by enhancing infiltration. The erodibility of soil refers to its susceptibility to erosion under specific conditions. Factors such as soil composition, structure, and organic matter content contribute to the erodibility of soil.(Ireland *et al.*,, 1939).

Soil erosion is influenced by a range of soil properties, such as texture, structure, moisture, roughness, and organic matter content that determine the soils aggregate stability (Vrieling, 2006). These soil properties can be determined using infrared and visible sensors, often examined by visual interpretation and image classification. Differences in soil erodibility can be studied by analyzing the spectral behavior of soils provided by the satellite imagery (Reusing *et al.*,, 2000). For example, a study by(Wang *et al.*,, 2003) successfully mapped the spatial distribution of soil erodibility using extrapolated erodibility values assigned in the field and Landsat TM band 7.

Singh *et al.*,(2004)on the other hand, found significant relationships between soil colors defined by the Munsell system and Landsat satellite imagery. Moreover, the soil's spectral reflectance is significantly influence by topsoil characteristics such as soil colour, iron oxides, moisture content (Toutin & Cheng, 2002). For example, Nanni *et al.,* (Nanni *et al.,*(2012)were able to determine and discriminate soil classes using discriminant analysis of spectral data derived from Landsat imagery. The results of the study confirmed the practicability of identifying individual soil classes using spectra data obtained from the surface for soil classification. The permeability of the soil determines how quickly water can infiltrate. Soils with good permeability allow water to penetrate more easily, reducing surface runoff and the potential for gully formation.

Mathieu, *et al.*,, (1997) noted that although topsoil characteristics can be a limitation for determining one specific property, they can however be effective in determining soil crusting as the removal of topsoil by soil erosion causes a decline of organic matter and iron oxides, consequently uncovering subsoil (De Jong *et al.*,, 1999). For example, Singh *et al.,* (2006) assessed the level of soil degradation by estimating soil colour from NOAA/AVHRR satellite data. Soil colour was determined using various vegetation indices, such as NDVI and MSAVI and a correlation was found between soil colour and vegetation indices.

Since erosive processes alter the soil's physical and chemical properties subsequently changing the colour, studying soil colour from satellite data can be beneficial in monitoring soil erosion processes Singh *et al.,* (2006). Mathieu *et al.,* (1997) highlight that while topsoil characteristics may have limitations in determining specific properties, they can effectively indicate soil crusting due to erosion-induced removal of topsoil and subsequent exposure of subsoil. This is supported by De Jong *et al.,* (1999), who state that erosion leads to a decline in organic matter and iron oxides.

Singh *et al.,* (2006) conducted a study using satellite data from NOAA/AVHRR to estimate soil degradation levels by analyzing soil color. They utilized vegetation indices like NDVI and MSAVI and found a correlation between soil color and vegetation indices. As erosive processes modify the physical and chemical properties of the soil, this leads to changes in its color. Therefore, studying soil color from satellite data can be advantageous in monitoring soil erosion processes, as concluded by Singh *et al.,* (2006).

Optical satellite data however can present a limitation in measuring topsoil reflectance due the vegetation interference(Lawrence & Ripple, 1998). Radar satellite data on the other hand can overcome this challenge as they provide spectral information beyond vegetation and soil surface in instances where soil erosion is exacerbated by surface crusting (Wulf & Adams, 2014). Soil surface roughness initiates and accelerates erosion, due to the high runoff volumes that collects downslope (Valentin *et al.,*, 2005).

SAR data can provide useful information on erosion processes radar satellites are sensitive to soil roughness and moisture. For example, a study by (Baghdadi *et al.,*(2002)investigated the potential of SAR data derived from ERS and RADARSAT sensors for determining possible runoff and soil erosion in northern France. The study found that the SAR data could determine the influence of soil roughness on soil erosion, thereby successfully discriminating and mapping various surface roughness classes (smooth, medium and rough) over agricultural fields.

2.6.3. Vegetation cover reflection to remote sensors

One commonly used vegetation index is the Normalized Difference Vegetation Index (NDVI), which is calculated as (NIR - Red) / (NIR + Red), where NIR is the reflectance in the near-infrared region and Red is the reflectance in the red region of the spectrum. NDVI values range from -1 to 1, with higher values indicating healthier and denser vegetation(Jain & Goel, 2002)**.**Another commonly used vegetation index is the Enhanced Vegetation Index (EVI). EVI is similar to NDVI but incorporates a correction factor to account for atmospheric influences and soil background reflectance. EVI is particularly useful in areas with high aerosol content or where the soil reflects a significant amount of near-infrared radiation(Bari *et al.,*, 2021)**.**

It is important to note that the relationships between vegetation indices and atmospheric or biological factors can vary depending on the specific index used, the vegetation type, and the environmental conditions. Additionally, other factors such as soil properties, temperature, and nutrient availability can also influence vegetation indices. Therefore, a comprehensive analysis considering multiple factors is necessary to fully understand the associations between vegetation indices and atmospheric/biological factors using MODIS time series products(Zeng *et al.*,, 2022).

NDVI is a popular vegetation index in soil erosion studies. For example, a study by Nadal-Romero *et al.,* (2012) performed an analysis of various spectral indices in assessing badlands dynamics. The results of the study indicated a clear distinction between vegetated and eroded areas and the study recommended using the simplest and most commonly used spectral Index (NDVI). However, despite its wide recognition, studies have documented the drawbacks of NDVI, such as its the over-saturation in high density biomass, sensitivity to soil brightness, soil colour, cloud and cloud shadow (Purevdorj *et al.*,, 1998; Mutanga and Skidmore, 2004; Govaerts and Verhulst, 2010). This consequently led to various modifications in efforts to overcome this disadvantage by reducing the soil effects of sparsely vegetated areas or bare soil (Xue and Su, 2017).
The Soil Adjusted Vegetation Index (SAVI) and Soil and Atmospherically Resistant Vegetation Index (SARVI) are one of most commonly used modifications of NDVI in soil erosion studies (Phinzi and Ngetar, 2017). Indices such as the SAVI, Modified Soil Adjusted Index (MSAVI) and Transformed Soil Adjusted Vegetation Index (TSAVI) were established in efforts to improve the detection of erosion features in areas with low vegetation(Taruvinga, 2009).

3. MATERIALS AND METHODS

3.1. Study Area Description

3.1.1. Location

The study was conducted at Mitke watershed is situated in the Benishangul-Gumuz National Regional State, Metekel Zone within the Pawe district (formerly known as Beles Valley). Geographically, it is located between 11°17'46" and 11°20'0"N latitude and 36°27'22" and 36°28'20"E longitude (Fig.1). The watershed is part of the Beles sub-basin, which is a part of the upper Blue Nile region in the northwestern region of Ethiopia. The Mitike catchment is approximately 160 km away from the Grand Ethiopian Renaissance Dam (GERD) and covers an area of about 488 hectares. The elevation within the Mitlke catchment ranges from 1071 to 1158 meters above sea level. The majority of the land in the area is relatively gentle and flat, with an average slope of 5% (Abbute, 1998).

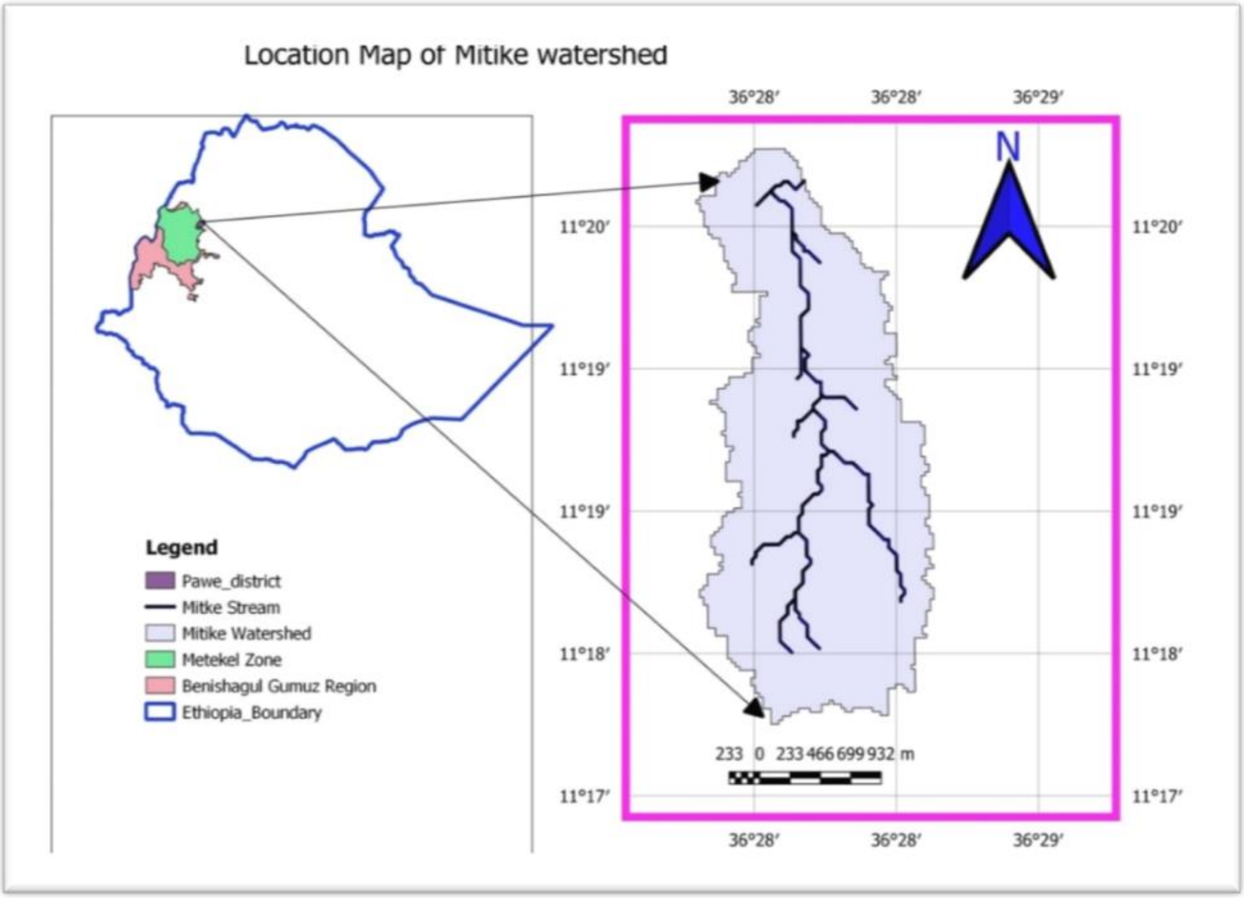

Figure 1.Map of the study area

3.1.2. Geology and Soils

The geology of Catchment consists of tertiary trap basalts and strongly folded and faulted Precambrian rocks (Nyssen *et al*.,, 2018). The watershed soil groups categorized as vertisols, 40 to 45%, Nitisols, 25 to 30%, and Luvi sols, 25 to 30% (Abbute, 2002).

3.1.3. Land use

The catchment encompasses different land uses such as cropland (113.2 ha), grazing land (104 ha), degraded land (100.04 ha settlement lands (65.4 ha) riparian (56.1), and irrigated land (53.2 ha). The dominant land uses in watershed cultivated land is followed open grazing, and degraded land 23.2, 21.3 and20.5%, respectively (survey, 2017).

3.1.4. Climate

The catchment is characterized as a hot to warm moist or sub-humid tropical climate lowland with very high rainfall (Figure 2). The area has a unimodal rainfall pattern, with an extended rainy season, from March to September. However, the peak rainy season is from July to August. According to records from 1987 to 2020, the mean annual rainfall is 1599. 8 mm. The mean annual maximum and minimum temperature is 32.6^{0}C and 16.6^{0}C, respectively. The coldest months are December and January whereas March and April are the hottest months (data from Pawe Agricultural Research Center).

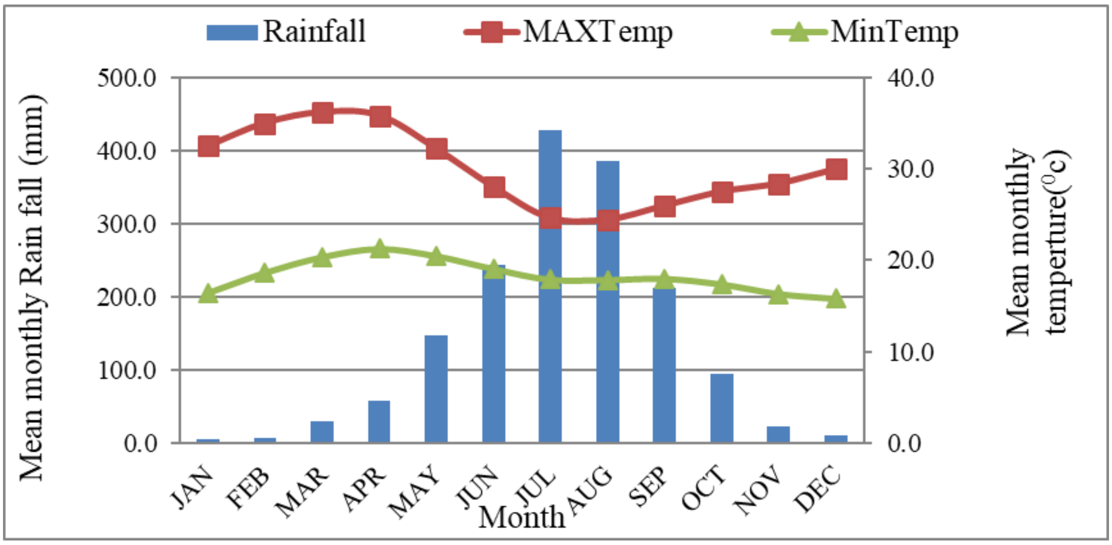

Figure 2.Monthly precipitation (mm) and mean monthly maximum and minimum temperature (^{0}c) (Pawe Agriculture Research Center Metrological Station for 1987-2020)

3.1.5. Population, Ethnic groups and Economic activities

The beneficiary of the Mitike watershed was listed by order of numbers and registered as downstream, upper stream and middle (Tesfay *et al.*, 2020). There was a total of 926 household beneficiaries in the watershed, out of which 260 upper stream, 331 middle stream and 335 downstream beneficiaries. The ethnic groups of in the catchment belongs Amhara, Hadiya, Kembata, Wolaita, Oromo and Agew. In the catchment way of living is crop-livestock mixed farming system and non- farm. In the catchment way of living are crop-livestock mixed farming system and non-farm. The dominant crops are grown in the catchment including maize (*Zeamays*), Finger millet (*Eleusinecoracana*), soya bean (*Glycine max*), rice (*Oryza sativa*) and groundnut (*Arachishypogaea L.*) of which soya bean and groundnut are major cash incomes. Cattle, mule, and goats are major livestock husbandry. In addition, on-farm activities such as daily laborer, petty trade, and charcoal production also another alternative sources for way of living. The farming system is mixed crop-livestock, characterized by rain-fed and continuous cropping(Abbute, 2002)

3. 1. Data collection, image processing, and classification

Digital elevation model (DEM), Multispectral remote sensing data (Landsat images), and Google Earth images were used to acquire data for the analysis of LULC. DEM and three time series (1985, 2005, and 2023) with 30m pixel resolution Landsat imagery including Landsat Thematic Mapper (TM), and the Enhanced Thematic Mapper Plus (ETM^+) and the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) scenes were used (Table 1). These data sources were obtained by downloading freely available images from the United States Geological Survey (USGS) website https://earthexplorer.usgs.gov/of earth explorer and projected to the Universal Transverse Mercator (UTM) projection system zone 37 N.

The year 1985 was chosen as the baseline for LULC changes analysis due to the reason that the 1984/85 drought induced an immediate government initiated resettlement program to move drought affected people into the basin (Abbute, 2002; Nyssen *et al.,*, 2018; WoldeMeskel, 1989). Images were sourced from path/row 170 and 052, covering the Beles basin fully (Table 1). Imagery processing was performed by using QGIS 3.26 and ERDAS Imagine 2015. Before the classification of images, preprocessing activities including atmospheric and geometric corrections, clip rasters, and mosaic band sets were done by the Semi-Automatic Classification Plugin (SCP) tools as described by Congedo

(2021). In addition, assess whether observing of green vegetation available or not, the normalized difference vegetation index (NDVI) was calculated as follows:

$$NDVI = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \quad \text{.......} \quad (1)$$

Where; NIR = Near-infrared, RED = Red band

The NDVI values varied from -1 to +1, indicating that the greater the NDVI value, the greater the fraction of green vegetation present in the area. The reflectance in the NIR area was measured by Landsat band 4 (0.8-9.94 mm), and the reflectance in the red region was measured by Landsat band 3 (0.63-0.69 mm). Conversely, the wavelength ranges for the NIR and red portions of Landsat 8 were different. As a result, they were calculated using bands 4 and 5 for red and NIR, respectively, yielding values spanning from 0 to 200 and fitting within an 8-bit format.

The green color indicated the existence of vegetation, whereas the other colors indicated the absence of green vegetation. These characteristics were helpful in classifying the Landsat imagery (Fig 2). Then, supervised image classification by the Maximum Likelihood Classifier Algorithm was performed (Richards & Jia, 2006; Solomon & Lukas, 2022). Furthermore, geometric and radiometric corrections were employed by ERDAS Imagine 2015 for image enhancement as presented in Figure 2.

After classification of images, validation of LULC classification was done using remotely sensed data or ground truth data. Reference data were obtained from Google earth images and Ground control Points (GPS points) (Fig. 2). A randomly stratified sample method was employed to determine the overall accuracy, Users' accuracy, Producers' accuracy, and kappa coefficient (Islami *et al.*,, 2022; Rwanga & Ndambuki, 2017).

Table 1.Description of imagery data used for LULC changes in the Mitike watershed

Date of imagery	Imagery type	Pixel Resolution	Path and Raw	Dataset Type
Jan 03, 1985	Landsat TM	30 m	170 / 052	LANDSAT 5
Jan 15, 2005	Landsat ETM$^+$	30 m	170 / 052	LANDSAT 7
Jan 14, 2023	Landsat OLI	30 m	170 / 052	LANDSAT 8

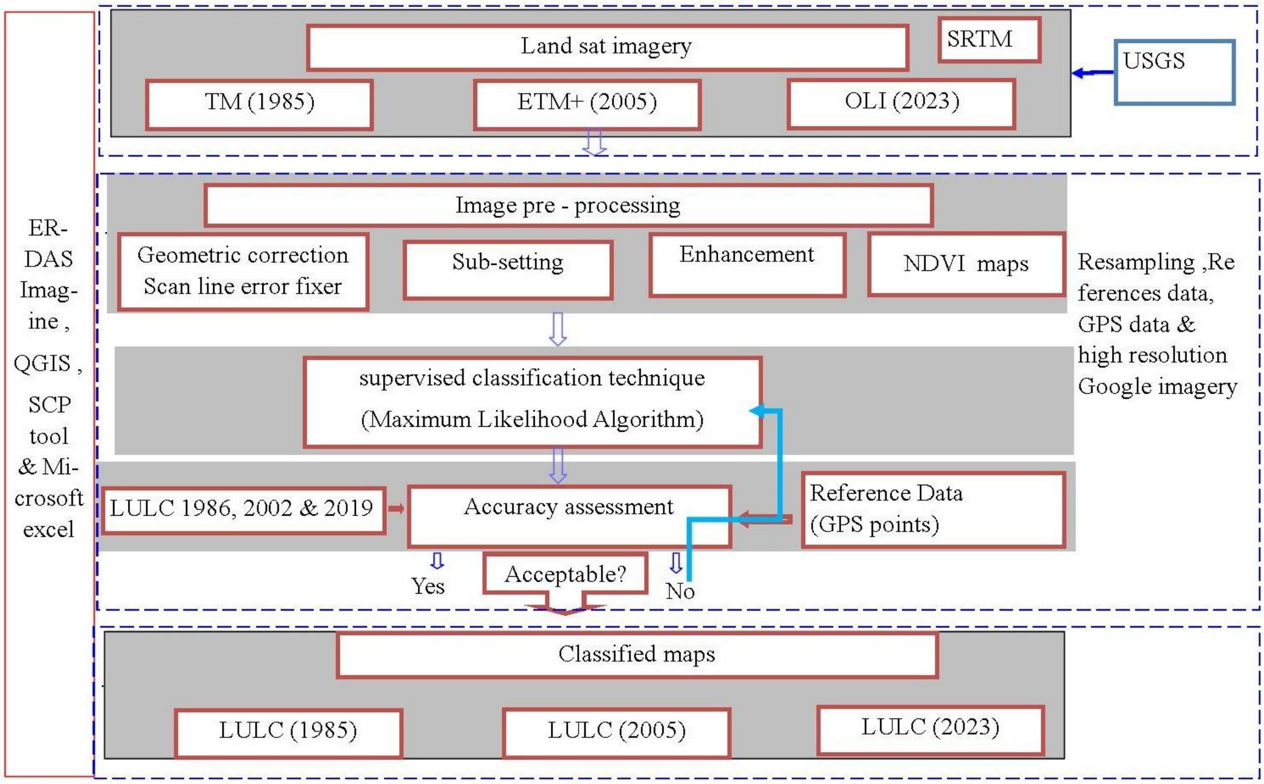

Figure 3.The methodological flowcharts for LULC change

3.3. Accuracy Assessment, LULC Classification, Change Detection and Interclass Conversion

Accuracy assessments of the classified images were undertaken by comparing the points in the classified LULC class with the reference layer. To determine the degree of the classification accuracy, overall accuracy measurement provides information on where the errors were created.In this study, overall accuracy assessment was executed by using the error matrix (Kuma *et al.*,, 2022).Calculating the overall accuracy involves adding together the number of values that were successfully categorized and dividing it by the total number of data.

$$\text{Overall accuracy} = \left(\frac{\text{The number correctly classified values}}{\text{The total number of values}}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

User's accuracy is the probability that a value predicted to be in acertain class actually is that class.

$$\text{User accuracy} = \left(\frac{\text{A diagonal number}}{\text{The row total}}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Producer's accuracy is the probability that a value in a given class was classified correctly

$$\text{Producers accuracy} = \left(\frac{\text{diagonal number}}{\text{The column total}}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

3.4. Gully Data Collection Method

Gully networks were mapped in Google Earth from the Digital Globe images at high resolution in 2023, based on the visual analysis of the images. Gully longitudinal profiles such as lengths were obtained by manually digitizing on-screen, which can be saved as KML files. Then, these digitized data were easily converted from KLM files to a shape file format supported by QGIS version 3.30.3. Gullies and other landscape features were clearly differentiated from their surroundings by using the Garmin 72 handheld Global Positioning System (GPS). Gully started and ended with detailed field survey data collected from May to September 2022. This data was used to collect visual judgments and corroborate the gully distributions. The field verifications allowed evaluating the location of digitized gullies, recognizing the gully status, and gully management activities by local communities. The total length of all gullies in watershed was computed by summing the lengths of each gully identified on the images, and the gully density Dg in each watershed was calculated by dividing Lt by the watershed area (Eq. (6) as described by Mesenbet *et al.*, (2019).

$$L_t = \sum_{i=1}^{n}(L_i) \quad (5)$$

where Lt = total gully length (km), n = the number of individual gullies, and Li = the length of each individual gully (km).

$$D_{g=L_{t/A}} \quad (6)$$

Where Dg = gully density (km km^{-2}) and A = watershed area (km^2).

$$\Delta L = L_t/\Delta T \quad (7)$$

Where ΔL = the change in total gully length (km yr^{-1}) and ΔT = the time between the consecutive images (yr).

Therefore, by overlaying the land use change maps coupled with gully erosion distribution maps, the variation of gully erosion with related to land use type conversion. Images were obtained from the Landsat TM in 1985, The ETM^+ in 2005 and OLI and TIRS scenes in 2023 in order to determine LULC dynamics. Then, due to cost of high resolution sat images, I used, Google Earth (GE) images at resolutions in 1985, 2005 and 2023 freely available. The interpretation of remote sensing images needs to be supported and validated with ground data, which was obtained from field investigations.

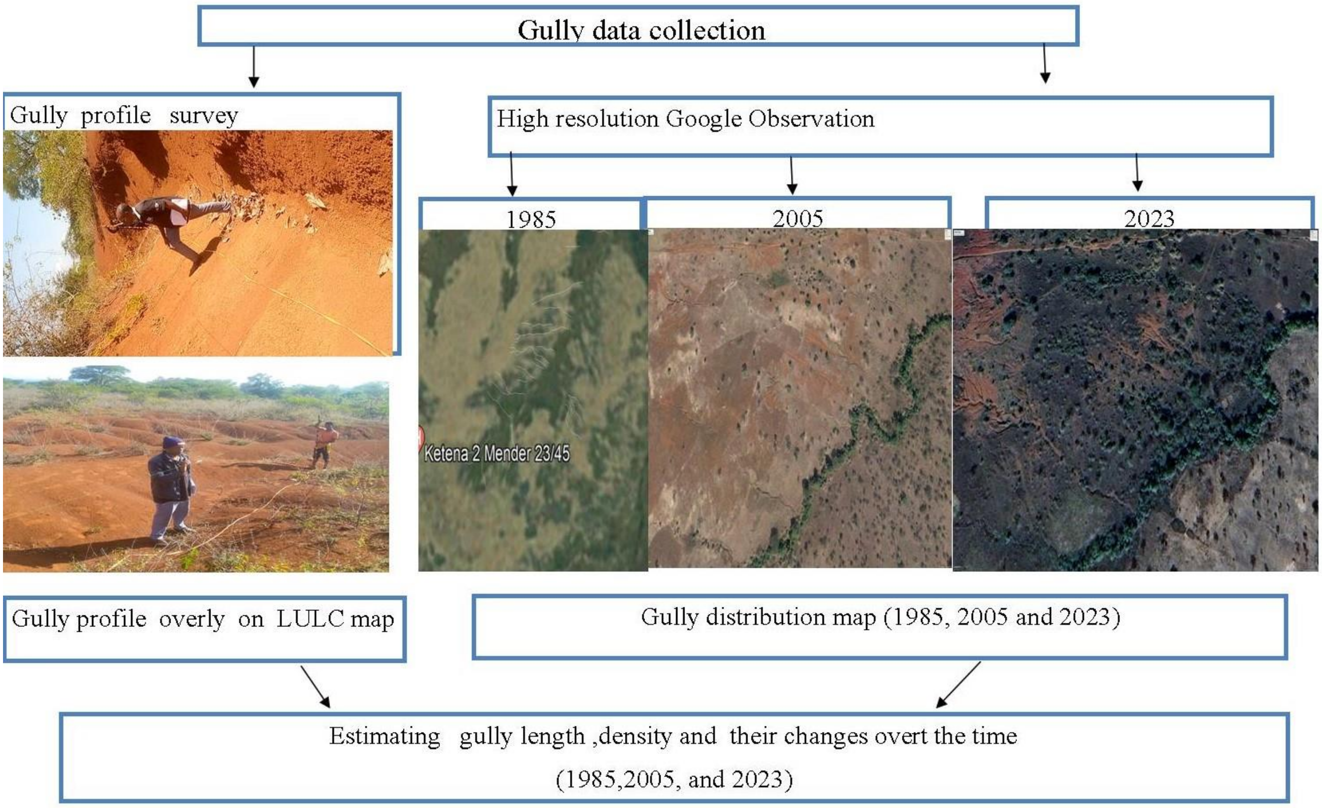

Figure 4.Gully mapping methodology

4. RESULT AND DISCUSSION

4. 1 Land use and land cover classification accuracy

It effectively informs us how frequently the class on the map will be present on the ground. On the other hand, the producer's accuracy reveals how frequently actual ground features are properly represented on the classified map. Overall classification, Producer’s, and user’s accuracies as well as kappa coefficient were calculated and presented in Table2 for 1985, 2005, and 2023, respectively. The overall accuracies for the three reference years ranged from 93% to 99% with the kappa statistic ranging from 0.89 to 0.99. These results indicated that in three reference years, the classified maps were within an acceptable

Table 2**.** The accuracy assessment report in percent of the classified LULC maps

LULC class	1985		2005		2023	
	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy
Forest	100	81.3	100	89.9	100	90
Woodland	93.8	96.8	88.9	98.6	100	100
Bamboo forest	88.1	100	0	0	0	0
Grazing	0	0	85.7	93.7	100	100
Crop land	0	0	100	98.2	100	100
Overall accuracy in %	93.0		95.4		99	

4.2 Spatio-temporal changes in land use and land covers

The LULC change analysis for the period (1985-2023) shows that croplands and grasslands have increased while natural forest and woodlands have decreased significantly. Lowland Bamboo was totally destroyed as mentioned Table 3 and Figure 4. While in 1985, the study area was dominated by natural forest, lowland bamboo forest and woodlands, which made up about 99.3% of the study area, the portion of these three classes decreased in 2023 to about 29% (forests 15.3% and woodlands 38.5%) , with 57.1% of the study area newly covered by artificial vegetation (croplands). Mariyea *et al.,* (2019) reported that in Pawe district lowland bamboo forestland cover had completely disappeared.

In Benishangul-Gumuz region alone the lowland bamboo covers an estimated area of 440,000 ha, though gradually it is disappearing from the landscape (Bessie *et al.*,, 2016).

In contrast to a 50 by 50 share of woodland and bamboo mentioned by KULS(1962). In absolute terms, cropland has expanded by an area of about 305.28ha over the last 38 years. It is the LULC type with the highest amount of change in the study area and replicates a mean annual expansion rate of 8 ha/year whereas forest and woodlands were decreased in percent 40.1 and55.5, respectively, in study period. Others reported a 1-83 % reduction in forests, woodlands, and grasslands while 0.3-222.4% gained cropland and built-up areas in LULC in different parts of Ethiopia (Abebe *et al.,*, 2021; Anley *et al.,*, 2022; Biratu *et al.,*, 2022; Gashaw *et al.,*, 2018; Gu *et al.,*, 2021; Mekuriaw *et al.,*, 2021; Tolessa, Senbeta, & Abebe, 2017).

In our study, LULC changes much faster on croplands (Table 3) than others could be susceptible to soil erosion subsequently, siltation and sediment accumulation on GERD reservoir where is located at outlet of Beles basin. This finding is in agreement with previous studies (Nyssen *et al.,*, 2018; Teklemariam *et al.,*, 2017) which reported that natural forest is frequently replaced by commercial farms and continuous settlement and resettlement programmers in the Beles basin leads to the highest soil erosion and siltation of the GERD reservoir.

The loss of forest covers and woodlands in the watershed is caused by a number of factors included: mechanized agriculture and crop-livestock mixed farming land demand expansion, massive deforestation, charcoal production, uncontrolled wildfire, resettlement, overgrazing, less attention land management practices and land use policy and population pressure. Studies conducted by (Abebe *et al.,*, 2021; Nyssen *et al.,*, 2018; Teklemariam *et al.,*, 2017; Woldemeskel, 1989) reported that the establishment of roads, large commercial farms, settlement hotspot and large sugar estates frequently removal forest and woodland cover change in the Beles basin without any mitigation measures.

Between 2002 and 2019, built-up areas were progressively increased and covered about 5,481.9 ha of the basin. Because of the Tana-Beles Resettlement Program, there is a dense road network, settlements, and agro-industrial development. In addition, pre-urban and urban establishments, including Jawi, Pawe, GilgelBeles, and Manbuk, as well as Nyssen *et al.,* (2018), reported that the current and ongoing wave of immigration is unplanned, following the establishment of roads, agricultural investments, and towns in thebasin.

Table 3. LULC classification results and changes in area coverage in ha from 1985, 2005 and 2023 in the Mitike watershed.

ULC type	1985 Area	(%)	2005 Area	(%)	2023 Area	(%)	1985-2005		2005-2023		1985-2023	
							Area	%	Area	%	Area	%
Forest	136.89	25.6	34.92	6.5	81.99	15.3	-101.97	-74.5	47.07	134.8	-54.90	-40.1%
Woodland	166.14	31.1	159.57	29.8	73.89	13.8	-6.57	-4.0	-85.68	-53.7	-92.25	-55.5%
Bamboo forest	228.15	42.6	0	0	0	0	-228.15	-100.0	0.00	0.0	-228.15	-100.0%
Grazing land	3.78	0.7	59.4	11.1	73.8	13.8	55.62	1471.49	14.40	24.2	70.02	1852.4%
Crop land	0	0	281.07	52.6	305.28	57.1	281.07	0	24.21	8.6	305.28	0
	534.96	100	534.96	100	4.96	100						

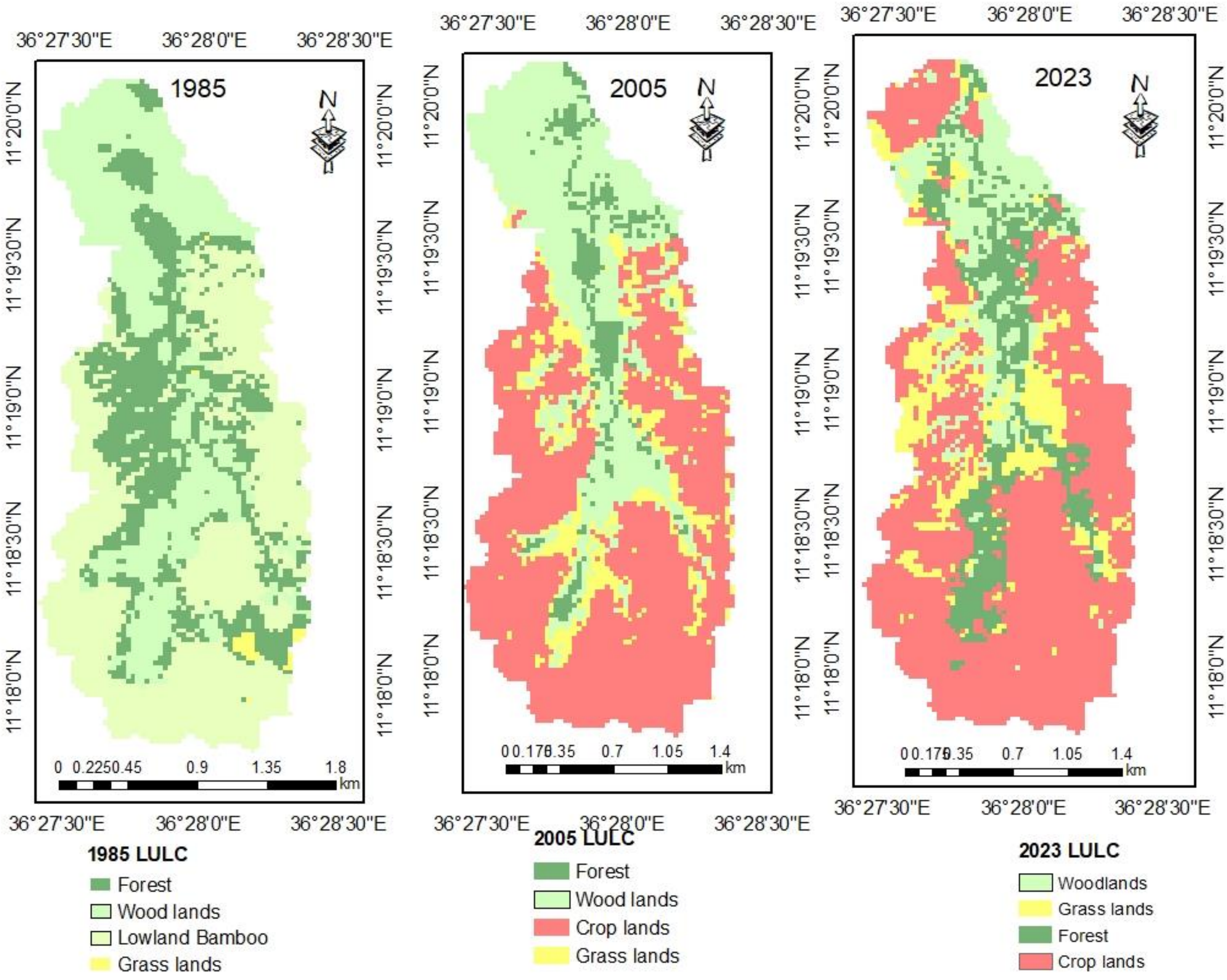

Figure 5. LULC maps of the Beles basin from 1985, 2005, and 2025

4. 2 Land Use and Land Cover Conversions

Over the 38 years, there were several conversions from one LULC type to another in Mitike. The respective LULC transitions in the study area are presented in Table 4. A considerable Mitike of the bamboo forest was converted to cropland (190.8ha) and grazing land (23.49ha), respectively. Around 34.5% (57.24ha) of the woodland and 39.3%

(53.7ha) of the forest were also converted to cropland in the Mitike watershed over the study period. Therefore, it is evident that the highest share of conversions within the bamboo forest, woodland, and forest classes in the watershed was towards croplands. Approximately 57% of the total landmass in the watershed was converted to cropland. This shows that key transitions in the watershed are mainly attributed to agricultural activities. A detailed scrutiny of the spatial distribution of these transitions as presented Table 4 shows that bamboo forestland in the upper, and middle watershed conversions to croplands.

The transition matrix revealed that, evidently, forest destruction, degradation and deterioration were caused either directly by human beings (for example, agricultural activities on 305.28ha) or indirectly by other factors. In the watershed were engaged in a permanent intensive crop-livestock mixed farming system and Tana-Beles resettlement, which supported mechanized agriculture; As a result, when comparing historical images over the years, it is easy to determine that the most dramatic development is the removal of the natural forest and woodland conversion to croplands.

Table 4.Transition matrix showing LULC changes in the Mitike watershed between 1985 and 2023

LULC types	2023				
1985	Forest	Woodlands	Croplands	Grassland	Total
Forest	**31.05**	25.29	53.73	26.82	136.89
woodlands	41.4	**44.01**	57.24	23.49	166.14
Bamboo forest	9.27	4.59	190.8	23.49	228.15
Grasslands	0.27	0	3.51	**0**	3.78
Total	81.99	73.89	305.28	73.8	534.96

4.4. Spatio-Temporal Distribution of Gullies in Watershed

The analysis of the reconnaissance gully survey and high-resolution Google earth imagery clearly showed the spatio-temporal distribution of gullies in the Mitike watershed as presented Figure 6 and Table 5. In Landsat and high Google earth imagery history in 1985 no any gully sign was observed in study area. Due to fact reason that the watershed was virgin land and about 99% it was covered by natural forests (bamboo, forest and woodland forests) and vacant by human beings. This result is similar to the previous study by KULS, (1962) report dense and very uniform forests that day light is largely dimmed in dry season. Moreover, Abbute (2002) also similarly repot Beles valley the currently named Mitike watershed unoccupied by inhabitant and favorable soil fertilely, mild rainfall and ample water resource. In Ethiopia history, in 1984/85 horrific and tragedy shocked drought and famine happened more than 70000 households moved from southern and northern parts of Ethiopia in to in this watershed (Woldemeskel, 1989). To secure livelihoods for settlers, there was massive mechanized farming, deforestation, establishment of modern infrastructure, and the use of synthetic agricultural chemicals since 1986 “Tana Beles Project” an Italian group specialized in cooperation with developing countries was appointed to implement it.

Gullies were observed in spatio-temporal distribution. Similarly, Setargie *et al.*,(2023) reported that gullies could occur in any climatic, soil type, lithologic, and substratum setting in Ethiopia, with and Yibeltal *et al.*,(2023) found evidence that gully erosion has been occurring in the northern highlands of Ethiopia for over 10 decades. Natural and human factors inducing gully erosion since 1935 in northern Ethiopia include a land tenure system unrestricted by any land management policy, rapid population growth, land use and land cover changes, and high runoff from precipitation (Getnet & Mulu, 2021; M. Li *et al.*,, 2021b; Nyssen *et al.*,, 2009; Teka *et al.*,, 2013; Zegeye *et al.*,, 2016).

4.5. Gullies Number, Length And Change Rates

Total gully number, length, and change rates increased with time within the watershed and spatio-temporal, as presented in Figure 6 and Table 5. The minimum and maximum coverage in percent in forestland (6.6%) and cropland (45.3%) in 2005 and closely similar trends in forest land (7.3%) and crop land (50.8%) in 2023, respectively. Under the land use/cover classification group in cropland, the highest gully formation was followed by grazing land, woodland, and forest land in percent 45.3, 26.3, 21.9, and 6.6, respectively, in 2005. Exactly similar trends in land use and cover classification group values were obtained for crop land, followed by grazing land, wood land, and forestland in percent 50.8, 21.2, 20.7, and 7.3, respectively, in 2023. Whereas the change in gully formation cropland and forest land is more or less similar (32 and 31.4%), wood land (19.6%) has more change than grazing land (5.6%) over reference periods.

In 1985, no observations were made on Google Earth. Due to the fact that the watershed was covered by jungle forest. In 2005, the total length and number of gullies were observed at 6983.5m and 25 remarks, while in 2023, the total length and number of gullies were recorded at 12524.2m and 44 remarks, respectively (Table 5). The results clearly show that the gully formation increased much more in 2005 than in 2023. Due to the fact that land use and cover dynamics. To alleviate resettlers livelihoods and transform modern agriculture under the theme “food self-sufficiency,” massive removal of forest and conversion to cropland. As a result, 2005 in remote sensing demonstrated that about 52.6% (Figure 5) of watershed coverage was changed to cropland and 45.3% (Figure 6) of gully was formed in cropland.

This is supported by Wolde Meskel (1989) pointed out Beles Valley Development Program 250,000 ha were covered by mechanized farming in which watershed established with in it. Nyssen *et al.*,(2018) found that changes affect mainly the central Beles valley the settlers started to cultivate the slopes, which gives them a typical “Wollo” aspect.

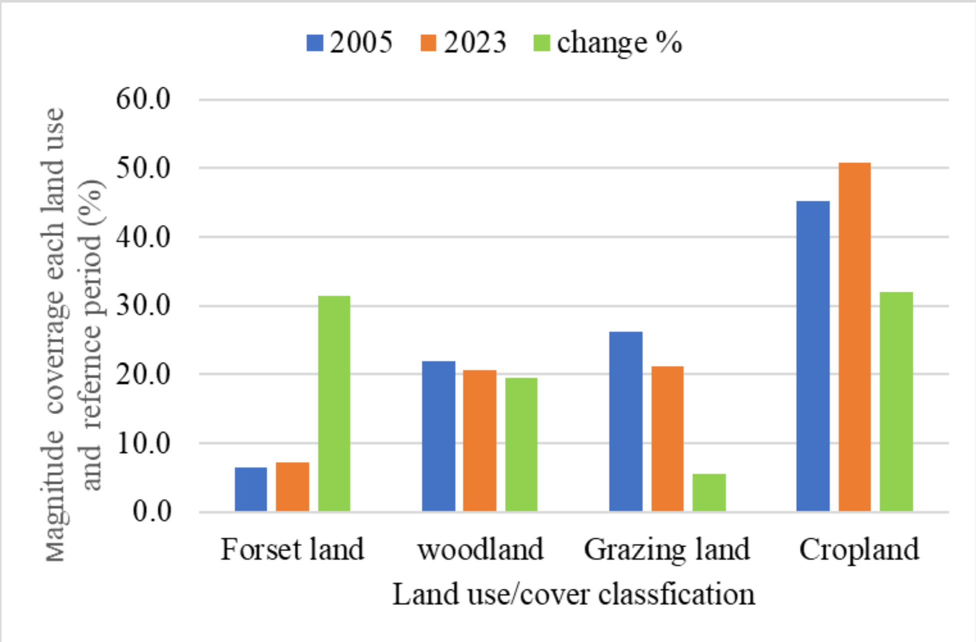

Figure 6 gully coverage of each land uses and each references period in percent

At Upper Awash, Central Ethiopian highlands, total gully length increased from 30.5 to 91.6 km over the period from 1965 to 2013 in a watershed with an area of 49.3 km^2 (Kropacek *et al.*,, 2016). Furthermore, an increase of gully length from 21.3 to 38.2 km between 1860 and 1920 in a58 km^2 watershed in Hungary was attributed to vegetation removal(reductions of 30% in forest cover and 3.1% in shrub cover) and cultivation activities (Gábris *et al.*,, 2003). In contrast to our findings, Nyssen *et al.*,(2006) reported an inconsistent gully development trend from 1960 to 2000 in the northern highlands of Ethiopia: although gully length increased from 1977 to 1990, major development of gullies ceased after 1995. Similarly, Frankl *et al.*,(2011) reported an increase in gully development from 1960 to 2000, and a decrease after 2000,which they attributed to gully management interventions.

The relationships between decadal values of gully length and LULC changes were sketched plots as described Figure 7. Positive and significant correlations were observed between gully formation number in different land uses in all study years. Statistically significant relationships revealed by high value of coefficient of determination (R^2) and correlation coefficient (r) which are derived through regression between gully formation and land use/cover changes (Figure 7). The coefficients of determination (R^2), for number of gully formation R^2=0, R^2=0.94 (r=92) and R^2=0.99 (r=92) for the years 1985, 2005 and 2023, respectively. The relationship between gully formed and land use/cover was relatively no gully formed during in1985. Due to the fact that large proportion of land was cover low land bamboo, forest, wood land and some extent grass land. However, in 2005 and 2023 the correlation coefficients still show strong relationship between gully formation and land use/cover changes in the watershed. The correlation coefficient (r) provides a good estimate of the overall fit of the regression model. Its large value indicates a strong relationship. Different ranges have assigned for the magnitude of r. As mentioned by Field (2006) rated values as low ($r \leq +0.3$), medium ($+0.3 < r > +0.5$) and high ($r \geq +0.5$). Generally, a higher slope value showed increment gully formation under different land use/cover and gully formation increment over years (Figure 7).

This finding is in agreement with the findings of Tebebu *et al.*, (2010) and Zegeye *et al.*, (2016), who showed that in sub-humid tropical areas, a rise in the groundwater table above gully bottoms due to high rainfall is a dominant cause of the expansion of gully erosion. Kropacek *et al.*, (2016) reported annual rates of increase in total gully length (200, 1200, and 400 m per year during the period 1967-1971/1972, 1971/1972-2006, and 2006-2013, respectively) in the central highlands of Ethiopia that are generally higher than the rates obtained in this study. The large difference in rates is mainly attributable to differences in watershed area.

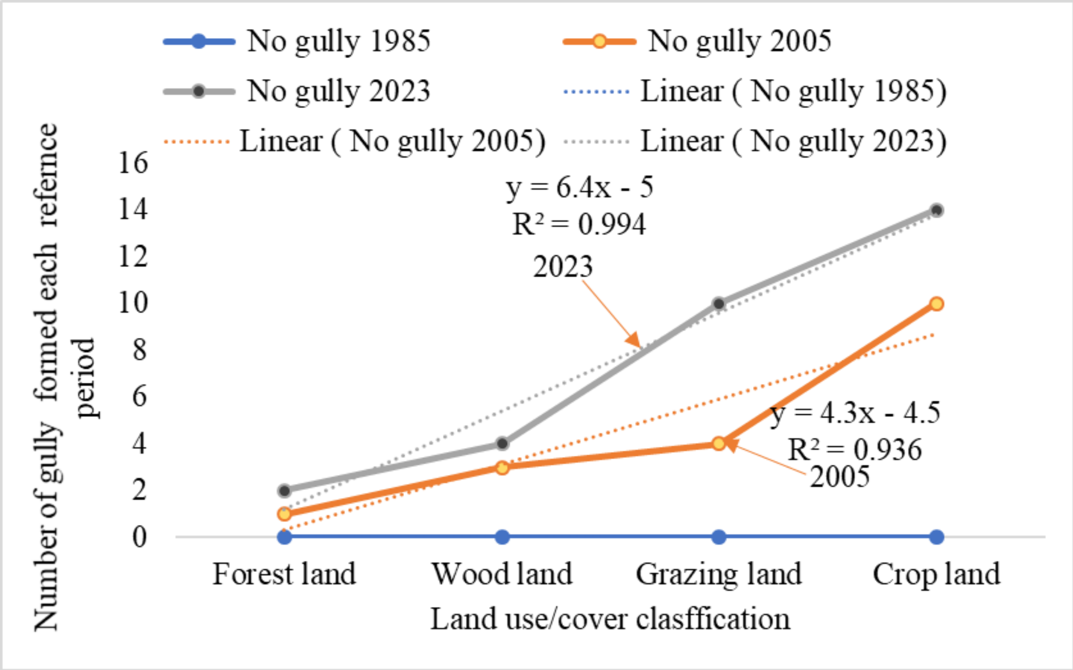

Figure 7 Number of gully formation with relation land use/cover changes in the Mitike watershed.

Figure 8 Field observation and sample taking gully formed areas by GPS

4.6. Gully Density

As displayed in Table 5, during the last four decades (1985-2023) gully density increased on average by 384 m per ha. In 2005 the gully density was recoded 17.1m per ha where as in 2023, its density also increased to 28 m per ha. The changes density was increased by 39.3% as compared to the previous last 18 years. As observed in the case of total gully length, gully density increased gully treatment measures in watershed. These findings are consistent with those of Kropacek *et al.*,(2016)and Guyassa *et al.*,(2018), who reported that gully density increased by12.2 m per ha during 1965-2013 in the Ethiopian Rift valley and by11.4 m per ha in 1935/1936 and 15.9 m per ha in 2014 in northern Ethiopia, respectively.

Gully density increases in South Africa of 64 m per ha in 1981 (Garland and Broderick, 1992), and gully density increases in Zimbabwe from 20.0 m per ha in 1948 to 30.0 m per ha in1973 (Firth & Whitlow, 1991) were caused by land use changes, from forest to cultivated and grazing lands. Our results are also similar to those of Zhang *et al.*,(2015),who found that in Kebai Region in Heilongjiang Province, China, gully density increases depended on elevation differences within a watershed; they reported increases of 57.5% in hilly watershed and of 52.9%, and 25.2% watersheds on a mesa and a plain, respectively, from 1945 to 2000. However, Sidorchuk *et al.*,(2003)showed that gully density increases at a high rate during the gully initiation stage.

Table 5**.** The number, length, density and their changes of gully in Mitike watershed

Year	No gullies	Total length	Gully density (m/ha)	chang e in no	change in length m	change in Density(m/ha)
2005	25	6983.5	13.1	25	-	-
2023	44	99162.5	18.5	19	2179	4.1

Statistically significant relationships are revealed by the high values of the coefficient of determination (R2) and correlation coefficient (r), which are derived through regression between gully density and land use and cover changes (Figure 8). The coefficients of determination (R^2) for gully density (R2 = 0), the predictor of land use and cover changes, account for none of the variation in gully density in 1985, R2 = 0.2 (r = 0.4), and R2 = 0.07 (r = 0.4) for the years 2005 and 2023, respectively. Although there were variations in the gully density and land use/cover change medium (+0.3 < r > +0.5), the correlation between gully density and land use/cover change for all land uses was positive and significant over the years. However, relationships are highly strong in woodland and grazing land relative to crop land relationships. The relationship between gully density and land use and cover changes is relatively lower in crop land due to the fact that a large proportion of gully density occurs in grazing land regardless of other land use in 2023. However, the correlation coefficients still show a positive relationship between gully density and runoff in land use and cover changes. Yibeltal *et al.*, (2019) noted similar findings gully formed in different land use types, including crop land, grazing land, and bush land, in upper Blue Nile Basin, Ethiopia. Moreover, Yibeltal *et al.*, (2019) also found that the lowest gully formed values were in bushland, whereas the maximum gully was observed in cultivated land, followed by grazing land. The study carried out in the Tabota Koromo and Koromo Danshe watersheds found that the causes of gully erosion in the watersheds were land cover change (deforestation), improper irrigation design, wrong discharge of water, expansion of agricultural land, overgrazing, and improper land use (steep slope cultivation, farming close to the gully bank and gully floor), which was in line with (Hassen & Bantider 2020). An earlier study on the controlling factors of gully erosion in the study areas also showed that slope, soil, and land use/land cover factors have considerable influence across watersheds in the three agro-ecological environments of the basin (Yibeltal *et al.*,, 2019).

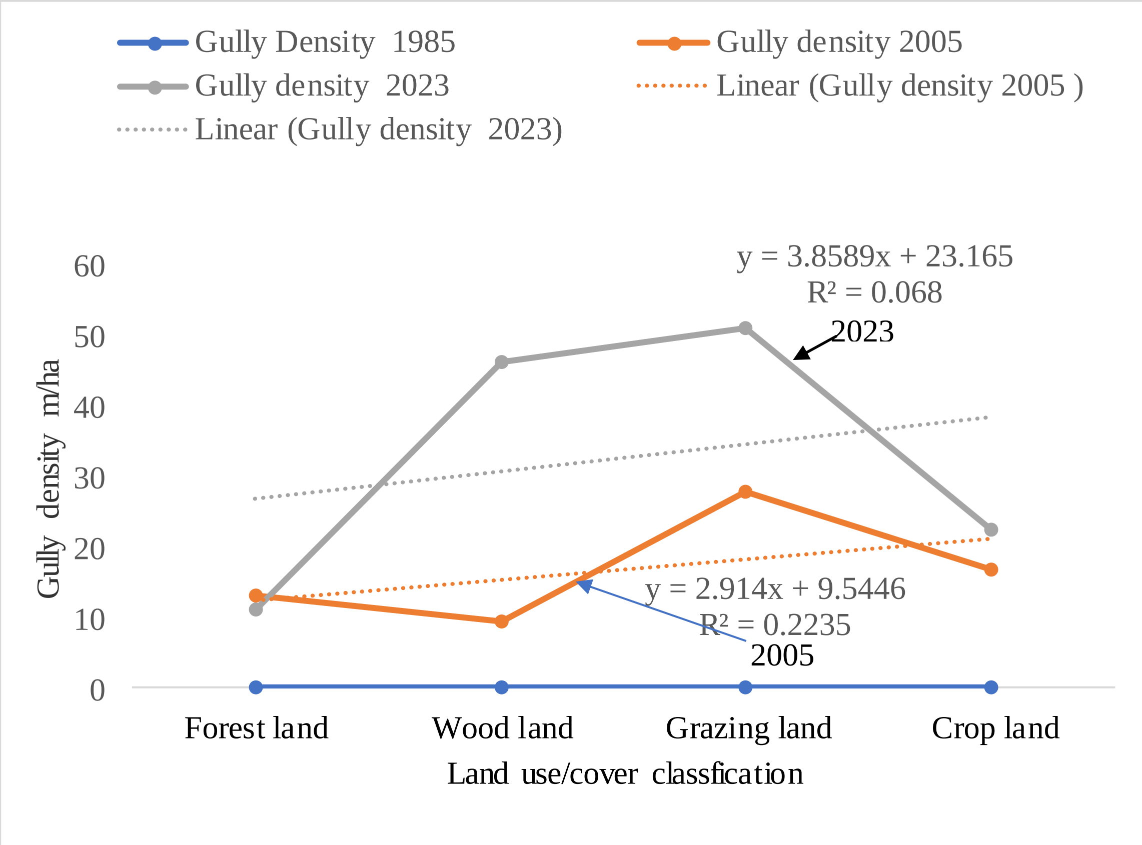

Figure 9 Gully density with relation land use/cover changes`

The Relationship between Land Use Types and Gully Erosion

Figure 9 reveals that the gully erosion condition in the Mitike watershed has deteriorated over past four decades. In addition, it highlights that the area of cropland subject to gully formation increased in both reference year. The dominant gully erosion was occurred in the crop land followed to grazing lands and woodland in 2005 and 2023 reference study year. Then, in 2005 about 76% gully erosion happened in crop lands and the remaining was occurred in grazing land and wood lands. Similarly, in 2023 also about 90% of gully erosion was occurred in cropland and remaining was occurred in grazing land and wood lands. As compare to between two reference periods the gully erosion increased by 26.8%. Crop land was the land use type on which gully erosion increased most rapidly gully erosion land use category, of which increased from 76% to 90 over the 38 years period, with an average annual increase of 2.6% (Table 4).

In 1985, in the watershed area was vacant as resulted the watershed was covered by lowland bamboo, woodland, forest and grazing land, respectively. In this reference year, any type of land use gully erosion was not appeared. Therefore, gully erosion of anthropogenic activities is the major contributor as shown Figure 4.While land use/cover change is demonstrably an important factor in gully erosion (Amare *et al.*,, 2021; Arabameri, Pradhan, *et al.*,, 2018),and affects the spatial distribution of erosion, research on how land use change impacts gully erosion intensity is less common. Following classification, validation and field verification of Landsat/TM images for 1965, 2005, and 2015, and this paper presents a detailed assessment of land use changes and its impact on soil erosion for a 50-year period in the black soil area in northeast China. The area is characterized by marked changes in both erosion intensity and gully length per km^2 during the last few decades and, indeed, demonstrates the highest rate of soil erosion in China (Gong *et al.*,, 2013; Liu *et al.*,, 2010; Y. S. Wang *et al.*,, 2013).

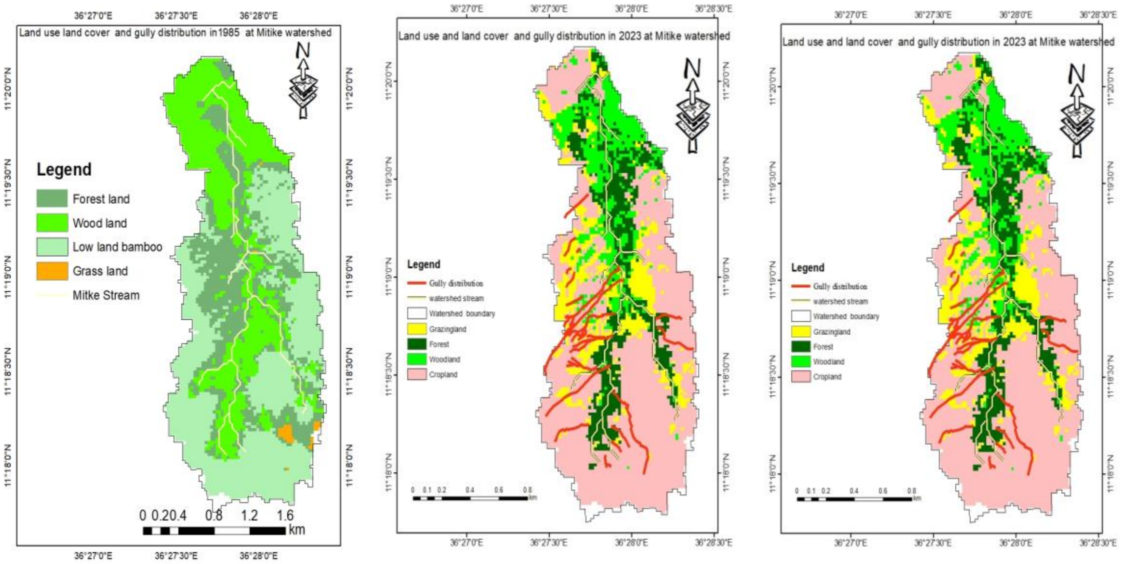

Figure 10 The Relationship between land use and land cover and gully erosion

4.7. The Relationship between Land Use Change and Gully Erosion Dynamics

By overlaying the gully erosion distribution maps together with land use change, the variation of gully erosion density related to land use type conversion can be obtained (Figure 6). Figure 6 reveals that it was the conversion of crop land and other that led to the most significant increase in gully erosion from 1985 to 2023. During this time 305.28 ha of land was converted to cultivated land in the study area and gully erosion density increased by 26.8%, with a mean annual change of 11.7 m per ha.

As shown in Figure 6, land use changes generally resulted in increased in gully erosion. For example, marked changes in gully density occurred following forestland, bamboo forest and woodland being converted to cropped land number gullies null to 13 and 20 in reference period 1985, 2005 and 2023, respectively. The results show that forest land, bamboo forest and woodland were easily eroded after being reclaimed into farmland, showing a trend of accelerated development of gully erosion. In addition, the increasing rate of gully erosion failed to slowdown even after cultivated land was converted to forest land, although the conversion of cultivated land to forest land would-be expected to inhibit further development of gullies. For instance, farmers usually construct drainage ditches parallel to the slope gradient in sloping cultivated lands to drain excess water from their fields. This design, however, concentrates the local flow and leads to gully formation(Figure 6). Monsieurs *et al.*,(2015)and Monsieurs *et al.*, (2015) also reported that improper design and construction of drainage ditches caused the initiation of gully erosion in the sub humid-tropical highlands of Ethiopia. Similarly, Casalı *et al.*, (1999) showed that conventional farming practices (and a lack of properly constructed channels for conveying excess water away from fields triggers gully formation.

The field observations also indicated that gullies formed as a result of incorrectly implemented SWC practices in cultivated lands in watershed in Figure 6. For example, improper alignment of cutoff drains, waterways, and soil and stone bunds may lead to the concentration of runoff and the development of gullies downslope. Intensive use of agricultural lands, human settlement, and overgrazing cause land degradation through gully erosion in northern Ethiopia (Moges & Holden, 2008; Nyssen *et al.*,, 2009). Our study results provide an overview of the role that intensive use of agricultural lands and incorrectly implemented practices plays in the formation and expansion of gully erosion in the Upper Blue Nile basin. Similarly,(Avni, 2005) reported that inappropriate land management practices can cause accelerated gully erosion. Poor cultivation practices can lead to gully erosion even in relatively flat areas (Kakembo *et al.,*, 2009).

In Ethiopia, gullies are common features in grasslands and rangelands because of overgrazing and soil trampling by cattle along cattle roads (Nyssen *et al.,*, 2004). In addition, it has been shown that vegetation disturbances are the major cause of the initiation of gully erosion after the introduction of livestock production in Australia and South Africa (Mararakanye & Sumner, 2017; Pringle *et al.,*, 2006). DeRose *et al.,*(1998) showed that clearing forest to expand grazing lands accelerates gully erosion.

Ethiopia have shown that rapid gully development is related to land use changes, the frequent land distribution system to farmers, and inappropriate land management practices(*Lanckriet et al.,*, 2015; Moges & Holden, 2008; Nyssen *et al.,*, 2004). In addition, Gábris *et al.,*(2003)noted that most gullies formed during periods of forest clearance and expansion of farming lands in north-eastern Hungary. In agreement with our findings,(Descroix *et al.,*(2008) reported that reductions in vegetation cover and overgrazing are the main factors causing rapid gully expansion in South Africa.

4.8. Gully Erosion and Land Use Change in Relation to Slope

By overlaying the land use change map, gully density map, and slope map, the variation of gully erosion density caused by land use change under different slopes during the period 1985 to 2023 can be obtained (Table 5 and Figure 7). Figure 5 shows that the conversion of bamboo forest, and wood land into cultivated land had increased the incidence of gullies, a pattern that is emphasized on slopes, especially those exceeding 5%. Results of the statistical analysis indicate that, when cultivated land is changed to wetland, gully density increases only gradually on slopes of less than 3%, but more rapidly when the slope angle exceeds 3%. This situation is similar when Crop land is changed to other.

The conversion of bamboo forest into cropland was the most significant cause of an increase in gully density on all slopes. The higher gully density on gentle slopes can be explained partly by the concentration of runoff from continuously cultivated and grazed landscapes in the study watersheds (Sultan *et al.,*, 2018).Kropacek *et al.,*(2016) also found that in the central highlands of Ethiopia gullies occur more extensively on gentle slopes. Poesen *et al.,* (2003) showed that increases in the upslope drainage area can lead to higher runoff volumes and result in gully incision downslope. In South Africa, gentle slope gradients have also been found to be more susceptible to gully erosion because they are associated with an increased drainage area, which leads to higher runoff amounts and gully erosion in grazing and cultivated lands on gentle slopes (Kakembo *et al.*,, 2009; Laker, 2004; Le Roux & Sumner, 2012; S. Zhang *et al.*,, 2015). Zhang *et al.*,(2015)reported that in Kebai Region in Heilongjiang Province, China, the threshold gradient for gully formation was 3°.Likewise, in northern Ethiopia severe gullying is observed on gentle slopes and gully density is lower on steep slopes (Tamene *et al.*,, 2006a).

Cultivated land was the land use type on which gully erosion increased most rapidly1. The percentage of cultivated land subject to erosion increased from 84.21% in 1965 to 87.81% in 20151. Additionally, the area of eroded cultivated land increased by 17.90 km^2 during this period. One possible reason for this is that access is limited to steep areas, so they are less exposed to disturbances by humans and livestock. An additional factor that often limits the formation of gullies (and erosion on general) on steep slopes are the shallow soils and high rock fragment cover.

Gully density and slope gradient are strongly related, but there exists a threshold gradient for gully formation (Poesen & Valentin, 2003). Similarly, in China, gully density increases with slope gradients up to 3° and decreases as the slope gradient increases above that threshold(S. Zhang *et al.*,, 2015).Cultivated land was the land use type on which gully erosion increased most rapidly1. The percentage of cultivated land subject to erosion increased from 84.21% in 1965 to 87.81% in 20151. Additionally, the area of eroded cultivated land increased by 17.90 km^2 during this period (Li *et al.*,, 2021b).

In contrast to our results, however, Guyassa *et al.*,(2018)have reported that in northern Ethiopia more gullies develop on steeply sloping landscapes. Other studies have similarly found that gullies are common features in hilly regions with steep slopes because high runoff velocities lead to gully formation(Gábris *et al.*,, 2003; Valentin *et al.*,, 2005). Moreover, our results showed that the effect of slope gradient on gully formation and development differed among the three agro-ecologies implying that site and slope specific information on initiation of gully erosion is very crucial to propose appropriate management strategies. The findings suggest that cultivating land on slopes, particularly those greater than approximately 4°, can rapidly exacerbate gully erosion1. The importance of implementing effective erosion control measures in cultivated land to minimize gully erosion and its detrimental effects on the landscape(Li *et al.*,, 2021b)

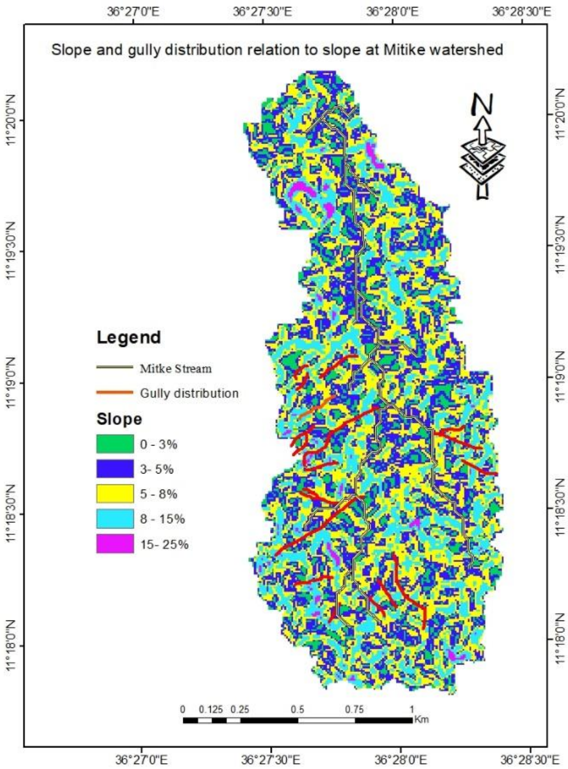

Figure 11 Gully erosion distributions in different slope in percent

5. CONCLUSION AND RECOMMENDATIONS

The results indicate that the overall accuracy for the three reference years ranged from 93% to 99%, with the kappa statistic ranging from 0.89 to 0.99, which is categorized as having a strong agreement value. The results from the 1985 classified image (initial period of study) showed that the dominant LULC types were bamboo forests, followed by woodlands and natural forests. During this period, the watershed was covered by natural resources and virgin land.

In 2005, croplands became the dominant LULC type, followed by other land uses in various proportions. A continuous increase in croplands was observed, while natural forests, grazing land, and woodlands decreased. This implies that the increase in cropland types in the area resulted from deforestation and conversion to croplands. The change results show that the bamboo forest was totally destroyed between 1985 and 2005, and there was a rapid reduction in woodland and forest land cover between 1985-2005 and 2005-2023. The 38-year change matrix analysis revealed that about 67% of the land had experienced changes in cropland.

Gully erosion is one of the main causes of land degradation, particularly in high rainfall and human activity-prone regions of Ethiopia. This study assessed spatio-temporal changes in gully length and density in the Mitike watershed due to land use and land cover changes, as well as the lowland agro-ecology of the Beles sub-basin in the Upper Blue Nile basin of Ethiopia. The greatest increases in gully erosion occurred when cropland and other lands were transformed, leading to an increase in gully erosion density of 18.5 m/ha. The number of gullies increased from 25 to 44 between 1985 and 2023, with gully density increasing by 13-18 m/ha during this period. Gully distribution was linked to land use and landscape position, with higher gully density in cultivated areas and where slope gradients were gentle. The results of this study indicate that careful site-specific identification of factors controlling gully initiation and development is crucial for developing appropriate management strategies for these three sites and other areas with similar agro-ecologies in the Upper Blue Nile basin. The study found that the greatest increases in gully density occurred with transformations in cropland and other types of land, leading to an increase in gully erosion density of 12 m/ha. The number of gullies also increased between 1985 and

2023. Overall, the information provided suggests that gully length has generally increased over time within the watershed, with factors such as deforestation and cultivation activities potentially contributing to this trend.

I recommended from above the conclusion that

- Awareness creation for communities where lives are in watersheds and the consequences of devastation to forest resources
- Appropriate land management practices will be implemented to protect soil erosion by water, particularly in crop land use types.
- Gully is a cancer of land, so appropriate gully rehabilitation measures should be implemented for sustainable use of the land and to increase land value.
- To sustain land management practices and gully restoration measures, they should be multipurpose for watershed communities.

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