SOIL EROSION AND SEDIMENT YIELD ANALYSIS IN SEMI-ARID TANZANIA

(CASE STUDY OF KONGWA DISTRICT)

By

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A dissertation submitted in the department of Geospatial Science and Technology in Partial fulfillment of the requirements for the award of Bachelor of Science degree in Geoinformatics at Ardhi University.

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I, Mbaga Darren Abraham, declare that the contents of this dissertation are the results of my own findings, obtained through studies and investigations. To the best of my knowledge, it has not been presented to any other university as a thesis for an award of Diploma, Degree or similar professional award.

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MBAGA DARREN ABRAHAM

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CERTIFICATION

The undersigned certify that they have supervised and proof read the dissertation and recommend for acceptance by the Ardhi University a dissertation document entitled "Soil erosion and sediment yield analysis in semi-arid Tanzania (case study of Kongwa district)"in fulfillment of the requirements for the Bachelor of Science degree in Geoinformatics.

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DEDICATION

This work is dedicated to my family (Mbaga's family), who have always encouraged and motivated me to thrive in my academics.

ABSTRACT

Soil erosion is a most devastating geological hazard and it is a severe problem in central Tanzania especially in the semi-arid regions, and the resultant sediment yield creates threats to sustainable agriculture and ecosystems. But the execution of different mitigation initiatives and policies used to adopt conservation practises in agricultural lands are unsuccessful or in effective due to the lack of spatial information on soil erosion areas. This study attempts to analyze soil erosion prone areas and sediment yield in the Kongwa district using GIS and remote sensing technique. The Revised Universal Soil Loss Equation (RUSLE) was used to estimate potential soil losses and sediment yield by utilizing rainfall, soil, Normalized Difference Vegetation Index(NDVI) and Digital Elevation Model (DEM) datasets. The results obtained demonstrate high soil erosion prone areas in the southern part of the Kongwa district, with the average annual soil loss equal to 66.24ton/ha/year and sediment yield of about 13.58 ton/ha per year. Generally, soil erosion prone areas have been idenified and sediment yield have been generated to support decision making processes regarding development of soil erosion control and adaptive measures for sustainable environment conservation measures. Based on the results obtained it is recommended that the sensitivity analysis of RUSLE model parameters should be carried out.

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LIST OF ABBREVIATION

CEMDO	Community Environmental Management and Development Organization
FAO	Food and Agriculture organization
GFW	Global Forest Watch
GIS	Geographic Information System
MODIS	Moderate Resolution Imaging Spectrometr
NBS	National Bureau of Statistic
NDVI	Nomerlaized Difference Vegetation Index
PESERA	Pan-European Soil Erosion Risk Assessment
RUSLE	Revised Universal Soil Loss Equation
SDR	Sediment Delivery Ratio
SWAT	Soil And Water Assesment Tool
USLE	Universal Soil loss equation
SY	Sediment Yield

CHAPTER ONE

INTRODUCTION

1.1 Background

Soil erosion has become a major issue in the world as it's estimated by FAO that there is a global loss of productive land through erosion of 5 to7 million hectares per year (Collins, 2001). About 65% of the African continent's farm land is affected by erosion-induced losses of topsoil and soil nutrients (FAO, 2018). Tanzania is also a victim of soil erosion as in the recent years it has led to an annual loss of 2.3 billion dollars reported due to land degradation in the semi-arid areas (Kirui, 2016). Soil erosion is defined as the net long-term processes that detach soil and move it from its original location to another (Lupia, 2004). Sediment yield is a consequence of soil erosion as, it occurs due to the impact of raindrop and the shear force of flowing water, when the sediment is detached from soil surface (Sanjay, 2015). Sediment yield is defined as the amount of sediment load passing through the outlet of a watershed, primarily by the flow of water and increase of down slope (Maqsoom, et al., 2020).

Soil erosion and sediment yield is a major cause of land degradation in Tanzania as it has lowered agricultural production potential, loss of soil fertility, also sedimentation disrupts drainage networks and increases the potential for flooding by blocking the drainage outlets, murky water prevents natural vegetation from growing in water, all these are the main consequences of soil loss and sedimentation (Balasubramanian, 2017). Soil erosion, along with soil compaction, low organic matter, loss of soil structure, poor internal drainage, and salinization and soil acidity issues, are all examples of soil degradation (Gobena, 2003).

Sediment yield is a key limitation to achieving sustainable land use and maintaining water quality in streams, lakes and other water bodiescite (Pavisorn, 2019). The eroded material derived from the highlands, watershed and banks are often stored within depressions in the land but may be transported during storm events, either in suspension or as bed load (Maqsoom, et al., 2020). The amount of soil sediment delivered into water systems through the processes of transportation, and deposition is a function of changes in surface drainage patterns, terrain structure, vegetation, and climate conditions (Kamaludin, 2013). Suspended sediment is empirically one of the best indicators of sediment delivery into the drainage system or watercourse from the land during the soil erosion process and this can be measured from point source discharge and non-point sources (Gelagay, 2017).

Soil erosion can be accelerated by two major agencies which are water erosion, wind erosion (Ann., 2005). Water erosion contributes a significant amount of soil loss each year which involves several types of erosion which are Rill erosion, gully erosion, bank erosion, splash erosion, landslides, and Streambank erosion (Telkar, 2014). The rate and magnitude of soil erosion can be determined by slope, soil texture and soil structure, soil organic matters, vegetation cover, and the land use of the area (Lupia., 2004). But through the application of different rehabilitation measures such as the use of contour and crop rotation system, avoiding overgrazing, reduced tillage, mulching, cover cropping, and cross-slope farming (Balasubramanian, 2017).

To estimate soil erosion and sediment yield some simple models are widely used for their simplicity, which makes them applicable even if only a limited amount of input data is availablecite (Gelagay, 2017). Although there are traditional methods such as ground surveys of erosion but the use of mathematical erosion models which predict the distribution of eroded land and sedimentation or through mapping then interpretation of remote sensing images have proven to be more efficient (Ellis, 1996). In the past century they have established a variety of models through experiments and observations, resulting in a change from empirical model to model based on physical processes, combining remote sensing, GIS, and other modern scientific and technology tools (Kenneth, 1991). Scholars in the United States have undertaken substantial studies and developed numerous models, including the USLE model, RUSLE model, and PESERA model (Zhen et al, 2020). Hence from the studies the effective way to determine the magnitude and the distribution of eroded land is by use of mathematical model as RUSLE (Hurni, 1985; Claessens, 2008; Kaushik, 2020).This is because of its low cost, applicability, and consistency of results, it has been modified to more suitably estimate the quantity of soil erosion from agriculture land as in Kongwa district (Pennock, 2019)**.**

Soil erosion has had multiple repercussions, particularly on agricultural lands, and the first step in mitigating soil erosion is to gather reliable information on places that are heavily affected by this problem, which will help to focus on those areas where they can avoid future soil deterioration. However, due to a lack of spatial information, the execution of many policies and mitigation initiatives used to adopt conservation practices in agricultural lands is unsuccessful (Kimaro, 2015). This has resulted in the incompleteness of several programs aimed at monitoring land degradation in order to improve the assessment of the sustainable development goal (SDG) 15.3.1 indicator ("proportion of degraded land over total land area"). However , only few studies have been published to address this problem at a local scale, for example study conducted by (Claessens, 2008)where he focused on regional scale as East Africa and using USLE model. However, this study share the common disadvantage of applying the USLE model which is default methodology and low resolution datasets at national scale to identify areas that are affected by soil erosion.This study will concentrate on identifying areas at a local scale that are prone to soil erosion using high resolution data and effective erosion model.

1.2 Statement of the Research Problem

Land rehabilitation programs have proven to be one of the solutions to combat soil erosion, but the implementation of different mitigation policies and programs, such as Community Environmental Management and Development Organization (CEMDO) for soil erosion, has been hindered. There is limited availability of reliable information on both the location and magnitude of the soil erosion and sediment yield. Mapping of environmental risks as soil erosion is a basic step to mitigate this problem and knowing the magnitude can help in creating sustainability of the land resources. Some studies have been focused on regional scales and used different models, but there is a need to narrow down the research to a local scale where most of the agricultural activities take place.

1.3 Objectives

1.3.1 Main Objective.

To analyze soil erosion-prone areas and estimate sediment yield in Kongwa district, Dodoma region.

1.3.2 Specific Objectives

The precise objectives for achieving the study's primary objective are as follows:

i. To identify factors contributing to soil erosion.
ii. To adapt the RUSLE model to map the prone areas for soil erosion.

iii. To estimate sediment yield from the model result.
iv. To validate the model results using observed data.

1.4 Research question

The research questions are:

i. What are the causes of soil erosion?
ii. Can the RUSLE model be used in mapping of soil erosion and sediment yield?
iii. How accurate is the model results?

1.5 Significance of the study

The following are some of the research's significance:

The findings of this study will be of greater significance to society and researchers since they will provide information on model parameters for mapping the location, magnitude of soil erosion and estimating sediment yield, particularly in areas with similar environmental conditions as semi-arid regions where much of this research has not yet been undertaken. Also better precautions measure will be employed in areas that are more prone to soil erosion and sediement yield through this study's findings

1.6 Beneficiaries of the study

The beneficiaries of this research include:

i. Environmental institution

   It will assist in providing credible information to environmental institutions on areas that should be prioritized for environmental management due to their considerable impact on land production.

ii. Famers

   The information obtained is useful to farmers since it allows them to identify locations that are prone to soil erosion and avoid them for improved agricultural yield. as different agricultural schemes can be well allocated to bring effectiveness in the production.

iii. Construction

   It will inform constructors about where to construct physical infrastructure such as roads, power poles, and houses, as well as how to deal with area sites facing soil erosion. Hence bringing effectiveness in the construction activities.

iv. Researchers

Researchers will benefit from this research information because they will have a reference or basic knowledge on soil erosion and sediment yield prone areas in semi-arid region. If they intend to conduct additional research on land degradation or environmental conservation challenges.

v. Policymakers

Because planners are the primary decision-makers at the regional level, this study is important because it will aid in the proper allocation of various environmental conservation projects that will help combat soil erosion.

1.7 Scope of the study

This research will look at the entire process of analyzing soil erosion-prone areas and estimating sediment yield, where this will include determining the magnitude and location of the areas by looking at a variety of environmental and climatic factors. It will be based on the RUSLE model, which has been updated to better estimate the amount of soil erosion on farmland areas as in Kongwa district. As the result will help in developing appropriate measures to mitigate the effects of soil erosion.

1.8 Description of study area

Kongwa district is located in the semi-arid section of Dodoma region, which is prone to drought. With an area of around 4041km^2, its located between latitudes 5°30S to 6°0S of the equator and longitudes 36°15E to 36°E East of the Greenwich Meridian. The district's administrative territory includes 22 wards, 87 villages, 383 suburbs, and two township authorities. The district is characterized by both high plateaus and hills with steep slopes, as well as an escarpment running east-west. Kongwa town is the District Headquarters and is about 86 kilometers from Dodoma town. Its altitude (height) is between 1000 and 2,000 meters above sea level. The District borders with Chamwino District in the western front; Kiteto District (Manyara Region) in the North; Kilosa District (Morogoro Region) in the East and Mpwapwa District in the southern front. Figure1.1 illustrates the location of the study area.

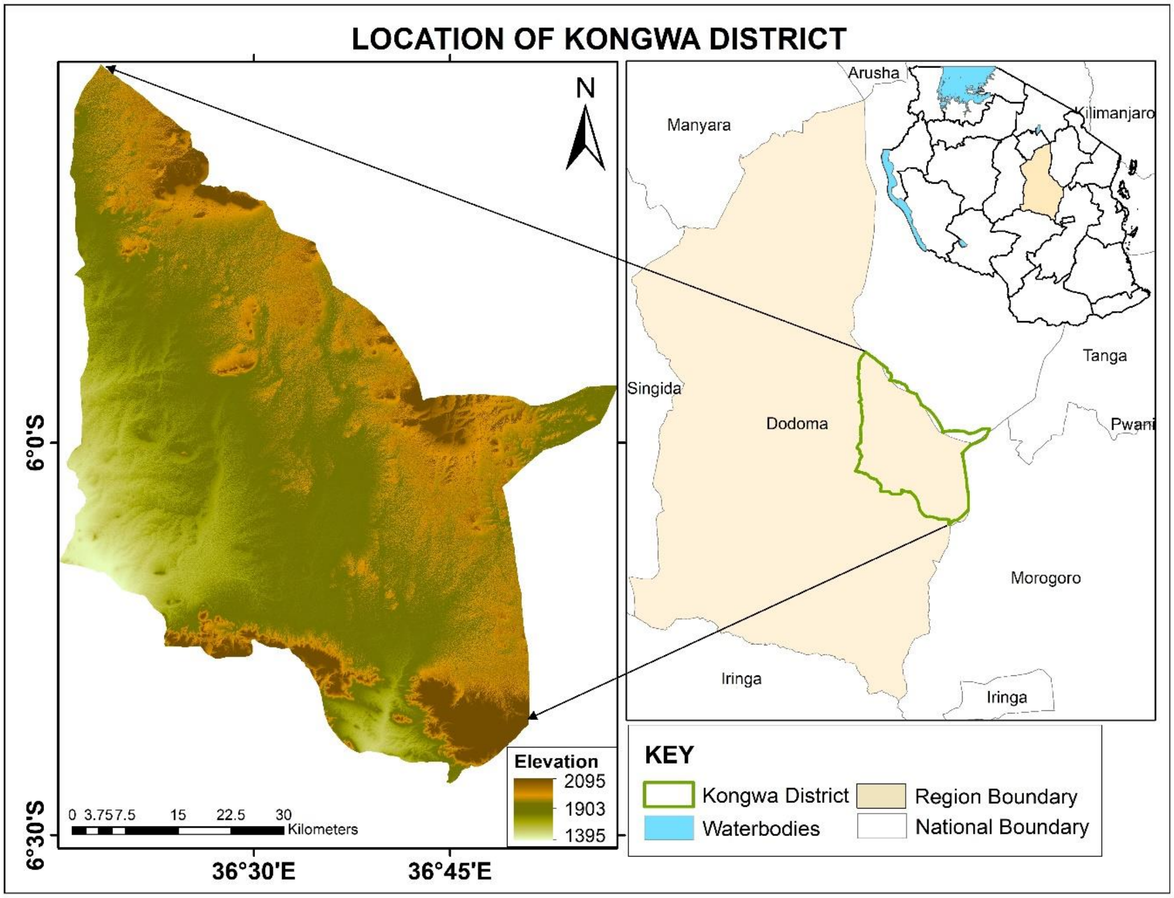

Figure 1.1 Study area

1.9 Software utilized

The tools and software used for the study are outlined below;

- Google earth engine

This online platform was used for downloading the NDVI and Rainfall datasets from MODIS and Terraclim data sources respectively

- R Software

The R programming language through the R studio platform was used for preparation and pre-processing of the data.

- Arc Map

This was used for data processing which is execution of the model and preparation of the model results and maps

1.10 Organization of thesis

The research consists of five Chapters. The first chapter contains background information, research problem, objective of the study, significance of the study, the study area and organization of the research. Chapter two presents a literature review about researches done on soil erosion modelling and estimation of sediment yield. Chapter three describes the methodology followed in order to conduct the current study. Chapter four presents the results and discussion about the findings. Finally, Chapter five describes the conclusions and recommendation.

CHAPER TWO

LITERATURE REVIEW

2.1. Overview

This chapter provides a review of literatures related to soil erosion, sediment yield, all parameters of the Revised Universal Soil Loss Equation(RUSLE), soil erosion model.

2.2 Soil erosion

Despite decades of concerted scientific inquiry and societal concern, soil erosion remains a severe hazard in many parts of the world. The rapid expansion of the world's population has resulted in increased land cultivation (FAO I. , 2015). This increases the strain on land and causes soil to lose structure and cohesion, making it more prone to erosion (Balasubramanian., 2017). Soil erosion is defined as the long-term net balance of all processes that detach and move soil away from its original site (Lupia., 2004). Also can be referred to the wearing away of a field's topsoil by natural physical forces such as water and wind. It's a long process that goes unnoticed, or it can happen quickly, causing significant topsoil loss. Soil erosion, whether caused by water, wind, or tillage, comprises three separate actions soil detachment, movement, and deposition.

2.3. Types of soil erosion:

2.3.1Natural or geological soil erosion:

This occurs when the top soils are gradually removed under normal conditions of physical, biotic and hydrological equilibrium. Sometimes, it is also called geological erosion it take place steadily but long time slowly which develops topographic feature like valley, plains, stream, channel (Telkar., 2018). The normal erosion tends to produce wavy or undulating land surface with alternating ridges and depressions. This is accomplished chiefly by means of slow migration of soil particles from soil surface in successive rains. In arid region, wind during the long dry season is an important factor for normal erosion (Dan, 2019).

2.3.2Accelerated soil erosion:

In accelerated soil erosion the loss of soil occur at a much faster rate than it is formed. It occurs due to disturbance in natural equilibrium of soil by the activity of human and animal through land mismanagement, destruction of forests, over grazing and unsuitable cultivation practices. When the removal of soil does not keep harmony with the soil formation and it is much faster than the latter, it is called accelerated soil erosion (Telkar., 2018).

2.4 Agencies or mechanism of soil erosion:

2.4.1 Water erosion

Soil erosion caused by rainfall is the application of energy from two distinct sources namely, the falling rain drops and the surface flow (Telkar., 2018). The energy of falling raindrop is applied vertically from above whose main role is to detach soil particle, whereas that of surface flow is applied more or less horizontally along the surface of the ground which transport the soil (Ann., 2005).

There are different forms of water erosion

i. **Sheet erosion**

Sheet erosion is characterized by the downslope removal of soil particles within a thin sheet of water, this removes a thin uniform covering of top productive/surface soil from large areas, often from field, during every rain which produces a run-off (Telkar., 2018). Sheet erosion occurs when the entire surface of a field is gradually eroded in more or less uniform way.

ii. **Rill erosion**

This is the kind of erosion which occurs when runoff starts and erosion is no longer uniform as the raindrop impact does not directly detach any particles below flow line in rills but increases the detachment and transportation capacity of the flow. Rills are small channels, which can be removed by timely normal tillage operations (Ann., 2005).

iii. **Gully erosion**

It is more prominent type of erosion in which heavy rainfall, rapidly running water and transporting water may result in deeper cavities called gullies (Telkar., 2018). Gullies cut the large fields into small fragments and in course of time, it makes them unfit for cultivation. Continuous flow of water through gullies further deepens the grooves and may ultimately result in ravines.

iv. Stream-bank erosion.

This erosion takes place on the banks of swollen rivers where it is most active. During the rainy season when fast running water streams take turn in some other directions, they cut the soil and make caves in the banks. As a result of this, quite often large masses of soils become detached and washed away from the banks and are deposited at places in course of streams (Telkar., 2018).

2.4.2 Wind erosion

Wind erosion is the detachment and transportation of soil particles by wind, this occurs when the wind generates sufficient lift and drag to overcome the forces of gravity, friction and cohesion (Balasubramanian., 2017). Wind erosion occurs when the land surface is left bare in regions that are arid enough, as a result of low rainfall, to allow the soil to dry out, and flat enough to allow the wind to carry the soil away over several consecutive days (Ann., 2005).

2.5 Causes of soil erosion

Water and nature of relief is the main cause of soil erosion at Kongwa district but other factors contributing soil erosion are summarized below considering both natural and human induced causes.

2.5.1 Natural causes

This are the main causative agent of erosion as the they can not be easily controlled as illlustarted below.

i. Heavy rains; frequent raindrops on soil particles leads wearing of the soil which is easily transported away due to the amount of water flowing downhill this causes the soil to be carried away so fast.

ii. Steep slope: gravity pulls harder hence the water flow faster downhill, this is the major cause of soil erosion at Kongwa district because of the nature of the relief high plateaus and hills with steep slopes, as well as escarpment.

iii. Sudden climatic change: as intense rainfall, erosion increases unexpectedly rapidly as rainstorms become more severe, drought, water dries up the land hence increasing the intensity of soil to be carried away.

2.5.2 Human-induced factors

This are causes of erosion that induced by human activities, they are illustrated below.

i. Deforestation: as from 2001 to 2020, Kongwa lost 1.67kha of tree cover, equivalent to a 13% decrease in tree cover since 2000 (GFW, 2022). This has been because of burning of trees for charcoal and also bushfires hence accounting for soil erosion in Kongwa district.
ii. Farming method: as the use of plough, excessive use of fertilizer and irrigation damages the land in Kongwa district. As due to presence of hill the poor farming methods makes the land venerable to soil erosion as there are few usage of proper faming methods to reduce impact of erosion in steep slope farms.
iii. Overstocking: The overstocking over an area leads to remove of upper soil. Kongwa is characterized with having large ranches of cattle's of about Kongwa 171,669 cattle's, this leads to over grazing which causes the wearing away of top soil of the land (NBS, 2007).

2.6 Erosion process in the semi-arid region

In semiarid areas, soils with little or no vegetation cover are exposed to torrential precipitation events, which are characterized by short durations and high intensities, and are prompt to the occurrence of physical and chemical processes that change the surface layer conditions, such as surface sealing and crusting (Vasquez-Mendez, 2011). When the surface is dry, a hard layer is formed (crust). Crusting soils are typical of these dry areas, where soil degradation is induced soils by diminishing infiltration rates and increasing runoff and erosion rates (Ries, 2008)

Semiarid areas are considered fragile environments where vegetation cover is scarce and where soil erosion processes occur rapidly and severely after rainfall events fall in these areas, hence vegetation is very significant in the regulation of surface hydrological processes (Vasquez-Mendez, 2011).

2.7 Soil erosion control measures

Some of the following measures can be implemented to prevent soil erosion by reducing surface runoff, reducing runoff speed and capacity, and enhancing soil absorbency to water. All this can be done by encouraging farmers to use contour ploughing and windbreaks, especially in the semi-arid region where there are frequent winds due to bare lands. Also cultivate land using a crop rotation system and strip cropping, where you leave unploughed grass strips between ploughed lands. Avoiding overgrazing and conserving wetlands to make sure plants grow on soil rich in humus (Lupia, 2004).

2.8 Ways of measuring soil erosion

Soil erosion cannot easily be measured over complex area like Kongwa District using traditional methods as ground surveys of erosion but by the use of mathematical erosion models which predict the distribution of eroded land or through mapping then interpretation of remote sensing images (Ellis, 1996). In the past century they have established a variety of models through experiments and observations, resulting in a change from empirical model to model based on physical processes, combining remote sensing, GIS, and other modern scientific and technology tools. Scholars in the United States have undertaken substantial study and developed numerous models.

2.8.1 Ground survey

Ground survey is done to visible soil erosion, where there is presence of rills and gullies within a field, and their associated deposits. The direct assessment of erosion in the field involves recording and measuring field evidence of the action of erosion such as rill and gully depth and extent, exposure of plant/tree roots, exposure of below-ground portions of fence posts and other structures, and the amount of sediment in drains (Dan, 2019). This is done through volumetric measurement of rills, gullies and fans where the amounts of wash and interrill erosion can also be estimated. This approach allows for the estimation of erosion rates at the field scale, rather than relying on extrapolations from plot-based data as the measurements are based on sampling the population of rills and gullies (Boardman, 2020).

2.8.2 Integrating remote sensing and GIS

Through the use of GIS and with high spatial data processing capabilities soil erosion mapping approaches become more robust and comprehensive. This involves the visual interpretation of the free high-resolution remote sensing images, detailed information on land use with several other factors which can help to determine soil erosion areas (Qinke, 2020).

2.8.3 Mathematical models

This tends to describe the behavior of the soil under the rainfall simulation, soil deformation such gullies and surface eroding rills are monitored by using different sources of data (Hossam, 2020). This helps to recognize the differential behavior of the various soil particles and provides greater insight into the movement of soil across both farmlands and other land. Example of recent most used models are USLE, RUSLE, SWAT and PESERA Models.

2.9 Modelling of soil erosion

Models of soil erosion are widely used both to generalize specific field studies for broader application and to provide erosion estimates under different scenarios of controlling factors (Dan, 2019). There are number of models developed in recent decades which are mostly divided into empirical, conceptual and physical. Large example are the RUSLE, USLE, SWAT, and PESERA. The different models have different strength and weakness but the most recent model is the RUSLE model with many researches in the world done on soil erosion have used this model (Hurni, 1985).

2.9.1 RUSLE MODEL

This is an upgrade version of USLE model with higher accuracy on the determination of soil loss over a large area and was developed to include additional data and practices (Hurni, 1985). RUSLE model is an empirical method, computerized algorithm most widely used around the world to predict long-term rates of inter-rill and rill erosion from field or farm size units subject to different management practices (Ganasri, 2016). Due to its clarity and simplicity, the method has been widely applied in several studies and provide estimates of mean annual soil erosion rate using six factors by considering Climate factors, Soil properties, topography of an area, vegetation cover and human impacts/conservation practice (Temesgen, 2020).

The advantage of using the RUSLE model is that it has expanded information on soil erodibility, a slope length factor that varies with soil susceptibility to rill erosion, improved factor values for contour terracing, strip cropping and management practices on range land area (Borrelli, 2021).The disadvantage of RUSLE is that it does not have the capability for routing sediment through channels, hence its application is limited to small areas. RUSLE model estimates the Average annual soil loss for a given site as a product of erosion factors (Renard, 1997) presented in Equation 2.1 of the RUSLE model.

Equation of RUSLE model

A= R*K*LS*C*P…………………………………………………………………….…….(2.1)

Where: A= Amount of soil loss (t/ha/yr.), R=Rainfall erosivity factor (MJ mm/ha/hour/year)

K= Soil erosivity factor (t ha h/ MJ mm/ha/hour/year), LS= Slope Length and steepness factor (unitless), C= Cover management factor (unitless) and P= Support practices factor (unitless)

2.9.2 Rainfall erosivity (R)

Rainfall erosivity contributes to large amount of soil loss and has significant impacts on soil erosion due to the impact of rain in the soil. The R-factor represents and measures the erosive force of a specific rainfall which is determined by the intensity, distribution, duration and pattern of rainfall whether for single storms or a series of storms, and by the amount and rate of the resulting runoff (Tadesse, 2014). The intensity of a specific rainfall is the highest determinant factor of the extent of water erosion (Blanco-Canqui, 2010). The R-factor was developed based on the alternative empirical equation in area with less moist climatic zone due to the lack of rain-fall (Hurni, 1985).

2. 9.3 Soil erodibility(K)

Soil erodibility is the susceptibility of soil to agent of erosion, its estimate the ability of soils to resist erosion, based on the physical characteristics of each soil (Balasubramanian., 2017). This is determined by inherent soil properties such as soil texture, structure, soil organic matter content, clay minerals and transmission properties (Tamene, 2022). Ground cover exerts a strong moderating impact on dissipating the energy supplied by agents of soil erosion. The soil erodibility factor (K), represents both susceptibility of soil to erosion and the amount and rate of runoff, as measured under standard plot conditions. The soil erodibility factor K measures the susceptibility of soil particles to detachments and transport by rainfall and runoff (Renard, 1997).

2.9.4 Slope length (L) and slope steepness (S)

The LS-factor reflected the effect of topography on erosion, which is proportional to the length and steepness of the slope which determined by DEM (Aafaf, 2017). The slope length factor is avital parameter in soil erosion modeling and computing the transport capacity of surface runoff, as the increase in the slope of area indicates the steepness in which soil per unit area increases (Panago, 2015). The equation of slope length factor includes the flow accumulation which is a raster of the accumulated flow to each cell and cell size is the length of a cell side (Mitasova, 1997).

2.9.5 Cover management (C)

The C-factor is defined as the ratio of soil loss from land with a specific vegetation to the corresponding soil loss (Wischmeier, 1978). The C-factor represents the effect of cropping and management practices on erosion rate. The value of C depends mainly on vegetation type, stage of growth, and cover percentage hence becoming an important factor to control risk of erosion due to the main concern on the nature of vegetation of land (Van der Knijff, 2000). The plant cover and techniques of cultivation are the main factors depending directly on the human action that would accelerate or reduce erosion according to the case.

2.9.6 Support practice (P)

The P Factor mainly represents how surface conditions affect flow paths and flow hydraulics. Its reflects the effect of contouring, tillage marks as how are credited with directing runoff around the slope at much reduced grades. However, slight changes in grade can change runoff erosivity greatly (Renard, 1997). The numerical value of P-factor is always between 0 and 1 according to the management of agricultural land. The P-factor value near to 0 indicates good conservation practice, and the value near to 1 indicates poor conservation practice (Wischmeier, 1978).

2.10 Coupling GIS, RS and Modeling

Remote sensing is the science and art of obtaining information about an object, area or phenomenon through analysis of data acquired by a device without physical contact. Remote sensing in the current world has been a powerful instruments for mapping soil erosion risk. Remote sensing helps to increase the accuracy of soil erosion models by making easy availability of accurate data with higher resolution, hence making soil erosion modeling to be fast and effective in a large area. A combination of RS, GIS, and RUSLE is an effective tool to estimate soil loss on a cell-by-cell basis (Kamuju, 2016). GIS tools are used for derivation of the RUSLE model factors and calculation of soil erosion loss

2.11 Sediment yield (SY)

The SY is the sediment load at last point of the slope length, in the channels, at the outlet or sediment basins (Lewoye, 2021). It is the sediment load normalized for the drainage area and is the net result of erosion and deposition processes within a watershed. Sediment yield is an important measure of geomorphic activity which represents the amount of sediment exported at the basin outlet over a period of time (Samad, 2016).

Sediment yield is the net result of erosion and deposition processes within a basin. Thus, it is controlled by those factors that control erosion and sediment delivery, including local topography, soil properties, climate, vegetation cover, drainage network characteristics (Lewoye, 2021).

2.11.1 Methods for Determining Sediment Yield.

The large variety of sediment yield methods can be placed into two broad categories: methods based on direct measurement and mathematical methods. Only those based on direct field measurements are considered a vigorous approach; mathematical methods are best indicators (Colman, 2018).

i. Direct Measurements

The direct measurement method includes the Long-Term Daily Discharge Records. This is the most accurate as the historical sediment discharge is calculated from a long-term sediment gage record. This uses the daily water discharge hydrography and the daily sediment concentration graph, then integrate them to get the daily sediment discharge (Samad, 2016).

ii. Mathematical methods

This involves the application of analytical techniques to calculate sediment yield from watershed, based on sediment and hydraulic parameters. There several techniques which are placed into four categories as sediment transport functions, soil loss equations for small watersheds, bank/gully erosion, and watershed models (Lewoye, 2021). These methods were developed because sediment yields are needed at locations where there are no direct field measurement, and these methods can estimate sediment yield at a specific point without addressing the movement of sediment from point to point within the system.

The RUSLE is one of the most widely used of these equations in sediment yield estimation. It was developed to predict the long-term average soil loss from agricultural land. The RUSLE with a sediment delivery ratio is appropriate for a preliminary estimate of sediment storage for a small area where sediment is expected to come from the watershed or upland area (Gelagay, 2017).

2.12 Sediment Delivery Ratio (SDR)

Sediment Delivery Ratio (SDR) is a fraction of gross erosion that is transported from a given area in a given time interval. It is a measure of sediment transport which accounts for the amount of sediment that is actually transported from the eroding sources to a catchment outlet compared to the total amount of soil that is detached over the same area above that point (Gelagay, 2017).

Sediment Delivery Ratio (SDR) is produced by computing the total area by using the empirical models to estimate SDR as shown as used by (Colman, 2018). SDR decreases with basin size, due to the fact that average slope decreases and the extent of sediment storage sites increases with basin area.

2.13 Soil erosion mapping and sediment yield studies

Different literatures have been writing on analyzing of soil erosion prone areas and estimating sediment yield in different areas as basins, mountain and semi areid areas. The use of Empirical mathematical model have resulted to effectiveness in identifying the soil loss in those areas as summarized below:

The study done on Integration of remote sensing, RUSLE and GIS to model potential soil loss and sediment yield (SY) which was conducted in Malaysia by (Kamaludin, 2013). He explored the potential soil loss distribution at the catchment of Pahang River where the soil loss values obtained ranged from 0 to 95.5 ton ha^{-1} yr^{-1} as the sediment yield of Pahang river catchment with an area of 5120 km^2 averaged at 1.19 ton ha^{-1} yr^{-1}. This showed that area was dominated by low erosion potential which means that most of the sub catchment of Pahang River contributes less to sediment yield in Pahang River.

The study done on Mapping potential soil erosion in East Africa using the Universal Soil Loss Equation and secondary data by (Lieven, 2008). He used the USLE model to estimate soil erosion areas, where he looked on spatially explicit of erosion patterns that would be a great help for planning soil conservation measures. He explained the difficult of using the USLE model at sub-continental level as in term of parameterization of the models and validation of the results.

The study done on to estimate and map mean annual soil loss rates in the Gedalas watershed of the Blue Nile Basin, Northeastern Ethiopia by (Yimam, 2019). Used the RUSLE model coupled with local perceptions to estimate soil erosion in the Blue Nile Basing. The result showed the estimated annual mean soil loss rate of the watershed was found to be 37 t ha^{-1} $year^{-1}$, which is more than two times higher as compared to the maximum tolerable soil loss value (16 t ha^{-1} $year^{-1}$) and the annual erosion rates range from 0 to above 935 ton ha^{-1} $year^{-1}$.

CHAPTER THREE

METHODOLOGY

3.1. Overview

This chapter describes overall the methods of data acquisition, data preprocessing and data analysis methods that were used in obtaining the results. This study adapts the RUSLE model on data processing towards achieving the main objective. The step-by-step process performance in this study is summarized in Figure 3.1.

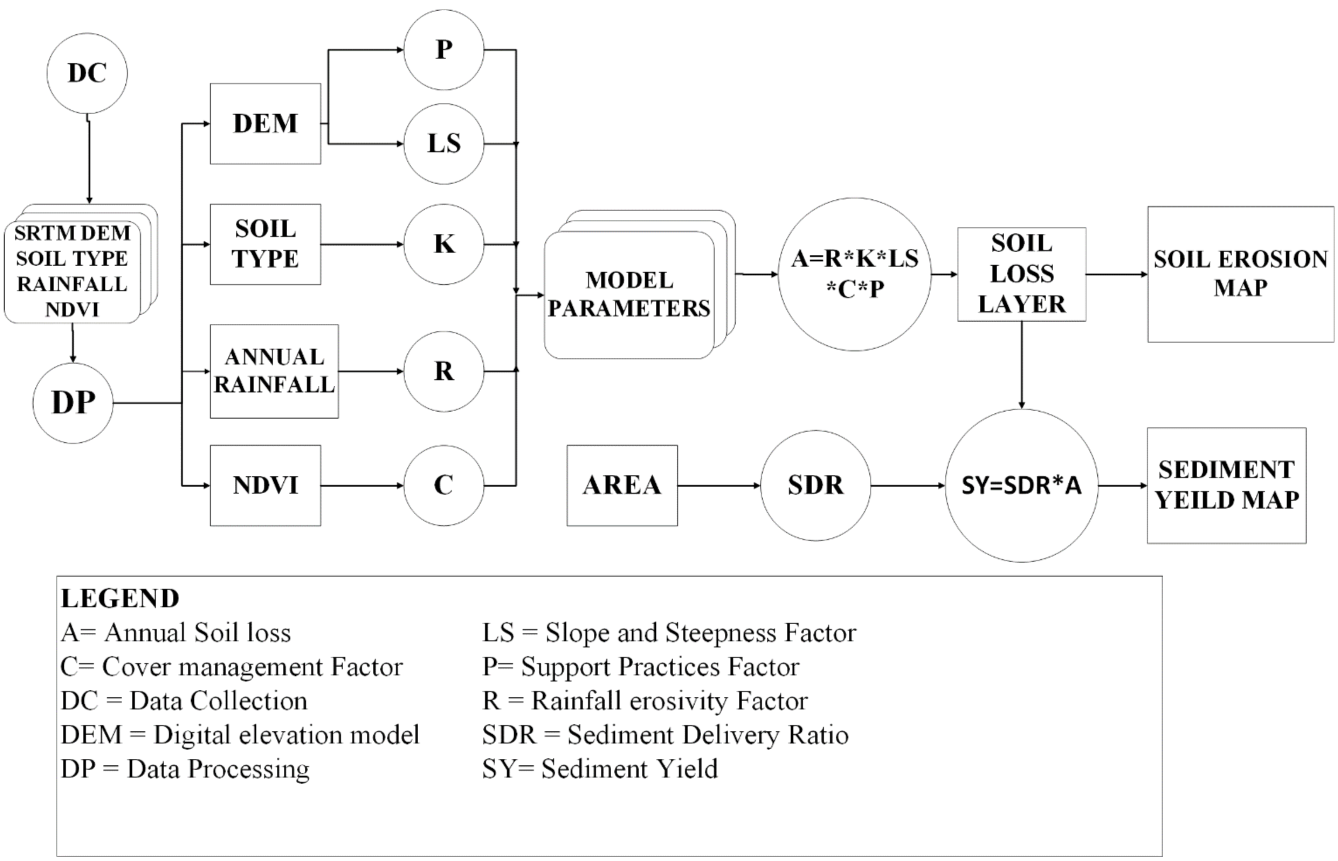

Figure 3. 1 Methodological flowchart

3.2 Data acquisition

The data used in this study are the rainfall data for 2020 in mm, Nomerlized Difference Vegetation Index (NDVI) data from Moderate Resolution Imaging Spectrometr(MODIS) from 2020, also the soil data and elevation data as summarized in the table 3.1.

Table 3. 1 Description of data

NO	DATA	SOURCE	RESOLUTION
1	Rainfall	(http://www.climatologylab.org/terraclim ate.html)	4km
2	Soil	(https://data.apps.fao.org)	
3	NDVI	(https://lpdaac.usgs.gov/products/mod13q1v006/)	250m
4	SRTM	(https://earthexplorer.usgs.gov/)	30m

3.3 Data pre-processing

3.3.1 Reprojection

The soil data from FAO was in a different coordinate system compared to the study area shapefile hence it was reprojected to geographic coordinate system so as it can correspond to other datasets and easier the further steps of processing.

3.3.2 Stacking

The monthly rainfall data for the each year was combined into one layer using stack function so that further pre-processing steps can follow hence makes the data ready for analysis.

3.3.3 Aggregation

For rainfall data the sum function was used to determine the total rainfall for the whole year which results into one aggregated layer with rainfall data. For NDVI data the mean function was used to determine the mean vegetation cover for the whole year which results into one aggregated layer with NDVI data.

3.3.4 Extraction

Since raster data had different coverage as they where downloaded with different extents , they had to be extracted using the administrative boundary shapefile using the crop and mask functions so as to obtain the raster layers with the same coverage as the area of interest and this was done using the raster package in R.

3.3.5 Gap filling

This was done on the downloaded Digital Elevation Model (DEM) as to remove the void or Filling holes hence this process increases the accuracy of the DEM

3.4 Model adaption

Due to environmental condition of Semi arid region of Kongwa District, the use of RUSLE model parameters have to change to fit the study area of semi arid region. The parameters of RUSLE model as described by (Renard, 1997) were modified basing on different current literature as using more accurate equations basing on geographical location of my study for each required parameter so as to fit my research, hence to increase the accuracy of the model.

3.5 RUSLE Model

The RUSLE model is used in this research to map the soil erosion prone areas as it has been revised to more accurately estimate the amount of soil erosion from both crop and rangeland areas and this is due to its reasonable cost, applicability, and reliability of results. The RUSLE model is designed to predict longtime average soil losses for specified conditions (Igwe, 2017). It combines several factors used for modeling the erosion such as climate, soil types, topography, and land use, hence when these factors are combined it gives the annual soil loss in terms of ton/ha.year and a single output map for areas affected by soil erosion. Equation 3.1 shows the input parameters of the RUSLE model.

The equation is: $\boldsymbol{A = R * K * LS * C * P}$……………………..…………………...................(3.1)

Where;

- **A** is the computed soil loss in terms of ton/ha.year.
- **R** is the rainfall-runoff erosivity factor expressed in MJ mm $ha^{-1}h^{-1}yr^{-1}$.
- **K** is the soil erodibility factor expressed in t ha^{-1} MJ mm^{-1}.
- **LS** is the length/slope steepness (unitless)
- **C** is the cover management factor **(**unitless)
- **P** is the supporting practices factor (unitless)

3.6 Preparation of RUSLE model factors

3.6.1 Rainfall Erosivity (R)

Using the rainfall data downloaded from TerraClim with a monthly temporal resolution and approximately 4km spatial resolution to calculate the rainfall erosivity factor. The data where averaged to get the annually average precipitation (rainfall) data of Kongwa. The average annual rainfall of Kongwa district is approximately between 750mm to1653 mm. The equation 3.2 is used in calculating R factor.

$$R = -8.12 + (0.562 * P) \qquad (3.2)$$

Where R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}) and P is the mean annual rainfall (mm)

3.6.2 Soil Erodibility (K)

Using the shapefile for soil types from FAO, i clipped the types of soil that are in Kongwa district which were used to obtain the content of each soil texture in each type of soil type as the percentage content of top soil of clay, sand, silt, and organic carbon. I calculated the values of K factor in raster calculator and edited the attribute table and the soil polygon data was converted into raster layer using polygon to raster tool. The equations below were used for calculating K factor.

$$K = F_{csand} * F_{cl-si} * F_{orgc} * F_{hisand} \qquad (3.3)$$

Where;

(fcsand) K values for soil with higher coarse sand content and higher for soil with little sand.

(fci − si) K values for soils with high clay-silt ratios.

(forgc) K values in soil with high organic content.

(fhisand) K values in soil with extremely high sand content.

$$F_{csand} = (0.2 * \exp[-0.25 * M_S * \left(1 - \frac{M_{silt}}{100}\right)]) \qquad (3.4)$$

$$F_{cl-si} = \left(\frac{M_{Silt}}{M_c - M_{Silt}}\right)^{0.3} \qquad (3.5)$$

$$F_{orgc} = \left(1 - \frac{0.25 * Orgc}{Orgc + \exp[3.72 - 2.95 * Orgc]}\right) \qquad (3.6)$$

$$F_{hsand} = [1 - \frac{0.7 * \left(1 - \frac{M_C}{100}\right)}{\left(1 - \frac{M_C}{100}\right) + \exp[-5.551 + 2.29(1 - \frac{M_C}{100})}] \qquad (3.7)$$

Where:

ms- The sand fraction content (%), msilt - the silt fraction content (%), mc - the clay fraction content (%), Orgc-organic matter content (%)

3 6.3 Cover Management (C)

The equation 3.8 was used to compute C Factor is based on remote sensing approach using Normalized Difference Vegetation Index (NDVI). NDVI layer was first pre-processed and aggregated to get the mean annual NDVI and then the formula was imported in the raster calculator.

$$C = \exp[-2 * (\frac{NDVI}{(1-NDVI)})] \qquad (3.8)$$

3.6.4 Topographical Factor (Ls)

The LS factor was calculated through the combination of slope layer and flow accumulation layer using the equation3.9 in raster calculator tool in ArcMap.

$$LS = [flow\ accumulation * \frac{Cell\ size}{22.13}]^{0.4} * [\frac{\sin slope}{0.0896}]^{1.3} \qquad (3.9)$$

3.6.5 Supporting Practice (P)

P factor is calculated with respect to the percentage of slope layer by using equation 3.10 in raster calculator tool in ArcMap.

$$\mathrm{P} = 0.2 + 0.03 * \mathrm{S} \qquad (3.10)$$

Whereby S is the slope gradient.

3.7 Sediment Delivery Ratio (SDR)

Sediment Delivery Ratio (SDR) was produced by computing the total area by using the empirical models to estimate SDR as shown in equation 3.11.

$$SDR = a*D^{-b} \qquad (3.11)$$

Where D is the drainage basin area; and a and b are correction factors related to the physical characteristics of the basin. The adjustment b variable has physical characteristics of sediment transport and is interrelated with the rain-flow phenomenon, and the negative sign signifies that with an area increase, the SDR decreases.

3.8 Sediment Yield (SY)

Sediment yield was quantified using the channel Area based SDR model, and the Annual soil loss of the area which had already been produced. Thus, spatially distributed map of sediment yield was produced through cell by cell multiplication of sediment delivery ratio (SDR) and the raster layer of mean annual soil loss in Arc GIS environment. SY values were calculated using equation 3.12.

$$SY = SDR \times A \qquad (3.12)$$

Where SY = sediment yield (ton ha^{-1} yr^{-1}), SDR = sediment delivery ratio and A = annual potential soil loss (A) (ton ha^{-1} yr^{-1}).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Overview

In this chapter the results obtained through the implementation research methodology and discussion are presented according to the intended objectives of this research which was to analyse soil erosion and sediment yield in semi arid area. These results include maps showing the factors that contribute to soil erosion and the factors for the rusle model, also the model results are presented after intergrating the factors and the sediment yield map of Kongwa district. The discussion section shows how the results have correlated with other studies done on similar geographic environment

4.1 Factors contributing to soil erosion.

4.1.1 Vegetation cover.

In Kongwa district, the results show that, distribution of vegetation cover is sparse especially in central part cover of the district compared to the southern part which is characterized by mountains and contains vegetation, this has accelerated the rate of soil erosion, vegetation has been cleared for grazing, woods, and cultivation thus left the bare land, see figure 4.1.

4.1.2 Slope

The slope map results from figure 4.2 show that, most of severely eroded parts in the south of the Kongwa district have high slope gradients and these areas has high rate of soil erosion. Generally, the steeper the slope, the greater is surface runoff velocity and volume and so the higher the erosion risk, with other variables held constant.

4.1.3 Soil type

In Kongwa district, soil type map results in figure 4.3 show that major components of soil are Ferric Acrisols, Chromic Cambisols, Eutric Nitosols. These soils are characterized by truncated soil profiles usually missing the ‘A’ horizon (mineral, mixed with humus, dark colored). They are generally shallow, have low organic matters and friable. That they are normally coarse and permeable makes their erodibility potential very high.

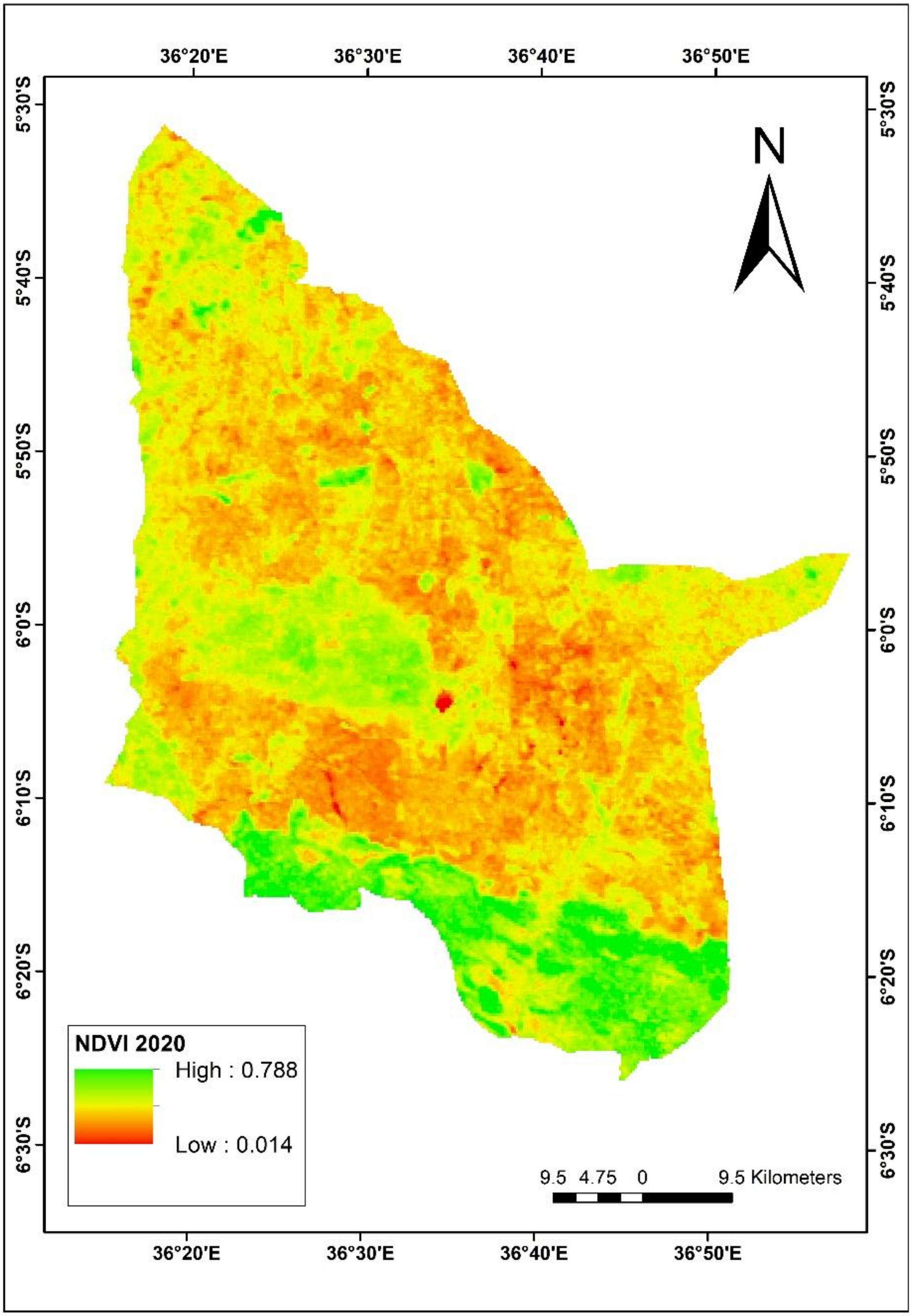

Figure 4. 1 Vegetation cover map

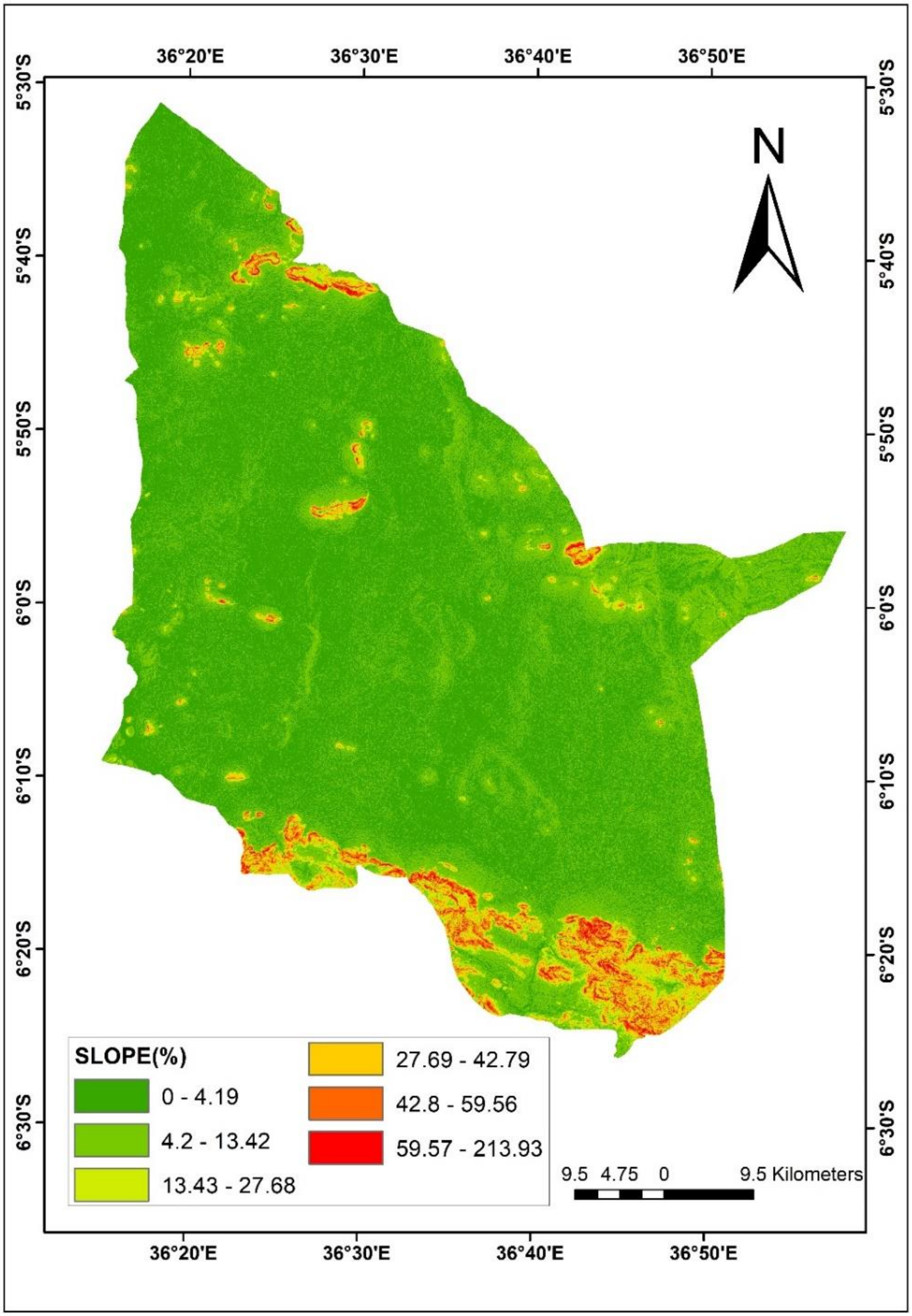

Figure 4. 2 Slope map of Kongwa district

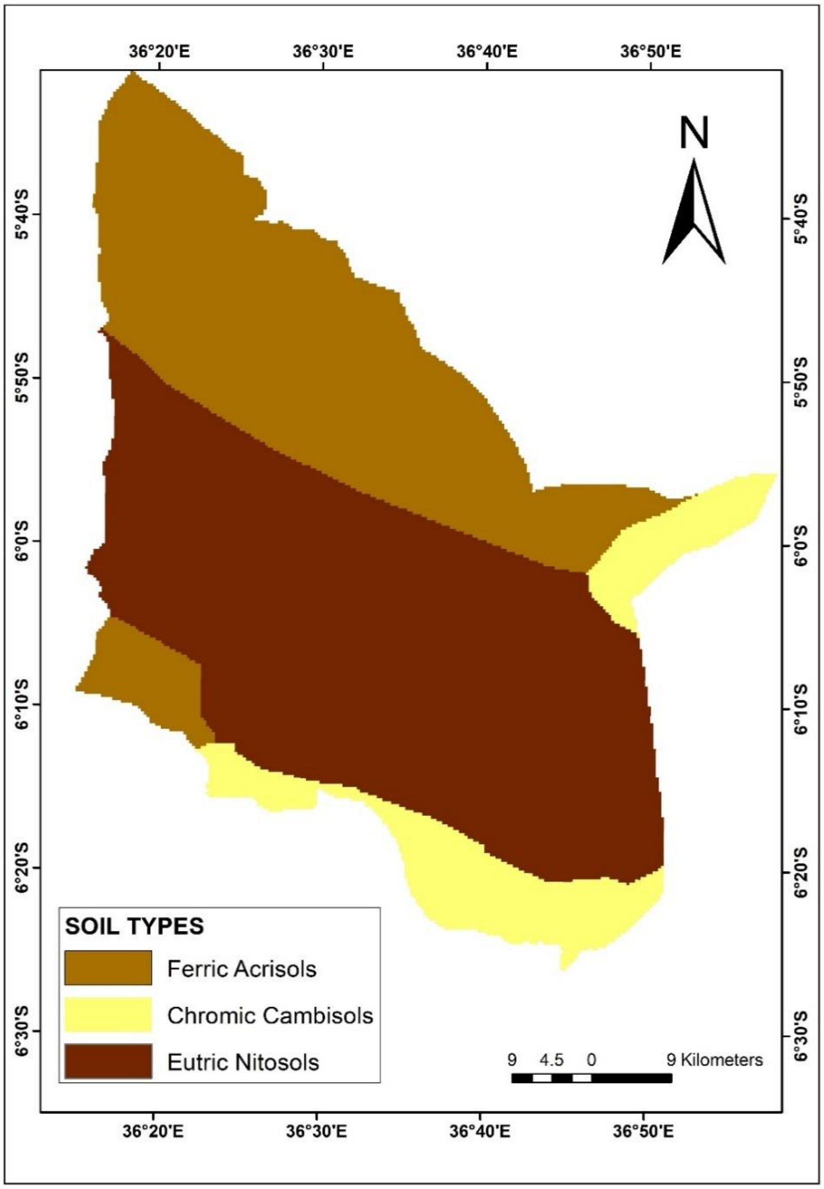

Figure 4. 3 Soil type map of Kongwa district

4.1.3 Rainfall

Kongwa district is semi-arid with a mean annual rainfall ranging between 750-1600mm as seen in figure 4.4. Rainfall in Kongwa is distributed between October to may but the most frequent rainfall events occur in January and are of high intensity causing rapid runoff capable of creating flashy floods in streams and rivers. In January the rainfall has the most erosive potential. At this time of the year much of the agricultural land area has been prepared and is ready for planting. The soils are therefore loose and erodible.

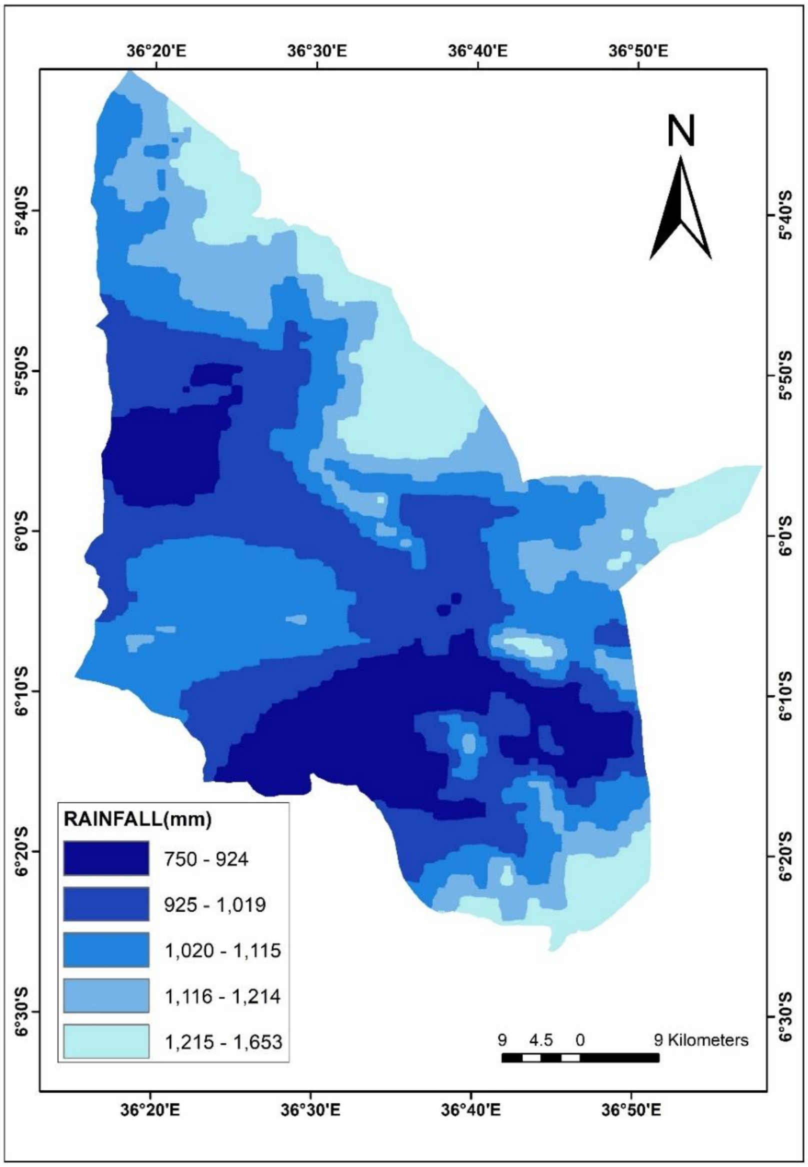

Figure 4. 4 Annual rainfall map of Kongwa district

4.2 Thematic map layers of identified factors for RUSLE model

4.2.1 Rainfall-runoff erosivity factor (R factor)

Rainfall erosivity was prepared for the calculation of R factor using the method described above in equation 3.2. The low values of R factor represent low rainfall intensity and vice versa is true. R factor map shows that rainfall Intensity is high in the northern part of the district and lower part of the district. An average R factor values in Kongwa district ranges from 413.38 to 920.87 MJ.mm/ ha. h. yr, see figure 4.5.

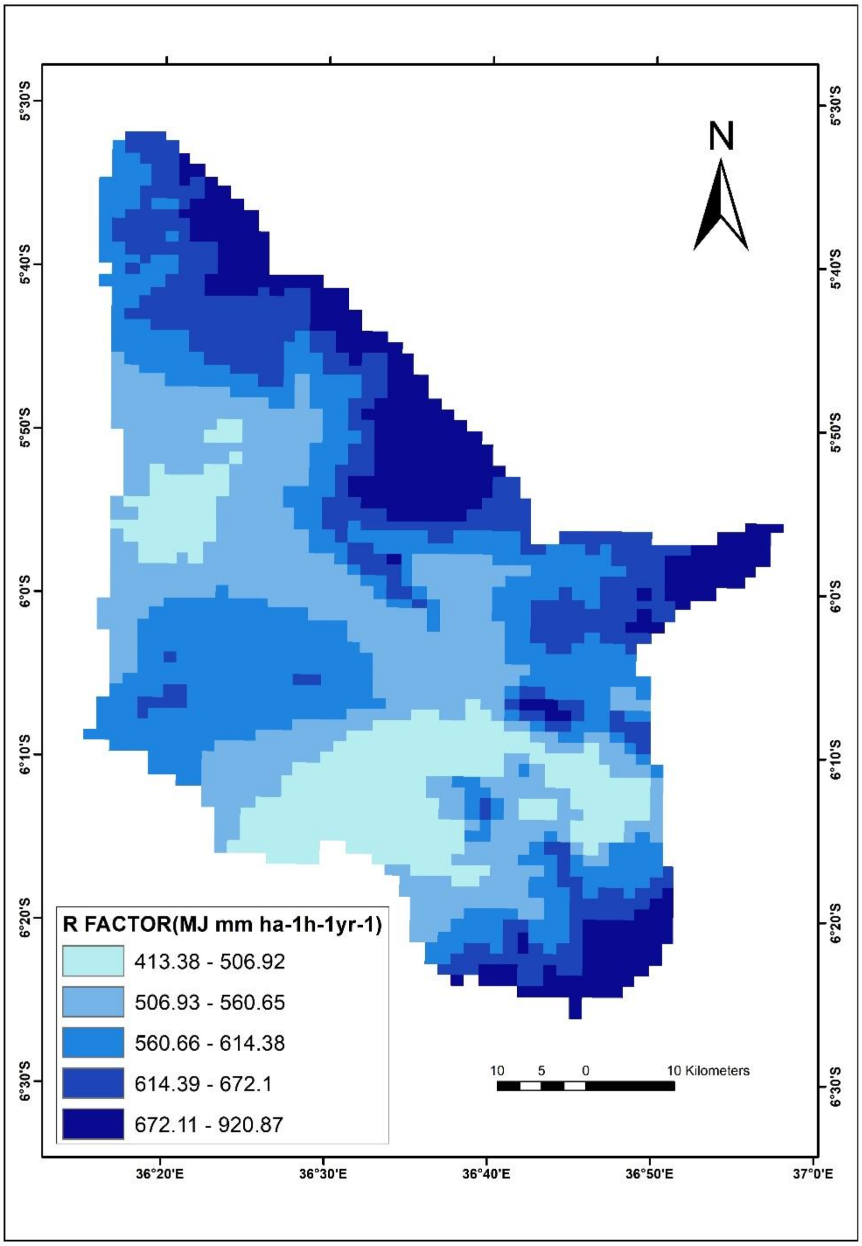

Figure 4. 5 Rainfall erosivity factor map of Kongwa district

4.2.2 Soil erodibility factor (K factor)

The K valueas were calculated basing on the equations showed in previoud chapter, In this case study K factor ranged from 0.121 to 0.139 with maximum as shown in figure 4.6 whereby the lower value of K factor is associated with the soils having low permeability and low antecedent soil moisture. The higher value of K factor is vulnerable to soil erosion because these are soils with low organic contents.

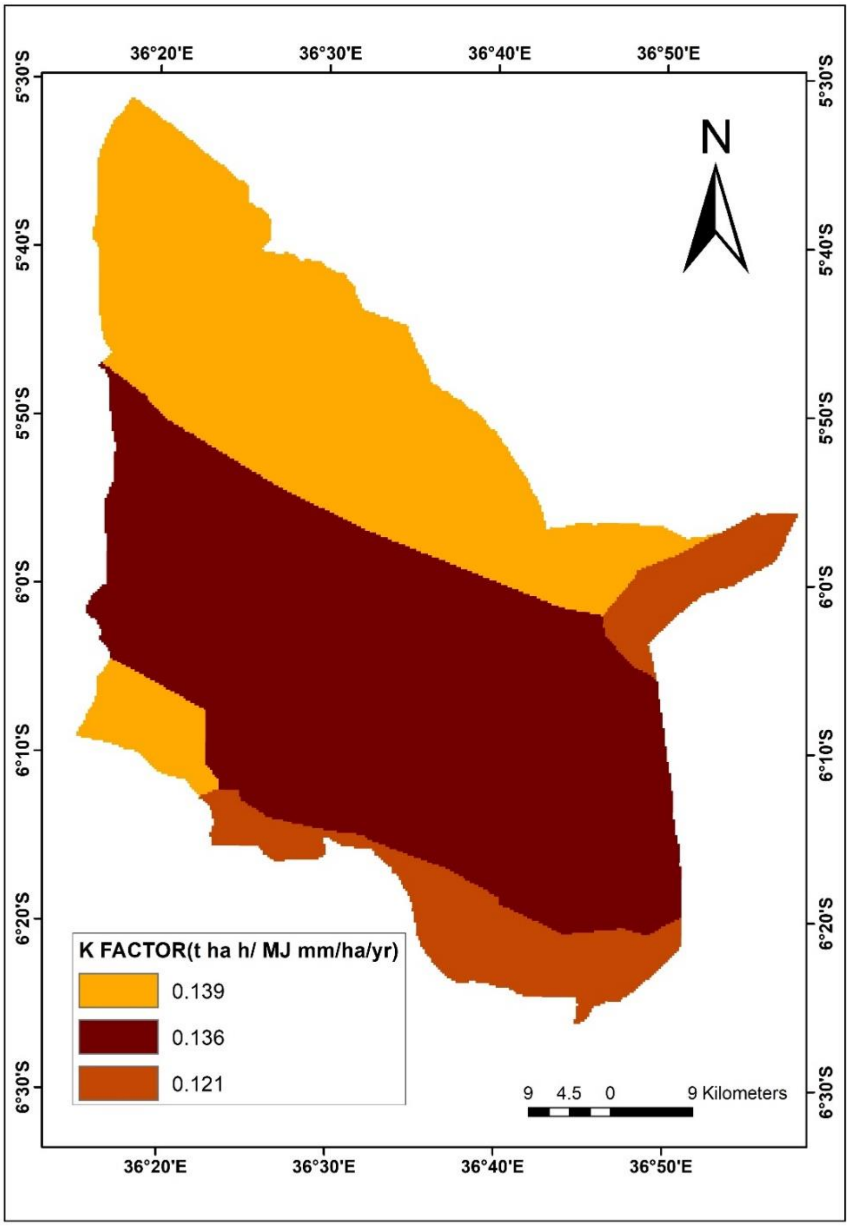

Figure 4. 6 Soil erodibility factor map of Kongwa district

4.2.3 Cover management factor (C factor)

In this case study C factor ranged from 0.001 to 0.97. The results from NDVI shows that, there is a sparse vegetation in Kongwa district, this lead to have high values of C factor in. The C factor was calculated by formular in equation 3.8 and showed that higher C values represent more potential for soil erosion and vice versa, high values of C factor are assigned to bare land where 0 value represent dense vegetation. The distribution of C factor is shown on a figure 4.7.

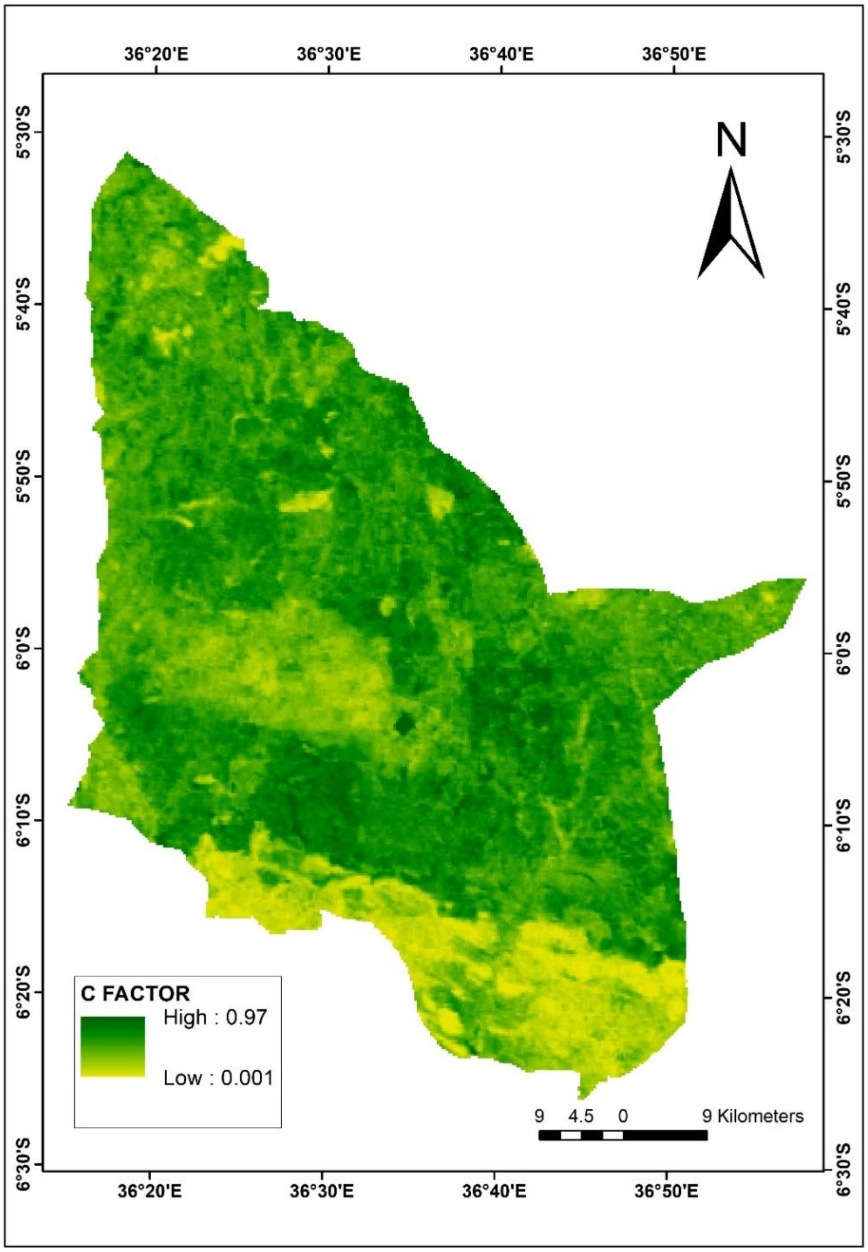

Figure 4. 7 Cover management factor map of Kongwa district

4.2.4 Slope length and slope steepness factor (LS factor).

The distribution of slope in Kongwa district ranges from 0 to 213.93 percent which represent very high range of slope, look on figure 4.8. The flow accumulation of the Kongwa district range from 0 to 1, when slope and flow accumulation increase LS factor also increases, LS factor value range from 0 in flat land to 5.73 in high land. The LS factor map implies that the high value in the south, greater its potentiality to erode in these zones.

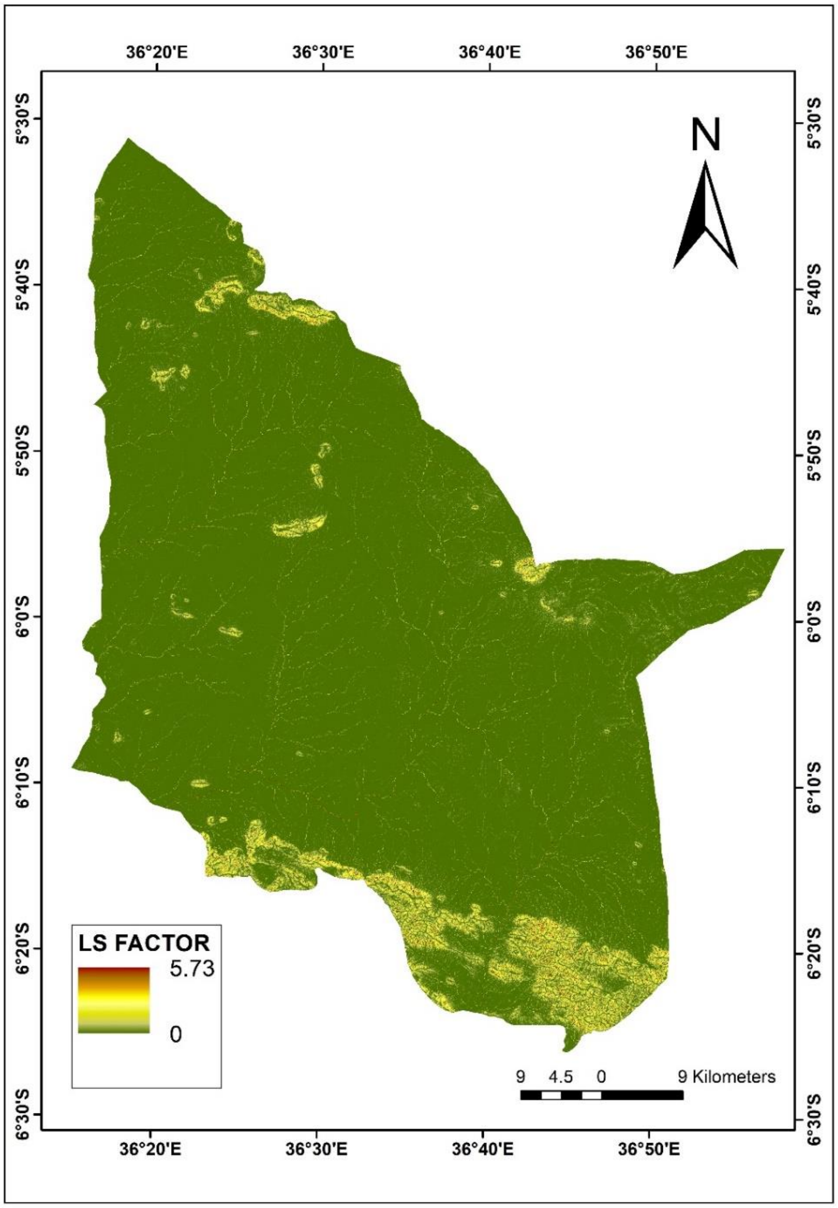

Figure 4. 8 Slope and steepness factor map of Kongwa district

4.2.5 Support practice factor (P factor).

P factor values is calculated from the slope values refer to equation 3.10 in recent chapter. The result in figure 4.9 shows that there is high degree distribution of P value in the center of the Kongwa district which ranges from 0.5 to 1, because of high slope in the area the support practices are no longer function. Higher P value represent high risk to soil erosion and vice versa is true.

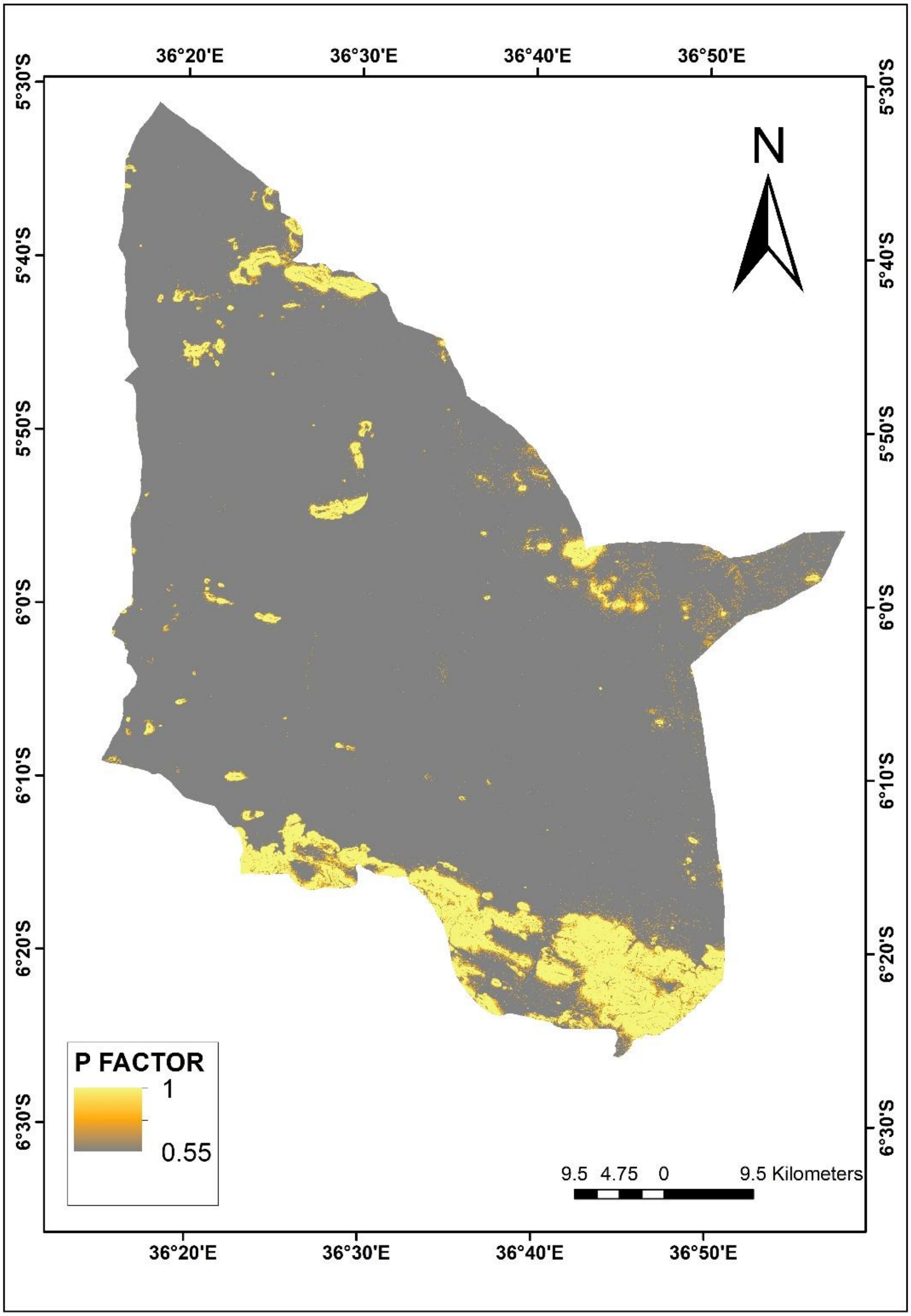

Figure 4. 9 Support practices factor map of Kongwa district

4.3 Soil erosion map

A map of soil erosion in Kongwa district shows that the risk areas are spatially confined in the areas of steep slope, lower support practices, shallow soils and sparse vegetation in the southern parts of the district as seen in figure 4.10.

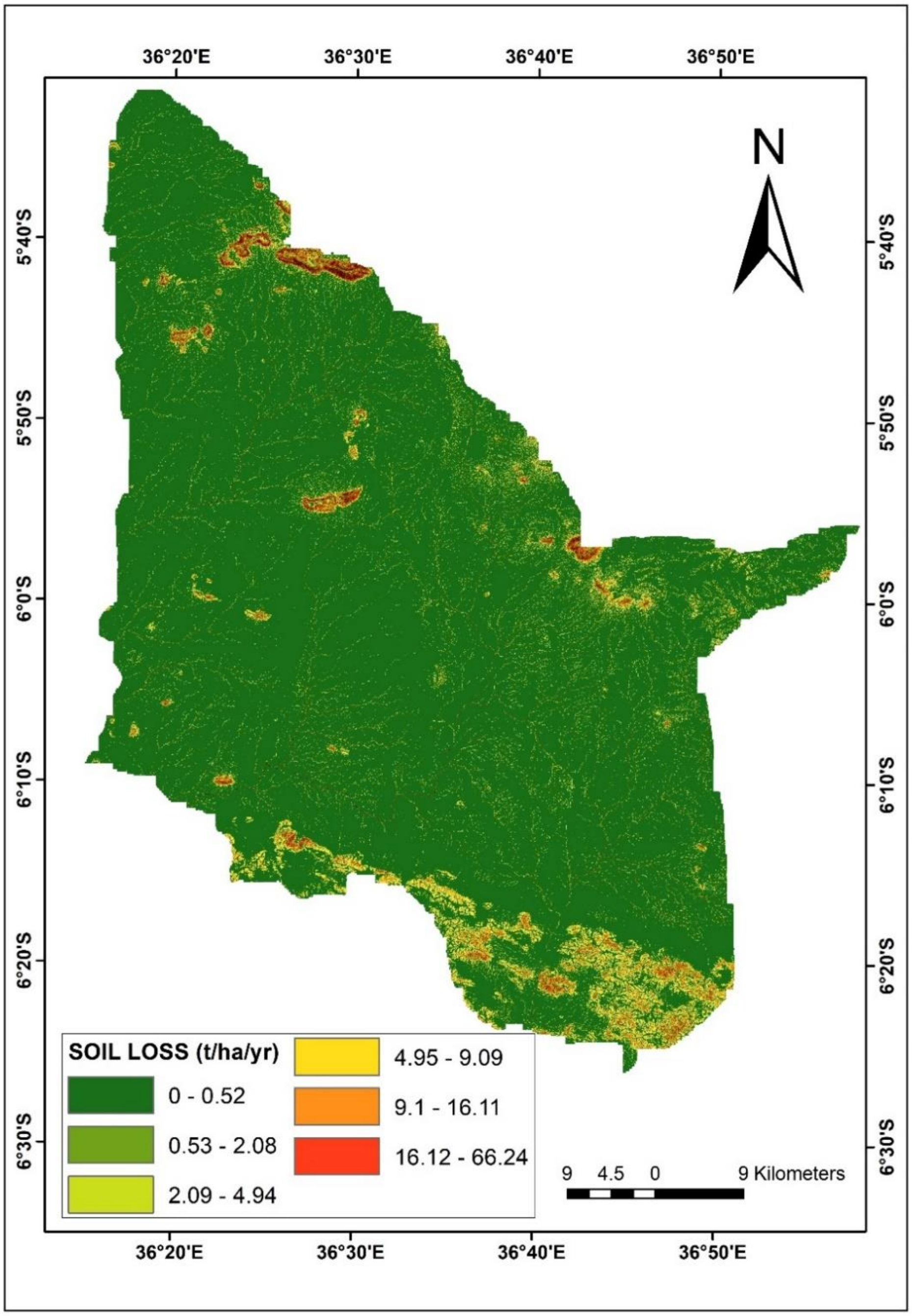

Figure 4. 10 Soil loss map of Kongwa district

Table 4. 1 Estimated soil loss in Kongwa District

Soil erosion risk	Soil loss (ton/ha. yr)	AREA(Km2)
Very Low	0 - 0.52	3625.47
Low	0.53 - 2.34	266.78
Moderate	2.35 - 5.97	55.25
High	5.98 - 12.73	13.31
Very high	12.74 - 66.24	2.17

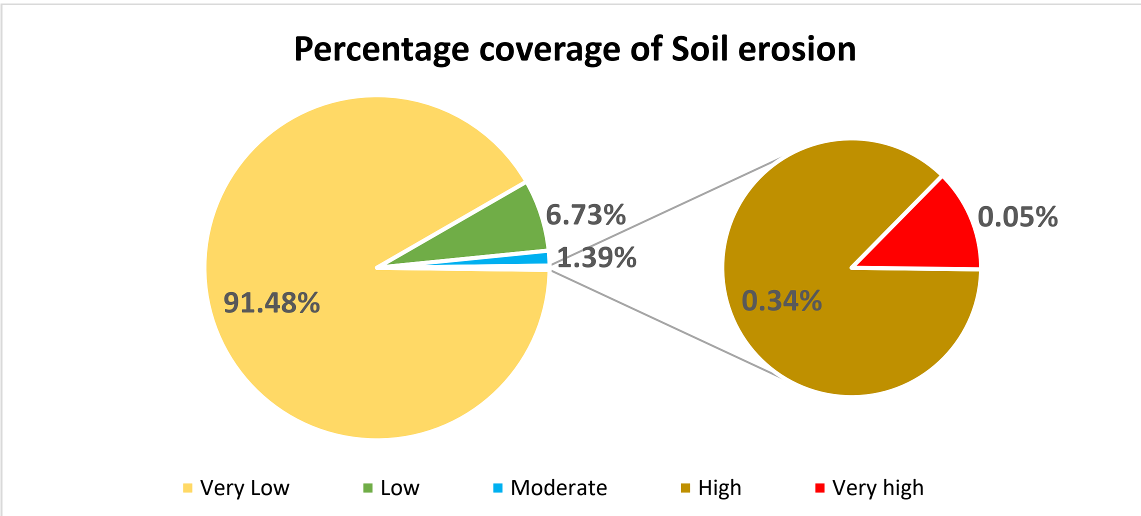

Figure 4. 11 Percentage coverage of soil erosion in Kongwa district

The analysis of the results in table 4.1 conclude that the annual soil loss estimated using RUSLE model is about 66.24 t/ha/yr in Kongwa district. It is also observed that the quantity of erosion varies mainly on topography and vegetation cover. Figure 4.11 reveales that about 4% of the area comes under high and very high erosion category. It is necessary to implement suitable soil conservation practices in such areas, especially by analyzing the impact of increase in agricultural area on soil erosion.

4.4 Validation of soil erosion prone areas

The validation of the soil erosion result was done through the high resolution satellite images to show the places that area eroded with respect to their specified locations on the soil loss map which is the model results as illustrated in figure 4.11.This provides evidence for the effeciency of the application of RUSLE model for identification of the area that are prone to soil erosion.

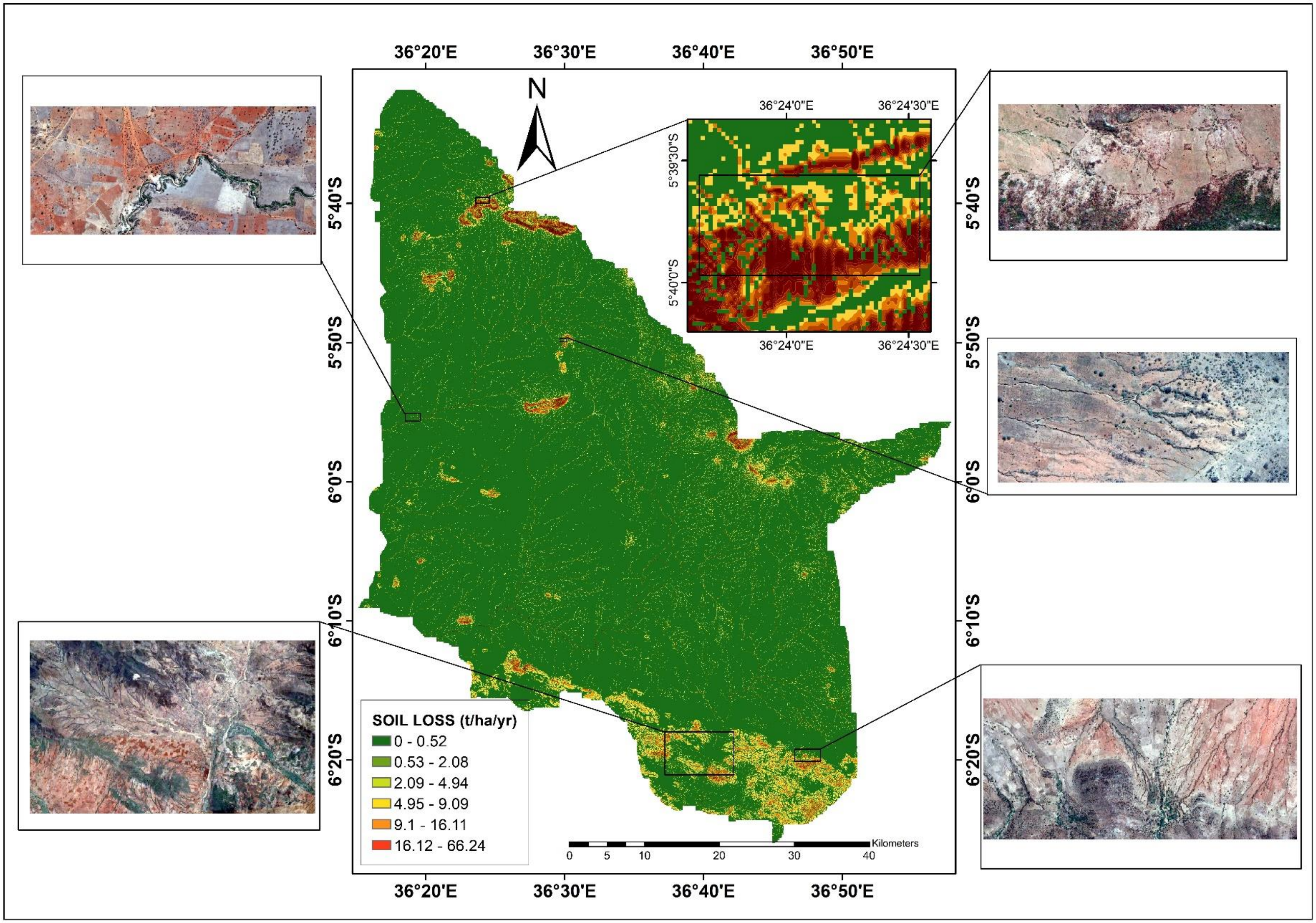

Figure 4. 12 Soil erosion validation map of Kongwa district

4.5 Sediment yield

The sediment yield concentrations is influenced mainly from surface runoff erosion, vegetation type and topographic factor. Figure 4.12 depicts the sediment yield distribution was classifed into fve categories according to their proportion of distribution. The annual sediment yield concentration in Kongwa district is found to be 13.58 t/ha/year. The sediment yield distribution from the entire district was followed by the same pattern of soil erosion and the deposition of the erosion came in the areas which are mainly affected by soil erosion.

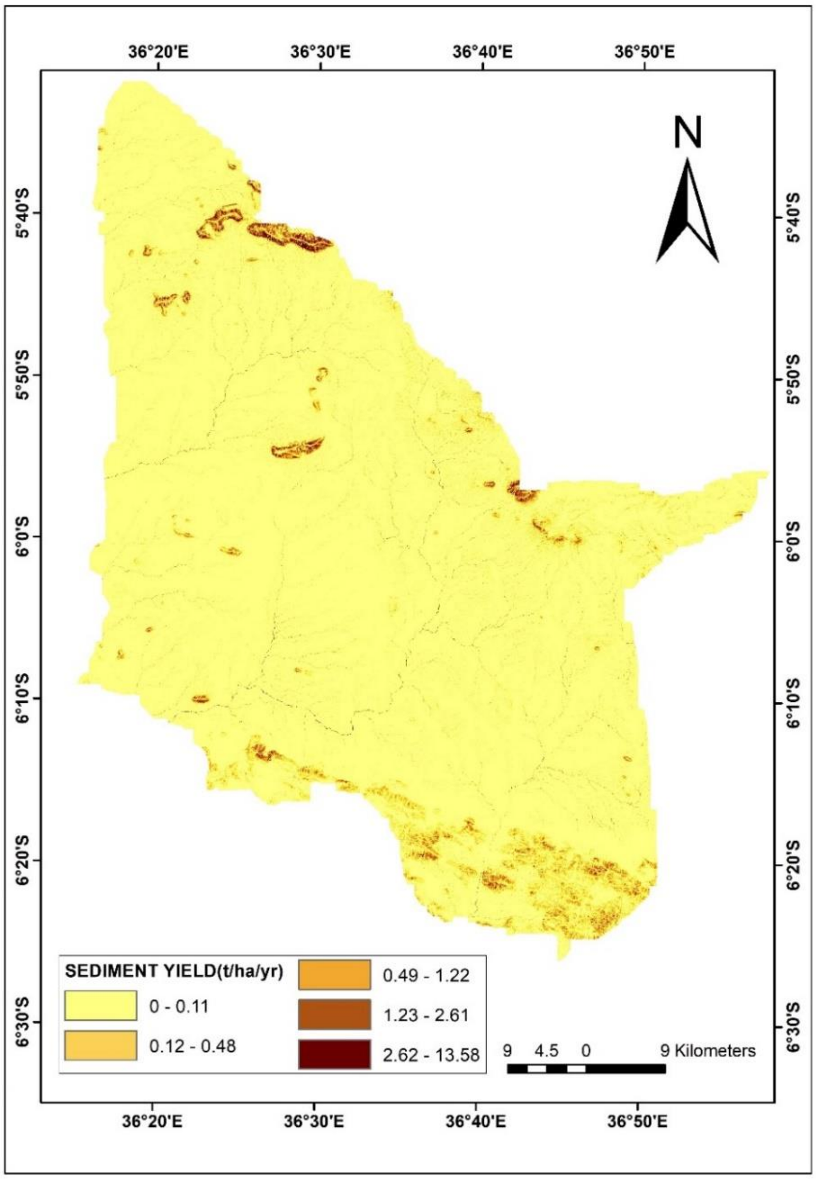

Figure 4. 13 Sediment yeild map of Kongwa district

4.6. Correlation between Sediment yield and soil erosion

The point data obtained from repective area for both the sediment yield and soil erosion were used for checking the correlation as seen in figure 4.14.

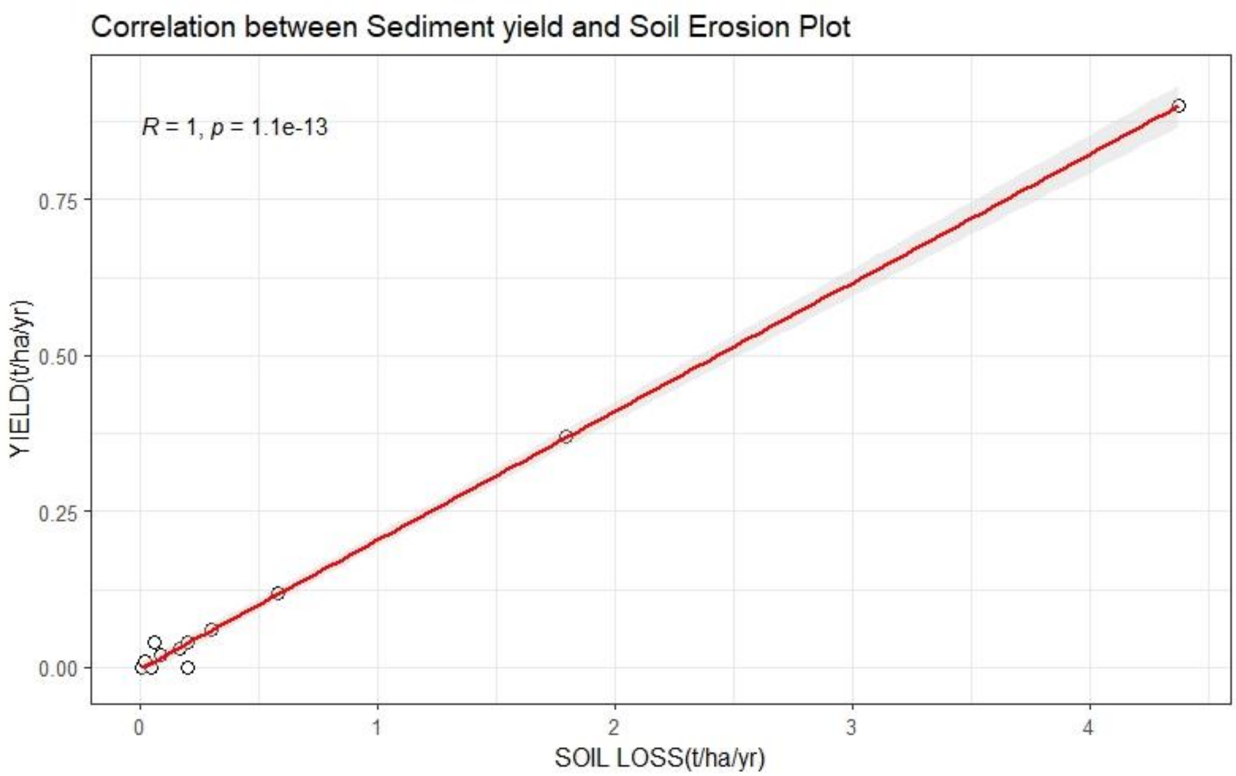

Figure 4. 14 Correlation between soil erosion and sediment yield

The correlation between soil erosion and sediment yield in figure 4.13, had a coefficient of determination of 1, confirmed that the contribution of sediment load is controlled by the total quantity of soil loss produced for each location. This is because the amount of sediment delivered to the downstream is determined by multiplying the expected soil erosion by the sediment delivery ratio.

4.7 DISCUSSION

Soil erosion is a severe issue, particularly in the Kongwa district, where various variables contribute to fast soil erosion and sedimentation. The rate of runoff and sedimentation is accelerated by factors such as the region's steep slope,poor vegetation cover and the impact of a raindrops and the cutting force of running water causes soil particles to detach. High intensity rainfall makes the detachment of soil particles quicker and causes the mass movement of sediments along the runoff generated in a sloppy area (Maqsoom, et al., 2020). The topography and high elevation are usually the main reason for high intensity precipitation hence increasing the influece of the land to be eroded (Ullah, 2018). As terrains with gentle slopes contributed low soil loss but the higher the slope the greater the soil loss, hence this all contribute to a higher value of soil loss in Kongwa district of 66.24 ton/ha. year.

The results have correlated with similar studies carried out in different parts, which have employed the RUSLE model and in areas having similar geo-environmental and rainfall characteristics and obtained similar results of high amount of erosion as seen in research done by (Thapa, 2020). He obtained a severe erosion of > 80 t/ ha-1yr-1 as due to the area is characterized by steep slope. Also (Prasannakumar, 2012) had a resultant map of annual soil erosion which showed a maximum soil loss of 17.73 t h-1 y-1 were he illustrated how the steep slope and intensity of rainfall influenced soil erosion. This validates the applicability of the proposed method in the study area as the soil erosion rate calculated in these studies are found to be appropriate and matching to this study.

The amount of soil erosion also influenced the amout of sediment yield of Kongwa district as the Sediment delivery ratio(SDR) decreases with increase in area or stream length, and this is also observed by other researcher (Colman, 2018). The obtained annual amount of sediment yield of 13.58 t/ha/yr which illustrated that only about 20% of the eroded material are to be deposited after erosion. This correlates to research done by (Mulemgera, 2008) where he predicted sediments yields ranging from about 6 t/ha.year to 12 t/ha.year and he compared with the observed sediment yield and obtained coefficent of determination (R^2) equal to about 0.53.

The correlation between soil erosion and sediment yield which had the coefficient of determination of 1 replicated that the contribution of sediment load is influenced by the total amount of soil loss produced for respective places. This is because the estimated soil erosion is multiplied by the sediment delivery ratio to determine the amount of sediment deliverd to the downstream.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study has been able to analyze soil erosion prone areas and sediment yield in Kongwa by integration of the RUSLE model and sediment yield modeling in the GIS environment, whereas it has estimated an annual soil loss (66.24 ton/ha/year) and sediment yield (13.58 t/ha/year). It has also revealed that there is a strong positive correlation of 1 between soil erosion and sediment yield which illustrates that there is relative increase of sediment yield due to increase in soil erosion. The study also demonstrates that poor vegetation cover, steep slopes, and severe rainfall are powerful factors of this high erosion. As visible in high resolution satellite images which validates that, erosion and sediment yield is a major concern that needs to be addressed properly.

5.2 RECOMMENDATION

Based on the findings and conclusions reached, this study advises the following,

1. The environment conservation planners should use the soil erosion map produced for restoring degraded land and vegetation (planting trees, reducing grazing), also advising a suitable cropping pattern (contouring, terracing and strip cropping) for agricultural land in local level. Also, Environment Impact Assessment (EIA) must be performed prior to allocation for the development of any new infrastructure.
2. The sensitivity analysis of RUSLE model parameters should be carried out to ensure effectiveness of model results.

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