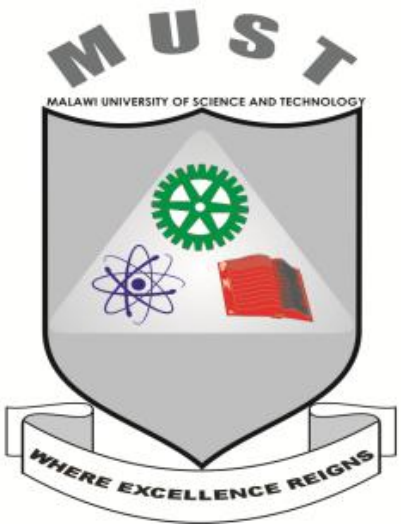


SOIL EROSION ASSESSMENT BY APPLICATION OF RUSLE MODEL IN NTCHISI DISTRICT.

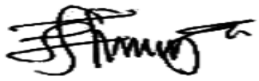
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Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirements for the Bachelor of Science degree in Geo-information and Earth Observation

DISSERTATION APPROVED BY:

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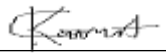
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DECLARATION

I **CHISOMO KAMATA** declare that this research project represents my own work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

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Abstract

Increased Soil loss is a major threat to the agricultural development in Malawi and by extension is also a major hindrance to the overall economic development of the country since the Malawian economy is dependent on agriculture. The problem of increased soil loss is a major trending issue in Malawi just as the case in Ntchisi District. The study aimed at assessing the soil erosion in Ntchisi District, specifically the impact of human activities that accelerate the rate of soil erosion, mapping areas that are vulnerable to soil erosion and assessing the increment rate of soil erosion.

The study used Revised Universal Soil Loss Equation model (RUSLE) to estimate the increase of the rate of erosion and mapping of vulnerable areas. RUSLE parameters were calculated using different datasets from secondary sources which are rainfall erosivity, soil erodibility, slope steepness and slope length, cover and management and the support practice. The rainfall erosivity was derived from a ten years precipitation data and was found as 297.401MJ.mm.ha^{-1}.h^{-1}.yr^{-}. The soil erodibility was calculated using GSD soil data and was found with a value of 0.1218Mg h/MJ/mm. The slope steepness and length were derived using the Digital Elevation model acquired from USGS and was found as 8.516. The cover and management using Landsat images for 2010 and 2020 to denote the influence of deforestation and overgrazing on soil erosion and was found as 0.031 and 0.041 respectively. The support practice was calculated from slope map and based on farming practices in the area and was found with the average of 0.67.

The RUSLE parameters were integrated where by used different cover and management factor as for 2010 and 2020. Using the 2010 cover and management factor the rate of soil erosion was **6.2004 Mg/ha/yr** and while using the 2020 cover and management factor, the rate of soil erosion was **8.474 Mg/ha/yr**. From 2010 to 2020 there has been an increment of **2.236 Mg/ha/yr**. which represents 36.67% Of soil loss due to vegetative cover loss as the result of deforestation and overgrazing that are constantly happening in Ntchisi district.

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I express my gratitude to the Almighty God, for granting me the capacity and ability throughout the period of my studies. This research is the result of valuable support from many individuals, their assistances in different ways have helped me in the successful accomplishment of this research work.

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List of symbols and Abbreviation/Acronyms

A	RUSLE Average Annual loss
C	RUSLE Cover and management
DEM	Digital Elevation Model
E	Rainfall kinetic energy
GIS	Geographic Information System
GoM	Government of Malawi
GSD	Geological Surveys Department
I30	30-minute rainfall intensity
K	RUSLE Soil Erodibility
L	RUSLE Slope length
MAP	Mean Annual Precipitation
NDVI	Normalized Difference Vegetation Index
P	RUSLE support practice
R	RUSLE Rainfall Erosivity
RDP	Rural Development Project
RUSLE	Revised Universal Soil Loss Equation
S	RUSLE slope steepness
SADC	Southern Africa Development Countries
USGS	United States Geological Survey

1. Background

Soil erosion is defined as the accelerated removal of topsoil from the land surface through water, wind and tillage. Soil erosion occurs naturally under all climatic conditions and on all continents. However, this phenomenon has been accelerated by human activities (up to 1,000 times) through intensive agriculture, deforestation and introduction of land-uses that are not well matched to the land-use capability. Soil loss is fueled by agents of erosion (such as wind, runoff, gravity, etc.) and further influenced by factors such as soil management, land use/cover management, topography, and soil type. Some of these factors are often modified by human activities in ways that can increase or slow down the rate of soil loss process.

During soil loss, the soil particles are first detached then transported before being deposited some distance away from the initial position. Soil loss is a major threat to the agricultural development in Malawi and by extension is also a major hindrance to the overall economic development of the country since the Malawian economy is dependent on agriculture (Omuto et al., n.d.). Not only does soil loss reduce the cultivable soil depth but it also takes away the fertile soils from the farmlands. The net effect is loss of agricultural productivity, increased expenditure on fertilizers, and a general decline in profitability of crop production. The study was conducted in Ntchisi district, central Malawi. The research was to assess soil erosion in Ntchisi district which aimed at assessing the rate of erosion and mapping risk erosion areas. The study used remote sensing data and the Revised Universal Soil Loss Equation (RUSLE).

1.1. Problem Statement

Soil loss which is a major threat to agriculture in Ntchisi district due to some human activities such as deforestation, overgrazing and bushfire setting that are heavily being conducted in the area. The net effect is loss of agricultural productivity, increased expenditure on fertilizers, and a general decline in profitability of crop

production. A solution to this is to conserve vegetative cover by avoiding bush fire, overgrazing and practicing afforestation and re-afforestation in de-forestated areas. Since the district is vast it is difficult to assess the area using local methods. Therefore, there is a demand to use GIS and Remote Sensing Application in assessing soil loss in the study area.

1.2. Main objective

To assess soil erosion by the application of RUSLE model Ntchisi district, central Malawi.

1.3. Specific objectives

1. To estimate annual soil loss increment in Ntchisi District
2. To map increment of vulnerable risk areas to soil erosion in Ntchisi District
3. To assess the impacts of deforestation and overgrazing on soil erosion in Ntchisi District.

1.4. Research Questions

1. What is the increment of soil loss in Ntchisi District?
2. Which areas have become vulnerable to soil erosion?
3. Does deforestation and overgrazing have impacts on soil erosion in Ntchisi District.

Significance of the study

The study will help to people know the soil erosion status of the district with respect to Agriculture. The information will be an eye opener to local people about the magnitude of soil erosion hence will make them to check their land use practices to minimize erosion. The results from the study will play a key role in agricultural sector as farmers have to increase amount of organic matter on their farms as recovering the lost fertile layer due to run-off.

2. Literature review

According to (Omuto et al., n.d.)Soil loss is a major threat to the agricultural development in Malawi and by extension is also a major hindrance to the overall

economic development of the country since the Malawian economy is dependent on agriculture. Not only does soil loss reduce the cultivable soil depth but it also takes away the fertile soils from the farmlands. The net effect is loss of agricultural productivity, increased expenditure on fertilizers, and a general decline in profitability of crop production. This study is part of the effort of the Government of Malawi (GoM) and its development partners in determining best approach to control the soil loss problems in the country. The study was set up to establish the current rates and trends of soil loss in Malawi as a baseline for future monitoring of soil loss in the country.

2.1. Soil Erosion

According to(*Soil and Nutrients Loss in Malawi: An Economic Assessment Carlo Orecchia Ministry of Environment and Protection of Land and Sea*, 2018)The major soil types in Malawi are dominated by Luvisols, Lixisols, and Cambisols, occupying three-quarters of the county. Lixisols are dominantly in the northern region, Luvisols in the central, and Cambisols along the Rift Valley and largely in the southern regions. Cambisols and Luvisols are soils with relatively good natural nutrient characteristics; hence, they are quite susceptible to exploitation through agricultural activities. They are also predisposed to soil erosion due to their chemical and physical characteristics. Lixisols do not have good natural fertility. Their low aggregate stability and slaking tendencies are undesirable agricultural characteristics. Altogether, the three soil types which occupy 76% of Malawi are susceptible to soil erosion. By implication, over three quarters of Malawi is predisposed to soil loss by virtue of soil types. The rate of soil loss is the amount of soil removed per unit area in a given time frame and is often expressed in ton/ha/year. The eroded soil that leaves a specified area is then deposited in another area, which can include another field or a watershed. The description of soil loss often focuses on the area where the soil has been removed. The detached soil particles may be deposited a few

centimeters away or even meters or kilometers away. The fate of the detached soil is not always in the ocean/lakes.

According to (*The Economic Impact of Soil and Nutrient Loss in Malawi*, 2018)The main land use/cover types in Malawi are farmlands, natural forests, forest plantation, wetlands, built-up areas, and lakes. Farmlands occupy the largest areas, with an increased coverage of 9% between 1991 and 2010. The majority of the farmlands have seasonal ground/vegetative cover owing to the seasonal types of crops grown in them. The produce provided by these farmlands is mostly used at the local level. The natural forest is dominantly used as game parks or forest reserves. They provide the country with tourist attraction benefits, fuelwood, medicinal plants, timbre, food, water catchment areas, above-ground carbon stocks, and the ground cover that protects the soil from agents of erosion. Some parts of these forested lands have been replanted with tree species such as pines, rubber, etc. Altogether, the forests occur mainly in the north of Malawi and in the upper parts of the central region.

According to (Leenaars, 2016) Mean annual rainfall in Malawi ranges from 725 mm to 2500 mm. This rainfall occurs during two seasons that are separated by a small window of a little less than three weeks. About 95% of this rainfall falls between November and April. The majority of this rain falls in the north and southern regions (in Mulanje and Phalombe). The rainfall "energy" is directly related to the total annual precipitation; implying that the areas with high rainfall regimes also have high rainfall energy for initiating soil loss.

2.2. Types of soil erosion based on erosion triggers

Soil erosion by water, that is, "water erosion" has been identified as the major threat to the agriculture landscape and farming systems. Water erosion in farmlands reduce the crop yield and change the land-use patterns that may induce a risk of food insecurity. Water erosion greatly contributes to the soil erosion hazard. Hazard is a

situation or potential condition to harm or threat to life, health or damage to property or environment. Researchers revealed increasing rainfall intensities and prolong seasonal dry periods due to climate variation have triggered an intensification of soil erosion and temporal probability of hazard occurrence such as mass movements. The anthropogenic factors such as land use change and forest fires further exacerbated the soil erosion hazard situation. Moreover, water erosion caused by environmental hazards was reported by many scholars with the main cause being highland developments in the recent past (Senanayake et al., 2020)

2.3. Factors that cause soil erosion

Deforestation is often correlated with an increasing demand for agricultural land, charcoal and fuel-wood, construction materials, large-scale and resettlement of people in forested areas. In turn this is often a consequence of unsuccessful policy measures to preserve forests.

According to (Zeraatpisheh et al., 2013). Land use and soil cover are considered the most important factors affecting the intensity and frequency of overland flow and surface wash erosion. The study confirms the relationships between deforestation, agriculture and soil erosion. Conversion of forest and grasslands into agricultural land is one of the main concerns worldwide in the context of environmental degradation and global climate change. Forest provides a good protection against surface runoff and soil erosion. Agriculture has caused a 7-fold increase in surface runoff and 21-fold increase in soil erosion. Many authors have demonstrated that in a wide range of environments both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases. Without exception, deforestation and substitution of forests by crops or meadows has led to a dramatic increase in soil erosion, resulting in gully development and shallow landslides that have increased the sediment load in rivers.

According to (Ngwira & Watanabe, 2019). Deforestation is known as one of the most important elements for changes in land use and land cover. It is recognized as

a major driver of the loss of biodiversity and ecosystem services. Globally, it has been occurring at an alarming rate of 13 million hectares per year. It is believed that high population growth coupled with the rapid expansion of agriculture is responsible for the accelerated rates of deforestation, especially in developing countries. Malawi is a developing country in which enormous pressure is being exerted on forest resources. Forest cover of the country reduced from 47% in 1975 to 36% in 2005. This is the highest deforestation rate in the Southern African Development Community (SADC) region, representing a net loss of some 30,000 to 40,000 hectares per year. This means that soil loss also increased as forest act as ground cover to control soil erosion by reducing the speed of rain drop as well as running water.

Overgrazing causes destruction of vegetative cover by eating and trampling, disturbance of root systems by scuffling, and compaction of the surface reducing infiltration and accelerating runoff and soil erosion (Naylor, 1995). Unsustainable grazing is one of the most diffused land management problems at the global scale and is associated with marginal, depopulated, and disadvantaged rural areas whose landscape is dominated by pastures, low value-added cropland, and fallow land (Papachristou et al., 1996). Overgrazing is regarded as a serious pressure on the natural environment and a well-known desertification driver in areas where morphology, climate, vegetation cover, and soil are unsuitable for intensive agricultural use (Brunner et al., 2008). According to (Sharma, 1997), soil erosion can increase dramatically due to overgrazing; causing increases of five to 41 times over the control at the mesoscale and three to 18 times at the macroscale based on the study conducted in India.

3. Research Design and Methodology

3.1. Research Design

This study used a quantitative approach in which calculated values for RUSLE model parameters for the years of 2010 and 2020 Landsat 5 and Landsat 8 satellite images, DEM, soil and rainfall data were analyzed. The workflow (figure 1) was adapted from (Behera et al., 2020).

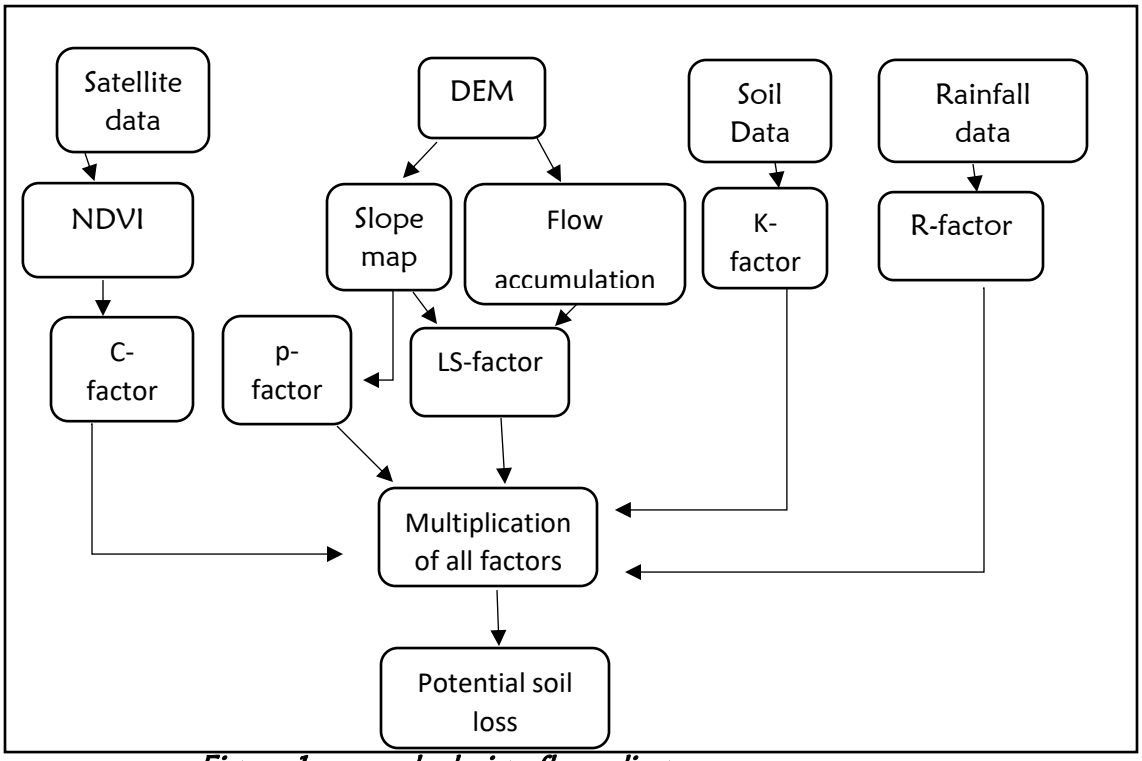


Figure 1 research design flow diagram

Source:(Behera et al., 2020)

3.1.1. Study Area

The study area is Ntchisi district located in the central region of Malawi. The total land area is 655 sq. km. The district has bordered by Dowa and Salima in the south west and south east respectively. Kasungu is in the west and Nkhotakota in the north west. The district lies along the Kasungu- Lilongwe plain which has gentle slope on the western side and undulating hills in the southern position. The north-eastern and eastern parts of the district are hilly whereas northern, southern and western are flat and rolling. Ntchisi has slopes ranging 1 to 2 degrees and is at an altitude of between 1300m to 1700 meters above sea level. Ntchisi has sandy loam soils in upland areas and has sand clay soils in dambos down the hills. The mean annual temperature varies between 22^0c in low altitude areas and 18^0c in high

altitude areas. The district annual rainfall ranges from 900mm to 1500mm. The natural vegetation of the area is typically savanna. Farming and agriculture make up to eighty-five percent of the local economy with couple of leading crops being beans and potatoes. Forestry, irrigation and livestock herding are other fields since the economy has very little private industry and government employs most of the people

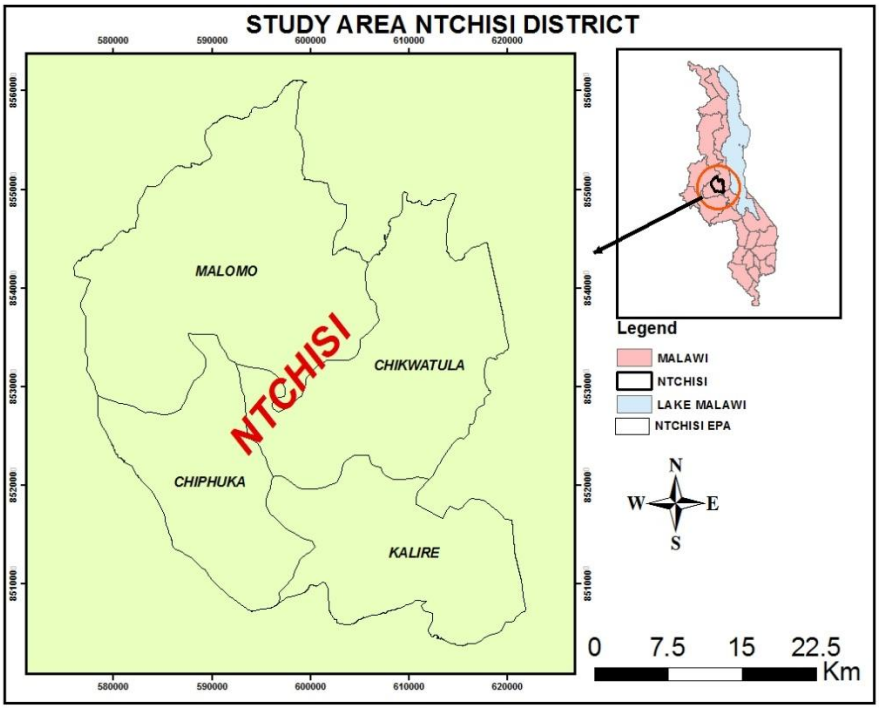


Figure 2 showing map of Ntchisi

3.2. Data and Methodology

3.2.1. Data

Landsat 5atm (2010) and Landsat 8 (2020) data were collected from USGS website used in calculating cover management factor for 2010 and 2020. Rainfall data were collected from Rural Development Project (RDP) office which is also central organization for data collection in the district. Further notice, the positions of the rain gauges used in this study have not been spoiled since the beginning of the record keeping, therefore, rainfall data may not have suffered from non-homogeneity. Rainfall data collected were for four stations present in the study area. Global Multi Terrain Elevation Data DEM data was collected from USGS website used for calculating slope length and steepness factor. Soil data were collected from Geological Survey Department of Malawi (GSD).

3.2.2. Geospatial Modelling and Analysis

The Geographic Information Systems (GIS) database creation and mapping techniques were used to create interactive maps of soil erodibility, rainfall erosivity, slope length and slope steepness, cover management factor map, support practice map and the integrated map of Revised Universal Soil Loss Equation.

3.2.2.1. Calculation Of RUSLE Model Parameters

Soil Loss Estimation by Revised Universal Soil Loss Equation (RUSLE). RUSLE model was used in this study to predict the soil loss and to identify the erosion-prone areas, and it was expressed as;

Equation 1 … $A = R \times K \times LS \times C \times P$

(1)

Where

A = Annual soil loss
R = Rainfall Erosivity factor
K = soil erosivity factor, Mg h MJ! mm!
L = slope length, m
S = slope steepness, %
C = cover and management factor
P = support practice

The annual soil loss was calculated by integrating RUSLE model factors and a map showing soil loss areas was produced.

3.2.2.2. Slope Length and Steepness

Digital Elevation Model is a digital file consisting of terrain elevations for ground position at regularly horizontal intervals. The Global Multi Terrain Elevation Data was used as the DEM collected from USGS in calculating LS factor within the study area. The GMTED data files were added in ArcGIS 10.5 to calculate slope length and slope steepness (LS-Factor) using Moore and Butch equation (Moore & Burch, 1986) given as;

Equation 2…$LS = (\text{slope length}/22.13)0.4 \times (0.01745 \sin(\text{slope steepness})/0.0896)1.4 \times 1.4$

Where slope length = Flow accumulation × Cell resolution.

3.2.2.3. Soil Erodibility

Soil data was collected from geological survey of Malawi. Soil data was used to calculate soil erodibility factor using the equation expressed as

Equation 3……. K= [2.1M 1.14(10-10) (12-a) + 3.25(b-2) + 2.5(c-3)]/100

Where M is the product of the percentage of silt + very fine sand the other percent of soil fraction other than clay. While a, b, c is the percentage of organic matter, the structure code and the permeability code, respectively.

The value of K-factor obtained from the equation was multiplied by a factor of 0.1313 to be able to express the results into international system of units.

3.2.2.4. Rainfall Erosivity

The precipitation of the four different stations were collected from Rural Development Project (RDP) and this data was displayed in Excel spreadsheet with an extension of CSV and had XY coordinates. This data was exported into ArcGIS to and it was interpolated to produce Ntchisi Mean Annual Precipitation map and rainfall erosivity was calculated from Mean annual Precipitation (MAP) map using Raster calculator by applying an equation proposed by (Kassam et al 1992) given as:

Equation 4……R = 117.6 $(1.00105^{(MAP)})$

Where; R= Rainfall Erosivity

MAP= Mean Annual Precipitation

3.2.2.5. Cover and management factor

Landsat 8 data was preprocessed using QGIS and ENVI software and was added in ArcGIS to calculate cover factor. Vegetation act as cover factor and slows the rate of soil erosion. Cover and management factor was derived from Normalized Difference Vegetation index (NDVI) using 2010 Landsat 5 and 2020 Landsat 8 data respectively where by the NDVI is given as

Equation 5……NDVI= (NIR-RED)/(NIR+RED)

Where, NDVI is Normalized Difference Vegetation Index,

NIR = surface spectral reflectance in the near-infrared band,

RED = surface spectral reflectance in the red band.

Cover and management factor was calculated using equation proposed by (Durigon et al., 2014) and adapted by (Colman, 2018) and is expressed as :

Equation 6 …….Cr_A=0.1((-NDVI+1)/2)

where C_{rA} = the cover and management (*C*) factor

NDVI= Normalized Difference Vegetation Index.

3.2.2.6. Support Practice

support practice was derived from slope map generated from DEM and contouring practice based on slope sourced from other studies. Slope raster image was vectorized. Areas were assigned P-Factor values based on slope % and after assigning values the vector file was rasterized where by the focus was the P-factor value.

4. RESULTS AND DISCUSSION

4.1. Slope Length and Steepness factor

The Length and Steepness factor in RUSLE model characterizes the influence of topography on erosion. Previous researchers in the field of soil erosion have defined slope length as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough where deposition begins or the flow is concentrated in a defined channel (Renard et al., 1997). When the length of slope is increased there is a corresponding increase in erosion owing to increased velocity of the water flow. Thus, soil loss increases proportionately with increase in length and incline of slope. The combined effects of slope length and slope incline give a good estimate of soil erosion rate. The slope length(L) given in meters(m) represents the effects of slope length on soil erosion. Slope steepness(S) given in degrees or percent rise accounts for effects of slope steepness on soil erosion (**appendix 1**).

The slope length (L) and slope steepness(S) when combined in GIS system forms LS factor also known as topographic factor. In this study, the LS factor was derived from digital elevation model (DEM). The precision of the results is based on the resolution of the DEM data, the higher the resolution the higher the precision. In this study were supposed to use ASTER DEM data which is 30m spatial resolution unfortunately the data set found on the United States Geological Survey (USGS) website was only for three quarter of the study area. Therefore, the Global Multi Terrain Elevation Model data which has a spatial resolution of 1kilometer and one band spectral resolution was used in this study.

The combined length and steepness factor was found with an average of **8.516**. In this study to calculate the LS Factor, used Moore and Butch equation (Moore & Burch, 1986) given as;

$$LS = (\text{slope length}/22.13)^{0.4} \times (0.01745 \sin(\text{slope steepness})/0.0896)^{1.4} \times 1.4 \quad \text{..... eq (2)}$$

Where slope length = Flow accumulation × Cell resolution

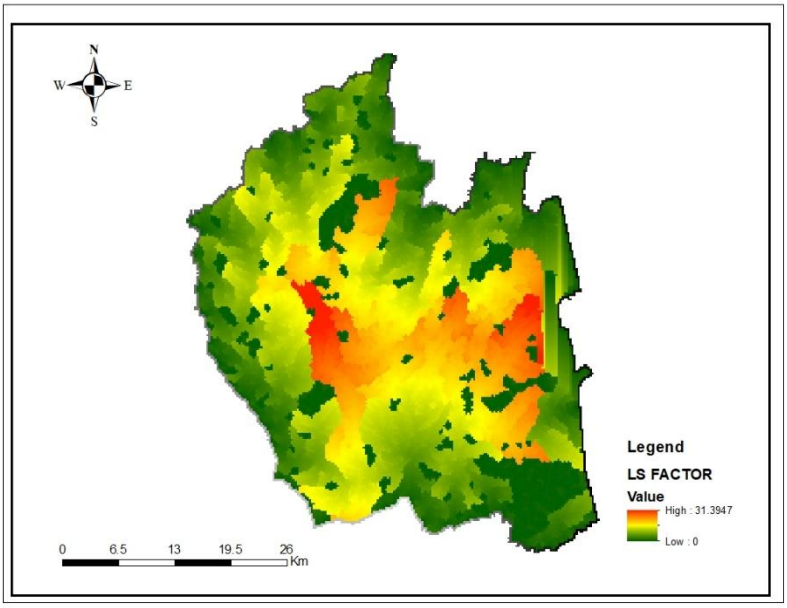


Figure 3 showing slope length and steepness

4.2. Soil Erodibility (K-factor)

Soil erodibility reflects the soil susceptibility to erosion. Mainly, it depends on the organic matter content, soil texture (silt, very fine sand, sand and organic matters), permeability and aggregate stability. Soil erodibility values for different types of soil can be obtained from nomographs. However, runoff plots under the standard conditions of fallow soil are a reliable way to measure the soil erodibility for local soil types. Soil reach in sandy have greater values of soil erodibility since the permeability is high and mostly it is poor in organic matter content. Due to lack of nomographs, this research used secondary data from Geological Survey Department of Malawi (GSD). Soil map was produced from the collected data and it is shown on figure 7. From figure 7, 60% of the study area has loamy sand areas followed by sandy loam soil which is very prone to erosion due to its structure. The area is also covered with sand clay loam soil and partly covered with sand, rock outcrops and escarpments. The soil data

collected was calculated based on soil properties found in attribute table content of soil collected from Geological Survey Department of Malawi (GSD). The K-factor values were calculated using the equation 2, given by:

$$K= [2.1M^{1.14} (10^{-10}) (12-a) + 3.25(b-2) + 2.5(c-3)]/ 100 \ldots\ldots \text{eq (3)}$$

Where, K = the USLE soil erodibility factor
a = percentage of organic matter
b = the structure code
c = the permeability code,
M=the product of the percent of silt + very fine sand and the percent of all soil fractions other than clay.

The permeability code and the structure code used in this study to calculate K-factor were obtained from the table 1 and table 2 respectively and were assigned based on soil texture shown on figure 4 labelled (a).

Table 1 Permeability information for the major soil classes(Renard et al., 1997)

Texture class	Permeability class	Saturated Hydraulic conductivity mm/hr	Permeability rating
Clay, Silty Clay	6	<1	Very slow
Silty clay loam, Sandy clay	5	1-2	Slow
Sandy clay loam, Clay loam	4	2-5	Slow to moderate
Loam, Silty loam, silt	3	5-20	Moderate
Loamy sand, Sandy loam	2	20-60	Moderate to rapid
Sand	1	>60	Rapid

Table 2 Soil structure codes for use in estimation of K value in USLE (Wischmeier, W.H., Smith, 1978)

Structure codes	Description
1	Very fine granular
2	Fine granular
3	Medium to course granular
4	Blocky, Platy or massive

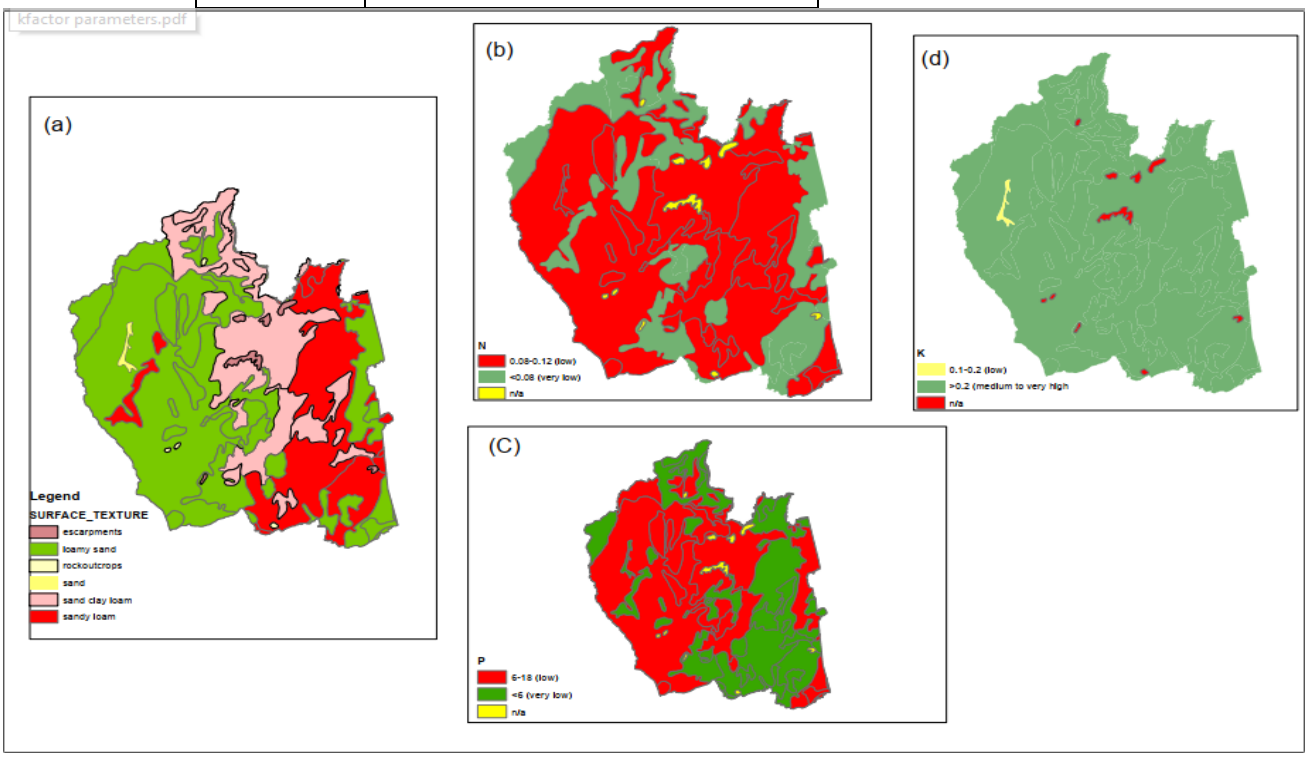


Figure 4 soil erodibility parameters (a is soil texture, b is nitrogen, c is phosphorus, d is potassium

The K factor values obtained by the equation was multiplied by a factor of 0.1313 to be able to express the results in the International System of Units. From the K-factor map in figure 8 shows that the study area has k-values ranging from 0.04 Mg h/MJ/mm to 0.9 Mg h/MJ/mm. The average K-factor value for the whole district was 0.1218 Mg h/MJ/mm.

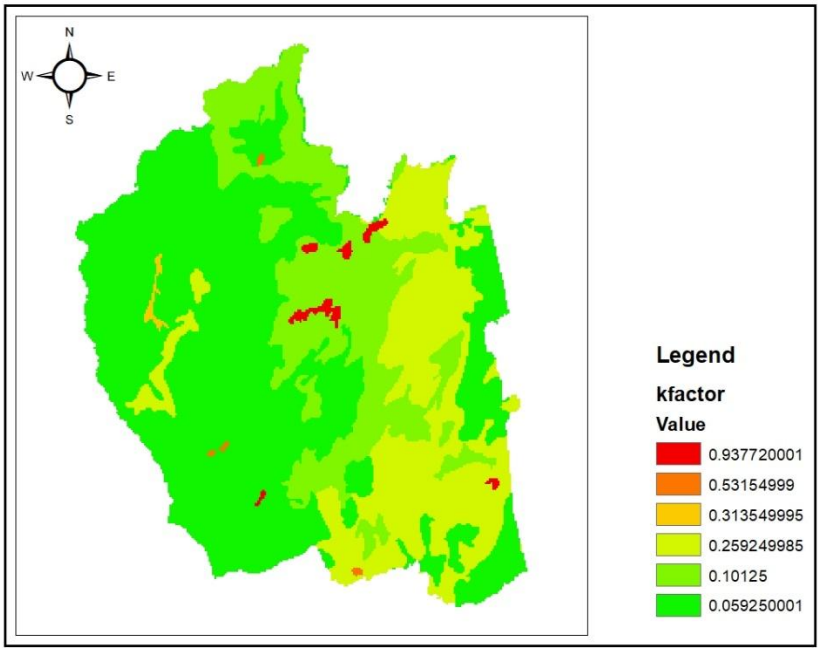


Figure 5map showing soil erodibility

4.3. Rainfall Erosivity (R Factor)

Rainfall erosivity is a term that is used to describe the potential for soil to be washed off from disturbed, de-vegetated areas and move with into surface waters during storms. It may also be defined as the potential ability of rain to cause the erosion. It is dependent upon the physical characteristics of rainfall, which include raindrop kinetic energy, terminal velocity (htt). For a given soil condition, the potential of two storms can be compared quantitatively, regarding soil erosion to be caused by them. The power of overland runoff flow to erode soil material is partly a property of the rainfall, and partly of the soil surface. Rainfall erosivity is highly related to soil loss. Increased rain erosivity indicates greater erosive capacity of the overland water flow. Soil erosion by running water occurs where the intensity and duration of rainstorms exceeds the capacity of the soil to infiltrate the rainfall.

Rainfall erosivity factor is determined by rainfall intensity data if it is available. Erosivity is calculated from the kinetic energy of rainfall (which in turn is estimated from the mean annual rainfall and 30minute rainfall intensity value using an equation given by (Morgan, 1995).

Equation 7 ..... R = EI30/1000 (3.11)

Where,

R= rainfall erosivity factor in metric units

E = Rainfall kinetic energy, Jm-2

I30 = 30-minute rainfall intensity, mmhr-1 (Morgan, 1995).

However, rainfall kinetic energy and intensity data are not available in most cases. There are different regression equations which are used to calculate rainfall erosivity factor based on regions. For southern Africa region there was no any regression equation. Therefore, the erosivity factor R that was adapted in this study was proposed by (Kassam et al 1992) for annual precipitation below 2000mm based on the easily available mean annual precipitation (MAP) and this equation is used when the annual precipitation below 2000mm which is applicable on the study area based on the data collected. It is given by a regression equation:

$$R = 117.6\ (1.00105^{(MAP)}) \quad \text{..... eq(4)}$$

Where; R= Rainfall Erosivity

MAP= Mean Annual Precipitation

By using equation 5, MAP used was calculated from table 3 below and it was found as 884.075 which is an average from the four stations.

Table 3 shows annual precipitation and mean annual precipitation of four Station in (mm)

Station	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	MAP
Malomo	775	865	750	625	1325	1000	550	825	785	865	836.5
Chipuka	765	850	795	525	715	775	645	775	785	850	748
Chikwatula	650	1300	975	910	1500	955	925	1235	1585	1365	1140
Kalira	800	1100	585	550	775	750	685	1000	850	1023	811.8

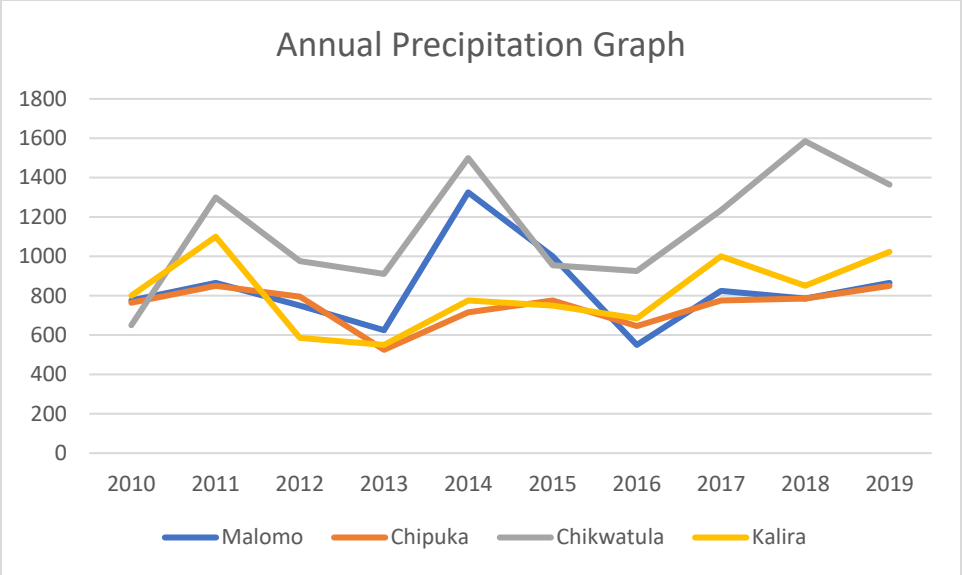


Figure 6 graph showing annual precipitation trend of four station

From the equation 4, the R-factor was found with a value of 297.401 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} on average of the four stations as specified on calculations below.

R-Factor Calculations

R= 117.6(1.00105$^{884.075}$) = 297.401 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}.

Using interpolation tools in ArcGIS maps showing mean annual precipitation and Rainfall Erosivity factor were produced. Chikwatula EPA having high values of both mean annual precipitation and Rainfall erosivity factor given as 1148mm and 389 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} respectively whereas Chipuka EPA having low values of both Mean Annual Precipitation and Rainfall Erosivity factors 748mm and 257.83 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} respectively while Malomo EPA and Kalira EPA having values in between 748mm to 1148mm for mean annual precipitation and 257.83 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}to 389 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} for rainfall erosivity factor.

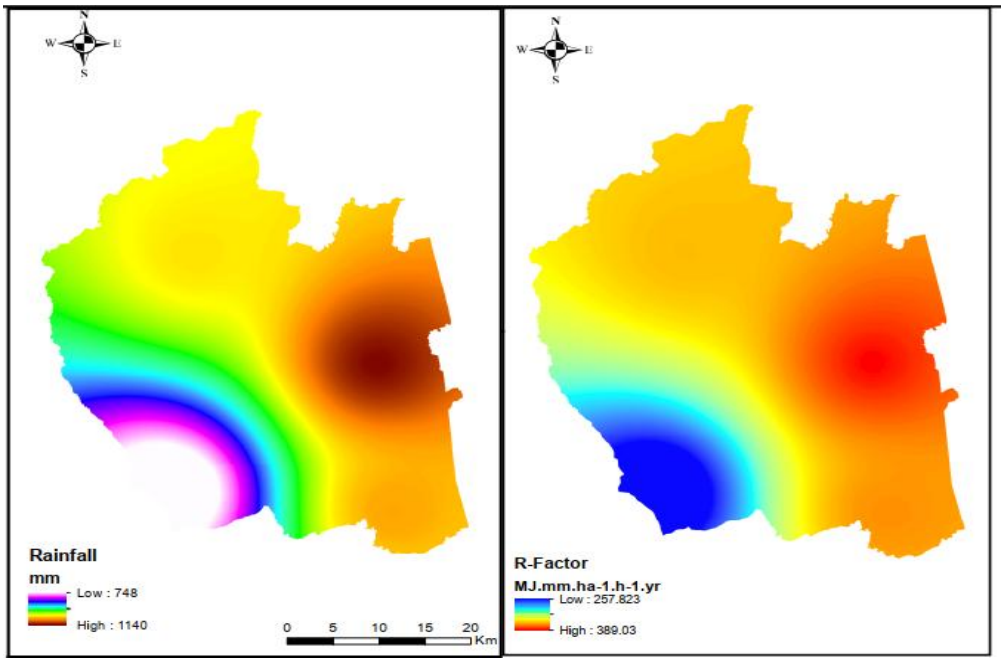


Figure 7 map showing mean annual precipitation and R-Factor

4.4. Cover and management factor (C-factor)

The cover management factor is used to express the effect of plants and soil cover. Plants can reduce the runoff velocity and protect surface pores. The C-factor measures the combined effect of all interrelated cover and management variables, and it is the factor that is most readily changed by human activities. This means that Cover and management (C) factor reflect the effect of Land Use Land Cover and management practices on the rate of soil erosion, and it is the ratio of soil loss from land covered by vegetation to the corresponding loss from continuous fallow. The *C*-factor value ranges between 0 implies very strong cover effects and 1 indicates no cover present and the surface treated as barren land. There are two ways of calculating C-factor, the first one is from literatures based on land use type and the second one is calculated using Normalized Difference Vegetation Index (NDVI) calculated from satellite images by applying C-factor regression equation.

In this study, used C-factor values calculated using Normalized Difference Vegetation Index (NDVI). Normalized Difference Vegetation Index is the ratio of the difference between Near Infrared and RED band reflectance to the sum of Near Infrared and RED

band reflectance and the values of NDVI ranges from −1 to 1 where higher value are for green vegetation, closest to 0 for bare soil, and negative values for water bodies.

For this study, the NDVI was used to estimate and map the cover and management (*C*) factor value of Ntchisi district. Normalize Difference Vegetation Index was calculated from the Landsat 8 and Landsat 5 satellite images after preprocessing in Qgis software by applying the equation given below. (NDVI Map in appendix 2)

$$NDVI = (NIR-RED)/(NIR+RED) \quad \text{..... eq (5)}$$

Where, NDVI is Normalized Difference Vegetation Index,

NIR = surface spectral reflectance in the near-infrared band,

RED = surface spectral reflectance in the red band.

After calculating the NDVI, the C-factor of the area was calculated using the equation proposed by (Durigon et al., 2014) and adapted by (Colman, 2018) and is expressed as

$$Cr_A = 0.1((-NDVI+1)/2) \quad \text{..... eq (6)}$$

where C_{rA} is the cover and management (*C*) factor

Since C-factor is influenced by vegetation, in this study used two different images to determine the influence of overgrazing and deforestation on soil erosion. 2010 Landsat 5 image and 2020 Landsat 8 image were used and both of these captured in September. Using equation 6, Calculated the NDVI where by having values ranging 0.1 To 0.7 for 2010 and having an average NDVI value of 0.188 while the 2020 image had NDVI values ranging from 0 to 0.6 and having an average value of 0.157 as shown in appendix 2.

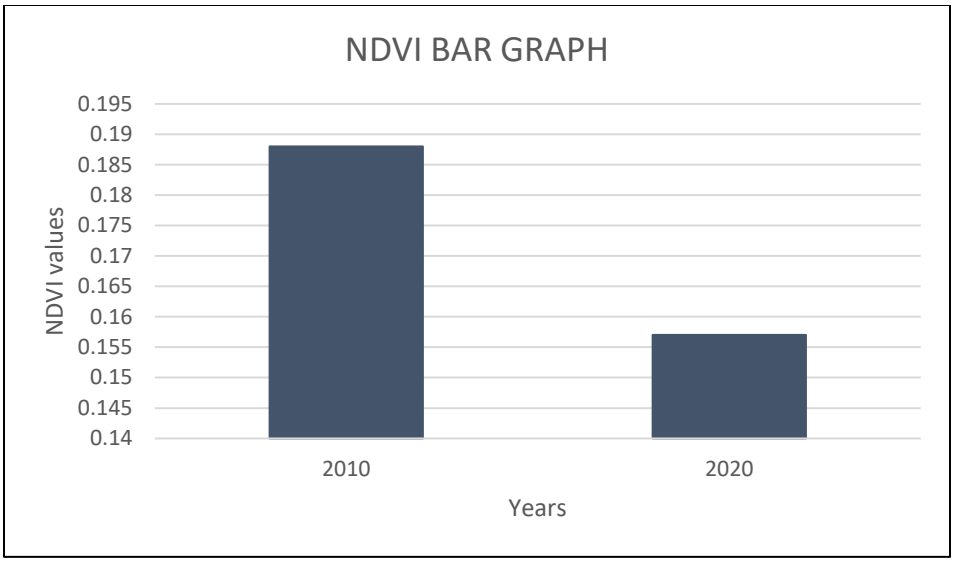


Figure 8 graph showing NDVI TREND 2010-2020

Using equation 7, the C-factor was calculated for the two images where by the 2010 image had an average C-factor value of 0.030 and the 2020 image had an average C-factor value of 0.041.

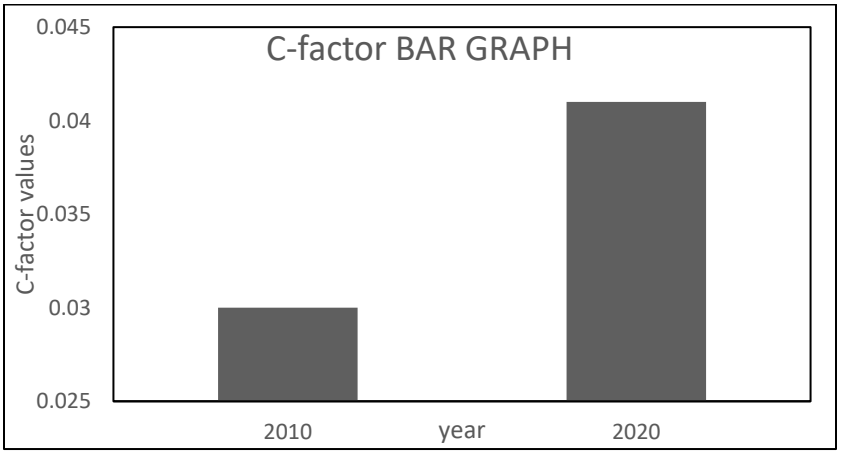


Figure 9 graph showing C-factor trend 2010-2020

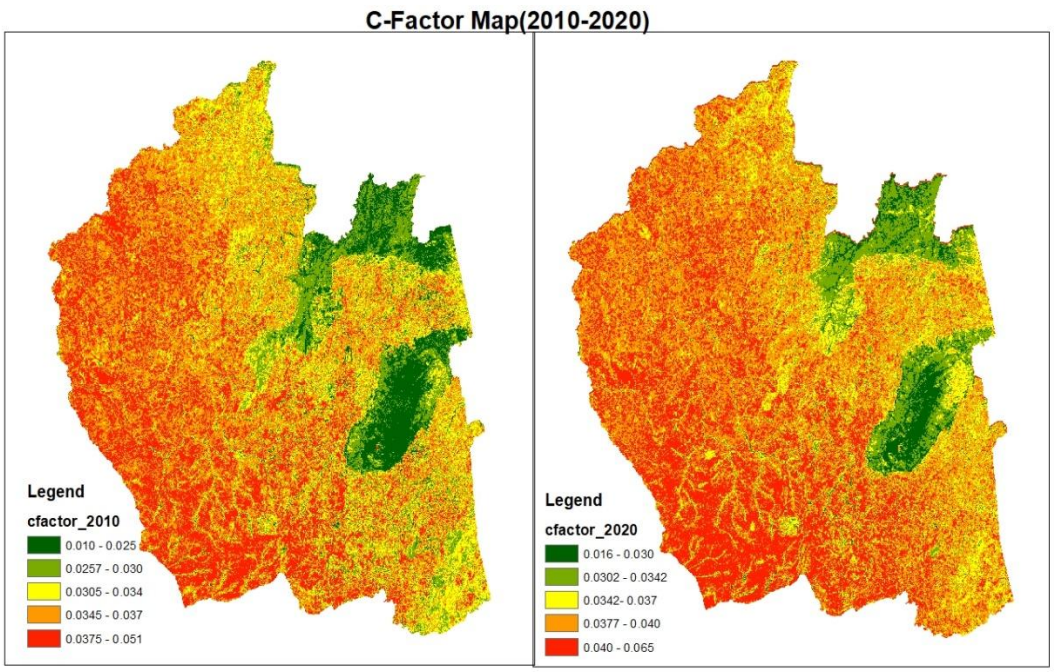


Figure 10 map showing C-factor (2010 and 2020)

4.5. Support Practice Factor

The RUSLE P-factor reflects the impact of support practices on the average annual erosion rate. It is the ratio of soil loss with contouring and/or strip-cropping to that with straight row farming up-and-down slope. The P-factor accounts for control practices that reduce the erosion potential of runoff by their influence on drainage patterns, runoff concentration, runoff velocity and hydraulic forces exerted by the runoff on the soil surface (htt). It is an expression of the overall effects of supporting conservation practices such as contour farming, strip cropping, terracing, and subsurface drainage on soil loss at a particular site, as those practices principally affect water erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the volume and rate of runoff. The value of P-factor decreases by adopting these supporting conservation practices as they reduce runoff velocity and encourage the deposition of sediment on the hill slope surface(Senanayake et al., 2020). The lower the P-factor value, the better the practice is for controlling soil erosion.

In this study, the p-factor was generated from slope (appendix1) and contouring practice (table 4) since the area practice contouring method unlike terracing and subsurface drainage. The average p-factor was found as 0.67.

Table 4 showing slope and contouring p-factor values (Karamage et al., 2017)

Slope%	Contouring(P-Factor)
0-7	0.55
7-11	0.60
11-17.6	0.80
17.6-26	0.95
>26	1

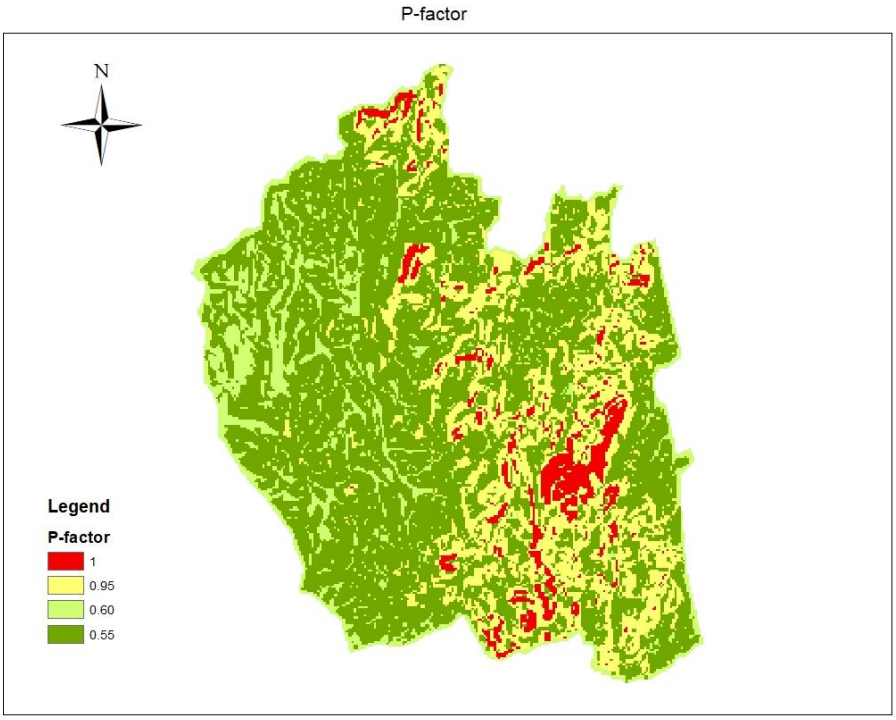


Figure 11 map showing p-factor

4.6. RUSLE MODEL

Soil Loss Estimation by Revised Universal Soil Loss Equation (RUSLE). RUSLE model was used in this study to predict the soil loss and to identify the erosion-prone areas, and it was

expressed by equation 1. This study, used two different C-factor values for 2010 and 2020 to denote the impact of deforestation and overgrazing on soil loss.

Using equation 1,

$$A = R \times K \times LS \times C \times P$$

Where by R=297.401MJ.mm.ha^{-1}.h^{-1}.yr^{-1}, K=0.1218Mg h/MJ/mm, P=, LS=8.516, P=0.67, average C=0.031 for 2010, average C=0.041 for 2020.

For 2010

A= 297.401 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} × 0.1218 Mg h/MJ/mm × 8.516 × 0.030 × 0.67 = **6.2004Mg/ha/yr**

For 2020

A= 297.401 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} × 0.1218 Mg h/MJ/mm × 8.516 × 0.041 × 0.67 = **8.474Mg/ha/yr.**

The increment rate percentage calculations

6.2004(2010) = 100%

8.474(2020) = Y%

(8.474 × 100) =6.2004 × Y

Y= 136.67%

Annual average Increment rate percentage = 136.67% - 100%

= 36.67%

The increment of vulnerable areas to erosion from 2010 to 2020 in Ntchisi district were shown on figure 12, where by some parts of the areas on the 2010 map became prone to erosion as portrayed on the 2020 map.

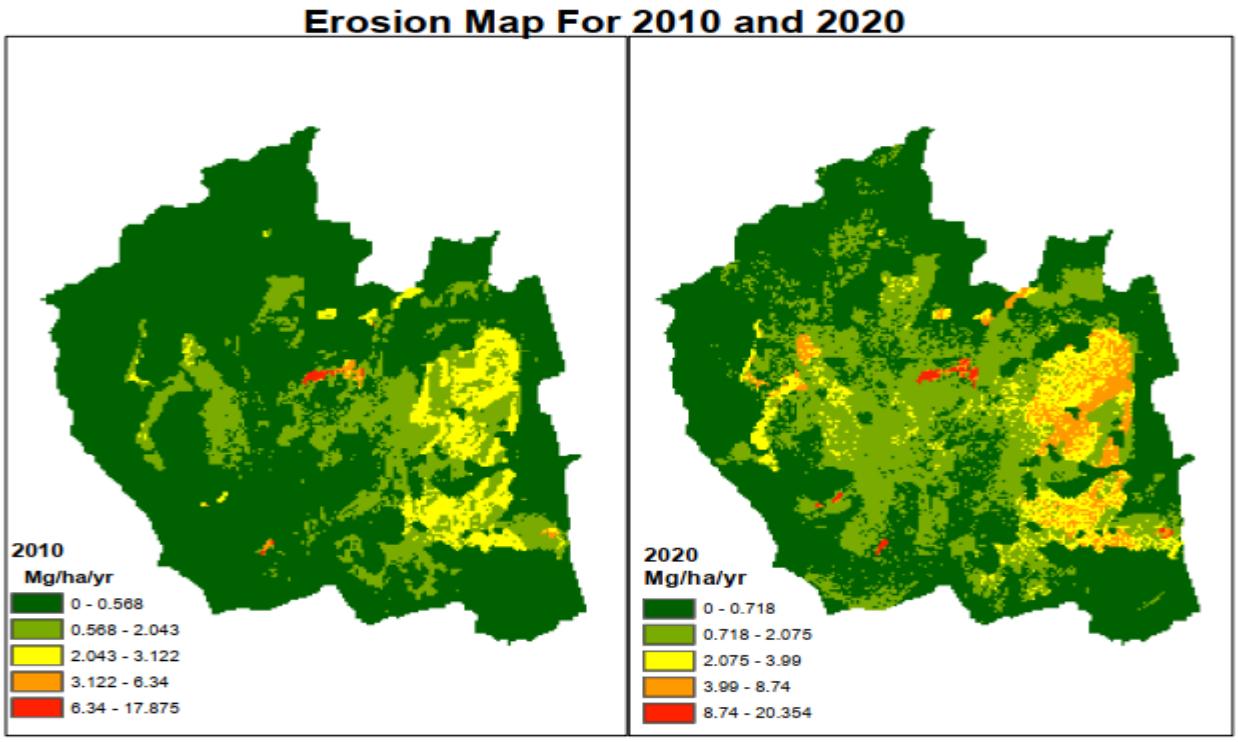


Figure 12 map showing erosion vulnerable areas

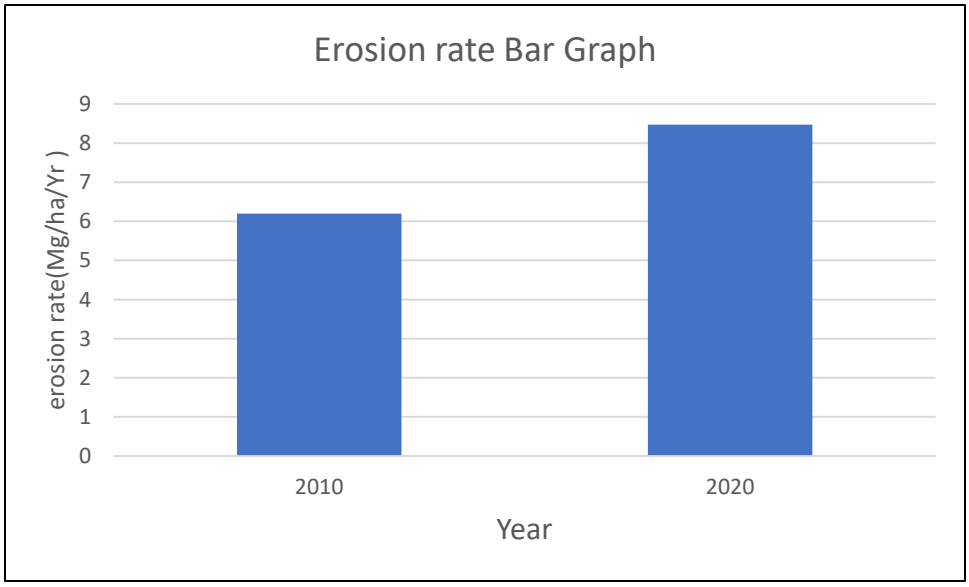


Figure 13 graph Showing erosion rate

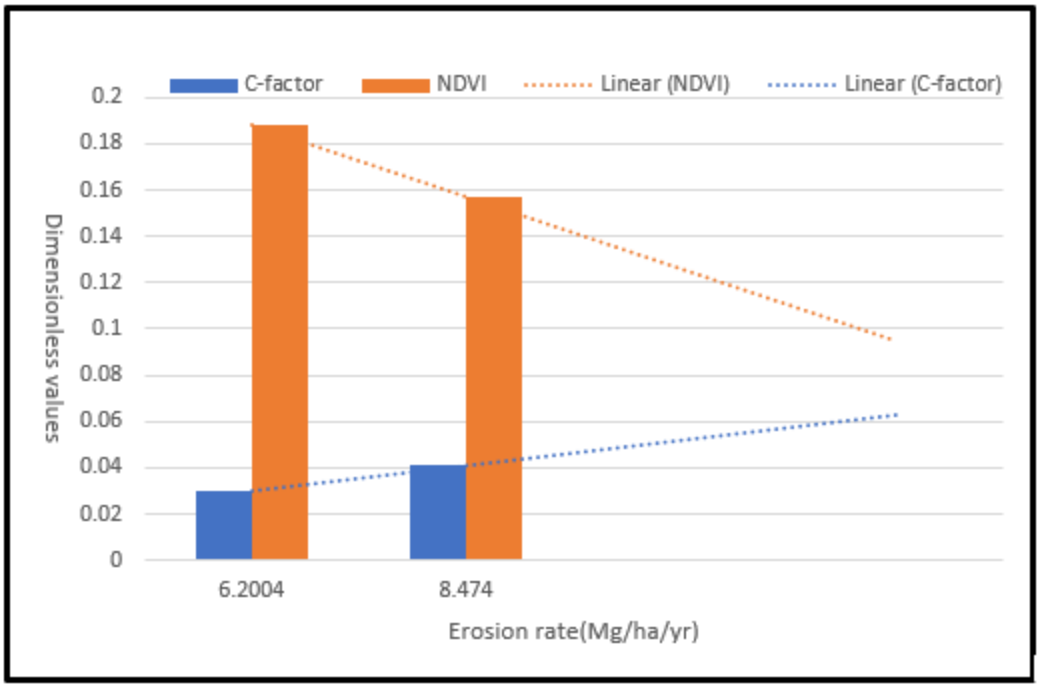


Figure 14 graph shows the relationship between c-factor and erosion rate

As illustrated in figure 14, it shows that the higher the c-factor value, the higher the erosion rate. C-factor value is derived from NDVI (chapter 4.4) where by the NDVI represents the ground vegetative cover. Therefore, the higher the NDVI value the lower the rate of soil erosion because of the presence of vegetative cover. Since NDVI is dependent on vegetative cover, therefore deforestation and overgrazing have impact on soil erosion as it disturbs the ground vegetative cover.

5. Recommendation and limitations

Since the information from this study is an eye opener to local people about the magnitude of soil erosion which make them to check their land use practices to minimize erosion. Therefore, it is recommended for people to change and adapt new land use practices that mitigate the rate of soil erosion and these practices are: afforestation in bare land as well as planting grass, reafforestation in deforested areas, avoiding overgrazing by introducing new ways of feeding animals like home feeding of animals.

Despite the results obtained in this study, there are some limitations which affected the accuracy of the results. Lack of accurate soil data to be used in calculating soil erodibility factor. Low spatial resolution of the Digital Elevation Model data which affected the accuracy of slope length and slope steepness. Lack of proper regression equation of modelling erosivity factor due to lack of rainfall kinetic energy and intensity data.

6. Conclusion

Soil erosion in Ntchisi district was assessed in this study using the RUSLE model in a GIS environment. Generally, some of the main findings in this study are related to its methodology. Results from this study revealed that there is an increase of the rate of soil erosion due to some human activities like deforestation and overgrazing which are constantly being practiced in the district. The results revealed that soil erosion is dependent on rainfall erosivity, soil erodibility, slope length and slope steepness, cover and management and lastly the support practice. Since rainfall erosivity, slope length and slope steepness are natural factors that cannot be controlled, therefore the main triggering factors induced by human activities are soil erodibility, support practice cover and management factor which was derived from vegetative cover in the study. There has been an increment of **2.236Mg/ha/yr** annual average soil loss and it represents **36.67%** increment between 2010 and 2020 where by the average annual soil loss for 2010 was **6.2004Mg/ha/Yr** and the average annual soil loss for 2020 was **8.474Mg/ha/Yr**. The results from this study also revealed areas that are vulnerable/prone to soil erosion shown in figure 12. The study also evaluates the impacts of overgrazing and deforestation on soil loss as it disturbance vegetative cover which is presented by NDVI as shown on figure 14.

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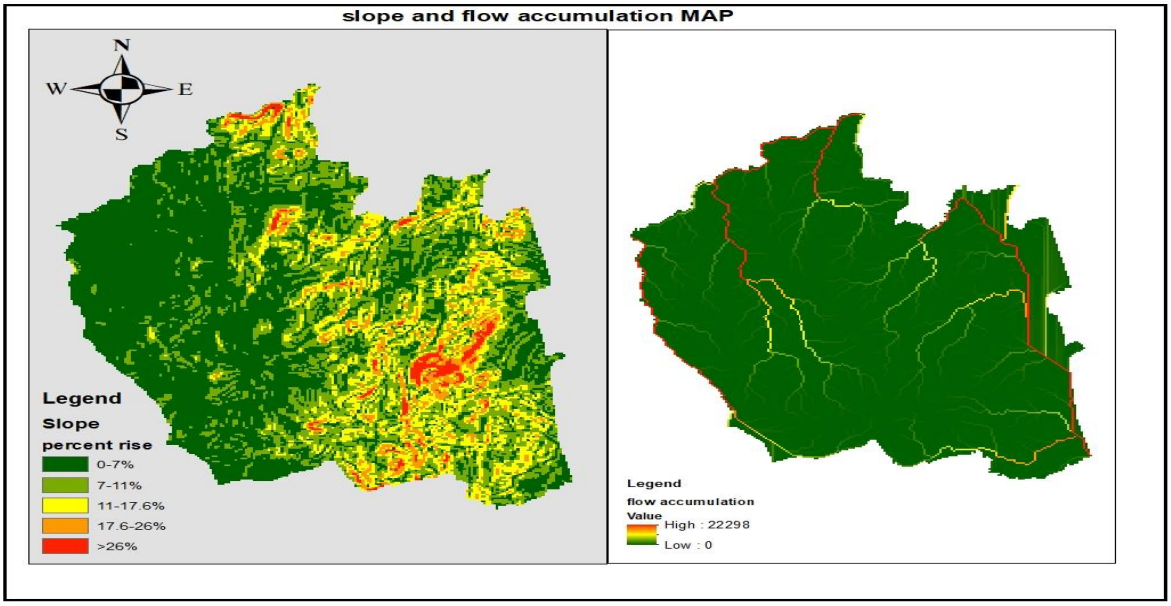
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8. Appendices

Appendix 1



Appendix 2

