SPATIAL ESTIMATION OF SOIL EROSION USING USLE MODEL

CASE OF RUNGWE DISTRICT

by

MTEY SIMON M

A Dissertation submitted in the Department of Geospatial Sciences and Technology in partial fulfilment of the requirements for the award of Bachelor of Science degree in Geographic Information System and Remote Sensing (GIS & RS) of Ardhi University.

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The undersigned certify that they have supervised and proof read the dissertation and hereby recommend for acceptance by Ardhi university of a dissertation document entitled "**SPATIAL ESTIMATION OF SOIL EROSION USING USLE MODEL IN RUNGWE DISTRICT"** for University Examination.

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Dr. Atupelye Komba Mr. Gadiel Mchau

(Supervisor) (Supervisor)

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I, Mtey Simon M declare that this dissertation is my own original work and that to the best of my knowledge, it has not been presented to any other University for a similar or any other degree award except where due acknowledgements have been made in the text.

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MTEY SIMON M

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ABSTRACT

Soil is a natural resource that may look robust and endless, but is in fact the fragile product of thousands of years of formation of topsoil, which lies closest to the surface of the land, contains essential nutrients for crops.

This study explores the vulnerability of soil erosion within the Rungwe district, highlighting the delicate nature of soil formation and its indispensable role in sustaining agricultural productivity. Soil erosion, the detachment and movement of soil particles by natural forces, is a critical environmental concern, resulting in diminished topsoil fertility, reduced agricultural output, water contamination, and land deterioration.

The widely employed Universal Soil Loss Equation (USLE) facilitates erosion rate estimation by considering contributing factors. To assess the annual soil erosion potential in Rungwe, the USLE model was applied to determine erosion intensity across the landscape. Results indicate diverse erosion levels, ranging from minimal to extremely high, with areas of dense vegetation exhibiting lesser erosion risk. Agricultural regions demonstrate moderate erosion potential, demanding soil conservation measures. Notably, the findings underscore the importance of targeted conservation strategies in high-risk areas, emphasizing the significance of preserving soil integrity for sustainable land use. This study's classification framework aids in assessing erosion severity and guiding conservation endeavors in the district.

The projected average annual soil loss varies from 0 to 48.34 t/ha/y. Areas with minimal soil loss (<1.4t/ha/y) were identified in heavily forested regions, while areas with low soil loss (1.5-6.8 t/ha/y) were primarily observed in densely planted areas and degraded forest zones. Agricultural areas were predicted to have moderately high soil erosion rates (6.9-18.3 t/ha/y), necessitating appropriate soil conservation measures to mitigate erosion. A high rate of soil erosion (>23.5 t/ha/y) was detected due to moderate slope values and elevated slope length and steepness factors. Based on the erosion risk categories, it was observed that 80-90% of the area faced negligible to slight erosion risk, while only 20-10% of the area faced moderate to extremely high erosion risk.

The study's results indicate that some areas in Rungwe district has a relatively low erosion potential due to its gentle slope. However, there are specific areas with moderate to high erosion risk that necessitate appropriate soil conservation measures to prevent soil loss and degradation

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ACRONYMS AND ABBREVIATIONS

GIS	Geographic Information System
USLE	Universal Soil Erosion Equation
FAO	Food and Agriculture Organization
USGS	United State Geological Survey
MODIS	Moderate Resolution Imaging Spectrometry
NBS	National Bureau of Statistic
NDVI	Normalized Difference Vegetation Index
PESERA	Pan-European Soil Erosion Risk Assessment
WEPP	Watershed Erosion Prediction Project

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Soil is a natural resource that may look robust and endless, but is in fact the fragile product of thousands of years of formation of topsoil, which lies closest to the surface of the land, contains essential nutrients for crops (Ganasri, 2015). It is this layer of soil that is endangered by wind and water erosion. Soil erosion decreases soil fertility, which can negatively affect crop yields. It also sends soil-laden water downstream, which can create heavy layers of sediment that prevent streams and rivers from flowing smoothly and can eventually lead to flooding. Once soil erosion occurs, it is more likely to happen again (Sulaeman, 2020).

Soil erosion is an extensive land degradation problem in many parts of the world. The loss of soil from the land surface by erosion is widespread globally and adversely affected by the productivity of all-natural ecosystems as well as agricultural, rangeland, and forest ecosystems

Soil erosion causes the loss of topsoil, which decrease the fertility in agricultural land. Spatial estimation of soil erosion essential for an agriculture-dependent country like Tanzania for developing its control plans. The study based on evaluated the factor contributing to the soil erosion using revised universal soil loss equation (USLE) model

Soil erosion is a significant problem in developing countries, particularly in India, where it affects agricultural production. Rungwe district, in Tanzania, is an agriculture-based district with a rugged topography due to hill erosion. To predict soil erosion, several models such as WEPP, WATSED, and USLE have been developed over the past 50 years (Bera, 2017). The USLE model is one of the most widely used for predicting soil loss and takes into account factors such as rainfall, soil erodibility, slope, land cover, and erosion control practices. GIS and remote sensing data are useful tools when analyzing soil erosion, particularly when assessing erosion at larger scales.

USLE Parameter Estimation: Each factor in the USLE equation requires specific parameters to be estimated. For example, rainfall erosivity is calculated using rainfall data, soil erodibility is determined from soil samples, and slope length and steepness are derived from topographic data.

These parameter estimations may involve statistical analysis and model calibration (Admankar & Patil, 2019)

Soil erosion is a significant problem that leads a loss of nutrients, decrease of soil fertility and reduce crop productivity. It is a form of non-point source pollution that causes river siltation, and water pollution, impacting normal flood discharge and hydropower project efficiency. Natural factors such as soil type, climate, human activities, land development and land use, deforestation and unstainable agriculture. The information can enable the local manager to implement appropriate measures to mitigate soil erosion contribute much to soil erosion (Li, 2015).

Rungwe district is one of district found in Tanzania. It has been used to for land use and land cover change detection due to dramatic factor contribute to soil erosion. Soil erosion in this area increase the rate of bare land. There are many efforts that involves the government and other non-governmental organization to emphasize the mitigation measures to reduce the factor contributing to soil erosion in Rungwe

1.2 Statement of the problem:

Soil erosion is a major environmental problem that affects many regions worldwide, including mountainous areas. In these regions, the combination of steep slopes, heavy rainfall, and human activities such as agriculture and logging can lead to high rates of erosion, causing significant ecological and economic damage. The existing of soil erosion in mountainous region is caused with several factors (Balasubramanian, 2017). Soil erosion causes the removal of topsoil by wind or water and it is influenced by different factors such as overgrazing, deforestation, agricultural activities and poor construction roads and infrastructure which decrease fertility on the land. In Tanzania many areas have been affected due to soil erosion which cause the topsoil to be swashed away by agent of soil erosion (Thanappan, 2023).Soil erosion is a major environmental problem that affects many regions worldwide, including mountainous areas. In these regions, the combination of steep slopes, heavy rainfall, and human activities such as agriculture and logging can lead to high rates of erosion, causing significant ecological and economic damage. USLE model used to calculate average annual soil loss per unit land area resulting from sheet and rill erosion (J Am Sci 2009;). This information will help to provide a better management and encourage to which type of mitigation should be taken instantly estimation of soil erosion factor and assessment of factor contributing to soil erosion

1.3 Objectives of the study

This section discusses the main objective and specific objective to give the overview of the desired outcomes of the research.

1.3.1 Main objectives

- To assess and quantify soil erosion rates of Rungwe district using the Universal Soil Loss Equation (USLE) model.

1.3.2 Specific objectives

- Quantify the influence of natural factors (rainfall characteristics, soil erodibility, topography) on soil erosion vulnerability using the USLE model.
- Spatially characterize the distribution of soil erosion across the study area using USLE model

1.4 Research questions

i. How do the combined effects of rainfall characteristics, soil erodibility, and topography contribute to variations in soil erosion vulnerability across the study area?

ii. What are the spatial patterns of soil erosion vulnerability revealed by the USLE model outputs, and how do they correspond to the distribution of natural factors such as rainfall, slope, and soil erodibility?

1.5 Significance of the study

The investigation concerning the rate of soil erosion using the USLE model carries significant implications. It offers a numerical assessment of soil erosion within the specific research area, aiding in the identification of erosion-prone regions and prioritizing them for necessary management actions. The study provides insights into the contributing factors of soil erosion, such as land usage, slope, and rainfall, enabling the development of effective measures to control erosion. Through utilizing the USLE model, it becomes possible to forecast soil erosion rates under different scenarios, facilitating the assessment of the effectiveness of diverse land management practices and policies.

1.6 Beneficiaries of the study

i. **Farmers**

Soil erosion studies are particularly beneficial to farmers as they provide them with an understanding of the extent and impact of soil erosion on their land. This knowledge empowers farmers to implement effective soil conservation measures, optimize land management practices, and enhance agricultural productivity.

ii. Environmental Conservation Organizations

Soil erosion studies are also beneficial to environmental organizations and conservation groups. These studies allow them to identify regions that are susceptible to erosion and ecological damage. With this information, they can concentrate their conservation efforts, carry out specific restoration projects, and advocate for the preservation of crucial habitats and ecosystems.

iii. Policy Makers and Government Agencies

Soil erosion studies are advantageous to policy makers and government agencies responsible for managing natural resources and land. The findings of these studies offer scientific evidence and data that aid in the creation of policies, regulations, and guidelines for sustainable agriculture practices, land-use planning, and erosion control. Additionally, the information obtained from these studies enables these organizations to make informed decisions and implement effective measures for managing natural resources and preserving the environment**.**

iv. Researchers and Academics

Soil erosion studies make a valuable contribution to the scientific knowledge and comprehension of erosion processes, thereby advancing the field of soil science and other related disciplines. Researchers and academics can employ the discoveries made in these studies to advance their research, create erosion models, and explore new and creative erosion control techniques.

1.7 Scope and limitations

This study enables in dealing with determining the distribution of soil erosion and assessing the factor influencing it in Rungwe district. As the problem states it will involve the use of remote sensing data and GIS techniques to perfume the study and making analysis. It also involves different method of GIS such as image classification supervised classification, modelling of soil erosion and modeling the factor for soil erosion. To estimate each factor in the USLE equation, certain parameters need to be determined. For instance, rainfall erosivity is computed based on rainfall measurements, soil erodibility is established through soil samples, and slope length and steepness are obtained from topographical data. The process of estimating these parameters may require statistical analysis and calibration of models.

1.8 Structure of dissertation

Chapter 1

In this section, an overview is given of the study by presenting relevant background information. It emphasizes the problem statement and discusses the significant factors that influence the study focus. The main and specific objectives are outlined, providing an overview of what the study aims to accomplish. The study importance, beneficiaries, and the scope and constraints of the study are also examined.

Chapter 2

In this chapter, a comprehensive review of relevant literature is conducted, focusing on topics such as soil erosion, models of soil erosion, and types of erosion. The chapter provides a succinct summary of previous studies that have explored similar research approaches and methodologies. It synthesizes information from various sources to establish the theoretical and conceptual framework for the research.

Chapter 3

This chapter details the methodology employed to achieve the research objectives. It includes a flowchart illustrating the step-by-step process followed in the study. The methods for data collection and processing are thoroughly described, outlining the specific tools and techniques utilized. This chapter also discusses factors that can be applied in model the soil erosion

Chapter 4

This chapter presents the results of the research and provides a detailed analysis of the findings. It includes maps and graphs to visually represent and interpret the data. The chapter explores the relationships and patterns observed among the variables, drawing conclusions based on the analysis. It also discusses any limitations or challenges encountered during the data analysis process.

Chapter 5

The last section of the study outlines the major discoveries and reaches conclusions in accordance with the goals. It examines the significance of the findings and their applicability to the wider field of soil erosion. also, this section offers suggestions for future research or initiatives based on the results. These suggestions aim to enhance the comprehension and control of soil erosion by proposing potential measures for preserving and promoting sustainable soil in mountainous regions and sustainable soil in mountainous area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter highlights various materials in literature of previous works, studies or researches conducted in different areas which in one way or the other were useful in this research based on the relationship of either the data, methodologies or techniques

2.2 Sustainable development goals (SDGs)

Sustainable Development is a development that considers the requirements of the current generation without compromising future generations (Obadia Kyetuza Bishoge, 2018). Sustainable development goals (SDGs) are goals adopted by the United Nations in 2015 in a universal call to end poverty, protect the planet and ensure peace and prosperity for all by 2030. The SDGs include;

1. Poverty alleviation in all areas.
2. Elimination of hunger by achieving food security and nutrition through the promotion of sustainable agriculture
3. Good health promotion at all levels.
4. Insurance of comprehensive and justifiable quality education.
5. The accomplishment of gender equality by empowering girls and women to participate fully in the socioeconomic and political sectors.
6. Guaranteeing the availability of and access to water and environmental health services.
7. Safeguarding access to sustainable and modern energy.
8. Improvement of full, inclusive, and productive employment opportunities for all.
9. Building of strong infrastructure for the realization of sustainable innovation and industrialization.
10. Elimination of inequalities within and among nations.
11. Ensuring safe and strong human settlements and cities
12. Safeguarding sustainable production and consumption forms.
13. Elimination of climate change and its effects.

According to these goals, they recognize that action in one area will affect the outcome in other areas and that development must balance sustainability in social, economic, and environmental aspects. Among the SDGs, goal number two explains the increase promotion in sustainable agriculture, which is an area of interest in this research because the soil erosion it also associated with the effect of rate of agriculture

2.3 Remote sensing and Geographic information system

Remote sensing is the science and art of obtaining information about an object, area or phenomena through analysis of data acquired by device that is not in contact with the object, area or phenomenon under investigation (Bera, 2017). Remote sensing utilizes measurement of energy of an object spectral characteristics and wavelength. Introduction of satellite images such as sentinels and Landsat images have facilitated implementation and development of remote sensing application through exploiting spectral and temporal characteristics the satellite images offer, it facilitated easy and fast identification of feature and this led to improvement of techniques such as classification (Meng, 2023), machine learning and index derivation. Researches have shown that classification methods are highly dependent on human and have some difficulty in water detection approach.

2.4 Soil erosion

This chapter highlights various materials in literature of previous works, studies or researches conducted in different areas which in one way or the other were useful in this research based on the relationship of either the data, methodologies or techniques agriculture. Soil erosion can have numerous negative impacts on the environment and human society, including reduced soil fertility, water pollution, increased flood risk, loss of biodiversity, and decreased agricultural productivity. It is a significant environmental problem that affects many regions worldwide (Thanappan, 2023), especially in mountainous areas where steep slopes and heavy rainfall can cause high rates of erosion. Strategies for mitigating soil erosion include the use of erosion control measures such as terracing, contour plowing, and vegetative cover, as well as the implementation of sustainable land use practices that help to maintain healthy soil and prevent erosion.

2.5 Soil component

Soil is the uppermost layer of the Earth's surface, consisting of a complex blend of organic and inorganic materials. Its primary constituents encompass mineral particles, organic matter, water, and air(Di Matteo & Spagnoli, 2023). The mineral particles originate from rock weathering and can be categorized based on size as sand, silt, or clay. The relative proportion of these particles in a soil sample determines It is texture, which influences its ability to retain water, availability of nutrients, and other physical attributes (Funk, 1983) .Organic matter in soil arises from the decomposition of plant and animal residues over time. It plays a critical role in soil fertility by providing nutrients for plant growth and enhancing soil structure and water retention capacity. The quantity of organic matter in soil can significantly vary depending on factors such as climate, land usage, and management practices.

Water and air are also vital components of soil. Water is essential for plant growth, nutrient absorption, and various physical and chemical processes within the soil. Air is necessary for plant roots and soil microorganisms to respire, as well as for maintaining soil structure and preventing waterlogging (BOUSSALIM et al., 2022). The composition and characteristics of soil exhibit considerable diversity, influenced by factors like climate, geology, topography, and land utilization. The constituents of soil and their interrelationships is crucial for sustainable soil resource management and the preservation of ecosystem well-being. Soil is the outermost layer of the Earth's crust that is not consistently uniform in texture, color, structure, and nutrient content due to various factors explained in this booklet. However, despite its variability, soil comprises of four primary components or fractions that are present in all types of soil, namely mineral, organic matter, water, and air. These four fractions can be classified into two categories: solid, which includes mineral and organic matter, and non-solid, which includes water and air

The component of soil which are in two forms combined together from the four are

i. Solid component

Around 50-70% of soil by volume is made up of the solid category, which comprises the mineral and organic matter fractions and gives soil its characteristic texture. The mineral fraction accounts for 95-99% of the solid category and is derived from weathered parent rocks over thousands of years(Funk, 1983). The characteristics of soil are largely determined by the type of parent rock it was formed from, as the mineral fraction makes up a significant part of the total soil volume. The mineral fraction is composed of four particles classified by their diameter: gravel (>2 mm), sand (0.02-2 mm), silt (0.002-0.02 mm), and clay (<0.002 mm). The proportion of these particles is critical for soil fertility and its response to management. Clay particles, being the smallest particles, are important as they have a negative electrical charge that enables them to hold and exchange nutrients. Clay soils are more fertile than sandy soils due to the presence of clay particles. The type and quantity of clay in the soil can affect the amount of nutrients held for plant use and the ease with which they are released to plants. Clay particles can stick to other clay particles, as well as sand and silt particles, due to their electrical charge, resulting in sticky soil (Verruijt, 2006). The significance of sticky soil in soil management and land degradation will be elaborated in the Soil Management and Land Degradation

ii. Non-solid component

The non-solid category of soil consists of two fractions, namely water and air. The ideal proportion of water and air in agricultural soil should range from 30-50%, depending on the soil type and time of year (Smith, 1978). Both water and air are crucial for plant growth, and the exchange of oxygen and carbon dioxide between the soil and atmosphere is necessary for root respiration to occur.

2.6 Soil formation

soil formation is influenced by factors such as parent material, climate, topography, biological activity, and time. The geology of the area is dominated by volcanic rocks, which contribute to the formation of soils with unique characteristics. The climate in Rungwe District is tropical, with rainfall patterns varying across the district (De Coninck, 2002). The area is characterized by highlands and mountains, which influence soil formation and erosion. Biological activity, including vegetation cover, animal activity, and human land use practices, also plays a significant role in soil formation and degradation in the district. The length of time that soil has had to develop varies across the district, with some areas experiencing long periods of soil formation and others undergoing rapid soil degradation due to human activities such as deforestation, overgrazing, and inappropriate land use practices (Van Breemen & Buurman, 2002). Understanding these factors is important for effective soil management and conservation in Rungwe District, to ensure sustainable use of soil resources and to maintain the productivity of agricultural lands.

2.6.1 Factors for soil formation

1. **Geology**

The mineral composition and grain size of the parent material strongly influence the type of soil that is formed. Materials that are suitable for clay formation and tend to form clay soils. Sandstones, on the other hand, have fewer clay-forming materials and therefore tend to form sandy soils (Dudal, 2005). Granites have both sand and clay-forming materials and may form sandy and clayey soils. The type of parent material and the surrounding climate are important factors in the transition from bedrock to soil. Soils can form from the bedrock material directly below or from material transported from elsewhere.

2. **Climate**

Rainfall and temperature also play a significant role in soil formation, as they influence the amount of water available for weathering of parent material rocks. High rainfall and high temperatures increase the rate of weathering, resulting in deep soils(Jenny, 1994). Dry climate periods can lead to soils being blown by winds and deposited in other locations.

3. **Biological factor**

Biological activity, including plant growth and soil organisms, is also important in soil formation. Plants add organic matter and support life within the soil, playing an important role in soil structure and nutrient cycling (Ghorbani et al., 2008). Human and animal activity, such as land clearing and burning, can have a significant impact on soil formation and degradation.

4. **Time**

The age of a soil is an important factor, as older soils may have had more time for nutrients and clay materials to leach to deeper soil depths or to be leached away completely. the process of soil formation is slow and occurs over long periods of time(Van Breemen & Buurman, 2002). Soils that have been forming for longer periods and have more developed layers and a greater diversity of microorganisms and organic matter. Over time, rocks and minerals in the parent material break down, and organic matter accumulates, resulting in changes in soil properties such as texture, structure, and nutrient content.

2.7 Soil profile

A soil profile is a representation of the soil in three dimensions, consisting of several horizontal layers or horizons. The characteristics of soil can vary significantly down the soil profile, including physical, chemical, and biological properties. Different horizons arise from various soil-forming factors, drainage regimes, and management practices, leading to a wide range of soil appearances (Batjes et al., 2016). Every soil profile comprises at least one horizon, and horizons can be classified into three broad groups: the topsoil, subsoil, and rock. The topsoil comprises the 'A' horizon(s), the subsoil comprises the 'B' horizon(s), and the rock comprises the 'C' horizon and/or an 'R' horizon. Within these broad groups, sub-horizons can also exist (Nachtergaele et al., 2010).Soil profiles can be classified into three groups based on the texture change vertically through the soil profile. Soil classification also considers the nature of the soil profile, which divides soils into three groups: Uniform, Gradational, and Texture Contrast (Duplex).

i. Gradational soil profiles

show a gradual increase in clay content down the soil profile, where each successive horizon passes gradually from one to another. These soils are often good for cropping, and examples can be found in some of the red soils

ii. Uniform soil profiles

Consist of texture difference, and no clearly defined texture boundaries can be found. For example, clay loam may continue from the topsoil (A horizon) down to the subsoil (B horizon) (Hartemink et al., 2020). The grey soils of the Wimmera are uniform and show clay texture in the topsoil and subsoil.

iii. Texture contrast soil profiles

It has a significant texture difference between the topsoil and subsoil. The texture usually changes abruptly, becoming more clayey in the transition from the topsoil to the subsoil (Hartemink et al., 2020). The significant change in texture between the topsoil and subsoil can often lead to structural problems with the subsoil impeding water and air movement and root growth

2.8 Soil structure

Soil structure refers to the spatial arrangement or organization of soil particles and other constituents within the soil, and how they are held together. Soil particles, such as sand, silt, and clay, can form aggregates or clumps that are held together by organic matter, minerals, and microbial activity. These aggregates can range in size from small aggregates visible to the naked eye to larger aggregates visible only under a microscope (Nachtergaele et al., 2010). The structure of soil affects many important soil properties, such as water infiltration and retention, air and nutrient exchange, root penetration, and soil erosion. Good soil structure is essential for healthy plant growth, as it enables the movement of water, air, and nutrients to plant roots while still providing adequate support for the plants. Soil structure can be influenced by various factors, including soil texture, organic matter content, soil compaction, and soil management practices

2.8.1 Soil structure decline

Soil structure decline is the process of breaking down natural, stable soil aggregates into smaller, unstable ones. When soil aggregates become small, they tend to block macro-pores and disperse, leading to further blockage (Ghorbani et al., 2008). This essentially causes a blockage of the plumbing system of the soil, leading to a decrease in water and air movement into and through the soil profile. This impairs root growth, reduces drainage, and leads to waterlogging, increased runoff, and soil erosion. The emergence of plants can also be affected by soil structure decline. Water is a crucial factor that can affect crop and pasture productivity, with seasonal rainfall being critical. However, poorly structured soils may be unable to store water for plant use. An unprotected soil surface can form a crust that is difficult for germinating seeds to penetrate, reducing emergence and productivity. There are five processes that can cause soil structure breakdown, including slaking, dispersion

2.8.2 Maintenance and improving of soil structure

There are several methods for maintaining and improving soil structure, including:

Minimal or direct tillage practices: Reducing the number of cultivations required a crop or pasture can decrease the disruption of soil aggregates. This can slow or halt the formation of plough pans and preserve earthworm and root channels.

- Stubble retention and maintenance of pasture cover: Keeping the soil surface covered with stubble or pasture can protect it from raindrop impact and prevent the formation of crusts. Groundcover can also insulate the soil from extreme temperatures and provide a food source for microorganisms (Ghorbani et al., 2008). A cover of at least 30-50% residue reduces wind velocities at the soil surface, which in turn reduces the energy available to erode soil particles.
- Improved crop rotations: Deep-rooted plants such as safflower, canola, and lupins can develop stable root channels in the subsoil that can be utilized by shallow-rooted crops. Deep-rooted legumes can add nitrogen to the soil and provide a disease break. Fallowing is not useful for improving soil structure(Lal, 2000).

2.9 Mathematical model for modelling soil erosion

A mathematical model plays a significant role in soil erosion research, offering a quantitative framework to simulate and predict erosion processes. These models employ mathematical equations to describe how various factors, including rainfall, runoff, soil properties, vegetation cover, and topography, interact to contribute to soil erosion. The application of mathematical models in soil erosion studies enables the simulation of erosion under different scenarios, such as changes in land use, climate, or management practices (Igwe et al., 2017). This helps inform land use planning and soil conservation efforts by providing estimates of erosion rates and sediment transport. Mathematical models in soil erosion research can be broadly categorized into empirical and process-based models. Empirical models establish relationships between observed erosion rates and factors like rainfall, slope, and soil properties. These models are relatively simple and user-friendly, but they may not fully capture the underlying erosion processes. Process-based models, in contrast, simulate the physical mechanisms involved in erosion, including rainfall detachment, soil transport, and deposition. These models require more detailed input data and are more complex to use, but they offer a more realistic representation of erosion processes and facilitate exploring the effects of different scenarios on erosion rates(Rose et al., 1983). Several mathematical models are employed in soil erosion research, such as the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Water Erosion Prediction Project (WEPP), and Soil and Water Assessment Tool (SWAT). These models employ diverse mathematical approaches to simulate erosion, but they all serve as valuable tools for predicting and managing soil erosion

i. WEPP MODEL

The Water Erosion Prediction Project (WEPP) is a mathematical model that simulates soil erosion and sediment transport due to rainfall and runoff. It is a physically-based, process-oriented model that uses mathematical equations to describe the interactions between various factors that contribute to soil erosion, such as rainfall, soil properties, vegetation cover, and topography (Laflen et al., 1997). WEPP simulates the hydrologic cycle by taking into account factors such as precipitation, infiltration, runoff, and evapotranspiration. It also simulates the erosion process by considering factors such as the detachment of soil particles from the soil surface, the transport of sediment by runoff and overland flow, and the deposition of sediment in lower areas. WEPP also considers the impact of vegetation on soil erosion, as it reduces the impact of raindrops on the soil surface and helps to hold soil in place.

ii. USLE MODEL

The Universal Soil Loss Equation (USLE) is a widely used model for predicting soil erosion. It estimates the long-term average annual rate of soil loss due to rainfall and runoff. USLE takes into account several factors that contribute to soil erosion, including rainfall erosivity, soil erodibility, slope length, slope steepness, and vegetative cover. Rainfall erosivity refers to the amount and intensity of rainfall, and is calculated by multiplying the rainfall amount by a factor that represents its erosive power (Todisco et al., 2022). Soil erodibility is a measure of the susceptibility of soil to erosion, and is determined by the soil texture, structure, organic matter content, and permeability. Slope length and steepness are also important factors, as longer and steeper slopes are more susceptible to erosion. Finally, vegetative cover is taken into account as it reduces the impact of raindrops on the soil surface, and helps to hold soil in place (Bera, 2017).

The equation of USLE model is given as

$$\mathbf{A = R * K * LS * C * P} \dots\dots \mathbf{(2.1)}$$

A = estimated long-term average annual soil loss (tons/acre/year)

R = rainfall erosivity factor (a measure of the amount and intensity of rainfall)

K = soil erodibility factor (a measure of the susceptibility of soil to erosion)

LS = slope length and steepness factor (a measure of the effect of slope on erosion)

C = vegetative cover factor (a measure of the impact of vegetation on soil erosion)

P = erosion control practice factor (a measure of the effectiveness of erosion control practices)

2.9.1 Estimated long-term average annual soil loss (A)

The estimated long-term average annual soil loss (tons/acre/year) serves as a crucial metric for understanding the magnitude and impact of soil erosion over time. It provides valuable information for land managers, conservationists, and policymakers to assess the sustainability of land use practices and implement effective erosion control strategies.

This measure enables comparisons between different locations, land management techniques, or scenarios, aiding in decision-making processes related to soil conservation, land use planning, and natural resource management (Girmay et al., 2020). It helps identify areas with higher erosion risks, prioritize conservation efforts, and evaluate the effectiveness of erosion control measure. By quantifying soil loss in tons per acre per year, the USLE model's estimated long-term average annual soil loss parameter allows for a standardized and comparable measure of erosion rates. It provides a useful tool to monitor soil erosion trends, evaluate the impacts of land management practices, and promote sustainable soil conservation practices for the preservation of soil resources

2.9.2 Rainfall erosivity factor (R)

Rainfall erosivity refers to the ability of rainfall to cause soil erosion by dislodging and transporting soil particles. It is influenced by various factors such as the amount of rainfall, the duration of rainfall events, and the intensity at which the rain falls. These factors collectively determine the erosive power of rainfall, as they directly impact the kinetic energy of raindrops that strike the soil surface (Majid Malik , 2015).

Rainfall erosivity factor is given as,

$$R = 0.5 + 1.73(Pfactor)\text{...}(2.2)$$

Where by P is the annual rainfall of Rungwe district

2.9.3 Soil erodibility factor (K)

The soil erodibility factor takes into account the physical, chemical, and biological properties of the soil that influence its resistance to erosion. These properties include the soil's texture, structure, organic matter content, permeability, and cohesion. Each of these characteristics contributes to the overall erodibility of the soil (Ramzi et al., 2017). Soil texture refers to the relative proportions of sand, silt, and clay particles in the soil. Soils with a higher clay content which means have a greater erodibility due to their finer particle size and reduced stability.

2.9.4 Slope length and steepness factor (LS)

The slope length refers to the horizontal distance along the slope from the top to the bottom, while the steepness refers to the vertical rise of the slope over a given horizontal distance. These two factors combined determine the overall gradient of the slope, which affects the velocity and amount of water runoff as well as the potential for soil erosion (Kruk et al., 2020). In the USLE model, the slope length and steepness factor quantify the erosive power of runoff water by considering the hydraulic force it generates as it flows down a slope.

The equation for topographic factor it is given as

$$LS = \left(Flow\ Accumulation * Cell\ Size \frac{}{22.13}\right)0.4 * \left(sin\beta \frac{}{0.0896}\right) \dots\dots\dots\dots (2.3)$$

Where β is the slope in degree

LS Topographic factor

2.9.5 Vegetative cover factor (C)

The C factor considers various aspects of vegetation, including its type, density, and spatial distribution, at a specific location. These factors collectively determine the effectiveness of vegetative cover in mitigating soil erosion(Smith, 1978). The density of vegetation refers to the degree of ground coverage by plants, including both above-ground foliage and below-ground root systems. Higher vegetation density typically results in greater soil protection, as it provides a more effective barrier against rainfall impact and helps to bind soil particles together.

2.9.6 Erosion control practice factor (P)

The erosion control practice factor, denoted as P, evaluates the efficiency of erosion control measures such as terracing, contouring, and conservation tillage. It considers the specific type and effectiveness of erosion control practices implemented at a given location. The P factor takes into account the type and effectiveness of the erosion control practices being employed at a specific location (Kruk et al., 2020). It serves as a measure or index to quantify the efficiency and impact of these practices on reducing soil erosion. The effectiveness of erosion control measures can vary depending on factors such as the slope of the land, soil type, climate conditions, and the maintenance and implementation of the practices themselves (Suryawanshi, 2022)

Table 2.1 USLE Parameters

USLE TERM	**ENGLISH UNIT**	**METRIC UNIT**
Annual soil loss A	Tons/acre-year	(Mg/hectare-year)
Soil erodibility factor K	Tons soil/100 ft. tons rainfall	(Mg ha h)/ (ha MJ mm)
Rainfall erodibility factor R	100s of ft. tons rainfall/ac-year	(MJ mm)/ (ha h yr.)
Practice factor P	Dimensionless	Dimensionless
Cover management factor C	Dimensionless	Dimensionless
Length and lope factor LS	Dimensionless	Dimensionless

CHAPTER THREE

METHODOLOGY

This is the stage which involve the data acquisition, data processing and the method in which data are being analyzed. Also, on the data processing we get several inputs that will be required for equation of soil erosion such as soil erodibility, slope length, topographical and slope gradient

This study adopts the USLE model for the whole research in order to obtain the objectives of the study. The USLE model estimates soil damages for ground slope in geographic information system platform. With the combined equation of geophysical and landcover factor and Also on the data processing we get several inputs that will be required for equation of soil erosion such as soil erodibility, slope length, topographical and slope gradient to obtain the yearly soil loss of the area. The process of data of this study is in one step to another as described below

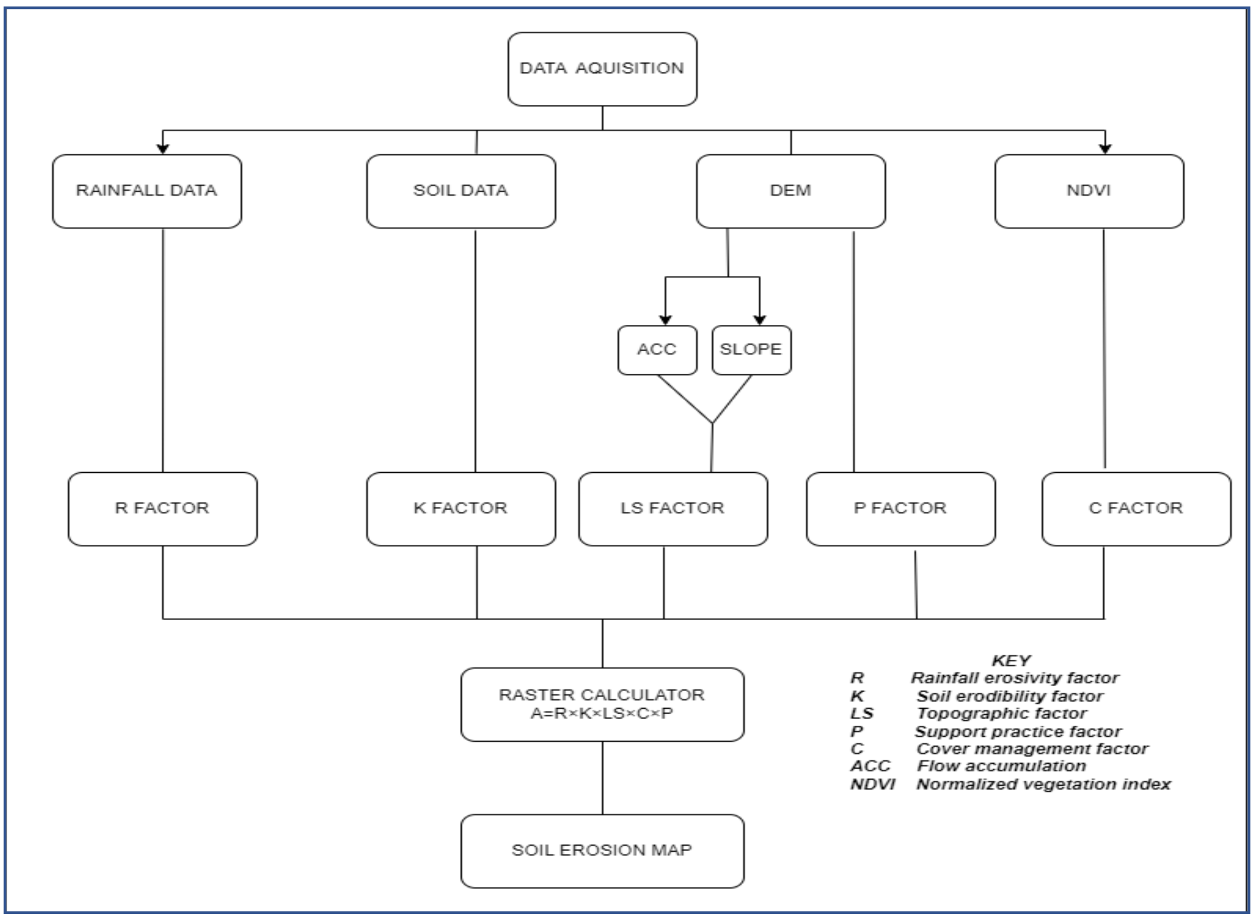

Figure 3. 1 Flowchart

3.1 Description of study area

Rungwe district is located in the southern highlands of Tanzania, near the Mbeya city between latitudes 7° and 9° south and longitudes 34° and 36° east. It covers an area of approximately 2400 square kilometers and has an elevation ranging from 500 to 2500 meters above sea level. Rungwe has a rugged topography, with slopes ranging from gentle to steep, and is characterized by a network of rivers. Rungwe district is a critical area for agriculture, supporting a diverse range of crops including maize, rice, sorghum, beans, and wheat. One of the prominent features of the Rungwe District is the Rungwe Volcanic Range, which includes Mount Rungwe, the third-highest peak in Tanzania. This volcanic range has significant geological and ecological importance, as it supports a variety of plant and animal species, including several endemic species

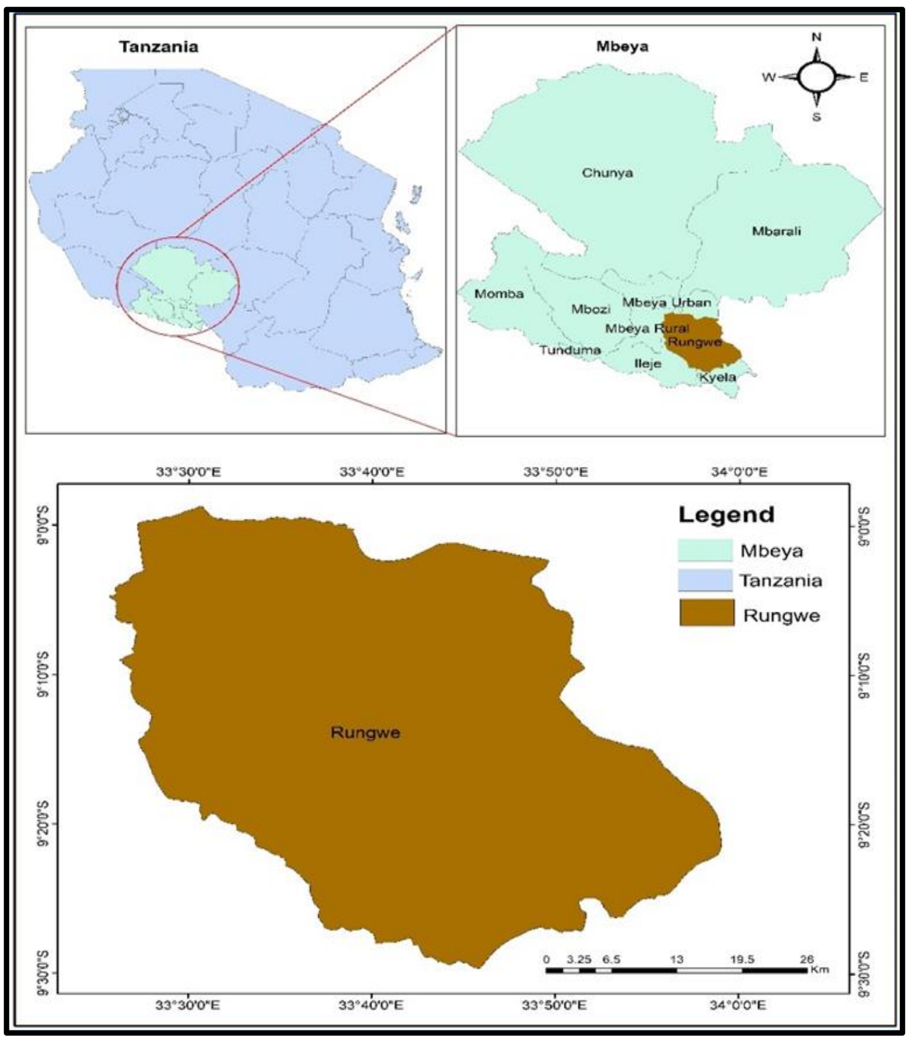

Figure 3. 2 Study Area

3.2 Data required

The data utilized in this research were obtained from diverse sources and were available in various formats. Table 3.1 describes the data collected and purpose in the research.

Table 3.1 Data used

S/N	DATA SETS	SOURCES	USES
1	NDVI	USGS https://earthexplorer.usgs.gov/	Measure the impact of vegetation cover on soil erosion (C factor)
2	SRTM DEM	USGS https://earthexplorer.usgs.gov/	Assess the role of slope in soil erosion (LS factor)
3	Rainfall data	TerraClim	Quantify the impact of rainfall on soil erosion vulnerability (R factor)
4	Soil data	International Soil Reference and Information Centre (ISRIC)	To analyze how soil properties contribute to erosion (K factor)

3.2.1 Soil data

The soil data sourced from International Soil Reference and Information Centre (ISRIC) provides essential insights into the soil composition within the Rungwe District. The data reveals the presence of four distinct soil types in the region, each with its own unique characteristics. Among these soil types, Mollic andosols Soil type emerges as the predominant classification, covering a significant portion of the district's landscape.

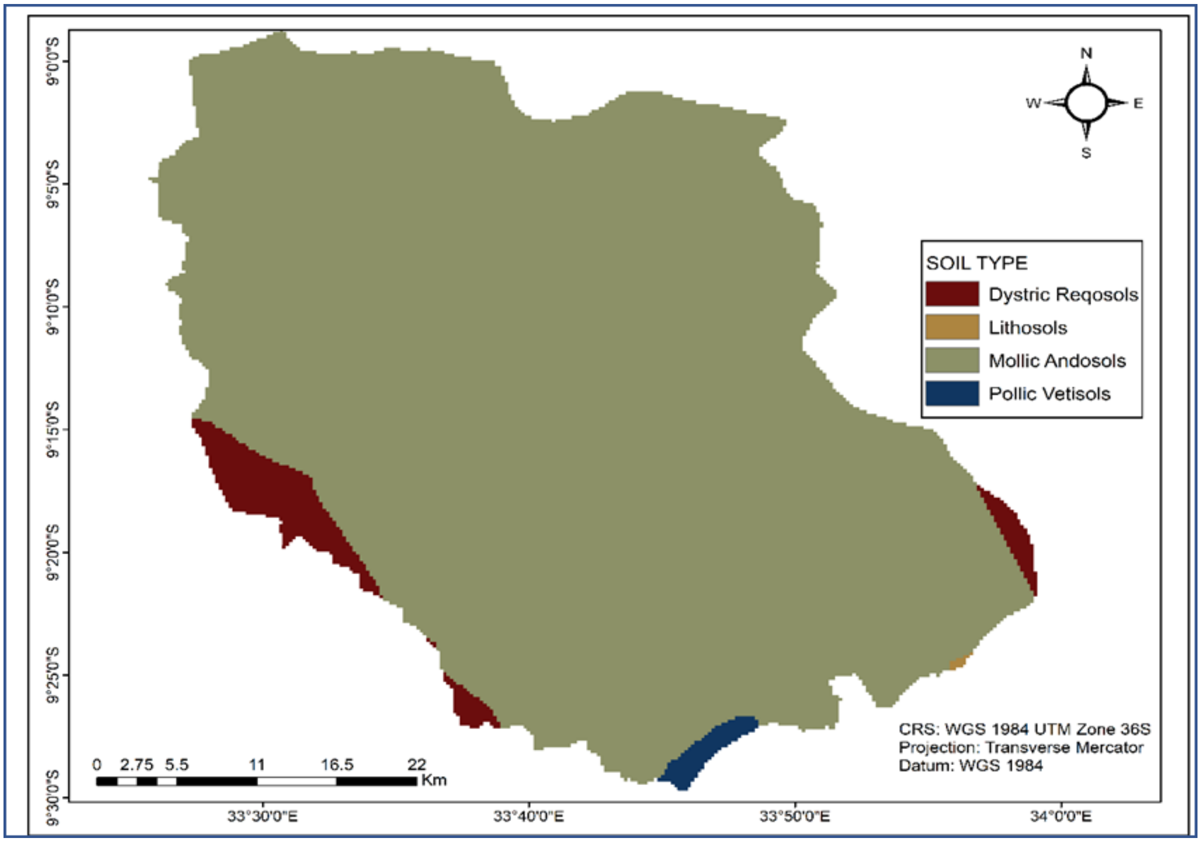

Figure 3. 3 Soil types of Rungwe district

3.2.2 SRTM DEM

The Rungwe District presents a diverse topographical landscape characterized by a wide range of slope angles (0-75) degrees, varying from gentle inclines to steeper grades. These slope variations contribute significantly to the district's geographical makeup, whereas the slope becomes steeper, the velocity and volume of surface runoff increase, resulting in a higher risk of erosion, assuming other factors remain constant**.**

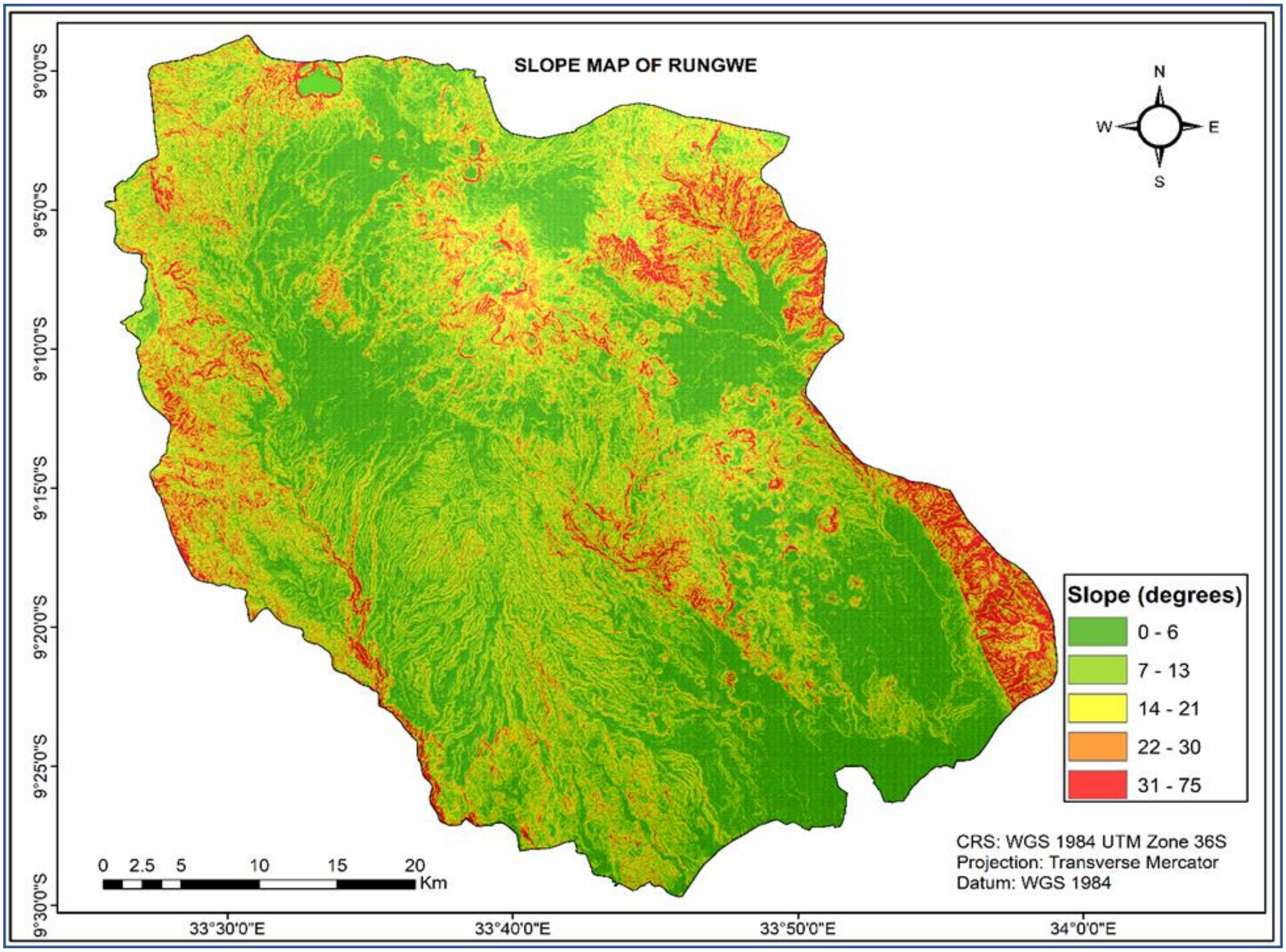

Figure 3.4 elevation of Rungwe district

3.2.4 Landsat image

Landsat 8 captures images of the Earth's surface in different spectral bands, including the red

and NIR bands required for NDVI calculation. By analyzing Landsat 8 imagery, the red and NIR reflectance values can be extracted for each pixel in the image. To obtain the NDVI values, the red and NIR reflectance values are used in the NDVI formula. The resulting NDVI values range from -1 to 1, where higher values indicate denser and healthier vegetation, while lower values represent less vegetation or non-vegetated areas. By utilizing Landsat 8 imagery and extracting NDVI values, the USLE model can assess the impact of vegetation cover on soil erosion and aid in land management decisions, such as identifying areas susceptible to erosion and implementing erosion control measures. To obtain the minimum and maximum NDVI values thresholds, it requires to set appropriate thresholds for each category, delineating the range of NDVI values associated with it. These thresholds should be determined by considering observed NDVI values and their correlation with on-ground vegetation cover conditions.

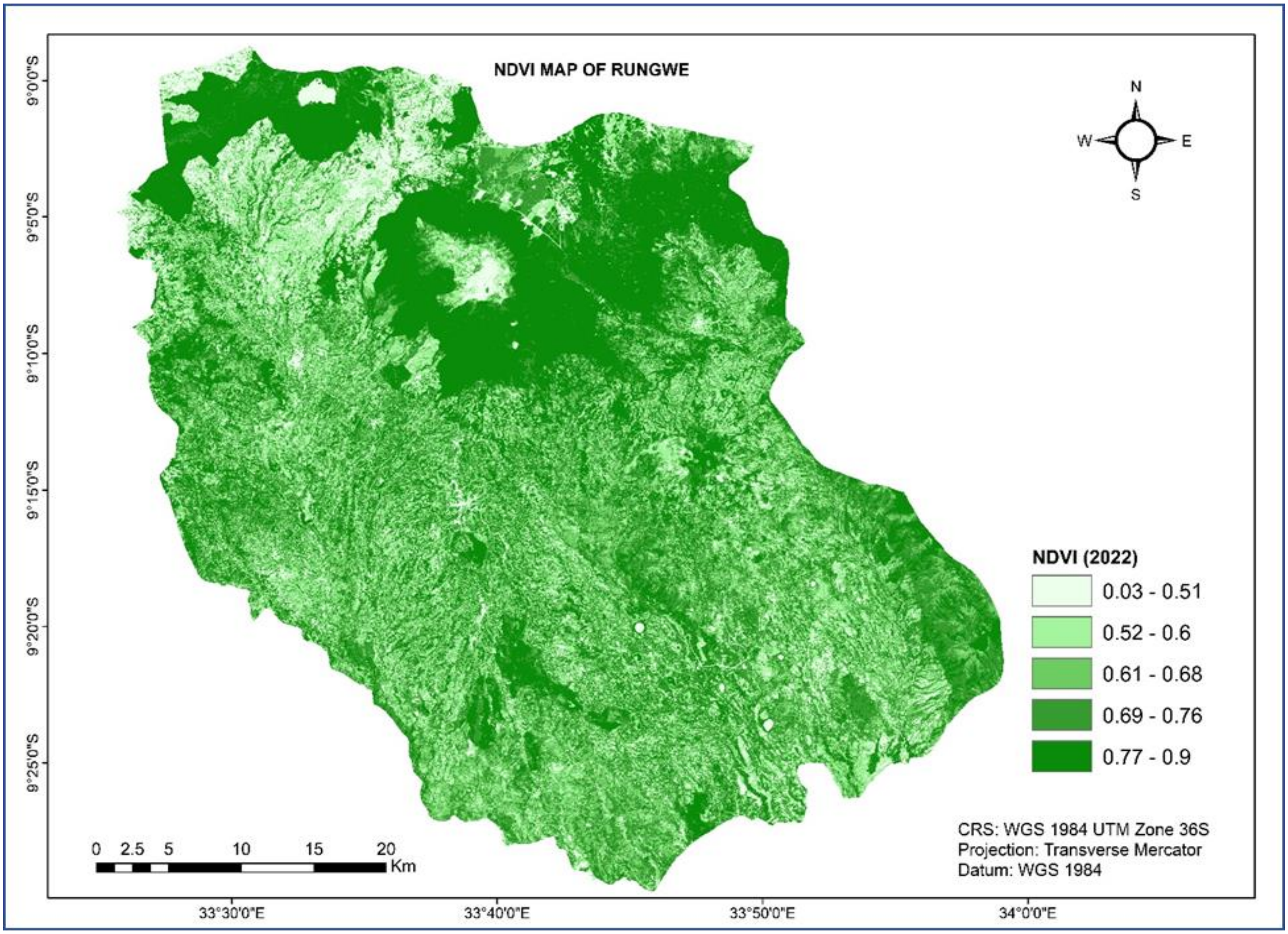

Figure 3. 5 NDVI map of Rungwe district

3.2.5 Preparation of model and model parameters

Different types of materials have been utilized to estimate soil erosion within the study area. These materials mainly include rainfall data obtained from the Tanzania Meteorological Department (TMD), soil data from FAO, ASTER DEM, and NDVI data. The calculation of soil loss in this area is based on the USLE soil loss equation:

$$\boldsymbol{A = R \times K \times LS \times C \times P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3.1)}$$

In this equation,

'A' represents the average annual soil loss.

'R' represents the rainfall-runoff erosivity factor.

'K' represents the soil erodibility factor.

'LS' represents the topographic factor.

'C' represents the cropping-management factor.

'P' represents the support practice factor

3.2.6 Annual average soil loss

In order to calculate the average annual soil loss using the USLE model, the collected relevant data for each of the factors mentioned, including data on rainfall erosivity, soil attributes, slope characteristics, NDVI, and any conservation measures implemented. It was used as an input it into the USLE equation to obtain an estimate of the annual average soil loss for the Rungwe district. Through gathering information on these variables and plugging them into the USLE equation, it enables to approximate the mean yearly soil loss for Rungwe district. This data can be valuable for purposes such as land administration and conservation initiatives, as well as for forecasting the consequences of soil erosion on soil fertility and water purity

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil erodibility factor (K)

The soil erodibility factor signifies the susceptibility of soil or surface material to erosion, its transportability, and the volume and speed of runoff in response to a given amount of rainfall. The appropriate K factor values for classified soils were obtained from previous research and relevant literature sources (Majid Malik., 2015). Rungwe district comprises four soil types, namely lithosols, Mollic andososls, Pollic vetisols, dystric reqosols. The findings revealed that the K factor ranged between 0.25-0.46 as illustrated in Figure 4.1 below

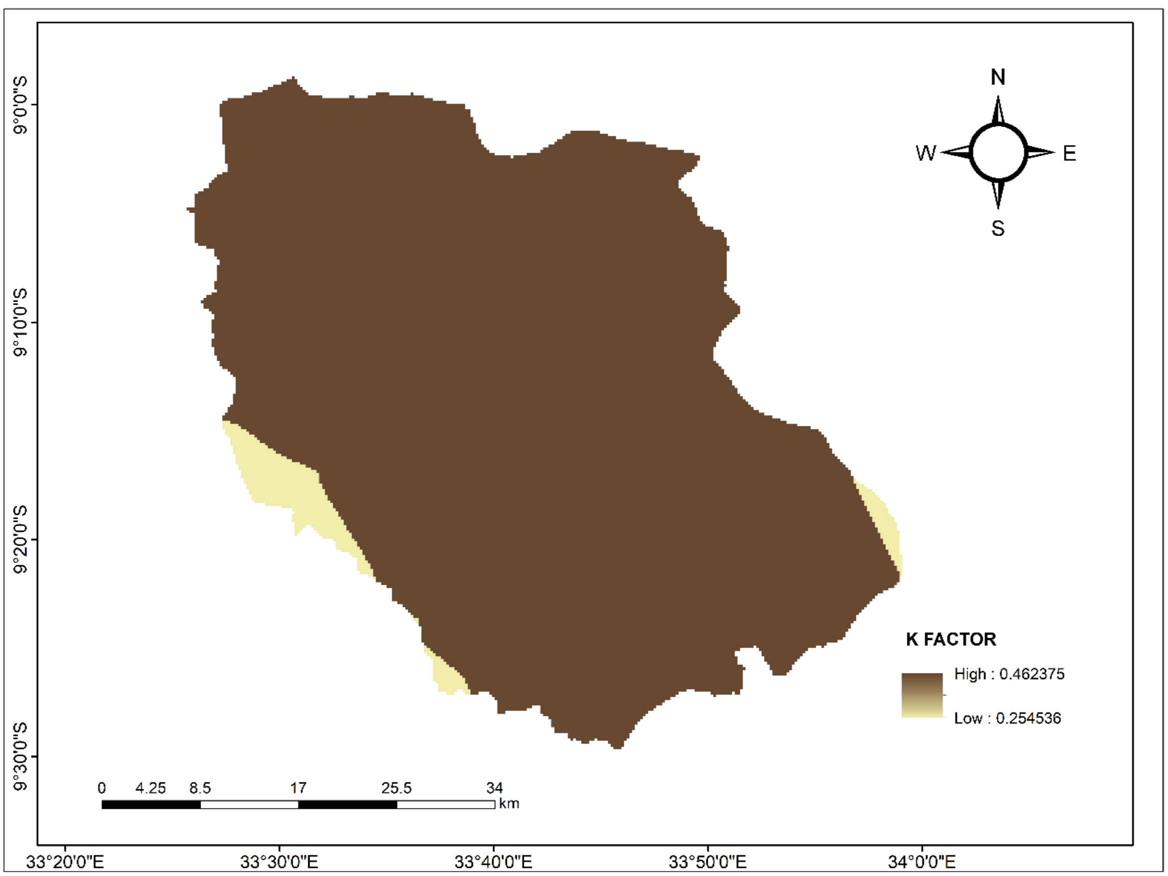

Figure 4. 1 soil erodibility factor

4.2 Topographic factor (LS)

The slope length factor (L) and slope steepness factor (S) primarily indicate the impact of topography on erosion. Slope length refers to the horizontal distance from the starting point of overland flow to the point where either the slope gradient decreases enough for deposition to occur or where runoff is concentrated in a defined channel(Renard et al., 2011). Slope steepness reflects the influence of the slope gradient on erosion. An increase in the L and/or S factor leads to higher velocities of overland flow and subsequently greater erosion. The Topographic Erosivity factor (LS) for the Rungwe district was computed by considering the flow accumulation and slope factor derived from the digital elevation model (DEM). The analysis revealed that the Topographic Erosivity factor in the Rungwe district was found to be within the range of 0 to 0.25 as shown in Figure 4.2 below.

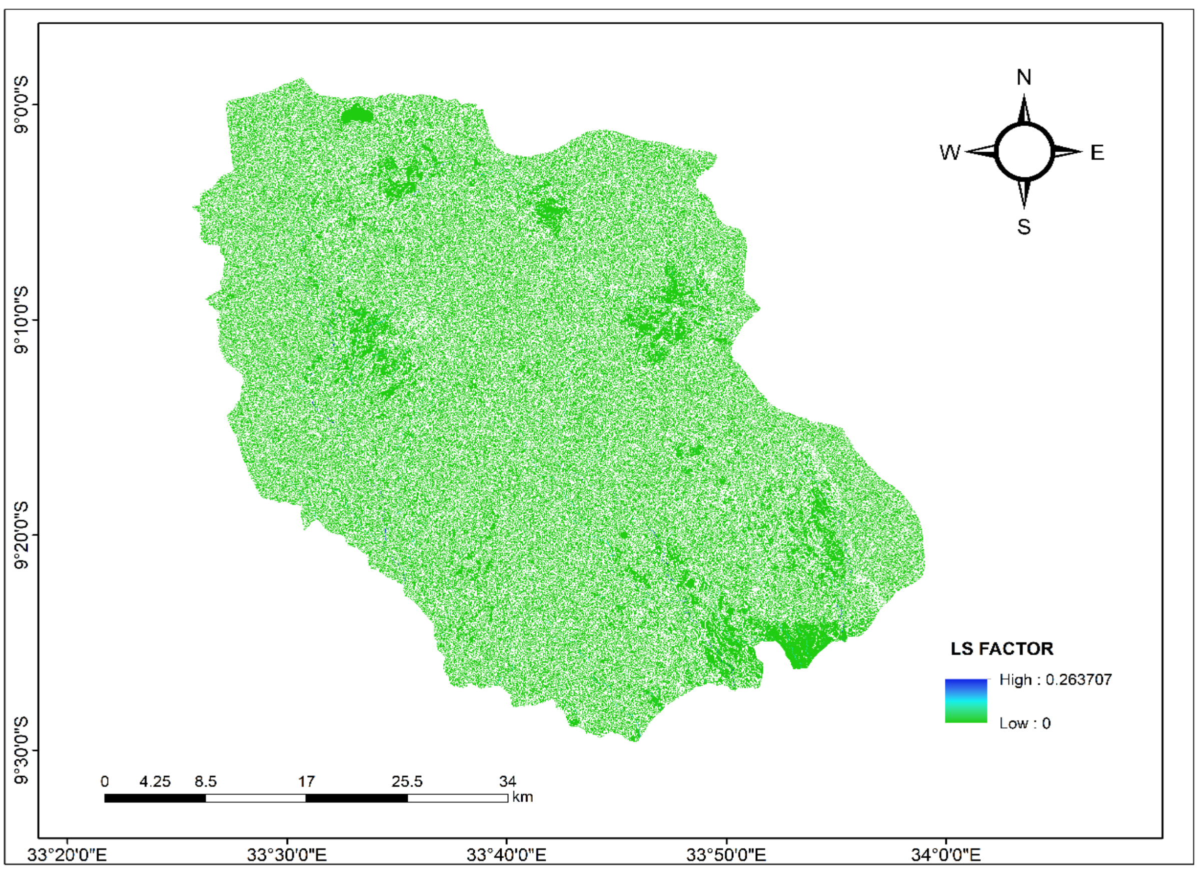

Figure 4. 2 Topographic factor (LS)

4.3 Cover management factor (C)

The cover management factor (C) plays a critical role in erosion as it represents a controllable aspect that can effectively reduce erosion, it is obtained from the NDVI. Apart from topography, land cover significantly influences soil loss. The C factor is less influential when the majority land cover consists of natural vegetation and plantation crops. Its value can range from '0' in water bodies to slightly above '1' in barren land (Toy et al., 2002). The results depend upon the classified which is from low 0. to 0.93 as can be seen from Figure 4.3 below.

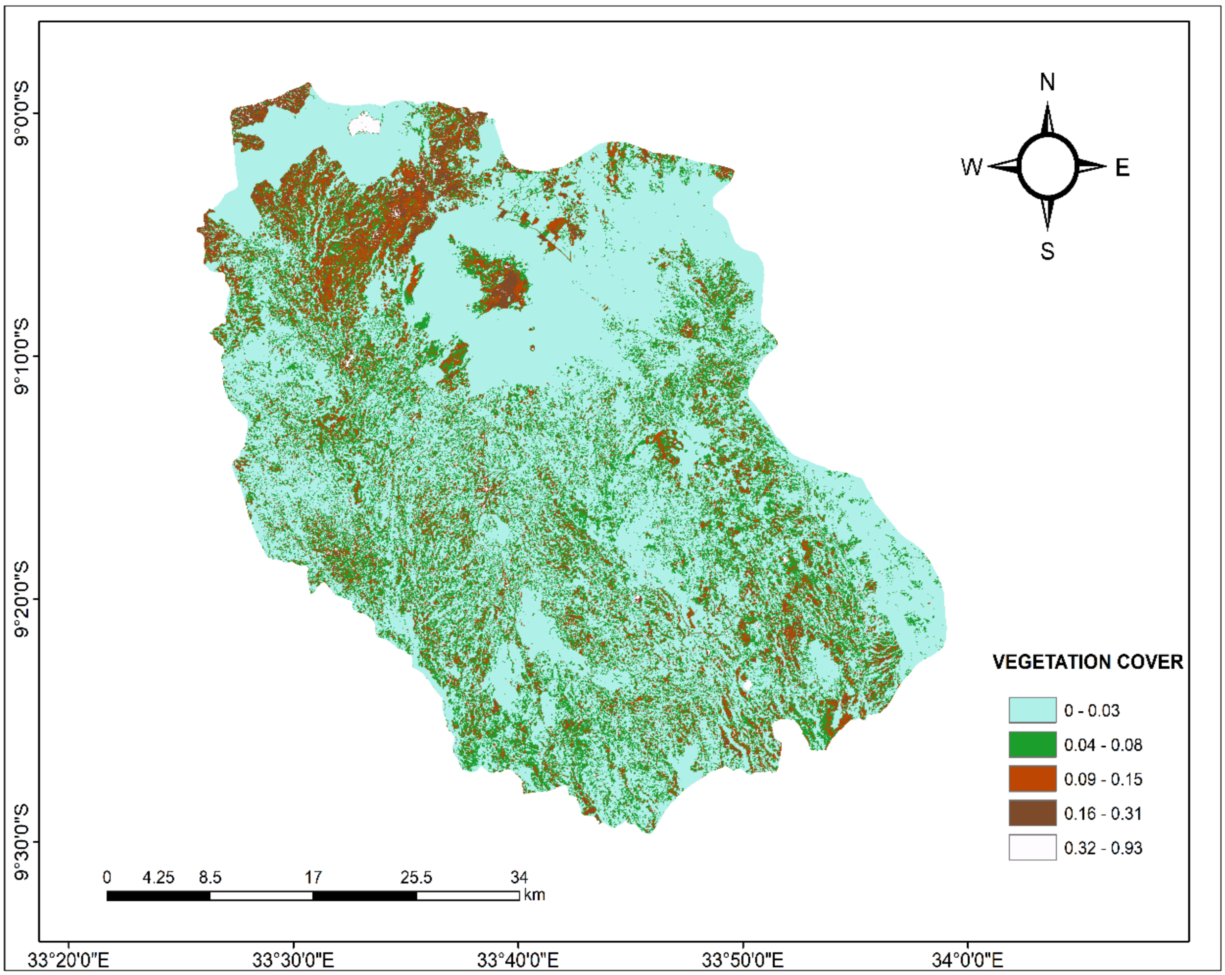

Figure 4. 3 Cover management factor (C)

4.4 Support practice factor (P)

The conservation practice factor (P) signifies the impact of implementing specific practices aimed at reducing water runoff and, consequently, minimizing erosion. Figure 4.4 shows the key practices that contribute to erosion reduction include contour tillage, strip-cropping along contours, and the use of terrace systems. The value of ranges from low to high of number 0.5 up to 0.9 in the area

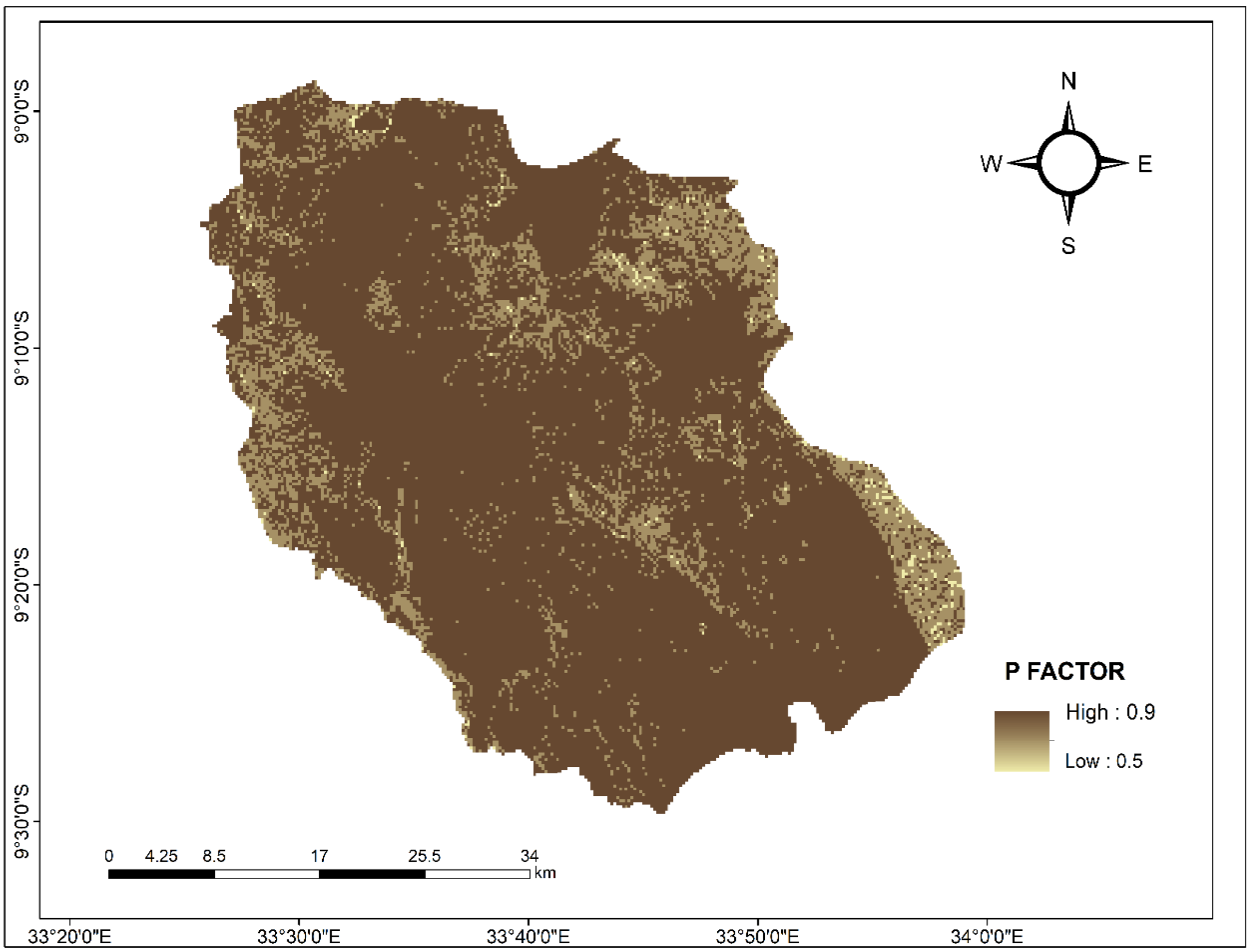

Figure 4. 4 Support practice factor (P)

4.5 Rainfall erosivity factor

The R factor was calculated using the method outlined in equation above, based on the concept of rainfall erosivity. Lower values of the R factor indicate lower rainfall intensity, while higher values indicate greater intensity. A map of the R factor reveals higher rainfall intensity in the northern part of the district, and lower intensity in the southern part. The average R factor values in Rungwe district fall within the range of 101.3 to 129.1 MJ.mm/ ha h yr., as shown in figure 4.5 below.

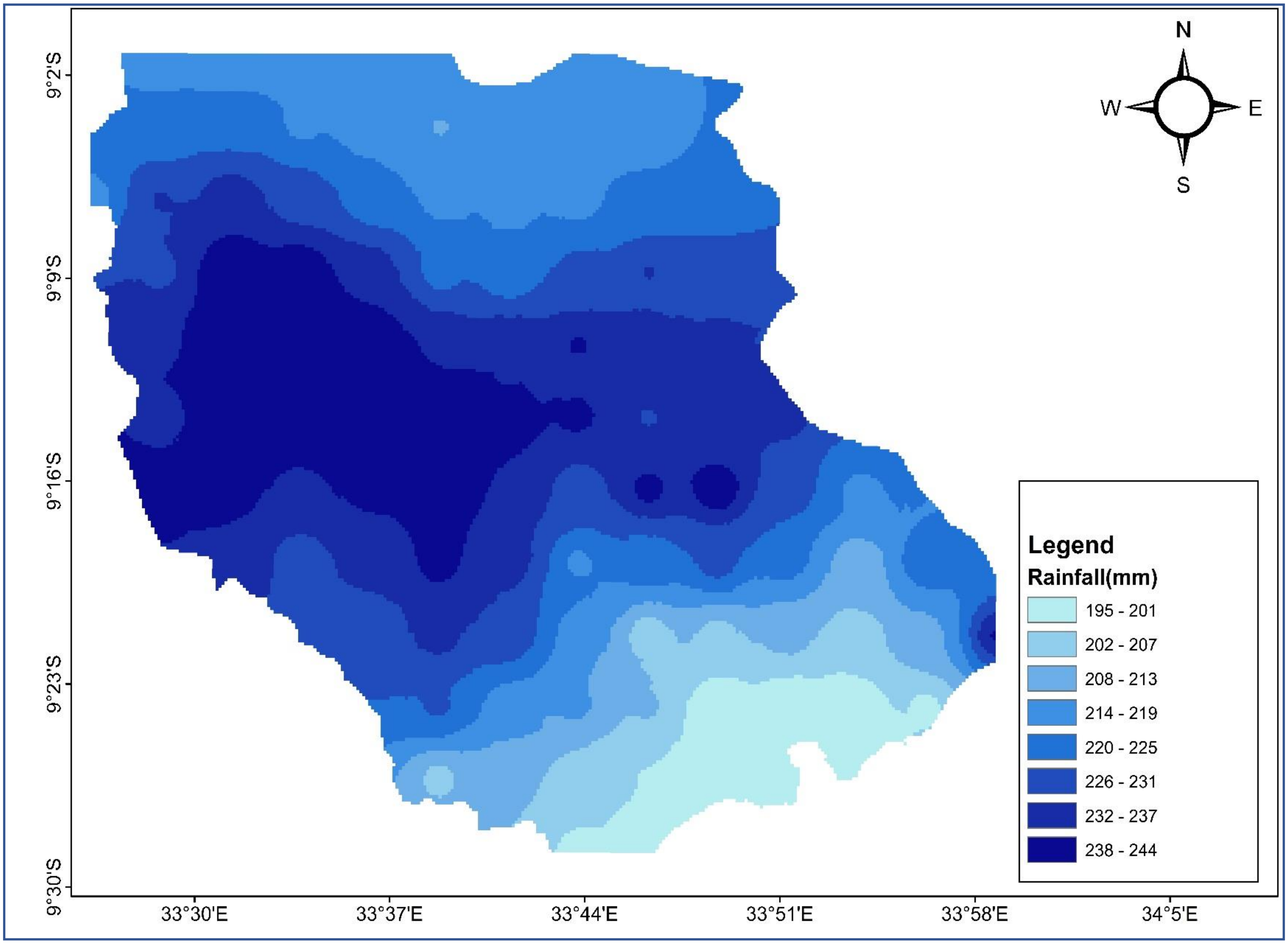

Figure 4. 5 Rainfall erosivity factor

4.6 Annual soil loss map

The findings of this study reveal that the northern and certain parts of the southern region within Rungwe district are highly susceptible to soil erosion due to the presence of slopes, inadequate land management practices, reduced soil coverage, and sparse vegetation. These factors collectively contribute to heightened erosion risks, as slopes facilitate water movement and soil detachment, poor land management fails to mitigate these effects, and limited vegetation cover leaves the soil exposed and vulnerable.

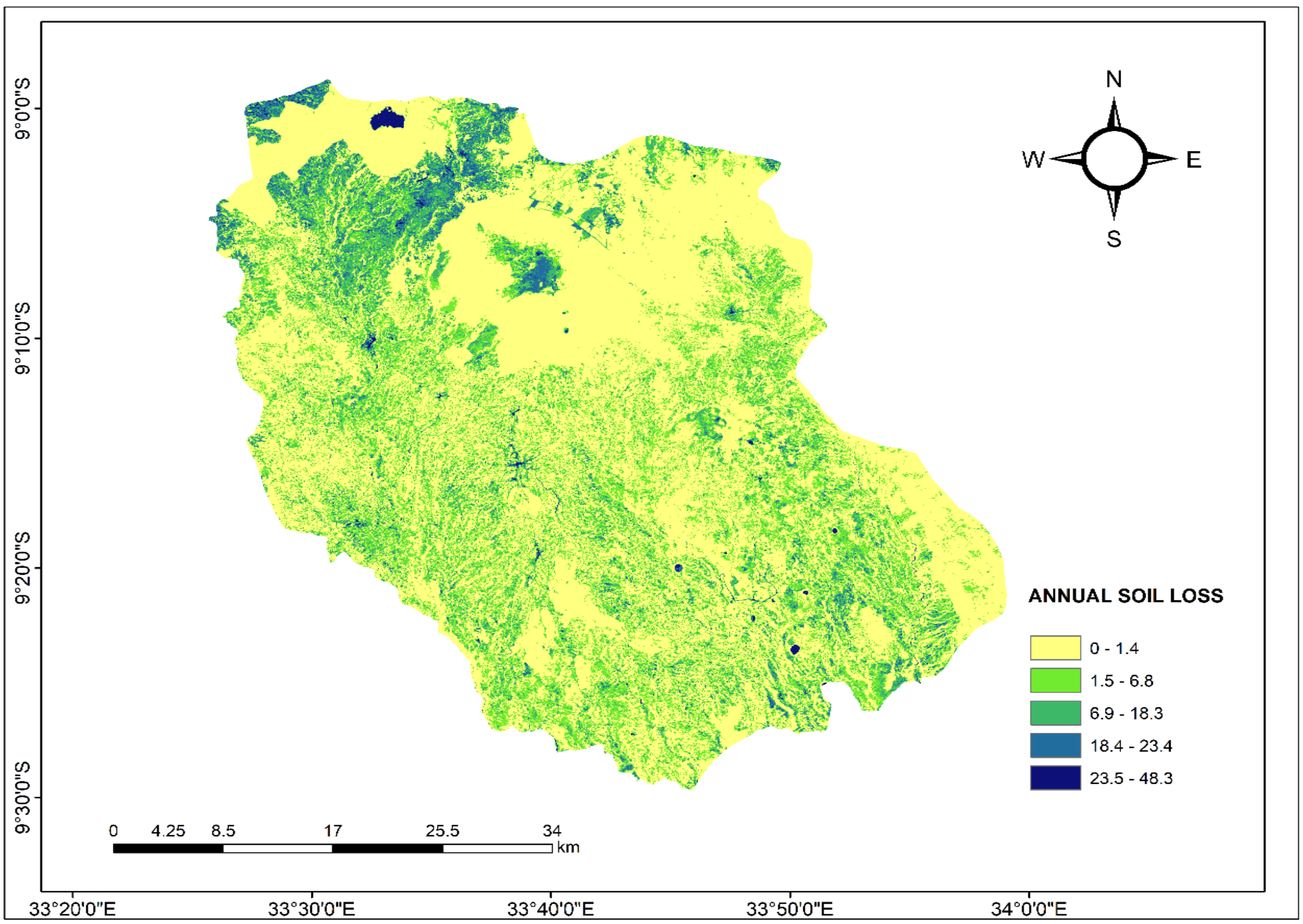

Figure 4. 6 Annual soil loss map

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1Conclusion

This study has been able to assess and quantify soil erosion rates of Rungwe district using the Universal Soil Loss Equation (USLE) model in which it enables to average calculate the annual loss of 48.3 tons per hectare per year. The integration of parameters within the USLE model through a Geographic Information System (GIS) framework has yielded insightful findings regarding soil erosion susceptibility in the Rungwe district. The study has effectively identified areas with heightened vulnerability to soil erosion, revealing an annual soil loss estimate of 48.3 tons per hectare per year.

The research underscores the pivotal role of specific factors, including insufficient vegetation cover, steep slopes, and intense precipitation, in driving the observed high erosion rates. Notably, the study's outcomes are further substantiated through the utilization of high-resolution satellite imagery via the Google Earth Engine platform.

These results collectively emphasize the urgent need for targeted soil conservation strategies in the identified high-risk zones to mitigate the adverse impacts of soil erosion. These findings align with similar investigations conducted in different regions using the USLE model. Such areas share comparable geo-environmental attributes and rainfall patterns, leading to consistent outcomes of substantial erosion, as demonstrated by (El Jazouli et al., 2017). It documented severe erosion exceeding 0.68 tons per hectare per year in the watershed, attributing this to the region & steep topography. Similarly, (Khairunnisa et al., 2020) study produced a map illustrating annual soil erosion, indicating a maximum loss of soil. This map emphasized the impact of steep terrain and heavy rainfall on soil erosion. These parallels reinforce the suitability

5. 2 Recommendations

Based on the findings of the study, there are several recommendations that can help to address the issue of soil erosion in Rungwe district:

1. Implement conservation practices: The use of conservation tillage, cover cropping, and other soil conservation practices can help to reduce soil erosion by improving soil structure and increasing vegetative cover.
2. Improve land management practices: Better land management practices, such as terracing, contour farming, and waterways, can also help to reduce soil erosion and control sediment transport.
3. Plant trees and vegetation: Planting trees and other vegetation can help to stabilize soils and reduce erosion by intercepting rainfall, increasing infiltration, and reducing runoff.
4. Build check dams and other erosion control structures: Check dams and other erosion control structures can help to slow down water flow, reduce erosion, and trap sediment.

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