

ASSESSING THE IMPACTS OF LAND USE ON SOIL EROSION IN T/A CHIWALO, PHALOMBE DISTRICT

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ABSTRACT

Soil erosion is one of the most common types of environmental hazards which leads to land degradation and affects countries worldwide. Soil erosion hits developing countries the hardest as it reduces their economies especially for nations whose economies are dependent on agriculture, such as Malawi. In Malawi, erosion ranks as the number one environmental problem. The phenomenon occurs naturally under all climatic conditions however it is often exacerbated by human activities such as land use changes which are often influenced by social and economic factors. Land use which relates to land cover is one of the most important factors that affect soil erosion (Wijitkosum, 2012). In this study remote sensing techniques, ArcGIS and RUSLE model were used to estimate the soil loss rate and assess the land use change between 1998 and 2020, and to analyze the effects of land use and land cover changes on soil erosion in the area of T/A Chiwalo situated in Phalombe district. The study results revealed that the average soil loss rate in 1998 and 2020 were 29ton/ha/yr and 13ton/ha/yr respectively, the soil loss rates were categorized into 5 classes based on the severity of soil loss. In both 1998 and 2020 low erosion (0-4ton/ha/yr) dominated in the area accounting for about 97.42% and 97.45% respectively whilst very high erosion (17-29ton/ha/yr) account for 0.02% in 1998 whilst in 2020 it accounted for 0%. Within these years the land use had also changed, the area initially covered by forests and bare land in 1998 significantly decreased by 2020 whilst the settlement and agriculture increased. The analysis of land use changes revealed that the changes in terms of the pattern and area influenced the erosion risk in the 1998 and 2020 period. The areas having little or no land cover showed higher erosion risk as compared to areas that had larger land cover. Analysis of the spatial distribution of erosion and land use in the area is essential for an agriculture-dependent country like Malawi and can be applied for guiding the development of conservation plans and controlling erosion under different land cover conditions and aiding decision makers.

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ACRONYMS/ABBREVIATIONS

GIS: Geographic Information System

RUSLE: Revised Universal Soil Loss Equation

FAO: Food and Agriculture Organization

USLE: Universal Soil Loss Equation

MUSLE: Modified Universal Soil Loss Equation

AGNPS: Agricultural Nonpoint Source Pollution

ANSWERS: Areal Nonpoint Source Water Environment Response Simulation

EPIC: Erosion Productivity Impact Calculator

SWAT: Soil and Water Assessment Tool

ARS: Agricultural Research Service

SCS: Soil Conservation Service

USDA: U.S. Department of Agriculture

DEM: Digital Elevation Model

SRTM: Shuttle Radar Topography Mission

DSMW: Digital Soil Map of the World

TM: Thematic Mapper

RGB: Red, Green and Blue

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1. CHAPTER 1: GENERAL INTRODUCTION

1.1. Background

Throughout all the generations people have been relying on soil to produce food to sustain themselves. Soil is one of the most important resources in the world, it is considered the cornerstone of food security and development, however, soil is often overlooked and neglected triggering the problem of land degradation. Land degradation affects about one-third of the earth's land and it reduces the productive capacity of agricultural land by eroding topsoil and depleting nutrients (Ordinary, 2014). Since a large portion of the world's population relies on agriculture for their economy and sustainability, the depletion of soil results in enormous environmental, social and economic costs. The most common form of land degradation is soil erosion.

Worldwide, erosion results in sedimentation, flooding, fertility loss, increased costs attributing to the application of fertilizers, reduced fishery and reduced food security. Approximately 80% of the world's agricultural land suffers moderate to severe erosion, while 10% accounts for slight erosion (Aulakh & Sidhu, 2004). (Ordinary, 2014) defines soil erosion as the removal of a mass of soil from one part of the earth and its relocation to other parts of the earth, wind and water are the major drivers of erosion. A study that was conducted in India showed that out of the 328.7 m ha of India's geographical area about 175 m ha (53.3%) is subjected to soil erosion (Telkar & Pote, 2018), experts estimated that about 40,000 hectares of our land is permanently lost to cultivation and much larger area is rendered less productive every year due to wind and water erosion.

Soil erosion is a common phenomenon in Africa. As in the case of worldwide, water erosion is South Africa's most widespread soil degradation problem which affects approximately 70% of the land (Africa & Outlook, n.d.). A study that was conducted showed that about 25% of the population directly depend on agriculture which utilizes about 80% of the total surface area of the country (Access, n.d.). Thus, the increased soil losses have had significant impacts on food security and social welfare costs.

In Malawi, soil erosion ranks as the number one environmental problem followed by deforestation and water resources degradation (Asfaw et al., 2018). The most common form of erosion is water erosion where water acts as the main agent of erosion. A survey that was conducted by the Food and Agricultural Organization at the national level to assess the soil loss risk in 2014 showed that most of the districts in Malawi were exposed to high to moderate risk of erosion (Omuto & Vargas, 2019). The overall factors contributing to high exposure to erosion were land use/ cover changes, rainfall, topography and soil property factors (Omuto & Vargas, 2019). Phalombe district was one of the districts that were involved in the soil loss risk assessment and as of 2014, the mean district topsoil loss rate was 10.22ton/ha/yr. high soil loss occurred mostly in mountainous regions and the other factors for the soil loss were the reduced vegetation cover and soil vulnerability. The study revealed that the overall leading factor of soil loss in the area was the land cover, however, the relationship between land cover and soil erosion was not clearly analyzed, and the study focused more on assessing the soil loss rate in the area.

The problem of soil erosion exists all over the world and is a big problem especially for developing countries like Malawi. Soil erosion is a complex phenomenon and is assessed using various approaches, most countries worldwide have adapted to the use of erosion models of which can be used to estimate the spatial distribution of soil loss in an area. Many models are used but the widely accepted model is the Revised Universal Soil Loss Equation (RUSLE) model (Mwawasi, 2013), this model represents the impact of rainfall, soil, topography and land use on rill and interrill erosion (Thapa, 2020). The model also helps to identify areas where introducing soil conservation methods would have the most impact on reducing soil loss (Mwawasi, 2013). This research aims to estimate the rate of soil erosion in T/A Chiwalo, Phalombe district and analyze the effect of land use and land cover on soil erosion.

1.2. Problem Statement

Soil erosion is a process that occurs naturally under all climatic conditions and on all continents (Thine Omuto & Vargas, 2019), however, erosion is exacerbated by human activities through intensive agriculture, deforestation and unplanned land use. Land use and cover are one of the major factors that influence soil erosion and an increase in

population exerts more pressure on land resources for settlement, agriculture and fuel, this further aggravates soil erosion. Soil erosion reduces soil productivity by changing soil properties and particularly by destroying topsoil structure, reducing soil volume and water holding capacity, reducing infiltration, increasing run-off, and washing away plant nutrients (Mwawasi, 2013).

In Malawi, soil erosion is a major threat to agricultural development (Asfaw et al., 2018) and if soil loss rates are not monitored and sustainable soil conservation measures are not put in place this might have impacts on food security and the country's economy. The soil loss survey that was conducted in Malawi by FAO covered all of the 27 districts including Phalombe, however, the study was too general as it covered large areas and it also focused on assessing soil loss rather than the cause of the loss. Therefore, the study takes a closer look at an area in Phalombe district, particularly the area under T/A Chiwalo. The aim is to estimate the average soil loss and analyze the effects that land use has on the soil in T/A Chiwalo, Phalombe.

1.3. Research Objectives

1.3.1. Main Objective

This study aims at analyzing the impacts of land use changes on soil erosion in T/A Chiwalo, Phalombe.

1.3.2. Specific Objectives

The specific objectives include:

a. To estimate the soil loss rate in 1998 and 2020 in the area using the RUSLE model.
b. To analyze changes in land use between 1998 and 2020 in T/A Chiwalo.
c. To find the relationship between soil loss and land use.

1.4. Research Questions

a. What is the average soil loss rate in T/A Chiwalo?
b. How does the land use/ cover affect soil erosion?

1.5. Significance of the study

This study aims to assess the impacts of land use changes on soil erosion along with estimating the average annual rate of soil erosion for T/A Chiwalo using the RUSLE model. This research will help in guiding the development of conservation plans and controlling erosion under different land cover conditions and aid decision makers in identifying areas where introducing soil conservation will have the most impact on reducing erosion. Selecting effective soil erosion control measures requires an understanding of how site conditions such as land use affect erosion. The study will also contribute toward filling a gap on soil loss information in the area of T/A Chiwalo.

2. CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

Soil erosion is a serious problem affecting many parts of the world, it is mainly aided by two agents: water and wind. According to (Asfaw et al., 2018) soil erosion is the absolute loss of topsoil and nutrients carried away from the land by water or wind and transported to other surfaces. Similarly, Mahabaleshwara & Nagabhushan, (2014) defines erosion of soil as the process of detachment of soil from the soil surface and its transport by rainfall and runoff. In both cases, erosion involves the loss of top soils by either water or wind. Erosion by water accounts for about 56 % and wind erosion is responsible for about 28 % of the total erosion that occurs(Mahabaleshwara & Nagabhushan, 2014). The remaining 16% accounts for mass wasting processes and glaciers. This means that much of the erosion is accelerated by water erosion, water erosion could either be in the form of heavy rainfall or flooding. Despite soil erosion being fueled by wind and water it is further influenced by factors such as soil management, land-use/ cover management, topography and soil erodibility (Thine Omuto & Vargas, 2019). In a nutshell, erosion is influenced by rainfall, land use, topography and soil type.

2.2. Impact of Land Use on Erosion

Land use which relates to land cover is one of the most influential factors that affect erosion. Vegetation or plant cover reduces soil erosion, its effectiveness depending upon the height and continuity of canopy, density of ground cover and root density (Balasubramanian, 2017). Roots play an important role in reducing erosion rate by binding the soil mass to increase its resistance to flow. Generally, forests are most effective in reducing erosion because of their canopy; dense grass is equally effective. Activities such as deforestation, mining, agriculture expose soil on land surfaces directly to the rains. This unprotected soil could be easily removed from the land surfaces by the combined action of rain and the resulting flow. Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues.

(Nunes, 2011) conducted an investigation to assess soil erosion under different land use cover types in a marginal area of Portugal between 2005 and 2006. The study involved several field experiments which were used to determine the rate of runoff under different land use types and soil characteristics. Six land use types namely cereal crops, fallow land, shrubland, afforestated land and pasture land were selected and experiments were conducted to determine soil characteristics. Upon determination of soil characteristics, small plots were inserted into the soil, each plot was under different plant cover and moisture conditions. A rainfall simulator was used to evaluate the main hydrological and erosional characteristics of the soil under different land use types. The study revealed that the shrubland produced less surface runoff and therefore less erosion, on the other hand cereal cultivation and tree planting accelerated runoff and erosion due to soil tillage which loosens the soil and reduces anti-erodibility. The erosion in Portugal had increased when arable farming expanded into marginal areas over the decades. Vegetation protects the soil from eroding through various ways such as rainfall interception by the plant which has two main consequences; it reduces the erosive power of impacting raindrops and reduces the volume of water reaching the soil surface (Nunes, 2011). This study clearly showed the relationship between land use types and soil erosion.

Another similar study investigated the impact of land use changes on soil erosion, land use changes between the years 1995 and 2017 were analyzed and the result showed that there was a significant increase in farms and built up areas from 51.4% and 0.3% in 1995 to 67.6% and 1.5% in 2017 respectively. Whilst forest and grass/shrub areas had decreased from 22.2% and 26% in 1995 to 15.3% and 15.5% in 2017 respectively (Kogo, Kumar, & Coech, 2020). Within these years the erosion processes had also increased from 0.3t/ha/yr. to 0.5t/ha/yr., where the highest erosion rates were observed in cleared forest areas.

2.3. Soil Erosion Models

Soil erosion is a complex phenomenon that is globally widespread causing substantial damage to the landscape (Koirala et al., 2019), the process is influenced by several factors such as rainfall, topography, soil properties and land cover. With the increasing pressure on natural resources and landscape, there has been an increasing need to predict the

consequences of any changes to the environment (Onuigbo et al., 2017). This led to the development of soil erosion models. Modelling provides a quantitative and consistent approach to estimate soil erosion and sediment yield under a wide range of conditions (Onuigbo et al., 2017). Soil erosion models can be divided into two main groups: empirical models and physically based models (Mwawasi, 2013). Each of the models that have been developed consider slope length and steepness, rainfall, vegetative cover, erosion control practices and soil properties as parameters that influence erosion. The most notable empirical model that was developed was the Universal Soil Loss Equation (USLE) (Zelenakova et al., 2019), a large number of other models were based on the USLE model for example the Revised Universal Soil Loss Equation(RUSLE) and the Modified Universal Soil Loss Equation(MUSLE) (Priess et al., n.d.) other models include Agricultural Nonpoint Source Pollution (AGNPS), Areal Nonpoint Source Water sheets Environment Response Simulation (ANSWERS), the Erosion Productivity Impact Calculator (EPIC) and Soil and Water Assessment Tool (SWAT) (Mwawasi, 2013). Each model differs in terms of its applications, requirements, intended use and output information. The USLE model seemed to meet the needs of researchers better than any other model so it is used throughout the world (Onuigbo et al., 2017). The modified version of the USLE is the Revised Universal Soil Loss Equation model (RUSLE).

2.4. RUSLE Model

The RUSLE model is recognized as a standard method to calculate the average risk of erosion (Priess et al., n.d.). It is a modified version of the USLE. The USLE was developed by W. H. Wischmeier, D. D. Smith, and others with the U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Purdue University in the late 1950s (Renard et al., 1991). It was based on data from more than 10,000 test plots throughout the East of the United States in 20 years (Mwawasi, 2013). The Universal Soil Loss Equation model (USLE) became the most widely used and accepted model to make long term assessments of soil erosion. The USLE model is represented by **equation (1)** (Ganasri & Ramesh, 2016):

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where,

A = Average annual computed soil loss (mg/ha/year)

R = Rainfall-runoff erositivity factor (mm/ha/year)

K = Soil erodibility factor (mg/ha/year)

LS = Slope length and steepness factor (dimensionless)

C = Cover management factor (dimensionless, ranges from 0-1)

P = Supporting practices factor (dimensionless, ranges from 0-1)

With additional research, experiments, data and resources becoming available, research scientists continued to improve the USLE which led to the RUSLE (Zelenakova et al., 2019). The RUSLE uses the same equation but there have been improvements in determining the parameters.

3. CHAPTER THREE: METHODOLOGY

This chapter will explain the research methodology that was used in this study. This encompasses the study area, research design, data collection and data analysis.

3.1. Study Area

Phalombe is located in the Southern part of Malawi and it is bordered by Mulanje in the south and west, Zomba in the north and also shares an international boundary with the Republic of Mozambique in the east. It lies at the latitude -15.8064 and longitude 35.6507. Phalombe is made up of six main Traditional Authorities namely Jenala, Mkhumba, Kaduya, Nazombe, Chiwalo and Nkhulambe. The focus of this study is the area under Traditional Authority Chiwalo and is shown in **Figure 1**.

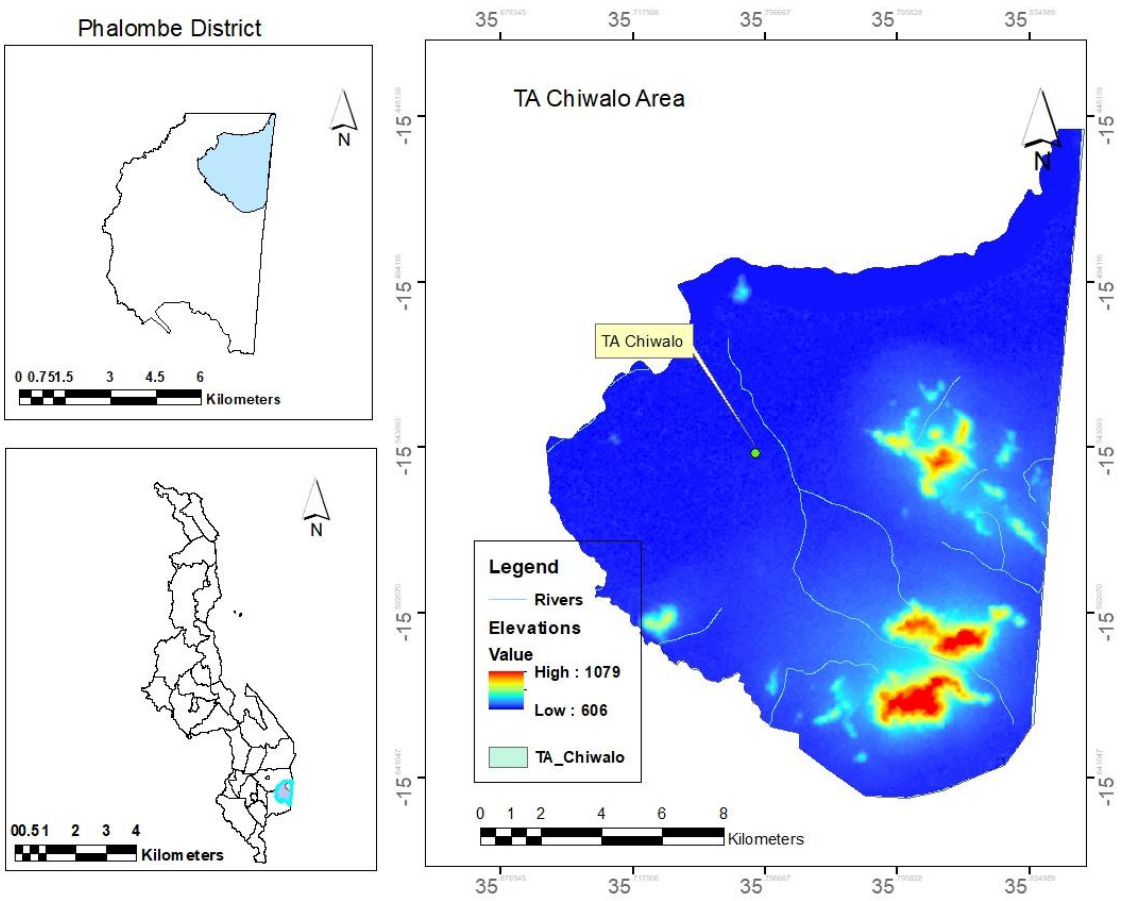


Figure 1: Map showing the area of interest

3.2. Research Design

In order to achieve the objectives of the study, a design was employed which involved quantitative data collection and analysis methods. The study mainly involved the collection of datasets such as Landsat 8 and Landsat 5 images, Digital Elevation Models (DEM), Rainfall data and Soil Maps which were used to estimate RUSLE parameters using ArcGIS 10.8. The RUSLE model is used to produce a soil loss map and determine the impact of land use on soil erosion. The study also involved some literature review to determine certain parameters that have weights assigned to them.

3.3. Data Collection

The spatial datasets used in this research together with their corresponding RUSLE factors used to estimate soil loss in the area are shown in

Datasets	Data Source	Description	RUSLE Parameter
Digital Elevation Model(DEM)	https://earthexplorer.usgs.gov/	SRTM DEM	LS and P
Satellite Image	https://earthexplorer.usgs.gov/	Landsat 8 image (year 2020) and Landsat 5 image (1998)	C
Soil Data	www.fao.org/geonetwork	Digital Soil Map of the World (DSMW) produced by the Food and Agriculture Organization (FAO)	K

Rainfall Data	Department of Climate Change and Meteorological Services	Rainfall Data for a period of 10 years (2010 -2019) from 5 rain gauge stations	R

Table 1.

Datasets	Data Source	Description	RUSLE Parameter
Digital Elevation Model(DEM)	https://earthexplorer.usgs.gov/	SRTM DEM	LS and P

Satellite Image	https://earthexplorer.usgs.gov/	Landsat 8 image (year 2020) and Landsat 5 image (1998)	C
Soil Data	www.fao.org/geonetwork	Digital Soil Map of the World (DSMW) produced by the Food and Agriculture Organization (FAO)	K
Rainfall Data	Department of Climate Change and Meteorological Services	Rainfall Data for a period of 10 years (2010 -2019) from 5 rain gauge stations	R

Table 1: Description of Datasets used

3.4. Data Analysis

In this study, the RUSLE model is used and is integrated with GIS techniques for estimating the erosion risk in T/A Chiwalo area. Application of the model considers slope length and slope steepness (LS), land management (C), support practices (P), soil erodibility (K) and rainfall erositivity (R) and is used to calculate the mean soil loss using equation (1). **Figure 2** illustrates the overall methodology used to determine the soil loss rate in the study. Upon collection of each data set, the study area was extracted.

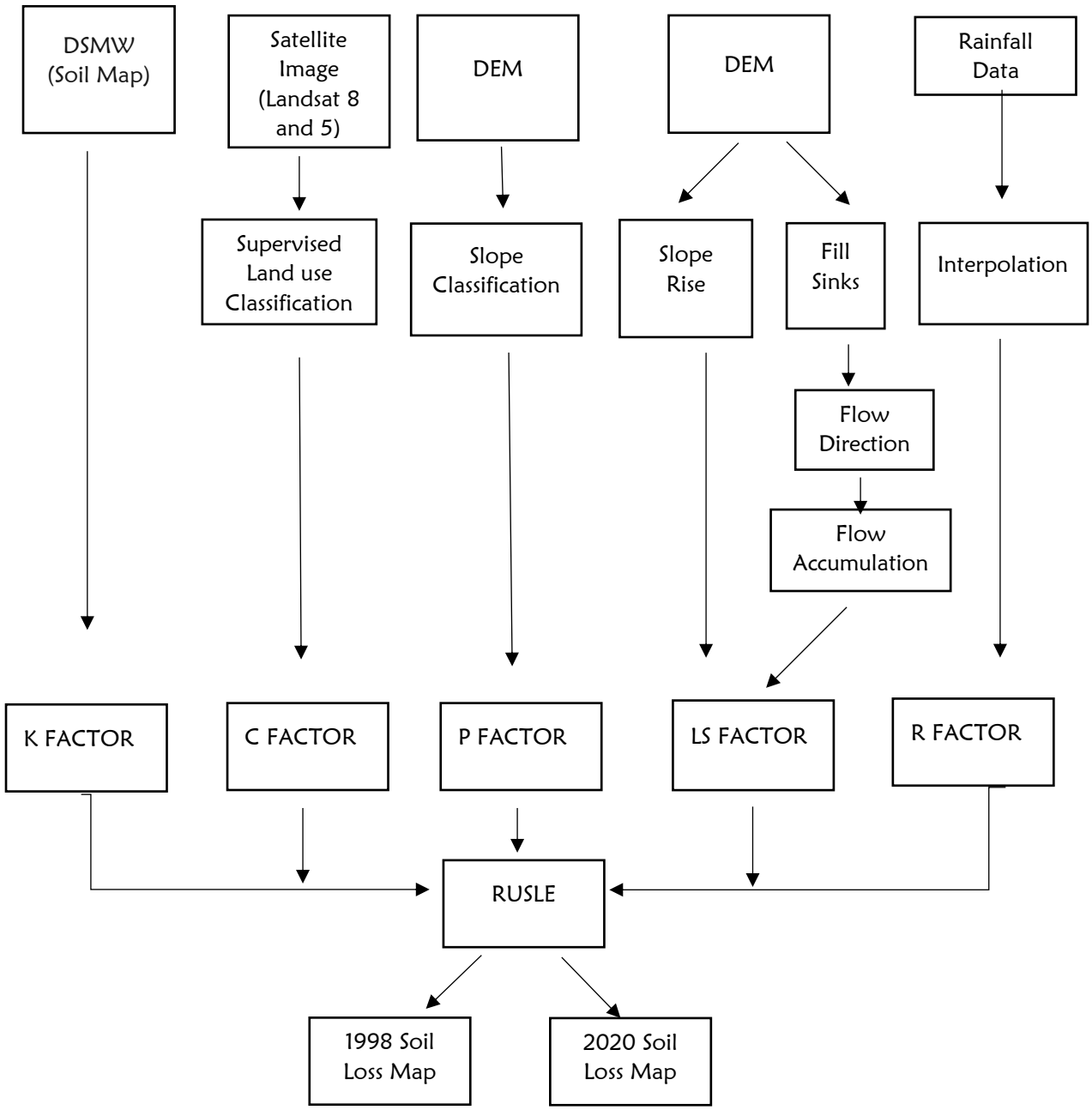


Figure 2: Methodology for estimating soil loss

3.4.1. RUSLE Parameter Calculation

3.4.1.1. Soil Erodibility Factor (K)

The soil Erodibility factor estimates the susceptibility of soil to detachment and the transportability of the sediment by rainfall and runoff. Soil erodibility ranges in value from 0.02 for the least erodible to 0.64 for the most erodible (USDA, 1990).

Soils with higher erodibility are more susceptible to soil erosion as compared to those with lower erodibility. The K factor map was generated from the Digital Soil Map of the World (DSMW) which was produced by FAO, the DSMW shows the soil distribution as well as the soil properties. The soil erodibility was estimated based on soil textures and organic content of the soil and since soil erosion affects the top layer of soil, only the properties of the top layer were taken into account. The soil map for the area of interest was firstly extracted in ArcMap, the resulting soil map showed that TA Chiwalo is dominated by one soil type namely Fluvisols (Je) and the K factor for each soil type was estimated in Microsoft Excel using the equations below (Thapa, 2020).

$$K = Fcsand \times Fsi - cl \times Forgc \times Fhisand \times 0.1317 \quad (2)$$

Where,

$$Fcsand = \left[0.2 + 0.3\, exp\left[-0.256 \times SAN\left[1 - \frac{SIL}{100}\right]\right]\right] \quad (3)$$

$$Fsi - cl = \left[\frac{SIL}{CLA + SIL}\right]^{0.3} \quad (4)$$

$$Forgc = \left[1.0 - \frac{0.25C}{C + exp(3.72 - 2.95C)}\right] \quad (5)$$

$$Fhisand = \left[1.0 - \frac{0.70 \times SN1}{SN1 + exp(-5.51 + 22.9SN1)}\right] \quad (6)$$

Where,

SAN, SIL and CLA = Sand content, Silt content and Clay content respectively

C= Organic carbon content

$$SN1 = \frac{1 - Sand\ content}{100}$$

3.4.1.2. Cover Factor (C)

The C factor is one of the most influential factors of soil erosion, especially in areas with a high percentage of bare land, unlike well forested areas. The C factor reflects the soil loss variations under different land use and cover conditions, land cover increases interception ratio and infiltration and reduces rainfall energy. Henceforth areas that are dominated by forested land have lower soil erosion rates. The c factor in this study was generated from images captured by Landsat 5 and Landsat 8 from the year 2020 which were then evaluated to create land use maps. In order to generate the cover factor map, T/A Chiwalo area was firstly extracted and then classified into land use types using supervised classification in ArcMap. The classified images showed 5 land use classes in the area, namely agricultural area, bare land, forest, settlement and water bodies. For each land use class, a c factor weighted value was assigned to it as shown in **Table 2**. The C Factor values were taken from existing literature sources (Chatterjee et al., 2013). The C factor is a non-dimensional number, ranging from zero to one, where values closer to one specify barren or bare land and values closer to zero specifying well protected land cover.

Table 2: Land Use Types and their C Factor values

Land Use Type	C Factor Value
Agriculture Area	0.4
Bare Land	1
Forest	0.004

Settlement	0.002
Water Bodies	0

3.4.1.3. Support Practice Factor (P)

This factor reflects the impact of erosion practices applied in an area on the soil loss rates. There are three main methods of erosion control namely contouring, strip cropping and terracing. This study applied the contouring method in the area, this method was chosen because it was a more familiar practice in the area. The P factor map was generated from the digital elevation model of the area where areas with certain slopes were assigned a specific p factor value which determines the impact of contouring on different slope steepness. The DEM for the area was extracted and then a slope map was generated from which the P factor map was made. The values of the p factor range from zero to one where values closer to zero represent good erosion control whilst values closer to one represent poor erosion control. The values were derived from existing literature, **Table 3** shows the p factor values for contouring on different slopes(Koirala et al., 2019).

Table 3 : P Factor Values

Slope Classification	P Factor (Contouring)
0-7	0.55
7-11.3	0.60
11.3-17.6	0.8

17.6-28.7	0.95
>28.7	1

3.4.1.4. Topographic Factor (LS)

The topographical factor constitutes two sub-factors which are slope length (L) and slope length steepness (S) both of which are determined using the Digital Elevation Model (DEM) using ArcMap. Slope length represents the effect of the length of the slope on erosion and is defined as the distance from the point of origin of the overland flow to the point where the slope decreases to the extent that deposition begins (Thapa, 2020), it determines the transport capacity of a slope. Longer slopes can transport more runoff as compared to shorter slopes. Therefore, soil erosion loss per unit area increases as slope length increases.

Slope steepness represents the effect of the steepness of a slope on erosion. Steeper slopes have higher gravity acting upon them thereby influencing the flow of runoff. Therefore, soil erosion per unit area increases as slope steepness increases. The DEM for the area of interest was firstly extracted then a slope map for the area was generated and fill sinks map was also generated from the DEM. Using the fill sinks map, a flow direction map was generated and finally, a flow accumulation map was then generated from the flow direction map. The topographic factor was calculated using equation (7) (Dahal, 2020).

$$LS = \left[FA \times \left[\frac{Cell\ size}{22.1}\right]\right]^{0.6} \times sin\left[\frac{Slope\ \times 0.01745}{0.09}\right]^{1.3} \quad (7)$$

Where,

LS = Slope Length and Steepness

FA = Flow Accumulation

3.4.1.5. Rainfall Erositivity (R)

The rainfall erositivity factor quantifies the effect of raindrop impact on soil particles and is expressed as mm ha^{-1} h^{-1} $year^{-1}$. Rainfall erositivtiy requires continuous precipitation data from different rainfall stations that enable its calculation thus 10 years rainfall data from 5 different rainfall stations were used in the study. **Table 4** shows the rainfall stations from which the data was taken and their respective coordinates. Upon collection of the rainfall data, Microsoft Excel was used to calculate the mean annual rainfall and then the rainfall erositivity was calculated using equation (8). In order to produce an erositivity map, the table from Microsoft excel was exported to ArcMap where the erositivity was interpolated across the area.

Table 4: Location of Gauging stations used in the study

Rain Stations	Coordinates	
	Longitude	Latitude
Mpinda	35	-15.36
Naminjiwa	35.62	-15.77
Tamani	35.53	-15.58
Namasoko	35.6	-15.68
Mimosa	36	-16

$$R = 38.5 + 0.35 \times M \quad (8)$$

Where,

R= Rainfall Erositivity

M= Mean Annual Precipitation

3.4.2. Land Use/Cover Change Analysis

The study made use of satellite images captured by Landsat 5 and Landsat 8 TM in 1998 and 2020 respectively. Bands 1 to 7 were used for image analysis where they were combined into a single RGB image for each Landsat data set (1998 and 2020). Upon composition of the bands, the images were then classified using supervised classification in ArcGIS. The two images were then combined using intersect tool to analyze which land use areas overlap and how land use has changed from 1998 to 2020.

4. CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter includes the results obtained from the study include factor maps, potential soil loss maps and land use change analysis.

4.1. Factor maps

The RUSLE model used in the study in T/A Chiwalo showed that the soil erodibility factor (K) ranges between 0 and 0.130322 (**Figure *3*Figure 3**), where 0 accounts for the water bodies and 0.130322 accounts for Fluvisol soil type. The cover management factor (C) ranges between 0.102674 and 0.489421 (**Figure 4**), the support practice (P) ranges between 0.55 and 1 (**Figure 5**). The topographic factor (LS) ranges between 0 and 13.6144 (**Figure 6**). The Rainfall erodibility factor (R) ranges between 60.7181 and 61.6529 mm/ha/h/yr.

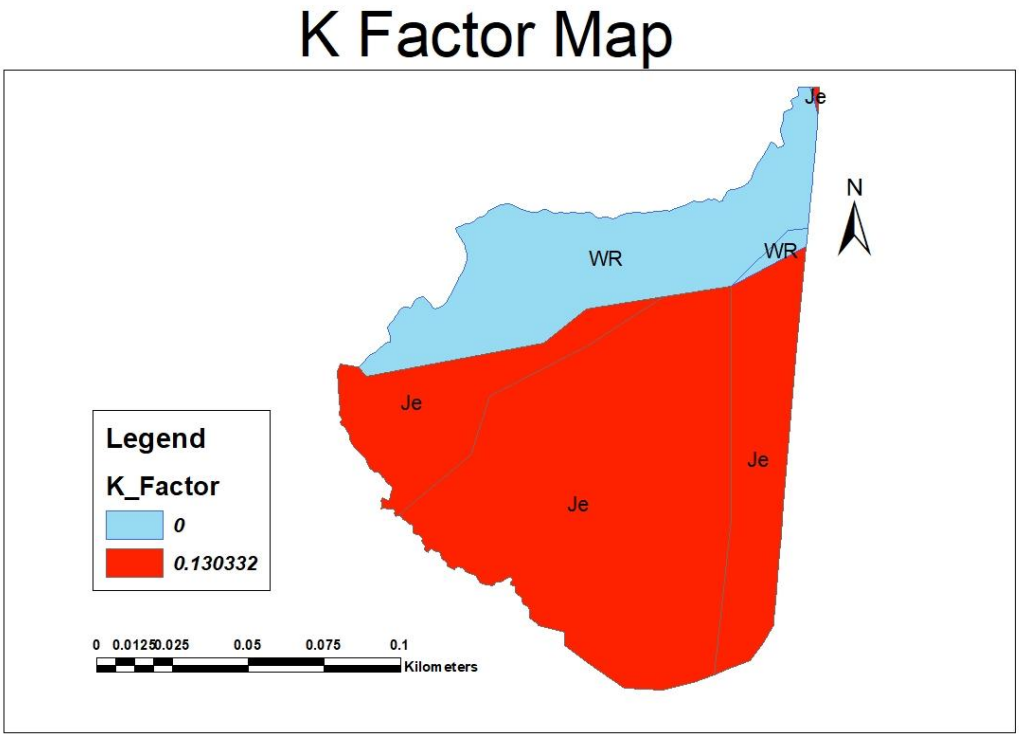


Figure 3: Soil erodibility (K) Map

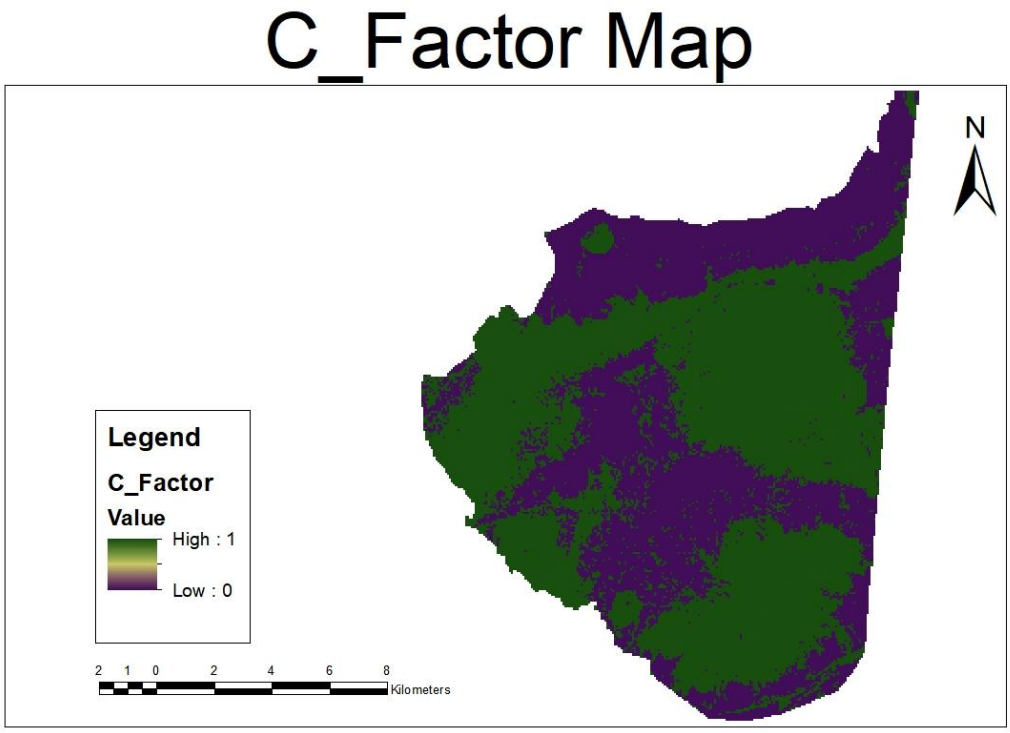


Figure 4: Cover management (C) Map

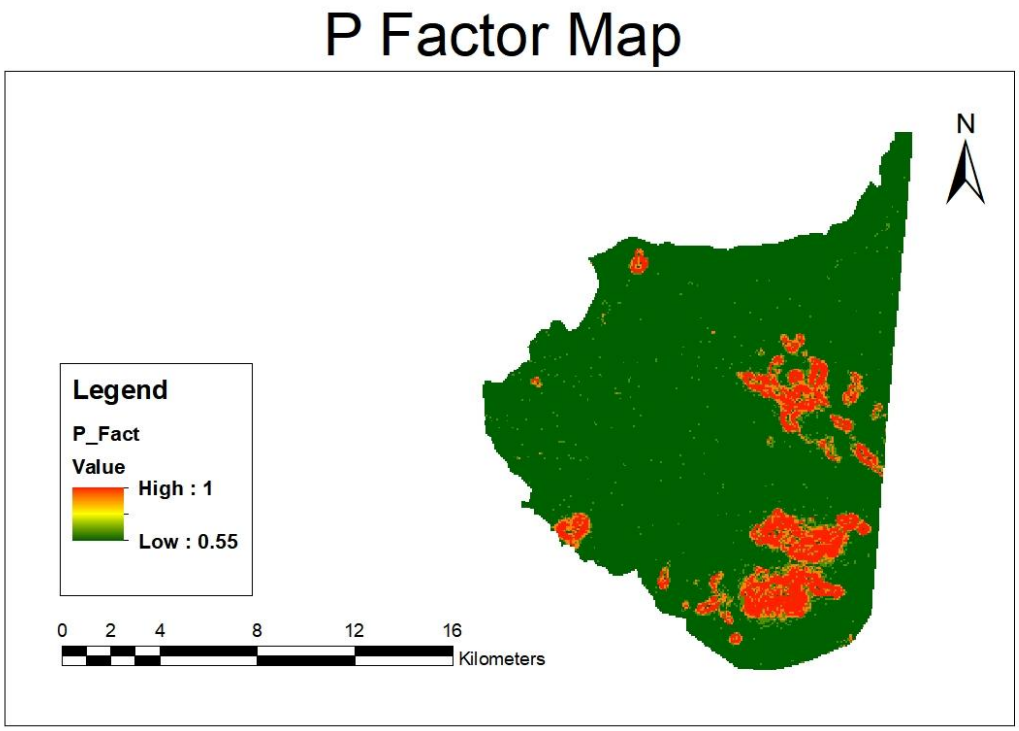


Figure 5: Support practice (P) Map

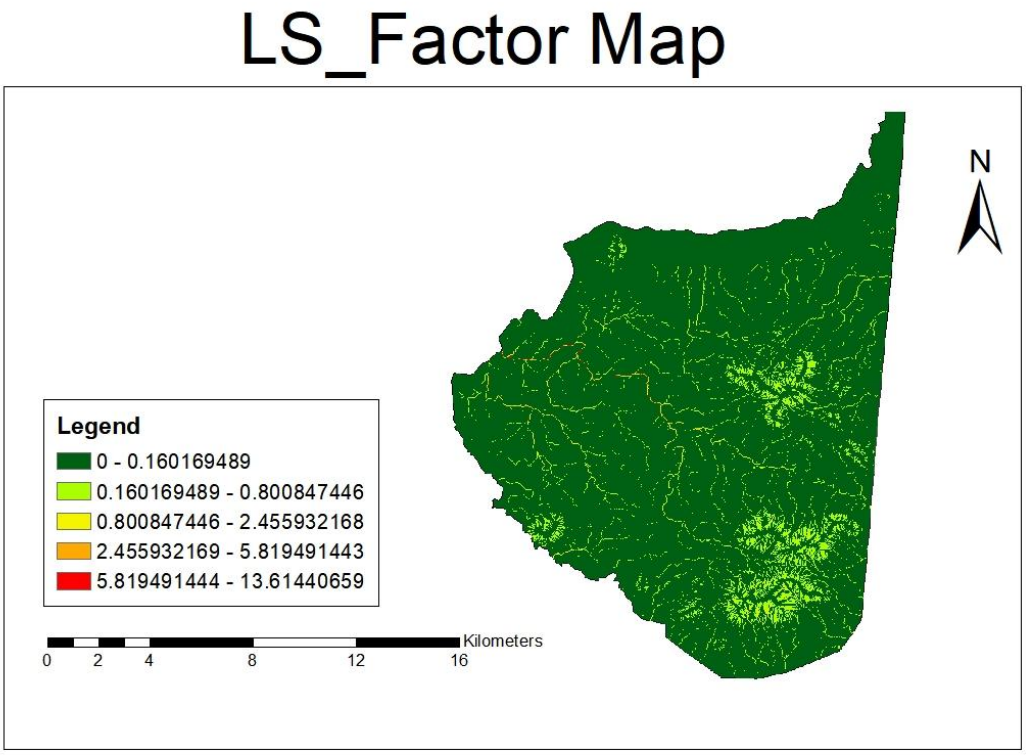


Figure 6: Slope length and steepness (LS) Map

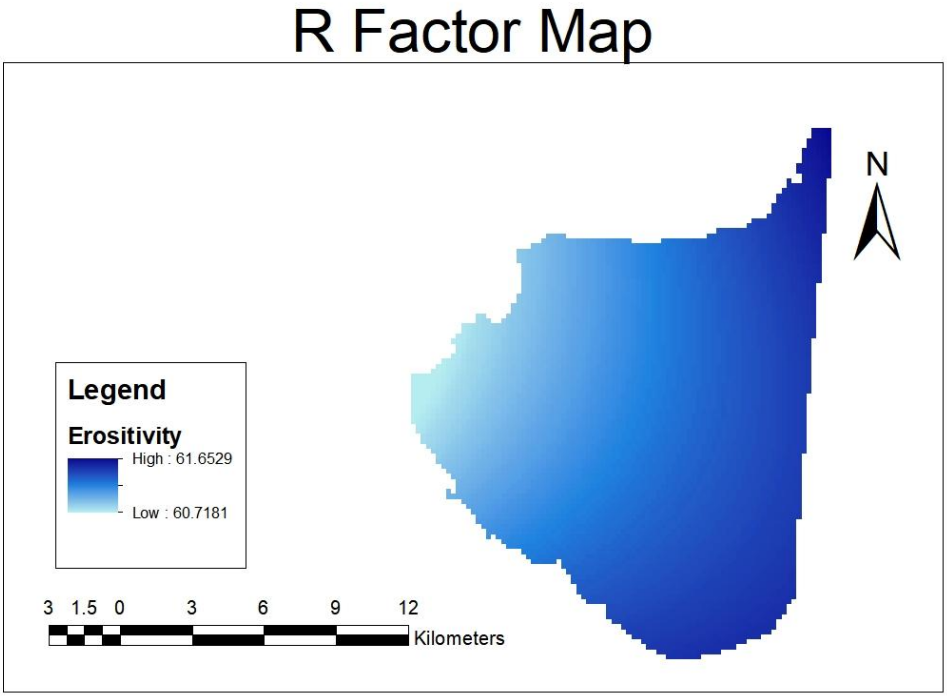
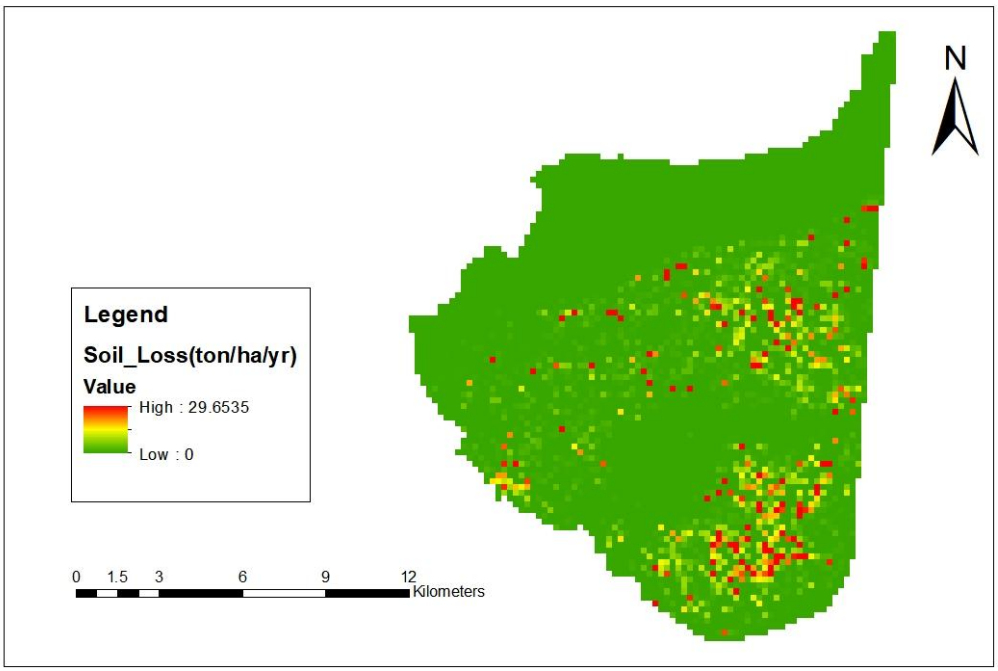


Figure 7: Rainfall erosivity (R) Map

4.2. Potential Soil Loss Rates

The potential erosion map of T/A Chiwalo was generated by multiplying the factor maps in ArcGIS using the raster calculator as shown in equation (1). The figures below show the average soil loss rates for 1998 and 2020 in the area which were 29.65ton/ha/yr and 13.412ton/ha/yr respectively.

(a)



(b)

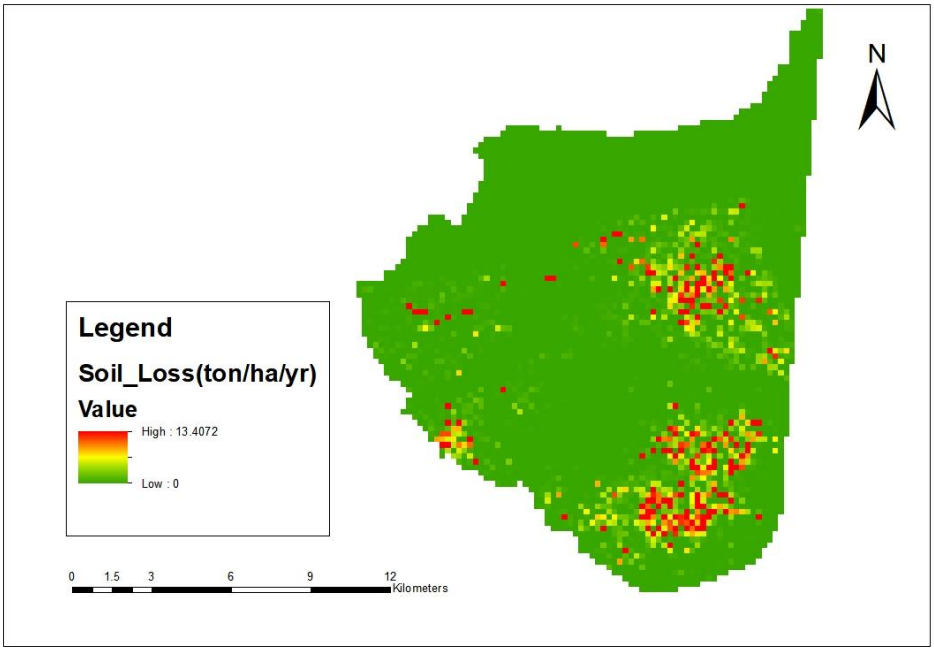


Figure 8: Soil Loss Rates (a) In 1998, (b) In 2020

The soil loss rates were categorized into 5 classes based on the severity of soil loss. The table below shows the spatial distribution of soil loss rates in both 1998 and 2020.

Soil Loss Rate (ton/ha/yr)	Category	Area_1998(ha)	Area_2020(ha)
0-4	Slight Erosion	21610.44	21617.54
5-8	Low Erosion	35.38	31.43
9-12	Moderate Erosion	2.69	5.3
13-16	High Erosion	5.57	4.2
17-29	Very High Erosion	4.20	0

The table shows that much of the area in both 1998 and 2020 was exposed to slight erosion (0-4ton/ha/yr). Between 1998 and 2020, the area in categories low, high and very high erosion had significantly decreased by 11%, 25.6% and 100% whilst the

area in categories slight (ton/ha/yr) and moderate (9-12ton/ha/yr) erosion had significantly increased by 0.03% and 97.02% respectively.

4.3. Land use/cover changes

The application of remote sensing and ArcGIS for interpreting the satellite images that were taken by Landsat 5 and Landsat 8 in 1998 and 2020 showed the land use could be classified into 5 types of classes namely agricultural area, forested area, settlement, bare land and water bodies. **Figure 9** shows the land use distribution in the years 1998 and 2020. The land use study between the two time periods; 1998 and 2020 revealed that the largest area of T/A Chiwalo was the bare land, in 1998 bare land accounted for 47.86% of the total area whilst in 2020, bare land accounted for 30.55% of the total area.

(a) (b)

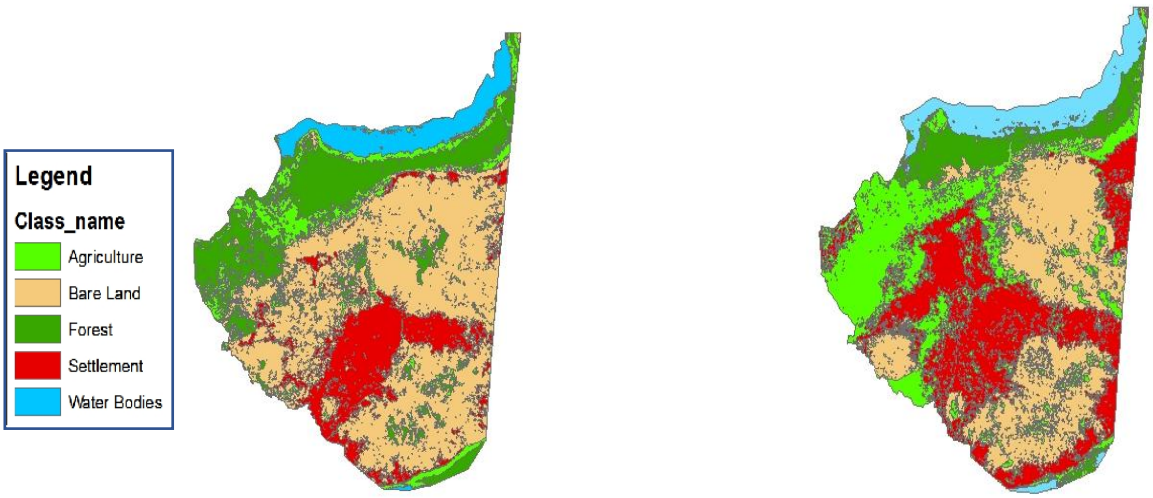


Figure 9: Land Use (a) in 1998, (b) in 2020

The table below shows the area occupied by the land use types in 1998 and 2020 respectively.

Table 5: Land Use of T/A Chiwalo in 1998 and 2020

Land Use	Area_1998(ha)	Area_2020(ha)
Agriculture	2215.46	5776.62
Bare Land	10615.7	6776.7
Forest	4357.41	1710.51
Settlement	3474.83	6132.2
Water Bodies	1518.73	1786.1
Total Area	22182.13	

From the table, it shows that area occupied by bare land and forest in 1998 had significantly decreased and the area occupied by settlement, agriculture and water bodies had significantly increased. In the year 1998 Phalombe had a total population of 231,990 and according to the most recent census by, 2018 the population was 429,450 and the projected population for 2020 was 453,359(Office, 2018). This shows that the population in Phalombe has increased within the years. The increase in population in the area influenced more people to settle in the bare lands thus explaining the reduction in bare land and expansion of settlement area. With the increase in population, people started to cultivate more in the area hence the agricultural area increased as well, common crops grown in the area are sorghum, maize, cassava, sweet potatoes and pigeon peas (FEWS NET, 2019). The growing population in the area also increased the demand for resources such as charcoal and firewood leading to increased deforestation. According to (Phiri, 2021) deforestation is a common phenomenon in Phalombe district, about 81.7% of the rural majority uses firewood. This clearly explains the decline in forested area. The increase in water bodies attributes to the continuous flooding which leaves behind water in dambo lands that increase the volume of the water bodies in the area.

Using the intersect tool, the land use map of 1998 and 2020 were combined to detect the spatial changes of land use. The results on the spatial changes are as shown in

Table 6: Spatial Changes in land use from 1998 to 2020

Area Change (ha)					
	2020				
	Agriculture	Bare Land	Forest	Settlement	Water Bodies
1998					
Agriculture	1248.79	187.68	344.68	229.15	203.93
Bare Land	2083.17	5727.04	0	2801.33	0
Forest	2071.68	536.50	1297.66	313.92	132.57
Settlement	364.80	324.37	0	2783.99	0
Water Bodies	3.99	0	67.19	0	1446.10

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1998					
Agriculture	1248.79	187.68	344.68	229.15	203.93
Bare Land	2083.17	5727.04	0	2801.33	0
Forest	2071.68	536.50	1297.66	313.92	132.57

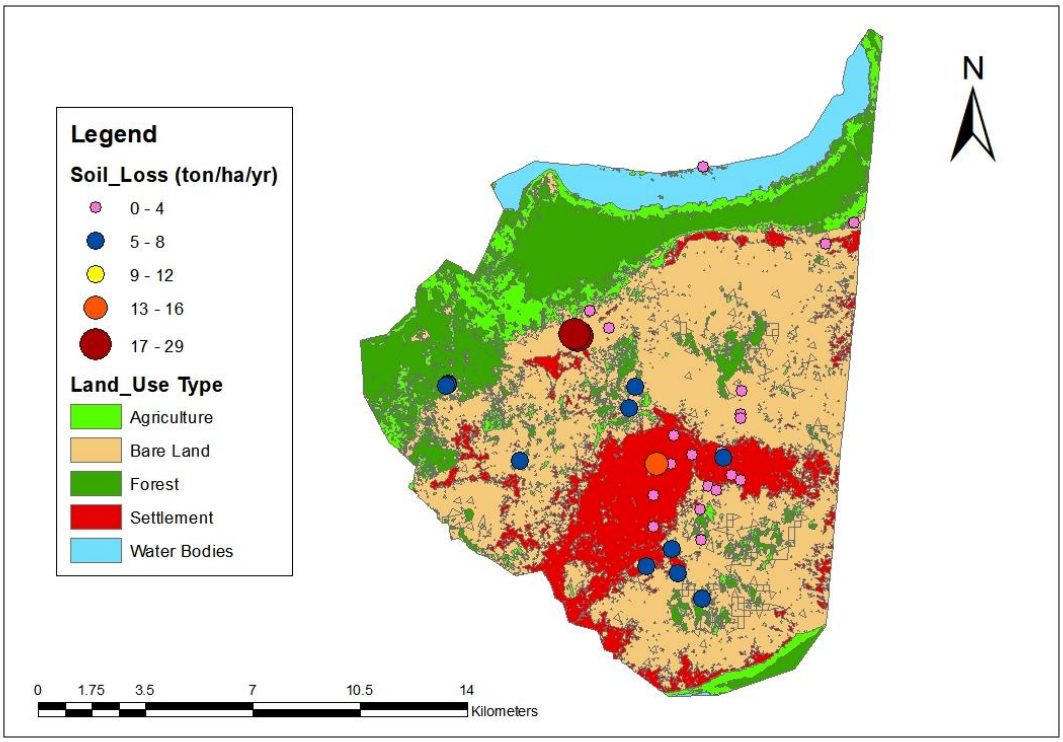
Settlement	364.80	324.37	0	2783.99	0
Water Bodies	3.99	0	67.19	0	1446.10

The results revealed that 8.47%, 15.56%, 10.35%, 9.21% of the agriculture area in 1998 changed to bare land, forest area, settlement and water bodies respectively in 2020 with about 56.33% remaining as agricultural land. Furthermore, 19.62% and 26.38% of the bare land in 1998 had changed to agricultural area and settlement land respectively in 2020 with about 53.95% remaining as bare land. As for the forest area, about 29.78% had remained as forest area whilst 47.54%, 12.31%, 7.2% and 3.04% changed to agriculture, bare land, settlement and water bodies respectively. In addition, 10.49% and 9.33% of the settlement land changed to agricultural area and bare land respectively whilst 80.12% remained settlement land. The results also showed that about 0.26% and 4.42% of the water bodies had changed to agricultural area and forest respectively whilst 95.22% of the water had remained as water bodies.

4.4. Impacts of Land use changes on soil erosion

The results showed that about 97.42% of the area was in the category of slight erosion (0-4ton/ha/yr) in 1998. In 2020, 97.45% of the area was exposed to slight erosion. This shows that in both 1998 and 2020 much of the area was exposed to slight erosion with only 0.02% exposed to very high erosion rates (17-29ton/ha/yr) in 1998 where as in 2020, 0% of the area was exposed to very high erosion rate. Figures below show the distribution of soil loss in the area in soil loss across different land use types.

(a)


Legend
Soil_Loss (ton/ha/yr)
0 - 4
5 - 8
9 - 12
13 - 16
17 - 29
Land_Use Type
Agriculture
Bare Land
Forest
Settlement
Water Bodies
N
0
1.75
3.5
7
10.5
14
Kilometers

(b)

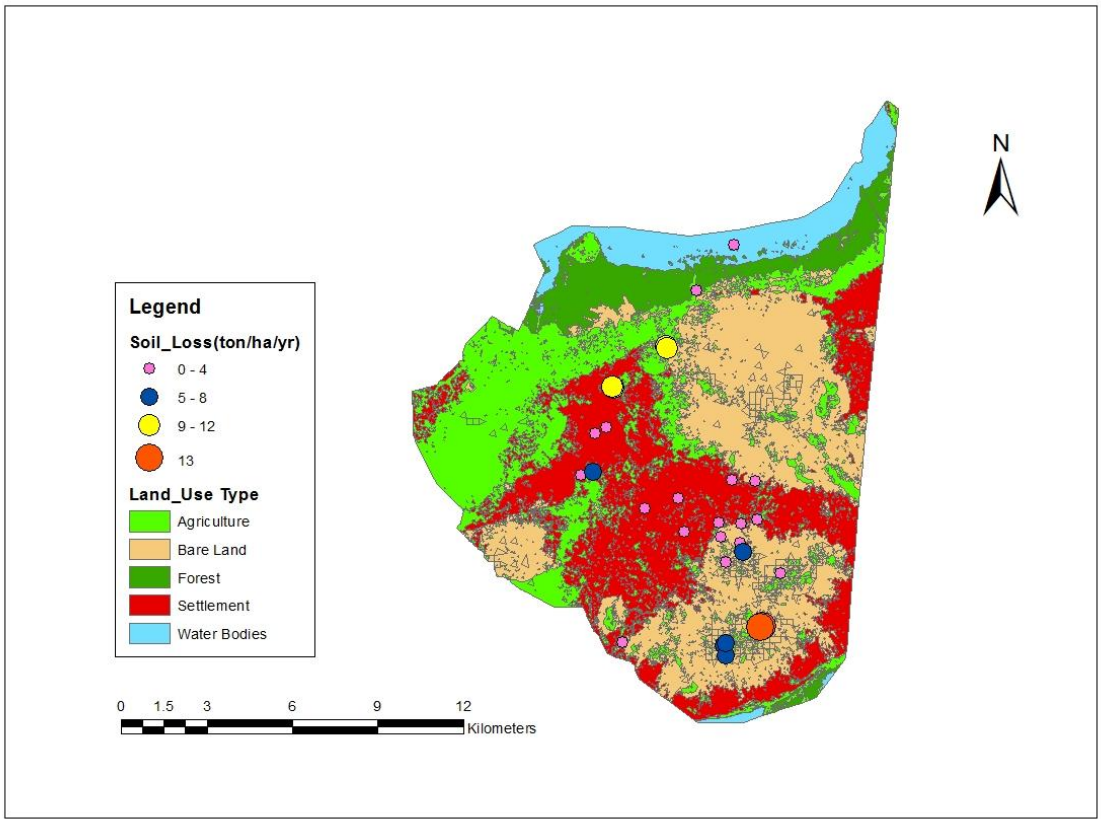


Figure 10: Distribution of soil loss across land use types (a) in 1998, (b) in 2020

It can be concluded that the soil loss increased in areas where land cover decreased for example the forested area in 1998 was not exposed to erosion but when it changed to agriculture and bare land in 2020, the rate of soil loss started to increase. Trees in forested areas reduce the rate of erosion by protecting the soil from the impact of the rain and increasing infiltration thereby reducing runoff, tree roots also help in binding soil particles reducing detachment of soil particles. This explains why forests showed low erosion rates in both 1998 and 2020. The area covered by natural vegetation in 1998 was gradually replaced by agriculture fields and by 2020 the agriculture field replaced 47.54% of the total forest area. When agriculture fields replace natural vegetation, the top soil is exposed and the constant manipulation of the land reduces the soil cohesion leaving the soil loose and prone to erosion. Crops grown in the area such as maize grow in rainy seasons, so during dry seasons, the land is left bare making it easy for the soil to be eroded. Apart from that, unsustainable agricultural practices such as slash and burn agriculture leave the

land open for soil erosion. The expansion of agriculture in 2020 caused soil loss rates to significantly increase in the area where the soil loss rates were initially low. In both 1998 and 2020, the highest erosion rates were attributed to the bare lands this is because bare lands have low infiltration and the soil is often compacted thereby increasing runoff rates thus increasing erosion. However, the bare land between 1998 and 2020 had significantly decreased, this explains why the average soil loss decreased from 29.65ton/ha/yr to 13.41ton/ha/yr. The settlement area had significantly increased in 2020 consequently increasing the soil loss in the area, this attributes to the construction activities that disrupt soil cohesion thereby making the soils prone to erosion. Water bodies were excluded from the analysis because they do not have any effect on erosion since runoff is not possible in water but on actual land.

The relationship between soil loss and land use was further analyzed in terms of area. **Figure *11*: Area under soil loss for each land use typeFigure 11** below represents the area under soil loss for each land use type in both 1998 and 2020.

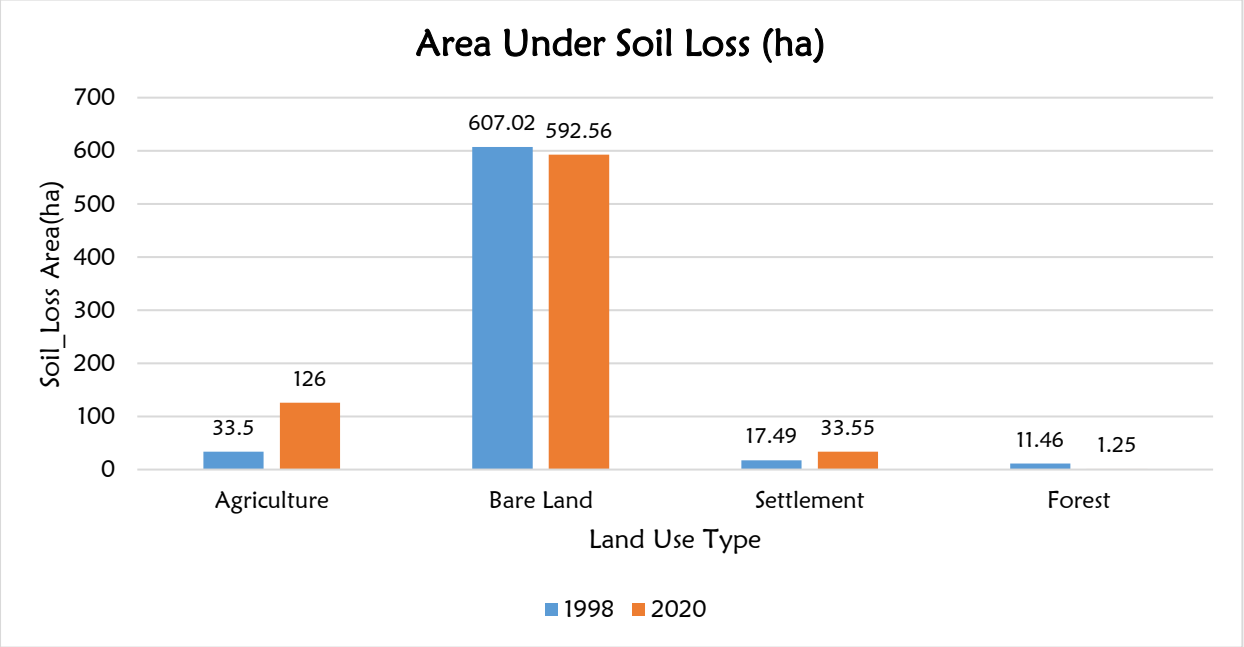


Figure 11: Area under soil loss for each land use type

In 1998, bare land occupied 10615.7ha (**Table 5**) of the total area and about 607.02ha was exposed to erosion and in 2020, the bare land decreased to 6776.7ha and about 592.56ha of the area was exposed to erosion. In 1998, forest area was

the second largest land use type covering 4357.41ha of the total area, however only 11.46ha of the area was exposed to soil loss and in 2020, forest declined to 1710.51ha, more than half the initial, and the total forest area under soil loss was only 1.27ha. For the settlement area, it occupied 3474.83ha of the total area in 1998 and by 2020 it increased to about 6132.2ha, the area under soil loss also increased from 17.49ha to 33.55ha within this period. In 1998 the total agricultural land was 2215.46ha and about 33.5ha of the land was exposed to soil loss, by 2020 the land expanded occupying 5776.62ha of the total area and about 126ha of the land was exposed to soil loss. In both 1998 and 2020 bare land covers most of the area under soil loss and despite decreasing by 36.16% from the year 1998 to 2020 in total bare land area, the area under soil loss only decreased by 2.47% meaning that bare land is highly prone to erosion. This attributes to the low infiltration and high runoff rates on the bare land which in turn increases the surface area for soil loss. Between 1998 and 2020 agriculture increased by more than half the initial area occupied in 1998, the increase in agricultural land led to the drastic increase of area under soil loss extending to areas that were initially forest area but had changed to agriculture fields. This shows that agricultural land offers a suitable environment for erosion processes. Although settlement covered a larger area than agriculture in both 1998 and 2020, agricultural land still accounted for the higher soil loss area, this proves that agricultural land has a higher influence on erosion as compared to settlement land. Furthermore, agricultural land covered less area as compared to forested land in 1998 however, more of the agricultural area was exposed to erosion as compared to the forest land. Additionally bare land and settlement land both occupied about 6000ha of the total area in 2020 however, the bare land still accounted for a higher soil loss area than the settlement land.

5. CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

The average soil loss rates of T/A Chiwalo in 1998 and 2020 were approximately 29.65 ton/ha/yr and 13.41ton/ha/yr respectively. The soil loss had significantly decreased by approximately 16.24ton/ha/yr. Within these years the land use types in terms of pattern and area had also significantly changed. The forest area in 1998 had significantly decreased by 2020 whilst the agriculture area, bare land and settlement had significantly increased. Forest areas showed little or no soil loss whilst bare land accounted for the most soil loss in the area followed by agriculture and settlement. It can be concluded that areas with little land cover showed higher erosion risk as compared to areas with more land cover. The results showed that bare land and agriculture have the highest influences on soil erosion as they had more areas exposed to erosion as compared to other land use types. Therefore, in an effort to reduce erosion, land cover management and soil conservation measures should be implemented in the bare lands and agricultural land. The results produce a spatial distribution of erosion over T/A Chiwalo and the estimation is essential for an agriculture-dependent country like Malawi and can be applied for guiding the development of conservation plans and controlling erosion under different land cover conditions and aiding decision makers. Further studies should be undertaken to monitor the effectiveness of the conservation measures that have been put in place.

This research was able to meet the research objective in analyzing the impact of land use on erosion and estimating soil loss in 1998 and 2020. However, the results can be improved by considering the following:

- More accurate land classification by incorporating ground information.
- Use of other soil loss models to ensure accuracy of soil loss estimation.

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